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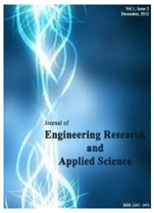

Material comparısons of mandibular square type plate fixators

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Abstract

The aim of the present study is to compare the plate materials for calculating stress distributions and displacements on the square type mini mandibular fixators. A model of the mandible was modeled aided with computed tomography (CT) images. The CT images were converted to the finite element model aided by reverse engineering methodology. 3 materials (Titanium Alloy, Chrome-Cobalt and Stainless Steel) for square type mini plate and fixators were designed. The finite element analyses (FEA) (In Slico) were performed with respect to displacement and stress distributions for both mandibular, and fixators its fixation screws. According to all FEA results, "Square" type fixators for linear fracture type had a minimum stress distribution. FEA is useful for comparing geometry and material variations of rigid mandibular fixations.

Keywords: Mandibular Fracture; finite element analysis; square type mini fixators

1. Introduction

Human beings need to continue the activities of eating and drinking in order to survive. Biting and chewing based on the jaw bone providing power to the teeth and the bone (mandible) are the most important of the mandibular activities. During these important functions or other external factors the mandibula can be fractured [1-7]. There are more causes of mandibular fractures as can be seen in Table 1.

Table 1. Causes of mandibular fractures in children [2]

Fall	59.5%
Road accident	24.5%
Sports and games crash	7.5%
Other (Animal kick, fight, drop the weight on)	8.5%
Total	100%

Rigid internal fixation is generally used to stabilize the segments of fracture for fast and regular bone healing, initiating early postoperative mandibular function and decreasing the amount of relapse [6-10]. In literature, although numerous studies have been conducted to compare the different types of fixation techniques, experiments comparing different fixation techniques concerning material and plate geometry comparisons are limited.

FEA is widely used in engineering and can also be used to solve complex problems in dentistry [10]. Several authors have reported the accuracy of FEA for describing the biomechanical behavior of bony specimens [11-13]. We had earlier reported the feasibility of FEA simulation to compare experimental studies and FEA simulations [14]. Vollmer et al. [15] have found a high correlation between FEA simulation and in vitro measurements of mandibular specimens (correlation coefficient =

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0.992). FEA is therefore a suitable numerical method for addressing biomechanical questions and a powerful research tool that can provide precise insight into the complex mechanical behavior of the mandible affected by mechanical loading [16-18]. Korkmaz [8] was explained that to formulate biomechanical justification of the positioning of different plates to achieve stable fixation of a fractured mandible with FEA simulation. Champy et al. [9] determined which location of mini-plate fixation was the most stable and also that the fixation locations of the mini-plate may influence mandibular stability.

Biomaterials are used for positioning and fixating the mandibula are metals, ceramics, polymers and composites. [6-25] Titanium, titanium-aluminum-vanadium alloys, stainless steel and cobalt-chromium alloys are used for fracture fixation. Teflon, polyurethane, PMMA, silicone rubber, and bio-compatible materials such as hydro-gels are used for different tissue fixations [26]. Titanium (Ti-alloys), chrome-cobalt alloy and stainless steel plates have been used for over two decades to achieve internal rigid fixation of mandible fractures. These plates are highly malleable and offer good resistance against directional and torque forces. The back site mandibular fractures are most frequent two different types of mandibular fractures. These fracture types are often fixed with 1 or 2 mini-plates. In contrast there is no literature on comparisons with different geometries and materials for the mandibular plates.

In this study, we compared mini-plate geometries and materials from the viewpoint of biomechanical stability and the complex biomechanical behavior of the mandible and screw-mini-plate system. For this, we used FEA simulations of two different types of mandibular crack with mini-plate fixation. This study also has a new concept with a finite element method for comparison and evaluation in terms of the deformation behavior of different materials and geometries of mandibular plates with different types (linear and oblique) of fractures (Figure 1).

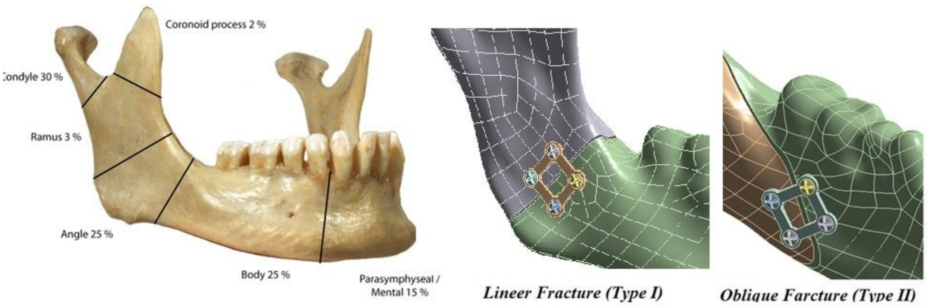


Figure 1. Mandibula fracture types.

2. Material and Methods

The 3-dimensional (3D) computer-aided exact geometry of the mandible obtaining process includes important steps. The most efficacious 3D model design with computer aided software with CT slices is an important step to get significant results in finite element simulations [27-35]. In this study, the average human Computerized Tomography (CT) images have been used. Modeling steps of literature studies were used for modeling [27-30].

In the field of medicine, computer-aided planning and modeling have been used frequently in recent years before surgical operations [27]. In this study, the main model was also modeled via CT images with computer aided modeling techniques. CT images of the jaw mechanism bones were obtained from a female patient aged 30 using a Toshiba Aquilion (64 DAS TSX-1014/HA) CT scanner in the radiology department of the Faculty of Medicine. CT images consist of parallel layers having a section range of 0.425 mm at the neutral position and a pixel resolution of 512 × 512 with 524 layers. Images were recorded in the Digital Imaging and Communications in Medicine (DICOM) format. These images were transferred to the MIMICS® 12.11 software. Both linear and oblique fracture models were created and completed digitally in the computer environment through the MIMICS® program, and fractured models were obtained aided by SOLIDWORKS®. All models and geometric arrangements were completed through a reverse-engineering program (GEOMAGIC®). After correction of the surface errors of the deformed and corrected models, 3D smooth solid models were developed. After geometric arrangements of the models were complete, finite element models were obtained by transferring them into the MIMICS® finite elements analysis (FEA) module content in steriolithography (STL) format. After these processes all models were designed of the fracture line and the plate-plate interface models, design and installation of the mandible surface with SOLIDWORKS® software. Also parts and assembly components have been completed as the same manner. The final step of the finite element model design was ANSYS® WB Design Modeler® phase. After the model obtained all loading and boundary conditions have been assigned with ANSYS® WB (Figure 2a). Plate geometries were designed with SolidWorks (Figure 2b).

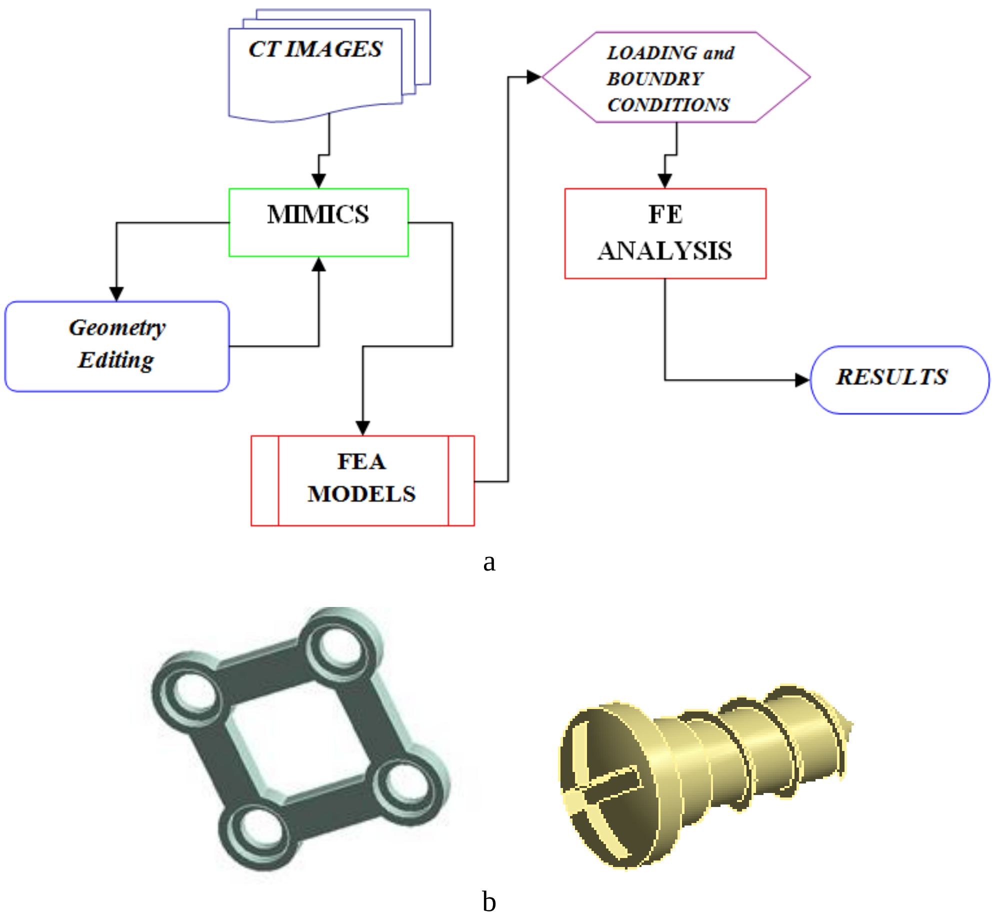


Figure 1. 3D modeling procedure chart and models.

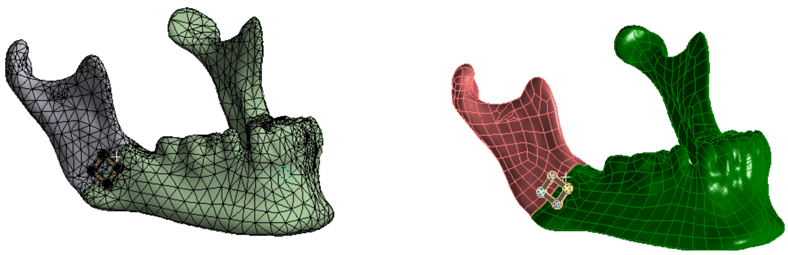
The isotropic material properties have been defined for each material. The modulus of elasticity (E) and Poisson's ratio (ν) of materials are given in Table 2. Mandible literature studies, by making use of the property of the material are considered to be linear. Ten-node tetrahedral elements were used (Figure 3a) to form the mesh of the finite elements models. We assumed that all FEA models had high slippage on the bone-plate interfaces. All finite element simulations were performed with ANSYS WorkBench®.

We used square type mini plate geometries for three different material properties (stainless steel, chrome-cobalt and titanium alloy) and two different mandibular crack rigid fixations. Two different finite element mesh types and element dimensions (mathematical equations) were used for convergence control ın ANSYS WorkBench®. Screws were designed with original diameter (Ø 2 mm) and the thicknesses for square type plate were selected 2 mm (Figure2b).

Table 2. Lineer Isotropic Material Properties [29-33]

	Poisson's ratio (ν)	Modulus of Elasticity (E) GPa
Ti-6Al-4V	0.342	113.8
Stainless steel	0.3	200
Cobalt-Chrome alloy	0.226	189.6
Mandibula	0.3	14

The effective force which occurred during biting was used for this study. Different studies in the literature used force values between 30 to 210 N. [29-34]. The loading and boundary conditions were applied similar to those literature studies as shown in Figure 3b [29-34], The model considers the inner parts of the mandible condyle fixed and effective force applied with the bite direction of the front teeth with the value of 150 N.



a b

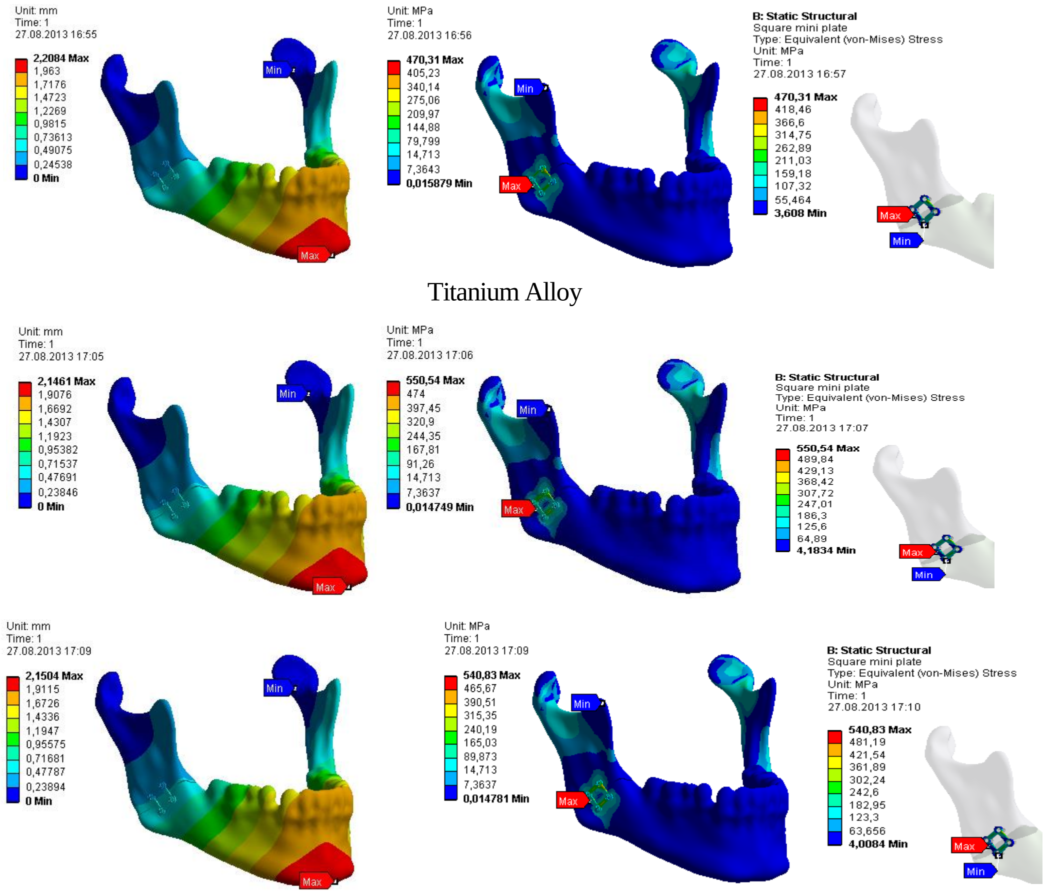
Figure 3. Mesh variations and 3d Model of Square type fixation.

3. Results

In this study, mini-plate material and geometry combinations were compared with finite element analysis which have been used several studies in literature [36-40]. This study focused on the stresses on bone, fixators and bone-plate interface. The von Mises stress contours were analyzed and discussed for both bone and fixators. Stress hypothesis (von Misses) shows a general effective stress pattern in material.

The contour maps of FEA results showed that von Misses stress for comparing geometry and material variations which was effective than the others. As shown on Figure 4, the highest equivalent stress in the FEA models of the mandibular fixation with mini plates were about 550 MPa for Stainless steel material and minimum stress value was 470 MPa for Titanium alloy. Comparing the 3 materials, mechanical stress within square type mini-plate fixators systems differed with the same positioning. When comparing different materials, the mechanical stress distribution within fixator systems presents different values with different locations for the same crack type.

When compared to all the FEA models with different materials, stress along the mandibular surface (Figure 4) and angle of the fractured area were absorbed (Figure 7) by all the mini-plates (Table 3, Table 4 and Table 5).



Chrome-Cobalt

Figure 4. “Square” Type mini plate FEA results.

Table 3. Equivalent stress (Von-misses) results (MPa)

	Ti6Al4V	Chrome Cobalt	Stainless steel
Square type mini plate	470	540	550

Table 4. Equivalent stress (Von-misses) results for oblique fracture (MPa)

	Ti6Al4V	Chrome Cobalt	Stainless Steel
Square type mini plate	167	199	221

Table 5. Deformation (Total) results (mm)

	Ti6Al4V	Chrome Cobalt	Stainless steel
Square type mini plate	2.20	2.15	2.14

4. Evaluation of bioenergy use

Finite element based studies verified with real limitations with different more cases in slico like in vivo studies. In conclusion, according to the FEA results for fixation of mandibular fracture with mini-plate provides stability according its design and material. Oblique fracture fixation of mandibula with Ti6AlV4 material had the most ideal conditions for minimal stress on square type fixators. Another result was, the optimal deformation achived (total) on the chrome cobalt material based mini plate.

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