Comparison of the rehabilitation of posterior atrophic edentulous mandible with different interforaminal implant placement concepts: a 3D finite element analysis

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ABSTRACT

Aim The study aims to compare the rehabilitation of the posterior atrophic edentulous mandible with different interforaminal implant placement concepts to apply an implant-supported fixed prosthesis, without needing any bone grafting procedure.
Material and methods Six models were created in a digital environment. Three, four, and five implants were vertically placed in different models; the Nobel Trefoil concept, the All-on-3, and the All-on-4 concepts were also simulated. In the Trefoil model, implants specific to this concept were used. In all models, the prosthetic emergence of posterior implants was simulated at the same point. Screw-retained fixed prostheses were placed on the implants. A spherical foodstuff force was applied to imitate the chewing forces from the canine and molar regions. The three-dimensional finite element method analyzed the stresses on bones, implants, and prosthetic structures.
Results The most balanced stress distribution was seen in the Trefoil concept, while the worst stresses were observed in the All-on-3. The stress obtained in the models with four and five vertical implants was very close. Increasing the number of implants slightly affected stress, however, reducing the number to three, significantly increased the stress. Inclined placement of the same number of implants increased stresses on bone.
Conclusions With its unique implants, the trefoil concept emerged as the optimal treatment option for fixed prosthetic restoration in the interforaminal area. The best option among the models with standard diameter implants is four vertical implants. Inclined placement of posterior implants did not reduce stresses. On the contrary, it increased stresses, unless the emergence profile was moved posteriorly or the implant lengths were increased.

KEYWORDS biomechanics, dental implants, implant-supported dental prosthesis, finite element analysis, mandible, mental foramen, alveolar bone atrophy, dental stress analysis

INTRODUCTION

Rehabilitation of a fully edentulous mandible is generally preferred dental implant-supported prosthesis to conventional complete dentures. In this context, dental implant patients have some options, including implant-supported removable prosthesis, implant-supported fixed prosthesis, and implant-retained prosthesis(1). Implant-supported fixed prosthesis significantly increases patient satisfaction. However, there may be some challenges with the volume of the bone. In this situation, patients need additional surgeries like bone augmentation, various different surgical and drilling techniques and/or nerve lateralization, thus increasing morbidity, time, and cost of treatment(2-4). As an alternative to these procedures, implants can be placed into the interforaminal region, which is known to be less affected by bone resorption in certain cases. Therefore, minimally invasive treatment options can be created with implants placed in different numbers and configurations between the mental foramen(5, 6).
One of the first examples of treatment methods based on interforaminal implant placement is the "Brånemark Novum concept" created by Per-Ingvar Brånemark. In this concept, one implant is placed in the midline, and the other two are placed vertically distally. An acrylic prosthesis with cantilever extensions is fixed on three implants on the same day with a prefabricated bar infrastructure made of titanium(7). After this concept, "All-on-4" was introduced by Malo et al. (8). In the All-on-4 concept, two implants are positioned vertically and parallel to each other in the anterior zone, two implants are placed at an incline distally in the posterior zone to shorten the cantilever extension, and to place longer implants (8). Oliva et al. (9), based on the All-on-4 concept, developed the All-on-3 concept with three implant placements in the lower and upper jaw. Conversely, as a different concept, Turkyilmaz et al. (10) placed a screw-retained prosthesis containing

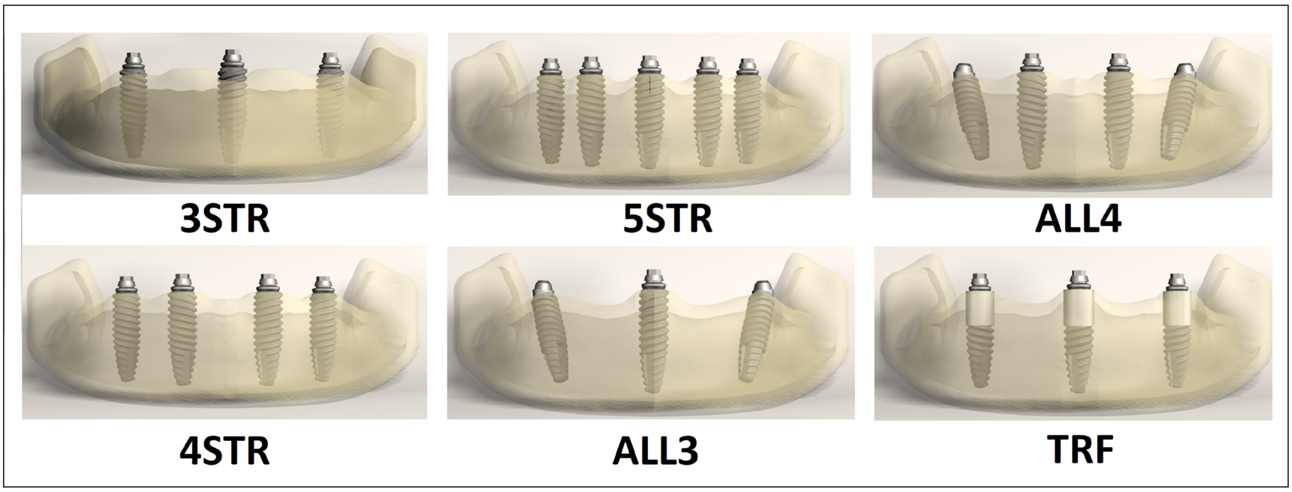

FIG. 1 Models of the present study

the distal cantilever with six implants in the interforaminal region of the posterior atrophic mandible.
Similarly, until now, many researchers have introduced different treatment concepts related to interforaminal implant placement and reported high success rates with these concepts(8,10,11). However, to the authors' knowledge, there needs to be more literature comparing all these concepts in the same study. In addition, performing such a study in vivo seems challenging due to many factors. For this reason, the three-dimensional (3D) finite element analysis (FEA) method, one of the frequently used in vitro methods, was chosen for the biomechanical comparison of different concepts in this study.
This study aimed to compare the stresses on bone, implants, and prosthetic structures against different dental implant placement concepts for the rehabilitation of posterior atrophic mandible to perform fixed prosthesis, and to determine the optimal number of implants and placement options in biomechanics by implementing the 3D FEA method. The study's null hypothesis was that stress distribution on the bone, implant and prosthetic components is affected by the implant number and angulation, and significantly decreases when the implant number is increased, and posterior implants are tilted.

MATERIALS AND METHODS

Modeling

The present study was performed after obtaining 3D computed tomography images of a patient with vertical atrophy in the posterior region and adequate bone volume in the anterior region. These were converted into a Digital Imaging and Communications in Medicine (DICOM) format. Then, this data was modified in a computer environment using the VRMESH (VirtualGrid) and Rhinoceros 3D (McNeel North America) software.
The edentulous mandible for the models was reconstructed as trabecular bone covered with a 2-mm cortical bone. Bone width of 8 mm along the entire alveolar crest, the bone height of 6 mm between the mandibular canal and alveolar crest in the posterior, and 14 mm in the interforaminal region were defined. The right and left mental foramina distances from the midline were arranged as 25 mm with a total 50-mm interforaminal distance. The distances of mental foramen from the lower and upper borders of the mandible were arranged as 8 and 5-mm, respectively. The diameter of the mental foramen was modeled as 3.5 mm. Also, the mandible covered was with a 2-mm thick mucosa. The implants and prosthetic superstructures were scanned using a 3D scanner (Dental Wings 7 Series, Model DW-7-140, Dental Wings) within a 10-µm accuracy ratio and imported to VRMESH software. All structures were modeled using Rhinoceros 3D.
Six different configurations were created by changing the number and incline of the implants and were labeled according to the configuration and number of implants(Fig. 1). In the 3VRT model, three implants were placed vertically into the interforaminal area. In the 4VRT model, four implants were placed vertically between the foramina. For the 5VRT model, five implants are positioned vertically into the interforaminal area. In TRF, Trefoil System was reflected with three unique implants belonging to this concept. For ALL3 Model, an All-on-3 concept with three implants was performed with one vertically placed anterior and two inclined posterior implants. For ALL4 Model, the All-on-4

	ELASTIC MODULUS (MPa)	POISSON RATIO
CORTICAL BONE	13700	0.3
TRABECULAR BONE	1370	0.3
MUCOSA	680	0.45
TITANIUM	117000	0.35
ACRYLIC	3000	0.35

TABLE 1 Elastic Modulus and Poisson Ratios

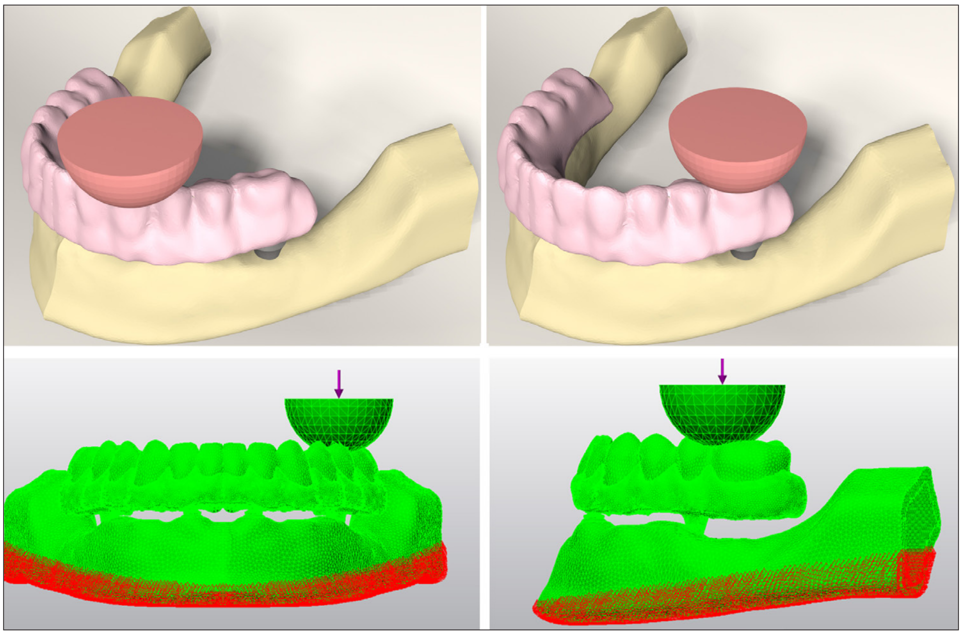

FIG. 2 Occlusal forces applied with spherical foodstuff from canine and molar regions

concept was performed with two vertically anterior implants and two posterior tilted implants(Fig. 1).

To ensure standardization in the study, the prosthetic emergence of posterior implants, regardless of the inclined and straightly placed, was made from the same point in all models so that the cantilever length of the prosthesis does not change. In the study, except for the TRF model, the implants simulated in all other models were implants of Nobel Biocare company with a diameter of 4.3 and a length of 11.5. In the TRF model, implants with a diameter of 5.0, a length of 11.5, and a 4.5 mm machined surface at the tissue level in the neck region, produced specifically for the same company's trefoil concept, were used. The prosthesis is designed as a titanium framework with cantilevers, a superstructure with a wrap-around acrylic denture base, and acrylic resin artificial teeth (12). Implants and prostheses are connected through screws via multiunit abutments.

Boundary and Loading Conditions

Boundaries of the models were constrained at the superior surface of the maxilla to ensure zero displacements, and all structures were modeled as tightly bonded. It was assumed that load transfers are performed according to the internal characteristics of the cortical and trabecular bones. The connection between the implants and the supporting tissues is designed to directly transfer the loads between the multiunit abutments and implants and the multiunit abutments and the prosthetic material. The mesh with 10-node quadratic tetrahedral elements was created with nodes/elements ranging from 5,000,138/2,393,043 to 8,223,345/4,343,705. It was assumed that the implants are 100% osseointegrated. All materials used in this study were homogeneous, isotropic, and linear elastic. The material characteristics of the prosthetic material, mucosa, cortical bone, trabecular bone, and implants were determined in Table 1. The FEA models were exported to ALGOR FEMPRO software (Algor) for 3D static analysis. To simulate the chewing forces more naturally, an occlusal load of 100 N was applied from a spherical solid material (12 mm in diameter), which placed the foodstuff in both the anterior (Left canine) and posterior (Left first molar) regions (Fig. 2).

Analysis

Principal stresses were evaluated to define local risk indicators of peri-implant bone resorption to evaluate trabecular and cortical bone. Maximum principal stress (Pmax) represented tension stress type, and minimum principal stress (Pmin) represented compression type stresses. All stresses were measured in megapascals (MPa). Peak stress values were considered for evaluation. Following similar studies, overloading of the bone was recorded when the Pmax or Pmin exceeded the uniaxial tensile or compressive strength, respectively. The strength of cortical bone was assumed to be 115 MPa under tension (Pmax) and 151 MPa under compression (Pmin)(12). Von Mises (vM) stresses were analyzed to evaluate stress formation in implants. Implants, abutments, screws, frameworks, and crowns were analyzed based on the vM criterion. Because the data obtained from FEA were mathematical calculations without variance, the results were not analyzed statistically, but evaluated with scales. All stresses are shown using color and quantity scales. The stresses in the bone, implant and prosthetic components were compared based on the vM criterion, and the principle of fatigue interpreted the results.

RESULTS

Stress in Peri-implant Bone

As a result of the foodstuff of 100 N applied to the models from the left canine region, the highest Pmax formed in

CANINE FORCES (MPa)	CORTICAL PMAX	CORTICAL PMIN	TRABECULAR PMAX	TRABECULAR PMIN
3VRT	2,5	-5,1	0,9	-0,9
4VRT	2	-2,8	0,8	-0,6
5VRT	2	-3,2	0,7	-0,5
TRF	0,7	-3,2	0,5	-0,6
ALL3	8,8	-11,3	3,7	-3,5
ALL4	4,1	-9,7	2,1	-1,2

TABLE 2 Stress (MPa) Values In Trabecular And Cortical Bones Against Canine Forces

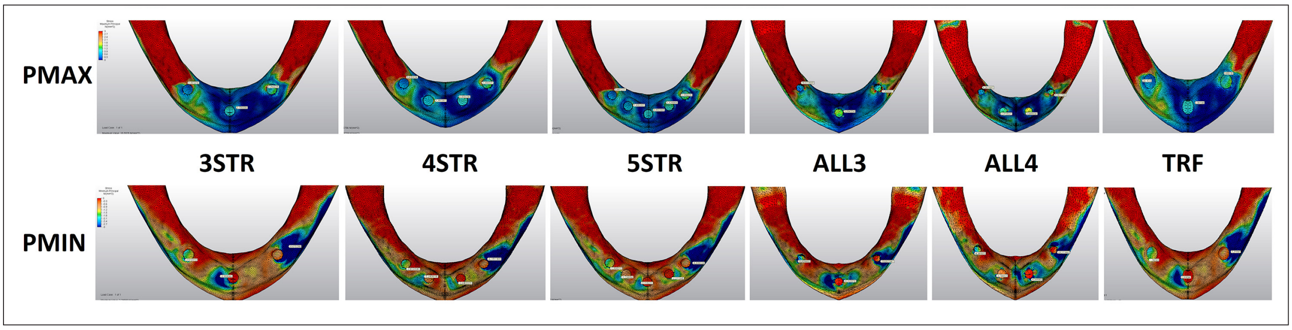

FIG. 3 Stress values and distributions in the cortical bone against canine forces

the cortical bone was observed in ALL3 with 36.4 Mpa and ALL4 with 30.9 MPa. In contrast, other models show stresses around 18 MPa, which are close to each other. When the Pmin formed in the cortical bone evaluated, ALL3 exposed to the highest compression force with -95.1 MPa. The lowest stress was observed in TRF as -12.4 Mpa. On the contrary, 3VRT and 5VRT were the other models with the lowest stress formation, giving the same stresses as -15,4 MPa (Table 2) (Fig. 3).

Considering the Pmax in the trabecular bone, it was observed that the highest stress occurred in ALL4 with 11.7 MPa, followed by ALL3 with 11.3 MPa. It has been observed that the stress formed in TRF (2.4 MPa) and 4VRT (2.6 MPa) were the lowest and quite close. The lowest Pmin in the trabecular bone was observed in 3VRT with -3.9 Mpa and TRF with -4.2 MPa. The highest was determined as -10.9 Mpa in ALL3, with a difference of approximately three times higher than the lowest stress. While the second-highest stress was found at -9.7 MPa in ALL4, the third-highest stress was found at -6 MPa in 4VRT. While low stresses occurred in 3VRT (-3.9 MPa) (Table 2) (Fig. 4).

When foodstuff forces of 100 N were applied to the models from the left first molar region, it was observed that the highest Pmax stress formed in the cortical bone occurred in ALL4 (100.4 MPa). At the same time, the second highest occurred in ALL3 (72.8 MPa). The lowest stress was seen in the 5VRT (12.1 MPa) with the model with the highest number of implants. The highest Pmin in the cortical bone was -302.8 MPa in ALL3 with 4-fold than the closest stress (ALL4 with -95,3 Mpa) and almost 18-fold the lowest stress (4VRT with -17,2 Mpa). The stresses in 3VRT (-24.2 MPa) and TRF (-23.4 MPa) are close(Table 3) (Fig. 5).

In the trabecular bone, the highest Pmax was 17.2 MPa in ALL3, followed by 5VRT (15.8 MPa) and ALL4 (12.6 MPa). Slightly higher stress occurrences were observed in 3VRT (9.9 MPa). In contrast, TRF (3.3 MPa) and 4VRT (2.6 MPa) were close. When the Pmin formed in the trabecular bone was evaluated, the highest stress was determined in ALL3 with -31.4 MPa. The closest to ALL3 was observed in ALL4, another model with inclined implants with -20 MPa. In the 3VRT (-7.6 MPa), 4VRT (-9.2 MPa), and TRF (-7,4 MPa), stresses were observed close to each other. Slightly higher in 5VRT as

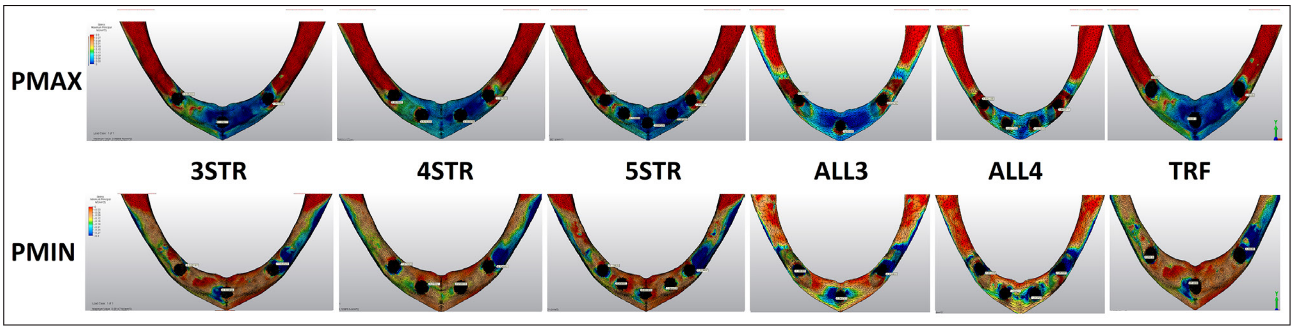

FIG. 4 Stress values and distributions in the trabecular bone against canine forces

MOLAR FORCES (MPa)	CORTICAL PMAX	CORTICAL PMIN	TRABECULAR PMAX	TRABECULAR PMIN
3VRT	4,6	-8,7	2,4	-1,3
4VRT	2,2	-3,6	0,8	-1
5VRT	3	-4,4	1,3	-0,7
TRF	2,6	-0,8	1	-0,9
ALL3	7,5	-15,3	2,9	-4,6
ALL4	12,3	-10,8	2	-3,7

TABLE 3 Stress (MPa) Values In Trabecular And Cortical Bones Against Molar Forces

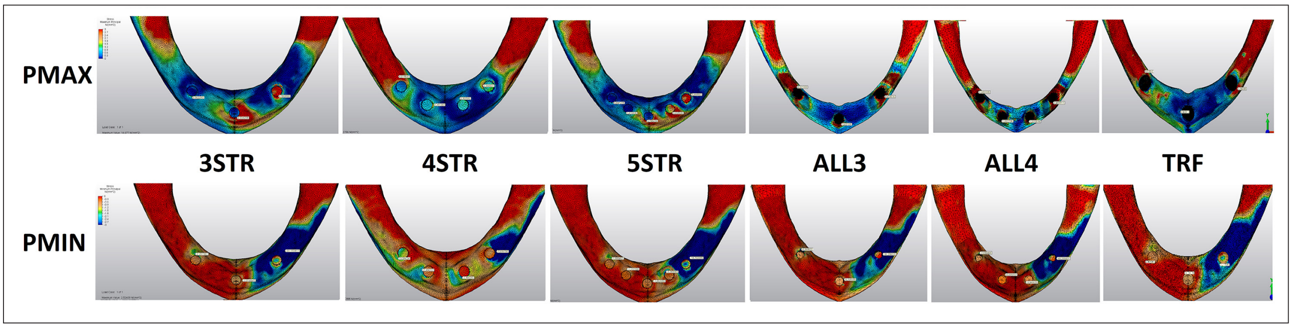

FIG. 5 Stress values and distributions in the cortical bone against molar forces

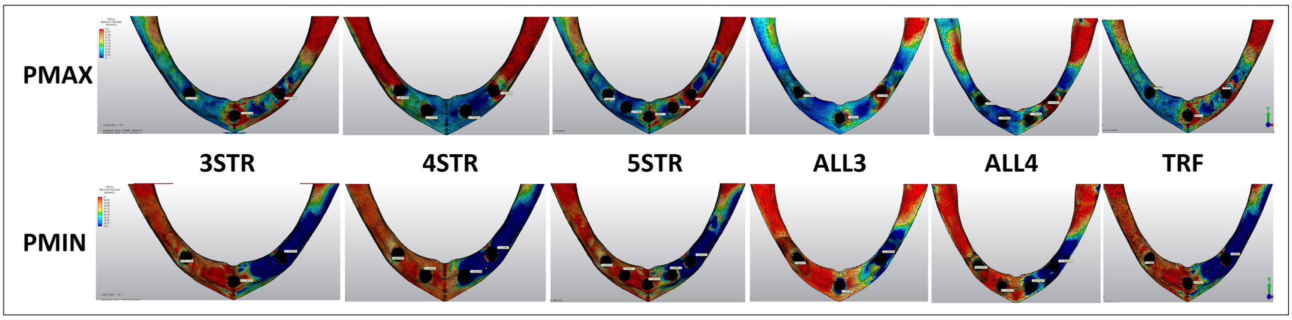

FIG. 6 Stress values and distributions in the trabecular bone against molar forces

CANINE FORCES (MPa)	IMPLANTS	MULTIUNITS	FRAMEWORK	CROWNS
3VRT	37,1	57,3	59,5	14,4
4VRT	13,3	42,3	87	13,1
5VRT	18,4	38,4	29,3	14
TRF	10	60.9	59,3	14,4
ALL3	36,7	270,6	100,7	12,2
ALL4	24,8	238,7	114,3	12

TAB. 4 von Mises Stress (MPa) Values In Implants and Prosthetic Components Against Canine Forces

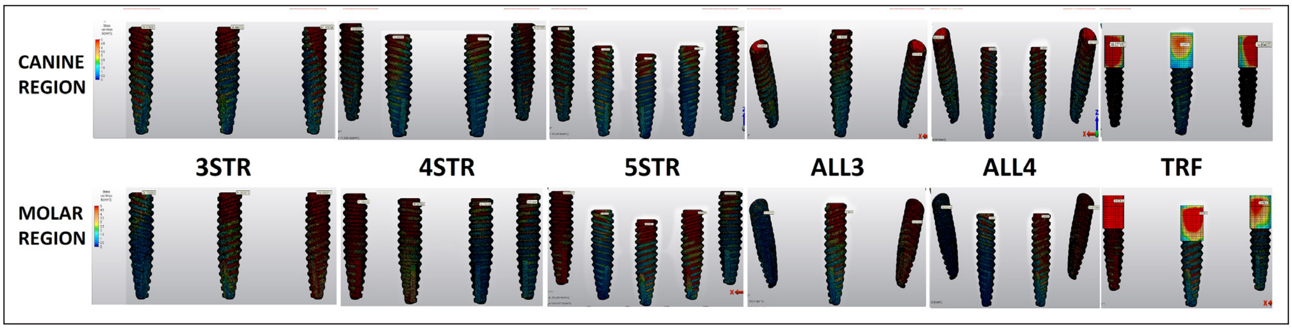

FIG. 7 Stress values and distributions in the implants against canine and molar forces

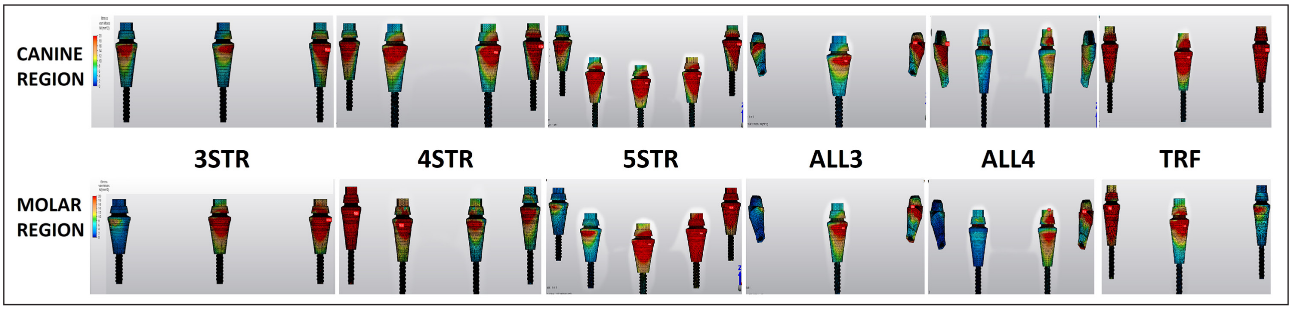

FIG. 8 Stress values and distributions in the multiunit abutments against canine and molar forces

MOLAR FORCES (MPa)	IMPLANTS	MULTIUNITS	FRAMEWORK	CROWNS
3VRT	71,8	168,2	159,8	5,6
4VRT	31,4	138,6	169	5,4
5VRT	32,2	135,4	85,9	5
TRF	18	185,3	168,8	5,6
ALL3	45,7	182,9	59,6	5,7
ALL4	25,7	186	56,1	5,4

TABLE 5 von Mises Stress (MPa) Values In Implants and Prosthetic Components Against Molar Forces

-15.2 MPa(Table 3) (Fig. 6).

Stress in Implants and Prosthetic Structures

When the average von Mises values formed on the implants against the forces applied from the canine region examined, the highest stress was observed in 3VRT (37.1 MPa), followed by the ALL3 (36.7 MPa) with a slight difference. The implants in ALL4 were the third highest stress group, with 24.8 MPa. 4VRT (13.3 MPa) and 5VRT (18.4 MPa) detected lower stress than other models. The least stress was observed in TRF with 10 MPa (Table 4) (Fig. 7).

When the stresses on the implants due to the forces applied from the molar region are examined, the highest Von Mises stress was 71.8 MPa in 3VRT. While the second highest was observed in ALL3 with 45.7 MPa, these were followed by 5VRT, 4VRT, and TRF from high to low, respectively. In 3VRT with the highest stress, approximately four times more stress was detected compared to TRF with the lowest stress (Table 5) (Fig. 7).

When the prosthetic structures' stresses against canine forces are examined, the highest stress for multiunit abutments and metal framework occurs in ALL3 (270.6 Mpa and 100.7 MPa) and ALL4 (238.7 Mpa and 114.3 Mpa) models with inclined implants. These values were 4 times higher than the closest stresses, especially for multiunit abutments. The lowest stress values were observed in the 5VRT model with

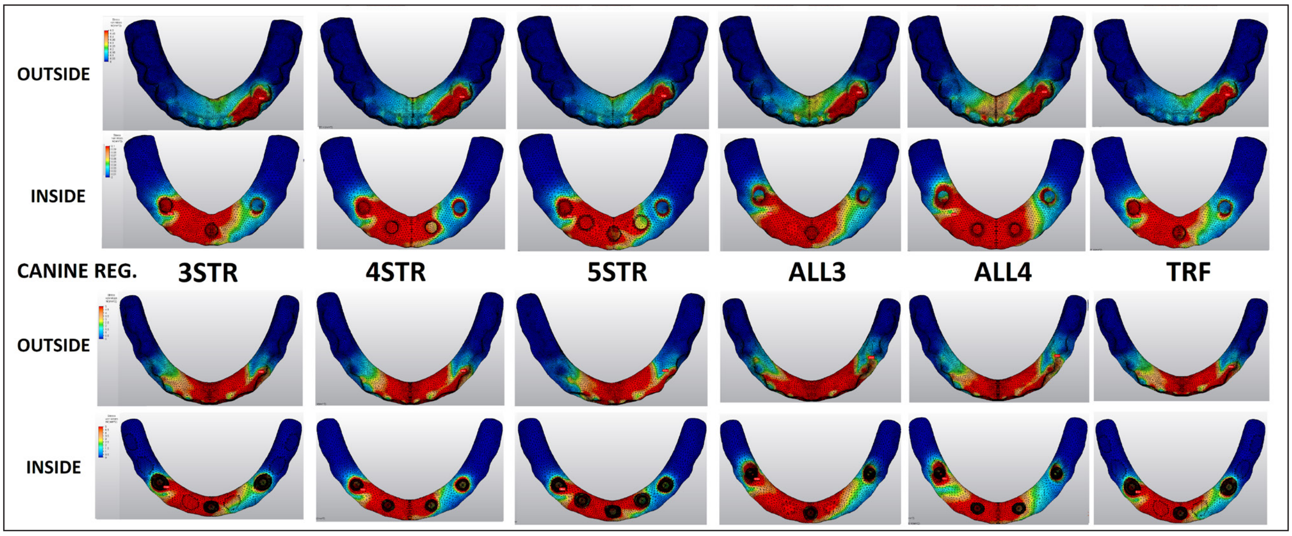

FIG. 9 Stress values and distributions in the metal framework against canine and molar forces

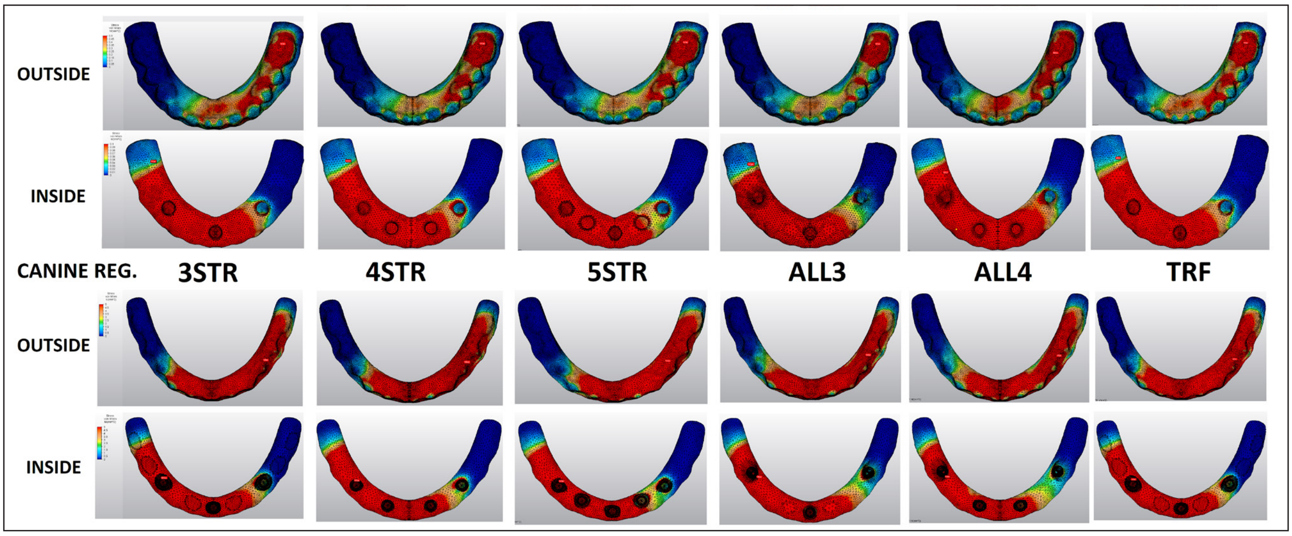

FIG. 10 Stress values and distributions in the acrylic prosthesis against canine and molar forces

the highest number of implants (38.4 Mpa and 29.3 Mpa). In acrylic prosthesis, inversely, forces close to each other ranging from 12 to 14.4 Mpa was striking in all models (Table 4) (Fig. 8, 9).

In stresses against molar region forces, the highest stresses on multiunits were similarly seen in ALL3 (182.9 Mpa) and ALL4 (186 Mpa) models. In contrast, other models with 3 implants, TRF (185.3 Mpa) and 3VRT (168.2 Mpa), also reached high-stress values. On the metal framework, the stress values on the 3VRT (159.8 Mpa), 4VRT (169 Mpa), and TRF (168.8 Mpa) models, which were 2-3 times higher than the other models, drew attention. However, all models gave values close to each other with stresses varying around 5 - 5.5 Mpa on the acrylic prosthesis (Table 5) (Fig. 8, 10).

DISCUSSION

This 3D FEA study compared the stresses on bones and materials against the chewing forces applied to fixed prostheses on implants with different concepts in the interforaminal area. The null hypothesis was substantially rejected, while the stress distribution decreased by an insignificant amount with the increase in the number of implants. Contrary to expectations, implant angulations increased the stresses.

In the literature, many different rehabilitation techniques are applied using the bone in the anterior region of the mandible. There have been changes from studies advocating that six or more implants should be placed for rehabilitating a completely edentulous jaw to studies suggesting that rehabilitation of the lower jaw with (3, 7, 9, 11, 13), or even only two implants give successful results today(12).

One of the first examples of treatment methods based on implant placement in the interforaminal bone in the anterior region, which is less affected by resorption by avoiding regenerative processes in edentulous jaws, is the "Brånemark Novum" concept created by Brånemark in the nineties. This concept is a treatment protocol in which prosthetic loading is performed on the same day by placing three implants in the anterior mandible. In this application, one implant is placed in the midline, the other two implants are placed vertically distally, and an acrylic prosthesis with cantilever extensions is fixed on three implants with a prefabricated bar infrastructure of titanium on the same day(7). Inspired by this technique, Hatano et al.(15) reported that in the 5-year follow-up of 3 standard-design implants placed in the interforaminal area in the edentulous mandible, this application might be sufficient to support fixed prosthetic rehabilitation even with immediate loading conditions(11). Gualini et al.(16) reported a survival rate of 91% for implants and 87% for prostheses after a 5-year follow-up of 15 patients rehabilitated with the Brånemark Novum concept with immediate prosthetic loading. In the "Nobel Biocare Trefoil™" concept, which was recently introduced by Nobel Biocare company based on the Brånemark Novum concept, implants with a 4.5 mm glossy surface in the neck area designed specifically for this concept, like the Novum protocol, were introduced and made of prefabricated prosthetic infrastructure for immediate loading. It has made it a widely used concept(17,18).

In the present study, the TRF model, one of the models with three implants, was simulated based on this concept and using unique implants belonging to this concept.

In the following years, the concept of "All-on-4" was introduced by Malo et al.(8). In this concept, two anterior implants were placed vertically, and the two implants in the posterior were placed at an incline distally to shorten the cantilever extension and placed longer implants. Malo et al.(19) reported a 5-year success rate of 98.1% and a 10-year success rate of 94.8% for implants in their study published on the All-on-4 concept, performed in 245 patients. In their systemic review, Soto-Penaloza et al.(20) reported a 99.8% survival rate for the All-on-4 concept at a follow-up of more than 24 months. The All-on-4 concept was simulated under the name ALL4 in the present study.

Oliva et al. (9), based on the All-on-4 concept, developed the All-on-3 concept with three implant placements in the lower and upper jaws, restored the implants with fixed prostheses, and reported a success rate of 100% at the end of a 5-year follow-up period. Ayna et al. (21) reported that, as a result of a 6-year follow-up of the All-on-3 concept, which they applied in 29 patients under the condition of immediate prosthetic loading, there was no implant loss and only a mean bone loss of 1.0 ±1.0 mm was experienced around the implants. This concept is evaluated in the ALL3 model in the present study.

In addition, there are implant-supported fixed prosthesis options in the literature, which are placed in interforaminal region in different numbers and positions determined by the clinician and the patient's choices/expectations(10,11,22). Turkyilmaz et al.(10) placed six implants in the interforaminal region of the posterior atrophic mandible and reported no complications after 28 years of follow-up of the screw-connected prosthesis containing the distal cantilever. Krennmair et al.(23) prepared cantilever extension fixed prostheses on four vertically placed implants in the interforaminal region in 38 patients and reported the survival rate of the implants as 100% and the success rate as 98.6% after a 5-year follow-up period. Collaert and Bruyn (24) made fixed restorations with an early loading protocol by placing four or five dental implants in the mandible and reported a survival rate of 100%. In the present study, vertical (3, 4) and (5) implant placements were simulated with the names 3VRT, 4VRT, and 5VRT.

In the present study, when the Pmax stresses were compared in the models with vertical implants (3VRT, 4VRT, 5VRT, and TRF), it was observed that the average least stress occurred in the TRF and 4VTR models. Although the TRF model is one of the models with the least number of implants in the present study with three implants, the reason why it gave the lowest stress may be that the diameters of the implants in this system (5.0 mm) are larger than the implant diameter (4.3 mm) used in other models. Also, it has a machined surface at the tissue level (4.5 mm), so even if the intraosseous length is the same, the total implant length is also longer. Thus, understandably, increasing the implant diameter and total length positively affects stress distributions (25, 26). Nevertheless, a more voluminous jawbone is needed to place a larger diameter implant. For this reason, it may not always be possible to apply this system alone without grafting methods. According to the results of the current study, placing four vertical implants (4VRT) in the presence of a lower volume of bone, where the Trefoil system cannot be applied, was more advantageous compared to other models.

In the present study, when Pmin stresses among vertically placed implant models were evaluated, it was observed that the stresses occurring in the bones between the models were nearly at similar levels. Even if the implant located in the midline in the 5VRT model contributes to some stress reductions compared to the 4VRT model, the difference is not very significant. For this reason, increasing the number of implants to five is unnecessary when the profit-loss account is made. Each increase in the number of implants brings additional cost and maintenance difficulties to the patient. Despite this, reducing the number of implants to 3 increases stress, especially in implants and multiunits. When the stresses on the implants are evaluated, up to 8 times more stress is seen in the 3VRT model. The severe stresses observed in the 3VRT model suggest that three implants placed using this diameter and specification will not be sufficient for the biomechanical rehabilitation of the edentulous mandible with fixed prostheses.

Like the current study results, some studies argue that three implants with standard dimensions and features are insufficient for rehabilitating the edentulous mandible. Heydecke et al.(27) reported in their systemic review that using 4–6 implants for implant-supported fixed full-arch prostheses provides an estimated 5-year survival rate and is a well-documented treatment option in studies. Researchers emphasized that it is unclear whether using three implants will achieve similar survival rates. Correa et al.(28) stated that prostheses supported by three implants are not suitable because three implants cannot provide sufficient support against occlusal loads, and the resistance of prostheses supported by four implants is better. Simamoto Junior et al.(29) stated that a decrease in the number of implants placed in the interforaminal region in the posterior atrophic mandible would create higher stresses around the implants. Therefore, using four or five implants instead of three will lead to lower biomechanical complications. In their biomechanical study, Fazi et al.(30) also reported that three parallel implants caused higher stress on the implants and bone than four implants. Correa et al.(28) compared the rehabilitation of the total edentulous mandible with 3 and 4 implant-supported cantilever extension prostheses placed vertically in the interforaminal region. The researchers also did not recommend using prostheses supported with only three implants because they do not adequately support occlusal loads.

In the present study, when the Pmax formed in the cortical bone around the implants in 3VRT, TRF, and ALL3, where the least implant is used with three implants was examined, the difference between the ALL3 model with the highest stress and the TRF model with the least stress up to 3 times. Among all models, the highest stress formation occurs in the inclined implant located on the force-applied side of the ALL3 model. Pmin stresses in the cortical bone gave the highest stress (-302,8 Mpa) of the present study, which occurred under these conditions in the ALL3 model. This stress is almost twice the maximum value of 152 Mpa for Pmin stresses used in the study evaluation criteria(12). This model is followed by the ALL4, which is also inclined. Despite this, other models gave stresses close to each other and caused up to 15 times lower stress formations. When the implants in the models are evaluated separately, the highest stress formation is seen in the region of the inclined implants on the side where the force is applied.

The biomechanical response of the All-on-4 concept is sensitive to the area on which the load is applied, and the loading of distal cantilevers causes excessive stress around the inclined posterior implants(31). Dogan et al.(32) examined the

All-on-4 concept regarding stress distribution with alternative designs. In the study, when the amount of force transmitted to the tissue between the long and inclined implants positioned posteriorly and the shorter and vertical implants with the same diameter positioned posteriorly, the amount of force transmitted to the tissue was found to be higher around the inclined implants than the short implants. Thus, they stated that applying the All-on-4 concept in highly resorbed crests does not provide a significant advantage to using short implants in the posterior. Similarly, in the present study, when the Pmax stress in the cortical bone was compared in the 4VRT and ALL4 models, it was found that the ALL4 model generated 4-5 times more stress. Although it was seen in the present study that the ALL4 model reduced the stresses on the framework compared to the 4VRT model, the stresses on the bone should be considered regarding the survival of dental implants and bone resorption formations. While the damages in the prosthesis can be compensated more quickly, the compensation of bone damage and resorption is more complicated. In the present study, vertical implants caused 2-3 times less stress than inclined implants.
According to the results obtained in the present study, techniques for angling posterior implants did not provide an advantage when the implant dimensions and emergence points remained the same, but on the contrary, increased the stresses on the bone. Similarly, in the ALL3 model, it was observed that the angulation of the implants had a negative effect on the stress formation compared to the 3VRT model with the same type and number of implants. Also, it has been observed that models with inclined implants have higher stresses on prosthetic components, especially multi-unit abutments, compared to other models. Similar to the results of the current study, Sannino (33) compared the implant angulations between 15-45 degrees in the All-on-4 concept and concluded that the stress formations increased as the placement incline in posterior implants increased. Although in the literature, increasing the implant length and shortening the cantilever length of the prosthesis by carrying the point of emergence of the implant due to the inclined implant placement in the All-on-4 technique has been highlighted as a biomechanical advantage (34), the effects of the All-on-4 or All-on-3 concepts were not simulated to standardize the models, and to reduce the factors that may affect the results, since implants with the same length and has the same point of emergence were used in all models in the present study.
Among the inclined models, the ALL3 model creates up to 2 times more stress than the ALL4 model. The ALL3 model has already reached the worst stress among all models. Similarly, in inclined models, Pmin stresses formed in cortical bone were observed in high amounts. In particular, the ALL3 model created three times more stress than the model with the second-highest stress. Especially in the ALL3 model, it was observed that the stress against forces from the molar region was relatively high in cortical bone, with 72.8 Mpa for Cortical Pmax and – 302.8 Mpa for Cortical Pmin. This value is well above the values known to may cause bone resorption. The situation is similar in canine region stresses up to 5 times to the nearest. ALL3 model also did not show a balanced stress distribution between the implants in the posterior region.

CONCLUSION

The Trefoil concept gave the most balanced results biomechanically. However, considering that more bone tissue will be needed around the implant, since the implants used in this concept are larger in diameter than those in other models, its application in every case poses a question mark. Four vertical implant placements are the most advantageous option among models with standard diameter implants. Although the use of 5 implants provides slightly less stress than four implants, it has been seen that increasing the number of implants does not provide a significant advantage when the additional costs are considered. It has been observed that inclined placement of posterior implants does not reduce the stresses but increases it, contrary to expectations, unless the length of the implant is increased, and the cantilever length of the prosthesis is not shortened. Increasing the implant length, one of the advantages of the All-on-4 concept emphasized in the literature, could not be evaluated in this study, so this concept was not found advantageous in the current conditions. The All-on-3 concept stood out as the study's model with the highest and most unbalanced stress distribution.

Competing interests
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