Original Article
Short implants to retain/support overdentures in extremely resorbed mandibles with different transverse widths: a finite element analysis

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Abstract: Lack of stability and retention of lower complete dentures are the main complaints of patients with extremely resorbed jaws. To resolve these problems, four-implant-supported overdentures have been preferred for rehabilitation. However, inserting fewer implants can ease surgical and prosthetic procedures. Therefore, this study aimed to evaluate the influence of short implant numbers and transverse mandibular widths on stress distribution of extremely resorbed mandibles with implant-retained/supported overdentures, using three-dimensional finite element analysis. Nine three-dimensional finite element models with three transverse widths that retained/supported an implant overdenture, with different numbers of supporting inter-foraminal short implants, were designed. To simulate a natural chewing environment, a spherical rigid material representing foodstuff was used in different biting configurations. Of all mandibular configurations, the highest compressive stress values were generated in two-implant-retained models. Measured stress values in three- and four-implant supported models were found to be closely related. Current study outcomes demonstrated that, regardless of transverse width, three-implant-supported overdentures may be an appropriate choice of treatment for patients with edentulous extremely resorbed mandibles. This modality can offer relatively cheaper treatment costs with the advantage of less complex laboratory designs.

Keywords: Edentulous mandible, short implant, finite element analysis, overdenture, transverse mandibular width

Introduction

Resorption of the alveolar ridge that occurs after tooth loss is a natural healing process [1, 2]. In advanced stages of edentulous, this resorption may progress to the basal bone of the mandible [3]. An extremely resorbed edentulous mandible is defined as a mandibular height in the symphyseal area of 12 mm or less, as measured on a standardized lateral radiograph [4].

According to the World Health Organization, the average life expectancy has increased in recent decades, resulting in an increase in the number of elderly people [5]. Therefore, clinicians are likely to increasingly encounter patients with extremely resorbed mandibles. Lack of stability and retention of lower complete dentures, decreased chewing ability, and esthetic and psychosocial factors are the main complaints

of these patients [3, 6, 7]. To resolve these problems and increase patient quality of life, overdentures that are supported by implants are frequently preferred [6]. Higher morbidity rates, increased costs of reconstructive augmentation procedures, and recent technological advances in the dental implant industry have made short implants the treatment of choice for extremely resorbed jaws [2, 3, 6, 8]. However, there is limited data regarding clinical outcomes of short implants in the interforaminal area of severely atrophic mandibles [3, 6, 9]. In addition, four-implant-supported overdentures have been preferred for rehabilitation of these patients [10, 11]. On the other hand, inserting fewer implants can ease surgical and prosthetic procedures, decreasing treatment costs in this patient population [3].

Transverse mandibular width (TMW) may play a role in determining the number of implants that
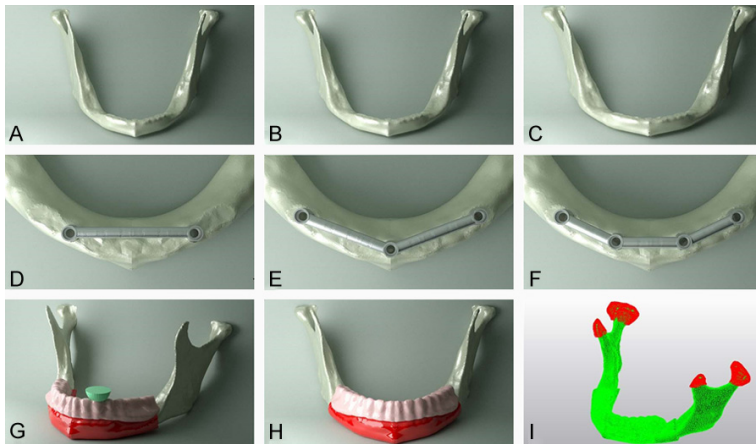
Figure 1. A. Narrow configuration of the mandibular arch on the horizontal plane. B. Standard configuration of the mandibular arch on the horizontal plane. C. Wide configuration of the mandibular arch on the horizontal plane. D. The bar attachment system for mandibular two-implant retained overdenture. E. The bar attachment system for mandibular three-implant supported overdenture. F. The bar attachment system for mandibular four-implant supported overdenture. G. Occlusal loading (100 N) on the left canine tooth using SRM to avoid localized contact. H. Mandibular FEM comprising the bone, mucosa, and overdenture. I. Boundary conditions of the mandibular FEM.

simulated with this technique [17, 18]. These advantages make FEA increasingly useful in dentistry, assessing the feasibility of new treatment modalities before conducting *in vivo* research [18, 19]. Therefore, before designing a clinical trial, this study aimed to evaluate the influence of short implant numbers and different horizontal configurations on the stress distribution of extremely resorbed mandibles with implant-retained/-supported overdentures, using 3D FEA. Tested hypotheses included: (1) Wide-sized mandible configuration will have greater influence on stress distribution on peri-implant bones; and (2) An increment in the number of implants reduces generated stress on peri-implant bones.

Material and methods

Data of 3D mandible finite element models (FEMs) used in the present study were obtained from the Visible Human Project (US National Library of Medicine, Bethesda, Md). Data was modified with the use of VR Mesh Studio (VirtualGrid Inc, Bellevue, Wash) and Rhinoceros 4.0 (McNeel North America, Seattle, Wash) software to simulate clinical situations of extremely resorbed edentulous mandibles. Subsequently, the transverse width of the lower jaw was increased and decreased by 11% to acquire narrow and wide dimension models, respectively, according to the maximum possible limits for mandible size modification. This provides sufficient horizontal space for bar-clip system arrangement (**Figure 1A-C**) [13, 14]. Moreover, in the inter-foraminal region, the uniform thicknesses of the mucosa and cortical bones were formed approximately 2.0 and 1.5 mm, respectively.

Models of extremely resorbed mandibles with three transverse widths that retained/supported an implant overdenture with different numbers of supporting interforaminal implants were divided into nine groups:

are required in edentulous mandibles. Also, it is complicated to postulate the extent to which overdentures are mucosa- and implant-supported or even completely implant-supported in extremely resorbed mandibles [12, 13]. Moreover, mandibular overdentures supported by the same number of implants may show varying degrees of rotational movement around the fulcrum line, due to differences in transverse width. Increased rotational movements lead to compromised stability and residual ridge resorption. Thus, determining the favorable implant number has great importance in extremely resorbed mandibles. However, the influence of a short implant number or TMW on the biomechanical behavior of extremely resorbed mandibles has not been examined in detail. This lack of knowledge has been confirmed by other researchers [3, 14].

Several methods, such as photo-elasticity, finite element analysis (FEA), and strain gauge measurement have been used for assessment of stress distribution in the stomatognathic system [15, 16]. Of these biomechanical methods, three-dimensional (3D) FEA may be more precise and convenient in predicting the effects of stress on dental implants and surrounding bones [16, 17]. Physical data, such as stress, strain, and displacement, can be obtained using FEA. Various clinical situations can be easily

Table 1. Young's modulus and Poisson's ratio of materials

Material	Young's modulus (MPa)	Poisson's ratio	Reference
Cortical bone	13700	0.3	Liu et al. [17], Peixoto et al. [8], Bilhan et al. [20]
Cancellous bone	1370	0.3	Liu et al. [17], Peixoto et al. [8], Bilhan et al. [20]
Mucosa	2.6	0.37	Bilhan et al. [20]
Titanium	110000	0.33	Bilhan et al. [20]
Gold	93000	0.33	Bilhan et al. [20]
Prosthesis (polymethyl methacrylate)	2700	0.35	Peixoto et al. [8]

• Model N2: narrow-sized mandible with two-implant-retained overdenture, model N3: narrow-sized mandible with three-implant-supported overdenture, and model N4: narrow-sized mandible with four-implant-supported overdenture.

• Model S2: standard-sized mandible with two-implant-retained overdenture, model S3: standard-sized mandible with three-implant-supported overdenture, and model S4: standard-sized mandible with four-implant-supported overdenture.

• Model W2: wide-sized mandible with two-implant-retained overdenture, model W3: wide-sized mandible with three-implant-supported overdenture, and model W4: wide-sized mandible with four-implant-supported overdenture.

In two-implant configurations, implants were inserted in the mandibular canine regions. In three-implant configurations, distal implants were bilaterally inserted in the mandibular canine regions, whereas central implants were inserted in the jaw midline. In four-implant configurations, two implants were inserted in the region of the mandibular lateral incisor and the distal implants were bilaterally inserted in the first premolar region (**Figure 1D-G**).

Short cylindrical screw-type implants (Straumann, Basel, Switzerland; diameter, 4.1 mm; length, 6 mm), abutment (RN synOcta 1.5 screw retained), occlusal screw, and bar and bar matrix were scanned using an optic scanner (Activity 880, Smart Optics Sensortechnik GmbH, Bochum, Germany). Obtained data were transferred to Rhinoceros 4.0 software for 3D modeling. Mandibular acrylic overdentures were designed to fit all implant models and its superstructures. The mechanical properties of the chosen materials were acquired from previous studies [8, 17, 20], presented in **Table 1**. The implant-bone interface and the contacts between bar attachment system and overdenture prosthesis were assumed to be static. Additionally, the contact area of the overdenture and mucosa was considered to be frictionless.

Geometries of the mandible, implant, attachment systems, and overdenture were then meshed with 3D parabolic tetrahedral solid elements and subsequently imported into mechanical simulation software (Algor Fempro, Algor, Beta Drive Pittsburgh, PA, USA). This data was used to evaluate patterns of stress distribution. The models had between 104,114 and 120,984 nodes and between 468,720 and 542,809 elements.

A spherical rigid material (SRM), with a 20 mm diameter, was used to represent foodstuff and accurately describe its interaction with overdentures (**Figure 1H**). The main aim of SRM models was to reduce calculation times and ease contact management. To simulate different biting configurations, foodstuff was positioned on the left incisors, left canine, and left first molar region. A load of 100 N was selected, according to previous studies [8, 17, 21]. Boundary conditions were established by the fixation of the condyle and coronoid process in all directions at the selected degree of freedom (**Figure 1I**). Maximum and minimum principal stress values for cortical bones and von Misses stress values for implants of all models were obtained, numerically produced, color coded, and compared among the models (**Figures 2-4**).

Results

Stress levels on cortical bones of each constructed models (narrow mandible: N2, N3, and N4; standard mandible: S2, S3, and S4; wide
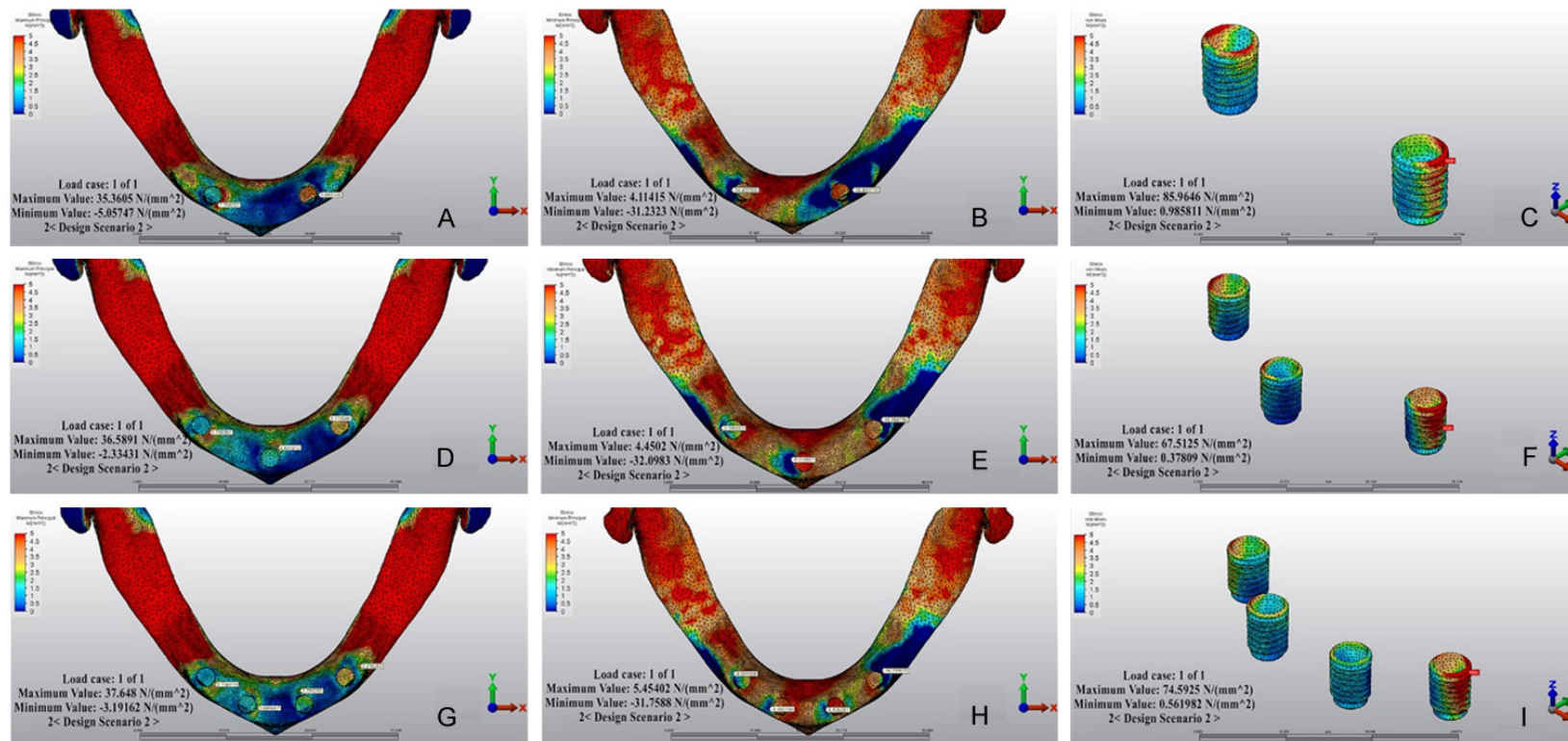
Figure 2. The stress distribution of narrow-sized mandible models under loading on the left canine. A. Maximum principal stress distribution in peri-implant cortical bone of N2 model; B. Minimum principal stress distribution in peri-implant cortical bone of N2 model; C. Von Mises stress values observed at implants in N2 model; D. Maximum principal stress distribution in peri-implant cortical bone of N3 model; E. Minimum principal stress distribution in peri-implant cortical bone of N3 model; F. Von Mises stress values observed at implants in N3 model; G. Maximum principal stress distribution in peri-implant cortical bone of N4 model; H. Minimum principal stress distribution in peri-implant cortical bone of N4 model; I. Von Mises stress values observed at implants in N4 model. *Colors indicate stress levels, from red (lowest) to dark blue (highest) for cortical bone and dark blue (lowest) to red (highest) for dental implants. The arrows indicate sites at which peak stress values occurred.*
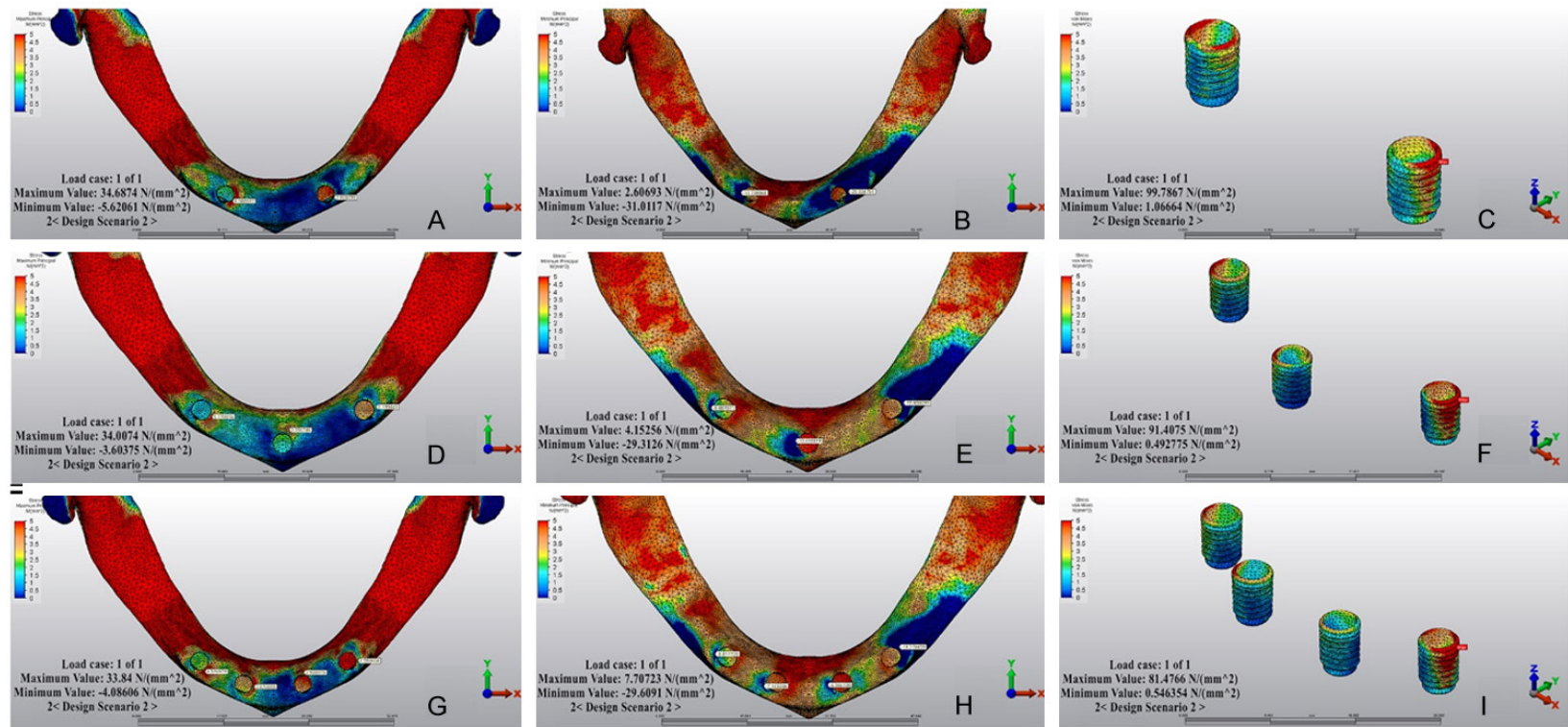
Figure 3. Stress distribution of standard-sized mandible models under loading on the left canine. A. Maximum principal stress distribution in peri-implant cortical bone of S2 model; B. Minimum principal stress distribution in peri-implant cortical bone of S2 model; C. Von Mises stress values observed at implants in S2 model; D. Maximum principal stress distribution in peri-implant cortical bone of S3 model; E. Minimum principal stress distribution in peri-implant cortical bone of S3 model; F. Von Mises stress values observed at implants in S3 model; G. Maximum principal stress distribution in peri-implant cortical bone of S4 model; H. Minimum principal stress distribution in peri-implant cortical bone of S4 model; I. Von Mises stress values observed at implants in S4 model.
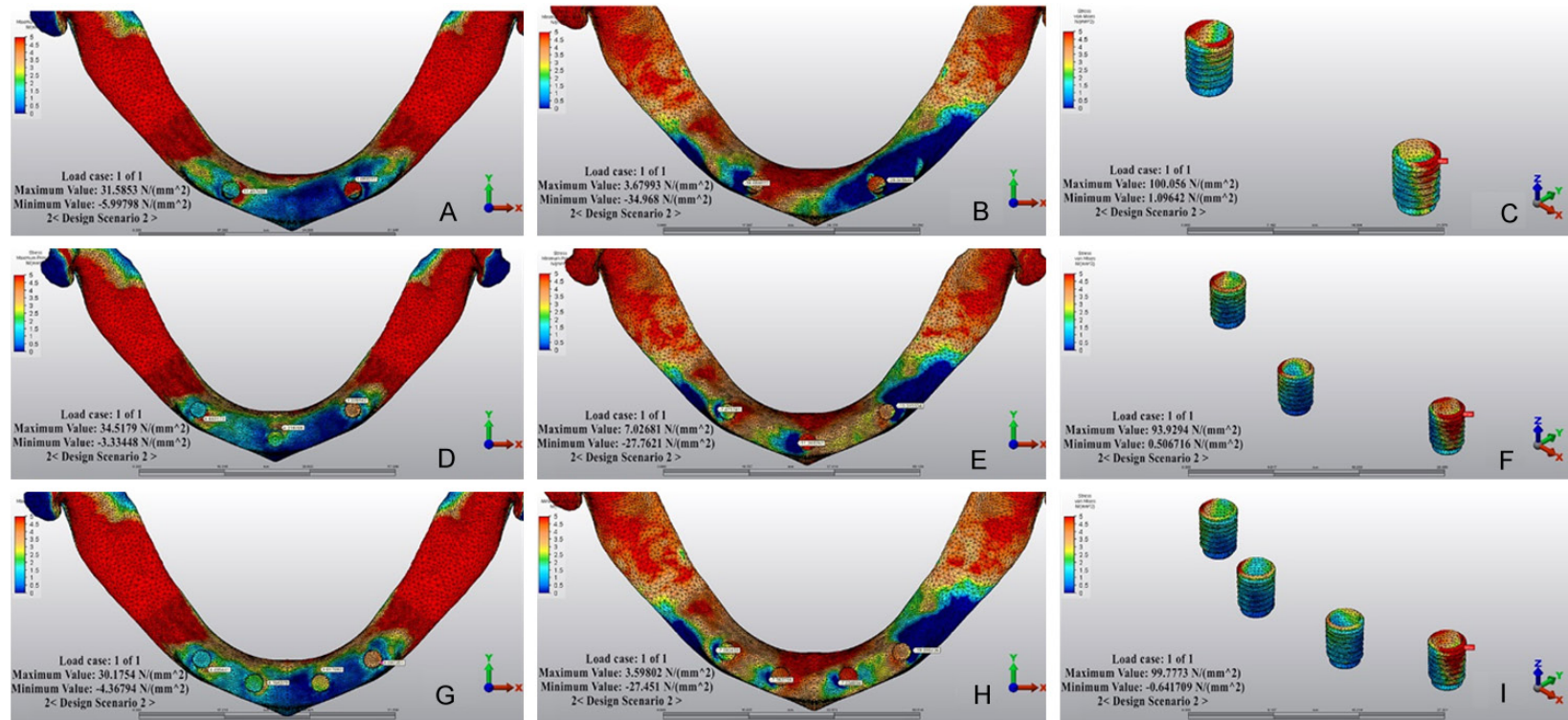
Figure 4. Stress distribution of wide-sized mandible models under loading on the left canine. A. Maximum principal stress distribution in peri-implant cortical bone of W2 model; B. Minimum principal stress distribution in peri-implant cortical bone of W2 model; C. Von Mises stress values observed at implants in W2 model; D. Maximum principal stress distribution in peri-implant cortical bone of W3 model; E. Minimum principal stress distribution in peri-implant cortical bone of W3 model; F. Von Mises stress values observed at implants in W3 model; G. Maximum principal stress distribution in peri-implant cortical bone of W4 model; H Minimum principal stress distribution in peri-implant cortical bone of W4 model; I. Von Mises stress values observed at implants in W4 model.
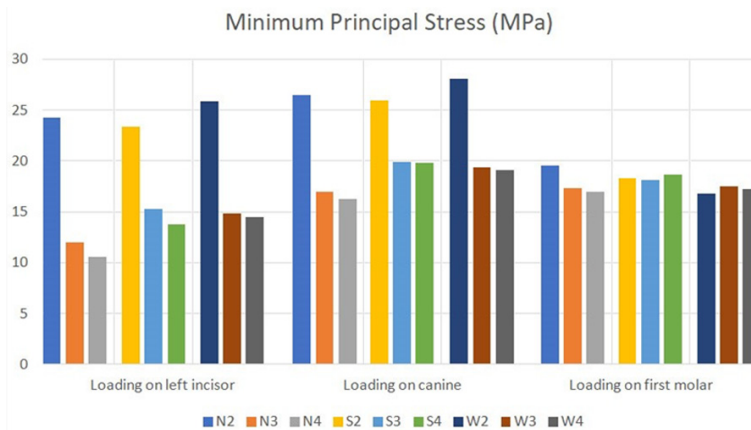
Figure 5. Comparison of the highest minimum principal stress values (MPa) for the cortical bone observed in each model with three different loading conditions.

mandible: W2, W3, and W4) under three loading conditions were evaluated. In this analysis, compressive stress values were higher than tensile stress values. Therefore, minimum principal stress values for cortical bones were compared among the models.

Stress on cortical bones

In models where loading was applied to left incisors and left canine teeth, respectively, the highest compressive stress value was generated at the distal side of the left implant in the W2 model (25.84 MPa and 28.05 MPa). The lowest stress value was generated at the distal side of the rearmost left implant in the N4 model (10.59 MPa and 16.22 MPa). Of all mandibular configurations, the highest compressive stress values were generated in two-implant-retained models. Measured stress values in three- and four-implant supported models were found to be closely related. In all implant combinations, compared with wide- and standard-sized mandible models, narrow-sized mandible models showed the lowest stress values. However, the S2 model demonstrated slightly lower values than the N2 model. When loading was applied to the molar region, compressive stress values measured, in all models, were close to each other. The highest compressive stress value was observed at the distal side of left implant in the N2 model (19.49 MPa), while the lowest compressive stress value was recorded at the distolingual side of the left implant in the W2 model (16.74 MPa). Minimum and maximum principal stress values, under

three types of loads for each model, are shown in **Figures 5**-**6**.

Stress on dental implants

The highest von Misses stress values were localized at the disto-cervical region of the most distal implant under ipsilateral loading. Loading on the anterior teeth produced higher stress values around the load-bearing implant and maximum von Mises stress values were always recorded in the two-implant-retained models. However, when loading was applied on the molar region, stress values measured, in all models, were close to each other. Of all implant combinations, implants in narrow-sized mandible models showed the lowest stress values, whereas those in wide-sized mandible models had the highest stress values. Except where loading was applied to molars, the left implant of the W2 model (58.05 MPa) had lower stress values than the S2 model (64.9 MPa) (**Figure 7**).

Discussion

The present study examined the influence of different implant combinations on stress distribution in peri-implant bones of extremely resorbed mandibles, using FEA. In all mandibular configurations, two, three, or four short implants were used. For more proper distribution of functional loads and enabling of an additional stability plane [22-25], a bar attachment system was selected. Tested hypotheses were partially confirmed in this study. Different configurations of mandibles showed no considerable effects on the stress distribution of peri-implant bones and, regardless of TMW, two-implant-retained overdenture models showed the worst stress distribution.

Stresses around dental implants may be affected by several mechanical and anatomical factors, such as type of loading, implant geometry and surface structure, material properties of the prosthesis, choice of attachment systems in implant overdentures, quality and quantity of surrounding bones, geometry of crestal bones, horizontal width of jaws, nature
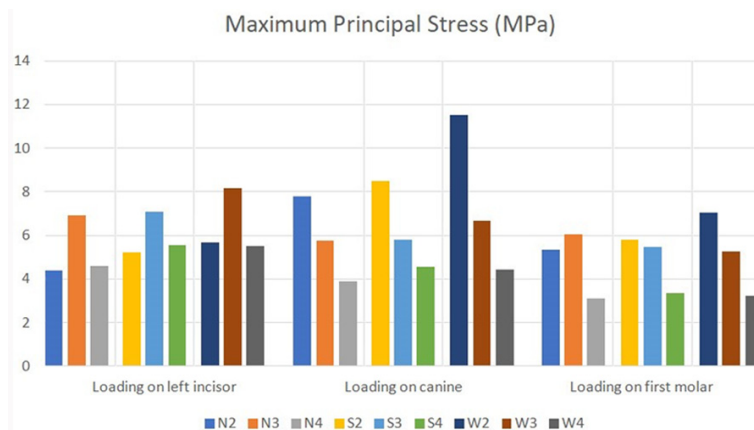
Maximum Principal Stress (MPa)

Figure 6. Comparison of the highest maximum principal stress values (MPa) for the cortical bone observed in each model with three different loading conditions.
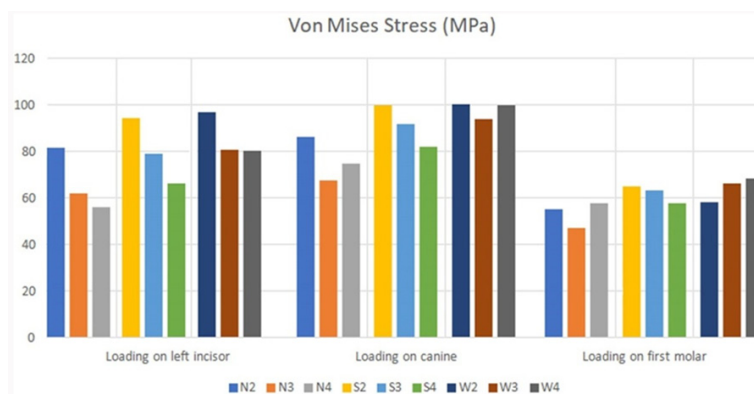
Von Mises Stress (MPa)

Figure 7. Highest von Misses stress values (MPa) observed at implants in each model with three different loading conditions.

of the bone-implant interface, and mucosal thickness [14, 20, 26]. Although most of the abovementioned factors have been discussed in detail by previous studies, the influence of TMW on bone stress distribution has not been clearly elucidated. Recently, de Almedia et al. [14] evaluated the influence of different transverse sizes of mandibles on the stress distribution around implants restored with a prefabricated bar system. However, for more appropriate adaptation of this prefabricated system, implants were positioned closer to the buccal and lingual sides in small and large-sized mandibles, respectively. Therefore, the highest stress values were reported in large and small-sized mandible models. Basically, an increase in the distance between implants would lead to higher compressive stress around peri-implant bones, due to increased lever arm lengths.

Thus, it was hypothesized that measured stress values would be higher in wide-sized mandibles than in narrow- and standard-sized mandibles in all implant configurations. However, results of this study could not demonstrate any considerable effects of TMW of extremely resorbed mandibles on stress distribution.

Severely atrophic edentulous mandibles can be a challenging situation for patients and clinicians. For these complex cases, treatment options include the placement of short implants, conventional implant insertion with prior augmentation procedures, and transmandibular implants [3, 6, 8]. Augmentation procedures have been associated with increased surgical morbidity and prolonged treatment times. Moreover, general anesthesia for this elective type of surgery may not always be tolerated in relatively older patients that possibly have many systematic diseases [2, 3, 6]. The use of transmandibular implants might increase the risk for mandibular fractures because of penetration of the lower mandibular cortical layer by implants [3, 8]. Moreover, previous studies have reported a considerable failure rate of transmandibular implant systems, raising doubts regarding the reliability of this treatment modality [3, 27, 28]. Therefore, short implants may be effective for patients with severely atrophic jaws. Additionally, knowledge of clinical outcomes of short implants has recently increased. Several studies have demonstrated similar success rates with short implants, compared with those with conventional length implants [3, 6, 29-32]. Due to the decreased bone-implant contact area, placement of four short implants is advocated in extremely resorbed edentulous mandibles [6, 10]. On the other hand, inserting fewer implants in these

cases can ease surgical and prosthetic procedures [3]. However, there remains a conflict regarding the effectsof implant numbers and generated stress inthe literature. Several studies have anticipated that, with an increase in the number of implants, stress would be more widely distributed and, therefore, generated stress values for the peri-implant bone would decrease [20, 33-35]. On the contrary, Meijer et al. [7] reported no differences in stress distribution between two- and four-implants in severely resorbed mandibles. In the current study, although the highest stress values were measured in two-implant-retained overdenture models, the stress distribution in three- and four-implant supported models were found to be similar. However, some concerns have been raised regarding the use of three-implant-supported overdentures because the bone around the middle implant may be associated with higher stress, particularly when a load is applied to posterior teeth [36]. Current study results demonstrate that, during load application on anterior or molar teeth region, maximum stress was always localized on the cervical region of the ipsilateral posterior implant in all three-implant-supported overdenture models. Similarly, Geçkili et al. [37] reported that the middle implants of three-implant-supported overdentures showed the least marginal bone loss, compared with the right and left implants. Therefore, regardless of mandibular width, three-implant-supported overdentures may be recommended for treatment of extremely resorbed edentulous. This treatment choice is relatively cheaper and offers the advantage of less complex laboratory designs, compared to 4-implant-supported overdentures [13].

Findings from this *in vitro* study may contribute to research regarding stress distributions in extremely resorbed mandibles. However, there were some limitations of FEA that must be considered. Thus, present results should be carefully interpreted. FEA allows the approximation of several clinical situations with a high degree of sensitivity for parameters, such as anatomical factors, material properties, and loading conditions in a virtual environment [14, 17]. Essentially, the cortical bone of the jaw is anisotropic and non-homogeneous. However, in this study, all constructed models were assumed to be homogenous, isotropic, and linearly elastic. Moreover, 100% osseointegration was established between the implant and bone, which

does not entirely represent clinical situations in practice. In the present study, to simulate the natural environment, a solid material was used to mimic foodstuff for different occlusal loadings. In several FEA studies, inclined and vertical loadings have been separately applied, but during chewing activity, vertical and horizontal forces are simultaneously transmitted to dentures. With the use of a large diameter SRM, loads can be applied across the cusp inclines and generated multi-vectoral forces, which are expected to more accurately simulate the natural chewing activity [16, 38]. According to present results, the loading site shows an important effect on stress distribution in the bone-implant system. Loading on the anterior teeth produced higher stress in all models, with the highest significance being observed in two-implant-retained models.

In view of all these findings, three-implant-supported overdentures may be an appropriate treatment choice for patients with edentulous resorbed mandibles. However, further prospective clinical research based on different mandibular widths is necessary to confirm current study outcomes.

Conclusion

Based on the results of this *in vitro* study, increasing the number of implants enabled more stress distribution on the implants, decreasing compressive stress on the peri-implant cortical bone. However, stress distribution levels in three- and four-implant supported models were found to be similar. Moreover, TMW showed no considerable effects on the stress distribution on peri-implant bones. Therefore, regardless of transverse width, three-implant-supported overdentures should be recommended for treatment of extremely resorbed edentulous mandibles.

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Disclosure of conflict of interest

None.

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