

Stress distribution patterns of implant supported overdentures-analog versus finite element analysis: A comparative *in-vitro* study

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Abstract

Aims and Objectives: The aim of this study was to assess & compare the load transfer characteristics of Ball/O-ring and Bar/Clip attachment systems in implant supported overdentures using analog and finite element analysis models.

Methodology: For the analog part of the study, castable bar was used for the bar and clip attachment and a metallic housing with a rubber O-ring component was used for the ball/O-ring attachment. The stress on the implant surface was measured using the strain-gauge technique. For the finite element analysis, the model were fabricated and load applications were done in a similar manner as in analog study.

Results: The difference between both the attachment systems was found to be statistically significant ($P < 0.001$).

Conclusion: Ball/O-ring attachment system transmitted lesser amount of stresses to the implants on the non-loading side, as compared to the Bar-Clip attachment system. When overall stress distribution is compared, the Bar-Clip attachment seems to perform better than the Ball/O-ring attachment, because the force was distributed better.

Key Words: Ball/O-ring, Bar-Clip, finite element analysis, implant retained overdenture, overdenture attachments, strain gauges

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INTRODUCTION

The ability to replace lost teeth with osseointegrated implants has improved the quality of life.^[1] The advantages of implant retained prostheses include improved mastication, increased passive tactile sensitivity, better retention compared to

the conventional ones.^[15] A minimum of two implants in anterior mandible, generally in the canine region, followed by rehabilitation with implant retained overdenture is the WHO guideline for rehabilitation of any completely edentulous patient.^[14-17,27,37,38,42]

The commonly used forms of anchorage include ball attachments and clips on a bar connecting the implants. It is important to ascertain whether implants need to be splinted together or whether freestanding implants alone can withstand the loads.^[7,9,11-13] The prognosis of the implants depends on the ability of the attachments to dissipate the stresses transmitted through them by the superstructures.^[6,7]

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Because of technical difficulties, *in vivo* measurements of forces with the transducers mounted directly on the implants are rare. Hence, *in vivo* models are fabricated, wherein strain gauges are used to measure the amount of stress being transferred to the implants, by the superstructure.^[58,60,61]

The present *in vivo* study compared the load transfer characteristics of Ball/O-ring and Bar/Clip attachment systems, using analog and finite element analysis models.

The objectives of this study were to compare the following:

- To evaluate load transfer characteristics of Ball/O-ring and Bar/Clip attachment systems in implant retained overdentures using analog models
- To evaluate load transfer characteristics of Ball/O-ring and Bar/Clip attachment systems in implant retained overdentures using finite element analysis models
- To compare the load transfer characteristics of Ball/O-ring and Bar/Clip attachment systems in implant supported overdentures obtained from analog and finite element analysis models.

MATERIALS AND METHODS

This study was carried out in two parts:

- Fabrication of analog model, followed by load application and analysis
- Fabrication of the finite element analysis model, followed by load application and analysis.

Methodology of analog model fabrication, load application and analysis

Fabrication of study models

Edentulous mandibular models were made from heat-cured polymethylmethacrylate resin. Implant analogs were placed in the canine region and retained with resin cement. Implant supported overdentures of heat polymerized polymethylmethacrylate were fabricated to be placed on the previously fabricated models [Figure 1].

Implants and attachments

A castable hader bar of length 22 mm and clip length 16 mm was used for the Bar-Clip attachment. This hader bar and clip attachment system was attached to the implant analogs placed earlier. A metallic housing with a rubber O-ring component and a ball abutment fixed to the implant analogs were used for the Ball/O-ring attachment [Figure 2].

Loading procedure

The denture after being placed on the model, with each attachment in place, loads were applied in the region of the occlusal surfaces of the second premolar and first molar region using a universal testing machine. Loads were increased gradually from 0 to 100 N in 10 N steps [Figure 3].

Methodology of finite element model fabrication, load application and analysis

Step 1: Obtaining the computed tomography scan images

A spiral computed tomography scan image of 3 mm sections of a 60-year-old completely edentulous male patient was obtained.

Step 2: Finite element modeling of mandible, denture, mucosa and implants

The implant analogs used for the *in-vitro* study were scanned and used to design the implants to be placed in the canine regions of the finite element model. Ball/O-ring and Bar/Clip attachment systems were fabricated using three-dimensional finite element meshing, using similar dimensions and mechanical properties as that of the analog model attachments.

Step 3: Incorporating mechanical properties in the finite element model

Mechanical properties such as Young's modulus and Poisson's ratio of mandible, denture, mucosa and implants are used for further analysis. All materials included in the finite element models were considered to be isotropic, homogeneous, and linearly elastic.

Step 4: Applying loads and constraints

Following the meshing of the mandible, implant supported overdenture and implant models, and incorporating the material properties, the models were constrained at the base [Figure 4].

Loading procedure

Loading was done incrementally from 0 to 100 N, increasing in 10 N increments for both Bar/Clip and Ball/O-ring attachment systems. The loading was done both unilaterally in the region of second premolar and first molar and also bilaterally in the same regions.

The results of the data obtained were compared and subjected to statistical analysis using one-way analysis of variance.

RESULTS

Results and statistical analysis obtained from analog model study procedure

Influence of load (in Newton) on the stresses being taken up by each implant was found to be significant ($P < 0.001$) [Table I]. The amount of the applied loads being transferred by each attachment into the implant when compared was found to be significant ($P < 0.05$). Higher stresses were recorded in Ball/O-ring on the side of applied load, followed by Bar/Clip and with Bar/Clip on the nonloaded side, respectively. Lower stress levels were recorded in Ball O-ring with implant on the nonloaded side [Figure 5].

Results and statistical analysis obtained from finite element analysis study procedure

Ball/O-ring attachment system

Red region indicates region of high-stress region while

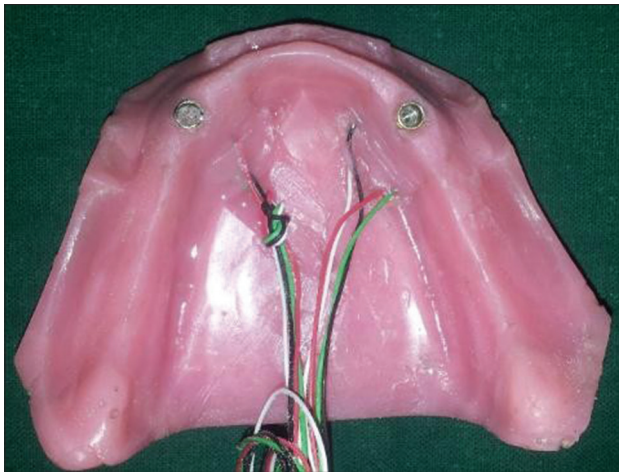


Figure 1: Implants with the load cells placed in the canine region

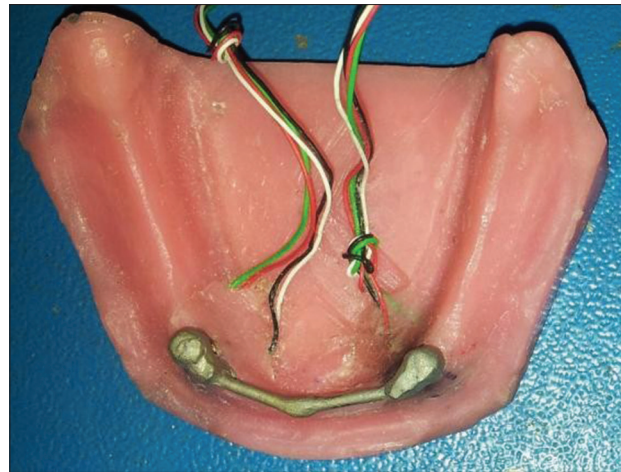


Figure 2: Bar attachment in place

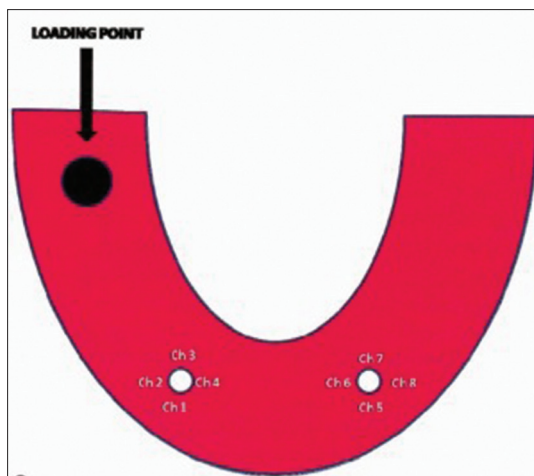


Figure 3: Attachment of strain gauges around the implants and loading point

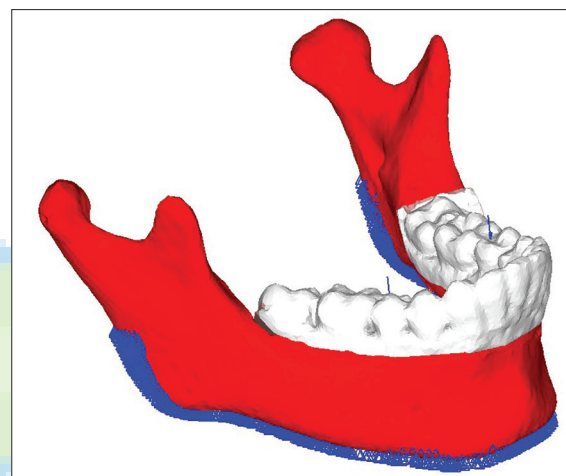


Figure 4: Loads and boundary conditions in Finite element analysis model

Table 1: Comparison between both the attachment systems in dissipating the forces applied on them

Source of variation	df	SS	Mean SS	F	P
Load	1	24124.009	24124.009	129.937	<0.001*
Attachment	1	241.114	241.114	1.299	0.261
Implant	1	16459.114	16459.114	88.652	<0.001*
Attachment×implant	1	2114.205	2114.205	11.388	0.002*
Error	39	7240.718	185.659	-	-
Total	43	50179.159	-	-	-

*Denotes a significant factor/significant difference between the levels of the factor. SS: Sum of squares

blue indicates region of low-stress concentration. In case of unilateral loading, it can be seen that stresses developed in the implant closest to the loading area are more [Figure 6].

Whereas when bilateral loads are applied, it can be seen that Von Mises stresses are developed on both sides almost equally [Figure 7].

Bar/Clip attachment system

In case of unilateral loading, it can be seen that stress is developed on both the sides, although loading is unilateral [Figure 8]. With bi-lateral load application, more or less uniform state of stresses was found to develop on both the sides [Figure 9].

DISCUSSION

An implant supported overdenture is subjected to various types of axial and nonaxial stresses, including the masticatory forces. The resultant of these forces is transmitted through the superstructure and the attachments to the implants and may lead to concentration of stresses in the different parts of the implants.^[12]

Cost is an important factor that determines the placement of implants. By reducing the number of implants required to

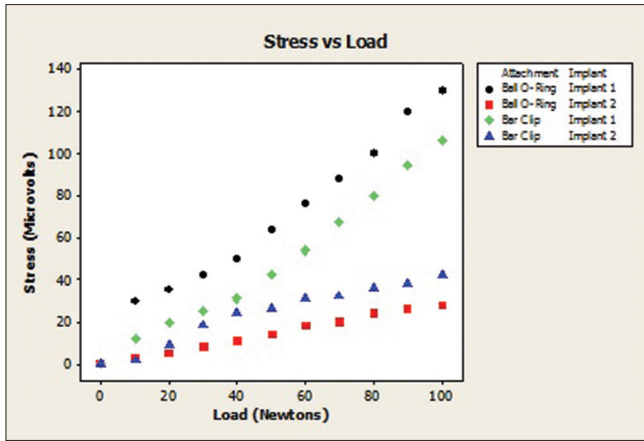


Figure 5: Effect of load (in Newtons) on stress (Microvolts)

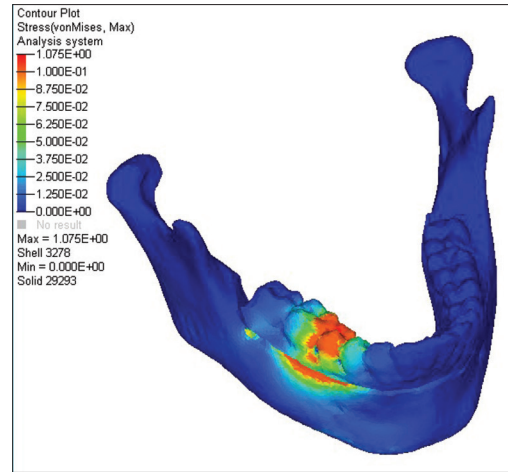


Figure 6: Von Mises stress due to unilateral loading for ball attachment system

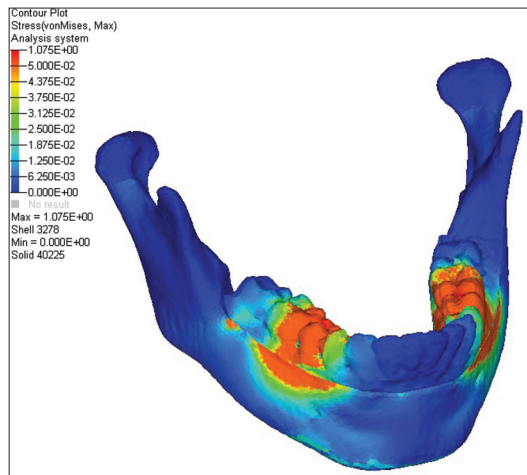


Figure 7: Von Mises stress due to bi-lateral loading for Ball/O-ring attachment

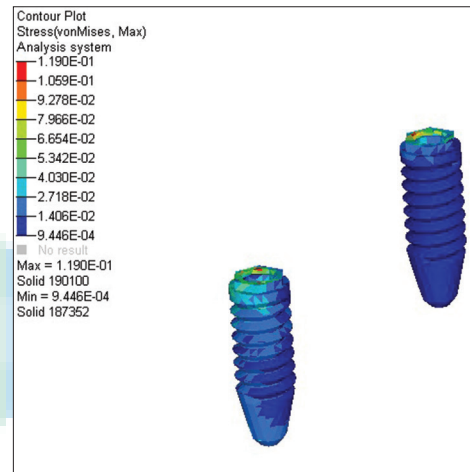


Figure 8: Von Mises stress due to unilateral loading for Bar/Clip attachment

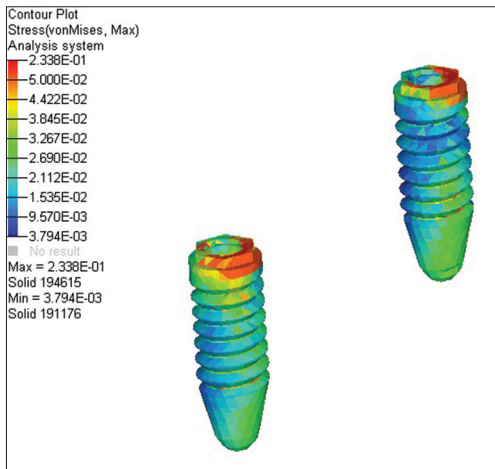


Figure 9: Von Mises stress due to bilateral loading for Bar/Clip attachment

support an overdenture, the cost can be considerably reduced. Two instead of four implants in the mandible can also offer an almost equal amount of stability to the denture.

The assumption that unfavorable loading of implants may lead to bone resorption has been neither confirmed nor rejected. Therefore, is it necessary to learn more about naturally occurring forces *in vivo*. Because of technical difficulties, *in vivo* measurements of forces with the transducers mounted directly on the implants are rare.^[61] In the present study, stress on the implant surface was measured using a strain-gauge technique and finite element analysis models.

The two most commonly used attachments in implant retained overdentures are the Ball/O-ring and Bar/Clip attachment systems. The need was to compare the stress distribution capabilities of the attachment systems so that clinicians can make an informed choice.^[1-6,8,10]

It was found that on ipsilateral loading, with Ball/O-ring, the strain was concentrated on the loading side implant. The stress on the loading side implant was small when the load

was slight because of the secondary splinting that occurs with ball attachments. The Bar/Clip attachment, on the contrary, produced higher stress on the nonloading side implant when compared with the Ball/O-ring attachment because of the primary splinting effect even at low pressure. Our results were consistent with previous studies that noted that the axial force on the loading-side implant was minimal with the Ball/O-ring attachment.^[1,3,5,6,10,18-21]

This may be the result of the stress-absorbing effect of the rubber O-ring component. Under our experimental condition, in which a ball attachment was used, minimum amount of force was transmitted to the implant body. The force may have been absorbed at the rubber O-ring component and anchor head connection. Therefore, in the long term, prosthetic complications such as screw loosening or the need to replace O-ring matrices may occur.^[22,34,35,41,43,44]

When comparison was done between Ball/O-ring and Bar/Clip attachment systems under unilateral and bilateral loading conditions, similar to the methodology followed under analog model with the finite element analysis models, it was observed that for unilateral loading, the Bar/Clip attachment dissipated less force as compared to Ball/O-ring.^[6,8,10,23-26] Whereas when the same model was subjected to bilateral loading, it was observed that the Ball/O-ring attachment configuration dissipated less forces compared to the Bar/Clip attachment. However, if one looks at the overall stress distribution, the Bar/Clip attachment system seems to perform better than the Ball/O-ring attachment system, as the forces are distributed better.^[22,28-33]

The models had been fabricated to simulate an experimental condition to compare the stress distribution capabilities of Ball/O-ring and Bar/Clip attachment systems, wherein, the implant length and diameter, location in the model, attachment type and dimensions were standardized for both analog and finite element analysis. Ball/O-ring attachment system may be considered a favorable attachment system, when the expected amount of force on the superstructure is in the low, but as we consider the superstructure being subjected to higher amount of stresses, the Bar/Clip attachment system can be considered more favorable, due to its potential to dissipate the stresses uniformly between both the implants with its splinting effect.^[36,39,40,46-48] As most of the stresses in a Ball/O-ring attachment system is primarily absorbed around the implant on the side of loading, if it is subjected to high amount of stresses over increased periods of time, it may lead to screw loosening and subsequent failure.^[45,49,50,57,61]

Excessive loading of the implants has been related to marginal bone loss, failure of osseointegration, and failure of implant and/or prosthetic superstructure component.

The implant-bone interface is rigid and transmits all loads directly to the adjacent bone. This condition produces a high level of stresses which can be counterproductive for long-term survival of the implants. Therefore, emphasis has been put on force transmission by each attachment system.^[62-64]

In this present study, the vital anisotropic tissues were considered isotropic. The loads applied were static whereas dynamic loading is seen during the masticatory function. Finite element analysis is based on mathematical calculations which are based on simulation of the structure in its environment. But living tissues are beyond the confines of set parameters and values since biology is not a compatible entity. The study did not take into consideration the resilient soft tissue covering the ridge.

Newer attachment systems such as locator attachments can be taken up as future studies to evaluate the stress patterns generated in such attachments.

CONCLUSION

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

- It was observed that for unilateral loading case, Bar/Clip attachment dissipated less force compared to Ball/O-ring and for bilateral it was observed that the Ball/O-ring implant configuration dissipated less force compared to the Bar/Clip attachment case
- Analysis of the results obtained from both, analog and finite element analysis models were taken into consideration and it can be concluded that the Ball/O-ring attachment system may be considered a favorable attachment system, when the expected amount of force on the superstructure is in the lower range and the Bar/Clip attachment system can be considered more favorable when a higher range of force is expected.

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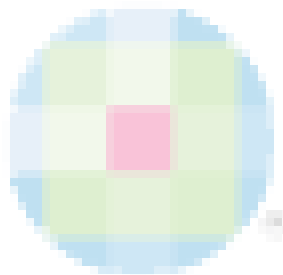
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