Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(4), 1607-1615 | ISSN:2251-6727

Evaluation of Stress Patterns in Mandibular Bone Around Implant-Retained Overdentures: A Three Dimensional Finite Element Study on Attachment Design Variability

[1] Dr. Abroo Hussain, [2*]Dr. Siddhi Tripathi, [3] Dr. Sunil Pal, [4] Dr. Shrestha Hegde, [5] Dr. Kriti Shankar, [6] Dr. Shubham Kumar, [7] Dr. Swatantra Agarwal

[1] Prosthodontist, New Delhi, India

[2*] Professor, Department of Prosthodontics and Crown & Bridge I.T.S - CDSR, Muradnagar, Ghaziabad, Uttar Pradesh, India

[3] Senior Lecturer, Department of Prosthodontics and Crown & Bridge I.T.S - CDSR, Muradnagar, Ghaziabad, Uttar Pradesh, India

[4] Senior Lecturer, Department of Prosthodontics and Crown & Bridge I.T.S - CDSR, Muradnagar, Ghaziabad, Uttar Pradesh, India

[5] Senior Lecturer, Department of Prosthodontics and Crown & Bridge I.T.S - CDSR, Muradnagar, Ghaziabad, Uttar Pradesh, India

[6] Senior Lecturer, Department of Prosthodontics and Crown & Bridge I.T.S - CDSR, Muradnagar, Ghaziabad, Uttar Pradesh, India

[7] Principal and Head, Department of Prosthodontics and Crown & Bridge, Kothiwal Dental College & Research Centre Moradabad, Ghaziabad, Uttar Pradesh, India

*Corresponding Author: Dr. Siddhi Tripathi, Professor, Department of Prosthodontics and Crown & Bridge, I.T.S - CDSR, Muradnagar, Ghaziabad, Uttar Pradesh, India

(Received: 16 May 2025 Revised: 20 June 2025 Accepted: 24 July 2025)

KEYWORDS

Attachment, finite element analysis, stress distribution, implant retained overdenture.

ABSTRACT:

Statement of Problem: Implant retained mandibular overdentures with splinted and unsplinted attachments have become an acceptable treatment modality in cases of compromised completely edentulous patients. However, owing to controversial data regarding the superiority of different attachment systems, the present study was conducted to evaluate stress distribution in mandibular bone surrounding implant retained overdentures with hader bar-clip attachment, ball attachment and combination of hader bar-clip with distally placed ball attachment using three dimensional finite element analysis.

Materials and Method: The physical models of implants, conventional mandibular complete denture and different attachments were converted to finite element model by series of software programs. A total number of 4 models were generated. Model A comprised of an edentulous mandible supporting removable mandibular complete denture. Model B, C and D comprised of a model of edentulous mandible supporting overdenture retained by hader bar with clip attachment, ball attachment and hader bar-clip system with distally placed ball attachment respectively. A static load of 100 N was applied perpendicular to the incisal surface of lower central incisors. The amount of stress distribution at canine region was evaluated and compared.

Results: The maximum von mises stresses recorded at the canine region for cortical and cancellous bone was 1.5 MPa and 0.14 MPa for model A, 3.11 MPa and 0.81 MPa for model B, 2.16 MPa and 0.27 MPa for model C and 2.90 MPa and 0.38 MPa for model D respectively.

Conclusion: Maximum von mises stress were greatest for hader bar with clip attachment followed by hader bar-clip with distally placed ball attachment and least by the ball attachment in mandibular bone surrounding implants retained overdenture. All three attachments had higher stresses at the canine region

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(4), 1607-1615 | ISSN:2251-6727

1. Introduction

Implant-retained mandibular overdenture is an acceptable treatment modality in the case of mandibular edentulism and denture complaints. Ample documented data is available to indicate their effectiveness over conventional complete dentures with respect to patients' appreciation of treatment and improvement in oral function. A variety of retentive mechanisms are available for attaching an overdenture to implants for stabilizing the prosthesis and consistent production of a determined-centric occlusion by the patient.[1] However, the selected attachment used in implant-retained over denture has a potential effect on implant survival rate, marginal bone loss, soft tissue complications, retention, stress distribution, maintenance complications and patient's satisfaction.[2] Hence favourable prognosis requires correct selection of the attachment system based not only on retention or cost aspects but also in biomechanics aspects, as it is the most fragile link between prosthesis and implant.[3,4]

Various attachments have been described in literature such as splinted attachments (bar attachment system), unsplinted attachments (ball attachment, locator attachment, telescopic attachment, o-ring attachment, magnetic attachment) or their combinations.[5-7] As stress distribution is an important factor for bone resorption during implant rehabilitation, the attachment system should present an adequate stress transfer to avoid bone resorption and improve treatment prognosis.[4,8,9] The ultimate choice of attachment type should be based on scientific evidence related to the clinical performance of the implants and attachments, on objective oral function, patient's expectation, prosthetic factors, anatomic factors as well as knowledge and skill of the dentist and laboratory technicians.[9,10]

Clinically, it is still not possible to assess stress/strain distribution of implant-retained overdentures at bone level but only at abutment level through strain gauge analysis. Furthermore, there are other methods based on simulation, such as photoelastic method and finite element analysis (FEA), which allow better understanding of transfer and distribution mechanisms of stress via implants to supporting tissue.

Biomechanical studies using finite element analysis by Barao et al.,[11] Menicucci et al.,[3] Amer et al.,[12] and Dashti et al.[13] have showed better stress distribution when ball attachment was used when compared to bar-clip system. Likewise, superiority of ball attachment over bar-clip attachment were reported in photoelastic studies conducted by Vedovatto et al.,[4] Pesqueira et al.,[7] Kenney et al.,[14] Silva et al.,[15] strain guage analysis by Manju et al.,[6] Sabra et al.[16] and in vitro study by Tokuhisa et al.[17] On the contrary, biomechanical studies using finite element analysis by El-Anwar et al.,[18] Bilhan et al.,[19] Jassim et al.,[20] Shishesaz et al.,[21] Satpathy et al.,[22] Vafaei et al.,[23] Polat et al.[5] and Tabata et al.[8] have documented lesser stress values for bar attachment as compared to ball attachment system.

Numerous studies have been conducted for evaluation of stress distribution around the implants supported mandibular overdenture with four implants and different cantilever lengths. However not many studies have been employed utilizing cantilever with two implants overdenture as the use of bilateral distal cantilever attached to two implants supporting an overdenture is still a matter of controversy. Misch[24] stated that when two implants are connected using a cantilevered bar, the prosthesis has less movement and moment forces are increased on implants. Increased tensile strain values at the bone-implant surface are not desired since they may cause bone loss through the induction of bone microdamage. In contrast, few studies[7,11] showed a minimal influence of distal bar cantilever on strain around two implants supported mandibular overdentures. Such distal cantilevers were also found to have little or no influence on the stability of peri-implant survival.

Very less studies have been conducted utilizing combinations of attachment systems. Barao et al.[11] reported that bar clip with distally placed o-ring attachment showed greater stress values compared to o-ring attachment and lesser stress values in comparison to bar-clip system. However contradictory findings were reported in photoelastic studies done by Goiato et al.[25] and Ribeiro et al.[26] Therefore the data is non-conclusive regarding the superiority of combinations of attachment systems over individually placed attachments.

Since there was no consensus in the literature about the biomechanical effects of different overdenture attachments for implant retained overdenture prosthesis, a study was planned to evaluate stress distribution in mandibular bone surrounding implant retained overdentures with hader bar-clip attachment, ball

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(4), 1607-1615 | ISSN:2251-6727

attachment and combination of hader bar-clip with distally placed ball attachment using three dimensional finite element analysis.

2. Materials and Methods

The analytic model of the study was developed from Cone Beam Computed Tomography (CBCT) slice images of the skull at a slice thickness of 1 mm. The images were recorded in Dicom format. The next step was thresholding, which uses the x-ray attenuation coefficient value of the various tissues to separate and isolate a particular area of interest. Using MIMICS (Version 8.11), which is medical modelling software used for the visualization and segmentation of CT/MRI images, mandible was separated by segmentation procedure and accurate representation of mandibular anatomy was made. With the help of Rapidform 2007 software, which is used to convert cloud data points to surfaces (points, splines, lines), the Dicom format of the images were converted to Initial Graphic Exchange Specification (IGES) format. Small defects were also corrected, the object was smoothened and the surface quality was optimized. This led to the generation of the geometric model of mandible.

The physical models of implants, conventional mandibular complete denture and different attachments were converted to geometric model by Computer-Aided Three-Dimensional Interactive Application (CATIA) using reverse engineering technique. CATIA is a multi-platform software which supports multiple stages of product development, including conceptualization, Computer-Aided Design, Computer-Aided Manufacturing and Computer-Aided Engineering. It offers a solution to shape design, styling, surfacing workflow and visualization to create, modify and validate complex innovative shapes and develop cyber-physical products.

Two implants (Nobel Biocare) of 13 mm length and 3.75 mm diameter placed at left and right canine region respectively in accordance to Abdelhamid et al.,[2] Polat et al.,[5] Pesqueira et al.[7] and Dashti et al.[13] Three different attachments were used in the study. First attachment was hader bar and clip attachment with hader bar length of 22 mm and clip length of 16 mm. Similar configuration was reported by Satpathy et al.[22] and Manju et al.[6] The distance between the inferior surface of the hader bar and the ridge was kept as 1 mm. This was in accordance to Rismanchian et al.[27] and Warreth et al.[10] who stated that this space was required to reduce the possibility of plaque and calculus deposition. Second attachment used was ball attachment with a ball diameter of 2.25 mm, cuff height of 1 mm and length of 3 mm. This was in accordance to Takeshita et al.,[28] Rambhau et al.,[29] Jassim et al.[20] Third attachment consisted of hader bar with distally placed ball attachment with a cantilever length of 7 mm on each side. Similar cantilever lengths have been reported conducted by Ebadian et al.[30] and Elsyad et al.[31] Each point of implants, conventional mandibular complete denture and the attachments had x, y and z coordinates for locating the points in 3-D space. The collection of these points is known as a point cloud. The point cloud and the detected features were used by CATIA to fabricate the geometric models.

Finite element modelling (FEM) uses the concept of representing the object by an analytic model consisting of a finite number of elements that are interconnected at a finite number of points called nodes. This collection of nodes and elements form finite element mesh. These are the building blocks of the numerical representation of the model.

The geometrical models of mandible, conventional mandibular complete denture and implant supported mandibular overdenture with different attachments were converted into finite element model using Hypermesh (version 13.0). Three-dimensional tetrahedral elements were used for creating finite element model. Node to node connectivity was given between cancellous bone, cortical bone and mucosa.

All material properties used in the study were assumed to be isotropic. The material properties assigned were Young's Modulus of Elasticity (E) and the Poisson's Ratio (v) for the construction of models (table 1).

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(4), 1607-1615 | ISSN:2251-6727

Table 1: Material Properties

S. No.	Materials	Young's Modulus (MPa)	Poisson's Ratio (v)
1.	Cortical bone	13700	0.3
2.	Cancellous Bone	1370	0.3
3.	Plastic clip	3000	0.28
4.	O-ring rubber	5	0.45
5.	Denture base resin	2400	0.35
6.	Acrylic teeth	3000	0.35
7.	Mucosa	680	0.45
8.	Implant	97000	0.35
9.	Co-Cr alloy	218,000	0.33
10.	Stainless Steel	19000	0.31

A total number of four models were generated. Model A (figure 1) was the control group and comprised of a model of edentulous mandible supporting removable mandibular complete denture. Model B, C and D were the experimental groups and had implants placed perpendicular to the occlusal plane in the canine region. Model B (figure 2) comprised of a model of edentulous mandible supporting an overdenture retained by two splinted implants with hader bar with clip attachment system. Model C (figure 3) comprised of a model of edentulous mandible supporting overdenture retained by two unsplinted implants with ball attachment system. Model D (figure 4) comprised of a model of edentulous mandible supporting overdenture retained by two splinted implants with hader bar-clip system and ball attachment system

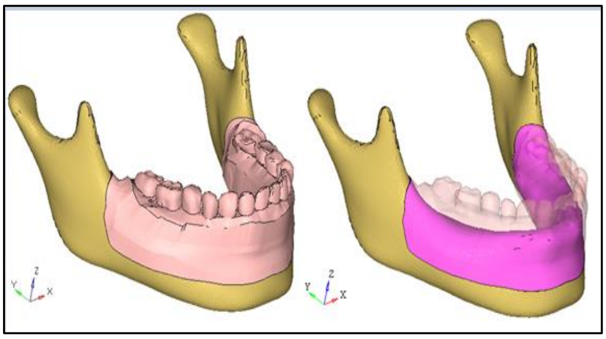

Figure 1. Model A (conventional mandibular complete denture)

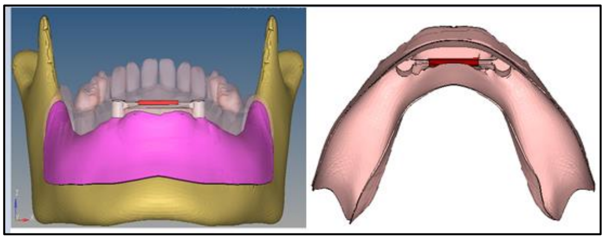

Figure 2. Model B (mandibular overdenture with Hader bar-clip attachment)

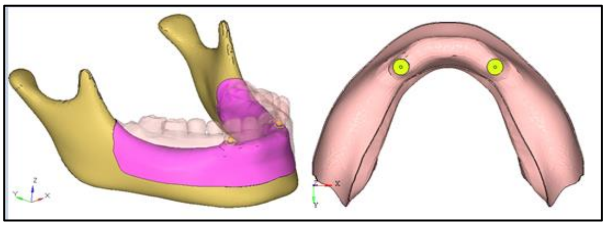

Figure 3. Model C (mandibular overdenture with Ball attachment)

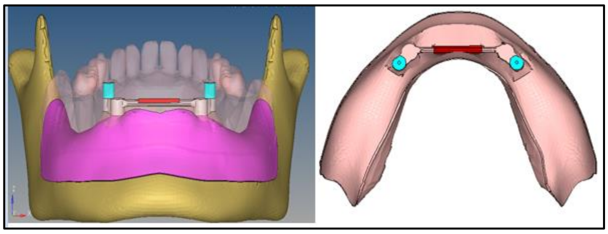

Figure 4. Model D (mandibular overdenture with Hader bar-clip and distally placed Ball attachment)

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(4), 1607-1615 | ISSN:2251-6727

The 3-D finite element models were loaded vertically. A static load of 100 N was applied perpendicular to the incisal surface of lower central incisors (figure 5).

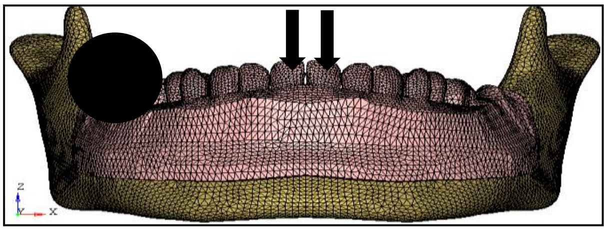

Figure 5. Application of vertical load of 100 N to the incisal surface of mandibular central incisors

After applying the load, a color coded display of the pattern of von mises stress at the mandibular bone surrounding implant supported overdentures with different overdenture attachment designs was made. The color coding used in the study depicted red as maximum and blue as minimum and the shades in between showed variation of stresses from maximum to minimum.

The data obtained from the study were evaluated to observe stress distribution on mandibular bone surrounding implant supported overdenture different attachment designs.

3. Results

The maximum stresses recorded around the bone surrounding implant supported overdenture with different attachment designs are depicted in table 2 and figure 6. The maximum von mises stress values recoded at the canine region for cortical bone was found in model B (3.11 MPa) followed by model D (2.90 MPa) and least by model C (2.16 MPa). All three models with attachments had higher stress values in comparison to model A with mandibular conventional complete denture (1.5 MPa).

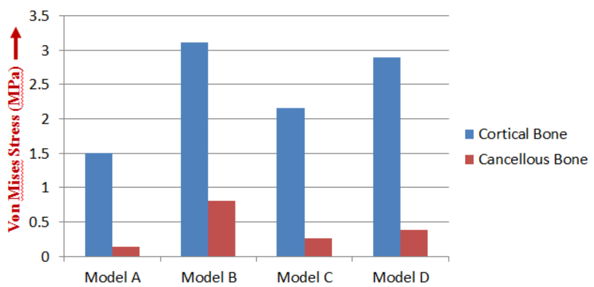

Figure 6. Von Mises stress contours (MPa) in cortical and cancellous bone at canine region

Table 2: Von-Mises stresses for cortical and cancellous bone at canine region for all models

Finite Element Models	Von Mises stress in cortical bone (MPa)	Von Mises stress [redacted]cellous [redacted]Pa)
Model A	1.5	[redacted]
Model B	3.11	0.81
Model C	2.16	0.27
Model D	2.9	0.38

For cancellous bone, the maximum von mises stress was found in model B (0.81 MPa) followed by model D (0.38 MPa) and least by model C (0.27 MPa). All three models with attachments had higher stress values in comparison to model A with mandibular conventional complete denture (0.14 MPa).

4. Discussion

The results of the present study indicated that the maximum von mises stress values recoded at the canine region for cortical bone and cancellous bone was seen in mandibular overdenture retained with hader bar-clip attachment (model B) followed by combination of hader bar-clip attachment with distally placed ball attachment (model D) and least in ball attachment (model C). All three models with attachments had higher stress values in comparison to mandibular conventional complete denture (model A). This was in accordance to the studies conducted by Barao et al.,[11] Vedovatto et al.,[4] Menicucci et al.[3] and Pesqueira et al.[7] where it was stated that the presence of implant and attachment system in overdenture groups decrease the amplitude of prosthesis movement leading to more stresses on the overdenture groups. Similar results have been reported by Tokuhisa et al.,[17] Manju et al.,[6] Jha et al.[1] and Goiato et al.[25] who found that the highest stresses in the cortical and cancellous bones for implant retained overdentures were lower than the ultimate strength of the respective bones. Hence bone resorption does not occur. Likewise Ribeiro et al.,[26] Amer et al.,[12] Dashti et al.[13] and Kenney et al.[14] documented that overdenture treatment improves denture retention and stability leading to a higher comfort and chewing efficiency in comparison to conventional complete dentures.

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(4), 1607-1615 | ISSN:2251-6727

Similar to the results of the present study, various authors[1,3,4,6,7,9,13,14,17] reported that ball attachment exhibits lower stress values owing to flexibility and resiliency provided by the o-ring rubber and the spacer in the o-ring system assembly. Barao et al.[11] stated that since o-ring rubber has low modulus of elasticity, it leads to stress-breaking effect, thereby minimizing stresses in implants, prosthetic component and supporting tissues. El-Anwar et al.[32] observed that smaller neck of the ball and socket attachment enables greater energy absorption, which reduces the amount of energy (stress) transferred to the mucosa, cortical bone and cancellous bone. Menicucci et al.[3] was of the opinion that mandibular deformation during load application creates torsion in the central part of the mandible. In case of ball attachment, since the two implants are independent and can thus follow the distortion of bone without affecting it, the stresses are minimised. However, with the bar-anchored mandibular implant-retained overdentures, the rigid bar connecting the two implants tends to counteract this movement, therefore more stress reaches the peri-implant bone. Hence, splinted implants have higher peak of stress concentration as compared to unsplinted implants.

In contradiction to the results of the present study, Polat et al.,[5] Tabata et al.,[8] Bilhan et al.[19] and Shishesaz et al.[21] reported that the use of rigid bars had a positive effect on load distribution while the use of solitary anchors resulted in a tendency towards greater forces on implants. According to them, the bar-clip system associated with 2 implants provides only an anteroposterior rotation movement of the prosthesis. Also, because of the prevention of independent implant movement owing to the splinting effect, bar-clip system can dissipate the stresses uniformly between the implants and thus produce a favorable effect on stress-strain distribution. On the contrary, ball attachment system associated with 2 implants allows multi-directional (anteroposterior, lateral and intrusive) movement. This greater amplitude of movement, mainly the intrusive one, is responsible for mucosa compression. In addition, although overdentures are implant retained, they are supported by tissue. Therefore resilience of the mucosa influences the amplitude of the movement of prosthesis. It has been hypothesized that soft mucosa allows greater prosthesis displacement under functional loads, increasing the stress concentration on supporting tissue surrounding the implants, which can lead to bone resorption and treatment failure. Similarly, Satpathy et al.[22] reported that owing to the absorption of most of the stresses around the implant on the side of loading in ball/o-ring attachment, incidences of screw loosening, need for replacement of o-ring matrices and subsequent failure might occur when they are subjected to high amount of stresses over increased periods of time.

For the combination of hader bar-clip with distally placed ball attachment, the present study reported that maximum von mises stresses were higher than ball attachment but lower than hader bar-clip attachment with distally placed ball attachment. The results of the present study were corroborated with the studies conducted by Barao et al.,[11] Celik et al.[33] and Pesqueira et al.[7] According to them, use of distal attachment on bar-clip system creates a fulcrum line around which the prosthesis rotates anteroposteriorly. Due to the elastic modulus of the resilient matrices that fit around the ball attachments, the stress magnitude on the implants is reduced. Also, such a design was supported by Mericske-stern et al.,[34] Jassim et al.[20] and Sadowsky et al.[35] who recommended 5 to 7 mm distal cantilever bar lengths on two implants supporting a mandibular overdenture. They also added that the total lengths of the cantilever must be shorter than the central bar segment and they must be not be extended beyond the distal aspect of first premolar. In contrast, Sabra et al.[16] stated that in case of distal cantilevers, lack of resistance to bending induced a higher risk of mechanical overloading. Likewise, Shishesaz et al.[21] reported that combination of bar-ball attachment experienced the most overdenture displacement under unilateral masticatory load and hence was an inferior design in comparison to ball attachment in terms of overdenture stability. Moreover, Misch[24] critiqued the design and suggested at least four implants to provide sufficient support to include a distal cantilever up to 10 mm on each side to limit the risk of screw loosening and other prosthetic complications.

In the present study, increased stresses in the cortical bone in comparison to cancellous bone for all the models could be explained by stress-transferring mechanism that occurs in the implant-bone complex. Stresses induced by occlusal loads are initially transferred from implant to cervical bone, whereas a small amount of remaining stress is spread to trabecular bone at apical region. It is also possible that higher strain values are observed in

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(4), 1607-1615 | ISSN:2251-6727

cortical bone because it presents higher modulus of elasticity as compared to trabecular bone and thus greater ability to transfer stress. These findings are in accordance with in vitro studies[2,3,9,18,21] that found higher stress concentration in cortical bone around implant neck. Also, in vivo study by Cakarer et al.[36] has demonstrated that bone loss is initiated in the region around the implant neck. Cortical bone stress concentration is a clinical concern owing to bone resorption around the neck of the implant. Therefore, it is imperative that excessive loads on the implants should be avoided as they may lead to bone loss through the induction of bone microdamage.[8,37]

However there are certain limitations in the present study. The results were obtained through a mathematical model, which cannot fully represent the complexity of the biological field. The mechanical properties of bone is extremely difficult to be modelled as it is highly heterogeneous, anisotropic and is also dependent upon age and sex of the individual. Consequently, it is not easy to introduce the correct material properties of specific bones. Moreover, due to the unknown level of physiological tolerance, additional scientific support is needed while extrapolating the results of the present study to clinical situations for defining the best of attachment systems. Long term prospective study should also be performed to validate the clinical significance of findings obtained through finite element analysis.

5. Conclusion

Within the limitations of this study, it was concluded that von Mises stresses were greatest for the hader bar with clip attachment followed by hader bar-clip with distally placed ball attachment and least by the ball attachment system in mandibular bone surrounding implants retained overdenture. The von Mises stresses recorded in mandibular bone surrounding implants retained overdenture for all the three attachments was higher in comparison to conventional mandibular complete denture.

References

1. Jha DUK, Singhal MK, Nair C, Dubey GN, Agarwal A, Badiya SK et al. An Evaluation of Attachments: Implant-supported Overdentures. J Dent Sci Oral Rehab 2016;7(4):174-7.
2. Abdelhamid AM, Assaad NK, Neena AF. Three dimensional finite element analysis to evaluate stress distribution around implant retained mandibular overdenture using two different attachment systems. J Dent Health Oral Disord Ther 2015;2(5):1-11.
3. Menicucci G, Lorenzatti M, Pera P, Preti G. Mandibular implant-retained overdenture: finite element analysis of two anchorage systems. Int J Oral Maxillofac Implants 1998; 13:369-76.
4. Vedovatto E, Mazaro JVQ, Filho HG, Carvalho PSPD, Mello CCD, Lemos CAA. Biomechanical analysis of implant assisted-overdentures with variations in the attachments systems. Mater Sci Appl 2015; 6:734-42.
5. Polat S, Uludag B. The effects of different attachment systems on stress in 2-implant retained overdentures. J Eng Sci Des 2014;2(3):267-71.
6. Manju V, Sreelal T. Mandibular implant-supported overdenture: an in vitro comparison of ball, bar, and magnetic attachments. J Oral Implantol 2013;39(3):302-7.
7. Pesqueira AA, Goiato MC, Santos DMD, Nobrega AS, Haddad MF, Andreotti AM et al. Stress analysis in oral obturator prostheses over parallel and tilted implants: photoelastic imaging. J Biomed Opt 2013;18(10):1-5.
8. Tabata LF, Assuncao WG, Barao VAR, Gomes EA, Delben JA, Sousa EACD et al. Comparison of single-standing or connected implants on stress distribution in bone of mandibular overdentures: a two-dimensional finite element analysis. J Craniofac Surg 2010;21(3):696-71.
9. Barao VAR, Assuncao WG, Tabata LF, Delben JA, Gomes EA, de Sousa EACD et al. Finite element analysis to compare complete denture implant-retained overdentures with different attachment systems. J Cranofac Surg 2009;20(4):1066-71.
10. Warreth A, Byrne C, Alkadhimi AF, Woods E, Sultan A. Mandibular implant supported ov erdentures: attachment systems and number and locate on of implants- Part II. J Ir Dent Assoc 2015;61(3):144-8.
11. Barao VAR, Delben JA, Lima J, Cabral T, Assuncao WG. Comparison of different designs of implant-retained overdentures and fixed full-arch implant-supported prosthesis on stress distribution in edentulous mandible – a computed tomography-

based three-dimensional finite element analysis. J Biomech 2013; 46:1312-20.

12. Amer MM, Rashad HA, Abdallah S. Stress distribution of implant retained obturators using different types of attachments: a three dimensional finite element analysis. Tanta Dent J 2015;12:30-40.
13. Dashti MH, Atashrazm P, Emadi MI, Mishaeel S, Banava S. The effects of two attachment types on the stresses introduced to the mandibular residual ridge: A 3D finite element analysis. Quintessence Int 2013;44(8):585-90.
14. Kenny R, Richards MW. Photoelastic stress patterns produced by implant-retained overdentures. J Prosthet Dent 1998;80(5):559-64.
15. Silva DPDS, Cazal C, Almeida FCSD, Dias RBE, Ballester RY. Photoelastic stress analysis surrounding implant-supported prosthesis and alveolar ridge on mandibular overdentures. IJDRD 2010;1-5.
16. Sabra SA, Nassani MZ, Baroudi K, Charkawi HE, Mohamed GF. Stress analysis of two attachment types for implant-supported overdentures in hemimandibulectomy cases. EC Dental Science 2016;5(5)1174-81
17. Tokuhisa M, Matsushita Y, Koyano K. In vitro study of a mandibular implant overdenture retained with ball, magnet, or bar attachments: comparison of load transfer and denture stability. Int J Prosthodont 2003;16:128-34.
18. El-Anwar MI, El-Taftazany EA, Hamed HA, Abd E, Hay MA. Influence of number of implants and attachment type on stress distribution in mandibular implant-retained overdentures: finite element analysis. Open Access Maced J Med Sci 2017;5(2):244-9.
19. Bilhan SA, Baykasoglu C, Bilhan H, Kutay O, Mugan A. Effect of attachment types and number of implants supporting mandibular overdentures on stress distribution: a computed tomography-based 3D finite element analysis. J Biomech 2015;48:130-7.
20. Jassim RK, Ibrahim IK. Finite element stress analysis study for stresses around mandibular implant retained overdenture MIR-OD. J Bagh Coll Dentistry 2014;26(2):30-6.
21. Shishesaz M, Ahmadzadeh A, Baharan A. Finite element study of three different treatment designs of a mandibular three implant-retained overdenture. Lat Am J Solids Stru 2016;13:3126-44.
22. Satpathy S, Babu CLS, Shetty S, Raj B. Stress distribution patterns of implant supported overdentures-analog versus finite element analysis: a comparative in-vitro study. J Indian Prosthodont Soc 2015;15(3):250-6.
23. Vafaei F, Khoshhal M, Movahed SB, Ahangary AH, Firooz F, Izady A et al. Comparative stress distribution of implant-retained mandibular ball-supported and bar-supported overlay dentures: a finite element analysis. J Oral Implanto 2011;37(4):421-9.
24. Misch CE. Contemporary Implant Dentistry. 3rd ed. St. Louis: Mosby; 2008.
25. Goiato C, Ribeiro PDP, Pellizzer EP, Pesqueira AA, Haddad MF, Santos DMD et al. Photoelastic analysis to compare implant-retained and conventional obturator dentures. J Biomed Opt 2012;17(6):1-4.
26. Ribeiro PDP, Goiato MC, Pellizzer EP, Pesqueira AA, Haddad MF, Alves-Rezende MCR et al. Photoelastic stress analysis of different attachment systems on implant-retained and conventional palatal obturator prostheses. J Craniofac Surg 2011;22:523-6.
27. Rismanchian M, Dakhilalian M, Bajoghli F, Ghasemi E, Eshkevari PS. Implant-retained mandibular bar-supported overlay dentures: a finite element stress analysis of four different bar heights. J Oral Implantol 2012;2:133-9.
28. Takeshita S, Kanazawa M, Minakuchi S. Stress analysis of mandibular two-implant overdenture with different attachment systems. Dent Mater J 2011;30(6):928-34.
29. Rambhau GJ, Arun KN, Vinod AS, Jaykumar GV, Kumar LK. Comparative evaluation of the effect of three different attachment systems on stress distribution patterns in two implant supported maxillary overdenture: a 3d finite element analysis. Int J Adv Res 2017;6(5):3570-3.
30. Ebadian B, Mosharraf R, Khodaeian N. Effect of cantilever length on stress distribution around implants in mandibular overdentures supported by two and three implants. Eur J Dent 2016;10:333-40.

31. Elsyad MA, Al-Mahdy, YF, Salloum MG, Elsaih EA. The effect of cantilever bar length on strain around two implants supporting a mandibular overdenture. Int J Oral Maxillofac Implants 2013;28:143-50.
32. El-Anwar MI, Mohammed MS. Comparison between two low profile attachments for implant mandibular overdentures. J Genet Eng Biotechnol 2014;12:45-3.
33. Celik G, Uludag B. Photoelastic stress analysis of various retention mechanisms on 3-implant-retained mandibular overdentures. J Prosthet Dent 2007;97:229-35.
34. Mericske-Stern RD, Taylor TD, Belser U. Management of the edentulous patient. Clin Oral Implants Res 2000;11:108-25.
35. Sadowsky SJ, Caputo AA. Stress transfer of four mandibular implant overdenture cantilever design. J Prosthet Dent 2004;92:328-36.
36. Cakarer S, Can T, Yaltirik M, Keskin C. Complications associated with the ball, bar and locator attachments for implant-supported overdentures. Med Oral Patol Oral Cir Bucal 2011;16(7):953-59.
37. Preiskel HW. Overdenture made easy: a guide to implant and root supported prostheses. London: Quintessence Publishing co; 1984.