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STRESS DISTRIBUTION OF IMPLANT-RETAINED OVERDENTURE WITH DIFFERENT ATTACHMENT SYSTEMS: A FINITE ELEMENT ANALYSIS

ДИСТРИБУЦИЈА НА НАПРЕГАЊЕТО КАЈ ИМПЛАНТ - РЕТИНИРАНА ПОКРОВНА ПРОТЕЗА СО РАЗЛИЧНИ СИСТЕМИ ЗА РЕТЕНЦИЈА: АНАЛИЗА СО МЕТОД НА КОНЕЧНИ ЕЛЕМЕНТИ

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Abstract

Objective: The aim of this paper is to analyze the force transmission and stress distribution of an implant-retained overdenture and to assess the influence of the overdenture retention system in the implants, peri-implant bone, and the posterior regions of the residual alveolar ridge. **Material and method:** A CBCT scan of the edentulous mandible was used to create a model. The tests were conducted on two models of a mandibular edentulous jaw, on which two implants were positioned in the interforaminal space. Different retention systems (ball, locator) and an acrylic removable prosthesis were placed in each model. The models were tested under axial loads of 150N, unilaterally and bilaterally, at the level of the first molar. These models were analyzed by finite element software (SOFIFTIK software package) using Von Mises stress analysis. **Results:** The highest stress values were observed at the implant necks and abutments in both models. Regarding the peri-implant bone and the posterior regions of RAG, the highest stress values were observed in the model with a locator attachment. **Conclusion:** According to the results of this study, we can conclude that ball attachments provide a more homogeneous distribution of load forces compared to locator attachments. **Keywords:** implants, overdenture, FEM (finite element method), biomechanics, attachments.

Апстракт

Цел: Целта на овој труд е да го анализира преносот на сила и дистрибуцијата на напрегање на имплант ретинирана покровна протеза, и да се процени влијанието на ретенцискиот систем на покровната протеза, во имплатите, пери-имплантната коска и постериорниот дел на резидуалниот алвеоларен гребен. **Материјал и метод:** Користено е CBCT скенирање на беззабната мандибула за создавање на модел. Испитувањата се спроведени на два модели на мандибуларна тотално беззабна вилица, на која во интерфораминалниот простор се позиционирани два импланти. Кај секој од моделите се поставени различни ретенциски системи(топка, локатор) и акрилатна мобилна протеза. Моделите беа тестирани под оптоварување со аксиални сили од 150N унилатерлно и билатерално на ниво на првиот молар. Овие модели беа анализирани од софтверот за конечни елементи (SOFIFTIK софтверскиот пакет) користејќи анализа на Von Mises стрес. **Резултати:** Највисоки вредности на напрегање беа забележани на вратот на имплантите и на абатментите во двата модела. Во однос на пери-имплантна коска и постериорниот дел на РАГ највисоки вредности на напрегања беа забележани кај модел со локатор атечмен. **Заклучоци:** Според резултатите од ова истражување, можеме да заклучиме дека, топка атечмените обезбедуваат, порамномерна дистрибуција на силите на оптоварување во спордба со локатор атечмените. **Клучни зборови:** импланти, покровна протеза, МКЕ (метод на конечни елементи), биомеханика, атечмени.

Introduction

For over a century, conventional dentures have been a non-invasive treatment option for complete tooth loss, also known as edentulism. However, in many cases, this rehabilitation does not meet patient expectations1. Edentulous patients often complain about the functionality of conventional dentures, particularly those made for the lower jaw (mandibular dentures). The resorption of the alveolar ridge is a crucial factor associated with the loss of stability and retention of the lower denture due to the reduction of the supporting tissue beneath the complete denture[2]. Overdentures (ODs) are a recognized method for prosthetic treatment of mandibular edentulism. Relatively affordable cost, simple clinical management, and significant improvements in retention and stability make this type of restoration an attractive treatment option for patients and dentists[3]. Following the McGill and York consensus, overdentures supported by two implants have become the preferred treatment for mandibular complete edentulism due to the favorable outcomes in improving orofacial function and patient satisfaction[4]. Implant-retained overdentures are usually retained on attachments, which allows for better retention and stabilization of the prosthesis. Various attachment-retention systems are used in implant-supported overdentures. Attachments are rigid or resilient connectors that absorb and orientate occlusal forces. Their function is to protect and preserve soft tissue and bones, provide retention, counteract forces that can dislodge the denture, and participate in transferring occlusal forces from the denture to the peri-implant tissue in an axial direction while distributing shear forces. If these forces are of high intensity or persist for long durations without compensation, exceeding the adaptive capacity of the affected tissue, they lead to morphological and functional changes in the least resistant tissues[5]. The ideal retention system for an implant-supported overdenture should be hygienic, easy to use, and ensure uniform and atraumatic transmission of occlusal loads to the bone[6]. Clinically, it is still impossible to assess stress distribution in the bone tissue caused by implant-retained overdentures. Bioengineering studies can evaluate the biomechanical characteristics of implants and dentures. Simulation-based methods, such as the finite element method (FEM), can be used to assess and quantify stresses on implants, peri-implant bone, and deformations of prosthetic components[7].

Objective

The **aim** of this study is to analyze force transmission and stress distribution in an implant-retained overdenture and assess the impact of the retention system on the overdenture, implants, peri-implant bone, and the posterior part of the residual alveolar ridge in conditions where a narrow mandibular ridge prevents the placement of standard-diameter implants.

Materials and methods

In accordance with the study's stated objective, numerical tests were conducted using a 3D model of a completely edentulous mandible analyzed through the finite element method (FEM). The 3D model was created based on CBCT (Cone Beam Computed Tomography) scans of an edentulous mandible. The study used a CBCT scan from a patient at the Clinic for Mobile Prosthetics at the Public Health Institution University Dental Clinical Center "St. Panteleimon" in Skopje. After obtaining written consent, the CBCT scan was performed at the University Clinic for

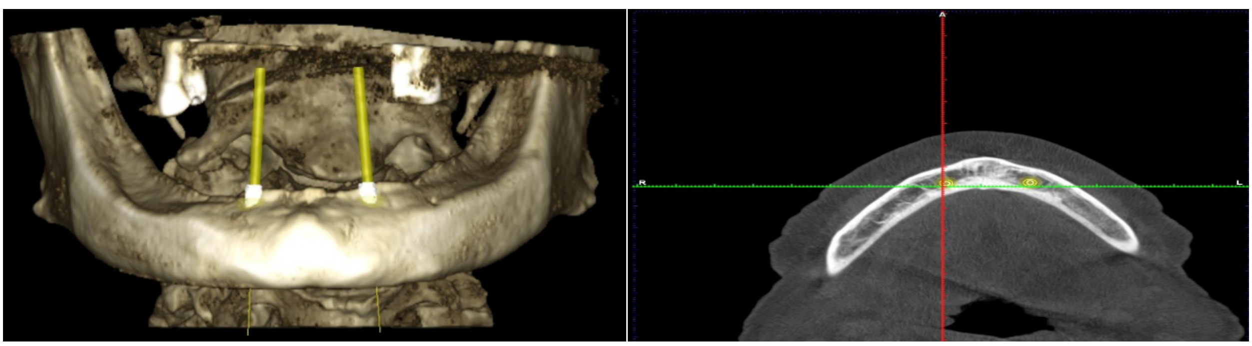


Figure 1. *CBCT radiographic images of an edentulous mandible with virtually positioned implants.*

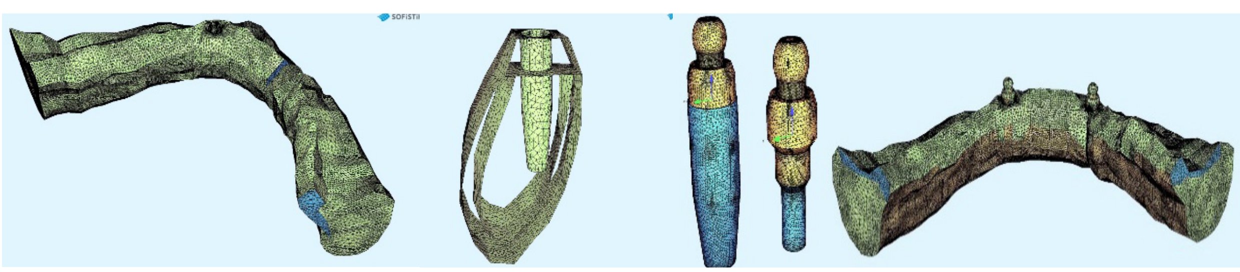


Figure 2. *3D finite element model of a mandible with implants and ball attachments*

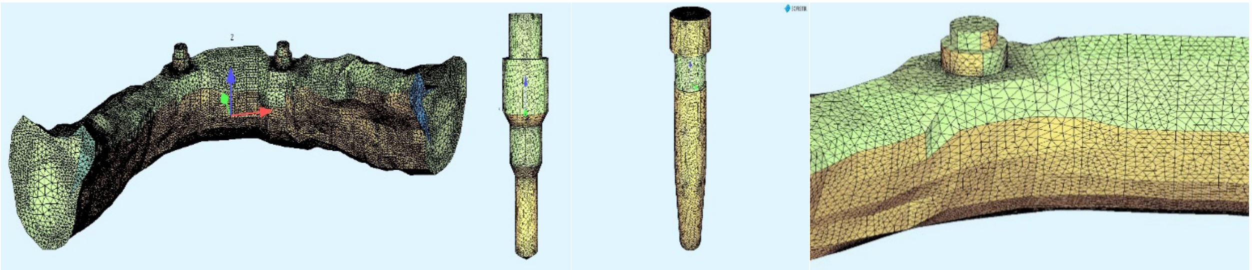


Figure 3. *3D finite element model of a mandible with implants and locator attachments.*

Maxillofacial Surgery in Skopje. Using the Romexis Planmeca software database, appropriate implants were positioned in the interforaminal space of the edentulous mandible.

The data obtained from the 3D radiography were used to generate a finite element mesh using the SOFISTIK software package. The boundary between cortical and cancellous bone was contoured.The contour data of the profiles were transformed into x, y, and z coordinate points. Tests were conducted on models of a completely edentulous mandible with two narrow-diameter implants (3.3 mm) placed in the interforaminal region.Each of the models has different retention systems, acrylic resin overdenture, and acrylic teeth

- **Model 1:** Two implants in the canine region with ball attachments
- **Model 2:** Two implants in the canine region with locator attachments

Material characteristics of the model

To perform finite element analysis, all model components must have precisely defined material properties. Most dental materials analyzed are assumed to be homogeneous, isotropic, and linearly elastic. The input parameters for all modeled objects include the modulus of elasticity (E) and Poisson's ratio (ν), derived from literature sources (Table 1).

Material characteristics of the model

The occlusal load was simulated with an axial force of 150 N, applied unilaterally and bilaterally to the first molar region. The study did not consider time as a factor in force application, meaning only short-term forces were analyzed. The study examined the impact of occlusal forces on the implants, peri-implant bone, and the posterior part of the alveolar ridge.

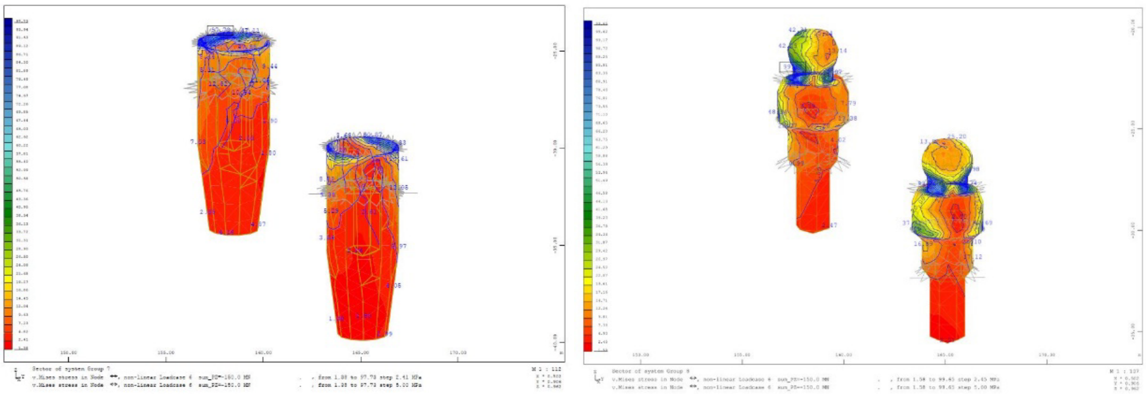
Results

The stress analysis conducted using the SOFISTIK software package provided results in the form of von Mises stress distribution maps with color-coded bands. These colors represent different levels of stress distribution, with red followed by orange, yellow, light green, green, light blue, blue, and dark blue, indicating the highest stress levels. With these different colors, the stress distribution pattern can be analyzed in different models. The stress values corresponding to each color are provided in the images.

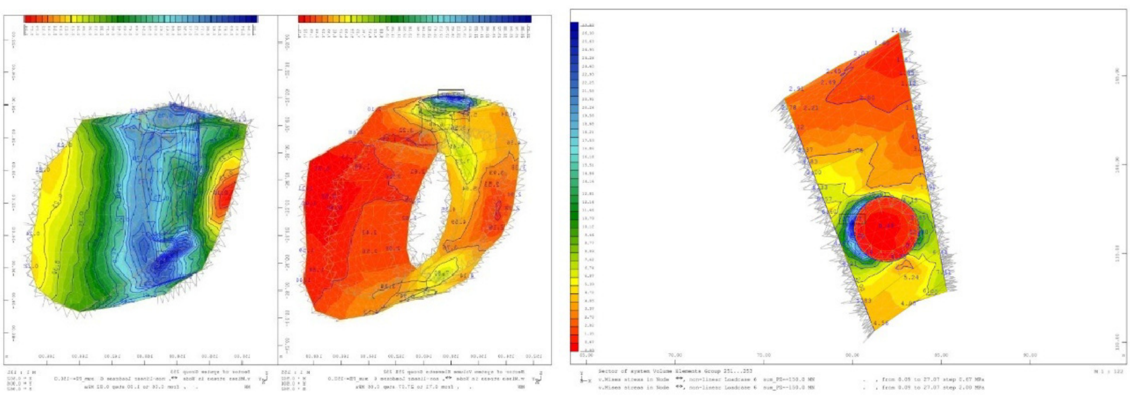
Table 1. Input parameters of oral tissues and prosthetic materials.

Material	**Elastic Modulus (MPa)**	**Poisson's Ratio (v)**
Implants/Attachments (Ti-6Al-4V)(21)	135,000	0.3
Cortical Bone (21)	13,700	0.3
Cancellous Bone(21)	1,370	0.3
Acrylic Resin(20)	3,000	0.35
Mucosa (20)	1	0.37
Nylon Cap (12)	350	0.40
Stainless Steel	19,000	0.31

Unilateral axial load of 150 N



a)



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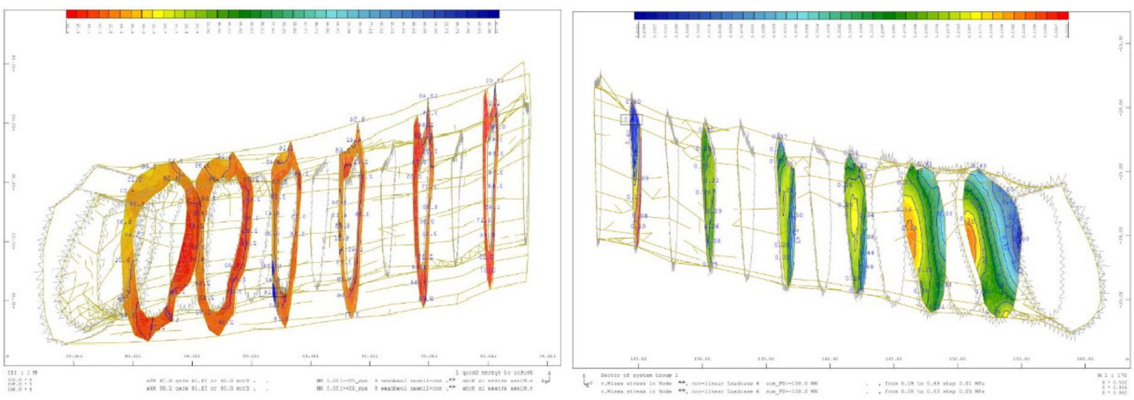
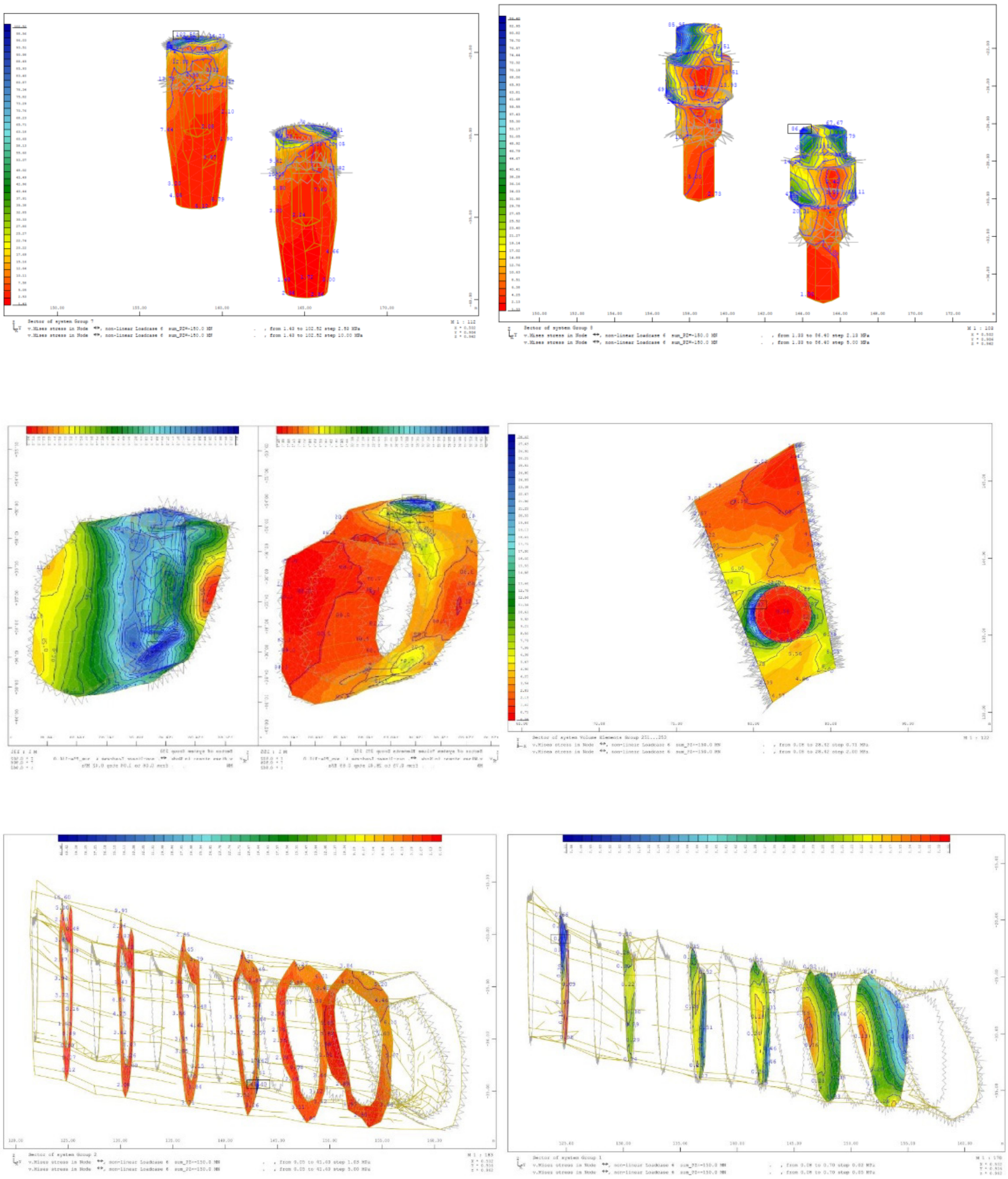


c)

Figure 5. *Von Mises stress (MPa) results for ball attachment, (a) implant, (b) peri-implant bone, and (c) posterior part of the RAG.*



a)

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Figure 6. *Von Mises stress (MPa) results for Locator attachment (a) implant, (b) peri-implant bone, and (c) posterior part of the RAG.*

Bilateral axial load of 150 N

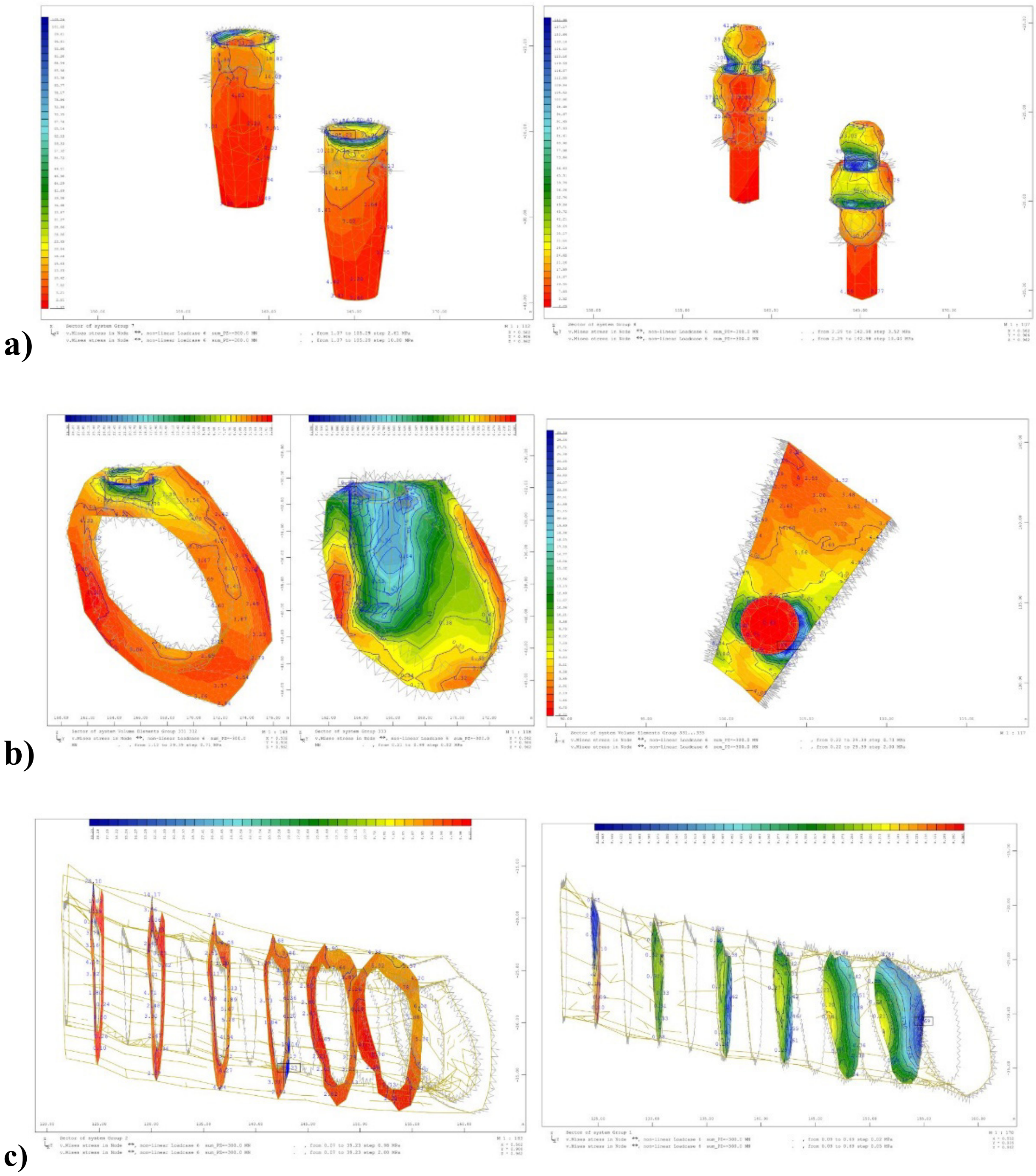

Figure 8. Von Mises stress (MPa) results for ball attachment, (a) implant, (b) peri-implant bone, and (c) posterior part of the RAG

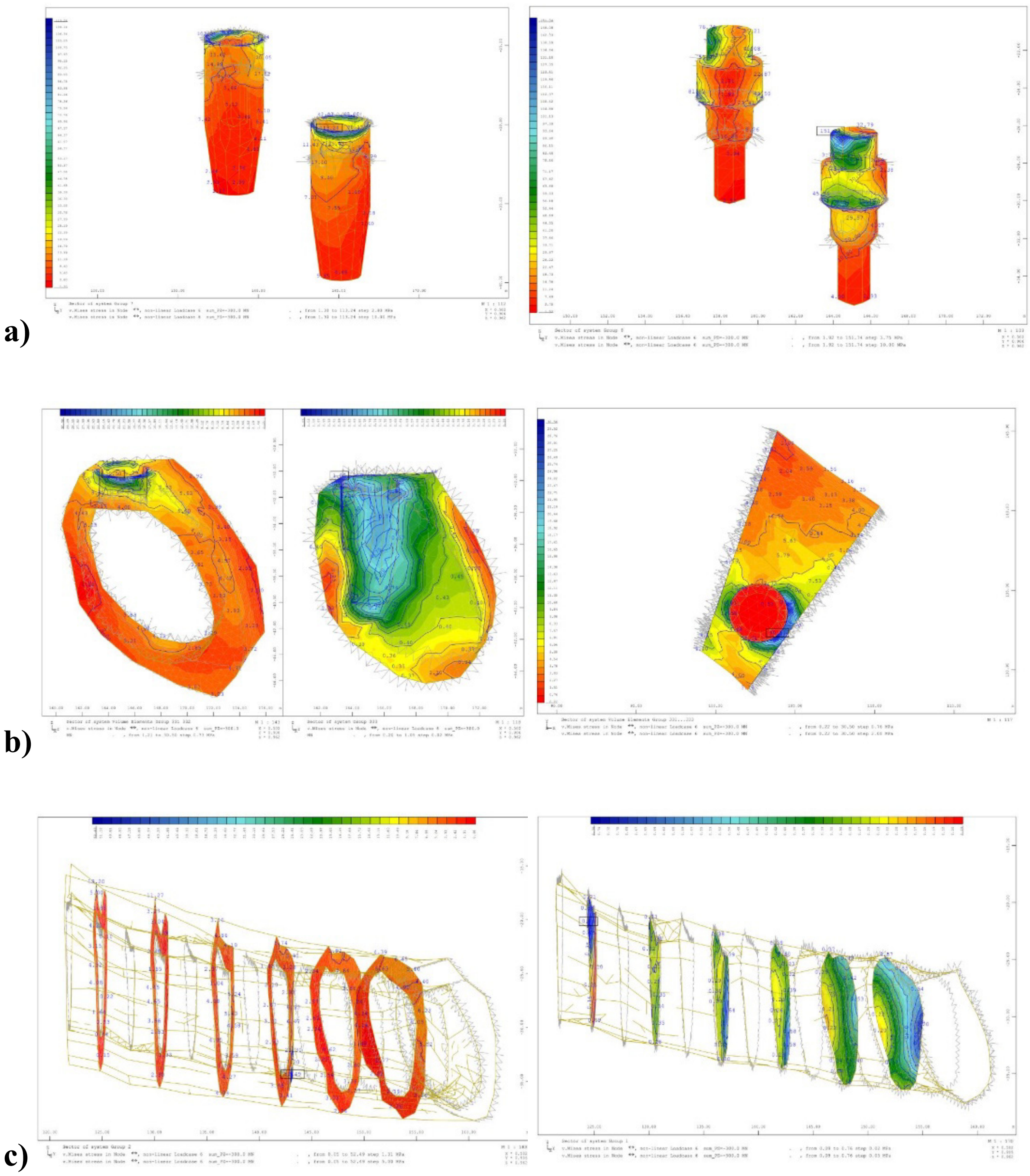

Figure 9. Von Mises stress (MPa) results for Locator attachment, (a) implant, (b) peri-implant bone, and (c) posterior part of the RAG

Tabular presentation of Von Mises stress values (MPa)

Table 2: Comparison of stress distribution for ball and locator under axial loading forces of 150 N, unilaterally.

Model	Implant		Peri-implant bone		Posterior region of RAG	
	body	abutment	cortical	cancellous	cortical	cancellous
Model-1 ball	97.73	99.65	27.07	1.00	31.60	0.62
Model-2 Locator	102.52	86.60	28.42	1.04	41.40	0.70

Table 2: Comparison of stress distribution for ball and locator under axial loading forces of 150 N, bilaterally.

Model	Implant		Peri-implant bone		Posterior region of RAG	
	body	abutment	cortical	cancellous	cortical	cancellous
Model-1 ball	105.29	142.98	29.39	0.99	39.23	0.69
Model-2 Locator	113.24	151.74	30.50	1.05	52.49	0.76

Graphical representation of Von Mises stress results (MPa)

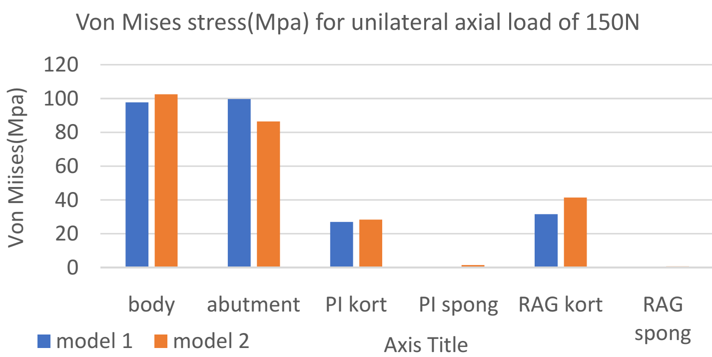

Figure 10. Comparison of stress distribution between the ball and locator attachment under a unilateral load of 150 N.

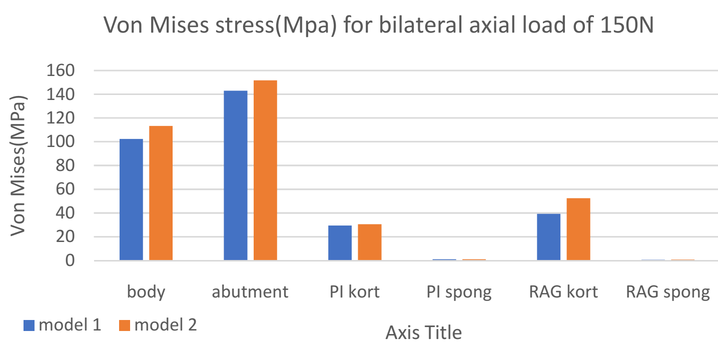

Figure 11. Comparison of stress distribution between the ball and the locator attachment under a bilateral load of 150 N.

Discussion

Despite a high survival rate of dental implants documented in various clinical studies, early or late failures of implant therapy remain unpredictable[6,19,20]. Structural problems and failures are often observed after prosthetic treatment. Due to the complexity of the masticatory system, numerous in vitro biomechanical studies on implant-supported restorations cannot fully clarify the mechanisms of osseointegration loss or implant fracture. This study aims to minimize the risk of clinical failures due to occlusal loading in the prosthetic treatment of completely edentulous mandibles by using FEM analysis, which accurately simulates conditions in the patient's mouth.The finite element method is a crucial tool in implant dentistry for studying stress distribution in bone tissue, biomechanics of dental implants and bones, implant-bone interfaces, and implant fatigue analysis. FEM is increasingly used by researchers due to advancements in virtual engineering that enable computer simulations under precise and stable conditions, reducing errors found in experimental studies[8]. Various factors influence stress distribution in implant-retained overdentures, including implant design, attachment type, loading conditions, and material properties of the implants, prosthesis, and bone[9]. This study investigates the effect of these factors on stress distribution to properly understand the biomechanics of stress transfer from the prosthesis to the attachments, implant, and surrounding bone in a two-implant overdenture. Data from related literature suggest that implants withstand axial forces better than horizontal and oblique forces, which, over time, may lead to bone loss, loosening, and potential implant failure. In this study, models were tested under an axial load of 150 N, as the literature indicates that the maximum chewing force for implant-supported overdenture patients is 150-170 N[10].One of the factors influencing the amount of force transmitted to the implant is the choice of the attachment system used for overdenture retention. The type of attachment used for retaining an implant-retained overdenture (IROD) is considered a crucial factor for implant success regarding the stresses occurring in the implant during function. Bhattacharjee et al. highlight the impact of the type of attachment on stress in the peri-implant bone as a conclusion from their analysis of literature data on this topic[11]. According to El-Taftazani et al., whenever the retention system is resilient, the stress in the bone around the implant is subsequently reduced, and some of the stress is transferred to the posterior part of the alveolar ridge. This results in better stress distribution, thereby reducing the maximum stress levels. Ball attachments are more resilient than locator attachments and, therefore, transmit less force. According to the authors, the resilience of these two attachments is closely related to the nylon caps used in the attachments. Since the volume of the nylon cap in the ball attachment is larger than that in the locator attachment, and because the ball attachment has a single retention mechanism while the locator has a dual retention mechanism, the ball attachment is more resilient and transmits less stress than the locator attachment[12]. This study confirms the same findings. The stress distribution in the model with ball attachments is more uniform, and lower Von Mises stress values appear in the implant, peri-implant bone, and the posterior part of the residual alveolar ridge (RAR).

Stress Distribution in the Implant

It is suggested that narrow-diameter implants have lower resistance to mechanical forces compared to standard-diameter implants. On the other hand, Morneburg et al. did not report any implant fractures over six years and two years of follow-up. According to the authors, implant fractures were avoided due to proper loading protocols, implant placement in the anterior part of the mandible, and the use of short attachments[13,14].This study showed that implants experience the highest stress when under load. Under an axial load, the highest stresses are observed at the neck of the implant body and the abutments in both models. The highest Von Mises stress values in the implant are observed in models with locator attachments. A recent finite element method study by Varela-Jimenez et al. determined that complications associated with narrow implants can be minimized by the mechanical advantages provided by a bar attachment. Connecting narrow implants with a bar would protect the implants from excessive loading and prevent fractures at the implant/abutment junction. Implant connections are made to increase the stability of the structure as a whole, achieve better stress distribution, and increase the total surface area receiving the load[15].

Stress Distribution in the Peri-implant Bone

The results of this study revealed that the stresses induced in the peri-implant bone upon loading were not high in the cortical and trabecular bone in the analyzed models. The highest stresses in the peri-implant bone are concentrated around the neck of the implants (i.e., in the cortical bone). Similar results have been reported in studies by Daas et al. and El-Zawahry et al.[16,17]. A review and meta-analysis conducted by Keshk et al. in 2017 on the impact of attachments on peri-implant bone resorption revealed no statistically significant differences among the analyzed attachment types regarding marginal bone loss, bleeding index, gingival index, and plaque index[18]. This result was also highlighted in this study. However, the different geometries of the two retention systems may reflect different, albeit not significant, stress distribution variations under a load.

Stress Distribution in the Posterior Part of the Residual Alveolar Ridge (RAR)

This study found no significant difference in Von Mises stress values in the posterior part of the RAR between ball and locator attachments. However, the model with ball attachments produced better results, with lower Von Mises stress values. Further in vitro studies using the finite element method have confirmed that ball attachments provide a more uniform distribution of loading forces on both sides of the residual alveolar ridge[19,20]. Menicucci et al. investigated stress distribution in the bone around the implant and the posterior part of the mandibular alveolar ridge in two-implant overdentures retained with ball and bar attachments using the 3D finite element method. The study suggests that ball attachments are preferable to bar attachments as they provide better stress distribution in the posterior part of the mandibular alveolar ridge[20]. Bollineni et al. conducted an evaluation and comparison of stress distribution in the peri-implant bone and posterior mandibular bone caused by an overdenture retained on narrow-diameter implants using two types of ball attachments: rigid and resilient. According to the author, when narrow-diameter implants are used, the stress in the peri-implant bone and the posterior part of the alveolar ridge increases. However, in patients with narrow ridges where implant placement with a standard diameter is limited, the precise selection of retention elements/attachmentsbecomes a critical factor in distributing masticatory forces. The conclusion is that overdentures retained on implants with resilient attachments show better stress distribution than those with rigid attachments[21].

The loss of implants and retention systems during oral rehabilitation has negative consequences on denture stability, mastication, and patient comfort. To prevent complications, a proper analysis of occlusal forces is recommended, along with an adequate number of implants, their optimal topographical placement, the selection of an appropriate prosthetic restoration, and continuous medical care for the patient to ensure timely and appropriate interventions to eliminate any deficiencies that may arise.

Conclusions

According to the results of this study, we can conclude that:

1. The highest stress values were observed at the implant necks and abutments in both models.

2. Regarding the peri-implant bone and the posterior part of the RAG, the highest stress values were observed in the model with a locator attachment.

3. Ball attachments provide a more even distribution of load forces compared to locator attachments.

Reference

1. Sharma S, Makkar M, Teja SS, Singh P. Implant-supported overdenture: a review. J Pharm Biomed Sci 2017; 07(7):270–277.
2. Kobayashi M, Srinivasan M, Ammann P, Perriard J, Ohkubo C, Müller F, Belser UC, Schimmel M. Effects of in vitro cyclic dislodging on retentive force and removal torque of three overdenture attachment systems. Clin Oral Implants Res. 2014 Apr;25(4):426-34. DOI: 10.1111/clr.12156. EPUB2013 Apr 9. PMID: 23566266.
3. Schmidt MB, Rauch A, Schwarzer M, Lethaus B, Hahnel S. Combination of Digital and Conventional Workflows in the CAD/CAM-Fabrication of an Implant-Supported Overdenture. Materials (Basel). 2020 Aug 20;13(17):3688. DOI: 10.3390/ma13173688. PMID: 32825488; PMCID: PMC7503874.
4. Geckili O, Cilingir A, Erdogan O, Kesoglu AC, Bilmenoglu C, Ozdiler A, Bilhan H. The influence of momentary retention forces on patient satisfaction and quality of life of two-implant-retained mandibular overdenture wearers. Int J Oral Maxillofac Implants. 2015 Mar-Apr;30(2):397-402. DOI: 10.11607/jomi.3774. EPUB2014 Dec 5. PMID: 25506644.
5. Stamenković D, Nastić M. Stomatološka protetika: parcijalne proteze. Beograd: Zavod za udžbenike i nastavna sredstva; 2000.
6. Ozan O, Ramoglu S. Effect of Implant Height Differences on Different Attachment Types and Peri-Implant Bone in Mandibular Two-Implant Overdentures: 3D Finite Element Study. J Oral Implantol. 2015 Jun;41(3):e50-9. DOI: 10.1563/AAID-JOI-D-13-00239. EPUB2014 Jan 28. PMID: 24471769.
7. Pammer D. Evaluation of postoperative dental implant primary stability using 3D finite element analysis. Comput Methods Biomech Biomed Engin. 2019 Feb;22(3):280-287. DOI: 10.1080/10255842.2018.1552682. EPUB 2019 Jan 24. PMID: 30676075.
8. Панчевска С. Тридимензионална анализа на дистрибуцијата на оклузалните сили кај парцијални протези со дистално слободни седла според методот на конечни елементи. (докторска дисертација) Скопје, 2010.
9. Satheesh Kumar P, Satheesh KK, John J, Patil G, Patel R. Force transfer and stress distribution in an implant-supported overdenture retained with a harderbar attachment: a finite element analysis. ISRN Dent. 2013 Dec 26;2013:369147. DOI: 10.1155/2013/369147. PMID: 24459589; PMCID: PMC3888690.
10. Helmy, M.A. Kothayer, M. Effect of two different overdenture attachments on the biting force and occlusal force distribution.Egypt. Dent. J. 2019, 65, 1723–1732.
11. Bhattacharjee B, Saneja R, Singh A, Dubey PK, Bhatnagar A. Peri-implant stress distribution assessment of various attachment systems for implant-supported overdenture prosthesis by finite element analysis - A systematic review. J Oral Biol Craniofac Res. 2022 Nov-Dec;12(6):802-808. DOI: 10.1016/j.jobcr.2022.09.002. EPUB 2022 Sep 7. PMID: 36159066; PMCID: PMC9490590.
12. El-Taftazani I, Moubarak A, El-Anwar M. Locator attachment versus ball attachment: 3-Dimensional finite element study. Egypt. Dent. J. 2011;57(2)
13. Morneburg T. R. Success rates of microimplants in edentulous patients with residual ridge resorption. The International Journal of Oral & Maxillofacial Implants. 2008;23(2):270–276.
14. S. Storelli, A. Caputo, G. Palandrani, M. Peditto, M. Del Fabbro. Use of Narrow-Diameter Implants in Completely EdentulousPatients as a Prosthetic Option: A Systematic Review of the Literature.

15. Valera-Jiménez JF, Burgueño-Barris G, Gómez-González S, López-López J, Valmaseda-Castellón E, Fernández-Aguado E. Finite element analysis of narrow dental implants. Dent Mater. 2020; 36:927-935.
16. Daas M, Dubois G, Bonnet AS, Lipinski P, Rignon-Bret C. A complete finite element model of a mandibular implant-retained overdenture with two implants: comparison between rigid and resilient attachment configurations. Med Eng Phys. 2008 Mar;30(2):218-25. DOI: 10.1016/j.medengphy.2007.02.005. EPUB 2007 Mar 26. PMID: 17383925.
17. El-Zawahry MM, Ibraheem EM, Nassani MZ, Ghorab SA, El-Anwar MI. Stress analysis of mandibular implant overdentures retained with one, two, or four-ball attachments: A finite element study. Dent Res J (Isfahan). 2018 Nov-Dec;15(6):437-443. PMID: 30534172; PMCID: PMC6243807.
18. Keshk AM, Alqutaibi AY, Algabri RS, Swedan MS, Kaddah A. Prosthodontic maintenance and peri-implant tissue conditions for telescopic attachment-retained mandibular implant overdenture: Systematic review and meta-analysis of randomized clinical trials. Eur J Dent. 2017 Oct-Dec;11(4):559-568. DOI: 10.4103/ejd.ejd_23_17. PMID: 29279687; PMCID: PMC5727746.
19. Menicucci G, Lorenzetti M, Pera P, Preti G. Mandibular implant-retained overdenture: finite element analysis of two anchorage systems. Int J Oral Maxillofac Implants. 1998 May-Jun;13(3):369-76. PMID: 9638007.
20. Unsal GS, Erbasar GNH, Aykent F, Ozyilmaz OY, Ozdogan MS. Evaluation of Stress Distribution on Mandibular Implant-Supported Overdentures With Different Bone Heights and Attachment Types: A 3D Finite Element Analysis. J Oral Implantol. 2019 Oct;45(5):363-370. DOI: 10.1563/aaid-joi-D-19-00076. Epub 2019 Sep 19. PMID: 31536445.
21. Bollineni U, Shetty R, Singh I, Gopalakrishna S.Influence of Attachment Configuration on Stresses in Completely Edentulous Mandibular Ridge with an Implant-retained Overdenture: A Finite Element Analysis.WorldJ Dent 2018;9(3)208-214