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Is it beneficial to support interforaminal implant placement techniques with ultra-short implants in the posterior region? A 3D finite element analysis

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ABSTRACT

Aim This study aims to evaluate the effects of ultra-short implants in the posterior region to eliminate the distal prosthetic cantilevers in interforaminal implant placement techniques on the stresses on the peri-implant bone, implants, and prosthetic structures.
Method Six models were created in a digital environment. In the interforaminal region, 3 and 4 vertically placed implants and All-on-4 techniques are modeled. In addition, models in which 4 mm implants support these techniques, in the posterior region, to eliminate cantilever extensions are simulated. 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 effects of supporting interforaminal implant placement techniques with ultra-short implants on peri-implant bone stresses were limited. On the other hand, significant stress differences were observed in stresses on implants, multiunit abutments, and prosthetic framework, especially against molar region forces.
Conclusion Supporting the cantilever extensions of interforaminal implants in the posterior region with ultra-short implants has been shown to have the potential to reduce technical complications on prosthetic structures significantly. Supporting interforaminal implant placement concepts with short implants in the posterior region could be a more risk-free approach, especially in extra-risky cases such as bruxism.

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

INTRODUCTION

In the mandible, after the loss of teeth, the posterior region of the mental foramen experiences more significant volumetric loss than the anterior region (1, 2). When the vertical limitations caused by the presence of the mandibular nerve are added, dental implant applications to the atrophic mandible posterior pose various difficulties for clinicians. In the solution to this situation, options such as grafting with various procedures, nerve lateralization, placement of dental implants in the interforaminal region, or using short implants come to the fore (3, 6).
Grafting procedures have some disadvantages for both clinicians and patients. Among them, there are additional and complex surgical procedures, additional costs, prolonged healing periods, and possible complications depending on the preferred surgical procedure (3, 4). Today, interforaminal implant placements are frequently used, mainly because of the expectation of patients to get their teeth at the most affordable cost, in the shortest time possible, and without surgical difficulties. These procedures include implant placements with conventional vertical implant placement techniques and various concepts such as All-on-4, which includes angulation of posterior implants (6, 9).
The most common feature of interforaminal implant placement techniques can be counted as containing posterior prosthetic cantilever extensions with different sizes. Although successful results have been reported in the literature with interforaminal placement techniques, the technical and biological complications that prosthetic cantilever extensions may cause on implants, peri-implant bone, and prosthetic structures are still being investigated (8, 10, 14).
As an alternative to these techniques, thanks to the developments in implantology and implant production technologies, short implants that can be used in limited vertical distances have been introduced to the market over time (3, 4, 13, 15, 16). In the literature, although short implants refer to different lengths in different periods, implants under 8 mm are generally accepted as "short implants" (17). When the literature is searched, it is seen that the shortest implants available in the mar-

ket today are around 4-5 mm, also referred to as "Extra-short"(18) or "Ultra-short"(16, 17) implants. Thanks to the short implants, implant placements without additional procedures are promised in many cases with severe vertical bone loss (3, 4, 13, 16, 18). On the other hand, increasing the number of implants also means additional costs for the clinician and the patient. Therefore, to support interforaminal placement concepts, the contribution of the use of these implants should be well evaluated in terms of profit-loss ratio.

This study aims to determine whether 4 mm ultra-short implants placed in the posterior region to eliminate the cantilever extension of interforaminal implant placement techniques will contribute to the treatment by biomechanical means.

The null hypothesis of this study is that ultra-short implants, placed in the posterior region, will reduce stress on prosthetic structures and contribute to the stresses on implants and bone structures. Clinically, reducing the stress on the prosthesis will reduce the technical complications, extend the life of the prosthesis and so contribute to the cost in the long term.

MATERIAL AND METHODS

Modeling

This study used three-dimensional (3D) computed tomography images of an actual patient with vertical atrophy in the posterior region and sufficient bone volume in the interforaminal region. First, this data has been converted to Digital Imaging and Communication in Medicine (DICOM) format. Then, these data were processed in a computer environment using VRMESH (VirtualGrid, Bellevue, USA) and Rhinoceros 3D (McNeel Europe, Barcelona, Spain) software.

For the models, a fully edentulous mandible was modeled as trabecular bone covered with 2 mm of cortical bone. Eight mm bone width along the entire alveolar crest, 6 mm distance between the mandibular canal and the alveolar crest, and 14 mm bone height in the interforaminal region were defined. The right and left mental foramen distances from the midline were arranged as 25 mm, and the interforaminal distance was 50 mm. The distances of the mental foramen to the lower and upper borders of the mandible were arranged as 7 and 4 mm, respectively. The mental foramen diameter was modeled as 3 mm. In addition, the mandible is covered with a 3 mm thick mucosa. In models with cantilever extension, a 20 mm cantilever distance was created between the prosthetic emergence point of the distal implant and the posterior end of the prosthesis. Implants and prosthetic superstructures were scanned with an accuracy of 10 µm using a 3D scanner (Dental Wings 7 Series , Model DW-7-140, Straumann Group, Berlin, Germany) and transferred to VRMESH software. All structures are modeled using Rhinoceros 3D.

Six different configurations were created by changing the number and inclination of the implants and labeled according to the implant configuration (R: Regular or S: Short) and number. (Figure 1) In the 3R model, three implants were placed vertically in the interforaminal space. In the 4R model, four implants were placed vertically between the foramens. For the ALL4 model, the All-on-4 concept is simulated, with two vertical implants anteriorly and two implants distally inclined by 30 degrees. In addition, 3R2S, 4R2S, and ALL42S models were created by placing "Straumann Tissue Level Roxolid" (Roxolid®, Institute Straumann AG, Basel, Switzerland) 4 mm short implants in both the right and left regions of all these models, just behind the mental foramen to coincide with the first molar region to eliminate prosthetic cantilever extensions. (Figure 1)

To ensure standardization in the study, the prosthetic emergence of the standard-length posterior implants was made from the same point in all models to guaran-

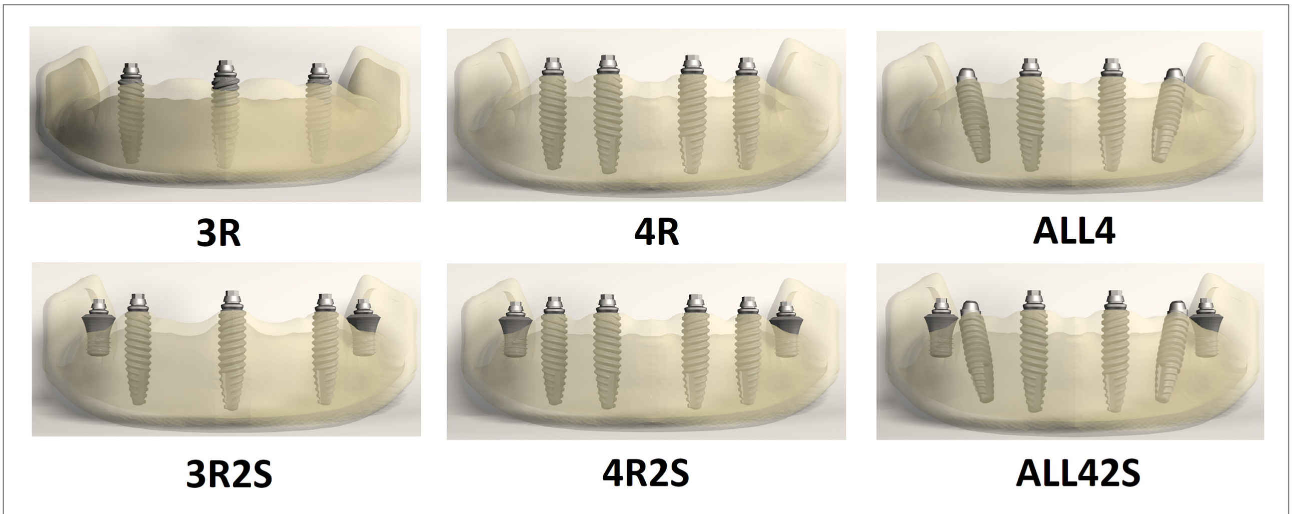

FIG 1 Models of the present study

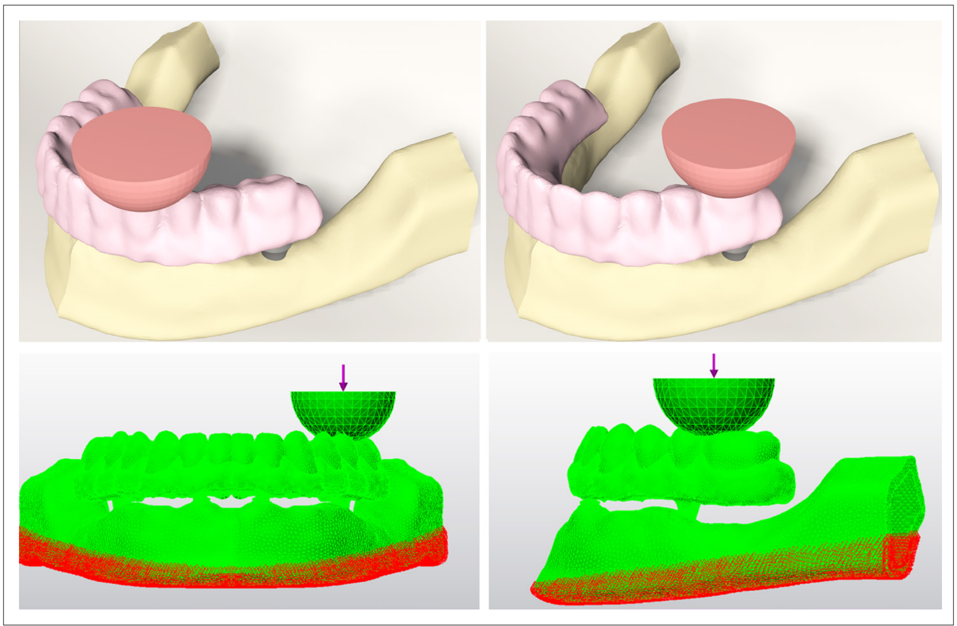

FIG. 2.
Occlusal forces applied with spherical foodstuff from canine and molar regions

tee that the cantilever length of the prosthesis does not change, regardless of whether implants are inclined or vertical. The standard implants simulated in all models in the study are "Straumann Bone Level Tapered Roxolid" implants with a diameter of 4.1 mm and a length of 12 mm. In addition, "Straumann Tissue Level Roxolid Standard Plus" implants, having 4.1 mm diameter, 4 mm length, and 1.8 mm machined surface at the tissue level in the neck region were used in the posterior regions. The prosthesis is designed as a cantilevered titanium substructure, an all-around acrylic denture base superstructure. Implants and prostheses are attached with screws via multiunit abutments. In all models, the prosthesis was composed of 12 feldspathic porcelain teeth, including the first molar. The teeth dimensions were standardized for each model.

Boundary and Loading Conditions

The boundaries of the models will be limited to the superior maxilla surface to provide zero displacements, all structures are modeled as tightly adhered. It is assumed that load transfers are made according to the internal properties of the cortical and trabecular bones. The connection between implants and supporting tissues is designed to directly transfer loads among implants prosthetic framework. The mesh with 10-node quadratic tetrahedral elements was constructed with nodes/items ranging from 6,246,138/3,383,053 to 7,623,446/4,163,805. It is assumed that the implants are 100% osseointegrated. All materials used in this study are homogeneous, isotropic, and linearly elastic. The defined modulus of elasticity and Poisson ratio properties of the prosthetic material, mucosa, cortical bone, trabecular bone, and implants are shown in Table 1.
FEA models were imported to ALGOR FEMPRO software (Algor Inc., Pittsburgh, USA) for 3D static analysis. To simulate chewing forces more naturally, a dynamic 100 N occlusal force was placed on prosthetic structures from a spherical solid material (12 mm in diameter) that mimics foodstuff in both anterior (Left canine) and posterior (Left first molar) regions. (Figure 2)

Analysis

Major stresses were evaluated to identify local risk indicators of peri-implant bone resorption to assess trabecular and cortical bone. The maximum principal stress (Pmax) represented the tension-type of stress, and the minimum principal stress (Pmin) was the compression-type stress. All stresses were measured in megapascals (MPa). Peak stress values were considered for the evaluation. Following similar studies, bone overload was noted when Pmax or Pmin exceeded uniaxial tensile or compressive stress, respectively. The strength of the cor-

	ELASTIC MODULUS (MPA)	POISSON RATIO
CORTICAL BONE	13700	0.3
TRABECULAR BONE	1370	0.3
MUCOSA	680	0.45
TITANIUM	117000	0.35
IMPLANT (TI-ZR; ROXOLID)	100000	0.3
ACRYLIC	3000	0.35
FELDSPATHIC PORCELAIN	82800	0.35

TABLE 1 Elastic Modulus and Poisson Ratios

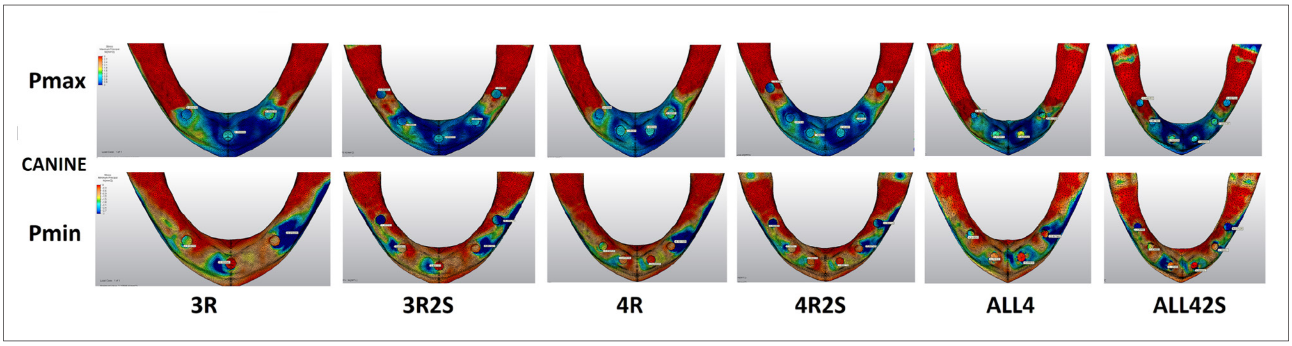

FIG. 3. Stress values and distributions in the cortical bone against canine forces

CANINE FORCES	CORTICAL PMAX	CORTICAL PMIN	TRABECULAR PMAX	TRABECULAR PMIN
3R	18,6	-15,4	4	-3,9
3R2S	20,9	-13,8	5,3	-3,6
4R	18,6	-17,2	2,6	-6
4R2S	23,3	-17,7	5,8	-6,7
ALL4	15,4	-15,7	5,8	-4,8
ALL42S	19,7	-16,2	6,1	-3,6

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

tical bone was assumed to be 115 MPa (Pmax) under tension and 151 MPa (Pmin) under compression(19). Von Mises (vM) stresses were analyzed to evaluate the stress generation in the implants. Implants, abutments, screws, frameworks, and crowns were analyzed according to the vM criterion. Since the data obtained from FEA are mathematical calculations without variance, the results were not statistically analyzed but evaluated with scales. All stresses are shown using color and quantity scales. The stresses in bone, implant, and prosthetic components were compared according to the vM criterion, and the fatigue principle interpreted the results.

RESULTS

Stress in Peri-implant Bone

As a result of 100 N force from foodstuff applied to the models of the left canine region, the highest Pmax formed in the cortical bone was in 4R2S with 23.3 MPa and 3R2S with 20.9 MPa. The lowest stress formation was in the ALL4, with 15.4 MPa. When the Pmin formed in the cortical bone was evaluated, the highest stresses with approximately -17 MPa were in the 4R and 4R2S. The lowest stress was in 3R2S at -13.8 MPa. (Table 2) (Figure 3)

When the Pmax stresses in the trabecular bone are examined, the highest stress occurred in ALL42S with 6.1 MPa, followed by 4R2S and ALL4 with 5.8 MPa. The 4R (2.6 MPa) stress was the lowest. The lowest Pmin in trabecular bone was in the 3R2S and ALL42S with -3.6 MPa. The highest stress formation was in the 4R2S with -6,7 MPa. (Table 2) (Figure 4)

When the stresses on the peri-implant bones in the canine region were evaluated in general, it was seen that the stresses on the bones were low and short implants in the posterior region did not contribute to the stresses on the peri-implant bones against the forces from the anterior region.

When 100 N food forces were applied to the models from the left first molar region, it was observed that the highest Pmax stress in the cortical bone occurred in 4R and ALL42S (18.6 MPa). The lowest stress was in the 3R2S and 4R2S

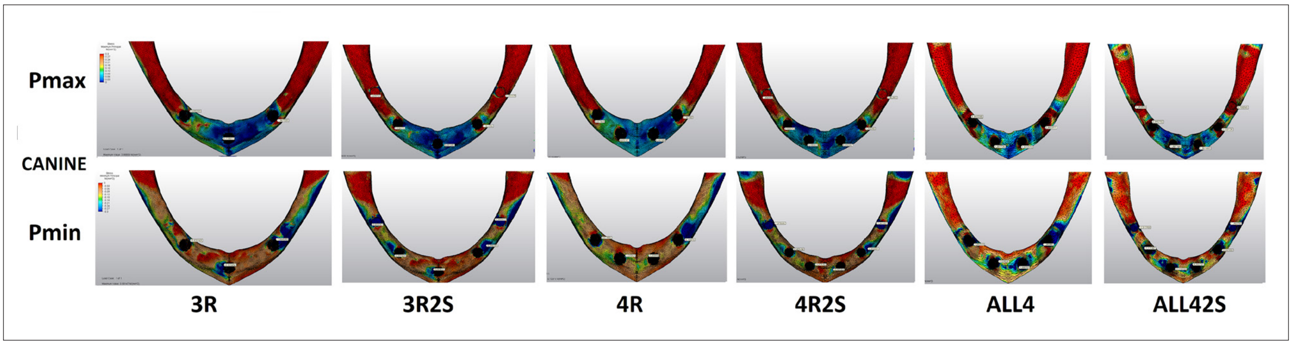

FIG. 4. Stress values and distributions in the trabecular bone against canine forces

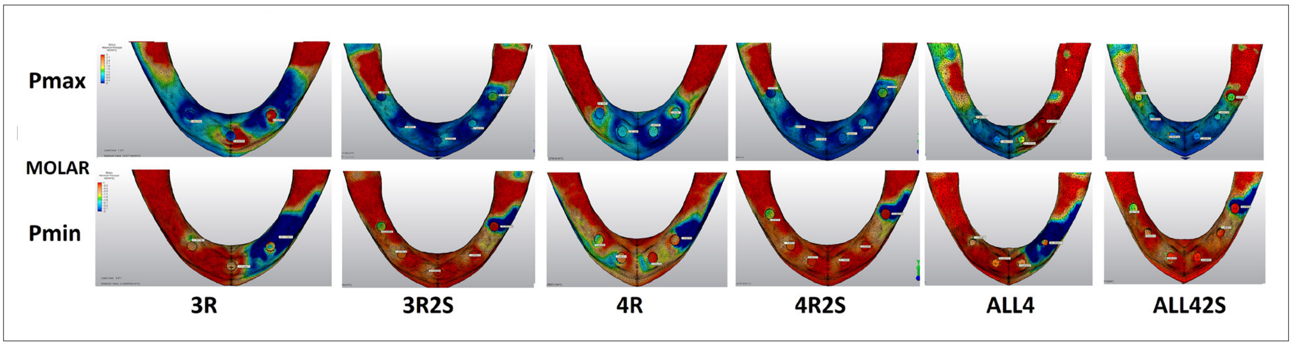

FIG. 5. Stress values and distributions in the cortical bone against molar forces

MOLAR FORCES	CORTICAL PMAX	CORTICAL PMIN	TRABECULAR PMAX	TRABECULAR PMIN
3R	14,7	-24,2	9,9	-7,6
3R2S	11	-18,3	8,7	-2,2
4R	18,6	-17,2	2,6	-9,3
4R2S	11,3	-20,9	9,7	-2,1
ALL4	16,7	-19	8,5	-4,5
ALL42S	18,6	-24,8	5,1	-4,1

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

(approximately 11 MPa). In cortical bone, the highest Pmin was in ALL42S and 3R at around -24 MPa. On the other hand, 4R caused the lowest stress with -17.2 MPa. (Table 3) (Figure 5)

In trabecular bone, the highest Pmax was in 3R with 9.9 MPa and 4R2S with 9.7 MPa. On the other hand, the lowest stress occurred in the 4R with 2.6 MPa. When Pmin formed in trabecular bone was evaluated, the highest stress was determined at 4R with -9.3 MPa. The lowest stresses occurred in 4R2S and 3R2S with about -2 MPa. (Table 3) (Figure 6)

Against the forces applied from the molar region, no severe stresses were encountered on the peri-implant bones. It is seen that short implants in the posterior region make a significant contribution, especially in the 3R, which includes three implants. Compared to the 4R, the 4R2S is more advantageous in the Cortical Pmax and Trabecular Pmin stresses. In contrast, the opposite is the case in other conditions. Compared to the ALL4, the ALL42S did not contribute, but it also created a disadvantage in some conditions.

Stress in Implants and Prosthetic Structures

When the mean von Mises values in the implants against the forces applied from the canine region were evaluated, the highest stress was observed at 3R2S (86.2 MPa), followed by 3R (81.2 MPa). The slightest stress was observed in ALL42S with 59.9 MPa. When the stresses on the implants in models with short implants, were evaluated against the forces from the canine region, it was seen that the stresses on the interforaminal region implants were more intense compared to those on short implants. (Table 4) (Figure 7)

Considering the stresses on the multiunit abutments, the highest stress was in the 3R, and the lowest was in the ALL42S. It is seen that the stresses occurring in the models containing four implants in the interforaminal region are close to each other. Short implant support reduced stresses in the other two conditions, except for the 4R2S.

When the stresses on the implants due to the forces applied from the molar region are examined, the highest Von Mises stress experienced was 203 MPa at 3R. The second highest was observed in ALL4, with 185.2 MPa.

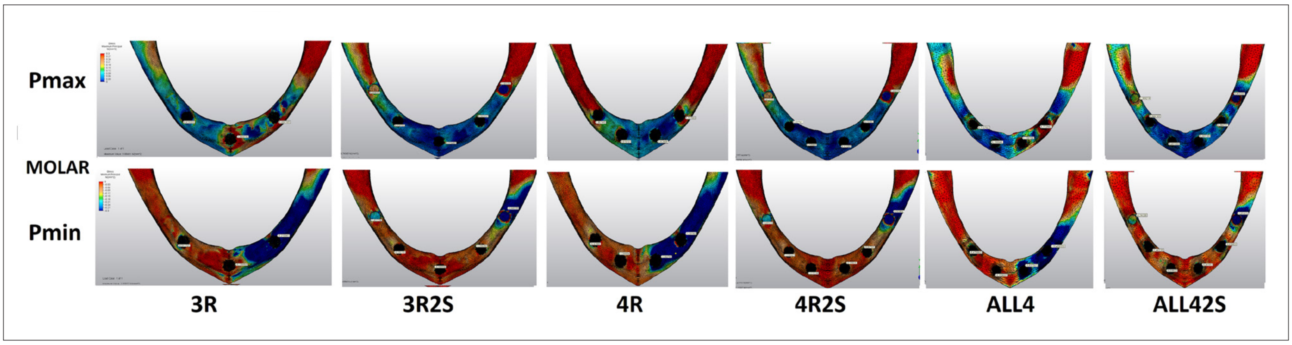

FIG. 6. Stress values and distributions in the trabecular bone against molar forces

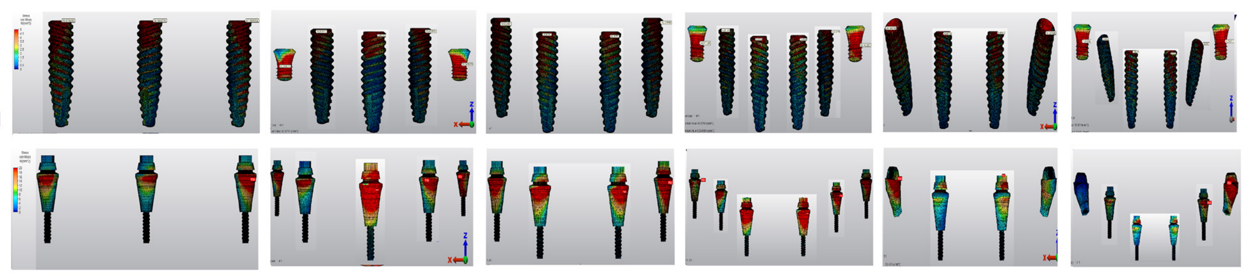

FIG. 7. Stress values and distributions in the implants against canine and molar forces

CANINE FORCES	IMPLANTS	SHORT IMPLANTS	MULTIUNIT	FRAME-WORK	CROWNS
3R	81,2	-	57,4	59,5	14,4
3R2S	86,2	61,1	51,4	45,3	13,4
4R	71,4	-	42,3	87	13,1
4R2S	77,9	68,3	44,1	92	12,7
ALL4	68,2	-	47,7	57,15	12
ALL42S	59,9	59,8	40,5	65,9	11,6

TABLE 4. Stress (MPa) Values In Implants and Prosthetic Components Against Forces From Canine Forces

MOLAR FORCES	IMPLANTS	SHORT IMPLANTS	MULTIUNIT	FRAME-WORK	CROWNS
3R	203	-	168,2	159,8	5,6
3R2S	46,2	46,2	33,6	24,2	5,4
4R	176	-	138,6	169	5,4
4R2S	43,7	43,7	34,9	23,6	5,5
ALL4	185,2	-	140,1	168,3	5,4
ALL42S	52,7	51,2	40,9	39,8	5,2

TABLE 5. Stress (MPa) Values In Implants and Prosthetic Components Against Forces From Molar Forces

About five times more stress was detected in the highest stressed 3R (203 MPa) compared to the lowest stressed 4R2S (43.7 MPa). Models with short implants caused lower stress occurrences than other models, and the stresses in these models were generally concentrated on short posterior implants. (Table 5) (Figure 7)

Like the stresses on implants, models with short implants have much lower stress densities on multiunit abutments. For example, the highest stress on the multi-units occurred in the 3R (168.2 MPa). In comparison, the lowest stress was observed in the 3R2S (33.6 MPa), approximately five times less in the short implant-containing version of this model.

When the stresses created by the prosthetic structures against canine forces were examined, the highest stress on the metal framework was observed in the 4R2S (92 MPa) and the lowest in the 3R2S (45.3 MPa). The stresses occurring in the acrylic prosthetic structure are very close. While the highest stress occurred in the 3R with 14.4 MPa, the lowest stress was observed in the ALL42S (11.6 MPa). The short implant supports generally did not cause significant differences in framework and acrylic structure. (Table 4) (Figure 8, 9)

The stresses on the metal framework, in the stresses against the molar region forces, were relatively high in the models without short implants compared to those with it. While the highest stress occurred in the 4R with 169 MPa, the lowest stress was observed at 23.6 MPa,

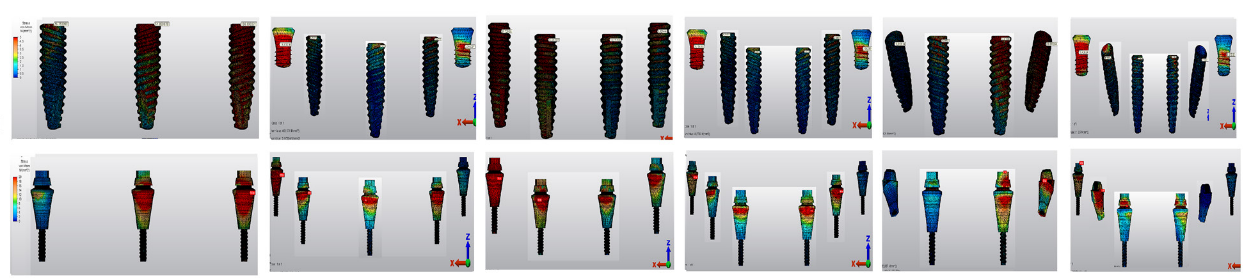

FIG. 8.Stress values and distributions in the multiunit abutments against canine and molar forces

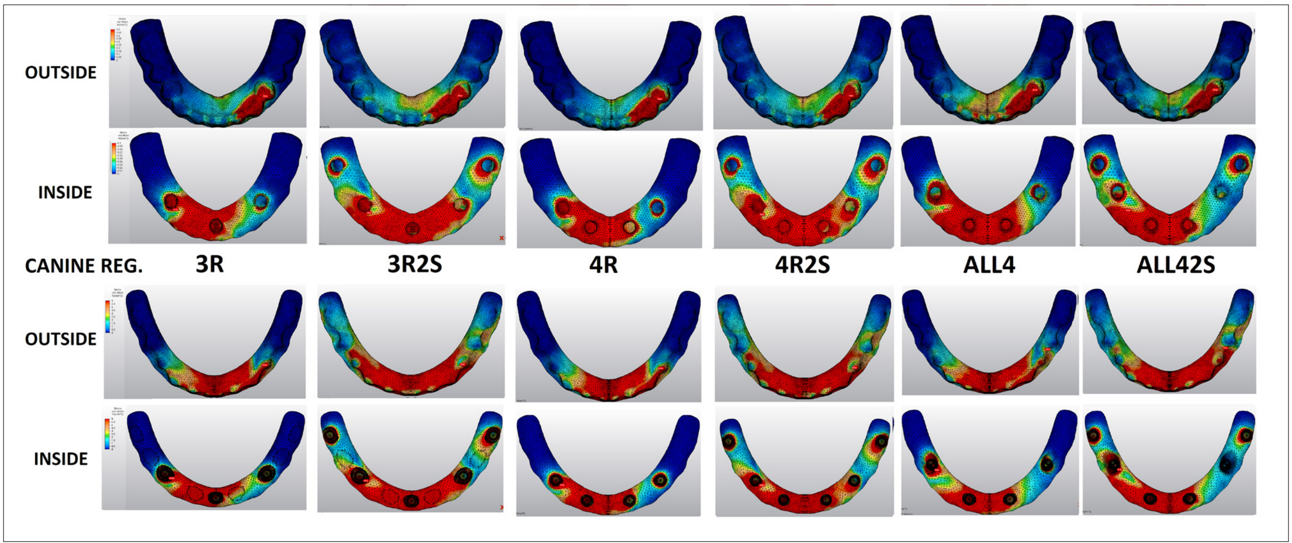

FIG. 9.Stress values and distributions in the metal framework against canine and molar forces

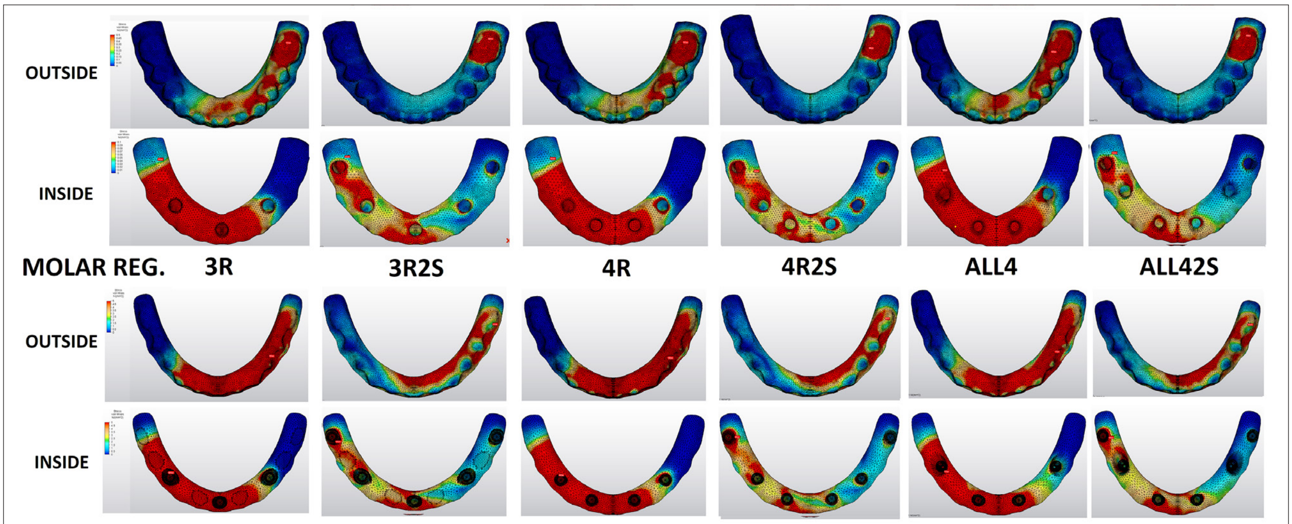

FIG.10. Stress values and distributions in the acrylic prosthesis against canine and molar forces

approximately seven times less, in the 4R2S,that is the short implant model of the 4R. On the prosthetic structure, the stresses are very close to each other, and there is almost no difference between the models. (Table 5) (Figure 8, 10).

When the stresses on the prosthetic structures are evaluated in general, short implants did not significantly contribute to the forces of the canine region. In contrast, the presence of short implants significantly reduced the stresses against the forces applied from the molar region, especially on the multiunit and metal framework.

DISCUSSION

The present 3D FEA study compared the stresses on bones and materials against the masticatory forces applied to fixed prostheses. When implant placements with different concepts in the interforaminal region and when these concepts are supported with short implants in the posterior region. While the null hypothesis determined according to the results of the study was rejected against the cutting forces applied from the canine region, it was confirmed against the grinding forces applied from the molar region, especially considering the high-stress values on the implants and prosthetic materials in models not supported by short implants.

FEA is a method used to investigate stress values on complex structures. Under normal conditions, it is impossible to clinically visualize the stresses caused by loading. However, 3D FEA makes it possible to study stresses around dental implants and bones and provides an understanding of mechanical resistance under loading conditions. Knowing and understanding biome-

chanical properties with such studies can help advance in having more predictable oral rehabilitations (20, 21).
Although grafting of the posterior atrophic mandible with various procedures or repositioning of the mandibular nerve restricting the vertical height has been successful in various studies, it has negative aspects in terms of increasing the cost and requiring interventional procedures with various risks and prolonging the treatment period. Patient expectations and clinicians' treatment options today solve the problem as soon as possible with conservative treatment methods. For this purpose, implant placement techniques in various configurations are frequently used in the interforaminal region between the two mental foramina, which is known to be less affected by bone resorption. With the increasing use of dental implants, the planning of the rehabilitation of the completely edentulous mandible with implant-supported fixed prostheses has changed over time. From the studies using six or more implants for rehabilitating an edentulous mandible over time (22), studies reporting that the rehabilitation of the mandible with three implants yielded successful results reached (23-25).
One of the most common techniques for fixed implant-supported rehabilitation of the edentulous mandible in recent years is the placement of 4 implants in different configurations. One of the oldest recommended techniques is placing four vertical implants in the interforaminal region and using prosthetic cantilevers, put forward by Brånemark (26). Although high success rates have been reported in this technique, it has also been reported that very long cantilever sizes in these applications can lead to various technical complications, especially in prosthetic materials (11, 27). This technique has been simulated in the present study with the name 4R.
As a result of seeking solutions to technical complications, distal angled implant placement techniques were proposed by Malo et al. (6) under the name of the All-on-4 treatment concept to take advantage of the interforaminal space, place longer implants, and allow more posterior positioning of the implants to reduce the length of the cantilever. The data of Malo et al. (9), which included high success rates with extended follow-up, were confirmed in studies conducted by many researchers in the following periods. Therefore, this concept is animated in this study under the name ALL4.
The use of 3 implants to rehabilitate the edentulous mandible was first introduced by P.I. Brånemark et al. (28). It was implemented under the Novum protocol. As a result of this study, researchers reported an implant survival rate of 98% in 3 years and of 93.3% in five years. Inspired by this technique, Hatano et al. (29), in the following years, applied a similar treatment method using standard implants. The researchers reported that three standard-design implants placed in the interforaminal region of the completely edentulous mandible would support fixed prosthetic rehabilitation even in the immediate loading state at a 5 years follow-up. This technique was investigated with the 3R model in the present study.
The common feature of all these interforaminal implant placement techniques is distal cantilever extensions in prosthetic structures for posterior areas where implant placement cannot be performed. Although it is known that implant-supported cantilever extension full-arch prostheses are generally successful and a safe treatment option, studies have shown that cantilever extensions cause some technical complications (8, 10, 11, 14, 27). Kim et al. (11) compared similar concepts with and without a cantilever and reported that implants in the cantilevered group lost significantly more bone in the posterior mandible. Furthermore, the cantilever length correlated positively with implant failure, technical complications, and bone loss ≥1.5 mm. In addition, Halg et al. (10) stated in their study that cantilever prostheses cause more technical complications. Finally, Aglietta et al. (27) reported that implant-supported cantilever-fixed dental prostheses' most frequent technical complications included veneer fractures, screw loosening, and loss of retention. However, no detrimental effects on bone levels were observed around implants near cantilever extensions.
The null hypothesis of this study is that these complications can be reduced by supporting the cantilever extensions with extra-short implants in the posterior atrophic mandible. Similarly, in their biomechanical study, Ogawa et al. (12) reported that supporting cantilever extensions with short implants in the posterior region produced better stress values in axial and bending forces than unsupported prostheses. Therefore, researchers argued that cantilever extensions should be supported with short dental implants in the posterior region. On the other hand, Tükel et al. (30), in their FEA study using tissue-level implants, concluded that the support of interforaminal implants with extra-short implants in the posterior region did not show the expected contribution. In particular, the researchers noted that the placement of 4 posterior extra-short implants does not make a significant difference compared to the placement of 2 extra-short implants.
Thanks to the developments in dental implant technologies, the durability of implants in narrower diameters and shorter lengths has also increased. As a result of these developments, the acceptable length of short implants has decreased over time from 8 mm to 6 mm and today as extra-short implants to 4 mm. Although the acceptable lengths of short implants have changed over time, reported success rates have remained similar (3, 4, 16, 18, 31). In the present study, the lowest possible bone volume allowing implant placement in the posterior mandibular region was determined, and 4mm tissue level implants belonging to Straumann Group company, which is known to be one of the implants with the shortest implant length that can be easily accessed in market conditions, were simulated.
Currently, available scientific data on ultra-short implants are limited and insufficient to reach a firm conclusion about 4 mm implants. However, Slotte et al. (32) reported that 4 mm implants allowed fixed prosthetic rehabilita-

tion in the atrophic mandible under healthy peri-implant conditions. Furthermore, in the 5-year follow-up of the same study, the survival rate of 86 extra-short implants was reported as 92.2% (13). Barausse et al. (16) reported that ultra-short implants of 4 mm show similar results at 5 years follow-up compared to longer implants placed in grafted jaws with increased vertical size. Therefore, researchers stated that their use might be preferable to bone grafting techniques in certain situations, as the treatment is less invasive, faster, cheaper, and associated with less morbidity. In addition, Segalla et al. (33) concluded that 4-mm implants show high survival rates after 33 month follow-up period.

In the present study, not only the chewing forces of the molar region, which are thought to be the main determining forces in the cantilever appendages, but also the shear forces from the canine region are simulated in order to simulate each condition. As a result, short implants in the posterior region did not contribute to the forces of the canine region as expected against the applied forces. On the other hand, the implants located in the anterior region and the peri-implant bone surrounding these implants met the stresses caused by these forces. Therefore, no significant reduction in stress formations was detected in the peri-implant bone, implants, or prosthetic components against canine region forces.

As expected, stress formations were seriously affected by the forces applied from the first molar tooth region, which corresponds to the tooth position where the cantilever extension ends and represents the grinding process. However, in terms of the cortical bone, which is known to be more affected by resorption in terms of peri-implant bones and coincides with the neck region of the implants, the stresses occurring in other models, except the All-on4 model, have decreased. Therefore, it can be inferred that short implant support will reduce stress concentration and accumulation in the cortical bone in cases where vertical implant placement is applied, thus reducing the possibility of neck resorption in implants from a biomechanical point of view.

On the other hand, in models without short implant support, it has been observed that the stresses on the distal implants are reduced by up to 5 times, thanks to the short implant supports. This is because the short implants met directly by taking these stresses over the distal implants. In fact, it is seen that the stress values on the implants in these models reach the highest numerical values on short implants. Nevertheless, the resulting stresses seem to be far below the fracture resistance of the Roxolid-type zirconium alloy implants. However, in the current study, an average force of 100 N was applied, according to the average of other studies in the literature (15, 34, 39). Therefore, the risk may arise in cases where these forces are increased slightly above the average or in cases where a significant increase in strength is expected on implants and prosthetic structures, such as bruxism, especially in clinical conditions.

It is known that the most significant risk factor of interforaminal implant placement concepts with prostheses containing cantilever extensions is the technical problems experienced in prosthetic structures (8, 10, 11, 14, 27). In the current study, especially against molar region forces, high-stress accumulations of up to 8 times were detected in models without short implant support on multiunit abutments and prosthetic frameworks. Furthermore, the stresses on the multiunits and the framework were higher than on the implants in almost all models. This finding can confirm that the most significant risk factor of these concepts is the fractures of the connection parts, such as multiunit screws, the fractures of the lower and upper structures of the prosthesis, and porcelain chipping due to the tensions experienced in these areas. Supporting these areas with short implants has reduced the resulting stresses to shallow levels. In addition, the resulting stresses are directly covered by the multiunit abutments on the short implants. According to the findings of the current *in vitro* study, although it is not possible to conclude that interforaminal placement concepts should be supported with short implants in all circumstances, with the experience of this clinician, using the short implant trump in cases where the risk of technical complications is anticipated may contribute significantly to long-term success.

CONCLUSION

Within the limits of this study, it has been observed that the quantified stress in interforaminal implant placement concepts could not generate failure in the implants after applying a 100-N foodstuff force, as the values did not exceed the yield strength of 825 MPa of the material of the implant and on the peri-implant bones. However, due to their cantilever extensions, stress formations on posterior implants, multiunit abutments, and prosthetic frameworks increase significantly, especially against the forces coming from the cantilever (molar) region. This situation can lead to technical complications such as multiunit abutment, connection screws, prosthetic framework fractures, and chipping in prosthetic structures. Therefore, eliminating the cantilever extensions by supporting this region with ultra-short implants can significantly reduce the frequency of these technical complications. This situation may be critical in bruxist patients who are expected to exert more than regular forces on implant-supported prostheses.

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