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RESEARCH AND EDUCATION

Biomechanical behavior of mandibular overdenture retained by two standard implants or 2 mini implants: A 3-dimensional finite element analysis

Pravinkumar G. Patil, BDS, MDS,[a] Liang Lin Seow, BDS, MSc, PhD,[b] Rashmi Uddanwadikar, BTech, MTech, PhD,[c] and Piyush D. Ukey, BTech, MTech[d]

ABSTRACT

Statement of problem. Mini implants (<3 mm in diameter) are being used as an alternative to standard implants for implant-retained mandibular overdentures; however, they may exhibit higher stresses at the crestal level.

Purpose. The purpose of this finite element analysis study was to evaluate the biomechanical behavior (stress distribution pattern) in the mandibular overdenture, mucosa, bone, and implants when retained with 2 standard implants or 2 mini implants under unilateral or bilateral loading conditions.

Material and methods. A patient with edentulous mandible and his denture was scanned with cone beam computed tomography (CBCT), and a 3D mandibular model was created in the Mimics software program by using the CBCT digital imaging and communications in medicine (DICOM) images. The model was transferred to the 3Matics software program to form a 2-mm-thick mucosal layer and to assemble the denture DICOM file. A 12-mm-long standard implant (Ø3.5 mm) and a mini dental implant (Ø2.5 mm) along with the LOCATOR male attachments (height 4 mm) were designed by using the SOLIDWORKS software program. Two standard or 2 mini implants in the canine region were embedded separately in the 3D assembled model. The base of the mandible was fixed, and vertical compressive loads of 100 N were applied unilaterally and bilaterally in the first molar region. The material properties for acrylic resin (denture), titanium (implants), mucosa (tissue), and bone (mandible) were allocated. Maximum von Mises stress and strain values were obtained and analyzed.

Results. Maximum stresses of 9.78 MPa (bilaterally) and 11.98 MPa (unilaterally) were observed in 2 mini implants as compared with 3.12 MPa (bilaterally) and 3.81 MPa (unilaterally) in 2 standard implants. The stress values in the mandible were observed to be almost double the mini implants as compared with the standard implants. The stresses in the denture were in the range of 3.21 MPa and 3.83 MPa and in the mucosa of 0.68 MPa and 0.7 MPa for 2 implants under unilateral and bilateral loading conditions. The strain values shown similar trends with both implant types under bilateral and unilateral loading.

Conclusions. Two mini implants generated an average of 68.15% more stress than standard implants. The 2 standard implant–retained overdenture showed less stress concentration in and around implants than mini implant–retained overdentures. (J Prosthet Dent 2021;125:138.e1-e8)

Implant-retained overdentures significantly improve the quality of life for patients with edentulous mandibles compared with those using conventional complete dentures,[1] and a 2-implant–retained mandibular overdenture has been suggested as the minimum treatment for a patient with an edentulous mandible.[1] Standard implants with a diameter of approximately 3.5 mm (or more) may not always be suitable in thin residual ridges and may require bone augmentation or modification. The success of mini implants has enabled their use in situations

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[a]Senior Lecturer in Prosthodontics, Division of Clinical Dentistry, School of Dentistry, International Medical University, Kuala Lumpur, Malaysia.
[b]Professor, Division of Clinical Dentistry, School of Dentistry, International Medical University, Kuala Lumpur, Malaysia.
[c]Professor, Department of Mechnical Engeneering, Visveswaraiyya National University of Terchnology, Nagpur, India.
[d]Director, NU OSSA Mediquip Pvt Ltd, Nagpur, India.

Clinical Implications

Two standard implants showed a better stress distribution pattern in the complete overdenture assembly as compared with 2 mini implants. Because of the higher stresses observed in the 2 mini implants and the crestal bone around them, the long-term success of mandibular overdentures with mini implants may be limited.

where standard implants could not have been placed without bone augmentation or modification. Mini implants have been generally considered to be single-piece, smaller-diameter implants (with diameter less than 3 mm),[2] and their cost is almost one-third to one-fourth of the standard implants. As mini implants are a single piece, there is no risk of abutment screw loosening and less risk of microorganisms harboring in peri-implant tissues.[2]

Finite element analysis (FEA) has been used to evaluate the stress distribution patterns generated in the components associated with implant overdentures. Meijer et al[3] investigated stress distribution by using a 2D model of the mandible with 2 implants by applying a vertical load of 100 N. Blessy et al[4] performed FEA analysis on a 3D model constructed from computed tomography (CT) scan images of a 22-year-old patient by using a detailed procedure for converting CT scan images for FEA analysis. Liu et al[5] evaluated strain distribution in the peri-implant bone of mandibular overdentures anchored by different numbers of implants under different loading conditions through 3D FEA and reported that the number of implants does not significantly affect the stain pattern. Jofre et al[6] carried out FEA and clinical trials evaluating marginal bone loss with 2 splinted versus 2 unsplinted mini implant–retained overdentures at 2-year follow-up. The FEA showed the minimum principal stress (-118 MPa) in the bone surrounding the unsplinted mini implants compared with that of the splinted implants (-56.8 MPa). After 2 years of follow-up in the clinical study, unsplinted mini implants showed marginal bone loss of 1.43 ±1.26 mm, whereas splinted implants showed 0.92 ±0.75 mm. Mangano et al[7] placed a total of 231 mini implants in 62 patients (almost 4 mini implants per patient) and reported an overall cumulative survival rate of 96.9% and a mean marginal bone loss of 0.38 ±0.25 at the 1-year follow-up and of 0.62 ±0.20 mm at the 4-year follow-up. Scepanovic et al[8] treated 30 patients with mandibular complete dentures retained by 4 immediately loaded mini dental implants and reported a 98.3% success rate after 1 year of loading. Considering the varied configurations of mini dental implant–retained overdentures (with 2 splinted, 2 unsplinted, 4 unsplinted, with or without immediate loading protocols), a clinically acceptable outcome trend has been observed in most of the previous studies.

Because a 2-implant–retained mandibular overdenture has been considered to be minimal care, it is important to know the biomechanical behavior of the mini implants as compared with that of standard implants to understand the stress distribution pattern, which may influence the long-term effect on crestal bone level changes. Pisani et al[9] investigated the biomechanical behavior of 2- and single-implant–retained mandibular overdentures with conventional or mini implants and O-ring attachments and concluded that the mini implants demonstrated higher overdenture displacement and lower stresses than did conventional implant overdentures for single- and 2-implant–retained overdentures.

To the best of the authors' knowledge, information on the comparative evaluation of the stress distribution pattern of standard and mini implants retaining overdentures using LOCATOR attachments is lacking. The purpose of this FEA study was to evaluate the biomechanical stress distribution in the mandibular overdenture, bone, and implants when retained with 2 standard or 2 mini implants under unilateral or bilateral loading conditions by using a 3D computer-aided design (CAD) model. The 3D model was constructed by using cone beam computed tomography (CBCT) images of a 59-year-old patient with an edentulous mandible. The hypothesis was that the 2–mini implant model would have higher stress concentrations in and around the implants as compared with 2 standard implants.

MATERIAL AND METHODS

This FEA study was approved by an institutional joint committee on research and ethics of the primary author's institution (Project ID: IMU 393-2017). A 59-year-old patient with an edentulous mandible was scanned by using CBCT, and the scanned images were saved as digital imaging and communications in medicine (DICOM) files. The DICOM images were imported to the digital image processing software program (Mimics; Materialise). Mandibular bone was extracted from the scanned data of all soft and hard tissues by selecting the range of the threshold values of the pixels (226 to 2154). The mandible was also separated out from the skull by manually cropping some of the intersecting pixels to create a 3D model of the mandible. A uniformly 2-mm-thick mucosal layer was formed on the 3D mandibular model by using the "Surface-offset" command in the 3Matics software program. A mandibular complete denture of the same patient was evaluated to ensure the occlusal anatomy was representative. The denture was

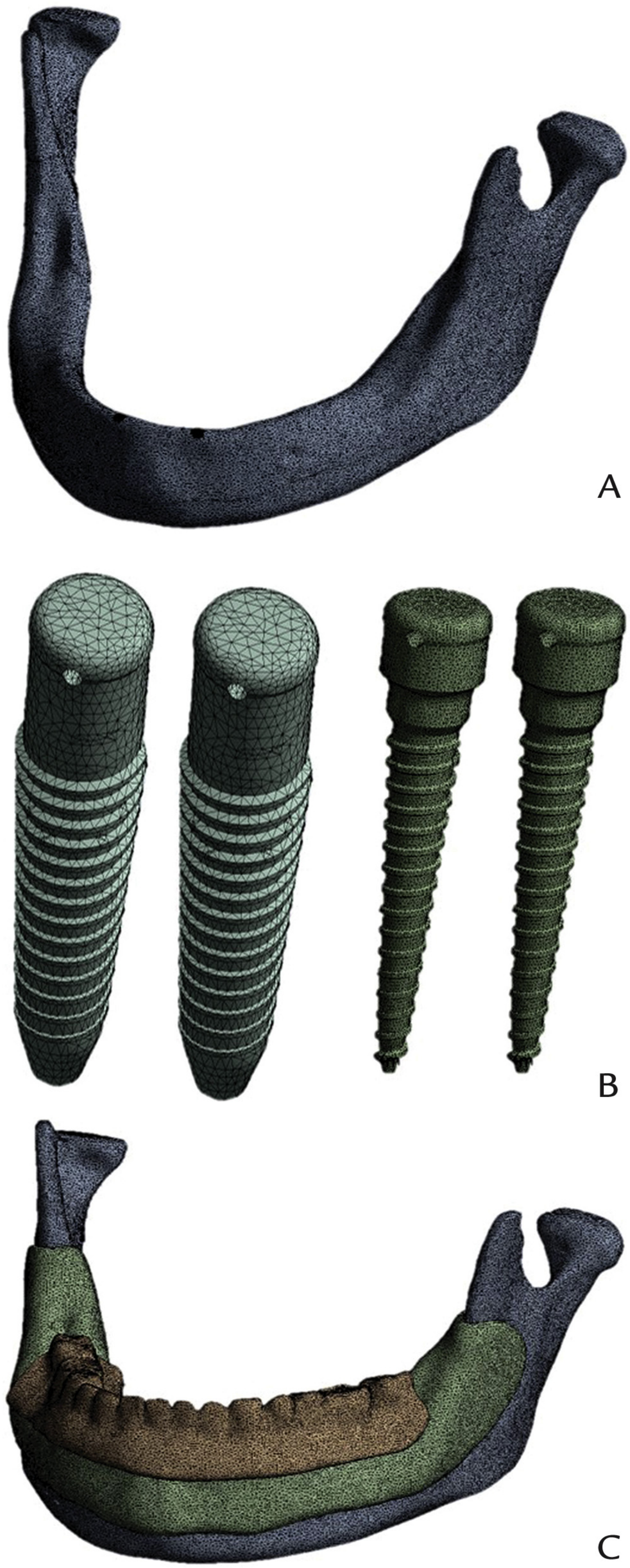

Figure 1. A, Meshed 3D model of mandible obtained from CBCT DICOM files of a patient with edentulous mandible. B, Meshed 3D model of mini implants and standard implants designed with SOLIDWORKS software program. C, Contacts achieved with individual meshed 3D model of mandible, implants with LOCATOR attachments, and denture to create overdenture assembly. CBCT, cone beam computed tomography; DICOM, digital imaging and communications in medicine.

Table 1. Mechanical properties of materials

Component	Material	Young Modulus (GPa)	Poisson Ratio
Overdenture	Acrylic Resin	8.3	0.28
Implant	Titanium	110	0.35
Mucosa	Mucosa	0.68	0.45
Mandible Bone	Mandible Bone	13.6	0.26

also examined for adequate flange extensions, retention, and stability. The denture was scanned by using an intraoral scanner (TRIOS; 3Shape A/S) outside the mouth, and the scanned image was saved as DICOM files. The intaglio surface of the denture was adjusted to uniformly contact the mucosal layer (which was designed with a uniform 2-mm thickness on the edentulous mandible) and to maintain uniform soft tissue thickness on the edentulous mandible model.

Although there are varieties of combinations of widths and lengths of the dental implants, average measurements were planned for modeling. With the aid of a commercially available CAD package (SOLIDWORKS; DASSAULT SYSTEMS), standard implants (3.5 mm in diameter, 12 mm in length) and mini implants (2.4 mm in diameter, 12 mm in length) were designed. The 2 standard implants or 2 mini implants were embedded in the mandible at the canine positions (as 2 different situations). The 3D model of the mandible (along with soft tissue layer), standard and mini implants, and the DICOM files of the denture were then imported to a 3D modeling software program (3Matic; Materialise) where individual components were meshed uniformly (Fig. 1A, 1B). Mesh models of mandibular bone with implants placed, mucosa, and overdenture were assembled on each other, and a surface mesh model was created for overall assembly in the software program (Fig. 1C). Errors such as shell elements, overlapping triangles, and intersecting triangles were removed by using the "autofix" command. Intersecting contacts were introduced between the surfaces of the overdenture, mucosa, mandible, and implant to simulate the interactions existing between these bodies. Contacts on LOCATOR attachments were essential to reproduce the behavior of the retention mechanism. The implants were considered completely osseointegrated, so a mechanically perfect interface was presumed between implants and bone. Implant and overdenture were also provided with bonded contact. The surface mesh model was then transferred to the volumetric mesh model. An additional flat surface was generated at the bottom, and boundary conditions were applied to fix the base of the mandible.

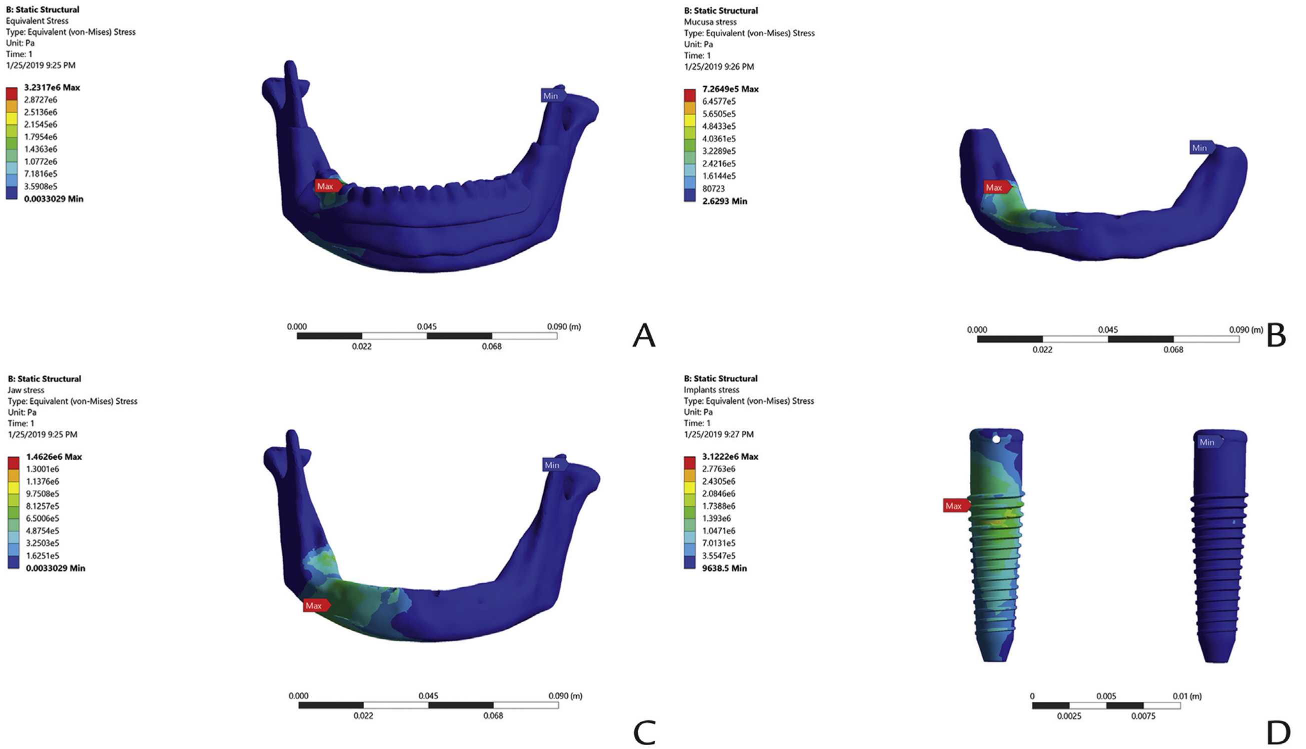

Figure 2. Stress analysis. A, Complete overdenture assembly for standard implants under unilateral loading. B, Soft tissues for standard implants under unilateral loading. C, Mandibular bone for standard implants under unilateral loading. D, Standard-sized implants for standard implants under unilateral loading.

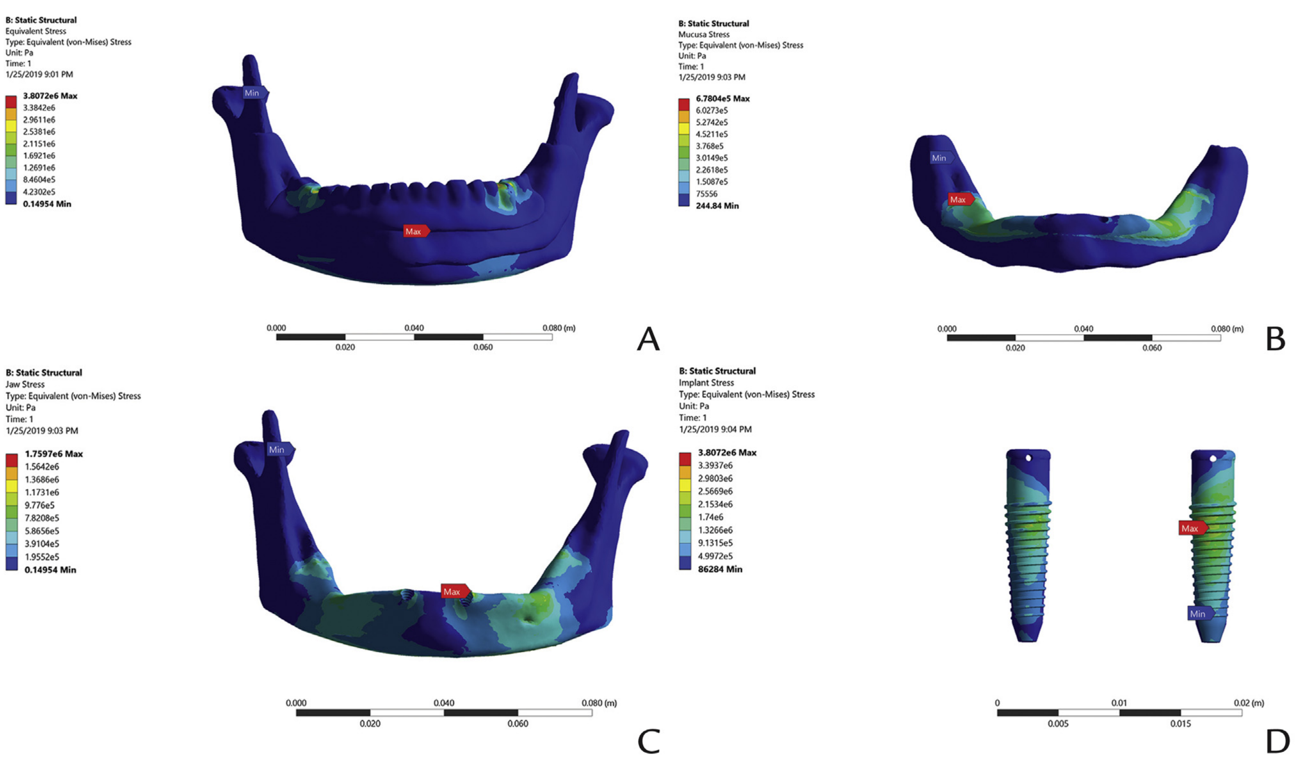

Figure 3. Stress analysis. A, Complete overdenture assembly for standard implants under bilateral loading. B, Soft tissues for standard implants under bilateral loading. C, Mandibular bone for standard implants under bilateral loading. D, Implants for standard-implants under bilateral loading.

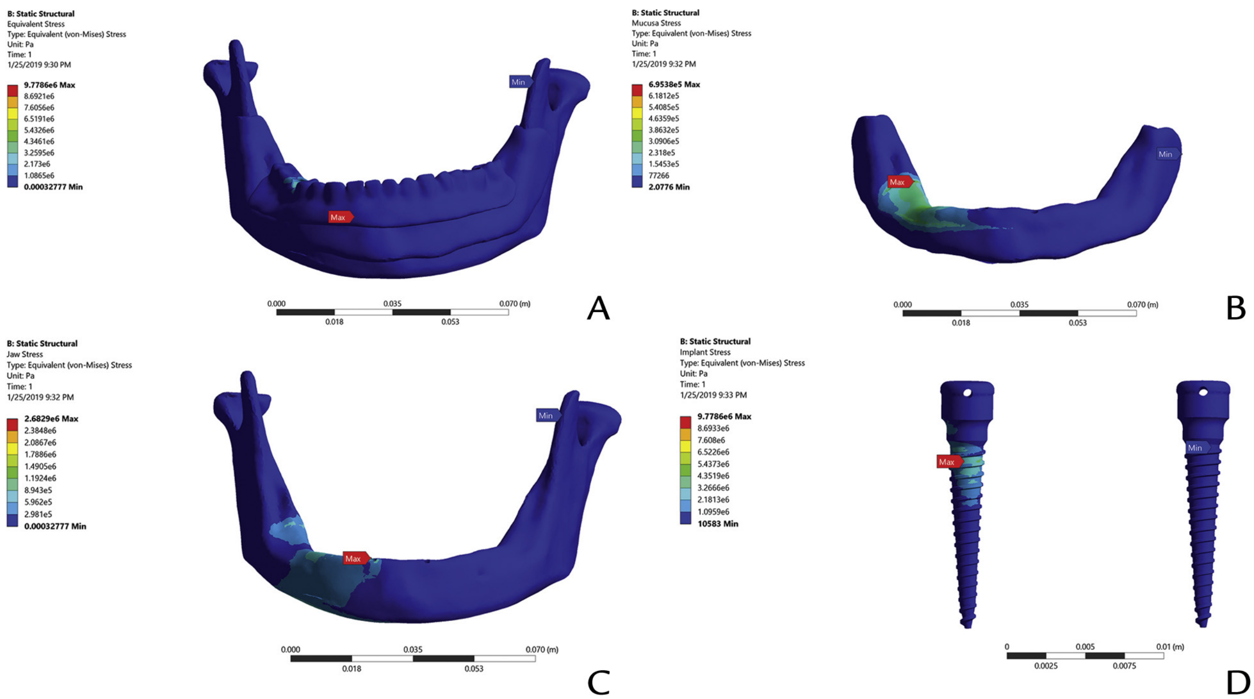

Figure 4. Stress analysis. A, Complete overdenture assembly for mini implants under unilateral loading. B, Soft tissues for mini implants under unilateral loading. C, Mandibular bone for mini implants under unilateral loading. D, Implants for mini implants under unilateral loading.

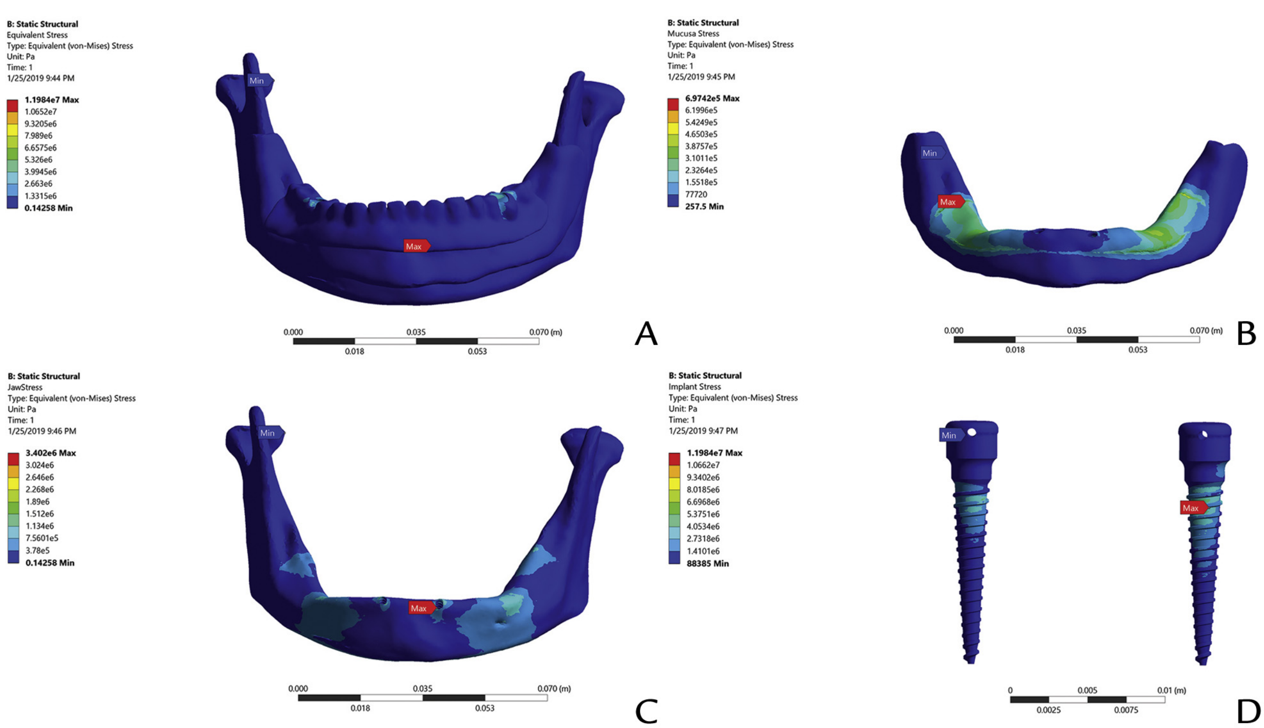

Figure 5. Stress analysis. A, Complete overdenture assembly for mini implants under bilateral loading. B, Soft tissues for mini implants under bilateral loading. C, Mandibular bone for mini implants under bilateral loading. D, Mini implants for mini implants under bilateral loading.

Table 2. von Mises stress and strain values for 2 standard and 2 mini implants under bilateral or unilateral loading conditions

Part of Overdenture Assembly		Unilateral Loading		Bilateral Loading	
		Stress (MPa)	Strain	Stress (MPa)	Strain
Standard implant	Denture	3.23	0.00122	3.72	0.00139
	Mucosa	0.72	0.00123	0.68	0.00103
	Mandible	1.46	0.0011	1.76	0.00013
	Implant	3.12	0.00011	3.81	0.00004
Mini implant	Denture	3.21	0.00122	3.83	0.00143
	Mucosa	0.7	0.00105	0.7	0.00143
	Mandible	2.68	0.0002	3.40	0.00026
	Implant	9.78	0.00009	11.98	0.0001

The volumetric mesh-model was imported from the 3D modeling software program to an engineering software program (ANSYS Workbench; ANSYS Inc) for a mathematical solution. The different situations studied were unilateral loading on the denture with 2 standard implants, unilateral loading on the denture with 2 mini implants, bilateral loading on the denture with 2 standard implants, and bilateral loading on the denture with 2 mini implants. The material properties, including the Young modulus and Poisson ratio for the denture, implants, mucosa, and bone, were allocated as in Table 1. A load of 100 N was applied vertically on the first molar tooth unilaterally and bilaterally as separate study conditions. Maximum von Mises stress and strain values were recorded. The results were evaluated by using maximum stress and strain values generated in each component of the model (Figs. 2-5). The higher stress values recorded in the assembly indicated lower stress distribution capacity of the implant type and vice versa and were considered to be the rationale for using this information in a clinical situation.

RESULTS

Maximum von Mises stress and strain values have been indicated in Table 2. The maximum stresses recorded for the entire overdenture assembly were recorded as the highest values of stress or strain shown by any of the individual components of the assembly, whether in the denture, soft tissue, mandible, or implant (Figs. 2A, 3A, 4A, and 5A). The stress and strain values observed in individual components were also recorded and analyzed. Maximum stresses of 9.78 MPa (unilaterally) and 11.98 MPa (bilaterally) (Figs. 4D, 5D) were observed in 2 mini implants as compared with 3.12 MPa (unilaterally) and 3.81 MPa (bilaterally) (Figs. 2D, 3D) in 2 standard implants. The stress values in the mandibular bone were almost double those of the 2 mini implants (2.68 MPa under unilateral and 3.4 MPa under bilateral loading) (Figs. 4C, 5C) as compared with standard implants (1.46 MPa under unilateral and 1.76 MPa under bilateral loading) (Figs. 2C, 3C). The stresses in the denture were in the range of 3.21 MPa to 3.83 MPa and in the mucosa between 0.68 MPa and 0.72 MPa (Figs. 2B, 3B, 4B, and 5B) for 2 implants in both implant/loading conditions. The strain values show similar trends with both implant types under bilateral and unilateral loading (Table 2). Under vertical loading on the mandibular molar tooth, the highest stress was observed at the mini implant as compared with the standard implant under unilateral and bilateral loading conditions. In the unilateral loading condition, the maximum strain of 0.00122 was observed in the denture with the mini implants as well as with the standard implants. Under bilateral conditions, the maximum strain of 0.00143 was observed in the denture with the mini implants as compared with the standard implants.

DISCUSSION

Forces generated during mastication are transferred to the implants, resulting in maximum stresses in peri-implant crestal bone. These generated stresses should be within a safe limit as higher stress concentration may cause crestal bone resorption and subsequent failure of treatment. The result of this study supports the hypothesis that standard implants show better stress distribution as compared with mini implants because of their geometry. Mini implants showed 68.2% more stress generation under bilateral loading and 68.1% more under unilateral loading (Fig. 6). The results indicated that the stress values varied little in the denture and the soft tissues but were higher in the mandibular bone and implants for the mini implant overdentures as compared with the standard implant overdentures. However, these findings conflicted with the results reported by Pisani et al.[9] de Souza et al[10] studied 2 mini implants against 4 mini implants and 2 standard implants and reported that the survival rate for 4 mini implants was 89%, for 2 mini implants was 82%, and for 2 standard implants was 99%. The results in the present FEA study indicated comparatively higher stress values in the bone with mini implants than with standard implants and suggest a lower clinical survival rate, as indicated by de Souza et al.[10] Jofre et al[6] performed FEA with 2 splinted versus 2 unsplinted mini implant–retained overdentures and indicated lesser stress values in bone surrounding the unsplinted mini implants compared with the splinted implants. Peri-implant bone could be affected by nonaxial loading, crown-to-implant ratio, type of implant-abutment connection, cantilever prosthetic elements, prosthetic misfits, properties of restoration materials, and the antagonistic tooth.[11] However, uniform stress distribution pattern could be one of the main factors for reducing peri-implant bone loss among the overdenture, attachments, implants, and underlying bone. The results of the present study

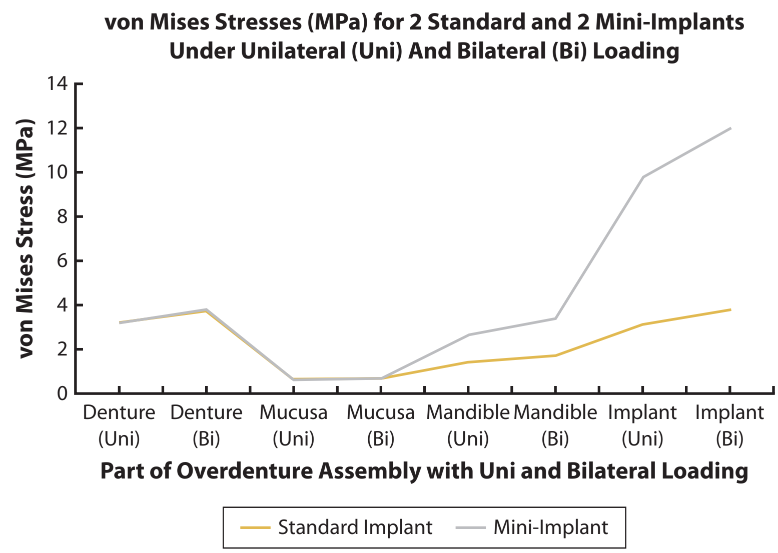

Figure 6. von Mises stress values of mini and standard implant–retained overdentures under unilateral and bilateral loading.

indicated that the stresses generated in the implants themselves are mainly at the crestal level and could be correlated with crestal bone loss. The 67% increase in stresses in mini implants was because of their reduced surface area and more tapered geometry (with increase in force per unit area with higher stress concentration) as compared with standard implants.

In the present FEA study, similar to mini-implants, standard implants were also designed as a single piece to standardize both groups. Retentive heads of both implants were copied to simulate LOCATOR attachments. In both groups, the size and shape of the male LOCATOR attachment heads were identical to fit to the universal female LOCATOR attachments. Only male LOCATOR attachments were simulated in this study. The thin flexible layer (around 1 to 2 mm) of the female attachment would cause an insignificant difference in stress values transferred from the overdenture to the underlying implants and the bone. This thin intermediate flexible layer creates additional junctional surfaces with the denture above and the male attachment below generating a large number of small junctional nodes and elements. These junctional notes and elements contribute to increase the complexity of the 3D mesh model and incorporate additional errors during analysis. Hence, the female component of the attachment system was not simulated for either group and can be considered as one of the limitations of the study.

All loads on human teeth, whether from orthodontic forces, mastication, or occluding, can be treated as either concentrated or distributed. Molar masticatory forces in complete dentures and implant overdentures have been reported to range from 30 N to 190 N.[12] In all the models, an average vertical masticatory load of 100 N (unilaterally or bilaterally) was applied to the occlusal surface of the first molar of the denture.[5] Two implants were virtually placed in the canine region. The canine position is considered to be the favorable position for 2-implant–retained mandibular overdentures.[8,13] ELsyad et al[13] evaluated the influence of implant position on the clinical and radiographic outcomes of LOCATOR-retained mandibular overdentures and concluded that the canine position is preferred over the first premolar position, as it was associated with reduced peri-implant pocket depth and marginal bone loss after 1 year. In the present study, polymethylmethacrylate (acrylic) resin was used as the denture base material. However, different types of denture bases affect the stress distribution pattern in overdentures.[14] Gibreel et al[14] performed a systematic review to study the effect of reinforcement on the mechanical behavior of implant overdenture bases and found that strains on the underlying supporting structures, including dental implants and the residual ridge, can be decreased and evenly distributed by using a metal reinforcement.

The 3D mandibular model was developed from a patient's CBCT images with the help of the Mimics software program to closely simulate human conditions. This software program is an interactive tool for the visualization and segmentation of CT images, magnetic resonance imaging images, and any other 3D rendering of the objects that facilitates processing of the scanned data for different engineering applications such as rapid prototyping, CAD, and FEA.[4] The software program also enabled the control and correction of segmented scanned images to extract the desired tissue based on their digital thresholding (the segmentation of the object that can be visualized by a colored mask). Thresholding will contain only those pixels of the image with a value higher than or equal to the threshold value. The low threshold values select the soft tissues of the scanned patient, and the high threshold values select dense parts such as the bone and teeth.

Although FEA studies can be carried out by using simulated natural structures, these results can be correlated to clinical practice and can be validated by evaluating the crestal bone loss around the implants with different diameter and/or geometry. The results of the present FEA study suggest higher crestal bone loss with thin implants (mini implants in this situation) compared with thick implants (standard implants in this situation) by keeping all other conditions the same.

CONCLUSIONS

Based on the findings of this finite element analysis study, the following conclusions were drawn:

1. Two mini implants generated an average of 68.15% more stress than standard implants.
2. A 2-standard implant–retained overdenture showed lower stress concentrations in and around implants than mini implant–retained overdentures.

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Corresponding author:
Dr Pravinkumar G. Patil
Division of Clinical Dentistry (Prosthodontics)
School of Dentistry
International Medical University
Jalan Jalil Perkasa- 19, Bukit Jalil
Kuala Lumpur 57000
MALAYSIA
Email: pravinandsmita@yahoo.co.in

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