Dental Research Journal

Original Article

Finite element analysis of stress distribution around short and long implants in mandibular overdenture treatment

Yeghaneh Memari[1], Parisa Fattahi[2], Amir Fattahi[3], Solmaz Eskandarion[4], Vahid Rakhshan[3]

[1]Removable Prosthesis Department, Dental School, Shahid Beheshti University of Medical Sciences, [2]Department of Restorative Dentistry, School of Dentistry, Islamic Azad University, [3]Dentist in Private Practice, [4]Dental Materials Research Center, Dental School, Islamic Azad University, Tehran, Iran

ABSTRACT

Background: Optimal stress distribution around implants plays an important role in the success of mandibular overdentures. This study sought to assess the pattern of stress distribution around short (6 mm) and long (10 mm) implants in mandibular two implant-supported overdentures using finite element analysis (FEA).

Materials and Methods: In this descriptive and experimental study two implant-supported overdenture models with bar and clip attachment system on an edentulous mandible were used. Two vertical implants were connected by a bar. The implant length was 6 mm (short implant) in the first and 10 mm (long implant) in the second model. Vertical loads (35, 65, and 100 N) were applied bilaterally to the second molar area. In another analysis, vertical loads of 43.3 N and 21.6 N were applied to working and nonworking sides, respectively, at the second molar area. Furthermore, the lateral force (17.5 N) was applied to the canine area of overdenture. The stress distribution pattern around implants was analyzed using FEA.

Results: The maximum von Mises stress was 57, 106, and 164 MPa around short implants and 64, 118, and 172 MPa around long implants following the application of 35, 65, and 100 N bilateral forces, respectively. Application of bilateral loads created 87 and 65 MPa stress around working and nonworking short implants, respectively; while these values were reported to be 92 and 76 MPa for long implants at the working and nonworking sides, respectively. Increasing the vertical loads increased the level of stress distributed around the implants; however, no considerable differences were noted between long and short implants for similar forces. Following unequal load application, the stress in the working side bone was more than that in the nonworking side, but no major differences were noted in similar areas around long and short implants. Following lateral load application, the stress distributed in the peri-implant bone at the force side was more than that in the opposite side. In similar areas, no notable differences were observed between long and short implants regarding the maximum stress values.

Conclusion: Using implants with different lengths in mandibular overdenture caused no major changes in stress distribution in peri-implant bone; short implants were somehow comparable to long implants.

Key Words: Dental implants, finite element analysis, overdenture

Received: July 2018
Accepted: May 2019

Address for correspondence:
Dr. Amir Fattahi,
5th Suite, No. 14, Almas
Building, Pesyan St.,
Valiasr Ave. Tehran, Iran.
E-mail: amiir.fattahi@gmail.com

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How to cite this article: Memari Y, Fattahi P, Fattahi A, Eskandarion S, Rakhshan V. Finite element analysis of stress distribution around short and long implants in mandibular overdenture treatment. Dent Res J 2020;17:25-33.

INTRODUCTION

Dental implantation is considered optimal treatment for the replacement of a lost tooth due to its high success rate. However, treatment planning and the surgical/impression approaches in implant treatment require high precision.[1-5] Factors such as implant site, prosthetic design, attachment type, diameter and length of implant, loading protocol, and prosthetic material. Moreover, the type of framework can all affect the long-term success of implants.[6-9]

Placement of long implants should not compromise the esthetics of the final restoration. This used to be particularly important when implants had machined surfaces and the placement of longer and wider implants was the conventional method of increasing the bone-implant contact area. Long and wide implants are usually associated with a high success rate. The success rate would be even higher if these implants are placed symmetrically in the jaw.[10,11] However, the posterior maxilla may be an exception to this rule due to several parameters,[12] including limited access, less visibility, inadequate interarch distance, bone loss after tooth extraction,[13-15] and low quality of bone (mainly Type IV). In the posterior areas, a thin layer of cortical bone often surrounds low-density trabecular bone, which decreases the success rate of implants placed in these areas.[16,17]

More recent studies have reported similar clinical success rates for short and long implants,[18-20] and it appears that short implants may be a suitable alternative to long implants in resorbed alveolar ridges.[21] Moreover, placement of short implants is often technically easier and safer than long implants due to lower risk of interference with anatomical structures like the maxillary sinuses.

Placement of short implants is also advantageous in cases with insufficient mandibular bone height where reconstruction surgery is not feasible. However, the ability of short implants to tolerate high loads at these areas (in comparison to long implants) is questionable. Finite element analysis (FEA) is a popular mathematical simulation in dentistry that can assess the stressed sites.[22,23] This study sought to assess comparatively the stress distribution pattern around short and long implants in mandibular overdenture using FEA, to check whether similar stress distributions would be observed around both implants under different loads.

MATERIALS AND METHODS

This *in silico* simulation study evaluated stress distribution patterns through below steps.

Modeling

Abaqus CAE version 6.10 software (ABAQUS Inc., Pawtucket, RI, USA) was used for this purpose. Each mandibular model (retromolar pad to retromolar pad), mandibular removable denture, two cylindrical implants, and an implant-supported bar were separately designed. In the mandibular model, cortical and spongy bones were defined. A simplified mandibular model was used with the average dimensions of a normal human mandible. In the simplified model of the mandible, implants were designed as homogeneous cylinders with 4-mm diameter and 6 mm and 10 mm lengths. A 16-mm bar was also designed attaching the two implants at canine areas. Mandibular overdenture was also designed according to the dimensions of the mandibular model and was attached to the bar and implants [Figure 1].

In the next step, contact elements, defined as elements in each model in contact with one another, were determined. By doing so, the action and reaction forces could be transferred to different parts of the model.

The understudy variable was the length of implants. Thus, two models with the same dimensions were evaluated. The only difference between the two was the length of implants and 6 mm (short) implants were placed in the first and 10 mm (long) implants in the second model.

Meshing

The components designed in the model (mandible, implants, bar, and implant-supported overdenture)

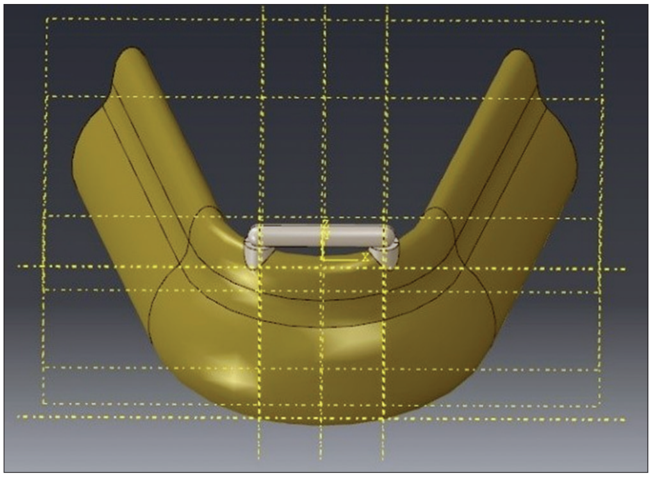

Figure 1: The created model.

were divided into small elements. Each component of the model was divided into several small elements with the same properties of the respective material (based on the data entered in the software). The accuracy of calculations may be enhanced by using smaller elements in a finite element model. Boundary conditions were defined as well. Boundary conditions define the movements in nodes and their correlations. Thus, in the designed model, the posterior end of the mandible and the mandibular base were restrained from load distribution. All nodes in the posterior regions of each model were stabilized along the x, y, and z axes to reconstruct jaw extension toward the ramus. The same was done for the base of the mandible to prevent internal movements.

Material characteristics

For logical analysis of the designed model, mechanical properties of different components of the model must be entered in the software. Thus, according to the available references,[24-27] mechanical properties of cortical and spongy bones in the mandibular model, mechanical properties of implants and bar, and also mechanical properties of implant-supported overdenture were entered in the software. The study was carried out taking into account the elastic behavior of materials, and all tissues, materials, and structures were considered isotropic and homogeneous. The Young elastic moduli were 13.7, 1.37, 110, and 4.5 GPa, respectively, for cortical bone, cancellous bone, implant titanium, and overdenture resin.[24-27] The Poisson ratios were 0.3, 0.3, 0.35, and 0.41, respectively, for cortical bone, cancellous bone, implant titanium, and overdenture resin.[24-27]

Load application

Based on the available literature,[24,28-32] load was applied vertically and horizontally. The magnitude and location of load in each of the two models were defined as 35N, 65N, and 100N vertical loads at the second molar areas to the implant-supported overdenture as well as bilateral vertical loads at the second molar areas to the implant-supported overdenture in an amount of 43.3N in the working side and 21.6N in the nonworking side, and also application of 17.5N horizontal load to the canine area of the implant-supported overdenture.[24,28-32]

The effect of load application in the above-mentioned protocols on the implant-bone interface and the peri-implant bone was evaluated. The Von Mises stress distribution in a series of points in four areas of buccal, lingual, mesial, and distal in the peri-implant bone was evaluated and recorded. These points in the bone crest started from the bone in contact with the implant and extended apically toward the bottom of the implant and from the bottom of the implant to the outer surface of bone and terminated at the bone crest. To increase the accuracy of results, all confounders were eliminated and only the understudy variable was evaluated.

RESULTS

Figures 2-11 show the patterns of stress distribution in peri-implant bone following load application to the overdenture. Various levels of stress are marked with different colors. In each Figure, areas bearing the same level of Von Mises stresses are marked with the same color.

In the short implant model, the amount of stress distributed in the peri-implant bone as the result of the bilateral application of 35N, 65N, and 100N vertical loads was 57.24 ± 1, 106.23 ± 2, and 164.14 ± 3 MPa, respectively. These values were 64.37 ± 1, 118.45 ± 2, and 172.03 ± 4 MPa, respectively, in the long implant model. Application of unequal vertical loads to the two ends of the overdenture (43.3N at the working side and 21.6N at the nonworking side) caused 87.27 ± 1 and 92.32 ± 1 MPa stress in the bone around short and long implants in the working side, respectively. These values were 65.15 ± 1 and 76.35 ± 1 MPa in the bone around short and long implants in the nonworking side, respectively. Application of lateral force to the

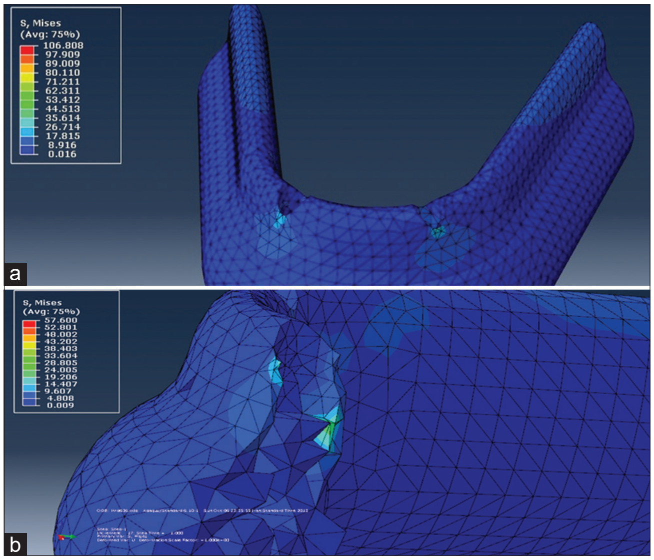

Figure 2: (a and b) Pattern of stress distribution in bone around short (6 mm) implants following the application of 35N vertical load.

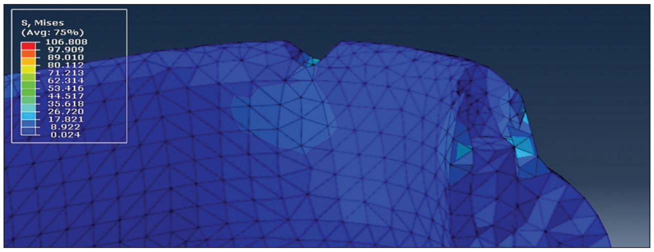

Figure 3: Pattern of stress distribution in bone around short (6 mm) implants following the application of 65N vertical load.

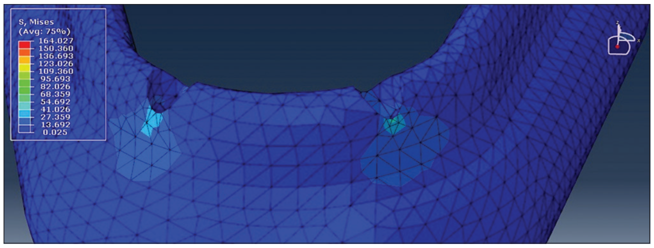

Figure 4: Pattern of stress distribution in bone around short (6 mm) implants following the application of 100N vertical load.

overdenture at the canine area caused 65.63 ± 2 and 71.12 ± 3 MPa stress in bone around short and long implants in the load application side, respectively. These values were 39.25 ± 1 and 42.07 ± 1 MPa in bone around short and long implants in the opposite side, respectively.

DISCUSSION

It was found that stresses might be heavier around long implants, although the difference might not be considerable. Placement of short implants is advantageous for both patients and clinicians. From the patient's point of view, the use of short implants eliminates the need for additional surgical procedures for autogenous bone grafting or nerve transposition. Thus, donor site morbidity and sensory disturbances of mental nerve following nerve transposition would be prevented. Moreover, unnecessary costs would be avoided, surgical time would decrease, and patient discomfort would be less. From the clinician's point of view, the placement of short implants is technically easier in the oral environment. Furthermore, short implants make implant treatment possible for patients who are not qualified for receiving long implants.

The current study evaluated the maximum level of von Mises stresses distributed in the crestal bone at four areas around implants and found no difference in this respect between short and long implants following load application to overdenture.

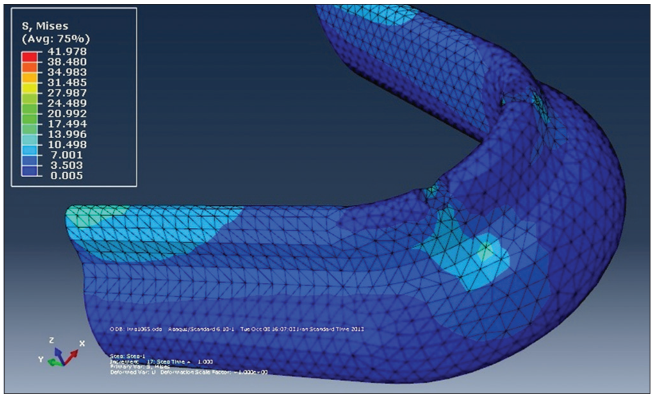

Figure 5: Pattern of stress distribution in bone around short (6 mm) implants following the application of lateral forces.

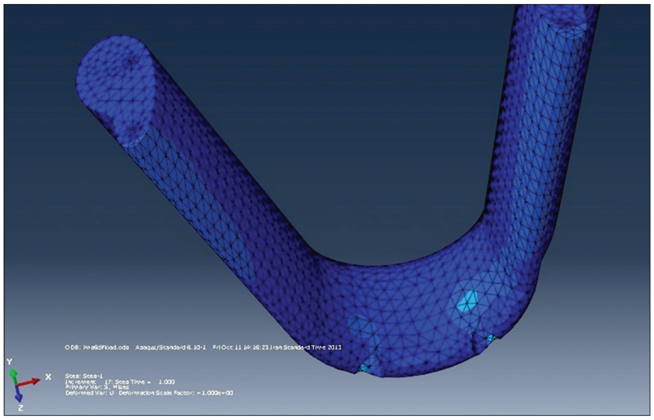

Figure 6: Pattern of stress distribution in bone around short (6 mm) implants in the working side.

Lower levels of stress were noted around short implants compared to long implants; however, this difference was not considerable. Thus, considering the advantages of short implants, they may be used for implant-supported rehabilitation and also for mandibular overdentures.

In contrast to our findings, Hasan *et al.*[33] reported higher levels of stress around short compared to long implants and demonstrated a less homogeneous pattern of stress distribution around short implants. However, it should be noted that in both their study and ours, the range of stress was quite higher than the physiological stress threshold suggested by the researchers.[33] The maximum levels of physiological stress and strain are reported to be 100 MPa and 3000 microstrains in cortical and spongy bones, respectively. Considering these values, it is assumed that short and long implants placed in the current study may be associated with a risk of overloading in some cases. Although some studies have reported the risks of placement of short implants and lower

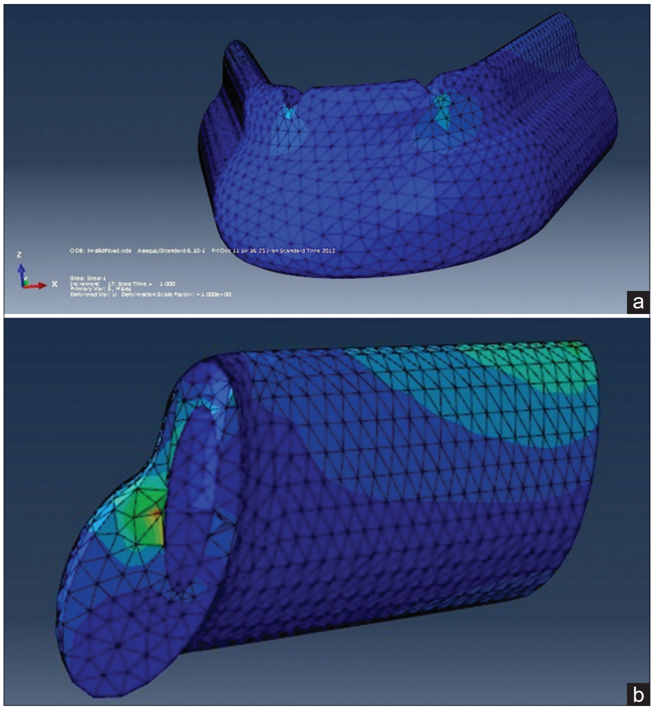

Figure 7: (a and b) Pattern of stress distribution in bone around long (10 mm) implants following the application of 35N vertical load.

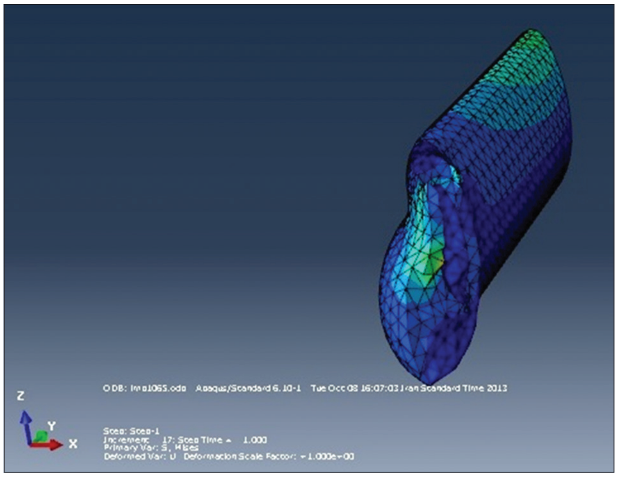

Figure 8: Pattern of stress distribution in bone around long (10 mm) implants following the application of 65N vertical load.

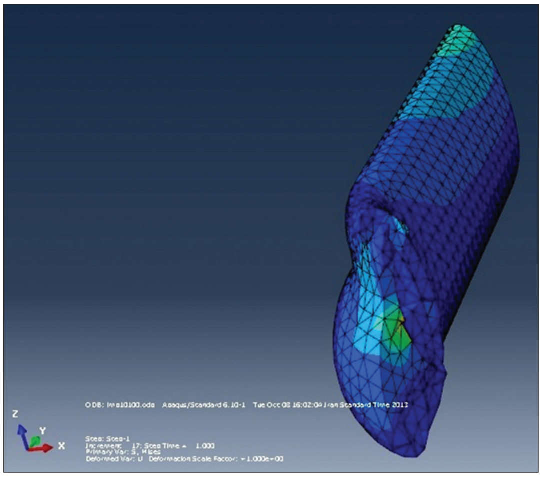

Figure 9: Pattern of stress distribution in bone around long (10 mm) implants following the application of 100N vertical load.

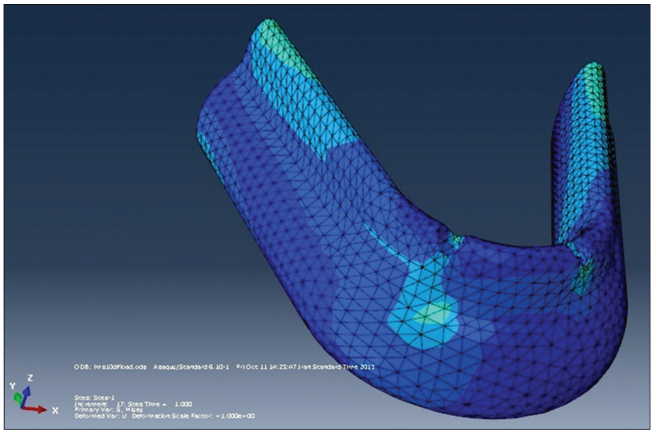

Figure 10: Pattern of stress distribution in bone around long (10 mm) implants following the application of lateral forces.

success rates compared to long implants, some others have confirmed their high success rate and favorable prognosis, with an overall success rate of about 90%–100%.[34-36]

The assessment of load distribution in bone around short and long implants by FEA in the current study revealed that the placement of short implants in cases with inadequate bone height can yield results similar to those of long implants. In the current study, no major difference was found in load distribution around short and long implants. The survival rate of short implants was reported to be within the range of 90%–100%.[36] Thus, in the clinical setting, when the placement of long implants is contraindicated, clinicians can still consider using short implants as suitable alternatives (although with slightly higher risks of failure).[36] Evidence also confirms the advantages of short implants and their equal efficacy to long implants. Renouard and Nisand[37] reported that short implants could be used for reconstruction of the severely resorbed maxilla as an alternative to complex surgical techniques.[37] Moreover, in a study by Grant *et al.*,[38] the survival rate of 8 mm implants placed in the mandible was reported to be 99% from the first-stage surgery to 2 years after functional loading. They also stated that short (8 mm) implants could be placed as an alternative to bone grafting in atrophic posterior mandible with inadequate height.[38]

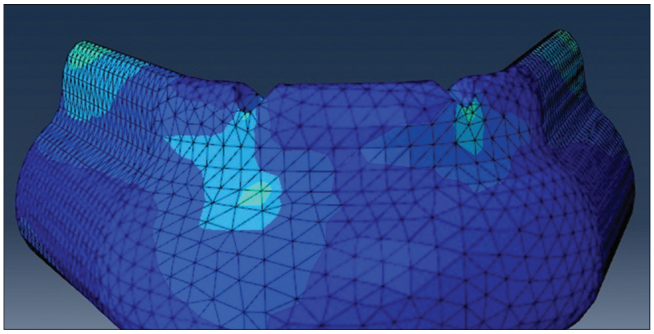

Figure 11: Pattern of stress distribution in bone around long (10 mm) implants in the working side.

Esposito *et al.*[39] found no significant difference in terms of the rate of failure or complications between short and long implants.[39] Moreover, Maló *et al.*[40] evaluated the outcome of the placement of 7 mm implants for the rehabilitation of atrophic posterior maxilla and mandible at 1 year after loading and reported relatively good survival rates for short (7 mm) implants. They also suggested the placement of short implants as a suitable alternative for the rehabilitation of resorbed areas.[40]

Quantity and shape of the mandibular residual ridge may dictate the position and number of required implants. In severely resorbed mandibular ridges, only short implants can be placed. Short implants provide limited implant-bone surface area. In other words, a small volume of bone must resist loads transferred through the implants. Increasing the number of implants increases the implant-bone surface area and enhances the load-bearing capacity of bone.

Bone is a complex, porous, anisotropic, composite structure with different physical properties at different sites.[41] The results obtained in the current study are probably attributed to the stress transfer mechanism of the bone-implant complex.[42] Mechanical distribution of stress occurs primarily at the bone-implant interface.[43] First, the occlusal stresses are transferred through the implant to the cervical bone. Limited amounts of the residual stress in trabecular bone are transferred to the apical region. Furthermore, a high level of strain is transferred to the cortical bone in contact with the implant because its modulus of elasticity is higher than that of trabecular bone and it also has high-stress transfer capacity.[42,44] In cortical bone, stress distribution is limited to areas in close contact with the implant; whereas, in trabecular bone, stress is distributed to more distant areas.[45] Misch in 1990 reported that the percentage of bone-implant contact in the cortical bone was significantly greater than that in the trabecular bone.[43] Moreover, the cortical bone is dense and more resistant to deformation. These findings have been confirmed by some *in vitro* studies.[44,46,47] Thus, inappropriate loading results in overaccumulation of stress and eventual bone loss. Stress distribution plays an important role in bone loss during the implant treatment period. The stress must be uniformly distributed around implants to decrease the risk of bone loss and improve treatment prognosis.

Although bone loss is a fundamental concept in dental rehabilitation, its exact mechanism has yet to be fully understood. Moreover, due to the complexity of bone structure and its heterogeneous mechanical properties, a specific safe threshold for stress or strain cannot be determined. Since microdeformation of bone is an important factor compromising the survival of implants, assessment of the level of stress and strain in bone is critical.[48]

The stress values reported in the previous studies do not necessarily indicate the behavior of materials in the clinical setting.[44] On the other hand, it has not been specified what proportion of biological changes like bone resorption or deposition occurs in response to stresses created in the clinical setting.[28,44] Nonetheless, FEA has yielded beneficial information in many studies and thus, is now extensively used for prediction of the behavior of materials in the clinical setting. For this reason, FEA was used in the current study to assess stress distribution in bone around short and long implants in a mandibular overdenture. FEA provides a numerical scale to determine the level of stress and deformation in structures with different geometries. In this method, a structure is divided into tiny blocks known as elements, and the behavior of structures is evaluated through simple equations. Type, order, and number of elements affect the accuracy of the results. Moreover, successful modeling of implants depends on accurate simulation of the geometry and surface structure of implants, structural characteristics of implant and bone, load application conditions, support, and bone-implant interface properties.[49] FEA is superior to the photoelastic method used in some previous studies. Despite the advantages of FEA, it has some shortcomings in the simulation of the behavior of biological systems in response to load application, similar to the photoelastic and load measurement methods.[50] The main problems against an accurate simulation of the mechanical behavior of dental implants include modeling of human bone and its reaction to mechanical load application.[51,52] All structures modeled in the current study were considered homogeneous with a linear modulus of elasticity. However, these structures, particularly the vital ones, may show totally different behavior in the clinical setting. For instance, it has been discussed that the mandibular cortical bone has some nonhomogeneous areas in its transverse cross section.[53] Thus, some differences may exist between the function and performance of different materials under *in vitro* and *in vivo* conditions. This decreases the generalizability of *in vitro* results to the clinical setting.[54]

Long-term clinical studies are required to assess the effect of stress distribution on the performance and success rate of short and long implants. Furthermore, the effect of bolus position during mastication on the pattern of stress distribution around implants must be investigated in future studies. Comprehensive evaluation of factors related to stress distribution around short and long implants in an overdenture may help improve the prognosis and prolong the clinical service of implants.

This study was limited by some factors. It was better to test more models, with various lengths and diameters of implants, to draw more comprehensive knowledge. Furthermore, although simulation studies provide valuable information, their results are limited to the very controlled virtual simulation, and cannot be generalized to clinical findings where ever-changing forces and stresses are presented in the mouth. Therefore, our results should be verified using *in vitro* and later indirectly using clinical studies. Finally, lack of statistical assessments disallows conducting any null hypotheses.

CONCLUSION

Within the limitations of this *in silico* simulation, the following results were obtained. The difference between maximum levels of stress distributed in bones around short and long implants was small. Basic stress values were slightly lower around short implants. Thus, the placement of short implants in cases with inadequate bone height might yield results similar to those of long implants.

Financial support and sponsorship

Nil.

Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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