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ORIGINAL RESEARCH

Influence of Attachment Configuration on Stresses in Completely Edentulous Mandibular Ridge with an Implant-retained Overdenture: A Finite Element Analysis

[1]Usha Bollineni, [2]Rohit Shetty, [3]Ipsha Singh, [4]Srivatsa Gopalakrishna

ABSTRACT

Aim: To evaluate and compare the stress distribution in peri-implant area and posterior region of completely edentulous mandible rehabilitated using implant-retained overdenture (IOD) with two types of ball attachment configuration, i.e., rigid and resilient.

Materials and methods: Two mathematical models were prepared simulating completely edentulous mandibular ridge. Model 1 represented implant with rigid stud attachment. Model 2 represented implant with resilient stud attachment. Both the models were subjected to the compressive force of 35 N. The stresses in the peri-implant area and posterior region of the mandible were evaluated and compared for both the models.

Results: The IOD with rigid stud configuration showed 12.1% higher peri-implant stresses than resilient configuration, whereas the resultant stress values in posterior edentulous region were 1.5% lower with resilient configuration.

Conclusion: Highest stress value was seen in the crestal part of bone around the implant with both rigid and resilient attachment configuration. Implant-retained overdentures with resilient stud attachment showed better dissipation of forces when compared with rigid attachment.

Clinical significance: Correct choice of attachment configuration can influence the peri-implant stresses in IOD, which in turn reduces the complications that can be a result of excessive stresses around the implant.

Keywords: Ball attachment, Implant-retained overdenture, Nylon cap, Peri-implant stresses, Resilient attachment, Single-piece implant.

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INTRODUCTION

Implant-supported prosthesis provides the best form of functional and esthetic replacement for missing teeth, and replacement of lost teeth with an implant-retained prosthesis has significantly improved the quality of life.[1] The rehabilitation of completely edentulous mandible by use of IOD has become a popular treatment modality.[2] The advantages of implant-retained prostheses over conventional complete denture include improved mastication, increased passive tactile sensitivity, and better retention of the prostheses.[3]

According to World Health Organization guidelines, the rehabilitation of a completely edentulous patient should be done with a minimum of two implants: generally in the canine, followed by rehabilitation with an IOD.[4]

There are various commercially available attachments which can be used to retain an implant overdenture, i.e., stud, bar, magnetic, telescopic, etc. The stud attachments consist of ERA attachment, ball attachment, and locator attachment.[5] The most commonly used form of attachment for IOD is the ball and socket type because of its simplicity of design, low cost, ease of handling, and minimal chair-side time.[5,6]

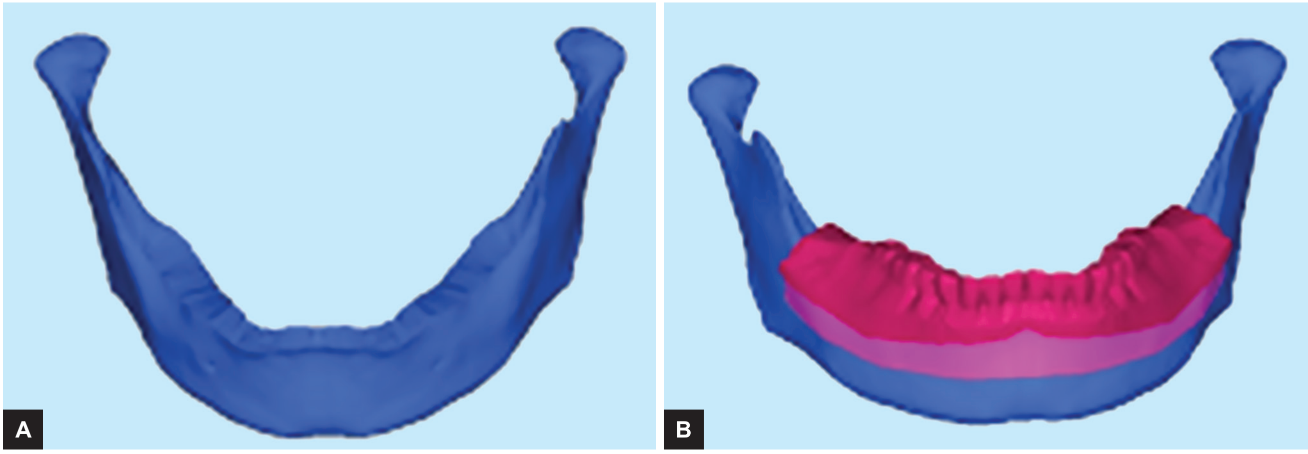
The prognosis of IOD depends on the ability of the attachments to dissipate the occlusal forces to the underlying bone.[7,8]

Currently, IOD using two implants with ball attachments is the most reliable and well-documented treatment option in rehabilitation of completely edentulous mandible.[9] Ball attachment is a type of stud attachment that consists of a metal ball (male part) attached to the implant abutment and the metal housing (female part) incorporated in the intaglio surface of the denture.[10]

The success of any prosthesis depends on the ability of the prosthesis to resist and dissipate the occlusal forces to the supporting structures. In implant-retained prosthesis, the occlusal forces when transferred to the underlying bone generate stresses in the bone which in turn can cause crestal bone loss around the implant and ridge resorption in the edentulous area. Therefore, it is important to control these stresses using different prosthesis design, type, material, occlusion, and attachment configuration. The attachment system acts as a link between prosthesis and the implant and the correct selection of it is important for uniform load distribution between the implant and the underlying residual alveolar ridge. According to

[1-4]Department of Prosthodontics, KLE Society's Institute of Dental Sciences, Bengaluru, Karnataka, India

Corresponding Author: Ipsha Singh, #210, 2nd main 11th cross, HIG colony, RMV 2nd stage, Bengaluru 560094 Karnataka, India, e-mail: ipsha.s@gmail.com



Figs 1A and B: (A) Completely edentulous mandibular jaw. (B) Mandibular implant-retained overdenture

literature, the choice of resilient or rigid attachment configuration in different clinical situations has always been questionable.[11,12] However, a resilient retention mechanism has an advantage of distributing occlusal forces to the underlying denture-bearing area as uniformly as possible in order to minimize bone resorption.[13]

There are various methods for evaluation of stresses around dental implant which include photoelastic study, finite element analysis (FEA), and strain measurement on bone surface. The FEA is a modern tool for numerical stress analysis, with an advantage of being applicable to solids of irregular geometry that contain heterogeneous material properties.[14] Such numerical techniques may yield an improved understanding of the reactions and interactions of individual tissues.[15] The science of FEA is purely a mathematical way of solving complex problems in the universe, as it gives easier mathematical solution to biological problems.[16] The advantages of FEA are applicability to linear and nonlinear as well as solid and fluid structural interactions, reproducibility and repeatability, noninvasive technique, and easy to simulate any biological condition in pre-, intra-, and postoperative stages.[15]

The stresses around the implant develop strain fields in the bone tissue which stimulate biological bone resorption. Uncontrolled stresses in the bone around implant can lead to pain, marginal bone loss, and even loss of osseointegration.[17] Therefore, it is of paramount importance to control the stresses around the implants

Hence, FEA was done to evaluate and compare the stress distribution in peri-implant area and posterior region of completely edentulous mandible rehabilitated using IOD with two types of ball attachment configuration, i.e., rigid and resilient.

MATERIALS AND METHODS

A three-dimensional computed tomography (CT) scan of completely edentulous mandible was made. A virtual model of mandible was simulated and it was meshed into sections (Fig. 1). Two single-piece implants (3.3 mm diameter × 11 mm length, Nobel Biocare replace) with ball abutment (2.5 mm diameter sphere × 3 mm length, Rhein 83 USA) (Fig. 2) were placed in the mandibular bilateral canine region. Two similar mathematical models were prepared.

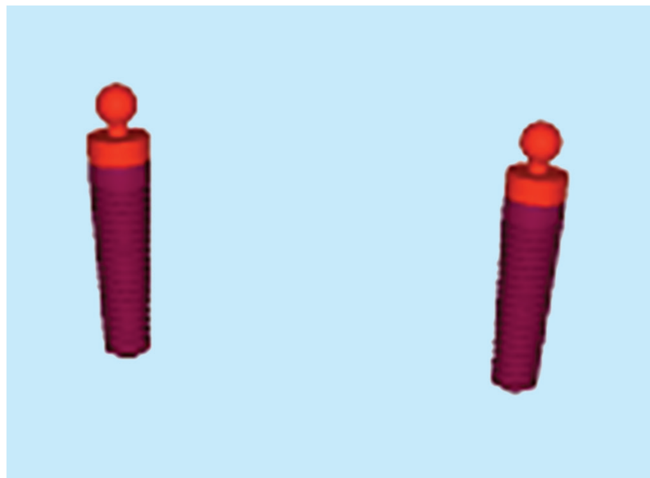
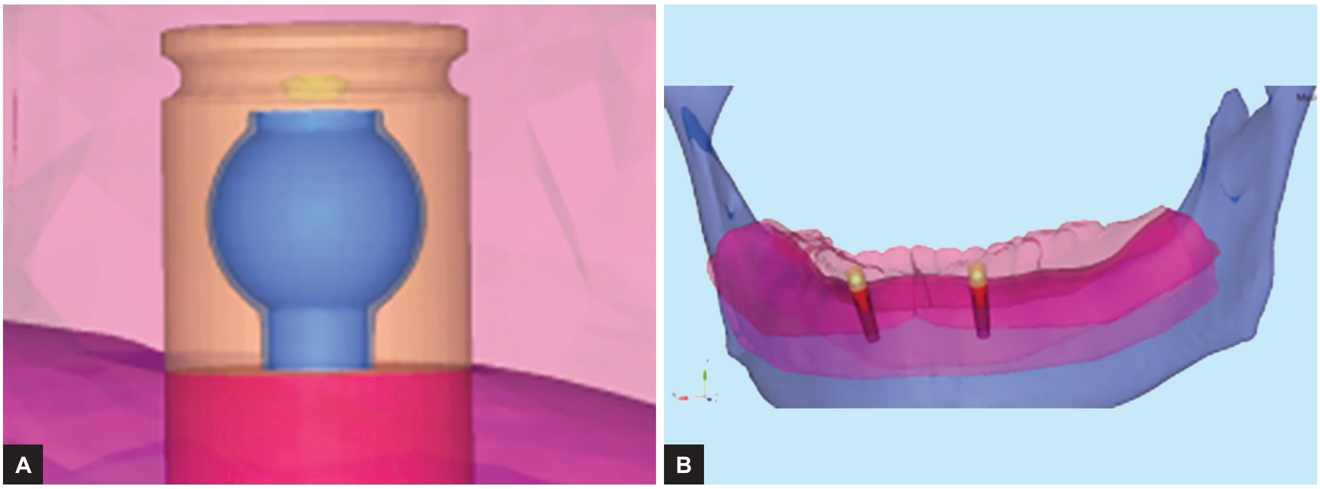


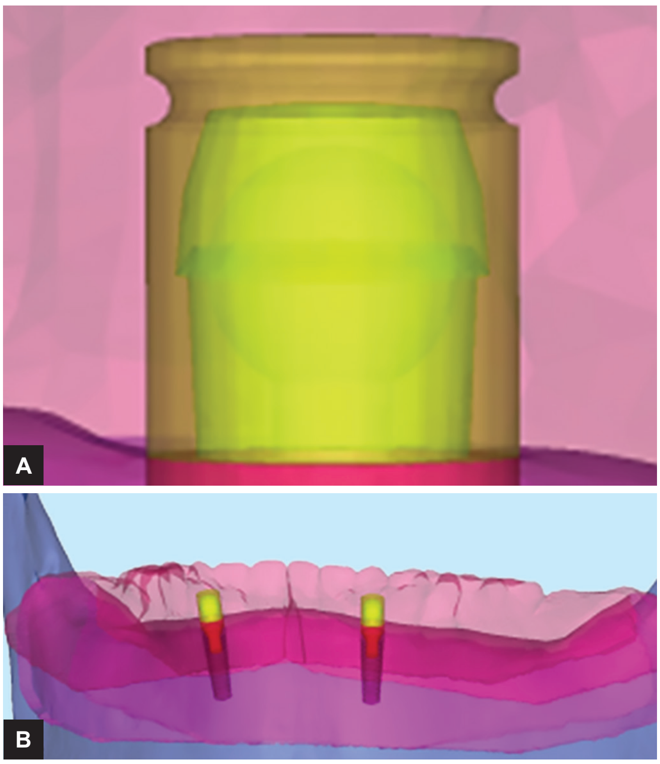
Fig. 2: Implants with ball attachments

Model 1 represented implant with rigid Dalbo Plus stud attachment and retentive plate threaded to the elliptical matrix (5.8 mm wide and 3.7 mm length with retentive plate, Stern gold) in the overdenture (Fig. 3). Model 2 represented implant with Dalbo Plus stud attachment with nylon retentive caps (with 5 mm external diameter and 3.2 mm height, Rhein 83, USA) and metal housing in the overdenture (Fig. 4).

In both the models, mechanical properties (Young's modulus and Poisons ratio) of bone, mucosa, implant, acrylic resin, rigid, and resilient attachment configuration were incorporated (Table 1). Both the models were subjected to the compressive force of 35 N. Forces were applied uniformly on the denture in vertical direction. The stresses in the peri-implant area and posterior region



Figs 3A and B: (A) Rigid attachment configuration. (B) Mandibular implant-retained overdenture with rigid attachment configuration



Figs 4A and B: (A) Resilient attachment configuration. (B) Mandibular implant-retained overdenture with resilient attachment configuration

Table 1: Mechanical properties of oral tissues and prosthetic materials in FEA[18]

Materials and oral tissues	*Young's modulus (MPa)*	*Poisson's ratio*
Bone in the interforaminal region	4,500	0.30
Cortical bone	13,700	0.26
Cancellous bone	1,370	0.30
Implant, ball (titanium alloy)	135,000	0.30
Nylon retentive cap for ball	4,500	0.35
Acrylic resin	4,500	0.35
Mucosa	1	0.37
Retentive plate	97,000	0.42

of the mandible were evaluated and compared for both the models.

RESULTS

Peri-implant stress and stresses in posterior edentulous ridge were evaluated and compared in models 1 and 2 using FEA (Table 2).

DISCUSSION

"The prosthetic rehabilitation with a conventional denture for patients with a completely edentulous mandible should no longer be the treatment of choice"—Mc Gill University, Montreal.[18]

Over a period of time, implant-retained prosthesis has become the most popular form of rehabilitation for edentulism. Survival and success of any implant-retained prosthesis are influenced by numerous factors.[19] The most important factor for determining the long-term success is the state of the peri-implant bone.[19] In particular, mechanical and technical risks play a major role in implant dentistry, resulting in increased rates of repair, excessive costs and time, and even complications that may not be easily corrected. Therefore, the potential complications and failures need to be evaluated before undertaking such interventions. Consequently, the number of biomechanical studies in the field of implant dentistry has dramatically increased in an effort to reduce failure rates.[19]

Table 2: Stress distribution (MPa) in alveolar ridge around implants and in posterior region, using rigid and resilient attachments

Attachment configuration	*Stresses in the residual bone around the implants*	*Stresses in the crestal part of the bone around the implant*	*Stresses in the posterior region of ridge*
Rigid	0.716162	95.25	0.448479
Resilient	0.70948	83.69	0.441619

Implant-retained overdenture in the mandible opposing a conventional maxillary complete denture is considered the basic treatment plan for any completely edentulous patients. In completely edentulous patients, implants can be used in conjunction with attachments to enhance the retention and stability of the dentures.[18,20]

The attachment system linking the implants with the denture has a major effect on the load exerted on the implants and the denture movement of IOD. In other words, the attachment system is a significant risk factor affecting technical complications of IODs.[21]

The most commonly used attachment for IODs is ball attachment. Low cost, ease of handling, minimal chair-side time, and their possible applications with both tooth and implant-supported prosthesis make it a popular choice among the clinicians.[5]

Naert et al[22] concluded that ball attachment is preferred because of less soft tissue complications with better patient satisfaction when compared with bar and magnet attachment. In a study conducted by Tokuhisa et al,[23] they compared the load transfer and denture stability in mandibular IOD. Among the ball, magnet, and bar attachments, it was observed that the use of ball attachment was advantageous with respect to optimizing stress and minimizing denture movement. van Kampen et al[24] conducted a study to compare the retention of bar-clip, ball, and magnet attachment in mandibular IOD. It was concluded that the ball attachment recorded the highest retentive value followed by the bar-clip attachment and the magnet attachment. Menicucci et al[25] conducted a study to compare stresses on the peri-implant bone by overdentures retained by ball and socket attachment and bar-clip attachment; the results revealed that stress on the peri-implant bone was greater with the bar-clip than with the ball attachment.

The ball attachment can be of rigid or resilient configuration. It is claimed that resilient retention configuration has an advantage of distributing occlusal forces to the underlying denture-bearing area as uniformly as possible in order to minimize bone resorption.[6] However, the choice of resilient or rigid attachment configuration in different clinical situations has always been questionable in the literature. Thus, this forms the basis for this study, which will assist clinicians to decide on the selection of attachment configurations providing broad stress distribution which decreases forces toward the alveolar ridge.[12] The aim of this study was to evaluate and compare the stress distribution in the peri-implant area as well as the posterior region of the mandible by using rigid and resilient ball attachment configurations.

In the present study, two mathematical models were created from a patient's CT scan using ANSYS software. The FEA models considered in this study constituted of mucosa, compact bone, trabecular bone, DPI heat-cure acrylic resin, teeth, Nobel Biocare implants, and Dalbo stud attachments (Rhein 83) of two different overdenture attachments. The material properties were incorporated into the FEA models.

One model represented rigid Dalbo Plus stud attachment with retentive plate element threaded to the elliptical matrix. The second model represented Dalbo Plus stud attachment with nylon retentive caps between metal housing and ball abutments.

In both the models, overdenture prosthesis was secured to implants through these retentive attachments. These models were then subjected to compressive force of 35 N which was applied uniformly on the dentures in a vertical direction using FEA, after which the von Mises stresses were evaluated around the peri-implant bone and in the posterior region of the mandible.

There are various methods which can be used to analyze stresses in the mandibular bone around the implant system. These methods include photoelasticity, FEA, and strain measurement. However, FEA is a numerical technique, which overcomes most of the problems associated with other methods and offers considerable potential for stress analysis investigations in dentistry.[26]

The FEA was initially developed in the early 1960s to solve structural problems in the aerospace industry and since then has been used extensively to solve problems in heat transfer, fluid flow, mass transport, and electromagnetic potential.[27]

In 1976, Weinstein et al were the first to use the FEA in implant dentistry.[27] The FEA, due to its simplicity and relative ease of use, has become more popular for the stress analysis on dental structures. Additional advantages of this technique are that the oral conditions can be simulated easily and different parameters can be altered relatively simply.[15,28]

In this method, there are different color codes on a scale of dark blue to red for varying degrees of stresses. They are dark blue, three shades of light blue, dark green, light green, yellow, orange, and red. The dark blue and red indicate minimal and maximum von Mises stress respectively.

In the present study, the color observed on the models indicated that there were highest von Mises stress values in the bone in contact with crestal part of implant of both rigid and resilient configurations. The rigid configuration showed 12.1% higher stresses than resilient configuration. The resultant stress values in posterior region were 1.5% lower with resilient configuration.

Higher stress values were observed in the crestal bone region around implants when compared with ridge to the posterior region irrespective of the configuration used. While evaluating overall stresses between the two configurations, the maximum von Mises stresses were seen below the condyle region for rigid attachments, whereas the resilient attachment did not show any von Mises stresses in that region.

This can be attributed to the fact that when IODs with resilient attachment are out of function, they rest entirely on the mucosa, but when subjected to functional load, the vertical forces are transmitted to the substructure and thus to the implant, thereby reducing the overall stress transmission to the ridge. Whereas, in the rigid attachment, no vertical movement during function is permitted, as the appliance is entirely implant-supported and the abutments withstand the entire masticatory load.[29]

Yoda et al[30] conducted a study on the effect of attachment type on load distribution to implant abutments and the residual ridge in mandibular IODs. It was concluded that the load on the residual ridge beneath the denture in IODS can be efficiently reduced using a ball attachment with resilient configuration.

Daas et al[16] conducted an FEA for a mandibular IOD with two implants using rigid and resilient attachment configurations. It was concluded that resilient attachment allowed for a better load distribution between the dental implants and the denture-bearing surface.

In contrast to the results of the present study, a study was conducted by Chun et al[12] on stress distributions in maxillary bone surrounding overdenture implants with different overdenture attachments. It was concluded that the movable-type Dalbo attachment generated the highest maximum effective stress in the bone, whereas rigid-type Dalbo attachment generated smallest maximum effective stress in the bone.

Elsyad et al[31] conducted a 7-year retrospective preliminary study on posterior mandibular ridge resorption associated with different retentive systems for overdentures and it was concluded that resilient liner attachment for bar IOD is associated with greater posterior mandibular ridge resorption compared with clip attachments. It was also concluded that attachment type, the initial mandibular ridge height, and relining times were associated with posterior mandibular ridge resorption.

Pesqueira et al[32] conducted a study on stress analysis in implant-retained obturator prosthesis with parallel and tilted implants and different attachment systems. It was concluded that attachment system has direct influence on the prosthesis. The individualized O-rings when compared with splinted implants and bar-clip provided lower values of stresses on the implants and supporting tissues.

Meijer et al[4] conducted a study on analyses of stress distribution in the peri-implant region to evaluate the influence of superstructures, length of implants, and height of mandible. It was concluded that the O-ring system transfers less stresses to the implants when compared with bar clip. This may be a result of stress absorbed by the female component of the system, which usually has a rubber ring surrounded by a metal capsule which can absorb or distribute the forces more homogeneously.

The stresses generated in the bone surrounding implant prosthesis also depend on the implant design, material, structure, and dimensions.[33] The implant diameter is reported to be more important than implant length in distributing stresses to the surrounding bone. In a study conducted by Eazhil et al,[34] it was concluded that there was a statistically significant decrease in von Mises stress as the implant diameter increased. Abraham et al[35] also concluded that the von Mises compressive and tensile stresses in the peri-implant bone were lower in the regular platform implant compared with the narrow platform implant. As the diameter of the implant used in this study was narrow platform (3.3 mm), the increased stresses in the peri-implant area and the posterior ridge can be attributed to it. But also clinically, what we encounter in the anterior mandibular region is usually a knife edge ridge, limiting the use of regular or large diameter implant in that area; therefore, when increasing the diameter of implant is not an option, the correct selection of the attachments becomes important in the distribution of stresses.

Based on the results of the present study, it was concluded that the choice of attachment for rehabilitation of a completely edentulous mandible with an IOD should be of resilient configuration. When compared with rigid attachment, the resilient attachment configuration shows more uniform distribution of stresses in the peri-implant area as well as the posterior residual ridge, and therefore minimizes the further resorption of ridges while the prosthesis is in function.

CONCLUSION

Within the limitations of the study, it was concluded that:

- Highest stress value was seen in the crestal part of bone around the implant with both rigid and resilient attachment configurations.
- When compared with rigid attachment, the resilient attachment configuration showed lesser value of stresses in peri-implant area and posterior region of ridge.
- Higher stress value was seen in peri-implant area when compared with posterior region of ridge with both rigid and resilient configurations.
- Resilient attachment configuration showed more uniform distribution of stresses when compared with rigid attachment configurations.
- The choice of attachment for rehabilitation of a completely edentulous mandible with an IOD should be of resilient configuration.

LIMITATIONS

It is a computerized *in vitro* study in which clinical condition may not be completely replicated. This FEA research should be supplemented with clinical evaluation.

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