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A THREE-DIMENSIONAL FINITE ELEMENT STRESS ANALYSIS OF TWO DIFFERENT IMPLANT DISTRIBUTIONS SUPPORTING AND RETAINING MANDIBULAR OVERDENTURES

Reham B. Osman* *and* Wael Abd El Razek**

ABSTRACT

Statement of Problem: Hinging mandibular overdentures retained by anterior interforaminal implants results in denture rotation and posterior basal bone resorption. Wide spread implant distribution and posterior implant placement can improve overdenture support.

Aim of study: To evaluate the biomechanical aspects of novel implant distribution used to support mandibular overdentures and compare it with commonly used design. The novel design consists of mid-symphyseal and bilateral posterior implants in the first molar region as opposed to conventional design with anterior mid-symphyseal and bilateral implants in the canine region.

Materials and Methods: Two finite element models were created. In the two models a mid-symphyseal implant was simulated. In the first model (D1), 2 more implants were placed in the canine region bilaterally while for the second model (D2), the 2 additional implants were placed posteriorly in the first molar region. Unilateral vertical and oblique loads were applied on central fossa of right first molar and palatal aspect of central incisors in each model. Von Mises stress distribution was evaluated in the implants and peri-implant bone. Denture displacement was also calculated for each model.

Results: There was a slight increase in maximum Von-Mises stress values recorded in both implants and peri-implant bone under both vertical and oblique load in D2 when compared to D1. D1 showed higher denture displacement values when compared to D2.

Conclusions: Posterior implant placement resulted in improved denture support and minimal denture displacement on the expense of transferring extra load to the posterior implants. However, increased functional load on posterior implants is expected to have a positive effect on preservation of the residual alveolar ridge. D2 is an acceptable alternative prosthodontic design to D1 when anatomical factor permits.

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* Lecturer, Faculty of Dentistry, Cairo University, Department of Prosthodontics
** Assistant Lecturer, Faculty of Dentistry, Cairo University, Department of Prosthodontics

INTRODUCTION

Mandibular implant overdentures have been successfully used for the rehabilitation of completely edentulous patients.[1,2] The distribution of stress/strain in implant/bone interface and basal seat bone is influenced by a number of factors including but not limited to implant positions and implant distributions.[3] In the 2,3 and 4 interforaminal implant retained overdentures, most of load is distributed on the posterior basal seat area where highest stress values[3] and bone resorption was reported.[4-6] The biomechanics of 2,3 or 4 interforaminal implants mandibular overdenture is similar to that of a Kennedy class I removable partial denture. Difference in compressibility between posterior ridge mucosa and osseintegrated implant will cause rotation of denture base around a fulcrum line passing through the two most distal anterior implants.[7] During mastication, the increase in compressive load on the distal overdenture base will increase potential of distal ridge resorption.[6] Furthermore, the disparity of support may also induce a high degree of forces and bending moments on the implant and consequently on the peri-implant bone especially if attachment system used does not permit sufficient rotation of denture base upon occlusal loading to compensate for mucosal resiliency. [8,9]

To optimize the biomechanical load distribution several approaches are suggested including functional impressions, maximum extension of the prosthetic base within the physiological limit of patients, periodic re-basing of the prosthetic seat as well as the proper selection of overdenture attachment systems.[9-11] All these techniques aim to distribute loads to the supporting structure in a uniform physiological manner. Another option would be to eliminate the lever movement in distal extension edentulous areas by implant incorporation. Implant placement at the distal edentulous ridge change the clinical situation from Kennedy Class I implant-and-mucosa supported overdentures to fully implant-supported Class III and minimize the distal denture base displacement with anticipated reduction in distal bone resorption and prosthodontic maintenance required.[12]

In a three-dimensional finite element analysis study, Petrie et al.[13] reported that the addition of 2 posterior short implants to 2 anterior implants resulted in a favorable outcome in maintaining bone mass under mandibular implant-retained overdentures.

However, the influence of posterior implant placement on stress/strain distribution in the implants and peri-implant bone is yet to be investigated. This will provide a better understanding of the biomechanical aspects before clinical recommendations can be made.

Therefore the aim of this study was to evaluate the biomechanical aspects of a novel implant distribution used to support a mandibular overdenture and compare it with conventional design using a three-dimensional finite element analysis (3D-FEA). The novel design consists of mid-symphyseal and bilateral posterior implants in the first molar region as opposed to conventional design with anterior mid-symphyseal and bilateral implants in the canine region.

MATERIAL AND METHOD

Model Design:

A 3D- finite element analysis model (3D-FEA) 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 and CBCT of a completely dentulous mandible. The mandibular model was constructed in two versions: the first version had 3 standard diameters titanium implants (3.8mm x 10mm) placed in the mid-symphyseal and canine region bilaterally (D1) whereas in the second model (D2) one implant was placed in the mid-symphyseal region and the two posterior implants were placed in the first molar area bilaterally (Fig 1).

Cuts of a size equal to implant dimension were then made into the bone all the way through the mucosa at canine and mid-symphyseal regions for D1 and at mid-symphyseal and first molar regions for D2 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.

Elements and Nodes

The FEA models were meshed with three-dimensional parabolic tetrahedral solid elements with surface-to-surface contact and mesh tolerance of 0.05mm to produce a high quality solid mesh. The total number of elements was 84537 and number of nodes was 155239 for both designs. The global average element size was set to 1mm.

Material properties

Mandibular bone was assumed to be homogenous, isotropic and linearly elastic as were the other materials used in the analysis. Table (1) shows the properties of each material used in the simulation.

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 overdentures and nylon caps were allowed to move freely on top of mucosa and ball abutments respectively. The implants were assumed to be completely osseointegrated, with a 100% bone-implant contact.

Constraints and loads

The entire assembly was restrained at the inferior border of the mandible to avoid any bodily displacement during the loading. 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. Denture displacement in each design was also recorded. The numeric data were then collected, color-coded and compared between the models.

TABLE (1) Material properties used for simulation

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

RESULTS

Von Mises Stress in Implants:

Under vertical loading in D1 and D2 the maximum Von Mises stress values recorded within the anterior and posterior implants were 7 MPa, 39.6 MPa and 14 MPa and 54.6 MPa respectively. The corresponding values under oblique load were 11.4 MPa, 125.7 MPa and 21.6 MPa and 141.3 MPa for anterior and posterior implants respectively.

Von Mises Stress in Peri-Implant Bone:

Similar to recorded stresses in implants, there was a slight increase in the maximum Von Mises stress values in peri-implant bone around anterior and posterior implants in loaded side in D2 when compared to D1 (Fig 2). Under vertical load, the maximum stress values were 3.6 MPa and 30 MPa for anterior and posterior implants respectively in D1 and 11.2 MPa and 45.2 MPa in D2. The corresponding values for anterior and posterior implants under oblique load were 6.5 MPa, 103.6. MPa, and 18.1 MPa and 117.4 MPa for D1, D2 respectively.

Denture Displacement:

D1 showed an increase in denture displacement compared to D2 under both vertical and oblique loads (Fig 3). The displacement values recorded were 159 µ, 81.5 µ and 385 µ, 231 µ under vertical and oblique load for D1 and D2 respectively.

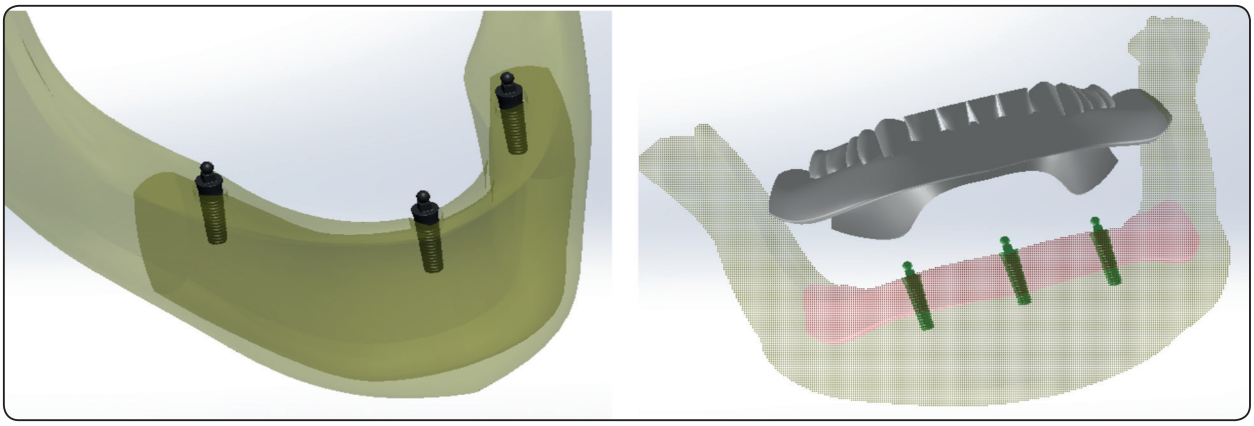

Fig. (1) Finite Element Model of 2 designs D1 and D2

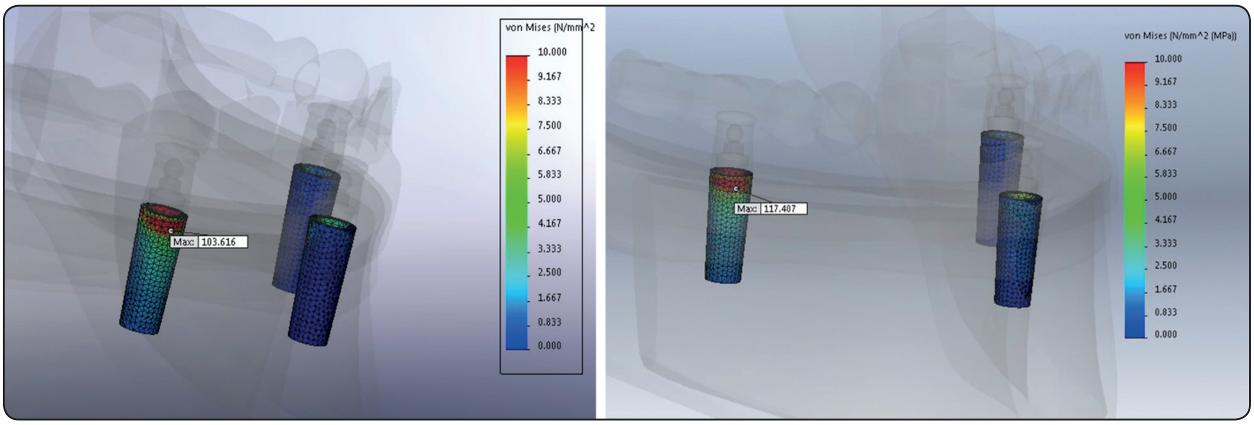

Fig. (2) Von Mises stresses in peri-implant bone under oblique load in D1 & D2

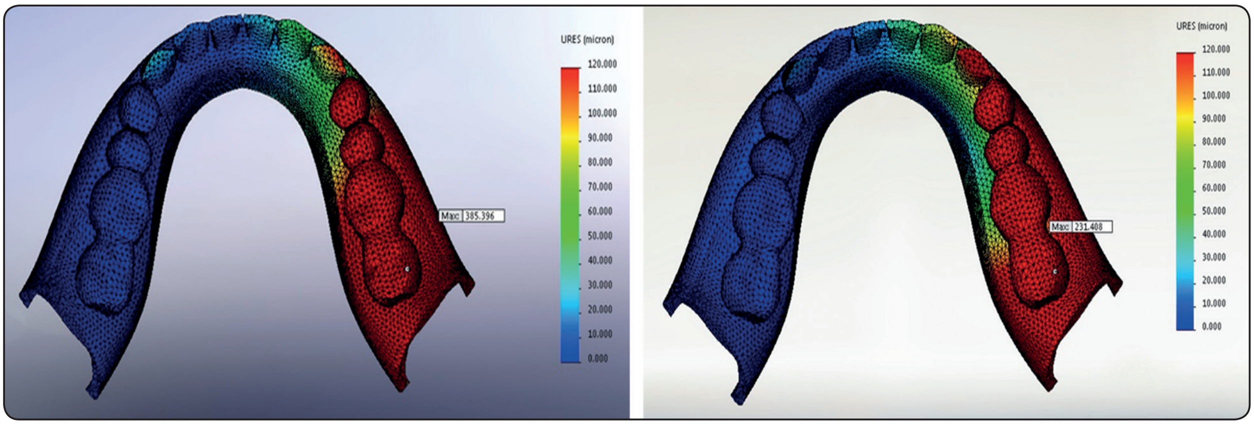

Fig. (3) Denture displacement under Oblique load in D1 and D2

DISCUSSION

The primary goal of the present study was to evaluate the biomechanical aspects of novel implant distribution used to support and retain mandibular overdentures and compare it with commonly used prosthodontic design. Overdenture displacement was also recorded and compared between the two designs. The proposed distribution involved a mid-symphyseal and bilateral posterior implants in the first molar region as opposed to conventional design with 3 interforaminal implants in the mid-symphyseal and canine region bilaterally.

Hinging mandibular overdentures retained by interforaminal implants result in denture rotation and posterior residual ridge resorption. The placement of posterior implants is suggested to favorably alter the biomechanical situation.[12] The analyses showed that with posterior implant placement, the denture displacement was significantly minimized and more of a load was shared with posterior implants. Physiological functional load transmitted to implants will have a positive effect on preservation of the residual alveolar ridge in vicinity of implants. [14] Furthermore, it is anticipated that in actual clinical situation, posterior spread of implants would improve the overdenture support, minimize hinging action of denture and modifies the Kennedy class I implant-and-mucosa supported overdentures to fully implant-supported Kennedy class III design.[12] Rotational movement of hinging mandibular overdenture compresses the mucosa underneath the denture base and influences the blood supply to underlying bone possibly leading to ridge resorption.[15, 16] Consequently, with the proposed prosthodontic design the expected distal ridge resorption and prosthodontic maintenance events will be minimized.[6] Relatively young, completely edentulous patients who could not afford a more sophisticated or fixed treatment option because of economical constraints were reluctantly managed with hinging implant overdentures for fear of posterior residual ridge resorption on prolonged use and can possibly be approached with such design.

Increased stresses recorded in implants in D2 are not clinically critical since mechanical properties of implant material can bear stresses of higher magnitude than those recorded in this analysis. Cp-Ti grade IV can bear stresses up to 500 MPa without irreversible deformation. Thus stress values of 54.6 MPa and 141.3 MPa recorded on posterior implants under vertical and oblique load respectively are unlikely to cause implant failure.

Potential Limitations of such proposed design would be anatomical and economical aspects. Completely edentulous patient usually experience posterior residual ridge resorption which may preclude posterior implant placement, nevertheless with the advancement in implant biomaterials and surface developments, short dental implants could be an option in the posterior region.

Areas of future research should evaluate patients' related outcomes of such a proposed design in terms of patients' satisfaction and functional activity. Improved denture support and decreased denture displacement can lead to a more psychologically satisfied patient and better masticatory efficiency.[17, 18] Nonetheless such assumptions should be validated first through clinical trials.

The limitations of FEA modeling technique used in this study should be mentioned. A condition of 100% osseointegration was assumed and static load was applied which does not represent the actual clinical situation. The physical structure of all materials modeled was simplified and considered to be homogenous, isotropic and linearly elastic which is not realistic. However, FEA technique is one of widely accepted mechanical tests which is used to provide a basic understanding of any clinical situation and aid in planning of further future in-vivo animal and human studies. [19]

CONCLUSIONS

Posterior implant placement resulted in improved denture support and minimal denture displacement on the expense of transferring extra load to the posterior implants. However, increased functional load on posterior implants is expected to have a positive effect on preservation of the residual alveolar ridge. D2 is an acceptable alternative prosthodontic design to D1 when anatomical and economical factors permit.

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