Comparative Evaluation of Distribution of Stresses in Osseointegrated Crestal and Basal Implant in Zygomatic Region of Maxilla

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Abstract

Aim  The aim of this study was to evaluate the distribution of stresses in osseointegrated crestal and basal implant in zygomatic region of maxilla and to identify the preferable implant option for better stress distribution.

Material and Method  The present in vitro study was performed to evaluate stress patterns in bone around basal and crestal dental implant under axial and oblique loading in maxillary zygomatic region with the help of a finite element analysis (FEA). To conduct this study, the following materials were used: computer software ANSYS, basal implants with dimensions 3.7 × 10 mm, and crestal implants with dimensions 3.7 x 10 mm. The amount of load transferred on the bone adjacent to the implant in an axial and transverse load of 100 N at 0 and 45 degrees, respectively, was placed on both types of implants. A three-dimensional (3D) scanner was used to generate 3D simulated model of basal and crestal implants. FEA modelling was generated that replicated the zygomatico maxillary region with special emphasis on bone architecture, bone density, angulation, width, and length of implant prototype. Further, material properties were defined for cortical bone, dense trabecular bone, low density trabecular bone, and titanium on the basis of Young’s modulus of elasticity.

Results  These values were used by FEA software (ANSYS) to generate a 3D mesh model of bone and implant. Finally, Von Mises (equivalent stress) (MPa) values on the implant were computed using FEA software. The values of maximum Von Mises equivalent stress on the implant collars, body, apex, and bony interface were obtained.

Conclusion  Maximum stresses were seen at the cortical bone with basal implant placed inside the bone. Stresses that are transferred more to the bone through implant promote bone remineralization. Maximum Von Mises stresses were observed on basal implant body. Thus, these greater stresses have the capacity to simulate mineralization in the cortical bone; this makes basal implant a suitable option for placement inside the cortical bone.

Keywords

- basal implants
- cortical bone
- FEA study

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Introduction

The most common treatment modality by academicians and practitioners while treating edentulous cases is with crestal implants. These crestal implants are inserted from top of alveolar crest into the bone and are indicated in situations where adequate vertical bone height is available.1

During crestal implant placement procedures, the focus is on volume of the available cancellous bone tissue. When the available vertical height of bone is less, treatment remedies to regain the bone volume are required, so that crestally approaching implants can be placed; this can be accomplished by surgical augmentation or guided bone regeneration procedures.2

The success rate of crestal implants is reduced in cases where there is need of bone augmentation. These augmentation procedures are more time consuming, increase overall cost of implant treatment, and delay the prosthetic loading protocol. Even at times no implant placement is performed and the patient is left without an adequate fixed restoration. Many patients at times are not willing to take implant treatment to avoid cumbersome procedures.3

Patients with severely atrophied jaw bones are not benefitted with crestal implants. This is particularly true of the posterior segments of the maxilla and mandible.

The implant technique of “basal osseointegration” has been developed with a view to address the situations with ridge resorption and surgical augmentation procedures, among other problems. Technique of basal implant placement involves anchorage of cortical bone with implant screws; this provides implant stability.

Under the alveolar process of mandible and maxilla, there is basal bone that is fixed and cannot be changed. This basal bone helps in retention of these unique and highly advanced implants as it provides good quality and quantity of cortical bone. These implants are also named as disc or lateral implants. In special cases, both conventional and basal implant can be used together to support edentulous areas.4

The posterior region of maxillae is not a favorable region for the placement of implant; this region is rich in trabecular bone. This region has very less density of bone. Thus, stability of implant cannot be achieved within this region. Zygomatic region of maxillae is rich in cortical bone support.5 The cortical bone does not undergoes resorption, thus favouring basal implant placement. A finite element analysis (FEA) study was conducted to evaluate the stress distribution and compare between basal implant and conventional implant in zygomatic region.

Material and Method

The present in vitro study was performed to evaluate stress patterns in bone around basal and crestal dental implant under axial and oblique loading in maxillary zygomatic region with the help of FEA. To conduct this study, the following materials were used: computer software ANSYS 18.1 software, United States (Fig. 1), basal implants (Simpladent, Switzerland) with dimensions 3.7 × 10 mm, and crestal implants (Simpladent, Switzerland) with dimensions 3.7 × 10 mm (Fig. 2).

To evaluate, the amount of load transferred on the bone adjacent to implant in an axial and transverse load of 100 N at 0 and 45 degrees, respectively, was placed on basal and crestal implant abutments.

The study was divided into three phases:

1. Preprocessing and modeling

To conduct this study, a FEA model was fabricated replicating zygomatico maxillary region with special emphasis on bone architecture, bone density, angulation, width, and length of implant prototype.

2. Processing and meshing

Material properties of constituent materials were defined. The three-dimensional finite element model was meshed using ANSYS preprocessor (ANSYS version 18.1 software, United States).

The FEA assumes the mechanical properties of the materials comprising the structure. The entire volume of bone was considered to be homogenous, isotropic material properties of the bone and implant to be used in study (Table 1).

3. Postprocessing analysis

The Von Mises equivalent stress (MPa) on the implant was computed using FEA software. All computations were performed on three-dimensional implant models (Fig. 3). The values of maximum Von Mises equivalent stress on the implant collars, body, apex, and bony interface were obtained.
Table 1 Mechanical properties of materials

<table>
<thead>
<tr>
<th>Bone type</th>
<th>Young’s modulus (MPa)</th>
<th>Poisson’s ratio</th>
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<tbody>
<tr>
<td>Cortical bone</td>
<td>14,700</td>
<td>0.3</td>
</tr>
<tr>
<td>Dense trabecular bone</td>
<td>1,470</td>
<td>0.3</td>
</tr>
<tr>
<td>Low density trabecular bone</td>
<td>231</td>
<td>0.3</td>
</tr>
<tr>
<td>Titanium</td>
<td>110,000</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Table 2 Descriptive Von Mises stress values with axial load (100 N) on different level of basal implant body

<table>
<thead>
<tr>
<th>Basal implant</th>
<th>Von Mises stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>240</td>
</tr>
<tr>
<td>Middle</td>
<td>120</td>
</tr>
<tr>
<td>Apical</td>
<td>120</td>
</tr>
</tbody>
</table>

Table 3 Descriptive Von Mises stress values with axial load (100 N) on different level of conventional implant body

<table>
<thead>
<tr>
<th>Conventional implant</th>
<th>Von Mises stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>27</td>
</tr>
<tr>
<td>Middle</td>
<td>82</td>
</tr>
<tr>
<td>Apical</td>
<td>27</td>
</tr>
</tbody>
</table>

Results and Observations

Von Mises Stress Values

Quantitative stress distribution in the bone and the implant was evaluated by color scale showing Von Mises stress distribution. The scale for stress ranged from high red to low blue. The maximum values were obtained from above scale in cortical bone, cancellous bone, and implant.

The maximum Von Mises stress values on basal implant at cervical part, middle part, and apical part were 240, 120, 120 MPa, respectively, with axial load of 100 N (Fig. 4 and Table 2).

The maximum Von Mises stress values on conventional implant at cervical part, middle part, and apical part were 27, 82, and 27 MPa, respectively, with axial load of 100 N (Fig. 4 and Table 3).
The maximum Von Mises stress values on cortical bone were 30 MPa with basal implant and 16 MPa with conventional implant with axial load of 100 N (Fig. 5 and Table 4).

The maximum Von Mises stress values on basal implant at cervical part, middle part, and apical part were 271, 542, and 271 MPa, respectively, with oblique load of 100 N (Fig. 6 and Table 5).

The maximum Von Mises stress values on conventional implant at cervical part, middle part, and apical part were 10, 42, and 10 MPa with oblique load of 100 N (Fig. 6 and Table 6).

The maximum Von Mises stress values on cortical bone were 134 MPa with basal implant and 120 MPa with conventional implant with oblique load of 100 N (Fig. 7 and Table 7).

This was seen with FEA results that higher stress values were found near implant bone interface in basal implants in comparison to crestal implants.

### Discussion

The success rate of crestal implants reduces in cases where there is need of bone augmentation. As there is need of surgical procedure, the number of visits as well as cost of treatment increases. In cases of resorbed ridges, the prognosis of treatment is poor. For these cases, basal implants were introduced when there is immediate need of their use. They receive their anchorage from cortical bone; this cortical bone does not resorb under masticatory forces.

The basal implants have the ability to produce macrotrajectories of forces through the bone, within the skeleton; these forces stimulate bone to develop and maintain high degree of mineralization, and these forces prevent any further atrophy.

To conduct this study, zygomatic region of maxillae was modeled on computer with the help of ANSYS 18.1 software. Implants of bi cortical screw (BCS) (basal implant) and king of single piece (KOS) (conventional implant) designs were modeled and virtually implanted into this zygomatic region of maxillae.

Further axial load of 100 N and oblique load of 100 N were applied and stress patterns were observed. Under 100 N of axial load and oblique load, maximum Von Mises stresses were observed for basal and conventional implant.

Under axial load of 100 N and oblique load of 100 N, maximum Von Mises stresses were seen at the body of basal implant. Under axial load of 100 N and oblique load of 100 N, minimum Von Mises stresses were observed for body of conventional implant.

Under axial load of 100 N and oblique load of 100 N, maximum Von Mises stresses were seen on cortical bone with basal implant inserted in bone and minimum Von Mises stresses were seen on cortical bone with conventional implant placed inside bone.

The maximum Von Mises stress observed at basal implant body with respect to cervical part was 240 MPa, and for middle and apical part it was 120 MPa under axial load (100 N) (Table 2 and Graph 1). High stress in basal implant is primarily transferred through the implant body to bone near the interface that will improve osseointegration. These stresses will produce microcracks in bone that will further lead to remineralization of cortical bone.

The maximum Von Mises stress observed at conventional implant body with respect to cervical part was 27 MPa, for middle it was 82 MPa, and for apical part it was 27 MPa under axial load (100 N). These stresses produced by conventional implant are very small in amount and would not be able to stimulate remineralization in cortical bone (Table 3 and Graph 2).

The maximum Von Mises stress observed at cortical bone with basal implant was 30 MPa and with conventional implant it was 16 MPa under axial load of 100 N. Comparatively higher stress is produced in bone with basal implant. This will lead to enhanced remineralization of cortical bone (Table 4 and Graph 3).

The maximum Von Mises stress observed at basal implant body with respect to cervical part was 271 MPa, for middle it was 542 MPa, and for apical part it was 271 MPa under oblique load (100 N). High stress in basal implant is primarily transferred through the implant body to bone near the interface that will improve osseointegration. These stresses will produce microcracks in bone that will further lead to remineralization of cortical bone (Table 5 and Graph 4).

The maximum Von Mises stress observed at basal implant body with respect to cervical part was 10 MPa, for middle it was 42 MPa, and for apical part it was 10 MPa under oblique load (100 N). These stresses produced by conventional implant are very small in amount and would not be able to stimulate remineralization in cortical bone (Table 6 and Graph 5).

### Tables

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Descriptive Von Mises stress values with oblique load (100 N) on different level of basal implant body</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal implant</td>
<td>Von Mises stress (MPa)</td>
<td></td>
</tr>
<tr>
<td>Cervical</td>
<td>271</td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>542</td>
<td></td>
</tr>
<tr>
<td>Apical</td>
<td>271</td>
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<table>
<thead>
<tr>
<th>Table 6</th>
<th>Descriptive Von Mises stress values with oblique load (100 N) on different level of conventional implant body</th>
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<tbody>
<tr>
<td>Conventional implant</td>
<td>Von Mises stress (MPa)</td>
<td></td>
</tr>
<tr>
<td>Cervical</td>
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<td></td>
</tr>
<tr>
<td>Middle</td>
<td>42</td>
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<tr>
<td>Apical</td>
<td>10</td>
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<table>
<thead>
<tr>
<th>Table 7</th>
<th>Comparison of Von Mises stress values with oblique load (100 N) on cortical bone with basal and conventional implant</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Type of bone</td>
<td>Basal implant (MPa)</td>
<td>Conventional implant (MPa)</td>
</tr>
<tr>
<td>Cortical</td>
<td>134</td>
<td>120</td>
</tr>
</tbody>
</table>
The maximum Von Mises stress observed at cortical bone with basal implant was 134 MPa and with conventional implant it was 120 MPa under oblique load of 100 N. Comparatively higher stresses produced were produced in bone with basal implant. This will lead to enhanced remineralization of cortical bone (►Table 7 and ►Graph 6).

There was huge difference in stress distribution between basal and crestal implants. Basal implants exert higher stress on cortical bone as compared with conventional implants. In this study under both axial load and oblique load, basal implants exert higher stresses. Thus they have the capacity for enhanced remineralization of bone and would lead to better osseointegration of implant with bone.

**Limitations**

The FEA is a mathematical study that may not simulate clinical situation. A complete optimum osseointegration was considered in the model that might not be there in clinical situation. All materials were considered linearly elastic and homogeneous compared with bone that is viscoelastic, isotropic, and heterogeneous. The resultant stress values obtained may not be quantitatively accurate but are generally accepted qualitatively.

The present in vitro study was conducted to evaluate the distribution of stresses in osseointegrated crestal and basal implant in zygomatic region of maxilla.

**Conclusion**

Maximum stresses were seen at the cortical bone with basal implant placed inside bone. Stresses that are transferred more to the bone through implant promote bone remineralization. Maximum Von Mises stresses were observed on basal implant body. Thus, these greater stresses have capacity to simulate mineralization in cortical bone; this makes basal implant a suitable option for placement inside cortical bone.
Minimum Von Mises stress concentration was seen for conventional implant; thus, it is observed that they are not suitable to place inside cortical bone as they will have no influence on mineralization of cortical bone. Stress levels were observed minimum at cortical bone with conventional implant placed inside bone.

**Conflicts of Interest**

None identified.

**References**

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