EFFECTS OF DENTAL AND ZYGOMATIC IMPLANTS ON STRESS DISTRIBUTION IN ZYGOMATIC BONE

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Abstract
Prosthetic rehabilitation of the upper jaw in patients with expansive bone and soft tissue defects is still a significant problem lack of retention and stability. Zygomatic implant is an alternative method for these patients. The purpose of this research was to evaluate the stress distribution in the zygomatic bone for three different implant-retained obturator prostheses configuration in a premaxillary with unilateral maxillary defect using a three dimensional finite element stress analysis. 3- dimensional finite element models were constructed based on computed tomograph data. Model 1; one zygomatic implant on defected side, two dental implant on nondefected side, model 2; two dental implant on nondefected side, model 3; one zygomatic implant on each side of the maxilla additionally one dental implant on non defected side. Bar attachments were used as superstructure. Vertical load 150 N was applied in three different ways and the stress distribution were observed and compared. In all loading conditions model 3 when compared another models, shows highest maximum principle stress value on zygomatic bone. Use of zygomatic implant with dental implant in the same part of the maxilla increased the stress values of the zygomatic bone.

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DENTAL VE ZİGOMATİK İMPLANTLARIN ZİGOMATİK KEMİKTEKİ STRES DAĞILIMINA ETKİSİ

Anahtar Kelimeler
Zigomatik implant
Obturator
3 boyutlu sonu elemanlar analizi
Stress dağılımı

ÖZET

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1. Introduction

Maxillary defects are generated by surgical treatment of benign or malignant neoplasms, congenital malformation, and by trauma. The size and location of the defects impact the degree of impairment. Such patients present complexity in speech, control of secretions, mastication, phonetics, deglutition, swallowing, and poor esthetics. This effect diminishes the patient’s quality of life and self esteem. To accomplish such problems obturator prostheses are provided. Prosthodontic treatment will restore the patients to a normal or near normal level of function (Patton et al., 1994; Sharma et al., 2005; Ahmet et al., 2007; Keyf, 2001; Ahila et al. 2011).

Construction of a maxillectomy obturator for any maxillary defect needs suitable retention, stability. Osteointegrated implants may act as a preferable source of retention provided appropriate quality and quantity of bone is available. Unfortunately, these anchorage parts are frequently limited because of tissue loss or resection, may be compromised by radiation of tissue beds and may be localized in patterns that prohibit effective anterior posterior spread and cross-arch stabilization. (Parel et al., 2001)

The zygomatic implant is a product of the remote bone anchorage concept and originally was developed for use in patients with challenging maxillary defects. More than 20 years of follow-up at the Brånemark Osseointegration Center (Göteborg, Sweden) has demonstrated a remarkably high rate of success for this implant when it is used to support a variety of maxillary defect prostheses.

The zygomatic bone was used for anchorage and support of a long fixture that together with conventional fixtures could be used as anchorage for epistheses, prostheses and obturators (Weischer et al 1997; Aparicio et al 2010). According to the present authors’ experiences, high primary stability can also be achieved with zygomatic implants but they mentioned that for successful treatment the important point is first of all careful patient selection, appropriate surgical approach and favorable prosthetic designs for biomechanic loadings (Aparicio et al 2006).

Al-Nawas et al emphasized that 9 of 20 zygomatic implants showed bleeding and increased probing depths that may be because of couldn’t supplied oral hygiene caused by the positioning of the zygomatic implant head, abutment and the design of the prosthesis (Al-Nawas et al, 2004).

The aim of this study was to investigate, by using finite element stress analysis, the effect zygomatic implant application of the stress distribution on the zygomatic bone when Aramany Class IV obturator prosthesis was subjected to three different loadings.

2. Materials and Methods

2.1. Construction of craniofacial bone models

The construction of finite element models considered in this research are generated of mucosa, compact bone, trabecular bone, zygomatic implant (Branemark System, Nobel Biocare AB, Goteborg, Sweden), dental implant, bar attachment system (Institute Straumann, Waldenberg, Switzerland), and obturator prosthesis (Figure 1). Cortical bone with 1.5-mm thickness was uniformly defined around the trabecular core body. Mucosa was sustained to be 1.5-mm thickness. Standard dental implants with a diameter of 4.1 mm and a length of 10 mm, zygomatic implants with a diameter of 4 mm and length of 35 mm, titanium U shaped dolder bar with a height of 3 mm, and titanium dolder bar matrix with a height of 4.5 mm were modeled in all models generated. The zygomatic and dental implants were oriented to the defective maxilla in three different configurations.

2.2. Boundary conditions

To create clinical situation, loading involved the administration of a simulated bite force as a distributed vertical load of 150 N to the occlusal surfaces of the
artificial teeth of the prosthesis. A 150-N vertical load was applied in three different methods: first, loading was applied to the defective side; second, to the nondefective side; and third, loading was applied simultaneously to both defective and nondefective sides. Both loading of the finite element models are shown in Figure 3.

![Figure 3](image)

**Figure 3.** Appearance of the loading on craniofacial model. (a) Occlusal view of the first loading, (b) Occlusal view of the second loading, (c) Occlusal view of the third loadings are shown.

2.4. Material properties

The material properties for the skull, dental and zygomatic implants and bar attachments were recognized to be homogenous and linearly elastic. Isotropic, homogeneous, and linearly elastic. The implants used in this study were modeled as a titanium alloy (Ti6Al4V). Bar attachments were assumed to be made of pure titanium, and the obturator prosthesis was modeled with a (poly metilmetakrilat) acrylic resin. The mechanical properties of the components of the models in this study were obtained from early literatures. The elastic modulus and Poisson’s ratios of the materials used in the analysis are shown in Table 1.

**Table 1.** Material properties of analysis objects

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus (E)(GPa)</th>
<th>Poisson’s Ratio (ν)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucosa</td>
<td>680</td>
<td>0.45</td>
</tr>
<tr>
<td>Cortical bone</td>
<td>13700</td>
<td>0.3</td>
</tr>
<tr>
<td>Ti6Al4V</td>
<td>110000</td>
<td>0.3</td>
</tr>
<tr>
<td>Acrylic resin</td>
<td>2700</td>
<td>0.3</td>
</tr>
<tr>
<td>Titanium</td>
<td>115000</td>
<td>0.35</td>
</tr>
<tr>
<td>Zygoma</td>
<td>11507</td>
<td>0.3</td>
</tr>
<tr>
<td>Matal</td>
<td>2470</td>
<td>0.407</td>
</tr>
<tr>
<td>Sinus</td>
<td>140000</td>
<td>0.3</td>
</tr>
</tbody>
</table>

2.5. Mesh Creation

The geometry was meshed using the Fembro software package. Later meshing the first model consisted of 91,088 nodes and 340,509 elements, the second model consisted of 109,698 nodes and 462,338 elements, the third model consisted of 79,398 nodes and 391,714 elements.

2.6. Maxillary prosthesis models

The 3D finite element analysis model of 3 different types of obturator prostheses was established. The configuration models were as follows:

Model 1 included placement of 1 zygomatic implant on the defected side of the maxilla in combination with 2 dental implant that were placed on the non defected side and completion of the restoration connecting with the fabrication of a rigid bar (Figure 4).

![Figure 4](image)

**Figure 4.** Front and occlusal views of the finite element craniofacial model after maxillectomy of the configuration 1 (model 1): 1 zygomatic implant and 2 dental implant.
Model 2 included placement of 2 dental implant on the non defected side of the maxilla and completion of the restoration connecting with the fabrication of a rigid bar (Figure 5).

**Figure 5.** Front and oclusal views of the finite element craniofacial model after maxillectomy of the configuration 2 (model 2): 2 dental implant

Model 3 included placement of 2 zygomatic implant on each side of the maxilla in combination with 1 dental implant that were placed on the non defected side and completion of the restoration connecting with the fabrication of a rigid bar (Figure 6).

**Figure 6** Front and oclusal views of the finite element craniofacial model after maxillectomy of the configuration 3 (model 3): 2 zygomatic implant and one dental implant

### 3. Results

The results which are depended on a qualitative analysis, in accordance with the degree of maximum principle stress (shown by a color scale) and a quantitative analysis indicated in Mpa. (Figure 7, 8, 9) Maximum principle stress values of model 1 are shown in figure 7 for the defective side, non defective side and both side loading conditions. In Model 1 the highest maximum principle stresses value was determined in the first and third loading. This highest stress was approved at the zygomatic bone’s near the part of the lateral wall and floor of the orbit.

**Figure 7.** The maximum principle stress distributions in the zygomatic bone under (a) first loading, (b) second loading, and (c) third loading conditions for model 1 (unit: MPa). Colors show level of stress from dark blue (lowest) to red (highest).

Maximum principle stress values of model 2 are shown in figure 8 for the defective side, non defective side and both side loading conditions. In Model 2 the highest maximum principle stresses value was determined in the first and third loading. This highest stress was recorded at the zygomatic bone’s maxillary border.
Maximum principle stress values of model 3 are shown in figure 9 for the defective side, non defective side and both side loading conditions. In Model 3 the highest maximum principle stresses value was determined in the second and third loading. This highest stress was recorded at the zygomatic bone’s near the maxillary and orbital border.

4. Discussion and Conclusion

Over the top stress at the implant placed bone is among the potential argument of peri-implant bone loss and failure of osseointegration therefore the estimation of the low level of stress is important for the achievement of the rehabilitation of the implant retained prostheses (Korkmaz et al. 2012, Quaresma et al 2008). A lot of different methods, for instance photoelastic stress analysis, strain gauge analysis and finite element stress analysis have been widely used for stress analysis (Chun et al 2005) Three dimensional finite element analysis technique has the following advantages; it is non-invasive; the amount of stress experienced at any given point can be theoretically calculated; the material properties of craniofacial structures can be assigned to the nearest one that possibly can simulate this environment in vitro unsean sides for example the sinuses can be visualized graphically; the point of application, magnitude and direction of a force may easily be varied to simulate a clinical situation; reproducibility does not affect the physical properties of the material involved; and the study can be repeated as many times as the researcher wishes (Konda and Tarannum 2012).

Kato and colleagues research the internal configuration and the structure of the edentulous zygomatic bone in cadavers using micro-computed tomograph, understanding that the existence of wider and thicker trabeculae at the apical end of the fixture advertises first fixation (Kato et al., 2005). Furthermore, Nkenke et al used calculated tomograph and histomorphometry to search thirthy human zygoma. The study related that the zygomatic bone includes of trabeculer bone unsuitable parameter for implant placement on the other hand the accomplishment of implants placed in the zygomatic bone was terminated by the implant crossing four portions of cortical bone. The portions are; upper border of the zygoma, at the ridge crest, root of the maxillary sinus, the sinus flor (Nkenke et al., 2003).

The use of zygomatic implants is essential to optimize load distribution and to increase prosthesis stability. When compared to a dental implants, the zygomatic implant has an incresaed tendency to bend under horizontal loads. This is correlated; the greatly increased length of zygoma implant and limited bone support in the maxillary alveolar crest (Sudhagar et al., 2011).

Schmidt and colleagues followed a retrospective analysis of patients rehabilitated with zygomatic implants on the maxillary resection patients and declared nine cases of particular or all maxillectomies rehabilitated using 28 zygomatic and 10 conventional implants. Nevertheless six zygomatic and three dental implants failed, they confirm that the combination of dental and zygomatic implants could be used in patients.

Figure 8. The maximum principle stress distributions in the zygomatic bone under (a) first loading, (b) second loading, and (c) third loading conditions for model 2 (unit: MPa). Colors show level of stress from dark blue (lowest) to red (highest).

Figure 9. The maximum principle stress distributions in the zygomatic bone under (a) first loading, (b) second loading, and (c) third loading conditions for model 3 (unit: MPa). Colors show level of stress from dark blue (lowest) to red (highest).
with expansive resection of the maxilla (Schimidt et al., 2004). In our study we designed our prosthesis models with zygoma and dental implants together. Conversely we find that use of zygomatic implant with dental implant in the same part of the maxilla increased the stress values of the zygomatic bone. When we use zygomatic and dental implants in different parts of the maxilla it can be acceptable values. Korkmaz et al designed four obturator prosthesis models retained with zygoma and dental implants and mentioned that it had less influence on von mises stress by increasing the number of dental implants of an affected side which was agreement in our results (Korkmaz et al. 2012).

Placement of zygomatic implants should be considered a major surgical procedure and proper training is needed. When compared with major bone grafting it is still less invasive technique and can be used in cases where bone grafts cannot be harvested for any reason (Aparacio and Hatan, 2008).

The distribution of stresses on zygomatic bone were more rational with the support of zygoma implants which can divide the stresses on affected side appropriately, so that it is adequate for the reconstruction of maxillary defects. Maxillary rehabilitation can be further improved by using zygomatic implants.

This is helpful for surgeons, dentists and prosthodontists to make optimal designs of prosthesis in clinical in order to enhance the patients quality of life as much as possible.

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Conflict of Interest

No conflict of interest was declared by the authors.

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