3D FINITE ELEMENTS ANALYSIS OF STRESS DISTRIBUTION ON THE POSTERIOR TILTED IMPLANTS ON ALL ON 4 CONCEPT

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ABSTRACT

Objective: The purpose of this study was to evaluate the stress distribution of fixed implant-supported prostheses using “all-on-four” concept for the treatment of mandibular completely edentulous ridge “in vitro study” by 3D finite elements analysis.

Materials and Methods: The finite element model components as the overdenture, mucosa, implants, angled base, abutment, cortical and cancellous bones were created in “Autodesk Inventor, then exported as SAT files. These components were assembled in ANSYS environment. The model was subjected to two loading conditions of 200N, vertically unilateral and, vertically bilateral at molar regions respectively.

Results: All values of deformations and stresses appeared on the model components (overdenture, implants, angled base, abutment, cortical and cancellous bones) were within physiological limits under all loads application.

Conclusion: Tilted implants at molar area did not affect the system behavior (did not show peak of stresses or deformation) and all values of deformations and stresses that appeared on the model parts (cortical, spongy bone, implant, base, abutment, and overdenture) were within physiological limits under all cases of load application.

KEYWORDS: all-on-four, stress distribution, finite elements, tilted implants.

INTRODUCTION

Use of conventional complete dentures is associated with several problems, such as insufficient of denture stability, support and retention. These problems lead to discomfort, reduction in chewing ability and, at times, may be socially embarrassing(1).

The osseointegrated implants introduced new methods for treating these patients. The implant supported overdenture are recommend to overcome these drawbacks mainly in mandibular removable dentures. These prostheses have many advantages including good stability, good retention, improve function, esthetic and reduce residual ridge resorption(2).

Biomechanical studies had showed that the implants overload is the main factor responsible for bone resorption, as functional loads are distributed directly to the bone. The excess of functional loads produces stresses that are receded from the retention system to fixtures and supporting structures, and the severity and extent of bone resorption is detected by the transmission and distribution mechanism of each retention system(2).

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The methodology of using titled implants maximizing the use of the sufficient bone without grafting has been reported, leading to successful clinical outcomes\(^3\text{-}^5\). As compared as the traditional implant treatment in which inadequate bone in the posterior area requires bone-grafting procedures involving greater chair time for the patient in addition to increasing cost and number of procedures.

It is approved that the two implant over denture is not the gold criterion of implant therapy, it is the minimum criterion that should be adequate for most people, taking in account achievement patient gratification, cost and clinical time \(^6\).

All-on-Four concept is a treatment modality to avoid unfavorable posterior areas is the use of inclined implants to allow for a preferable anteroposterior spread of dental implants. Thus, four implants are placed axially in the anterior region of edentulous jaw, while the posterior implants are inclined distally to maximize implant length and avoid vital structures \(^7\).

Variety of techniques and methods have been employed for assessing and analyzing the stresses transmitted through fixed implant-supported prostheses designs to their abutments and supporting structures. Finite elements analysis (FEA) is a numerical method of analysis for stresses and deformations in structures of any given geometry. The structure is modeled and then discretized into smaller and simpler domains called "finite elements". These elements are connected together through nodes forming a meshwork. Boundary conditions, Materials properties and loads are assigned and then the calculations are made to come up with the results. The type, arrangement and total number of elements affect the accuracy of the results. Finite element analysis (FEA) has been used widely to portend the biomechanical interpretation of different dental implant designs as well as the effect of clinical factors on the success of implantation. As more in-depth understanding of stress profiles encountered by the implant, and more importantly in the surrounding jawbone, could be gained through the use of finite element method (FEM) \(^8\).

**MATERIALS AND METHODS**

Anterior implants were positioned at canine area parallel to each other and perpendicular to occlusal plane. Distal implants were positioned at first molar, also distal implants were inclined distally to form a 30-degree angle to the occlusal plane \(^9\).

The model was virtually planned with On-Demand 3D software to define the sites for implant application.

**Implant installation**

*On the planned virtual model:* Four threaded titanium dental implants (Dentium NR line Inc, Korea), the root form of dental implant had a nominal platform diameter of 3.2 mm, a length of 11 mm and the shape connection of internal 10° conical with body diameter 3.1 mm \(^{10}\).

**Geometric Model:** The 3D FEA model components as the overdenture, mucosa, implants, angled base, abutment, cortical and cancellous bones were created in “Autodesk Inventor” Version 8 (Autodesk Inc., San Rafael, CA, USA), then exported as (Standard ACIS Text) SAT files. These parts were assembled in ANSYS environment (ANSYS Inc., Canonsburg, PA, USA). The design of the implant was taken from the manufacturer data. The system analyzed in this investigation and formed of the available root form threaded titanium dental implant (Dentium NR line Inc, Korea) and angled base. The root form of dental implant had a nominal diameter of 3.1 mm and length of 11 mm (Implant GFX 30 11 S, Platform 3.2).

The simulated peri-implant bone involved an inner layer representing spongy bone was of 22 mm length and 14 mm width covered by an outer thin layer of cortical bone of 2 mm thickness. The simulated...
covering mucosal layer was of 2 mm thickness\(^{(11,12)}\). All parts of implant complex, mandible and their assembly are appeared on Inventor screen. All these parts in addition to the fixture and abutment were exported from Inventor as SAT files \(^{(13)}\). Then set of Boolean operations were accomplished to assemble all the model parts before meshing.

All materials to be used in this study were supposed to be isotropic, homogenous and linearly elastic and its properties are listed in Table 1.

**TABLE (1)** Material properties of used in the finite element model.

<table>
<thead>
<tr>
<th>Material</th>
<th>Young's Modulus [MPa]</th>
<th>Modulus Ratio</th>
<th>Poisson’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical (^{(11)})</td>
<td>13,700</td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>Cancellous (^{(11)})</td>
<td>1,370</td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>Implant – abutment – (Ti) (^{(14)})</td>
<td>110,000 (Per ASTM E8-04)</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>Mucosa (^{(15)})</td>
<td>10</td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>Overdenture (^{(16)})</td>
<td>2,700</td>
<td></td>
<td>0.35</td>
</tr>
</tbody>
</table>

**Meshing:** Set of Boolean operations between the modeled components were performed before getting the complete model assembled. The meshing of these parts was done by 3D solid element (SOLID187) which has three degrees of freedom (translation in main axes directions) \(^{(15)}\).

**Loads and boundary conditions:** The model was subjected to two loading conditions as 200 N at first molar (Unilateral Vertical), and 200 N at first molar (Bilateral vertical), the model was investigated after each loading condition. The lowest plane of the model was considered fixed in the three dimensions as a boundary condition.

The model was proved against similar studies\(^{(12,13)}\) and showed very good result. The Linear static analysis was performed on a Workstation HP Z820 (Dual processors, 2.1 GHz, 32 GB RAM), using a commercial multifunctional finite element software package (ANSYS version 16.0).

**RESULTS**

Two loading conditions were analyzed as follows;

1. Uni L6 - V200
2. Bi L6 - V200

All model components (the overdenture, mucosa, implants, angled base, abutment, cortical and spongy bones) were demonstrated in each run (case study). The model parts results were taken as screen shots from ANSYS. The definition of most important results obtained and demonstrated shown below as follows;

- \( S_t \): Max tensile stress
- \( S_{int} \): Max Stress Intensity (shear indicator)
- \( S_{von} \): Von Mises (Equivalent) stress

**1- First molar (Unilateral Vertical)**

The Equivalent stress distribution computed for the overdenture evaluated under unilateral vertical load were 3.019 MPa. The maximum stress intensity of overdenture and mucosa appeared on lingual surface at first molar implant. The maximum shear stress of abutment, cortical and cancellous bone appeared on mesiolingual surface of first molar implant while in implant appeared on occlusally (Fig.1) and Table (2).

![FIG (1) Overdenture result, the maximum stress intensity appeared on lingual surface at first molar implant.](image-url)
TABLE (2) $S_{von}$, $S_1$ and $S_{int}$ result of Unilateral Vertical load 200 N at First molar

<table>
<thead>
<tr>
<th>Model components</th>
<th>First molar (Unilateral Vertical) 200 N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S_{von}$:  $S_1$:  $S_{int}$:</td>
</tr>
<tr>
<td>Overdenture</td>
<td>3.01923:  3.83353:  3.45453:</td>
</tr>
<tr>
<td>Implants</td>
<td>6.68657:  2.56641:  7.41907:</td>
</tr>
<tr>
<td>Abutment</td>
<td>44.5922:  13.9544:  46.9865:</td>
</tr>
<tr>
<td>Angled base</td>
<td>44.5922:  13.9544:  46.9865:</td>
</tr>
<tr>
<td>Mucosa</td>
<td>9.66059:  7.33823:  10.2673:</td>
</tr>
<tr>
<td>Cortical bones</td>
<td>6.80554:  2.73361:  7.22124:</td>
</tr>
<tr>
<td>Cancellous bones</td>
<td>0.570417: 0.328891: 0.629773:</td>
</tr>
</tbody>
</table>

The equivalent stress distribution computed for the abutment evaluated under unilateral vertical load was within the physiological limit (44.5922 MPa) which was < 0.3-0.5 % of Young’s Modulus of abutment (110,000 MPa).

2- First molar (Bilateral Vertical)

The Equivalent stress distribution computed for the mucosa evaluated under bilateral vertical load were 11.412 MPa. The maximum Equivalent stress of overdenture, cortical and spongy bone appeared mesiobuccal surface of first molar implant. The maximum Equivalent stress of abutment appeared mesial side on top of angled base at first molar implant and in mucosa appeared crestally, while in implant appeared lingually. (fig.2) and table 3.

FIG (2) Mucosa result: the maximum tensile stress appeared at the crest of first molar implant

TABLE (3) $S_{von}$, $S_1$ and $S_{int}$ result of Bilateral Vertical load 200 N at First molar

<table>
<thead>
<tr>
<th>Model components</th>
<th>First molar (Bilateral Vertical) 200 N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S_{von}$:  $S_1$:  $S_{int}$:</td>
</tr>
<tr>
<td>Overdenture</td>
<td>3.10709:  4.06993:  3.57946:</td>
</tr>
<tr>
<td>Implants</td>
<td>9.47198:  2.96867:  10.8456:</td>
</tr>
<tr>
<td>Abutment</td>
<td>44.0273:  13.7582:  46.3648:</td>
</tr>
<tr>
<td>Angled base</td>
<td>44.0273:  13.7582:  46.3648:</td>
</tr>
<tr>
<td>Mucosa</td>
<td>11.4126:  9.41379:  12.0744:</td>
</tr>
<tr>
<td>Cortical bones</td>
<td>10.2534:  10.6889:  10.8477:</td>
</tr>
<tr>
<td>Cancellous bones</td>
<td>0.574631: 0.47783: 0.634146:</td>
</tr>
</tbody>
</table>

The equivalent stress distribution computed for the overdenture evaluated under bilateral vertical load was within the physiological limit (3.10709 MPa) which was <0.3-0.5% of Young’s Modulus of overdenture (2,700 MPa).

The equivalent stress distribution computed for the mucosa evaluated under unilateral and bilateral vertical load was not within the physiological limit (9.66059 MPa) and (11.412 MPa) respectively which was > 0.3-0.5 % of Young’s Modulus of mucosa (10 MPa).

All values of deformations and stresses that appeared on the model parts (cortical, spongy bone, implant, base, abutment, and overdenture) were within physiological limits under the two cases of load application.

DISCUSSION

The all on-four treatment concept appears as a trial to allow treatment with adequate time and cost through immediate implant-supported prosthesis, providing relatively the most simple and predictable treatment in edentulous patients with atrophic jaws(15, 16).

The all-on-four protocol is developed by Dr. Paulo Maló, 4 implants, modifying the angulations of the two most distal to the midline, the all-on-
four technique is a system that allows complete rehabilitation with maxillary and/or mandibular fixtures in the edentulous patient. This technique can be applied in a high percentage of cases with success rates above 95% (17, 18).

In this study short and narrow implants were placed in the model, this concept is an alternative prosthetic option for atrophic ridge which may provide several surgical advantages including reduced treatment time and costs and less skill necessary to perform the surgical intervention, less morbidity by avoiding more extensive bone augmentation procedures, easier removal in case of failure, and predominantly, an increased number of sites available for implant therapy (10). To improve the surface area for osseointegration, threaded implants are generally preferred to smooth cylindrical ones. So threaded implants were selected in this study (19).

The present report used 3D models to assess the stress distribution in implant-retained overdentures. The models of this study were allowed to evaluating the stress distribution on buccal, lingual, mesial and distal implants areas.

In this condition CAD/CAM software” AutoDesk Inventor version 8.0 “is used in drawing the models with specific heights and width measured from the constructed model as these parts were exported as SAT file then imported into the finite element analysis used. The latter has been usually used for 3D modeling as it allows the fulfillment of reliable analytic or free form parts depending on an efficient management of curves and surfaces (20).

The different loading conditions that were mentioned in this study were according to other investigators, 3D finite element models of a 3-unit cantilever bridge were subjected to 150 N occlusal load to assessed two different superstructure materials and two several implant designs, To assess the distribution of stresses within the bone surrounding the implants, 3-dimensional finite element analysis was conducted using four mathematical models of unilateral 3-unit cantilever fixed partial dentures supported by two implants (21).

In this study, loads will apply on the occlusal aspects of the superstructure to simulate real masticatory movements, but with a FEA, precise calculations cannot be made, because there is great variation in the magnitude of the mechanical factors for bone, and in addition, masticatory movements and their magnitude vary enormously between the individuals.

Theoretically, the problem of predicting loads on the fixtures is a statistically indeterminate problem in mechanics. In most cases occlusal loads lie between 50 N and 2400 N. Furthermore, the masticatory loads are dynamic and oblique relative to occlusal aspects of the fixtures. However, in this study a 200 N vertical Unilateral and Bilateral loads were used. Simulating such a loading condition can be assumed as a realistic masticatory pattern.

The result was in harmony with Maló et al. (22) who reported with excellent prognosis with percentage 97.2% and 100% for the mandible in a 1-year prospective study when 92 Nobel-Speedy implants were placed in 23 sequentially treated patients, also it was in agreement with Balshi et al. (23) who conducted a retrospective study (up to 6 years follow-up) of 152 patients with 200 arches rehabilitated with 800 implants using the all on-four treatment concept and reported a progressive implant success rate of 97.8% for the mandible.

Monje et al. (24) in a meta-analysis investigating if we compare between cervical bone resorption surrounding the tilted and straight implants, we find no importance difference in weighted mean cervical bone resorption between tilted and straight fixtures in the short and medium terms.

Also result of this study are in accord with retrospective studies (25, 26) based on biomechanical properties, which demonstrated that tilted implants, have a good clinical outcomes on the load distribution. In addition, a biomechanical
rationale in tilting distal implants allows decreasing in cantilever length because of the more posterior location of the tilted implants, leading to a more appropriate stress distribution\textsuperscript{25,27}.

The finite element modeling technique used in this study has some limitation during the reaction of biologic systems to applied loads, as do all modeling systems, including photoelastic analysis and strain gauges measurement. However, the sum of this report may provide a broader understanding about the potential stress concentration locations.

This report suggests long-term clinical research to assessed the effect of the observed stress levels on the surrounding structures and implants\textsuperscript{28}.

CONCLUSION

Within the limitations of this study, the following conclusion can be drawn:

- All values of deformations and stresses that appeared on the model parts (cortical, spongy bone, implant, base, abutment, and overdenture) were within physiological limits under all cases of load application.

- Tilted implants at molar area had no significance the system behavior (did not show peak of stresses or deformation).

REFERENCES


3. Pomares C. A retrospective clinical study of edentulous patients rehabilitated according to the ‘all on four’ or the ‘all on six’ immediate function concept. Eur J Oral Implantol. 2009;2(1):55-60.


