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Edentulous mandible with four splinted interforaminal implants exposed to three different situations of trauma: A preliminary three-dimensional finite element analysis

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Abstract

Background/Aim: An increasing number of elderly patients with implant-prosthodontic rehabilitation of the edentulous mandible frequently show increased life activity, and consequently, a greater number of aged patients is at risk for maxillofacial trauma. The aim of this 3-dimensional (3D) finite element analysis (FEA) was to evaluate the biomechanical effects of the edentulous mandible (EM) with and without four splinted interforaminal implants exposed to three different trauma applications including assessment of different mandibular fracture risk areas.

Materials and Methods: In a 3D-FEA study design, EM with and without four splinted interforaminal implants were exposed to the application of 1000 N at the symphyseal, parasymphyseal, and mandibular angle region. On four pre-defined superficial cortical mandibular areas (symphysis region, mental foramen region, angle of mandible, and mandibular neck) representing regions of interest (ROI), the von Mises stresses were measured for the three trauma applications. For all ROIs, stress values were evaluated and compared for the different force application sites as well as between EM models with and without interforaminal implants.

Results: For EM with and without four splinted interformaninal implants, all traumatic loads generated the highest stress levels at the mandibular neck region. However, in the EM with four splinted interforaminal implants, an anterior symphyseal force application generated significantly ($P < .01$) increased stress values in the parasymphyseal (mental foramen) region than in EM without implants. For force applications at the parasymphaseal region (mental foramen) and at the angle of the mandible elevated, von Mises stress values were noted directly at the application sites without difference between edentulous mandibles with and without four interforaminal implants.

Conclusion: In an edentulous mandible model with four splinted interforaminal implants, the condylar neck and the mental foramen represent the predilectional risk areas for mandibular fracture for both anterior symphyseal and lateral parasymphyseal force application.

KEYWORDS
finite element analysis, four splinted interforaminal implants, stress value, trauma application

1 | INTRODUCTION

The use of dental implants has become a well-accepted treatment modality for oral rehabilitation of edentulous mandibles.[1–4] Although the use of two interforaminal implants has been postulated as a standard treatment procedure for stabilization of an implant-retained overdenture, the placement of four interforaminal implants used for fixed prostheses has been shown to provide more denture stability, denture retention, and patient satisfaction.[1,2,4–7] In addition, the use of four connected interforaminal implants for fixed mandibular prostheses as the widely accepted "all-on-4" concept has received increased attention within the wide range of different implant-prosthodontic rehabilitation modalities.[6–11]

The target group of patients for implant-prosthetic rehabilitation of edentulous jaws primarily includes the elderly population.[1,2,6–8] This elderly population has been shown to be physically highly active, and it may therefore be assumed that this active and agile group of elderly patients may be increasingly exposed to the risk of physical trauma.[12,13]

Considering that the use of dental implants will continue to increase due to significant clinical implant-prosthodontic advancements, maxillofacial surgeons will also encounter an increased rate of maxillofacial trauma in patients with dental implants.[14–16] As shown in several epidemiologic studies, mandibular fractures represent one of the most common facial injuries and they are predominately related to falls, motor vehicle accidents, violent crime, injuries, sports, and work accidents.[12,17–19] However, only scarce information is available on the evaluation of trauma in patients with dental implants.[20,21] Kan et al[20] and Ayali and Bilginayler[21] investigated unsplinted implants exposed to traumatic situations using finite element analysis. According to their findings, a more beneficial stress modulation was found for implants placed in the lateral incisor region than for those in canine regions when frontal trauma occurred.[20,21]

As only a few studies on trauma exposure in the edentulous jaw have been published, they are primarily experimental studies that are used for evaluation.[20–24] Finite Element Analysis (FEA) has become widely accepted as it features a non-invasive tool that provides valuable results for estimating different parameters of the complex biomechanical behavior of the mandible.[22–24] De Santos et al[23] used FEA to evaluate the edentulous mandible without dental implants and with application of frontal and/or lateral forces, and they found the main stress values were in the mandibular neck region and in all regions of force application.

In addition, there are only a small number of reports of mandibular fractures induced by, during or after implant placement procedures.[25–27] According to the findings of Torsiglieri et al[25] and Steiner et al[26] in an atrophic setting, dental implant placement may weaken the bony structures. In atrophic mandibles, fractures also tend to occur as a result of reduced vascularity and decreased blood flow. However, there is still a lack of information on how osseointegrated dental implants may influence the stress modulation of an edentulous mandible in the presence of traumatic forces.[23] To date, no study has evaluated the effect of splinted four interforaminal implants as used for fixed prostheses exposed to trauma applied to the symphysis, corpus, or angle of the mandible.

Therefore, the aim of this three-dimensional finite element analysis (3D FEA) study was to evaluate the biomechanical effects of an edentulous mandible treated with four splinted interforaminal implants exposed to three different types of trauma (symphyseal, corpus, and the angle of the mandible). It was initially hypothesized that increased cortical stress values representing a higher mandibular fracture risk will occur in the condylar neck as well as in the regions corresponding to the force application. In addition, it was assumed that four splinted interforaminal implants may increase the symphyseal stress values in a frontal trauma situation as a result of an implant-induced bone weakening.

2 | MATERIAL AND METHODS

Scanned computed tomography (CT) images of a 68-year-old male patient with a completely edentulous mandible (ProMax, Planmeca) served as the morphological basis for the FEM mandible models. The CT data selection was based on the patient's medical record status representing age-appropriate health and bone status without any morphological and mineralization variabilities. The generated raw image data with a pixel resolution of 651 × 651, 96 kV and increment slices of 0.2 mm in thickness were then exported to a computer in DICOM format. The anatomical data of cortical and cancellous mandibular structures were acquired by semi-automatic segmentation of CT layer using Amira software® (Visage Imaging). After cross-linking point clouds (Delauney triangulation) to three-dimensional polygon meshes, morphologically identical models of the cancellous and cortical mandible were generated (Figure 1).[28–30]

The resulting rough polymesh models were transformed to the reverse-engineering software Geomagic Wrap (Geomagic Studio) to generate a smooth computer-aided design (CAD) model of the mandible.[31]

Established CAD tools in Inventor™ software (Autodesk GmbH) was chosen for the virtual design of all constructable elements, such as suprastructure, abutments, and implants.[28–30] Dental implants and corresponding abutments were modeled on imported Camlog® CAD Data. The dimensions of 13 mm in length and 3.8 mm in diameter were selected for the implant models. Based on the detailed proportions of Screw-Line Promote + Dental Implants (tapered) (Camlog® Winsheim), the models included detailed assessments of the external thread and internal housing. The dimension of 1 mm in height and 3.8 mm in diameter was selected for the corresponding abutments, based on imported CT data.

Subsequently, four implant models were positioned in the interforaminal region of the model of the edentulous mandible. The two anterior implants were placed vertically in the lateral incisor region with an inter-implant distance of 13 mm. Both posterior implants were positioned parallel to the anterior implants in the region of the first premolar with a mesial distance of 5 mm to the mental foramen.[32] The distance of the posterior implants from the anterior ones had a constant dimension of 12.5 mm.[32] In relation to the neck of the implants selected including a machined collar of 0.4 mm, the implants were placed in a slight supracrestal position (0.4 mm) according to the manufacturer's instructions (Camlog® Winsheim). In addition, implants were placed in a horizontal direction representing adequate surrounding cortical and cancellous bone. The implants had a distance ranging from 0 mm (cervical regions) to 3.5 mm (apical regions) to the inner cortical wall.

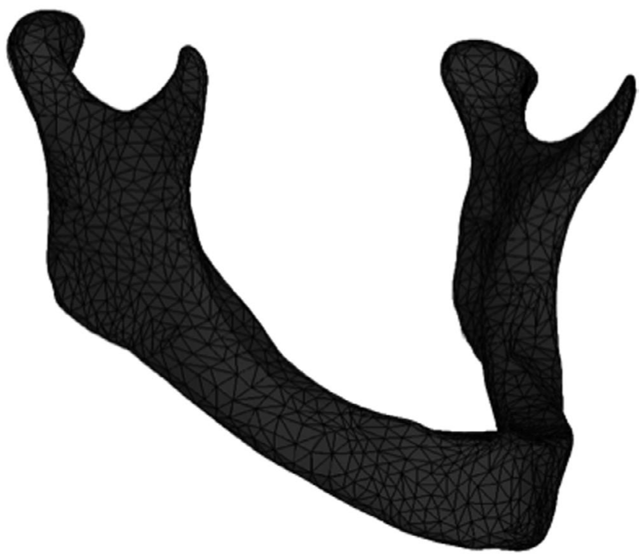

FIGURE 1 The three-dimensional polygon meshes of the model of an edentulous mandible

Subsequently, abutment models and a model of a suprastructure corresponding to a splinted fixed titanium framework similar to a bar or a fixed implant-prosthodontic reconstruction were added to the model with four incorporated interforaminal implants.

The combination of all resulting solid models was processed in Inventor™ software® (Autodesk GmbH) using Boolean operators (addition and subtraction).[28–30] The study design then consisted of two different models: model-A was an edentulous mandible without dental implants (EM; Figure 2A), while model-B represented the combination of the edentulous mandible with 4 splinted interforaminal implants (4-I-EM, Figure 2B).

The resulting models A and B were entered into the FEM Simulation section of Inventor™ software® and then three-dimensionally (3D) cross-linked to build corresponding FEM models.[28–30] The FEA method represents a mathematical technique that allows for the reduction of complex geometries into a finite number of elements (voxels), each with a simple geometry. The elements used for cross-linking in the FEM models were parabolic tetrahedrons with four nodes at each corner and one node in the center of each edge.[21,28–30] The numbers of generated tetrahedrons and nodes of both models were as follows: model-A: noduli: 233 532; tetrahedra 140 820; model-B: noduli 818 925; tetrahedra: 532 064.

The material properties of the materials that were simulated corresponded to standard values described in the literature.[22] The implants, abutments, and suprastructure as well as the cortical and cancellous bone were characterized as isotopic and elastic structures, respectively.[22] These were assigned values for the Young modulus (cortical bone: 13.70 GPa, cancellous bone: 1.370 GPa, Titanium alloy (Ti-6Al-4V): 110.0 GPa; Poisson ratio:cortical bone: 0.33; cancellous bone: 0.3, Titanium alloy (Ti-6Al-4V): 0.34).[21,28,29,33,34] For the implants, the abutments as well as the suprastructure were designed with the material properties corresponding to titanium alloy (Ti-6Al-4V), as reported in previous FEA and clinical studies.[20,21,34]

In three different simulations for each model, a traumatic load of 1000 N was applied in a perpendicular direction to the cortical bone surface of the symphysis, the parasymphyseal region (mental foraminal region) and the lateral body (mandibular angle) region (Figure 3).[19,20,32] The mandible was constrained in

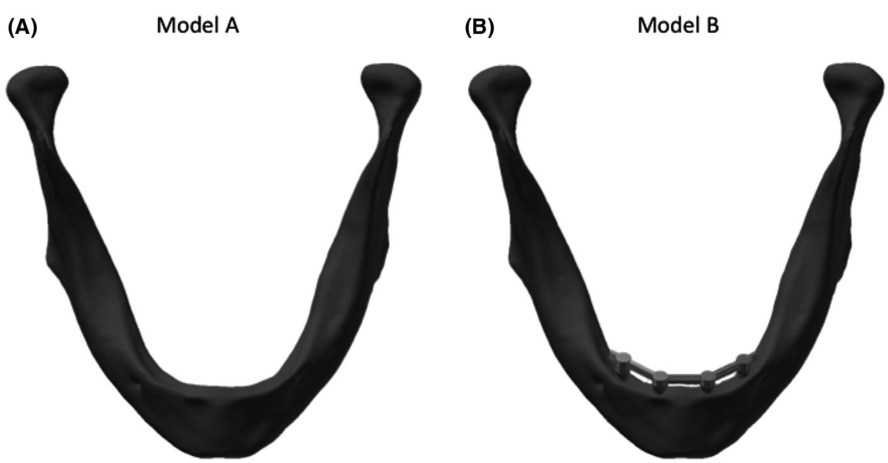

FIGURE 2 3-D edentulous mandible model without (A) dental implants (model-A) and 3-D edentulous mandible model with (B) four splinted interforaminal implants (model-B)

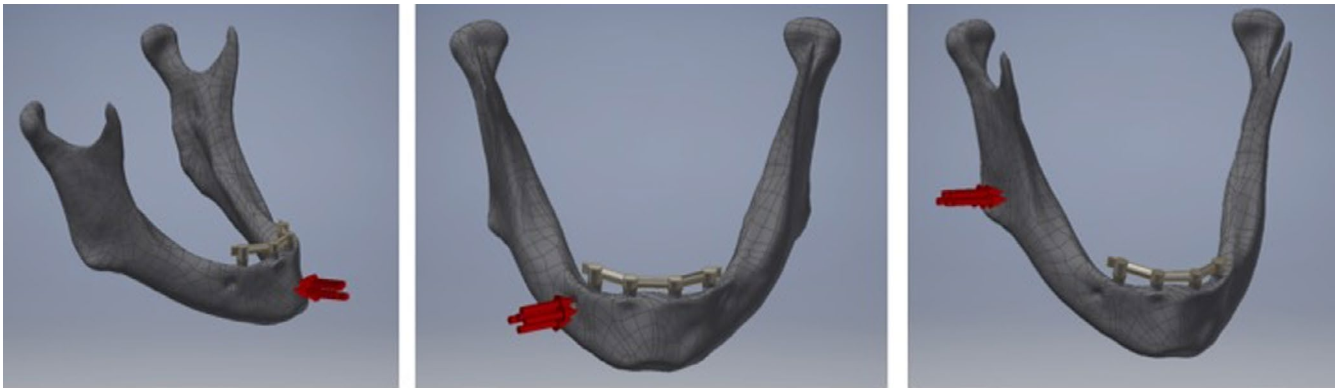

FIGURE 3 Simulation of (A) frontal symphyseal, (B) parasymphyseal, and (C) mandibular angle trauma by application of a force of 1000 N

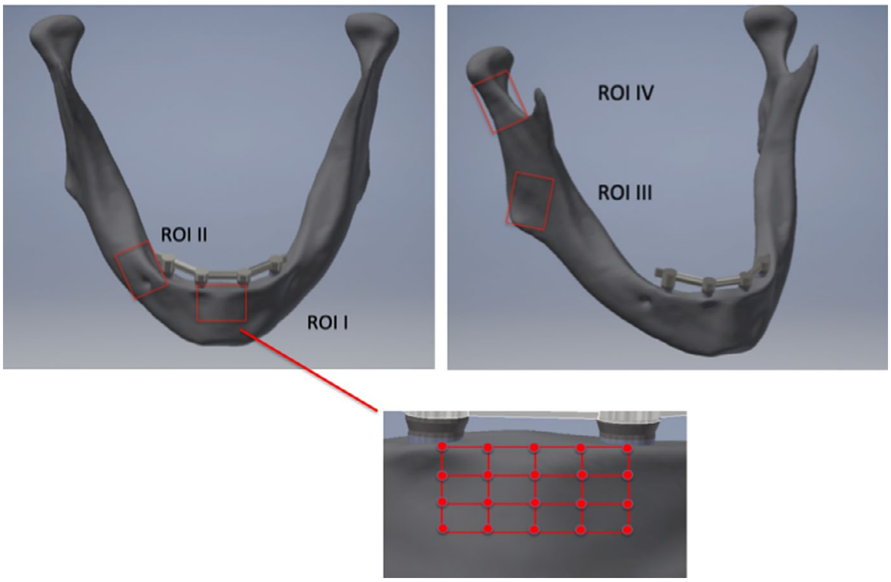

FIGURE 4 The regions of interest evaluated for von Mises stress values. (ROI 1 = anterior mandible; ROI 2 = mental foramen region; ROI 3 = angle of the mandible region; ROI 4 = condylar neck region; homogenous allocation of the 20 pre-defined measurement points identical for all ROIs)

the proximal portion of the condyles to prevent free movement in the *x*-, *y*-, and *z*-axes during traumatic loading for simulating the presence of masticatory muscles during trauma.[35–37] The contact conditions between the single model units of implants, abutments, and suprastructure were defined as constrained. The bone tissue/implant interfaces were assumed to be fully bonded (ie, implants with 100% osseointegration).[34] For both models, the force load and application as well as the boundary and contact conditions were identical.

The traumatic cortical stress was evaluated in detail for four defined specific areas which were selected on the basis of important regions involved in traumatic fractures in the recent literature.[21,23] The evaluated sites, including mandibular body, mental foramen area, and mandibular angle area as well as condylar neck, were defined as regions of interest (ROI) and were located as follows (Figure 4):

- ROI 1: region between the anterior implants (next to alveolar crest).
- ROI 2: region posterior to the lateral implants, in the mental foramen area.
- ROI 3: mandibular angle area.
- ROI 4: region at the condylar neck area.

All four ROI showed a homogeneous area dimension of 10 × 5 mm, and the effective stress measurements in ROIs were calculated at 20 homogeneously distributed pre-defined points of measurement at specific superficial cortical mandibular areas. The inter-point distances, the allocation, and the number of measured control points were identical for every region of interest in both models (Figure 4). Therefore, an exactly identical stress evaluation of all trauma simulations in both models could be obtained. The traumatic stress results were evaluated at these predilectional sites according to von Mises equivalent stress distribution.

Parameters (von Mises stress values) of ROI 1, ROI 2, ROI 3, and ROI 4 for model-A (without implants) and model-B (with four splinted interforaminal implants) have been tabulated as means ± standard deviation and, additionally, boxplots with log-transformed y-axes are presented. Interindividual (intermodel) comparisons of stress values between ROI 1, ROI 2, ROI 3, and ROI 4 between model-A (EM) and model-B (4-I-EM) as well as interindividual (intermodel) comparisons of ROI 1/2/3/4 for model-B (4-I-EM) were performed. For the intraindividual comparison of normally distributed continuous variables, repeated analysis of variance or—in the case of non-normality (verification using the Kolmogorov-Smirnov test with Lilliefors correction)—Friedman rank analysis of variance was used. For the interindividual comparison of normally distributed continuous variables, the independent two-sample t test or—in the case of non-normality—the exact Mann-Whitney-*U* test was used.

The type I error rate was set to 5% (two-sided) without any adjustment. Therefore, the results of the inferential statistics are descriptive only. For statistical analysis, the statistical computing software R Version 3.6.1 (R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org) was used.

3 | RESULTS

Figure 5 shows the individual finite element stress values (von Mises stress) evaluated for model-A (without implants) and for model-B (with four splinted interforaminal implants) when subjected to frontal symphyseal (Figure 5A,B), lateral parasymphyseal (mental foramen region) (Figure 5C,D), and lateral angle of the mandible (Figure 5E,F) application of 1000 N of traumatic stress. Detailed data for all models (EM, 4-I-EM) and regions of interest (ROI 1, ROI 2, ROI 3, ROI 4) expressed as means and standard deviations are presented in Table 1.

Figure 6 shows the cortical stress values for ROI 1, ROI 2, ROI 3, and ROI 4 for the edentulous mandible without (EM) and with four splinted interforaminal implants (4-I-EM) exposed to the three different types of traumatic force application. Regardless of the type of force application, the highest stress values (von Mises stress) were invariably found at the ROI 4 at the mandibular neck for model-A (mean: 265.1 MPa; 186.1 MPa; 127.2 MPa) and model-B (172.4 MPa; 153.3 MPa; 119.9 MPa), respectively. For each model, the stress values measured at the mandibular neck (ROI 4) differed significantly ($P < .001$) from those measured at the symphysis (ROI 1), the supramental (ROI 2), and the mandibular angle regions (ROI 3) (Table 1).

With a symphyseal force application (Figure 6A), the von Mises stress evaluated did not differ for the frontal symphyseal area (ROI 1) between model-A and model-B ($P = .748$) (Figure 6A). However, for the 4-I-EM model a frontal symphseal force application led to an significant increase ($P < .001$) of the stress values in the mental foraminal region (ROI 2) but reduced the stress level in the mandibular angle (ROI 3) and mandibular neck region significantly (ROI 4) (Table 1; Figure 6A) ($P = .002$; $P = .025$).

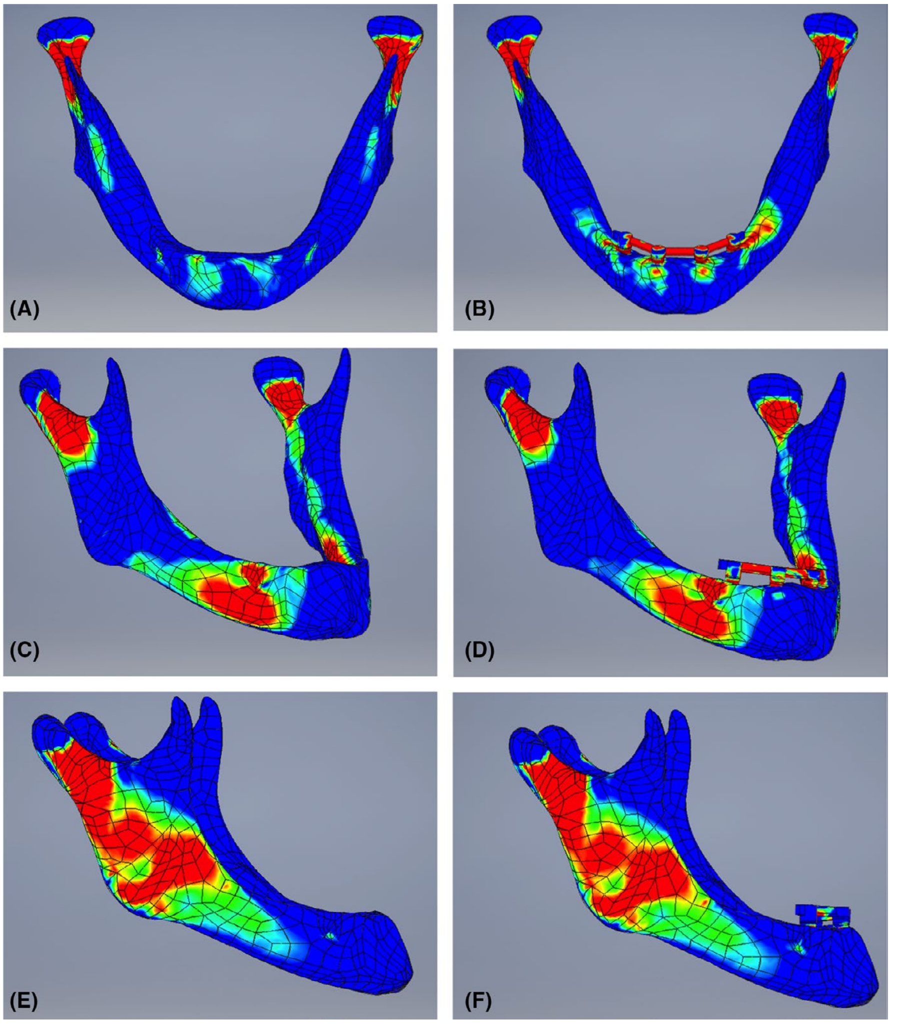

FIGURE 5 The Finite element stress values (von Mises stress) for EM model-A (A) and 4-I-EM model-B (B) exposed to symphyseal trauma. The Finite element stress values for EM model-A (C) and 4-I-EM model-B (D) exposed to parasymphyseal trauma. The Finite element stress values for EM model-A (E) and 4-I-EM model-B (F) exposed to angle of the mandibule trauma

TABLE 1 Stress values for the four regions of interest (ROI) in relation to three different force applications and between edentulous mandible with and without four splinted interforamional implants

	Four interforaminal implants	Without implants	
	Stress value (MPa)	Stress value (MPa)	P value
Symphyseal force			
ROI 1	37.8 ± 11.5	38.9 ± 9.9	.748
ROI 2	51.7 ± 24.5	17.1 ± 8.3	**.001**
ROI 3	12.1 ± 3.4	16.5 ± 2.9	**.002**
ROI 4	172.4 ± 88.7	265.1 ± 153.1	**.025**
Parasymphyseal force			
ROI 1	21.5 ± 14.4	19.2 ± 15.9	.560
ROI 2	66.6 ± 28.4	57.5 ± 32.4	.301
ROI 3	20.8 ± 4.5	21.6 ± 5.8	.610
ROI 4	153.3 ± 95.2	186.1 ± 119.1	.342
Angle of the mandible			
ROI 1	18.2 ± 6.0	20.9 ± 4.9	.135
ROI 2	23.9 ± 9.8	20.8 ± 8.0	.271
ROI 3	77.9 ± 13.7	77.6 ± 13.4	.931
ROI 4	119.9 ± 50.9	127.2 ± 58.8	.718

Lateral traumatic force application at the mental (parasymphyseal) region (Figure 3C; Figure 5D; Figure 6B) and at mandibular angulus region (Figure 3D; Figure 5F; Figure 6C) did not produce any differences in stress values for ROI 1(P = .560), ROI 2 (P = .301), ROI 3 (P = .610), and ROI 4 (P = .342) between the mandible without (EM model-A) and with interforaminal implants (4-I-EM model-B) (Figure 6).

Figure 7 shows the stress values for three different types of force application explicitly for EM with four interforaminal implants (4-I-EM) relative to each other and in context with all ROIs evaluated. Excluding the mandibular neck with its invariably highest stress values without any significant difference between the three different types of force application performed, direct force application was correlated with high stress values only for the parasymphyseal and the mandibular angle region.

For ROI 2 (parasymphyseal region) and for ROI 3 (mandibular angle region), with both being located at a distance to the splinted interforaminal implants, direct force application resulted in high cortical stress levels at the application area.

In contrast, direct force application at the symphyseal region showed significantly higher stress values in the adjacent mental foramen region than in the symphyseal region. For frontal (symphyseal) trauma application, the risk of mandibular fracture is transferred from the direct force application site to the adjacent parasymphyseal mental foramen region (Figure 7).

Detailed differences of the stress values evaluated for ROI 1, ROI 2, ROI 3, and ROI 4 exposed to symphyseal, parasymphyseal, and angle of the mandible force application are presented in Figure 8. The stress values for ROI 1 (Figure 8A) and ROI 3 (Figure 8C) differed significantly (P = .001) between the three force applications. For ROI 2 (Figure 8B) and ROI 4 (Figure 8D), the force application did not reveal significant differences in the stress values evaluated (P = .133; P = .86, respectively).

4 | DISCUSSION

Fixed implant-prosthetic restorations supported on four interforaminal implants represent an established and well-proven treatment modality for the rehabilitation of mandibular edentulism.[6–11]. Epidemiological investigations have shown that an increasing number of elderly patients with implant-supported rehabilitation of edentulism lead an increasingly active life taking part in numerous sporting and leisure time activities.[12–14] Thus, it can be concluded that the primary target group for implant-prosthetic rehabilitation will be exposed to an increased risk of trauma in the future.[6,7,13,14,38]

An injury sustained by a fall on the face represents a frontal trauma that may result in maxillo-mandibular fractures.[14–19] While falls on the face may be caused by general medical neurologic or cerebrovascular disorders, a frontal or facial collision or impact may also be the result of an accident during physical or sporting activities. In obvious contrast, a lateral impact of force will mostly be associated with physical violence.[16–19]

In a 3D-FEA study, three different impact sites of force (symphyseal, mandibular body, and mandibular angle) and their effects on the fracture risk of the edentulous mandible were evaluated. Apart from the invariably highest stress values in the mandibular neck, increased stress levels were always seen at the sites of the respective application of force. Consequently, it was concluded that apart from the mandibular neck, an increased fracture risk must also be assigned to the site of the direct force application.[23] In addition, several case reports have also shown that the edentulous mandible will be especially weakened by the insertion of implants and that fractures may develop in the region of the implants.[25–27]

The initial hypothesis that increased cortical stress levels will be found in the edentulous mandible with four splinted interforaminal implants in the region of the mandibular neck and at the sites of the direct impact of force could only partly be confirmed by the results obtained.[20–23] The results for the present FEA confirmed that with different applications of force (symphyseal, mandibular body, mandibular angle), the highest stress levels—and consequently the highest fracture risk—could again be seen in the region of the mandibular neck.[23,36,37] Thus, the results of de Santos et al[23] for the edentulous mandible without any implants, and the results of Bilingylar and Ayali[21] for implant-treated edentulous mandibular models could be confirmed. According to Schwartz-Dabney and Dechow,[39] the bone is narrower in the mandibular neck so this region has less bone strength and a greater tendency to fracture and this can be assumed as a potential explanation.[17,18,23,39]

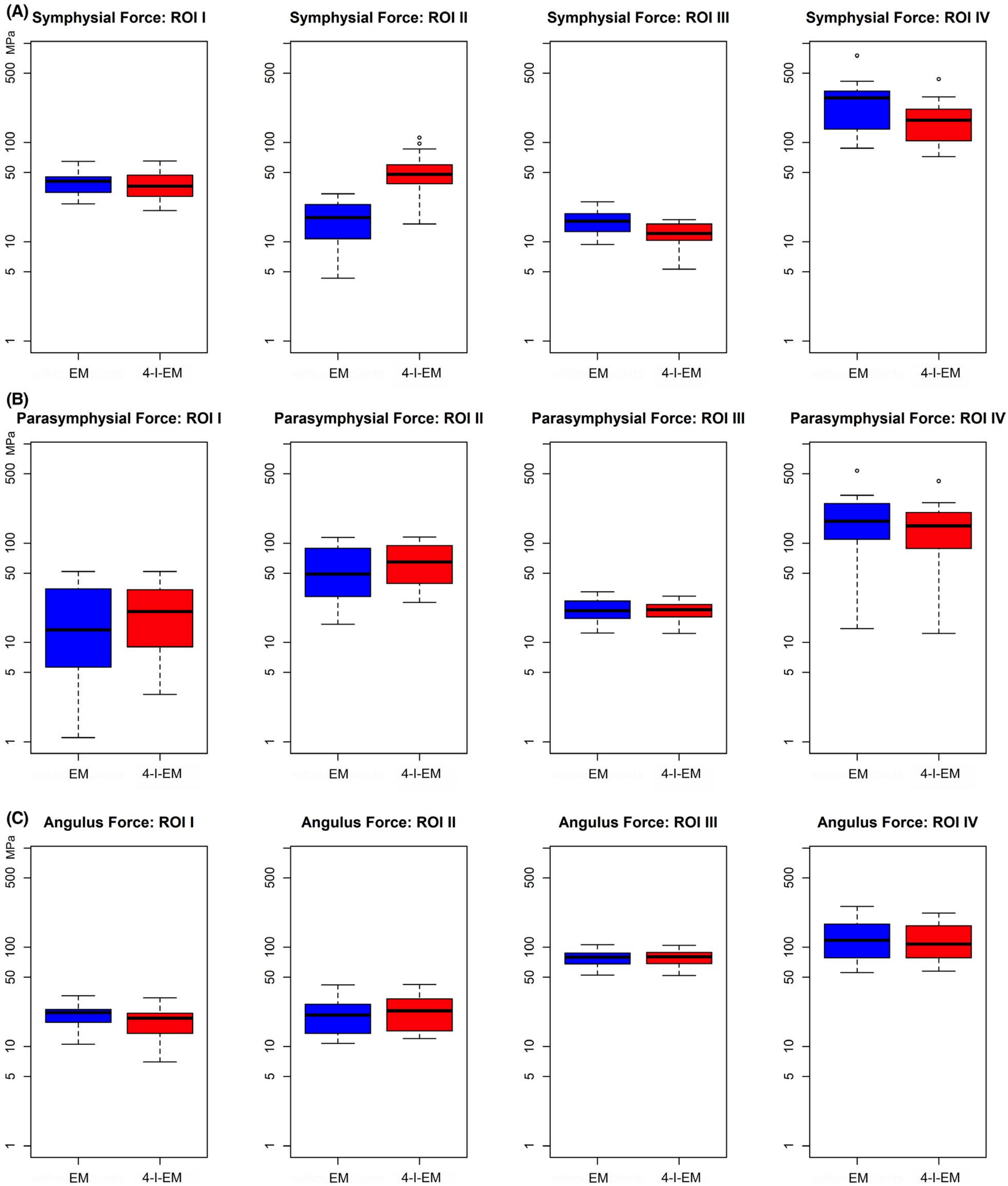

FIGURE 6 Intermodel comparisons of stress values for ROI 1, ROI 2, ROI 3 and ROI 4 for model-A (EM) and model-B (4-I-EM) with symphyseal (A), parasymphyseal (B), and angle of the mandibule (C) trauma application

In obvious contrast, the assumptions that the sites of direct force application would also show increased cortical stress levels and an increased fracture risk could not be confirmed for all regions of the mandible with four interforaminal implants.[23,35,36,39] Strikingly, no increased stress levels at the site of force application could be seen with a frontal force application on the edentulous mandible with interforaminal implants as compared to edentulous mandibles without any implants.[23] In the event of a frontal force application, the impacting kinetic forces will be absorbed in the region of the interforaminal blocking and transmitted to the neighboring regions.[40–42] Therefore, no increased cortical stress levels at the site of direct force application will develop, but much rather the increased stress levels as well as the fracture risk will be transferred to the adjacent region of the mental foramen.[41,43,44] It can be assumed that the external implant

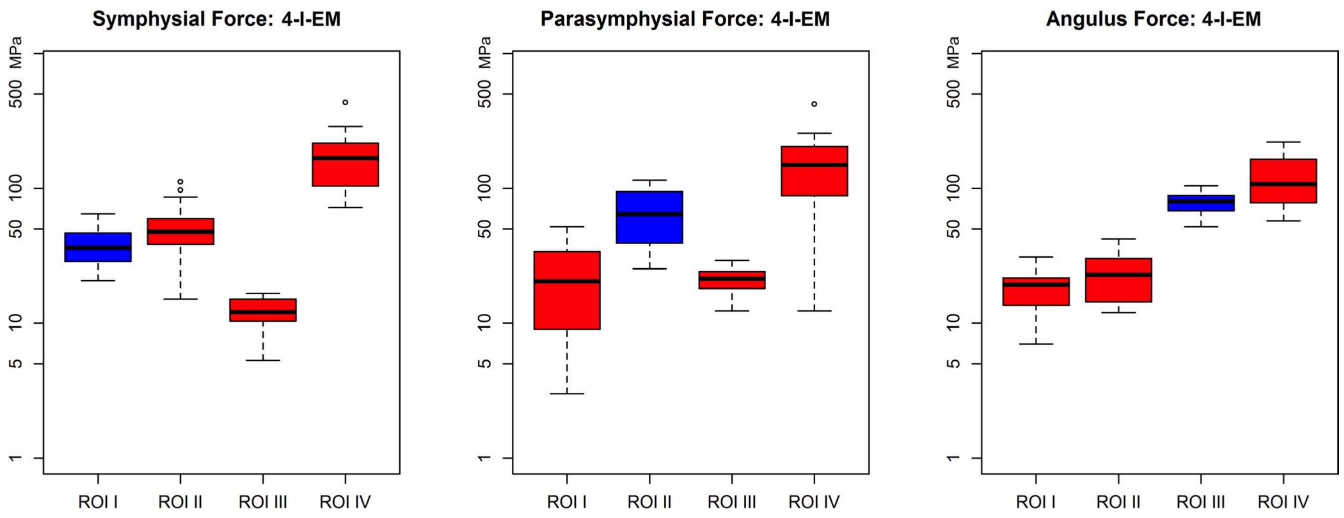

FIGURE 7 The stress values for three different types of force application explicitly for EM with four interforaminal implants (4-I-EM) in context with all ROIs evaluated

splinting, representing an external fixation, will function as a force transducer and that the external stabilization will counteract the initial weakening of the mandible by the implants.[45–47] In addition, it could be noted that with a frontal trauma, the stress values in the region of the mandibular neck will be reduced compared to the models without implants. The kinetic energy of the trauma will be absorbed by the implant splinting and transmitted into the mandibular neck to a reduced extent.[21,23,48] Therefore, the stress level reduction found in the area of the mandibular neck may also indicate a reduction of the fracture risk for the mandibular neck.[48]

It was interesting to note that at sites without external splinting, a direct force impact will still be associated with increased stress levels and an increased risk of fracture.[23,47] Anterior implant splinting appears to have no effect on the force impact in the region of the mandibular body or the mandibular angle on account of the remote location of the external stabilization. Thus, the initial hypothesis that the site of direct force application will also represent the site of the increased fracture risk has been confirmed again and the characteristics of an edentulous mandible without implants may thus also be used for edentulous mandibles with four interforaminal implants.[23,43,48] In accordance with previous findings of de Santos et al,[23] the results showed that a direct force application in the region of the mental foramen and in the region of the mandibular angle will invariably induce increased stress levels in the edentulous mandible with or without implants and be associated with an increased fracture risk in these regions.[42–44]

As a striking feature, the area of particular risk in the case of a frontal application of force is shifted away from the symphyseal region toward the region of the mental foramen.[44] With this obvious shift, the virtually identical site—namely the region of the mental foramen—could be identified as the site with increased stress levels and as the region of risk with both frontal symphyseal and lateral parasymphyseal force application.[23,43,44] Thus, regardless of the site of the force application, it is especially the region of the mental foramen—in addition to the mandibular neck—that must be considered as a predominant risk area and as predilectional site of fracture.[44,48]

Changes of fracture pattern and relocation of potential injuries to sites allowing for better surgical access and/or facilitated treatment procedures suggest specific advantages for both clinicians and patients.[48–50] Reducing the risk for condylar neck fracture with symphyseal frontal trauma application by splinted four interforaminal implants is also of clinical significance considering that condylar neck fractures will frequently require greater efforts for surgical interventions, recovery, and postoperative care.[20–23,47,51,52]

Considering the limitations of the study, it must be pointed out that the present study had an experimental design that represented only changes in the objects being evaluated.[20,41,42] As the risk for mandibular fracture is predominantly also influenced by the varying degree of mandibular atrophy and mandibular bone quality, a detailed quantitative statement as to what extent implant placement and, consequently, implant splinting may protect or negatively affect several regions cannot be made.[53,54]

In summary, the findings showed that in the case of frontal trauma, four splinted interforaminal implants as being used clinically in the "All-on-4" concept will reduce the stress levels and the fracture risk in the area of the anterior implants and the mandibular neck and may increase the same in the region of the mental foramen.[23,47] Stress absorption of the impacting forces in the implant region and, consequently, also increased stress values in the mandibular corpus are considered as responsible factors. It could be seen that a direct lateral force impact in the area of the mandibular body and the mandibular angle was not affected by the splinted interforaminal implants. In such a case, the stress levels and the fracture risk remain restricted to the site of the force application.

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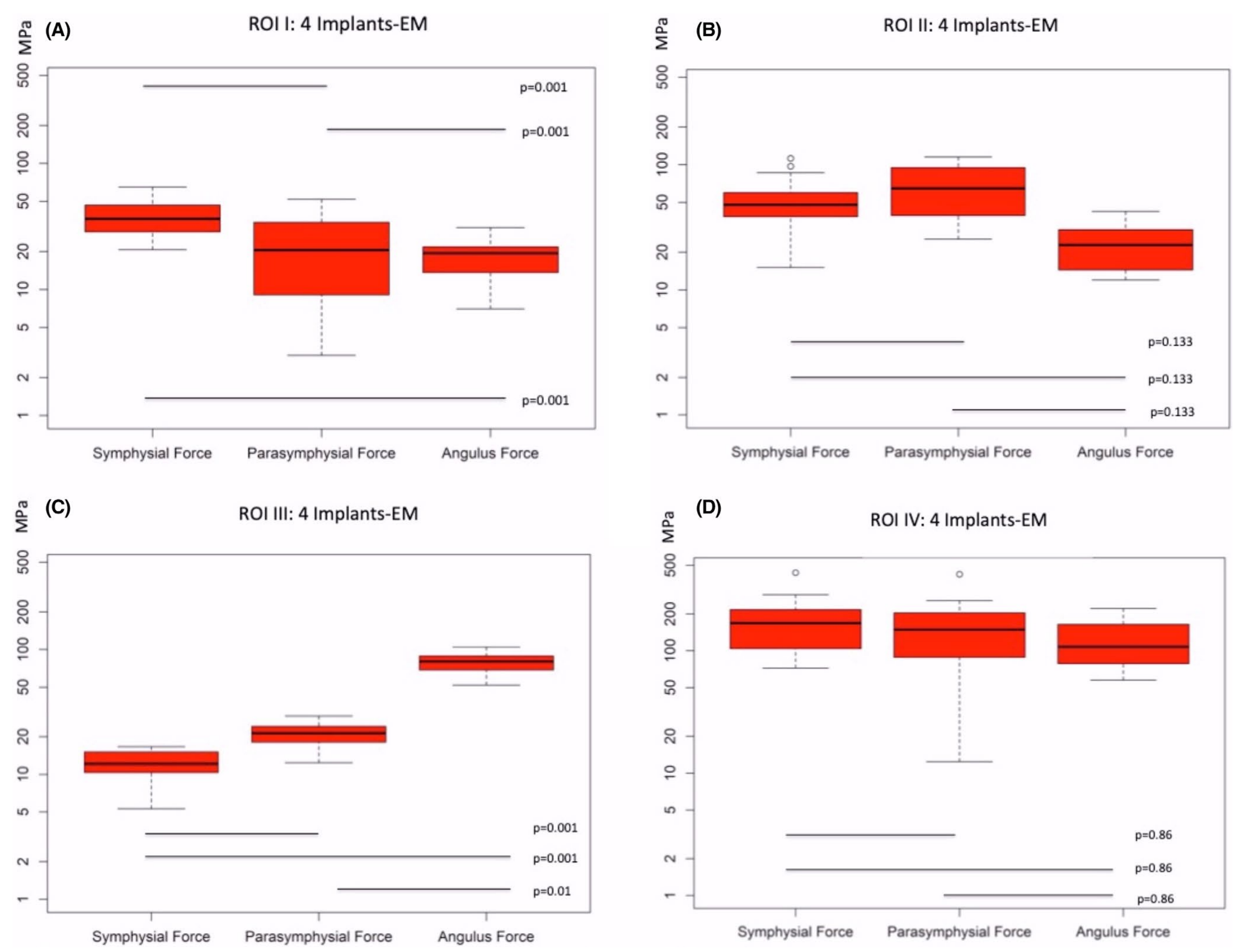

FIGURE 8 Comparison of stress values evaluated at ROI 1 (A), at ROI 2 (B), at ROI 3 (C), and at ROI 4 (D) for symphyseal, parasymphyseal, and angle of the mandible force application

CONFLICT OF INTEREST

The authors confirm that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Stefan Krennmair involved in study design/conception, material preparation, data analysis, draft preparation, and statistic analysis. Stefan Hunger involved in methodology, investigation, and statistic analysis. Lukas Postl performed draft preparation, review, and discussion. Philipp Winterhalder involved in data analysis, methodology, and investigation. Svenia Holberg involved in investigation and data acquisition. Michael Malek involved in draft preparation, discussion, and review. Christof Holberg involved in review, supervision, and discussion. Ingrid Rudzki performed review and discussion.

ETHICAL APPROVAL

The study design of FEA Simulation does not require ethical approval. This article does not contain any studies with human participants or animals performed by any of the authors.

DATA AVAILABILITY STATEMENT

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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