Ann Med Res

Current issue list available at AnnMedRes

Annals of Medical Research

journal page: www.annalsmedres.org

Comparison of the effects of implant locations and overdenture designs on the implants and bone stress: A finite element analysis

Elifnur Guzelce[a,*], Emre Tokar[b], Ozgul Karacaer[b]

[a] *University of Health Sciences, Hamidiye Faculty of Dentistry, Istanbul, Türkiye*
[b] *Gazi University, Faculty of Dentistry, Ankara, Türkiye*

ARTICLE INFO

Keywords:
Dental implants
Denture
Finite element analysis

Received: Aug 10, 2022
Accepted: Oct 12, 2022
Available Online: 21.01.2023

DOI:
10.5455/annalsmedres.2022.08.235

Abstract

Aim: The effects of implant locations and prosthesis design (palate less, full palate) on stress values of the implant and bone in maxillary overdenture prostheses were examined and compared with finite element analysis.

Materials and Methods: Full palate and palate less four implant supported finite element overdenture models have created with different implant locations (bilateral lateral-1. premolar, canine- 2. premolar, 1. premolar -1. Molar). Static loads have applied with food stuff method on 1. Molar region. Von mises stress on implants and implant parts, maximum and minimum principal stress generated in peri-implant bone have calculated with finite element analysis method (FEA).

Results: As a result, it was observed that the palate less design creates more stress on the implants and bone compared to the full palate design. In addition, stress formation was observed to be higher in models with implant positions are posterior.

Conclusion: In implant supported overdentures (ISO), palatal coverage ensures more balanced distribution of stresses occurring around the implants and implant parts, regardless of the location of the supporting implants.

Introduction

Nowadays ISO have become common option treatment for edentulous patients who are not satisfied with their removable prosthesis. ISO has many advantages such as good chewing function, stability, retention, and phonation compared to traditional methods thus, it improves the patient's comfort and quality of life [1]. Two implant supported mandibular overdenture prosthesis are the first treatment option for mandibular edentulous patients [2]. And if patient's situation, maxillary bone, and occlusion are proper maxillary overdenture prosthesis are good treatment options for maxillary edentulous cases.

In implant-supported prostheses, stress caused by chewing loads on implants and supporting tissues is an important issue. Overloads cause to biomechanical complications with bone loss around the implant, and long-term failure of the implants occur [3]. The type and location of implants, design of prosthesis should be carefully evaluated when planning the stage of treatment in order to ensure a proper force transmission to implants and peri implant bone [4]. Minimum two implants provide adequate support for prosthesis in mandibular overdenture, but maxillary ISO have shown quite lower success rates than mandibular overdentures because of the bone quality in the maxilla [2]. It has been reported that six implants are ideal for maxillary overdenture prosthesis and at least symmetrically four implants should be placed. There are also several studies comparing two, four and six implants [5]. It has been stated that as the number of implants increases, chewing forces are spread over a larger area and destructive effects of the mastication forces are reduced [6]. In studies there is a clear conclusion has been reached regarding implant locations in maxillary ISO, however, many studies have shown that canine and premolar regions are ideal for implant placement in terms of anatomical considerations and biomechanics of the prosthesis. Thus, anteriorly positioned implants are suggested to experience less stress formation in ISO [7].

Palateless overdentures have provided lots of advantages such as less in weight, comfortable chewing, perception of temperature, effective phonation but this type of denture design does not have enough mechanical properties when compared to full palate prosthesis [8-10]. In addi-

*Corresponding author:
Email address: eguzelce@hotmail.com (Elifnur Guzelce)

tion, retention and rigidity problems can be seen in ISO palateless prosthesis. For this reason, stress is transmitted uncontrollably over the implants and bone. In studies, it was observed that there was more implant loss in the palate less ISO prosthesis. Therefore, full palate and palate less designs have some advantages and disadvantages. In both prosthesis designs, the Poly Methyl Meta-Acrylate (PMMA) should be strengthened with Cobalt Chromium alloy (Co-cr) to prevent fracture deformation, to strengthen the prosthesis and to ensure the proper transmission of stress [11].

To the authors' knowledge, although there are studies on palate design, a finite element study evaluating palatal design in the maxillary ISO generated with LOCATOR with implant positions has not been previously reported. In this study, the effect of different implant locations and denture designs on stresses of implants and bones were observed with FEA in maxillary ISO. The aim of this study is to evaluate the effects of different implant locations, on the stresses create on support implants and bone in maxillary full palate and palateless ISO. The null hypothesis of the study is that stress distribution will be more successful in full palate overdenture prostheses, and the more posterior the implant locations are, the more balanced stresses will occur on the support implants and bone under chewing forces.

Materials and Methods

In this study, four implants were placed in three different positions on the maxillary crest. Cobalt chromium metal framework supported overdenture prostheses with full-palate coverage and without palate coverage were designed on the implant embedded models. 100 N load was applied to the prosthesis using the food stuff method in the 1st molar tooth region. Stress values, distributions and condensation areas of the implants, cortical and trabecular bone were evaluated. The study was performed using static linear analysis with three-dimensional finite element stress analysis method. Three different maxillary models were tested and stress results of them compared with each other:

In the current study, 4 implants were placed on the full toothless maxillary crest. Four implants were used in each maxilla model.

> MODEL 1: Two implants were placed in the lateral incisor tooth region, and two implants were placed in the first premolar tooth region. Overdentures were fabricated with full palatal coverage and without palatal support.
>
> MODEL 2: Two implants were placed in the canine tooth region, and two implants were placed in the second premolar tooth region. Overdentures were fabricated with full palatal coverage and without palatal support.
>
> MODEL 3: Two implants were placed in the first premolar tooth region; two implants were placed in the first molar tooth region. Overdentures were fabricated with full palatal coverage and without palatal support.

Finite element models

Computers with Intel Xeon ® R CPU 3.30 GHz processor and Windows 7 Ultimate Version Service Pack 1 operating system were used for the arrangement of the 3D network structure and making it more homogeneous, creating the 3D solid model and finite element stress analysis. Models were transferred to Algor Fembro (ALGOR, Inc.Pittsburgh, USA) software in ".stl" format, which has universal value for 3D modelling programs, to perform geometrically generated analyses with VR Mesh software (Virtual Grid Inc, Bellevue City, USA). It was introduced to the Algor Fembro software that the materials to be used and the model belongs to the maxilla. Elasticity modulus and Poisson ratio values that define the physical properties of the materials were loaded. (Table 1) [12-15].

An edentulous adult tomography was taken to construct the geometric model of the upper jaw. The jawbone was scanned on Conical Beam Tomography (ILUMA, Orthocad, CBCT, 3M Imtec, Oklahoma, USA). The sections obtained by scanning were converted to DICOM 3.0 format and imported into 3D-Doctor (Able Software Corp., MA, USA). In 3D-Doctor software, bone tissues were separated on sections using an interactive segmentation method. The segregated sections were turned into a 3D jaw model with the "Complex Render" method. Dimensional and topographic arrangements were made in VR Mesh software related to the jaw model. Spongy bone was obtained from the bone tissue via offset method. The spongious bone was obtained from bone tissue by offset method and the bone texture was modeled according to this. In the current study, the type 3 maxillary bone was modeled in the light of literatures [12].

Four dental bone level implants with 12 mm length and 4.1mm diameter were placed into the virtual edentulous models with three different location planning. The dental implants have bone level design (ITI Straumann, Institute Straumann AG, Basel, Switzerland), and shoulder type abutments were preferred to compatible with tested dental implants. Low profile stud attachments (Locator® R-TX, Zest Anchors Inc, Escondido, CA, USA) were inserted into the connection of the implant for retention of overdenture prosthesis. In this study, implants and prosthetic components were scanned using 3D with Smart Optics 3d scanner (smart optics Sensortechnik GmbH, Sin-

Table 1. Elastic modules and poison ratios of materials used.

Material	Young's Modulus (GPa)	Poisson's Ratio	References
Titanium implant and abutment	110	0.35	[12]
Cortical bone	13.7	0.3	[12]
Trabecular bone (D3)	1.37	0.3	[12]
Mucosa	0.68	0.45	[13]
Co-cr	218	0.3	[14]
PMMA	8.3	0.28	[13]
Locator Cap	3	0.28	[15]

terstrasse 8, D-44795 Bochum, Almanya) Rhinoceros 4.0 software (3670 Woodland Park Ave N, Seattle, WA 98103 USA) was applied to harmonize data between the upper and lower parts of the prosthesis, implant screws and bone tissues.

The maxillary cortical bone, spongiosis bone, mucosa, lower and upper parts of the prosthesis and implants were moved to the model to reflect true morphology in order to obtain exact modeling of the maxilla. The infrastructure materials were modelled with a thickness of 0.5 mm and the modelling process was completed by placing them in the correct coordinates in 3-dimensional space with Rhinoceros software and force transmission was achieved.

Loading and border conditions

Bone implant connection status: It was assumed that there was a tight connection between the bone and implants across the entire interface since implants were assumed to be 100% osseo-integrated to the bone. The boundary conditions of the tested models were fixed immobilized in each Degree of freedom (DOF) under the jawbone. In all sections of the maxilla, it was fixed against rotations and displacements in all directions, with all the possible movements removed. All models fixed in this way in Rhino program were transferred to Algor Fempro software by preserving 3D coordinates. Models were converted into solid models according to the Bricks and Tetrahedral elements system.

Application of load

The models were exposed to 100 N force while applying to the first molar tooth area through the overdenture using the food stuff method. In the food stuff method, a hemisphere is placed in the area where the force is desired, and the force was transmitted to the prosthesis through this hemisphere and analyzed in the angled forces coming into the prosthesis. In this study, an application imitating chewing forces was made by applying force in this way [16]. The FEA method was used to measure and evaluate principal stresses on the bone and von mises stresses on the implant.

Calculation of finite element values and evaluation of results

Values obtained as a result of finite element stress analysis are the result of mathematical calculations without variance. Therefore, statistical analysis cannot be performed. The stress amount and distributions of the cross-section images are evaluated and interpreted with precision. At the end of the finite element stress analysis, the Fempro computer program can determine the value of 25 different stresses. The stresses that occur as a result of applied forces are, compression, tensile stress and shear stress. In the analysis results, positive values indicate tensile stresses and negative values indicate compression stresses. Whichever stress type has the greater absolute value in a stress element, the stress element is under the influence of that stress type and it is that stress type that should be evaluated.

Principal stress value is important for brittle materials. Because failure occurs when the maximum principle stress is equal to or greater than the highest tensile strength and the absolute value of the minimum principle stress is equal to or greater than the highest compressive strength. Von mises stress is defined as the onset of deformation for drawable materials such as metal and is calculated from the 3 principle stress value.

Results

Von Mises, maximum and minimum principal stress values and images are shown in Table (2-4). The stress values and distribution of the implants, cortical bone, and trabecular bone are shown in Figure (1-6).

In this study, stress values on the implants which are closest to the force applied area were compared. Among all

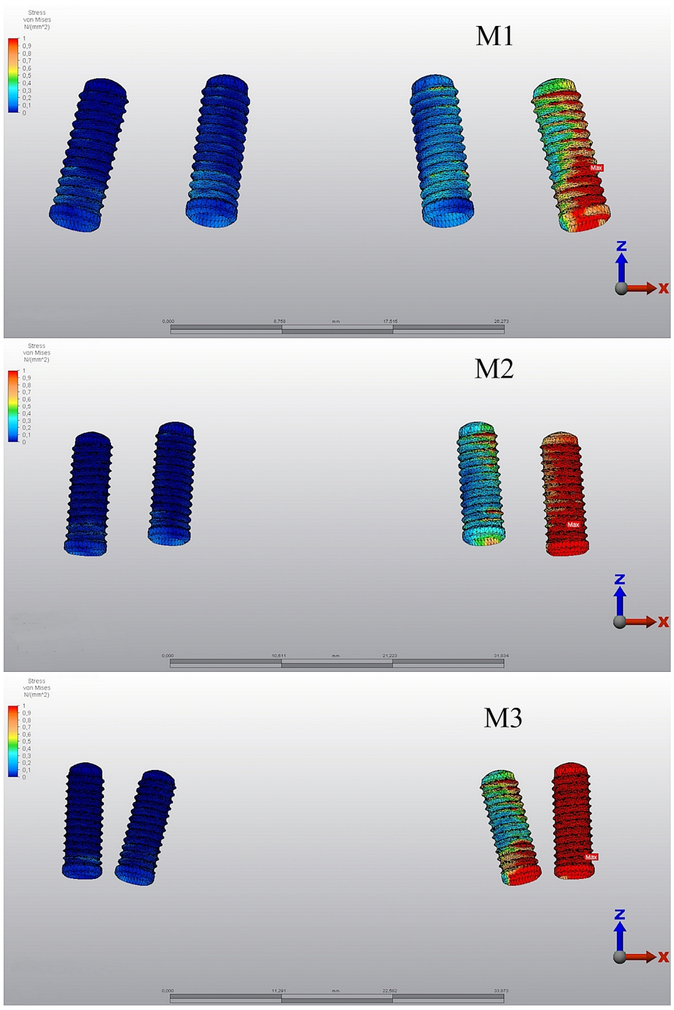

Figure 1. Von mises stress values (N/mm^2) on the implants for full palate M1, M2, M3 respectively.

Table 2. Maximum Von-mises stresses (N/mm^2) in the distal implants.

	M1	M2	M3
Full palate	8.70	9.10	11.07
Palateless	9.0	9.75	11.50

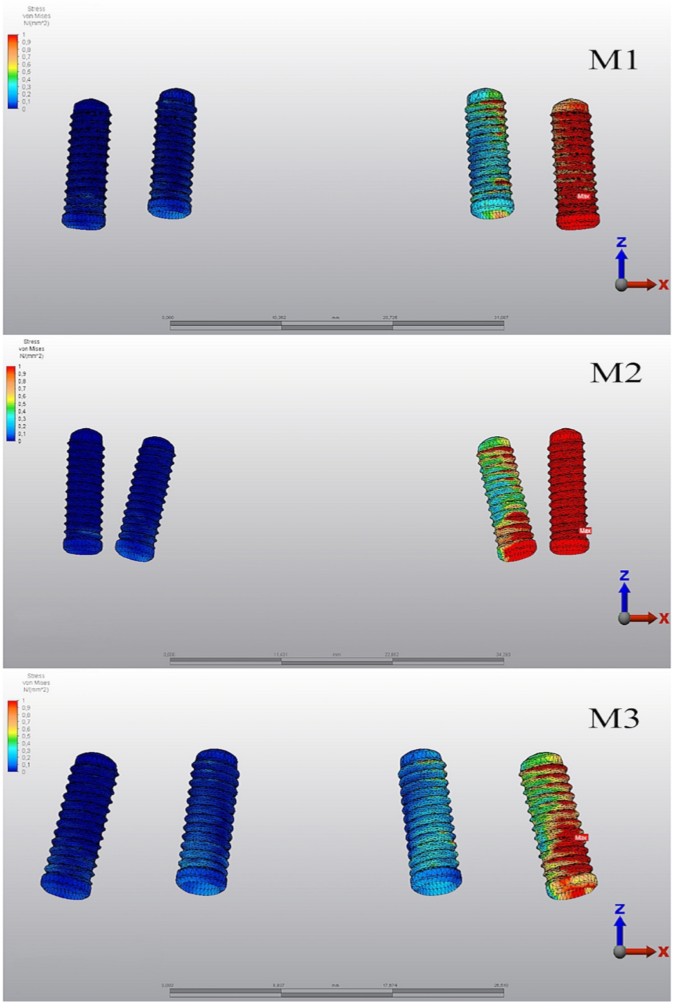

Figure 2. Maximum and minimum principle stress values (N/mm^2) on the cortical bone in full palate M1, M2, M3 respectively.

Table 3. Maximum and minimum principle stresses (N/mm^2) in the cortical bone.

		M1	M2	M3
Full palate	Max principle stress	1.76	2.80	9.25
	Min principle stress	-3.18	-3.33	-4.01
Palateless	Max principle stress	1.81	2.95	9.73
	Min principle stress	-3.34	-3.40	-4.98

Table 4. Maximum and minimum principle stresses (N/mm^2) in trabecular bone.

		M1	M2	M3
Full palate	Max principle stress	0.37	0.69	0.74
	Min principle stress	-0.63	-0.64	-2.88
Palateless	Max principle stress	0.39	0.72	0.75
	Min principle stress	-0.65	-0.68	-2.92

tested models, highest stress values were measured in the distal side of the implants. When comparing full-palate and palateless ISOs for all models, higher stress values were observed on the implants in the palateless ISOs.

In addition, it was observed that the stress values on the implants decreased as the implant locations approached the anterior, regardless of whether the prostheses were palate or non-palate. The highest stress concentrations on the implants were measured in the implant neck regions. (Figure 1-2) (Table 2).

In the current study, maximum and min principal stresses were evaluated for cortical and trabecular bone. Lower principal stress values were observed in the trabecular bone than in the cortical bone. For cortical bone and trabecular bone, the highest stress values were found in peri-implant region in all models and prosthesis design, mainly on the distal side (loading region) of the distal implants. (Figure 3-6) (Table 3-4).

Discussion

As a result of this in vitro study, we observed that maxillary ISO prostheses with full palate planned on anteriorly placed implants are more advantageous in terms of force transmission on the implants and tissues than palate-less maxillary ISO's which planned with implants placed on posteriorly. The design of the maxillary ISO needs to be planned with care to reduce the stress on the tissue and implants. Therefore, several factors should be considered such as the number of implants, implant location and the palatal coverage of prosthesis. In the literature, there have been numerous studies evaluating the number of implants as support for ISO designs. In the current study, effects of palatal support of maxillary ISOs with various implant positions were evaluated on the stress values of implants and supporting bone. In this study, full palate and palate-

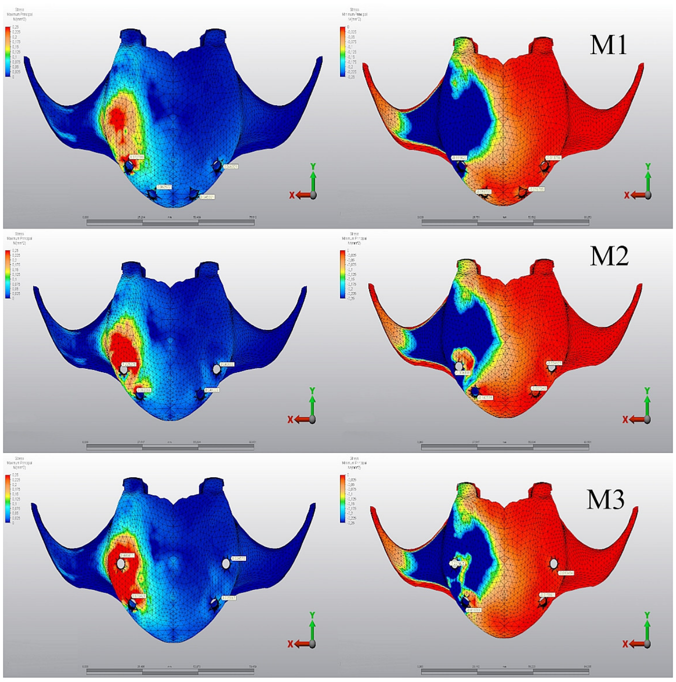

Figure 3. Maximum and minimum principle stress values (N/mm^2) on the cortical bone in full palate M1, M2, M3 respectively.

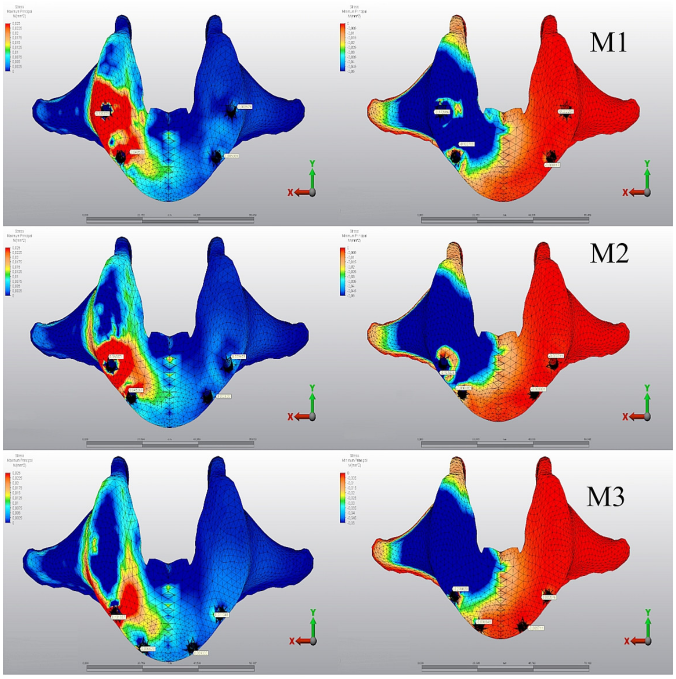

Figure 4. Maximum and minimum principle stress values (N/mm^2) on the trabecular bone in full palate M1, M2, M3 respectively.

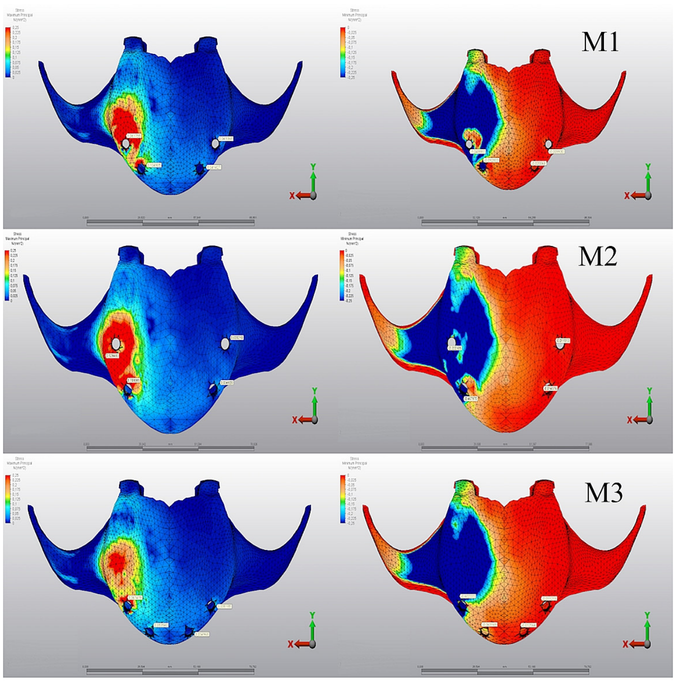

Figure 5. Maximum and minimum principle stress values (N/mm^2) on the cortical bone in palateless M1, M2, M3 respectively.

less ISOs were created with implants located in three different locations (M1: bilateral lateral-1. premolar, M2: canine- 2. premolar, M3:1. premolar -1. Molar) to observe the effects of implant locations and prosthetic design (full palate, palateless) on the stresses on the supporting bone and implants.

Lewis et al. [17] suggests that ISOs supported by two im-

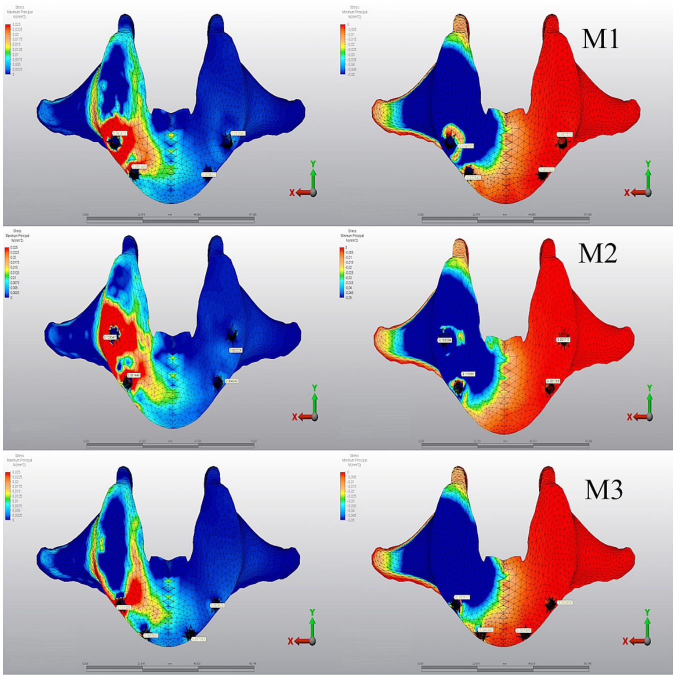

Figure 6. Maximum and minimum principle stress values (N/mm^2) on the trabecular bone in palateless M1, M2, M3 respectively.

plants cannot be recommended due to rotational motion of prosthesis and adverse effects on the denture bearing areas. There are numerous studies recommending at least four implants to support maxillary ISOs [18,19]. Slot et al. [6] compared four and six implant-supported maxillary ISO designs and concluded that a six-implant supported ISO was the most successful in terms of survival of both implants and overdenture. However, Cavallaro and Tarnow [19] claimed that four implants supported maxillary ISO are 100% successful. Calvert et al. [20] compared prostheses supported by four and six implants in terms of implant survival, and the group supported by four implants was found to be more successful than those supported by six implants. Sadowsky et al. [21] evaluated maxillary implant prostheses with an emphasis on the number of implants and anchor design. They concluded that there should be a minimum of four implants to support the maxillary ISO.

Reinforcement PMMA with Co-cr has been suggested to prevent fracture deformation, strengthen the prosthesis, and provide appropriate stress transmission in both palate and non-palate overdentures. It has been reported that metal reinforcement embedded in the base of the prosthesis, or a rigid palatal metal substructure is required to prevent problems caused by the stress that occurs during function, especially in palateless prostheses, compared to full-palate designs [11]. In the present study, four implant supported (full palate and palateless) overdenture prostheses were modeled while creating the FEA models in parallel with the previous studies [6,17-20]. The present study was also observed less stress on the implants and the bone around the implant in all tested models with different implant positions, with full-palate ISOs compared to ISOs without palatal support.

For overdenture prostheses, the force transmitted to the supporting bone by the implants are related to the location of the implants as well as the number of implants. The wide distribution of implant locations in the maxillary arch, such as the canine and molar regions, significantly reduces the stress on the implants and supporting bone. However, cantilever designs are also an important issue in planning of prosthetic superstructure [22,23]. Takahashi et al. [24] tested three main types of supports (two, four, and six implant arrangements) in maxillary ISOs with distributions that are combinations of two anterior, two premolar, and two molar implants. Tension in premolar and molar implants was similar in all numbers and distributions. However, the tension on anterior implants increased as the number of implants decreased. In the current study, three different implant planning locations (M1: lateral – 1st premolar, M2: canine – 2nd premolar, M3: 2nd premolar – 1st molar) were compared with each other. As similar with previous research, this study was demonstrated more significant stress formation in the distal implants and tissue around the implant compared to anterior implants. When compared the stress values of the distal implants between the models (M1-M2-M3), higher stress values were noted in Model 3 (2nd Premolar – 1st molar), where the implants were placed more distally, than the other models.

El-Saih [5] researched effects of palatal support and implant locations on the stress distribution of edentulous maxilla with four dental implant support. The author fabricated palateless overdentures for the patients. Patients were divided into two groups in terms of implant locations: canine / premolar distribution (group I), canine / molar distribution (group II). As a result of the study, resorption in the neck region of the implants was found significantly less in group II. El-Amier et al. [7] investigated different types of overdenture designs supported by 4 implants. They divided the models into two groups according to the distance between the implants. One of the groups was planned as canine and 2nd premolar (14 mm between implants) support and the second group was established as canine and 1st molar (22 mm between implants) support. They observed that retention of prosthesis increased while the distance between the anterior and posterior implants increased. Damghani et al. [25] surveyed the stress on the palate during the use of palatal prosthesis supported by four implants. The authors compared the implant positions by keeping 8, 16 and 24 mm between the anterior and posterior implants. As a result of the study, they stated that when 16 mm or 24 mm distance is left between the anterior posterior implants in the maxillary arch, the designs over four implants are not different from the designs supported by 8 implants in terms of stress on the palate.

Elsyad et al. [26] reported that ISOs placed over the canine/molars create a posterior cantilever and cause more stress around the distal implants. They showed that cantilevers in implant-supported prostheses increase the possibility of off-axis force transmission and overload, which causes peri-implant bone loss and possible prosthesis failure. Duyck et al. [23] followed up implant supported prosthesis cases and reported that when biting force is applied to a distal cantilever in over-implant prostheses, the highest axial forces and bending movements are recorded in distal implants. The effect of undesirable forces due to cantilevers may increase with the length of the anterior-posterior prosthesis and the type of bone around the implants.

The aim of this study is to examine the effects of implant positions on the stress values of the implant and bone in full palate or palateless maxillary overdenture prosthesis. In ISOs, the palatal part is undesirable for maintaining oral sensation and function [9,10]. Palateless dentures are lighter in weight as they do not completely cover the palate, resulting in better stereognosis, comfort, tongue orientation, taste, and temperature perception, as well as more effective phonation, chewing and swallowing [8-10,24] . On the other hand, palateless dentures provide less retention, rigidity, or strength than palatal prostheses [24,27]. Moreover, in some clinical reports, palateless overdentures have been associated with more prosthetic and implant complications than full palate prostheses [24,27,28]. Takahashi et al. [4] compared the shear stresses on full palate and palateless maxillary overdentures supported by different numbers of implants placed in different locations on the jawbone and reported that the tension is much higher in dentures without palatal support than in dentures with full palatal coverage. These results are consistent with previous reports on maxillary complete dentures and support the idea that palateless dentures are more likely to show denture base deformation and fracture than palatal dentures. In addition, these results suggest that palateless ISOs transfer more stress to the supporting tissue and may cause complications as noted in previous reports. El Mekawy et al. [29] compared the effect of palatal covarage on retention forces in mini-implant supported overdentures. They reported that mini-implant-supported overdentures with complete palatal coverage showed higher retentive properties.

In this study, 100 N force [13,15] was applied to the molar teeth area with the food stuff method [16,30], similar to previous studies, in order to imitate the chewing forces. In this method, a hard spherical surface is used to represent the food item. The main purpose of using hard surface models is to limit computation time and facilitate contact management. It is aimed to compare isotropic and anisotropic configurations [16]. Instead of analyzing angular and perpendicular forces separately, horizontal, vertical and oblique forces can all be analyzed [16,30].

The limitations of this study, like similar FEA studies [13,15], are that materials are assumed to have isotropic linear elasticity and bone is considered to be homogeneous. Furthermore, the bone-implant interface is considered to be adherent and in tight contact across the entire interface. However, these assumptions are not possible in clinical conditions. Therefore, further clinical studies are needed on this subject.

Conclusion

The current study demonstrates to the following conclusions within limitations:

1. The implant locations that show the most balanced stress distribution in the implants and the bone around the implant is M1, M2 and M3, respectively.

2. It has been observed in ISO that palatal covering ensures a balanced distribution of stress.
3. More stress occurs on the supporting implants that was placed in the anterior region of the maxillary crest, no matter whether the prosthesis design has full palatal coverage or without palatal support.

Acknowledgements
No external financial support was received for the study.

Ethics approval
Our study is an in vitro 3D finite element stress analysis study. Ethical approval is not required.

References

1. Laurito D, Lamazza L, Spink MJ, et al. Tissue-supported dental implant prosthesis (overdenture): The search for the ideal protocol. A literature reviews. Ann Stomatol (Roma). 2012;3:2-10.
2. Thomason JM, Feine J, Exley C, et al. Mandibular two implant-supported overdentures as the first-choice standard of care for edentulous patientsnts-The York Consensus Statement. Br Dent J. 2009;22:185-86.
3. Mizuno Y, Takahashi T, Gonda T, et al. Mechanical analysis of a palateless denture. Int J Prosthodont. 2013;26:419-22.
4. Takahashi T, Gonda T, Tomita A, et al. Influence of palatal coverage, and implant distribution on denture strain in maxillary implant overdentures. Int J Oral Maxillofac Implants. 2016;31:43-8.
5. Cleave RJ. Maxillary insufficiency implant and tooth-retained maxillary overdenture: a clinical case report. J Oral Implantol. 2000;26:29-33.
6. Slot W, Raghoebar GM, Vissink A, et al. A comparison between 4 and 6 implants in the maxillary posterior region to support an overdenture: 1-year results from a randomized controlled trial. Clin Oral Implants Res. 2014;25:560–6.
7. El-amier, Nesma, et al. Effect of implant location on palateless complete overdenture retention: An in vitro study. Journal of oral & maxillofacial research. 2018;9:30-3.
8. Zhang H, Sone M, Yamamoto H, et al. Influence of experimental palatal plate on mandibular position during continuous phonation. J Prosthodont Res. 2009;53:38-40.
9. Strain JC. The influence of completed dentures upon taste perception. J Prosthet Dent 1952;2:60-67.
10. Shannon IL, Terry JM, Nakamato RY. Palatal coverage and parotid flow rate. J Prosthet Dent. 1970;24:601-7.
11. Takahashi T, Mizuno Y, Gonda T, et al. Metal reinforcement of a complete maxillary denture without a palate: a preliminary report. Int J Prosthodont. 2015;28:188-90.
12. Zarb GA, Schmitt A. Osseointegration for elderly patients: the Toronto study. J Prosthet Dent. 1994;72:559-68.
13. Patil PG, Seow LL, Uddanwadikar R, et al. Biomechanical behavior of mandibular overdenture retained by two standard implants or 2 mini-implants: A 3-dimensional finite element analysis. J Prosthet Dent. 2021;125:138.
14. Koca OL, Eskitascioglu G, Usumez A. Three-dimensional finite-element analysis of functional stresses in different bone locations produced by implants placed in the maxillary posterior region of the sinus floor. J Prosthet Dent. 2005;93:38-44.
15. Kim MJ, Hong SO. Finite element analysis on stress distribution of maxillary implant-retained overdentures depending on the Bar attachment design and palatal coverage. J Adv Prosthodont. 2016;8:85-93.
16. Bonnet AS, Postaire M, Lipinski P. Biomechanical study of mandible bone supporting a four-implant retained bridge: finite element analysis of the influence of bone anisotropy and foodstuff position. Med Eng Phys. 2009;31:806-15.
17. Lewis S, Sharma A, Nishimura R. Treatment of edentulous maxillae with osseointegrated implants. J Prosthet Dent. 1992;68:503–8.
18. Kappel S, Klotz AL., Eberhard L, et al. Maxillary implant overdentures on two or four implants. A prospective randomized cross-over clinical trial of implant and denture success and survival. Clin Oral Implants Res. 2021;32:1061-71.
19. Cavallaro JS, Tarnow DP. Unsplinted implants retaining maxillary overdentures with partial palatal coverage: Report of 5 consecutive cases. Int J Oral Maxillofac Implants. 2007;22:808-14.
20. Calvert G, Lamont T. Four implant bar-connected implants sufficient to support a maxillary overdenture. Evid Based Dent. 2013;14:49-50.
21. Sadowsky SJ. Treatment considerations for maxillary implant overdentures: a systematic review. J Prosthet Dent. 2007;97:340-48.
22. Kim Y, Oh TJ, Misch CE, et al. Occlusal considerations in implant therapy: clinical guidelines with biomechanical rationale. Clin Oral Implants Res. 2005;16:26-35.
23. Duyck J, Van Oosterwyck H, Vander Sloten J, et al. Magnitude, and distribution of occlusal forces on oral implants supporting fixed prostheses: an in vivo study. Clin Oral Implants Res. 2000;11:465-75.
24. Takahashi T, Gonda T, Mizuno Y, et al. Influence of palatal coverage, and implant distribution on implant strain in maxillary implant overdentures. Int J Oral Maxillofac Implants. 2016;31:36-42.
25. Damghani S, Masri R, Driscoll CF, et al. The effect of number and distribution of unsplinted maxillary implants on the load transfer in implant-retained maxillary overdentures: an in vitro study. J Prosthet Dent. 2012;107:358-65.
26. Elsyad MA, Elsaadawy MG, Abdou AM, et al. Effect of different implant positions on strain developed around four implants supporting a mandibular overdenture with rigid telescopic copings. Quintessence Int. 2013;44:679-86.
27. Osman RB, Ma S. Prosthodontic maintenance of overdentures on zirconia implants: 1-year results of a randomized controlled trial. Int J Prosthodont. 2014;27:461-8.
28. Dudley J. Maxillary implant overdentures: current controversies. Aust Dent J. 2013;58:420-3.
29. Nishimura Y, Takahashi T, Gonda T, et al. Influence of implant distribution and palatal coverage on the strain of splinted implant and overdenture in maxillary implant overdentures. Int J Oral Maxillofac Implants. 2021;36:281-8.
30. Ozan O, Kurtulmus-Yilmaz S. Biomechanical Comparison of different ımplant ınclinations and cantilever lengths in all-on-4 treatment concept by threedimensional finite element analysis. International Journal of Oral & Maxillofacial Implants. 2018;33: 64-71.