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COMPARATIVE STUDY BETWEEN CONVENTIONAL AND MINI DENTAL IMPLANTS OF DIFFERENT DIAMETERS SUPPORTING MANDIBULAR OVERDENTURES.
A FINITE ELEMENT STRESS ANALYSIS STUDY

Sahar A. Ghorab* *and* Reham B. Osman*

ABSTRACT

This study was conducted to provide an understanding of the biomechanical behavior of different diameters MDIs and compare it with conventional diameter implants when supporting an overdenture . Three different models were designed .The first model has two standard diameter implants (3.8x12mm) (D1), the second (D2) has 2 mini-dental implants (2.4x12mm) and the third model (D3) has 2 of ultra-small diameter (1.8 x 12mm) all implants were placed at canines region. 3D finite elements stress analysis was performed to evaluate biomechanical situation in both the implants and the peri-implant bone under vertical and oblique loading of the overdentures. It can be concluded that the stress values affecting the peri-implant bone and the implants are reciprocal to dental implant diameter and the use of MDIs as overdenture abutments should be limited to cases with limited bone quantity.

INTRODUCTION

According to the glossary of Oral and Maxillofacial Implants, the term mini dental implant (MDI) is defined as an implant fabricated of the same biocompatible materials as other implants but of smaller dimensions.[1, 2, 3]

Mini dental implants are fabricated from commercially pure titanium with ultra-small diameters ranging from 1.8 to 2.4 mm.[3, 4]

In the past mini dental implants (MDIs)or small diameter implant (SDIs) were widely used in orthodontic treatment as temporary anchorage for tooth movement and in prosthodontics for temporary stabilization of overdentures. Surprisingly, after the completion of treatment, these implants were often found to be osseointegrated and difficult to remove. From this accidental finding, the idea arises for using mini implant in long term treatments situations for rehabilitation of partially and completely edentulous cases.[3,4,5]

Recently MDI have been used in management of various clinical situations due to its atraumatic and minimally invasive surgical technique.

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*Lecturer Prosthodontist, Faculty of Oral and Dental Medicine, Cairo University.

MDIs are used in cases of atrophic residual ridge[3,6,7] to improve the quality of life of completely edentulous patients .It also has a great value in management of ectodermal dysplasia cases. Using MDIs makes it possible to tackle the underdeveloped alveolar ridge and the decreased occlusal vertical dimension often encountered in such cases[8] .

A number of clinical trials evaluated the clinical and radiographic outcomes of mini implants and compared it to that of conventional implants.[9,10]

The results revealed favorable clinical and radiographic outcomes of MDIs and no significant difference between both implant types regarding marginal bone loss ,patients satisfaction and prosthetic complications[10].

However, from a biomechanical point of view, it is contended that stress values affecting the crestal cortical bone are inversely proportional to the dental implant diameter. And consequently MDIs are liable to cause high level of strains in the surrounding bone due to its small diameter.[11,12,13,14]

In their review of literature, Flangan and Mascolo suggested that for MDIs to be successful , the longest possible length must be used to compensate for the reduced implant diameter. to reduce the force per square millimeter applied to bone when loaded .[3]

In an in-vitro study, Sabet et al. investigated the difference between ERA attachment and ball attachment when used with mini-dental implant for retaining mandibular overdenture. They concluded that ERA attachment transmitted less forces to the peri-implant bone while ball attachment provided more retention .[15]

In a strain gauge analysis study, Warin et al. evaluated the influence of implant number on the strains transmitted to the peri-implant bone and retromolar pad area when MDIs were used to retain mandibular overdentures[16]

The authors simulated4 clinical situations were simulated. The first was for the conventional complete denture, and the other three models were of over dentures retained by 3, 4 and 2 MDIs placed in the intraforaminal area. The results revealed that number of MDI was not of significance regarding the total compressive strain.

However, to the author best knowledge there are no in-vivo or in-vitro studies available that evaluated the influence of different implant diameters when considering MDIs as treatment of choice for the management of completely edentulous patients. Therefore, the aim of the present study was to evaluate the biomechanical influence of different diameters of MDIs when used for retaining mandibular overdentures and compare it to the conventional diameter ones.

MATERIAL AND METHOD

Model Design

A 3D- finite element analysis model (3D-FEA). Model of an edentulous mandible restored with an implant overdenture was simulated using Image Materialise Mimics (Materialise, Leuven, Belgium), INUS Rapidform XOR3 (INUS technology, Inc) and Solid Works (Solid Works Corp., 2014, SP0.0, premium package, Concord, MA, USA) softwares. The mandibular model was constructed in three versions: the first version had 2 standard diameters titanium implants (3.8mm x 12mm) placed in the canine region bilaterally (D1) whereas in the other two models 2mini-dental implants were placed in the canine regions bilaterally. The diameter of mini-implants used was 2.4mm x 12mm in one model (D2) and 1.8mmx 12mm in the second model(D3). the image of modeled implants is shown in figure 1.

The model was created by importing CBCT of a completely dentulous mandible into Image Mimics software where 3D calculations were performed to produce STL file of mandible with natural teeth. The STL of mandible with natural teeth was then exported into Rapidform XOR software to produce

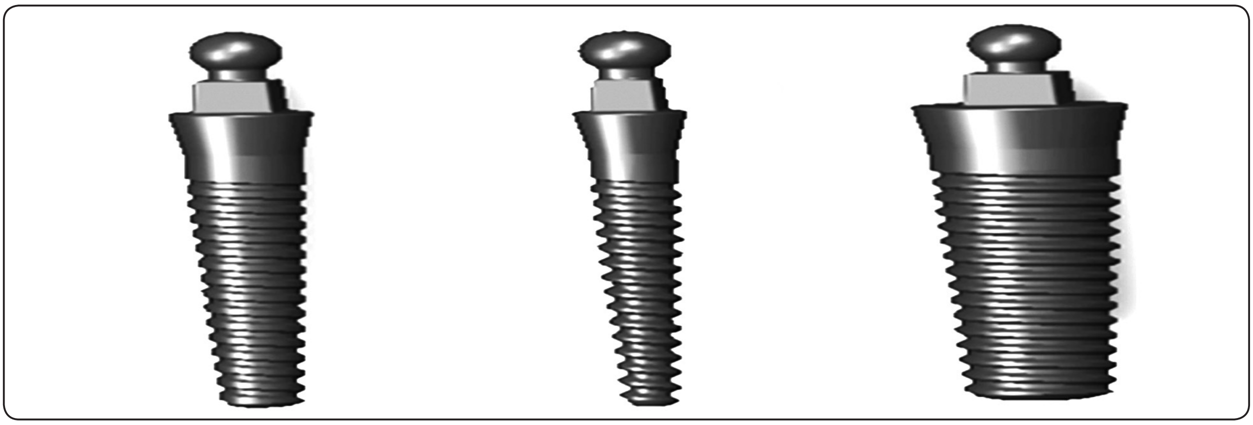

Fig. (1): Model of analyzed implants: Right: Standard Æ 3.8 mm implant, Left: Æ 2.4mm mini-implant, Middle: Æ 1.8 mm mini-implant

cut sections along the bone and teeth respectively. The cut sections were then exported into IGES format to Solid Works software where cross section planes and sketches of bone, mucosa, denture base and teeth planes were drawn .The cross-sections were then interconnected with each other to produce the mandibular model (fig.2).

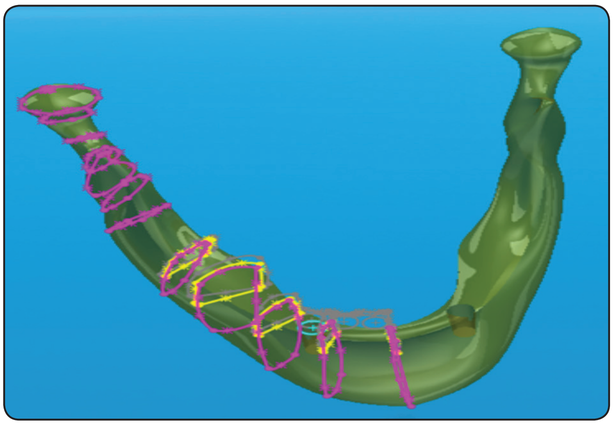

Fig.(2) : Drawing of mandibular model on Solid Works software

Cuts for each implant were then made into the bone all the way through the mucosa. The holes were axially cut at canine regions for D1 and at canine and lateral incisor regions for D2 and D3. Circular cross section of the cuts had a diameter of 3.8, 2.4 and 1.8 mm and a length of 12mm to receive the implants of the same diameter. Modeling of the nylon caps and implants was performed freehand and was aided by product description of some of the commercially available products with some modifications to produce the desired implant and attachment dimensions for this study (Fig 3).

The overdenture was designed to provide full coverage of primary and secondary stress bearing areas of the mandible. The position of nylon caps was engraved in the fitting surface of the denture ensuring at least 2mm of acrylic above the caps. At the end, all the components were assembled together guided by common origin point. (fig.4)

The nylon cap diameter was 1.8 from the internal side and 3.3 from the outer side . The height was 2.25 mm, this applies to all models since the ball attachment is the same size of 1.8 mm. The metal housing internal diameter was 3.5 mm.

Elements and Nodes

The FEA models were meshed with three-dimensional parabolic tetrahedral solid elements with surface-to-surface contact to produce a high quality solid mesh. The number of elements and nodes for each model is shown in table 1. The global average element size was set to 1mm. The mesh tolerance was set to 0.05mm.

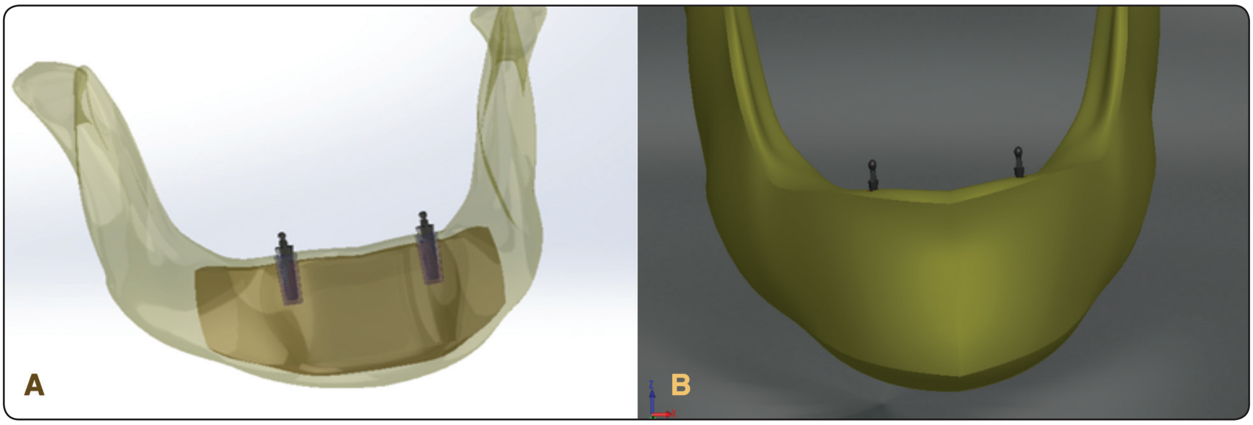

Fig (3): Simulated models: (A) model with standard Æ implants, (B) model with mini-implants once simulated with Æ 2.4mm and once with 1.8 mm

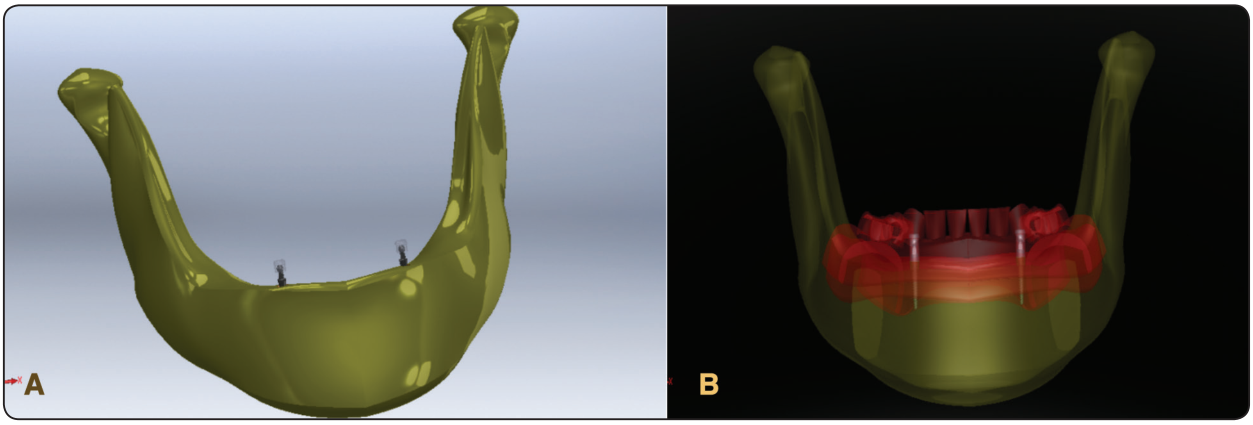

Fig. (4) simulated model for all the components (implants, attachment and overdenture)

TABLE (1) Number of elements and nodes in each model.

Design	Number of Elements	Number of Nodes
D1	992495	1395187
D2	1027884	1442892
D3	1138176	1597413

Material properties

In absence of data concerning the precise properties of mandibular bone, it was assumed to be homogenous, isotropic and linearly elastic as were the other materials used in the analysis. Table (2) shows the properties of each material used in the simulation, as obtained from previously published data.

TABLE (2) Properties of simulated material

Materials	Components	Elastic Modulus (MPa)	Poisson's ratio
Cortical - bone	1- Mandible. 2-Bone cylinders.	13,700	0.3
Trabecular - bone	Mandible	1370	0.3
Titanium	1. Implants. 2. Ball abutment	103.400	0.35
Acrylic	Overdenture	4500	0.35
Mucosa	Mucosa	1	0.37
Nylon	Nylon Caps	28.3	0.4

Boundary condition

All the components were assumed to exhibit a fixed bond at the interface with the contacting structures, except for nylon cap/implant and fitting surface of denture/mucosa interfaces where a no-penetration (slip) contact was assumed. The implants were assumed to be completely osseointegrated, with a 100%bone-implant contact. The overdentures and nylon caps were allowed to move freely on top of mucosa and ball abutments respectively.

Constraints and loads

The entire assembly was restrained at the inferior border of the mandible to avoid any bodily displacement during the loading. This site was chosen as it is distant from the loading area and allows forces to be transmitted with minimal effect on the resulting strain.

Loads of 200 N were applied vertically and obliquely to fossae of acrylic resin denture teeth and lingual inclines of buccal cusps respectively. The forces were applied unilaterally on the posterior teeth of the fourth quadrant. Further, 50 N vertical load was applied on the incisal edge of anterior teeth of denture.

FE iterative solver software (FE Plus Solver, Solid Works Corp., Concord, MA, USA) was used to compute the maximum equivalent stresses (Von Misses stresses) in the peri-implant bone and implants of each model. The numeric data were then collected, color-coded and compared between the models.

RESULTS

Stress Distribution in Implants:

The maximum stress values recorded on the implants in three models are shown in (Table 3), under vertical loading, the maximum Von Mises stress values were comparable in the implants between D1, D2 and D3 under vertical loading. The maximum stress values recorded within the implants were 52.6, 55.7, and 56.8 for D1, D2, and D3 respectively. While, under oblique loading, the maximum stresses were almost doubled with 2.4mm diameter implants in D2 (209 N), and tripled with 1.8mm ones in D3 (286 N) when compared to standard diameter implants in D1 (94.3N). Under vertical loading in D1 and D2 the maximum stresses were mainly located distobuccally at the neck region of the most distal implant on the loaded sided (Fig 4). Whereas with D3, the maximum stresses were observed more apical at the shoulder of the implant when compared to D1 and D2 (Fig 4).

Under oblique loading distribution pattern was close to that observed under vertical loading. The maximum stress values were located at the buccal aspect of the neck of the most distal implant on the loaded side in D1 and D2, however with wider spread pattern of stress to involve the both the neck and shoulder of implant in D2 as shown in figure(5). While in D3, there was more apical spread of stress distribution, with maximum stresses being observed at the first implant thread.

TABLE (3): The maximumVon Mises stress values on the implants in the three models under both vertical and oblique loading.

Maximum Von Mises stresses	1.8mm MDI	2.4mm MDI	Standard 3.8 mm
Vertical load	56.8 N	55.7 N	52.6 N
Oblique load	286 N	209 N	94.3 N

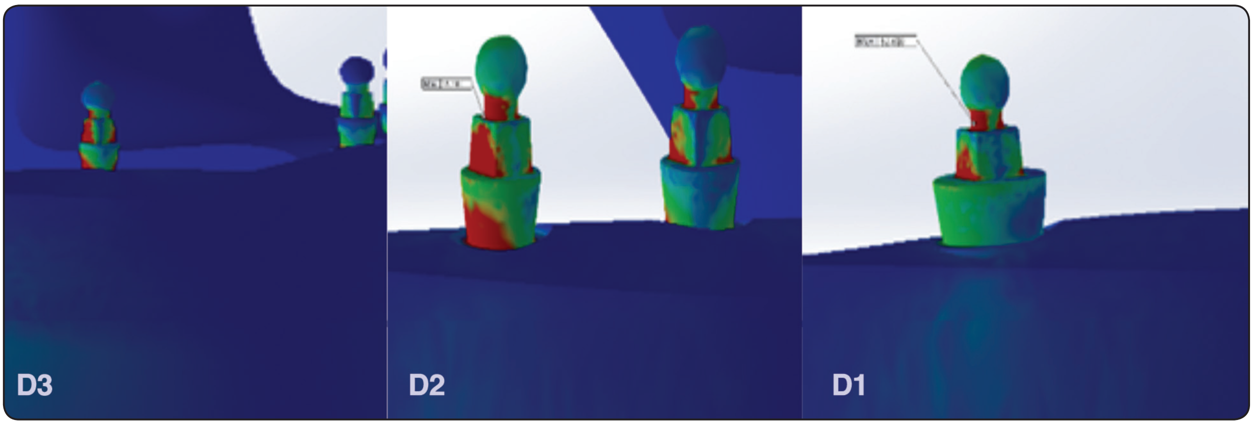

Fig (5): Von Mises stress distribution in implants under vertical load: D1, D2, D3

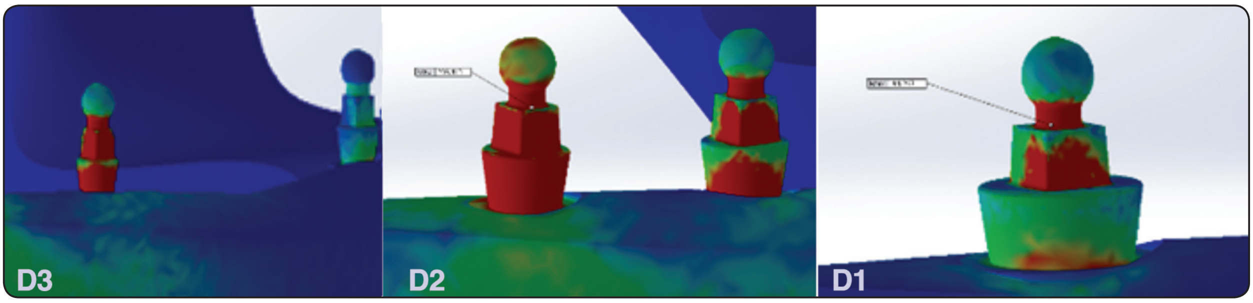

Fig. (6) : von Mises stress distribution in implants under oblique load: D1, D2, D3

Stress Distribution in Peri-Implant Bone:

The general pattern of stress distribution in peri-implant bone was similar to that observed in the implants under both oblique and vertical loading as shown in figure 6& 7. With the reduction in implants diameter, there was a trend towards the more apical spread of stress, where stresses reached bone at the level of first thread with Æ 2.4mm implant and almost the level of the apex of the implant with Æ 1.8 mm implant.

There was a significant difference in the stress values between the models under both vertical and oblique load. Under vertical load, the maximum stress values were 13.7 N, 29.5 N and 54.2 N for D1, D2 and D3 respectively.(Table 4)

The corresponding values under oblique load were 22.7 N, 160.3 N, and 273.8 N for D1, D2 and D3 respectively.

TABLE (4): The maximumVon Mises stress values on the peri- implants area in the three models under both vertical and oblique loading.

Maximum Von Mises stresses	1.8mm MDI	2.4mm MDI	Standard 3.8 mm
Vertical load	54.25 N	29.53 N	13.73 N
Oblique load	273.81 N	160.38 N	22.76 N

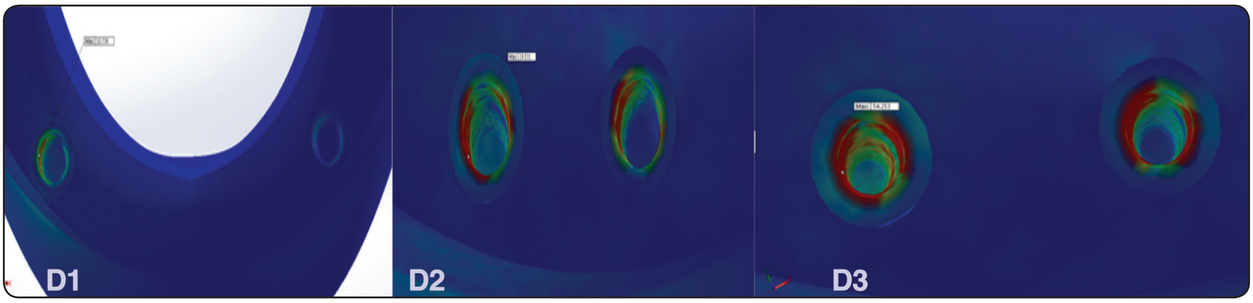

Fig (7): Von Mises stress distribution in peri- implants area under vertical load: D1, D2, and D3

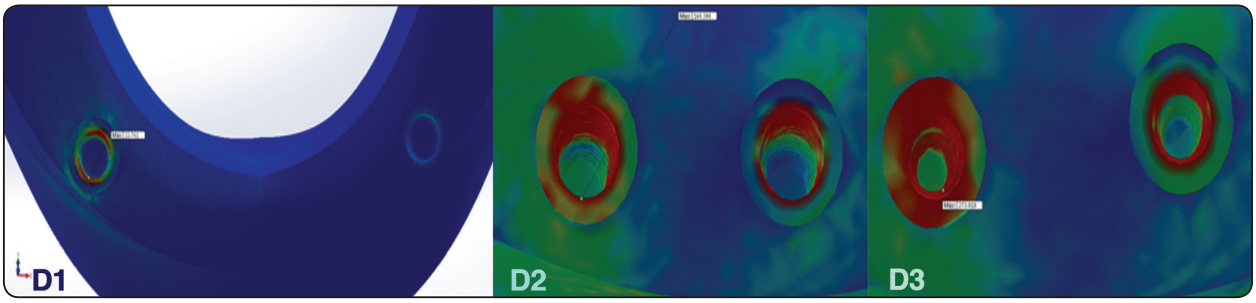

Fig. (8): Von Mises stress distribution in peri- implants under oblique load: D1, D2, D3

DISCUSSION

Use of mini-dental implant is now a common proposed solution for stabilization of mandibular overdentures especially in cases with poor bone quantity in facio-lingual dimension to avoid bone grafting procedures. MDIs are minimally invasive and more cost effective when compared to conventional diameter implants. Furthermore, one-piece design of MDIs allow for immediate restoration of function and esthetics during the healing period. Nevertheless, the increased concerns regarding the biomechanical behavior of MDIs used to retain mandibular overdentures merits further investigations.

This study was conducted to provide an understanding of the biomechanical behavior of different diameters MDIs and compare it with conventional diameter implants when supporting an overdenture.

Three different models were designed. The first model has two standard diameter implants (3.8x12mm) at the canine region (D1), the second (D2) has 2 mini-dental implants (2.4x12mm) and the third model (D3) has 2 ultra-small diameter implants (1.8x12mm) at canines areas. The three models have overdenture superstructure.

3D finite elements stress analysis was performed to evaluate biomechanical situation in both the implants and the peri-implant bone under vertical and oblique loading.

Direct comparison of the findings of this study with other studies was not possible due to paucity of similar data in the literature. However, the results of this study complement previously published work. Which showed that the increased implant diameter resulted in better dissipation of masticatory forces and decreased the stresses around the implants[11, 17-20]

The smaller the area of bone contacting the implant body, the greater the overall stress recorded. Whether increase in selected implant length can compensate for reduced implant diameter of MDIs or not still necessitate further investigations.

Despite the increased stress values recorded for MDIs as compared to conventional diameter implants, it may be suggested that the generated stresses in the two- MDIs mandibular overdentures are within the physiologic limits of the bone.

El-sayad et al.[10] reported a cumulative success and survival rate of 4-MDIs mandibular overdentures of 96.4% and 92.9% respectively at 3-year follow-up period. The dimensions of implants used in the later study were 1.8mm in diameter and 12 to 16 mm in length.

In general, the highest stress values on implants were recorded in D3 (286 N) with Ultra-thin implant diameter of 1.8 mm followed by D2 (209 N) then D1 (94.3 N).

With the conventional implants, the maximum stress values were recorded at the disto-buccal aspect of the implant on the loading side. With the decrease in implant diameter there was a more apical spread of stress distribution. In D1 the maximum stresses were observed at the implant neck and extended more apically with D2 to involve the implant neck and shoulder while with D3, maximum stresses were observed at the first implant thread.

A similar pattern of stress distribution was observed in peri-implant bone under both oblique and vertical loading. With the reduction in implants diameter, there was more apical spread of stress, where stresses reached bone at the level of first thread with ϕ 2.4mm implant and almost the level of the apex of the implant with ϕ 1.8 mm implant.[21,22,23]

The mechanical distribution of stresses occurs primarily in cortical bone at bone-implant interface and provides mechanical immobilization allowing better distribution of stresses with the conventional implants.

When a single posterior load was applied, force concentration may result in maximum stress values at the disto-buccal aspect of the distal implant on the loading side under different loading conditions[16] .In case of MDIs, the smaller implant diameter will result in reduced contact surface area and less bone implant contact thus the forces will be more apically disturbed as was observed in this study. With ϕ 2.4mm implants, the maximum stresses were recorded in the peri-implant bone at the level of the first thread and with ϕ 1.8 mm implant the stresses were recorded at the apex of the implant. In the same context it was reported that when the maximum stress concentration occurs in trabecular bone, it occurs around the apex of the implant

As a matter of fact, the presented models are only an approximation of the clinical situation. The bone was modeled as a homogenous material isotropic and linearly elastic structure whereas, In reality, it is not. Modeling the bone as trabecular architecture might lead to a situation of 100 % simulation for osseo-integration between implants and bone[22].

Also, the stress analysis was performed using static load, which does not quite simulate the complex intra-oral dynamic forces. However, the results provide a comparative overall insight on the influence of different implant diameters on stress and strain pattern when MDIs are used for the support of mandibular overdentures. Areas for future research should involve the evaluation of different lengths of MDIs, different attachment systems available, as well as the biomechanical behavior of MDIs while modeling different bone structures and architect. Models that involve two-piece design for MDIs should also be investigated and its influence on biomechanical load distribution should be evaluated.[22, 23]

CONCLUSION

Within the limitations of this study, it can be concluded that the stress values affecting the peri-implant bone and the implants are reciprocal to dental implant diameter and the use of MDIs should be limited to cases with limited bone quantity where extensive surgical procedures are to be avoided.

REFERENCES

1- Laney, W.R.: Glossary of oral and maxillofacial implants .Quintessence publishing Co.2007:40,102.

2- Flanagan, D., Mascolo, A.: The mini dental implant in fixed and removable prosthetics: a review.J.Oral Implantol.,2011:37:123-132.

3- Shatkin,T.E., Shatkin S., Oppenheimert, B.D., Oppenheimet, A.J.:Mini dental implants for long- term fixed and removable prosthetics : a retrospective analysis of 2514 implants placed over a five-year period .Compend. Contin.Educ.Dent.,2007:28:92-99.

4- Christensen,G.J.: The mini-implant has arrived.J.Am. Dent.Assoc.,2006:137:387-390.

5- El-Attar, M.S., El-Shazly, D., Osman, S., El-Domiati, S., Salloum, M.G.:Study of the effect of using mini-transitional implants as temporary abutments in Implant overdenture cases .Implant Dent.,8:152-158,1999.

6- Griffitts, T.M., Collins, C.P., Collines, P.C.: Mini-dental implants: an adjunct for retention , stability and comfort for the edentulous patient. Oral Surg.Oral Med. ,Oral Pathol.,Oral Radio.,Endod.:100,81-84,2005.

7- Preoteasa,E.,Imre,M.,Preoteasa,C.T.: A three-year follow-up study of overdentures retained by mini-dental implants. Int. J.Oral Maxillofac.Implant.,29:1170-1176,2014.

8. Kilic, S., Altintas, S.H., Altintas, N.Y., Ozkaynak, O., Bayram, M., Kusgoz, A.,Taskesen,F.:Six-year survival of a mini dental implant-retained overdenture in a child with ectodermal dysplasia .J. Prosthodont.,26:1-13,2017.

9. Aunmeungtong, W., Kumchai, T., Streitzel, F.P., Richart, P.A., Khongkhunthian, P.: Comparative Clinical Study of Conventional Dental Implants and Mini Dental Implants for Mandibular Overdentures:A Randomized Clinical Trial. Clinical Implant Dentistry and Related Research,19:2,328-340,2017.

10- El-Sayad, M.A., Gebreel, A.A., Fouad, M.M., El-Shoukouki, A.H.: The clinical and radiographic outcome of immediately loaded mini implants supporting a mandibular overdenture.A 3-year prospective study.J.Oral Rehabil. ,38:827-834,2011

11- Bagg. I., Cappelloni, I., Digirdamo, M., Maceri, F., Vairo, G.: The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three-dimentional finite element analysis.J. Prosthet. Dent.,100:422-431,2008

12-Ding,X.,Zhu,X.H.,Liao,S.H.,Zhang,X.H.,Chen,H.:Implant-bone interface stress distribution in immediately loaded implants of different diameters : a three-dimentional finite element analysis ,J.Prosthodont. :18:393-402,2009.

13-Kheirallah,I.S.,Younis,J.F.,: Peri-implant biomechanical responses to standard,short-wide and mini implant supporting single crowns under axial and off-axial loading (an in-vitro study). J. Oral Implantol.:40:42-52,2014.

14- Chang,S.H.,Huang,S.R.,Huang,S.F.,Lin,C.I.,:Mechanical response comparison in an implant overdenture retained by ball attachments on conventional regular and mini dental implants: a finite-element analysis.Comput.Methods Biomech.Biomed. Eng.19:911-921,2016.

15- Sabet,M.E., Shawky, A.M.O.A., AlyRagab, D.A.M.: Evaluating the use of ERA Mini DentalImplants Retaining Mandibular Overdenture (InVitro Study) J.Dentistry, 4:197,2014.

16- Warin, P., Rungsiyakull, P., Rungsiyakull, C., Khongkhunthian, P.: Effect of different numbers of mini-dental implants on alveolar ridge strain distribution under mandibular implant-retained over dentures.,J.Prosthodont. Research, 62:35-43,2018.

17- Holmgren,E.T.,Seckinger,R.J.,Kilgren,L.M.,Mante,F.,:Evaluating parameters of osseointigrated dental implant using finite element analysis : a two-dimensional comparative study examining the effects of implant diameter, implant shape, and load direction .J .Oral Implantol.,24:80-88,1998.

18- Lener,H.:Minimal invasive implantology with small diameter implants. Implant Practice ,6:86-92,2013.

19- Luigi, B., Ilaria, C., Michele, G., Franco, M.: The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: A three-dimensional finite element analysis. J.Prosthet. Dent. 100:422-431, 2008.

20- Hassan,I.,Heneman,F.,Ailahrach,M.,Bourauel,C.:Biomechanical finite element analysis of small diameter and short dental implant.Biomed.Tech.,55:341-350,2010.

21- Barbier,L.,Vander,J.,Krzesinski,G.,Schepers,E.,VanderPerre,G.:Finite element analysis of non-axial versus axial loading of oral implants in the mandible of the dog .J.Oral Rehabil.52:847-858,1998.

22- Aunmeungtong, W., Khongkhunthian, P., Rungsiyakull, P.: Stress and strain distribution in three different mini dental implant designs using in implant retained overdenture: a finite element analysis study.Oral Implantol.: 9:202-212,2016.

23. Ma Xuanxianz LT. Single implant prosthesis. In: Lianping Geng., editor. Newly developed technology of prosthetic dentistry in China in 1990s. Chengdu: Sichuang Science and Technology Publishing House; 1998. pp. 1–20.