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Original research

Stress distribution of four implant supported overdentures with tilted standard-sized implants and mini implants*

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Purpose

The goal of the current study is to evaluate the stress distribution when tilted implants and mini-implants are used to support a mandibular overdenture.

Materials and Methods

Three-dimensional (3D) finite element models of mandibular overdentures were established using four, axial, standard-sized implants (SA model), four standard-sized implants with the mesial ones axial and the distal ones tilted (ST model) and four mini-implants (MA model) with Locator attachments. On each model, a 100 N load was applied to the overdenture in four different directions; bilateral vertical, unilateral vertical and oblique load on the posterior region, and a vertical load on the incisors. The stresses distributed at the peri-implant bone, implants, the prosthetic components, and the overdentures were evaluated.

Results

Non-axial posterior loading caused higher stress values in the implant and the prosthetic component than axial posterior loading. Lower stress values of the implant and the prosthetic component were observed in the ST model than SA model. The stress distribution in the overdenture at posterior loads were mostly observed around the implants.

Conclusion

Less prosthetic complications may be expected when the treatment option in the ST model is used. Fatigue fractures may occur around the implants in the overdentures, precautions are advised.

Keywords: *Tilted implants, mini-implants, finite element analysis, locator, overdenture*

Introduction

The conventional rehabilitation of edentulism was used to be complete dentures. Their difficulty of use, low patient satisfaction, and reported high success of dental implants, resulted in declaration of McGill Consensus in 2002. According to the McGill consensus (1), the first treatment option to suggest to patients with edentulous mandible is complete dentures supported with two implants. Number of implants can be increased to three or four in order to create an angular relationship and prevent the movement of the denture towards the soft tissues (2). Overdentures supported by three or four implants are recommended when increased retention is needed in situations such as high muscle attachment or prominent mylohyoid ridges (3).

Rehabilitation with an implant-supported fixed restoration is primarily preferred to a rehabilitation with an overdenture if possible. It is stated that edentulous mandible can be rehabilitated with a fixed restoration by four implants in the interforaminal region, which tends to have substantive residual alveolar bone when the rest has been resorbed, with imme-

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diate loading when tilted but long implants are used distally (4,5). But unfortunately, fixed rehabilitation does not always meet the needs of the patient. Sometimes an implant-supported overdenture can be preferred because of its lower cost or to replace other lost tissues as well as teeth to obtain labial and buccal support to achieve esthetics. Using distally tilted implants instead of axial implants to support mandibular overdentures with non-splinted, single attachments has commercially came up with as they are used to support fixed prosthesis with the advantage of reduced cantilever length (6). But any study about this treatment concept has not been published yet therefore it lacks evidence.

Mini implants have been used for several years in partially edentulous situations when the interdental space is inadequate or adjacent teeth roots are convergent limiting the implant area. They are also preferred in edentulous situations when the crest is narrow and atrophic without any bone augmentation procedures (7). But there is limited number of studies about the stress of bone or prosthetic components generated by mini-implant supported overdentures and the application is not thoroughly justified yet (8).

The goal of the current study is to evaluate the stress distribution when locator attachments are used on tilted, interforaminal, standard-sized implants and axial mini-implants by using a finite element analysis (FEA). The influences of bilateral vertical loading, unilateral vertical loading, unilateral oblique loading and loading from the incisal site are investigated.

Materials and Methods

An edentulous mandible was modeled according to the tomography examination file of a patient who already had computed tomography examination from the database of the clinic of Bezmialem Vakıf University (Planmeca ProMax 3D Mid, Planmeca OY, Helsinki, Finland). 1 mm cross-sections were recorded in Digital Imaging and Communications in Medicine (DICOM) format. This file was opened with 3D Slicer software (9,10). The mandible was segmented by manual and automatic methods and the mesh-cleaning of the Standard Triangle Language (STL) data was carried out with MeshLab software (11).

The implants (Bluesky implants and miniSKY implants, Bredent medical GmbH & Co.KG, Senden, Germany) and the locator attachments (SKY locator, SKY locator angled, miniSKY locator; Bredent medical GmbH & Co.KG, Senden, Germany) used in the models were modeled according to the STL files received from the manufacturer. A mandibular overdenture was then designed with a cusp angle of 30°.

Three different models were constructed using the structures mentioned above only with the differences in implant type and implant inclination. All models included four implants with locator attachments to support the overdenture. The implants of all models were positioned in the interforaminal region with their apical end 13.5 mm away from each other. In the first model (SA model: Model with standard, axial implants) the implants having a length of 12 mm and diameter of 4.1 mm were positioned vertically to the occlusal plane. In the second model (ST model: Model with standard, tilted implants), the mesial implants having the same dimensions as model 1 were positioned vertically to the occlusal plane and the distal implants with a length of 16 mm and a diameter of 4.1 mm were tilted 35° distally elongating inter-implant distance. The distance between the mesial implants was 13.5 mm as in other models and the distance between the mesial and distal implants 17.5 mm in the crestal region. In third model (MA model: Model with mini, axial implants), four mini-implants having a length of 12 mm and diameter of 2.8 mm were positioned vertically to the occlusal plane to support the overdenture 13.5 mm away from each other (Figure 1).

The three-dimensional geometries of the mandible, implants and locator attachments were modeled and meshed in ANSYS Revision 14.5 software (ANSYS Revision 14.5, Canonsburg, Pennsylvania, USA). The meshing was performed with 3D four-node tetrahedron elements. The total number of elements and nodes are given in Table 1.

The edentulous mandible consisted of a constant 2 mm thick cortical bone covering the trabecular bone, covered by the mucosa with a thickness of 2 mm. The locator attachment consisted of three parts; the abutment on the implant, nylon replacement and the titanium cap in the denture. The implant, abutment and the cap were made of Ti-6Al-4V titanium alloy. All material properties were obtained from the literature (Table 2) and all materials were considered to be isotropic, homogeneous and linearly elastic. A total implant-bone osseointegration was assumed so a mechanical-

Figure 1. *The 3D FE models of the mandible and the prosthetic components: The SA model is four axial, standard-sized implants model; the ST model is four standard-sized implants model with the mesial ones axial and the distal ones tilted and the MA model is four mini- implants model.*

Table 1: *The total number of elements and nodes.*

	SA model	ST model	MA model
Node number	844831	630526	1082712
Element number	552145	408912	751121

Table 2: *The material properties used in the study.*

	Young's modulus (MPa)	Poisson's ratio	Reference
Ti-6Al-4V	103400	0.35	Sertgöz and Güvener (12)
Cortical bone	13700	0.3	Barbier *et al.* (13)
Cancellous bone	1370	0.3	Barbier *et al.* (13)
Overdenture	4500	0.35	Brunski *et al.* (14)
Mucosa	1	0.37	Menicucci *et al.* (15)
Nylon	28.3	0.4	Liu *et al.* (16)

ly perfect interface between the two structures existed in the models letting no movement to occur during analysis. To reproduce the clinical situation, contact was applied at the overdenture–mucosa interface and between parts of the attachments. The analysis was carried out with the FEA software ANSYS Revision 14.5. Von Misses equivalent stresses was calculated for all components.

Temporomandibular joints and masticatory muscles of temporal, masseter, medial pterygoid and lateral pterygoid were integrated in the models. The temporal muscle attached to the coronoid process of the mandible, the masseter muscle attached to the angle and lower half of the lateral surface of the mandible ramus, the medial pterygoid attached to the lower and back portion of the medial surface of the ramus and mandible angle, and the lateral pterygoid attached to the neck of the mandible condyle (Figure 2). Each muscular area was defined with 10 nodes of the elements. The temporomandibular joints were fixed in the upper parts of the condyles resulting in a rigid contact of the condyles and the glenoid fossae. Movements of rotation and translation were not allowed as in a previous study (17).

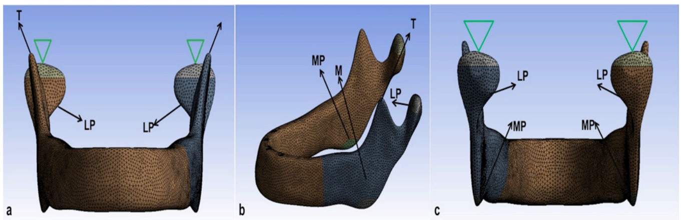

Figure 2. *The boundary conditions of the models. Arrows indicate the direction of the forces applied by the muscles (T: temporal; LP: lateral pterygoid; MP: medial pterygoid; M: masseter). The green triangles show the temporomandibular joint fixations. a- frontal view, b- lateral view, c-lingual view.*

The stress distribution of the related structures was evaluated at four different loading conditions that happen during different phases of chewing and biting. The loading conditions were; 1- The denture was loaded with vertical loads bilaterally on the first molar teeth region (BV load: bilateral vertical load). 2- The denture was loaded with a vertical load unilaterally on the first molar tooth region (UV load: unilateral vertical load). 3- The denture was loaded unilaterally at the posterior region. The direction of the load had an angle of 30° long axis of the teeth to simulate the early phase of mastication when the bolus is placed on the working side and there is no contact on the nonworking side (17) (UO load: unilateral oblique load). 4-The denture was loaded on the incisal surfaces of the incisal teeth as in the act of biting (Figure 3) (AV load: anterior vertical load). A recent systematic review has declared that mean maximum bite forces of implant supported overdentures from various studies ranged between 78.5 and 132.01 N (18). The total static load of 100 N was used at all conditions because it was in the declared range and 100 N was used in the literature of similar studies (5,17,19-21). The load was applied on the center of the occlusal surface in BV, UV and UO loading conditions.

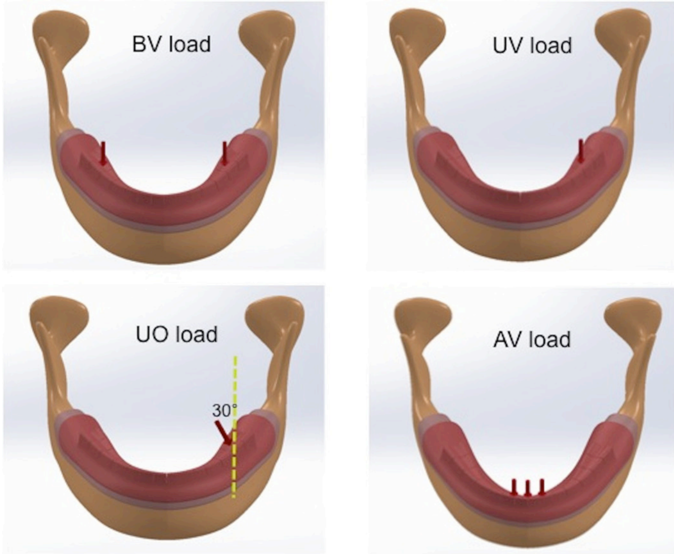

Figure 3. *The application of the masticatory force of 100 N at various places and with different inclinations. All four loading conditions are shown with their abbreviations.*

Results

Stress distribution in the peri-implant bone

The highest stress values of all structures are shown on Figure 4. The stress distribution of periimplant bone can be seen in Figure 5. Higher stress values were observed in the cortical bone than the trabecular bone. UO load and AV load caused higher stress levels (Fig 4).

The highest stress value of the cortical bone was observed when the ST model was loaded with UO load (31.29 MPa) followed by ST model loaded with AV load (28.08 MPa) (Figure 4 and 5). The lowest stress value of the cortical bone was observed when SA model was loaded with BV load followed by MA model and ST model loaded with BV load (5.06 MPa and 5.11 MPa respectively). When ST model was loaded with BV load and UV load, its highest stress values were around the mesial implants, differing from the other models having their highest stress values around distal implants.

Stress distributions on the implants and the prosthetic components

The stress levels of the implants and the prosthetic components and their distributions can be seen in Figure 4 and

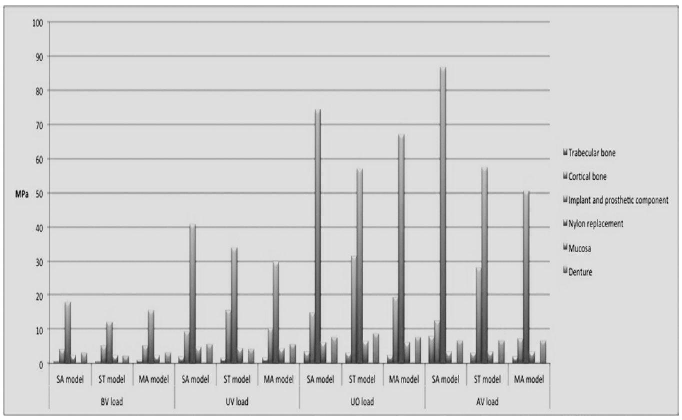

Figure 4. *The maximum stress levels of the structure of the models at different loading conditions.*

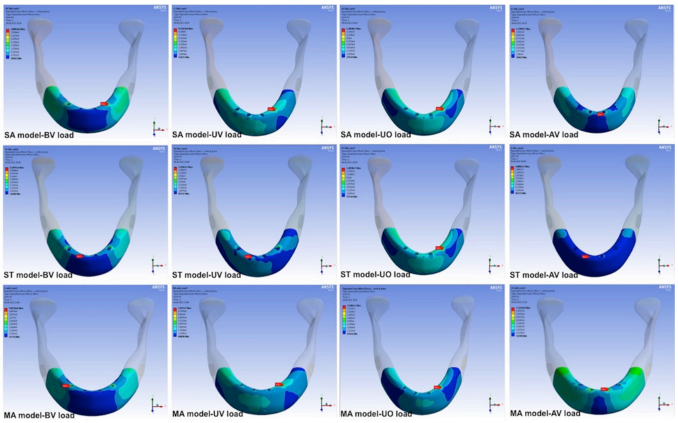

Figure 5. *The stress distribution of cortical bone of SA model, ST model and the MA model when loaded with BV load, UV load, UO load and AV load.*

6. The implant and the locator component displayed the highest stress values among other structures for all models at all loading conditions (Figure 4). The highest stress level was in SA model loaded with AV load (86,61 MPa). The SA model had higher stress levels for all loading conditions. According to the stress distribution, the stress areas were wider on the distal implants when the models were loaded posteriorly although the highest stress of the models was sometimes observed on mesial implants of the loaded side. Only ST model loaded with UV and UO load was an exception, having highest stress levels on the mesial implant of the unloaded side (Figure 6).

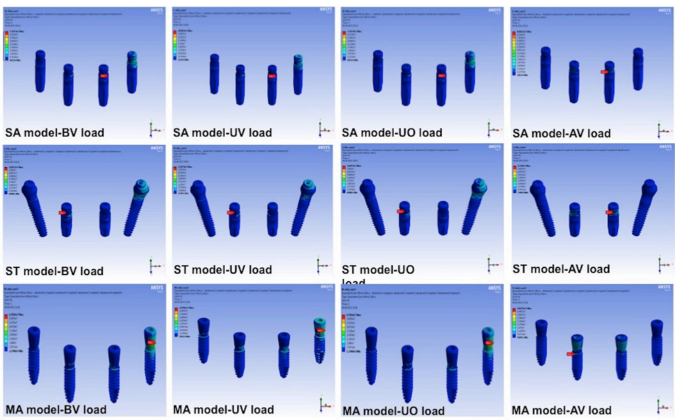

Figure 6. *The stress distributions of the implants and the prosthetic components of SA model, ST model and MA model when loaded with BV load, UV load, UO load and AV load.*

Stress distribution in the mucosa, nylon replacements and overdenture

Stress levels in the mucosa was quite low in all models for all loading conditions; it did not exceed 0.25 MPa (Figure 4). Any remarkable difference between the high stress values of nylon replacements was not observed between the three models for all loading conditions. The stress values differed in the range of 2.31 MPa (under BV load) and 6.58 MPa (under UO load) (Figure 4). There was not any remarkable difference between stress distribution of overdentures of the models at all loading conditions. Higher stresses developed when ST model was loaded with UO load (8.6 MPa) (Figure 4). The stress of the overdenture under posterior loads were mostly observed around the implants, not at the loading positions (Figure 7).

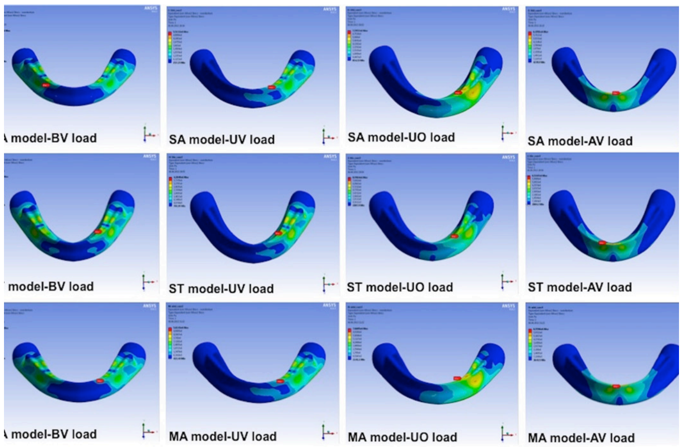

Figure 7. *The stress distributions of the overdenture of the SA model, ST model and MA model when loaded with BV load, UV load, UO load and MI load.*

Discussion

Overload is explained as forces exceeding the mechanical or biological capacity of load bearing of the structures as the bone, oral implants or the prosthesis causing mechanical failure or loss of osseointegration (22). The stress generated from overloading can be related to several consequences in the peri-implant bone, implant and the prosthetic component, mucosa, nylon replacement of a locator attachment and the overdenture. In the peri-implant bone, stress is related to implant's longevity and support (5). When implant is loaded, stress is transferred to its first material contact; peri-implant cortical bone; explaining the marginal bone loss (22). Naert *et al.* (23) has shown the correlation between marginal bone loss and high occlusal stress on the implants. This study has evaluated von Misses equivalent stresses which is applicable to ductile materials such as implants, prosthetic components and overdentures. Because of its non-ductile feature, bone should be evaluated with principal stress. However, the stress distribution in the bone was not totally excluded, but its limitations should be borne in mind. The results of the stress distribution of the bone are approximate.

The SA model in the study is overdenture supported by four interforaminal implants; a treatment modality that has been investigated and pleasing results were obtained (24). This accepted treatment modality is compared with overdentures supported by four standard-sized implants with distally tilted ones (ST model) and by four mini-implants (MA model). The ST model also displayed higher stress concentrations than SA model and MA model in other loading conditions (Figure 4). This finding probably depends on that in the ST model the overdenture is more implant-supported than the other models. Liu *et al.* (16) has suggested that as the number of implants increase, strain in the peri-implant bone also increases because more of the chewing force is shared by the implants. In the current study it can be claimed that the locator attachments on the distal implants were more distal than the models with axial implants (SA and MA); so, the mucosa-supported part of the overdenture was shorter for the ST model (Figure 1). That caused the mucosa support of the overdenture decrease and the implant support of the overdenture increase and more of the load to be borne by the implants than SA and MA models. Takahashi *et al.* (25) has stated that with All-on-4 concept the stress in the cortical bone around the implants decreased. The differences in these findings can be attributed to different prosthodontic applications The prosthesis evaluated in the aforementioned study was fixed and only implant-supported, while the prosthesis evaluated in the current study is an overdenture utilizing mucosa support in addition to implant support. Therefore, the part of the overdenture on the distal side of the implants cannot be considered as an actual cantilever. According to this result, it can be presumed that patient satisfaction for this treatment option can be higher than the other options due to more implant support than SA and MA models. The authors suggest further investigation of this assumption for future studies.

When the unilateral posterior loading conditions are compared, non-axial oblique UO load caused higher stress values in the denture and the implant and the prosthetic component than UV and BV load (Figure 4). This finding is in accordance with other studies stating that non-axial loading is more detrimental than axial loading for oral implants (26,27). For implant-supported overdentures, compressive forces are best to maintain the implant integrity, but shear and tensile forces tend to distract or disrupt the implant-bone interface (28). These harmful non-axial forces can also affect the denture, implants and prosthetic components. However, evaluating oblique forces on dental implants is stated to be more realistic than axial loading in stress analyzing studies of dental implants because function generates non-axial forces. It is also emphasized that excessive horizontal loading should be avoided for implant-supported restorations (29). In order to decrease the non-axial forces, the authors would like to advise using lingualized occlusion as the occlusal scheme of the implant-supported overdentures as it is also advised in the literature (28,30). In lingualized occlusion, the lingual cusp of the maxillary posterior teeth glides in the shallow central fossae of the mandibular posterior teeth providing buccolingual stability and thus diminishing lateral forces[24]. Besides its biomechanical advantages in implant-supported overdentures, it is indicated that masticatory performance and patient satisfaction increases with lingualized occlusion where the occlusal wear over time decreases (31,32).

The lower stress value of the implant and the prosthetic component assembly is remarkable in the ST model under all loading conditions when compared with the SA model (Figure 4). The more implant-borne denture in the ST model may have led to higher stress in the cortical bone but the smaller distal extension length has probably led to a smaller lever arm thus less stress in the implant and the prosthetic component. This finding can be interpreted as less complication related to the implant and the prosthetic component, such as screw loosening, can be expected when the overdenture is supported with four standard-sized implants including distally tilted ones. But this assumption should also be supported by further clinical studies.

The stress concentration on the mesial implants and prosthetic components of the unloaded side observed in the ST model under UV and UO loads are also probably due to varying lever formations (Figure 6). Higher stress levels in the implant and the prosthetic component may be related to complications of the unloaded side within this assembly. Using both sides during chewing can be advised to the patient to eliminate this complication risk. Or repeated prosthetic complications can lead the clinician think that the patient is using the non-damaged side of the overdenture while chewing when this treatment option is used. However, these assumptions should be verified with clinical studies.

According to the findings of the study, the nylon replacements have similar stress levels for all three models at all loading conditions (Figure 4). It can be presumed that deterioration of the nylon replacement will not differ between SA, ST and MA models; and there will not be a more frequent need to change the nylon replacements for any of the treatment modalities. There is a need for clinical studies to verify this finding.

No remarkable stress values were observed in the mucosa in any models at any loading conditions (Figure 4). This finding is probably due to less mucosa support of the four-implant supported overdentures when compared with overdentures supported with a fewer number of implants such as one or two (16).

The stresses distributed in the overdentures at loads exerted at the posterior regions were mostly observed around the implants; so, it can be predicted that denture fractures may occur around the implants (Figure 7). Although locator attachments have a low profile among other single attachments, the acrylic resin is still thin because of the bulk of the attachment and prone to fracture (33). Reinforcing the acrylic resin can be considered at the regions around the implants when these treatment modalities are applied.

There are several limitations for this study. The material properties about the biological tissues are assumed to be constant where it is quite variable from one individual to another or even within the same individual. The transversely isotropic and inhomogeneous cortical bone is taken as homogeneous, isotropic and linearly elastic (16). Peri-implant tissues are complex and their simulation with this method is an approximation (34). Also, a complete osseointegration was assumed in the models and this assumption may not be reflecting the clinical situation with varying osseointegration percentages from 30% to 70% (35). So, comparing the stress concentration areas and relative values of different treatment modalities are aimed in FEA studies instead of reporting the absolute values of stress (36). Von Misses stresses were evaluated in the current study although it is not applicable for non-ductile bone tissue. It is appropriate only for ductile materials such as the implants, prosthetic components, nylon replacement and the overdenture yet the bone was not excluded completely. The stress values observed in the study do not exceed the strength of the materials but fatigue analysis could not be carried out. So conclusions about fatigue were only assumptions. Only one mandible was evaluated but different mandibles could have variations in the stress distribution and a statistical analysis could not be carried out. To reproduce the clinical situation, contact was applied at the overdenture–mucosa interface and between parts of the attachments but any friction coefficient was not applied which is another limitation for the study.

Conclusion

Non-axial posterior loading cause higher stress values in the implant and the prosthetic component than axial posterior loading in the overdenture treatments supported by four standard-sized axial implants (SA model), by four standard-sized implants with distal ones tilted (ST model) and by four mini axial implants (MA model). Lower stress values of the implant and the prosthetic component were observed in the overdenture treatments supported by four standard-sized implants with distal ones tilted (ST model) than overdenture treatments supported by four standard-sized axial implants (SA model) under bilateral vertical (BV), unilateral vertical (UV), unilateral oblique (UO) and anterior vertical (AV) loading conditions. Stress distribution of the overdentures was observed around the implants for all three treatment options (overdenture treatments supported by four standard-sized axial implants (SA model], by four standard-sized implants with distal ones tilted [ST model] and by four mini axial implants [MA model]) under posterior loading conditions (bilateral vertical [BV], unilateral vertical [UV], unilateral oblique [UO] loading).

Türkçe özet: *Açılı standard implant ve mini implant destekli tam protezlerde gerilimin değerlendirilmesi Amaç: Bu çalışmanın amacı mandibular implant üstü tam protezleri desteklemek için açılı implantlar ve mini implantlar kullanıldığındandaki gerilim dağılımını değerlendirmektir. Gereç ve Yöntem: Dört adet, düz, standart büyüklükte implanta sahip (SA model); dört adet, mezialdekiler düz ve distaldekiler açılı, standart büyüklükte implanta sahip (ST model) ve dört adet, düz mini implanta sahip (MA model) Locator tutuculu implant üstü mandibular tam protezlerin üç boyutlu (3D) sonlu eleman modelleri oluşturuldu. Her modelde implant üstü tam proteze bilateral dik, unilateral dik, unilateral oblik ve kesicilerden dik olacak şekilde dört farklı yönde 100 N kuvvet uygulandı. Peri-implant kemikte, implantta, protetik komponentlerde ve protezde dağılan gerilimler değerlendirilmiştir. Bulgular: Dik olmayan posterior yükleme, dik yüklemeye göre implantta ve protetik komponenette daha yüksek stress değerlerine sebep olmuştur. İmplant ve protetik komponentte ST modelde SA modele göre daha düşük gerilim değerleri gözlenmiştir. Posterior yüklemelerde implant üstü tam protezde gerilim dağılımı implantların etrafında daha yoğun gözlenmiştir. Sonuç: ST modeldeki tedavi seçeneğinin kullanıldığı durumlarda daha az protetik komplikasyon beklenebilir. İmplant üstü tam protezlerde implantların etrafında yorgunluğa bağlı kırılmalar meydana gelebilir. Anahtar kelimeler: Açılı implantlar, mini implantlar, sonlu elemanlar analizi, locator, implant üstü tam protez.*

Ethics Committee Approval: Not required.

Informed Consent: Not required.

Peer-review: Externally peer-reviewed.

Author contributions: IT, VT, AÜ participated in designing the study. IT, VT, IT participated in generating the data for the study. IT, IT participated in gathering the data for the study. IT, VT, IT, AÜ participated in the analysis of the data. IT wrote the majority of the original draft of the paper. IT, VT participated in writing the paper. IT has had access to all of the raw data of the study. IT, AÜ has reviewed the pertinent raw data on which the results and conclusions of this study are based. IT, VT, IT, AÜ have approved the final version of this paper. IT guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

Conflict of Interest: The authors declared that they have no conflict of interest.

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