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Numerical Stress Analysis of the Plates Used to Treat the Tibia Bone Fracture

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Abstract

Tibial fractures are one of the most frequent bone fractures caused by accidents or falls because of the tibia's slender shape. In the tibial fractures close to the joint surface, a plate and screws may be the ideal method of fixation. While using the plate and the screws the estimation of the stress on the plate and screw gains importance before beginning the treatment. In this study, it is aimed to conduct a numerical simulation which uses finite element methodology, to estimate the von Mises stress subjected to the plate and screw which is used in tibia fracture treatment. A titanium plate and 4 screws on it are used for treatment of the fracture. The fracture angle varies as 0˚, 15˚, 30˚, and 45˚. The compressive force affected on the plate is estimated to be 750 N. Moreover, the bone is simulated 3D, by using commercial software, *ANSYS Structural*.

Keywords

Tibia Fracture, Finite Element Model, ANSYS, Biomechanics

1. Introduction

A fracture, or break, in the shinbone just below the knee is called a proximal tibia fracture. The proximal tibia is the upper portion of the bone where it widens to help form the knee joint. In addition to the broken bone, soft tissues (skin, muscle, nerves, blood vessels, and ligaments) may be injured at the time of the fracture. Both the broken bone and any soft-tissue injuries must be treated together. In many cases, surgery is required to restore strength, motion, and stability to the leg, and reduce the risk for arthritis [1].

The knee is the largest weight-bearing joint of the body. Three bones meet to form the knee joint: the femur (thighbone), tibia (shinbone), and patella (kneecap). Ligaments and tendons act like strong ropes to hold the bones together. They also work as restraints—allowing some types of knee movements, and not others. In addition, the way the ends of the bones are shaped help to keep the knee properly aligned [1].

Tibial shaft fractures are common injuries that can occur after falls, car accidents, sports injuries, and other activities. Tibial fractures come in different shapes and sizes, and each fracture must be treated with individual factors taken into account. In general, tibia fractures can be separated into three categories based on the location of the fracture. Tibial shaft fractures, tibial plateau fractures and tibial plafond fractures. A tibial shaft fracture can be treated by several methods depending on the type of fracture and alignment of the bone. The most common treatments include; casting, intramedullary (IM) rodding, external fixator and finally plates and screws [2].

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When a human bone fracture occurs, various types of internal fixation devices like bone plates are applied to the fracture site to promote bone structure stabilization. As a rule, such bone plates are used to fix long-bone fractures with several fastening screws and are usually made of non-corrosive metals such as stainless steel and titanium alloys [2]. Therefore, a pre-estimation of the stresses which may subject to those plates gains importance. Finite Element (FE) analysis has recently been used by numerous researchers to predict the structural behavior of the bone with plates under a considered load. Some of them, published in archival journals are listed below.

Kim *et al*. [3] investigated the healing efficiency of flexible composite bone plates applied to a tibia with diaphyseal oblique fractures. To construct the FE model, the time-dependent properties of living tissue (callus) were estimated using healing rates that were updated at every healing period using iterative calculations of the interfragmentary strain distributions according to oblique angles and plate properties.

FE analysis was carried out to estimate the interfragmentary strain distribution at the fracture site of a tibia according to the bending stiffness and contact conditions of composite bone plates with simplified rectangular cross-section, and polymeric porous layers at the contact area by Kim *et al*. [4]. They found that a composite bone plate with polymeric porous layers provided positive effects on callus generation at the fracture site, and effectively reduced the contact stress at the contact area.

FE analyses were performed by using the FE code COSMOS/M by Wong *et al*. [5]. The 3D "lower leg" FE model was used included the tibia and the fibula. The bony structures were generated by segmentation of a data set of computed tomography from the Visible Human Project.

Kim *et al*. [6] focused on the use of composite bone plates in healing long-bone fractures such as transverse fractures of the tibia using FE analysis by taking into consideration the contact conditions and the material property variations of calluses in relation to the healing period.

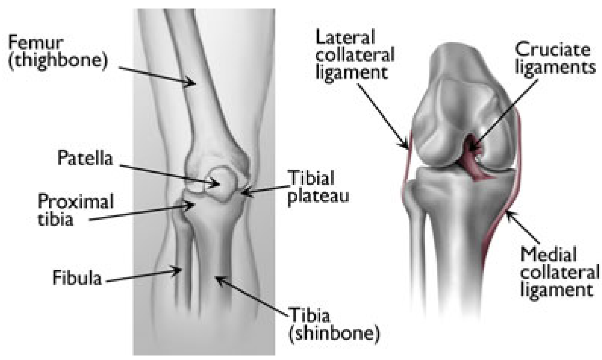
Aizat *et al*. [7] performed a numerical study which compared the stability provided by two commonly used implants (anterolateral plate vs. medial distal tibia plate) in treating these types of fracture. A 3D model of a six-part fracture fragment involving the distal tibia was reconstructed and simulated using computer aided software.

Degirmenci [8] analyzed the plaque fixation of human forearm fractures by using FE method. A 3D model of intact bones was based on the CT scan data and 1mm fracture gap modeled in CAD software. Forearm bone was fixed by four-holes and six-holes plaques and analyzed individually influence of varied load conditions and von-Mises stress distribution was calculated.

In this study, a numerical study which desires to estimate the stresses on the plate used to fix the tibia bone fraction was performed by using FE method. Tibia bone was fixed by four-hole plate and the fracture was assumed to have various angles, as 0˚ to 45˚.

2. Material and Methods

Human bones are composed of cortical bones and trabecular bones as indicated in **Figure 1**. Cortical bones are formed of dense and hard tissue with an anisotropic material property in the longitudinal and circumferential directions. In contrast, trabecular bones are sparse and weak, and are regarded as an isotropic material from a ma-



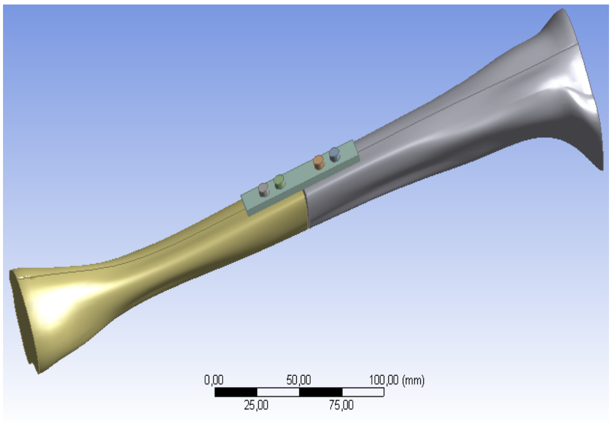
(a) (b)

Figure 1. Anatomy of tibia [1] (a) The proximal tibia is the upper portion of the bone, closest to the knee; (b) Ligaments connect the femur to the tibia and fibula.

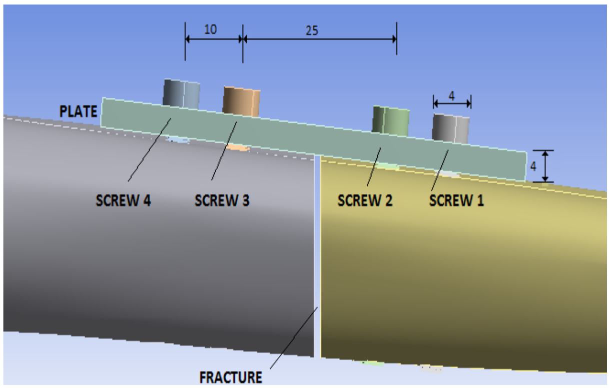
croscopic point of view [9].

Since the mechanical properties of tibia vary based on the gender, age and ethnic root, the researchers have not used any constant value in the numerical analyses. Hence an average sum from the literature is considered in the present study. The major bone properties used in FE analysis are summarized in **Table 1**. Furthermore, the density is assumed to be 4428.8 kg·m^{-3} for whole solid structure.

The titanium plate which is used for connecting the fractured bones and the screws on it is modeled 3D by using ASYSS Structure. The Workbench Static Analysis is used for creating the model. **Figure 2(a)** and **Figure 2(b)** shows the whole numerical model and a detailed section. The gap between the fractured bone parts is assumed to be 1 mm, and 4 screws were used for the connection. The angle of the fracture varies as 0˚, 15˚, 30˚, and 45˚. The dimensions of the screw and the plate are shown in **Figure 2(b)**.



(a)



(b)

Figure 2. (a) Numerical model (b) Dimensions of the plate and screws.

Table 1. Mechanical properties of the tibia bone.

	Young's Modulus E (GPa)	Poisson's ratio *v* (--)
Tibia bone	$E_1 = 11.7$ $E_2 = 12.2$ $E_3 = 20.7$	$v_{12} = 0.420$ $v_{13} = 0.237$ $v_{23} = 0.231$ $v_{21} = 0.435$ $v_{31} = 0.417$ $v_{32} = 0.390$
Titanium plate	104	0.31
Screws	104	0.31

A fine mesh is created by considering the size of the element near to the screw holes at least 0.005 mm, and using the free mesh algorithm (**Figure 3**). A fixed support process is applied to the bone, which means the lower part of the bone is fixed and the load is applied to the upper part first, and then the opposite way is done (**Figure 4**). A constant compressive load 750 N is subjected to the bone for each fraction angle.

3. Results and Discussions

Plates and screws are less commonly used, but are helpful in some fracture types, especially those closer to the

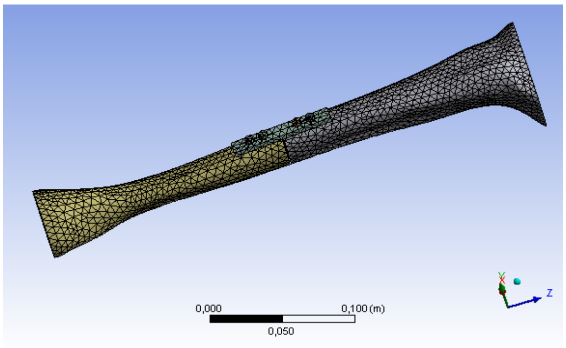
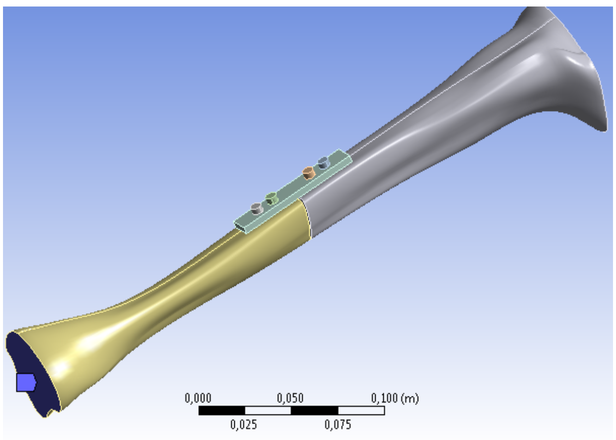
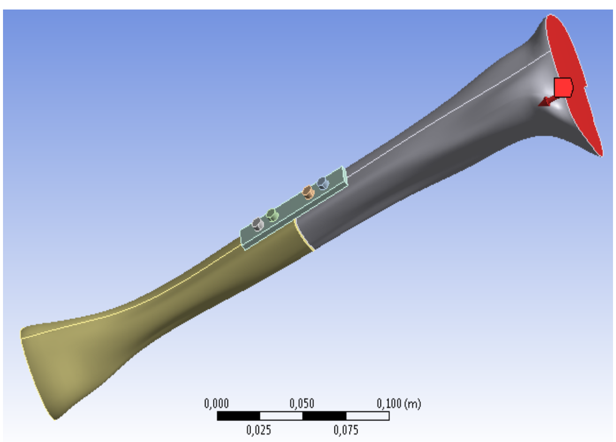


Figure 3. Mesh structure.



(a)



(b)

Figure 4. Applying boundary conditions.

knee or ankle joints. Most surgeons choose an IM rod for tibial shaft fractures unless the fracture is too close to the joint to allow for placement of the IM rod. In these fractures close to the joint surface, a plate and screws may be the ideal method of fixation [10].

The external loads generated by muscles near the fractured tibia produced bending deformation at the plate-bone assembly. Since this behavior, some interfragmentary strain at the fracture gap may generate. The inter-fragmentary strain strongly affects the generation and development of curing tissues, especially during the early bone healing process [4]. Therefore, estimation of von Mises stress under the compressive load (750 N) gains importance.

The von Mises stress around the screws and plate has been calculated. The results are shown in **Figure 5** and **Figure 6**. As clearly seen from the figures, the maximal Von Mises stress is obtained on the Screw 2, when the

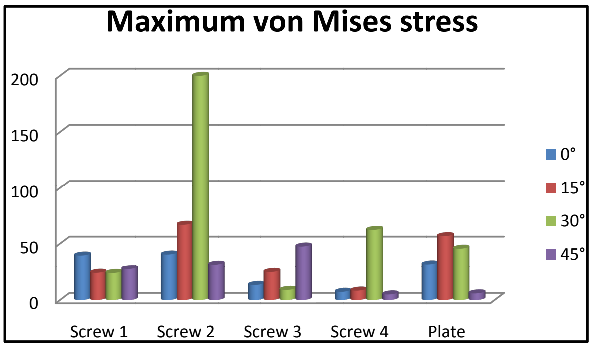
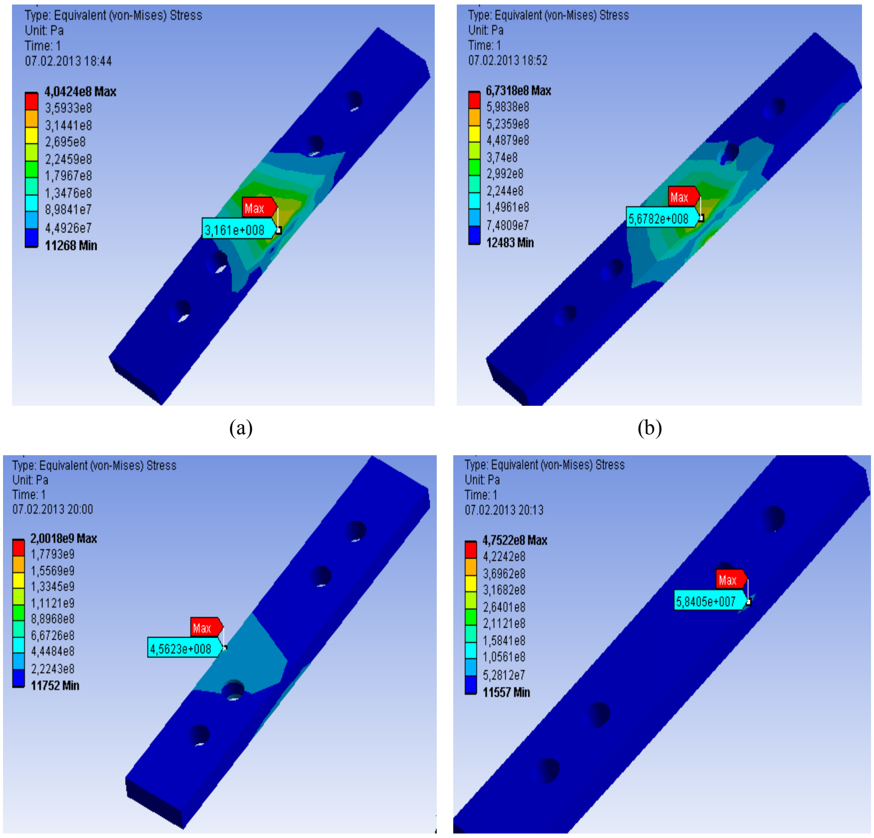


Figure 5. Maximal von Mises stress on the plate and the screws ($\times 10^7$ GPa).



(a) (b)

(c) (d)

Figure 6. Contour plot for the maximum von Mises stresses (a) 0˚; (b) 15˚; (c) 30˚; (d) 45˚.

fracture angle is 30˚. It is evident that the Screw 2 is close to the fracture so it is an expected situation. The minimum von Mises stress is found when the fracture angle is 45˚ on the Screw 4.

4. Conclusion

The purpose of the present study is to evaluate the use of the maximal Von Mises stress calculated by finite element analysis as a measure for examination of the fracture mechanisms of the tibia bone. The maxima stress is found on the screw next to the fracture gap. It is also found that the fracture angle 30˚ causes the highest stress on the screw and the plate.

Acknowledgements

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