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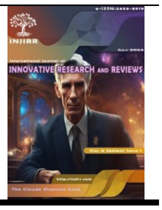

RESEARCH ARTICLE

Three-Dimensional Finite Element Analysis of Zygoma Implants in A Patient with a Maxillary Defect

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ABSTRACT

The purpose of this study was to analyze stress distributions in zygoma implants (ZIs), supporting bones, superstructures, and implant screws placed in the defective and non-defective areas of the maxillary bone of a patient with a maxillary defect. Three-dimensional (3D) finite element models (FEMs) were constructed based on computed tomography (CT) data. ZIs of the same size were placed in the defective and non-defective areas. After applying the force, the stress on the implants, surrounding bones, and implant screws was evaluated. Stress distribution and displacement were greater in the implant and surrounding bone on the defective side. While the stress was higher in the cortical bone on the defective side, the stress was more on the cancellous bone on the defective side. More stress was observed on the implant screw on the defective side. A ZI placed in the defective area in patients with maxillary defects should be supported by another ZI on the non-defective side.

Contents

1. Introduction

Maxillary defects due to tumors and trauma are clinically common. Irregular geometric contours of the maxilla and maxillary sinus make reconstruction of the defect difficult. Generally, obturator prostheses, regional pedicle flaps, and bone grafts with titanium plates and meshes are used in maxillary reconstruction. Defect prostheses are preferred over other surgical procedures because the latter cause more suffering in the patient [1, 2]. Zygoma implants (ZIs) have become a standard procedure in patients with maxillary defects without severe maxillary atrophy or severe periodontal disease. ZIs offer a therapeutic treatment process with a high success rate without the need for bone grafting [3–9].

ZIs were first used by Parel et al. [10] in 1988 in the prosthetic rehabilitation of patients with maxillary defects. ZIs have been used to restore function to patients following partial maxillectomies, where all of the support was derived from the zygomatic bone [11]. However, the relevance of the alveolar or palatal bone for ZIs has been called into question [12]. For this reason, it is necessary to compare the stress distributions of ZIs placed in areas with and without defects using a model obtained from the computerized tomography (CT) of a patient with a partial maxillary defect. While only the zygomatic bone supports the ZI in the defective region,

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it also supports the palatal and maxillary bone in the non-defective region.

A recent review of studies including 1143 ZIs showed a survival rate of 98.4% after follow-up ranging from 6 months to 10 years [13]. Obturator prostheses framework models focus on the Aramany class IV obturator model. Aramany class IV defects are well-known in the resection of the premaxilla and the posterior maxilla on one part [14, 15]. This kind of enormous defect has an excessive and egregious impact on the biomechanics of supporting tissues [16]. In bone remodeling, charge degree stresses between 4 MPa and 8 MPa behave as stimuli and increase bone density. However, a charge degree stress of 9 MPa causes resorption and reduced bone density [17].

The aim of this study is to compare and evaluate the stress distributions in ZIs, supporting bones, superstructures, and implant screws placed in the non-defective and defective areas of the maxillary bone of a patient with maxillary and mandibular defects. The hypothesis of this study is that more stress will be seen on the implant, implant screw, and surrounding bone tissue placed in the defective area, and this implant will show more displacement.

2. Materials and Methods

A CT image of a patient with partial defects in the mandible and edentulous maxilla as a result of a gunshot injury was used to obtain a three-dimensional (3D) image. A linear static structural analysis was applied to the 3D model of the patient's maxilla consisting of ZIs to determine the equivalent stress distribution and displacements on the maxilla and the implants. For this, the reverse engineering method was used. A 3D model of the patient's head was created, and two ZIs containing two components (a zygomatic implant and multi-unit abutment) were assembled to the 3D model using computer-aided design software. The first step was to create Digital Imaging and Communications in Medicine (DICOM) files of the patient's head using a clinical CT scanner (GE Medical Systems, USA) with a slice thickness of 0.625 mm. The scanned DICOM files were imported into the 3D Slicer software, and a preview of a 3D model was obtained. The upper section of the head from the maxilla was split, and image processing was applied to the DICOM files to create a surface model of the head. For this, the threshold tool was used. Other various tools in the software were also used to obtain a clear and smooth model surface (Figure 1).

The final clear and smooth 3D surface model was exported as a stereolithographic (STL) file. The STL file was imported into the Ansys SpaceClaim software, and the repair and skin tools were used to rearrange the topology of the surface model and to obtain the proper 3D solid model of the head. The upper section of the final 3D solid model was split off to apply boundary conditions. Also, the 3D solid model was emptied with the shell tool as amount of 2.0 mm and filled the inside. The purpose of this was to create cancellous and cortical bone on the model.

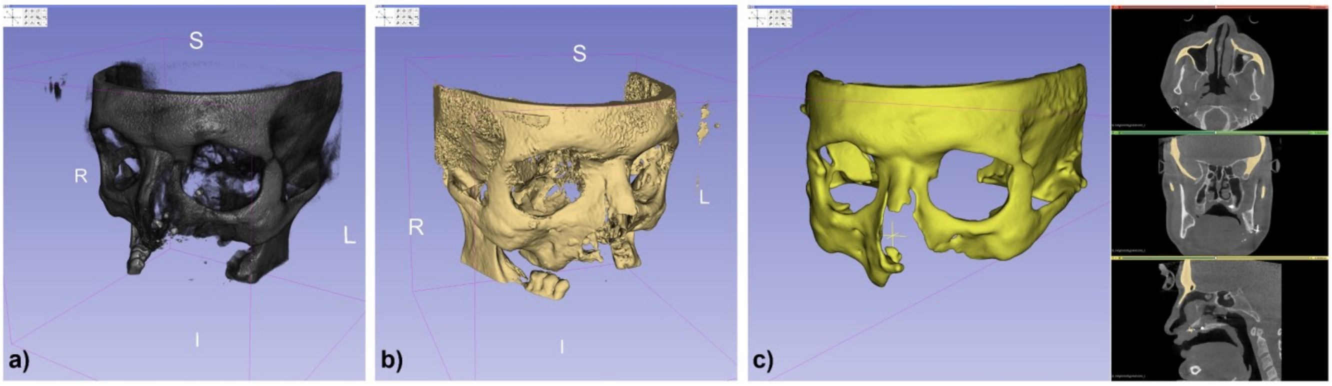

Figure 1 a) The 3D model preview of the patient's head created using DICOM files. b) Preview of the 3D model of the head split at the maxilla. c) The 3D surface model of the split head. d) The 3D surface model of the split head after cleaning and smoothing processes and the islands which were applied threshold tool on the DICOM files.

The final 3D solid model was exported as a Standard for the Exchange of Product Data (STEP) file and then imported into the Autodesk Inventor Professional software in order to assembled the ZIs. ZIs were assembled to the maxilla of the 3D head model at the appropriate angles and locations (Figure 2).

Cancellous and cortical bones on the model have been holed from where the implants placed. The multi-unit abutments were positioned on the same plane, and the distance between the two left and right implants was 40 mm. The angle between the ZI and multi-unit abutment was 0° for the left implant and 45° for the right implant. The assembled model was exported as a STEP file, which was then imported into Ansys Workbench for static structural analysis. A 100% osseointegration situation was assumed for the two ZIs.

The upper section of the head was defined as a fixed support. A force of 150 N was applied to the implants in the +Z direction and 300 N to the cheeks of the head in the -Z direction. An element size of 1 mm was used for the meshing, and 229,061 pieces of mesh element were created (Figure 3).

Table 1 presents the three different material properties used for the implants and cancellous and cortical bones.

Table 1 Material properties used in the analysis

Materials	Modulus of Elasticity E (GPa)	Poisson's Ratio
Zygomatic Implants	110.00	0.33
Cancellous Bones	1.00	0.30
Cortical Bones	13.40	0.30

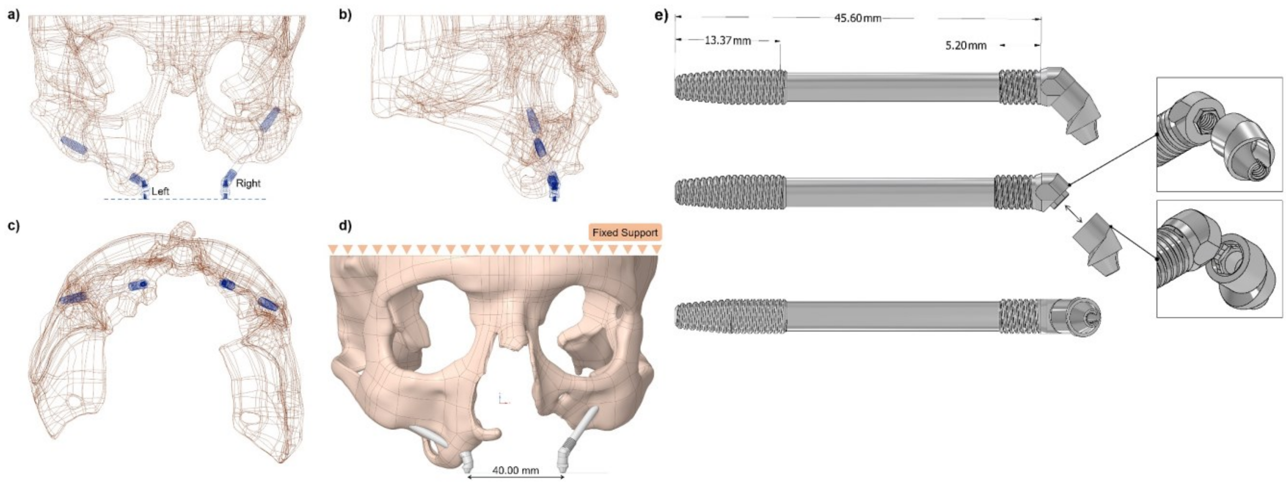

Figure 2 Different views of the 3D solid model assembled with ZIs: a) wireframe front view, b) wireframe right view, c) wireframe bottom view, d) final 3D solid model assembled with ZIs and the boundary condition, and e) zygomatic implants.

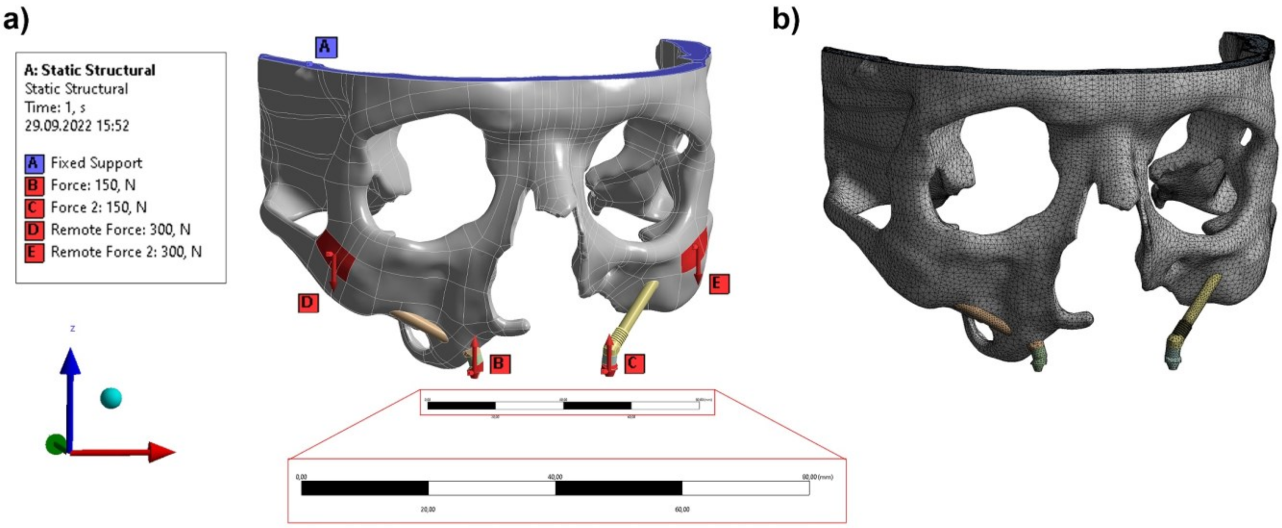

Figure 3 Finite element model of the head under loading: a) Locations and boundary conditions of the external forces. b) Mesh view of the model.

3. Results

The von Mises stress values of the ZIs placed in the defective and non-defective areas are given in Figure 4.a. The maximum stress value was observed in the multi-unit attached to the ZI located in the defective area, while the minimum stress was observed in the apical part of the ZI located in the non-defective area. This may be due to the lack of bone support for the implant in the defective area. A visual of the amount of displacement that occurred to the ZI as a result of the application of force is given in Figure 4.b. According to Figure 4.b, the maximum displacement was observed in the multi-unit part of the ZI in the defective area without bone support, while the minimum displacement was observed in the apical part of the same implant within the zygomatic bone. This may be due to the lack of bone support of the ZI due to the defect. No displacement was observed in the ZI placed in the non-defective area.

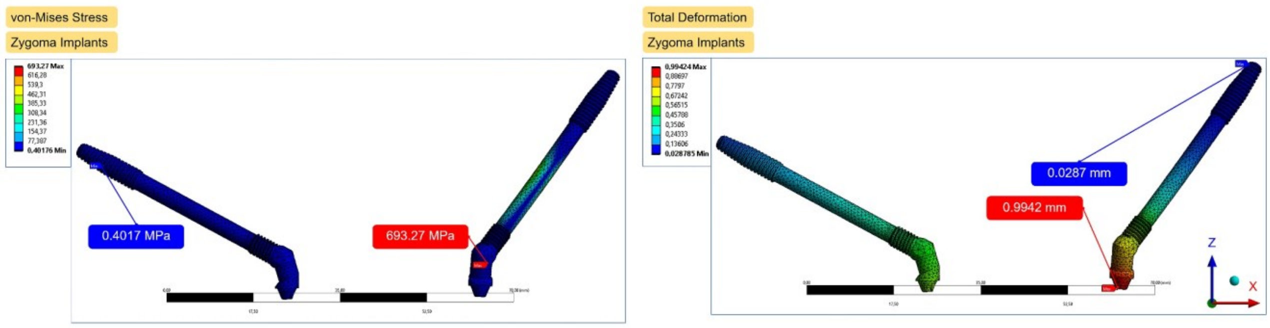

Figure 4 a) Maximum and minimum von Mises stress values of ZIs, and b) displacement of ZIs.

The von Mises stress values formed in the cortical bone as a result of the force applied to the ZIs are given in Figure 5.a. According to Fig 5a, the maximum stress value was observed close to the exit profile of the implant in the defective region, while the minimum stress value was observed in the region close to the initial profile of the implant in the zygomatic bone in the non-defective region. The von Mises stress values in the cancellous bone as a result of the force applied to the ZIs are given in Figure 5.b. According to Figure 5.b , the maximum stress value was observed in the non-defective region. This may be due to changes in bone structure due to trauma.

The von Mises stress values seen in the screw of the ZIs placed in the non-defective area are given in Figure 6.a. Accordingly, while the maximum stress value for the implant screw was observed in the upper region of the exit profile of the implant, the minimum stress value was observed in the lower region of the same part. The von Mises stress values seen in the screw of the ZIs placed in the defective area are given in Figure 6.b. Accordingly, the maximum stress value for the implant screw was seen in the lower part of the zygomatic bone, while the minimum stress value was observed in the upper part of the zygomatic bone.

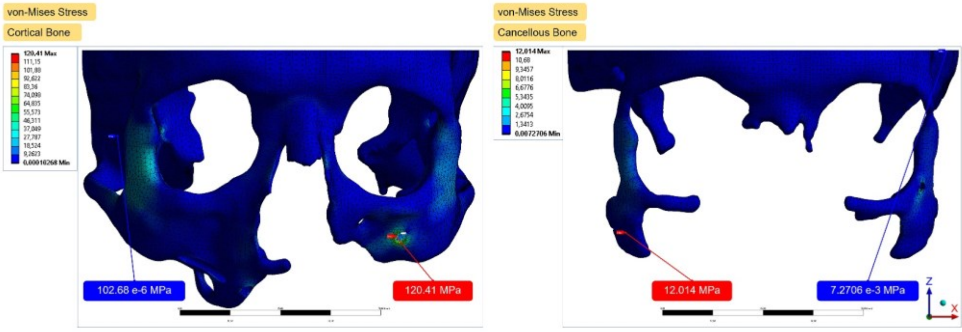

Figure 5 Von Mises stress values observed in a) cortical bone and b) cancellous bone.

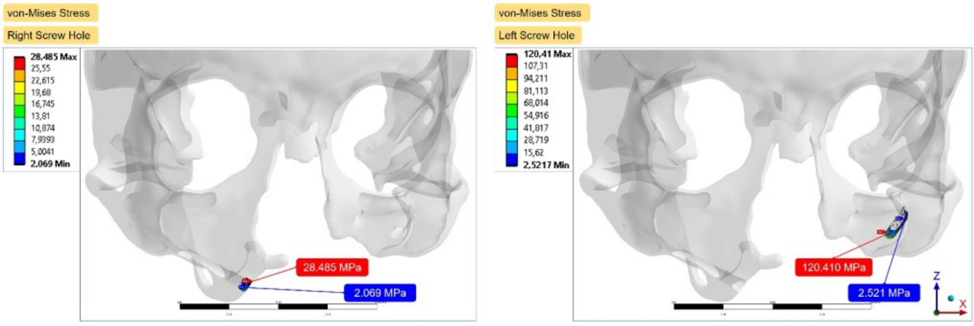

Figure 6 Von Mises stress values observed in the screw of the implant in a) the non-defective region and b) the defective region.

4. Discussion

ZIs are used in patients who do not have sufficient bone support for dental implants and who cannot undergo bone augmentation [18]. Compared to conventional implants, they show a high success rate [19]. Most of the support for ZIs is provided by the zygomatic bone in which the apex is embedded. The head of the implant opens into the mouth in the direction of the palatal aspect of the alveolar structure of the maxilla [12–20].

FEA is a digital technique widely used in engineering and biomechanics. This technique is being accepted by more and more doctors due to its invasive nature for simulating different defect types and evaluating prosthesis planning suitable for the defect. In addition, with the visual monitoring of the analysis process and its closeness to reality, it provides researchers with the opportunity to evaluate and examine any region of interest [21, 22].

Akay and Yaluğ [23] created three different Aramany Class IV models by placing a ZI in the defective area and one dental implant, two dental implants, or ZI in the non-defective area. They obtained the least stress distribution in the model in which they placed ZIs on both sides. In our study, we aimed to evaluate the stress distribution occurring only in ZIs placed in the defective and non-defective areas because if a ZI is considered in a patient with a maxillary defect, it should be supported with a ZI on the non-defective side. In the prosthesis planning of patients with a partial maxillary defect, placing ZIs in both the defective and non-defective region has not been evaluated. For this reason, the aim of this study was to evaluate the implants placed in the defective and non-defective region, the von Mises stress values in the surrounding bone tissue and implant screws, and the amount of displacement observed in the implants. According to the results of the FEA, the hypothesis of the study was accepted.

Miyamoto et al. [24] evaluated the stress levels of the ZI and the dental implants on the non-defective side in a hemi-maxillectomy FEA model. Their model showed the stress distribution in ZIs that are not supported by the maxillary bone, similar to our study. In the related study, a large masseteric force was applied on the ZI. As a result, high stress was detected in the zygomatic bone, but less stress was detected in the bone supporting the implant than in the rest of the bone.

It has been reported that better results are obtained with bilateral placement of ZIs than dental implants not only in patients with maxillary defects but also in patients with atrophic maxilla [25, 26]. Romeed et al. [27] evaluated the stress levels on ZIs on the 3D model they obtained from the CT of a patient with atrophic maxilla. Similar to the results of our study, they found more stress in the maxillary bone in ZIs supported by maxillary and zygomatic bone.

Ayinala and Shetty [28] used ZI-supported removable prostheses in the rehabilitation of a maxillary defect caused by a tumoral mass and reported that the patient's quality of life increased due to the improved aesthetics and function. Vosselman et al. [29]reported successful results in maxillectomy patients with 3D-guided ZI placement followed by immediate prosthesis.

To simulate occlusal force, previous studies used a vertical load of 150 N applied to the occlusal surface along the ZI axis [30–33]. To simulate the action and pass downward and backward, previous studies applied a distributed occlusal force of 300 N to the insertion area of the masseter muscle on the zygomatic arch and zygomatic process of the maxilla [30–34]. In the present study, we applied a force of 150 N to the ZI in the vertical direction and 300 N in the region of the masseter muscle. As titanium alloys are known to tolerate stresses up to 900 N/mm2 without irreversible deformation [35], the force of 150 N applied to the system was unlikely to cause implant failure. As in-vivo fracture of a ZI has been reported [36], due caution should be exercised to prevent overloading and excess axial and lateral forces on implants and superstructures [30].

5. Conclusion

Within the limitations of the present study, we conclude the following. This study provides valuable information in terms of the amount of stress in the ZI placed on the defective and non-defective side and the surrounding bone in terms of increasing prosthesis retention in patients with maxillary defects. Based on the results obtained, ZI placed on the defective side in patients with maxillary defects should be supported by another ZI on the non-defective side.

Ethics approval

The authors confirm that the journal's ethical policies have been followed as stated in the journal's authors' guidelines. Approval for conducting the research was obtained from the Ethics Committee of Ataturk University Dentistry, Erzurum, Turkey.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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