Implant-Retained Mandibular Bar-Supported Overlay Dentures: A Finite Element Stress Analysis of Four Different Bar Heights

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Proper stress distribution on dental implants is necessary in bar-retained implant overlay dentures. We aimed to comparatively assess this stress distribution according to different bar heights using finite element models. A three-dimensional (3D) computer model of mandible with 2 implants (ITI, 4.1 mm diameter and 12 mm length) in canine areas and an overlying implant-supported bar-retained overlay denture were simulated with 0-, 1-, 2-, and 3-mm bar heights using ABAQUS software. A vertical force was applied to the left first molar and gradually increased from 0 to 50 N. The resultant stress distribution was evaluated. Bars of 1 and 2 mm in height transferred the least stress to the implants (3.882 and 3.896 MPa, respectively). The 0-mm height of the bar connection transferred the highest stress value (4.277 MPa). The amount of stress transferred by 3-mm heights of the bar connection was greater than that of 1- and 2-mm bar connections and smaller than that of 0-mm bar connection (4.165 kgN). This 3D finite element analysis study suggested that the use of Dolder bar attachment with 1- and 2-mm heights could be associated with appropriate stress distribution for implant-retained overlay dentures.

Key Words: dental implants, dental stress analysis, dentures, finite element analysis, implant-supported dental prostheses, overlay dentures

INTRODUCTION

Dental implants have been used increasingly to replace missing teeth in partially and completely edentulous patients. The rationale of using dental implants is sometimes to improve retention of the prostheses.[1] Though prostheses fully supported by

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Figure 1. Noncontact measuring device (ATOS II).

implants are preferred, implant-retained overlay dentures are attractive treatment options because of their relative simplicity, minimal invasiveness, and affordability, especially for patients presenting persistent problems with conventional complete dentures.[2–5] The application of attachments improves the retention of implant-retained overlay dentures.[6] However, attachments transmit vertical and/or horizontal load to the supporting implants and consequently cause stress in the bone surrounding the implants.[7] Low levels of mechanical stress may lead to bone atrophy.[8] On the other hand, overload of an implant may result in marginal bone resorption, periodontal bone loss, pressure necrosis and, finally, failure of osseointegration.[8–10] Crestal bone loss and early implant failure after loading results most often from excess stress at the implant-bone interface.[11] Therefore, the design of implant-supported overlay dentures should ensure proper stress distribution to the bone around implants.[12,13]

Bar height is one of the influencing factors in the magnitude of the load transferred to the implants in bar-supported dental prostheses. The stress around dental implant systems is analyzed using several methods, including photoelastic study, finite element analysis (FEA), and strain gauges on bony surfaces. FEA offers several advantages over the other methods, including accurate representation of complex geometries, easy model modification, and the representation of the internal stress and other mechanical quantities.[14–21] The present study then used FEA to compare the stress magnitude and distribution around implant-retained, bar-supported overlay dentures with 4 different bar heights. The null hypothesis was that the stress distribution in bone around implants is similar in different bar heights of a given implant-supported, bar-retained overlay denture.

Materials and Methods

In this in vitro study, the whole mandibular body under a standard complete removable denture and its overlying overlay denture were simulated. Rami, gonial angles, condyles, and coronoid processes were not reproduced then. Transparent acrylic resin model of highly resorbed mandibular bone was used for simulation.

Two ITI cylindrical implants (Institute Straumann AG, Waldenburg, Switzerland), 4.1 mm in diameter and 12.0 mm in length, were placed in the region of the former hypothetical canines, perpendicular to the residual ridge in the transparent acrylic model. They were set 22 mm apart, similar to the mean natural distance between two natural canines.[22] Fixtures were held in place with a resin cement to further simulate osseointegration.

Overlay denture abutments were attached to the fixtures. ITI mini-titanium Dolder bar with spacer and ITI mini-titanium bar matrix (Institute Straumann AG) were used. The connecting bar was horizontally set parallel to the plane of occlusion and aligned perpendicular to a line bisecting the angle between the posterior edentulous ridges to allow rotation of the prosthesis.[23,24] A bar-supported overlay denture was then prepared on the model. The three-dimensional (3D) geometry of the whole system was digitized by a noncontact, highly accurate mobile ATOS system (ATOS II, GOM, Germany) (Figure 1), and the resultant dense points cloud was transferred to CATIA modeling software (BM, Kingstone, NY).

The modeling process was performed (Figure 2), and digitized 3D models with 4

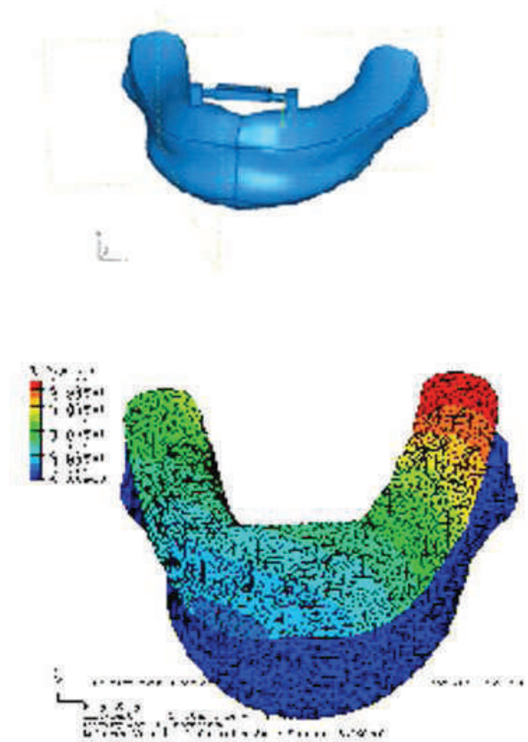


Figure 2. Three-dimensional model of mandible and mandible plus prosthesis (for 2-mm bar height).

different bar heights (0, 1, 2, and 3 mm between mucosa and inferior border of the bar) were transferred to ABAQUS FEA software (Hibbitt, Karlsson & Sorensen Inc, Plymouth, Mich) in the form of an STP file. The corresponding elastic properties such as Young's modulus and Poisson ratio were determined based on the literature[25,26] and assigned to the different layers of the simulated denture-mandible complex (Table).

In total, the model consisted of 31 082 trilateral elements with 96 635 nodes. The analysis was performed on a Pentium IV 2400 computer with 256 MB RAM (Toshiba Information Equipment, Manila, Philippines).

The support of the finite element model was provided by a mandible base, which was made of cortical bone. A moderate level of biting force on an implant-retained overlay denture was simulated. An increasing loading was simulated from 0.1 to 50 N on the artificial first molars. Load was applied first vertically and then obliquely (mastication was simulated). Stress levels were calculated for each model according to von Mises yield criterion, which states that a given material starts to yield when stress reaches a critical value. The von Mises stress is used to predict yielding of materials under any loading condition from results of simple uniaxial tensile tests.[15,27]

Results

It was found that crestal bone bears the highest stress levels compared to other areas. Based on this observation, authors decided to focus on crestal bone in the present study.

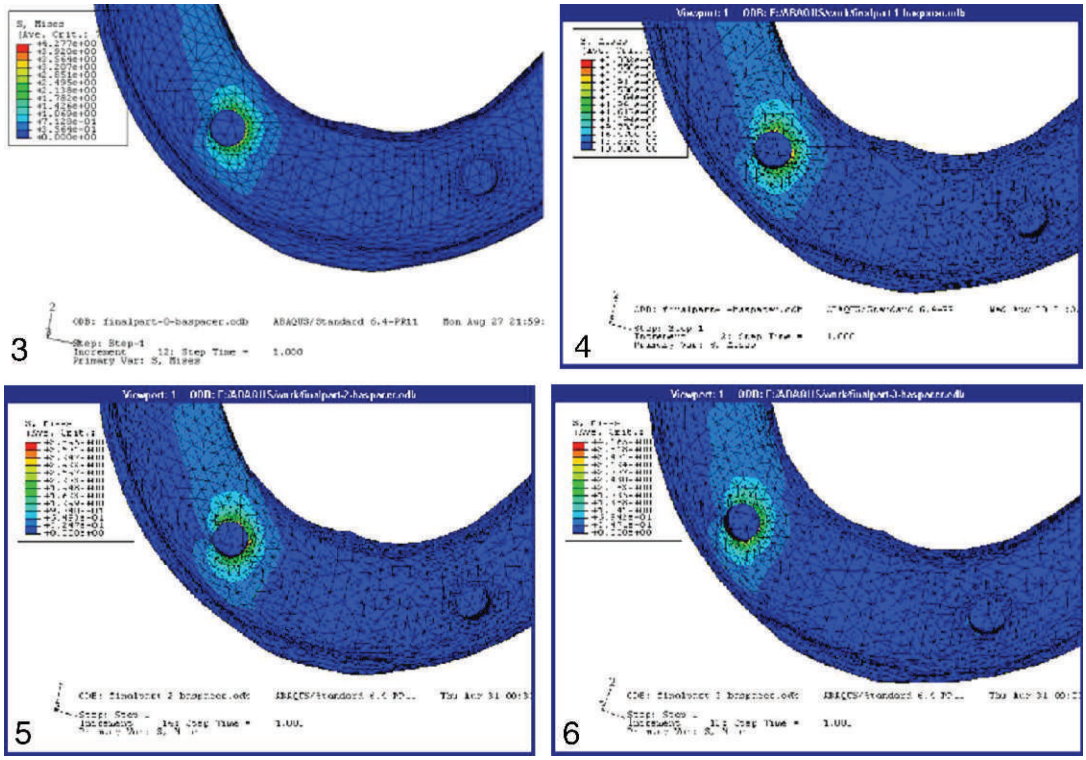
Stress distribution for 0-mm bar height (bar in contact to tissue)

The maximum stress associated with the application of 0.01 N load was equal to 3.338×10^{-1} kgN observed in the mesial crestal area of the contralateral fixture. The area of maximum stress (AMS) remained at the mesial crestal of the contralateral fixture until the application of 7.5 N load by which the stress reached 6.937×10^{-1}

Table

Material properties used for the precise simulation of the finite element analysis model

Material	Young's Modulus (E)	Poisson Ratio (ν)
Titanium fixture/bar/abutment	115×10^3	0.35
Cortical bone	13.7×10^3	0.30
Medullar bone	7.930×10^3	0.30
Mucosa	0.345×10^3	0.30
Prosthesis	2.65×10^3	0.24



Figures 3–6. Figure 3. Stress distribution pattern in the ipsilateral implant due to the exertion of 50 N force under 0-mm bar height. **Figure 4.** Stress distribution pattern in the ipsilateral implant due to the exertion of 50 N force under 1-mm bar height. **Figure 5.** Stress distribution pattern in the ipsilateral implant due to the exertion of 50 N force under 2-mm bar height. **Figure 6.** Stress distribution pattern in the ipsilateral implant due to the exertion of 50 N force under 3-mm bar height.

kgN. Afterwards, the AMS was transferred to the mesiolabial crestal of the ipsilateral fixture and remained there with load increase. The maximum stress around the implant with 50 N load was equal to 4.277 kgN within the mesiolabial crestal area of the ipsilateral fixture (Figure 3).

Stress distribution for 1-mm bar height

The maximum stress around the implant with 0.01 N load was equal to 2.400×10^{-1} kgN and was observed in the mesial crestal area of the contralateral fixture. The AMS remained at the mesial crestal until the application of 7.5 N load by which the stress reached 5.347×10^{-1} kgN. Afterwards, the AMS was transferred to the mesiolingual crestal of the ipsilateral fixture and remained there with load increase. The maximum stress around the implant with 50 N load was equal to 3.882 kgN, and the AMS included the mesial crestal and the lingual crestal areas of the ipsilateral fixture (Figure 4).

Stress distribution for 2-mm bar height

The maximum stress around the implant with 0.01 N load was equal to 1.83×10^{-1} kgN and was observed in the mesial crestal area of the contralateral fixture. The maximum stress around the implant with 6.06 N load was equal to 4.316×10^{-1} kgN in the same area. The AMS was then transferred to the mesiolingual crestal of the ipsilateral fixture and remained there with load increase. The maximum stress around the implant with 50 N load was equal to 3.896 kgN, and the AMS included the mesial crestal and the lingual crestal areas of the ipsilateral fixture (Figure 5).

Stress distribution for 3-mm bar height

The maximum stress around the implant with 0.01 N load was equal to 2.87×10^{-1}

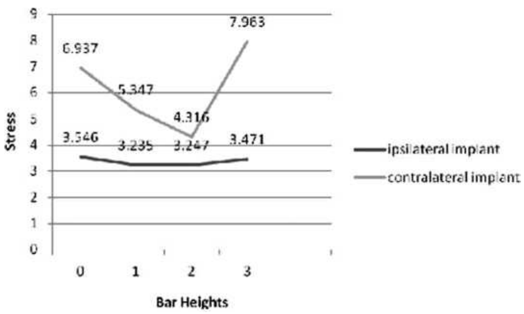


Figure 7. Maximum stress values for ipsilateral and contralateral fixtures according to the different bar heights. Though contralateral values are in the minuses, they are illustrated above the X-axis for the ease of comparison and also to save space.

kgN and was observed in the mesial crestal area of the contralateral fixture. The maximum stress around the implant with 7.5 N load was equal to 7.963×10^{-1} kgN in the same area. The AMS was then transferred to the mesiolabial crestal area of the ipsilateral fixture and remained there with load increase. The maximum stress around the implant with 50 N load was equal to 4.165 kgN (Figure 6).

Discussion

The null hypothesis was rejected since bar height significantly influenced the stress distribution pattern in the bone surrounding the fixtures. The highest and the lowest stress values were respectively associated with 0-mm bar height and 1- and 2-mm bar height. While the correlation of overload to implant failure has been well established,[8–11] the precise relationship between bar heights and stress distribution is not adequately understood. In the present study, an implant-retained mandibular model was developed to evaluate the effect of different bar heights by means of FEA. To the best of our knowledge, there are no similar studies reported in the literature.

El-Sheikh and Hobkirk[12] examined the effect of superstructure design on force transmission in two implant-retained over dentures and concluded that the retentive design when no clips have been placed on the distal cantilevers will be associated with significantly decreased stress on the implants.

Meijer et al[8] in a FEA study evaluated stresses around dental implants in mandibular overdenture with and without bar attachment. They concluded that differences in stress concentration between the models with and without bar were small, and direction of the bite force had much more influence.

Menicucci et al[21] used a three-dimensioned FEA model to comparatively assess the stress level in peri-implant bone in implant-retained bar and clip bar-supported overlay dentures. The stress in peri-implant bone was lower with the application of ball attachments than that of the bar-supported overlay dentures.

In the current study, 3D FEA was used. Three-dimensional FEA is thought to be a good representative of stress behavior in supporting bony anatomies.[15] The FEA model created in this study was a multilayered complex structure involving mucosa, cortical bone, and cancellous bone. It is important to note that the stress distribution may be influenced greatly by the materials and properties assigned to each layer. Computer modeling offers many advantages over other methods in considering the complexities that characterize clinical situations. It should be noted that these studies are extremely sensitive to the assumptions made regarding model parameters, such as loading conditions, boundary conditions, and material properties.[10]

When applying FEA to dental implants, it is important to consider a combined load of axial and horizontal because it represents more realistic occlusal direction. Therefore, in the present study, load was applied to the imaginary central fossa of the first molar.

In the present study, the least amount of stress was associated with bar heights of 1 and 2 mm, and the maximum stress values were recorded for 0-mm bar heights. Authors think this might be attributed to the two types of class I lever. In the type I, the crestal area of the implant serves as a pivot point, and the bar serves as the moment arm. In the type II, abutments (bar height) serve as resistance arm, and the bar serves as fulcrum. In 1- and 2-mm heights of the bar, the resultant force produced by the two lever types is seemingly the lowest.

In a vertical dimension, the bar should be more than 2 mm away from the soft tissue to provide easy access for hygiene.[11] Although bone is not an isotropic material, the bony structures in the model were assumed to be homogenous and isotropic with linear elasticity. These were the limitations of the present study. Comparing qualitative results from this study and other 3D FEA studies reveals that if a fixed bond between implant and bone is assumed, then extreme stresses are found in the crestal region around the neck of the implant.[7,9–11] To reduce high stress peaks, attention must be paid to the direction of the bite force; but while the direction of the bite force cannot be changed, the magnitude can be influenced by the design of the overdenture.

It is not yet possible to make reliable clinical conclusions based on the FEA assessments within the implant literature. Results of the present study may contribute to further interpret the findings from future retrospective or prospective clinical and radiologic studies.

Conclusions

Within the limitations of this study the following conclusions may be made: (1) Biomechanically, a 1- to 2-mm bar height from the mandible may be associated with the best stress distribution pattern in implant-retained bar-supported overlay dentures. (2) Biologically, a 2-mm bar height from the mandible seems to be the best when implant-retained bar-supported overlay dentures are being fabricated.

Abbreviations

3D: three-dimensional
AMS: area of maximum stress
FEA: finite element analysis

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