Analysis of Stresses Induced in Mandibular Bone as a Result of Occlusal Forces Applied on Implant Supported Overdenture with Different Teeth Inclinations (Three Dimensional Finite Element Analysis)

SARA Z. MOHAMMED, M.Sc.; MOATAZ M.B. EL MAHDY, Ph.D.; SAYED M.M. EL MASRY, Ph.D. and MOHAMED E. EL SAYED, Ph.D.
The Department of Prosthodontics, Faculty of Dentistry, Suez Canal University

Abstract
Use of implant as overdenture abutments has become part of accepted clinical practice and control of occlusal forces applied on dental implant is an important factor in implant success.

Aim: This study aimed to identify and compare the effect of vertical and oblique occlusal loads applied on posterior flat teeth of mandibular implant supported overdenture at different inclinations using flat teeth with Finite Element Analysis applied.

Material and Methods: Three models of lower implants supported overdenture with different posterior teeth inclination were drawn (first model with zero tilt, second with inward inclination and the third model with outward inclination) stress analysis using finite element analysis (FEA) was done for the three models.

Result: The model with the outward inclination of the posterior teeth achieved the least values of stresses while the model with the zero tilt inclination achieved the highest values.

Conclusion: Arranging posterior teeth with outward inclination reduce the stresses in certain cases.

Key Words: Finite element analysis (FEA) – Posterior flat teeth – Mandibular implant – Teeth inclinations.

Introduction
OVERDENTURE help partially to overcome many of the problems caused by conventional complete dentures like progressive bone loss, poor stability and retention, loss of periodontal proprioception and low masticatory efficiency [1].

Success of different removable prosthesis depends partially on occlusion which plays a major role in the effectiveness and longevity of the prosthesis. With dentures, the quantity and intensity of contacts determine the amount and the direction of forces that are transmitted through the bases of the denture to the residual ridges [2], that is why the occlusal scheme is an important factor in the design of complete dentures. The extrapolation of occlusal concepts from natural teeth to dental implants has been an unavoidable progression simply because no alternative, scientific, or empirical theory has been put forward. In short, occlusion for dental implant supported or retained restorations has largely been an extension of natural tooth occlusion and/or complete denture occlusion with a few twists [3]. Finite Element Analysis has been viewed as the most suitable tool to measure occlusal stresses mathematically, model by numerous scholars [4]. There is a consensus that the location and magnitude of occlusal forces affect the quality and quantity of induced strains and stresses in all components of the bone implant prosthesis complex [5]. FEA method allows predicating stress distribution in the contact area of the implants with cortical bone and around the apex of the implants in trabecular bone [6].

Material and Methods
For constructions of this model a volunteer patient was selected to undergo a C.T scanning. This patient was male, 40 years old with no developmental abnormalities, no gross defects, no previous surgery (to avoid defects) and completely
healed sockets after extraction this was done on June 2011. An edentulous mandible was restored with implant supported overdenture retained by two implants placed in the interforaminal region and was C.T scanned. Three mathematical models were created with the following differences: first model with zero tilt inclination of posterior teeth, second model with inward teeth inclination and third model with outward teeth inclination, each model was subjected to vertical and oblique load.

Steps of construction:

1- Getting the geometrical outline using CT scanning in Ismailia General Hospital, 2- Editing and preparing the CT cuts, 3- Three dimensional drawing of the model components (Fig. A), 4- Assembling of the three dimensional components (Fig. B), 5- Defining the material properties for each component, 6- Defining contacts and gaps between components, 7- Defining model fixture and restrain for each model (Fig. C), 8- Defining loads applied on each model, 9- Meshing the models (Fig. D), 10- Running the analysis, 11- Collection of results.

For each model two different loads were applied. Each load was applied on a separate study: Group 1 load: Unilateral vertical load (100 N per item) on the central fossae of premolars and molars on the right side.

Group 2 load: Oblique load (100 N per item) on the lingual inclines of the buccal cusps of premolars and molars on the right side. And oblique load (100 N per item) on the buccal inclines of the lingual cusps of premolars and molars on the right side.

Fig. (A,B): Steps of drawing the different parts of the denture model. Fig. (C): Fixation of the model. Fig. (D): Meshing of the model.
Results

In this study the effect of the different inclination of the flat posterior teeth undertwo sets of loads (vertical and oblique).

Tables (1,2) show the von misses stress value under oblique load at implant; molar area and denture bearing area maximum values were recorded in the zero tilt model.

Tables (3,4) show the von misses values under vertical load at implant, molar area and denture bearing area on both working and non working side maximum values were recorded in the zero tilt model.
### Table (1): Working side of the model under oblique load.

<table>
<thead>
<tr>
<th></th>
<th>Buccal inclination</th>
<th>Lingual inclination</th>
<th>Zero tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implant avg</td>
<td>4.8856mPa</td>
<td>12.713mPa</td>
<td>186.83mPa</td>
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<tr>
<td>Molar area avg</td>
<td>3.314mPa</td>
<td>2.254mPa</td>
<td>8.3919mPa</td>
</tr>
<tr>
<td>Denture bearing area avg</td>
<td>4.9436mPa</td>
<td>9.9185mPa</td>
<td>60.47mPa</td>
</tr>
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</table>

### Table (2): Non working side of the model under oblique load.

<table>
<thead>
<tr>
<th></th>
<th>Buccal inclination</th>
<th>Lingual inclination</th>
<th>Zero tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implant avg</td>
<td>6.95mPa</td>
<td>14.495mPa</td>
<td>182.07mPa</td>
</tr>
<tr>
<td>Molar area avg</td>
<td>2.14mPa</td>
<td>9.8576mPa</td>
<td>33.05mPa</td>
</tr>
<tr>
<td>Denture bearing area avg</td>
<td>5.72mPa</td>
<td>14.5mPa</td>
<td>27.23mPa</td>
</tr>
</tbody>
</table>

### Table (3): Loading sideworking side of the model under vertical load.

<table>
<thead>
<tr>
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<th>Buccal inclination</th>
<th>Lingual inclination</th>
<th>Zero tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implant avg</td>
<td>1.6408mPa</td>
<td>35.166mPa</td>
<td>48.674mPa</td>
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<tr>
<td>Molar area avg</td>
<td>6.91mPa</td>
<td>33.88mPa</td>
<td>66.46mPa</td>
</tr>
<tr>
<td>Denture bearing area avg</td>
<td>16.32mPa</td>
<td>60.29mPa</td>
<td>120.29mPa</td>
</tr>
</tbody>
</table>

### Table (4): Non working side loading side of the model under vertical load.

<table>
<thead>
<tr>
<th></th>
<th>Buccal inclination</th>
<th>Lingual inclination</th>
<th>Zero tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implant avg</td>
<td>6.95mPa</td>
<td>14.50mPa</td>
<td>182.27mPa</td>
</tr>
<tr>
<td>Molar area avg</td>
<td>3.05mPa</td>
<td>3.10mPa</td>
<td>12.90mPa</td>
</tr>
<tr>
<td>Denture bearing area avg</td>
<td>4.07mPa</td>
<td>28.87mPa</td>
<td>49.07mPa</td>
</tr>
</tbody>
</table>

### Discussion

Using three dimensional finite element stress analysis (3D FEA) has been introduced as it is proved to be a superior theoretical tool over dimensional finite element stress analysis [7].

Results of 3D FEA were compared with in vivo strain gauge (SGA) measurements and within vitro experimental measurements in tendency there was a high level of agreement regarding the quality of strains, as determined by both techniques, although the mean values obtained with Ex vivo SGA (EV-SGA) were higher than those found with nonlinear FEA (NL-FEA). However, the strains recorded by NL-FEA did not differ significantly \(p < .05\) from the strains recorded by EV-SGA. So the 3D FEA is considered an appropriate method for investigation of stress throughout a three dimensional structure, and it was selected for bone stress evaluation in this study [8].

The implant positions planned in used model were selected according to the strategy by Misch [9]. The same implant was used in all models. The length and diameter is selected to suit the bone height and thickness in the model of designed mandible. The location and number of implants to support overdenture is of a major importance for superstructure design. Utilization of two implants has been demonstrated in many numerous long term studies worldwide to be clinically successful, economically advantageous to the patient and structurally sufficient to retain an overdenture. Implants in the anterior mandible should be placed in the canine or lateral position. Implants positioned in this slightly more anterior position to reduce tendency for denture to rotate around the fulcrum provided by the denture, as The denture base may lift when the patient incises anteriorly if implants are placed too far distally [10].

Almost all of the elastic properties of selected living and non-living materials are available in the literature [11]. Young’s modulus and Poisson’s ratio are used in models to simulate reality as closely as possible. For example, alveolar bone (both cortical and cancellous portions), implant, denture base can be included in the model properties.

**Load magnitude:** The influence of force on peri-implant stress was investigated [12]. In varied models, 100 N forces were applied vertically and separately to the central fosse of posterior teeth. In another study loading was simulated by applying an oblique load (vertical load of 100 N and horizontal load of 20 N) from buccal to palatal region at 4 different locations [13]. In this study the opposing is assumed to be a complete denture and The occlusal load on implant-supported mandibular overdenture was selected to be 100 N.

**Load direction:** Because the load was used is static it was essential to test the effect of both vertical and oblique load to achieve more realistic modeling. In this study vertical load and oblique loads as naturally in vivo the occlusal forces exerted on an abutment (tooth or implant) Vary in direction and magnitude the largest forces occur along the axial direction while the lateral component of the occlusal force is significantly smaller [14].
**Under vertical load:** Under vertical load the first model (zero tilt model) showed the highest value of stress concentration than the second model (lingua inclination model) and the third model (buccal inclination model), as a rule bone resorption results in an overall reduction of the bone-implant interface raising the bone stresses all over the interface and consequently the maximum stress. According to previous studies of Brunski et al. and Eskitascioglu et al., this result is strongly influenced by occlusal contact, and cusp inclination increases the stress on the implant and related components [15,16].

**Under oblique load:** Under oblique load the third model (zero tilt model) showed the highest value of Von Misses stress concentration than first and second model. The maximum stresses was found to be at the stresses are located buccolingually around the implant neck increased with the progression depth, stress concentration in the cortical bone occurred mainly at precrestal bone and the neck of the implant corroborating the results of Pleasure’s FEA studies evaluating the stress in implants modeled with or without framework while Papavasiliou et al., studies noted that lateral or inclined forces applied to an implant produce maximum stress at the neck of the implant or at the level of the third screw and crestal bone [17,18]. Naturally stresses around the implant was not only caused by the flexure of the bone due to movement of the implant interface relative to the surrounding bone but also by the bending of the mandible due to muscular forces [19] but this cannot be applied to the FEA because of the limitation of the program and this one of the advantage of the FEA. Mainly the stresses under oblique load were much higher than those obtained under vertical load.

At the molar area and denture bearing area first model (zero tilt model) showed the highest values of stress concentration while the third model (buccal inclination model) showed the minimum values. The complexity of applied loads during function, both in terms of their magnitude and direction, in combination with alterations in the directions of principal stresses in the posterior stress field as well as in their magnitudes, induce a complex multiaxial stresses in overdenture with flat teeth. Model with an inward inclination on lingual direction, as proposed by several authors [20,21] induces high tensile principal stress in both the implant area, molar area and denture bearing area, this arrangement may have a detrimental effect on crack initiation and propagation associated with opening, shearing, and tearing modes, which are due to tensile, in-plane, and out-of-plane shear loads, respectively. The molar area and denture bearing are in third model, with outward inclination of flat teeth on the buccal direction is characterized by reduced principal stress, this agree with studies by Prombonas and Vlissidis [22] The stress state with flat teeth in outward inclination may increase the fatigue life of the denture by reducing the tensile and shear maximum stress [23].

Loading condition is the most important factor than bone qualities and implant lengths affecting the biomechanical aspects for alveolar bone and implant systems. Lateral occlusal forces produced a lateral bending moment that significantly increased the bony strain and implants stress values when compared with axial loads force regardless the different bone qualities and implant length. During the mastication process load transferred was mainly supported by the mucosa of the denture bearing surface, the working side of the overdenture was shifted down under the action of the food stuff. This motion involved a lift of the non-working side of overdenture leading to compression of the mucosa of the denture bearing area, in this study the stresses in the non-loaded side was greater than that in the loaded side as said by Menicucci et al., [24] who used 3D FEA to evaluate transmission of masticatory load in mandibular retained overdentures.

**Conclusion:**

Under the limitations of the present study, the following conclusions can be drawn:

- The stress pattern with flat teeth is independent of the inclination of flat occlusal surfaces.
- Arranging flat posterior teeth with inward inclination on the buccolingual direction increases the stress.
- Since the stress values were lower in model with the outwardward inclination of the posterior teeth, the arrangement of flat teeth with outward inclination on the buccolingual direction should be used in cases where high loading is expected.

**References**


