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THE STRESS ANALYSIS OF HUMAN TIBIA UNDER AXIAL LOADING USING FINITE ELEMENT METHOD

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ABSTRACT

Carrying loads, supporting and protecting the organs, and enabling locomotion, thus making strength and rigidity are the basic functions of bone. Prevention of bone fractures are major interests worldwide since bone fracture, such as shoulders, femoral, tibial fractures etc. The aim of this study is to obtain analysis of loaded areas over a full tibia according to applied axial loading via a three dimensional finite element model. A whole tibia of a healthy adult male was scanned using computer tomography (CT) device A 3-D model of tibia was produced from the data of these slices. 3D tibia was imported to ANSYS. Cortical and cancellous bone materials were assumed to be linear, elastic, isotropic and homogenous which has been found adequate for most studies of bone stress and strain analysis. The model was automatically meshed, 10 mm into three-dimensional 10-node tetrahedral elements (SOLID 92) using ANSYS. The model was analyzed for compressive forces, such that 750N, 900N and 1000N were uniformly distributed over the joint surface of the tibia and distal tibia was fully constrained. Von Mises stress on the tibia naturally increased with increasing axial loading. The biggest planar compressive stress was observed on the XZ plane. The biggest directional shear stress was observed on the X direction. Directional compressive stresses on the tibia vary. There was not a significant change in the stresses in both Y and Z directions as the axial compressive load was increased.

Keywords: Axial loading, Bone, Tibia, Finite Element Method

1. INTRODUCTION

Three-dimensional (3D) finite element (FE) analysis have widely been used to study the biomechanical behavior of bone in advanced research and consequently involving the theory of bone, modeling, interaction of bone and muscle, the design of implants as well as the evaluation of fracture risks in clinical applications.

Many investigators focused on an extensive experimental validation of mechanical behavior of the whole bone composite model and bone holding power, and have worked to acquire a thorough understanding of the load sharing mechanism between implant and bone in a fractured tibia under physiological-like loadings [1-2].

Additionally, FE methods are widely used in understanding load transfer in prosthetics and assessing prosthesis performance. Several FE models have been developed based on certain assumptions.

Relatively few finite element studies have examined the proximal tibia. The intact and implanted tibia has readily been analyzed using axi-symmetric two-dimensional and three-dimensional FE models [3-4]. Medial open wedge tibial osteotomy is a current surgical intervention for the correction of varus knee deformities [5].
Recently in the field of orthopedics, numerous mechanical analyses using FE method have been carried out on stresses and strains occurred in bones. These methods are particularly useful for estimating mechanical circumstances in a bone while alternating conditions that cannot be measured by mechanical tests in vivo [6].
From this point of view, this study therefore concerns a three dimensional modeling of tibia using FE methods, and analyzing compressive and shear stresses on tibia in response to axial loadings.

2. MATERIALS AND METHODS

A whole tibia of a healthy adult male was scanned using computer tomography (CT) device (Philips Medical Systems Nederland B.V.) at Radiology Department of Faculty of Medicine (Inonu University, Malatya, Turkey), for a length of 444 mm compiled with 148 slices of 3mm thickness.
A 3-D model of tibia was produced from the data of these slices. The data was first imported into MIMICS (Materialise), and the threshold method was used to differentiate between the cortical and cancellous bone regions and the bone marrow cavity. 3D tibia model obtained by MIMICS program was imported to ANSYS (Fig 1), as well as the mechanical properties of bone were also imported to ANSYS via MIMICS. Cortical and cancellous bone materials were assumed to be linear, elastic, isotropic and homogenous which has been found adequate for most studies of bone stress and strain analysis [7-8]. The cortical and cancellous bone were assumed to have a Poisson's ratio of 0.3 and an elastic modulus of 17000 MPa and 700 MPa [9-10], respectively.
The model was automatically meshed, 10 mm into three-dimensional 10-node tetrahedral elements (SOLID 92) using ANSYS (Fig. 2). The whole FE model consisted of 152052 elements, 227056 nodes. SOLID92 tetrahedral element is the best choice for meshing human bone, because these elements have quadratic displacement behavior they are thus well suited to model irregular geometries [11].

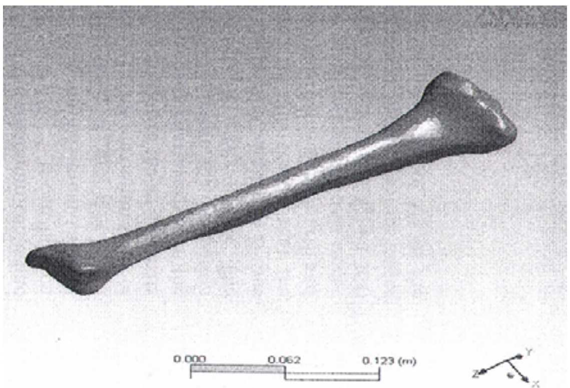

Figure 1. The 3-D tibia bone model

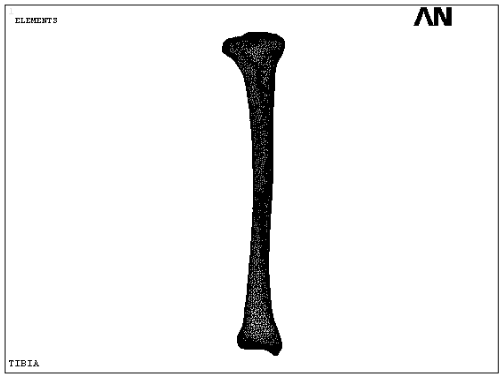

Figure 2. Finite element mesh of tibia

The model was analyzed for compressive forces, such that 750N, 900N and 1000N were uniformly distributed over the joint surface of the tibia and distal tibia was fully constrained.

3. RESULTS

It is known that the tibia bone is one of the most cracked bones, and it is too difficult to fix it. According to the Swiss National Insurance reports, in 1945, it has been reported that 40% of cracks occurred in tibia and fibula have caused permanent defects [12]. It has been reported that, for a sportsman, in case of a cracked fibula and tibia 40 weeks, an only tibia 35 weeks and an only fibula 18 weeks requires for recovery [13]. It has been reported that in England for such fractures without surgical treatment approximately 2226 pounds and in surgical case 3272 pounds need to be spent. Further in case of shortened tibia, osteoarthritis and the time loss which in fact has the most precious corporal and moral effect nothing to evaluate.

Analyzing of bone fracture can be carried out by using Von Misses criteria. The approach can provide useful information for examination of bone under various stresses. The total stress increases as the load is increased according to Von Misses criterion. (Fig. 3 and 4)

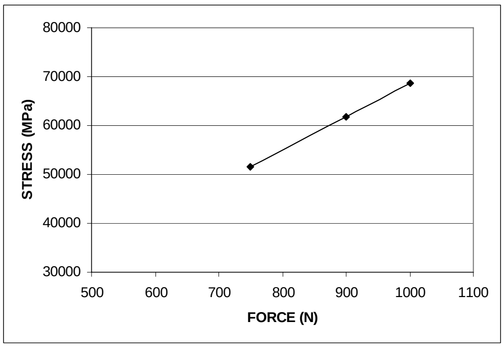

Figure3. Stress analysis of tibia under axial loading condition according to Von Mises Criteria

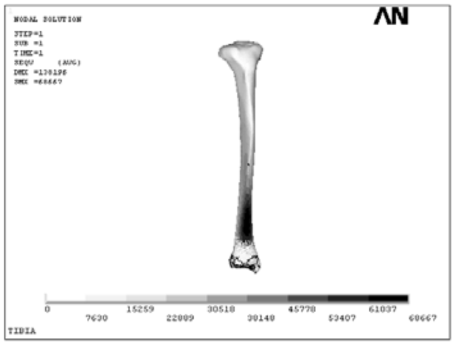

Figure 4. Stress analysis of tibia according to Von Misses Criteria

From the planar compressive stress analysis, the result is shown in figure 5, it can be observed that the planar compressive stresses also vary; while XZ and YZ planar stresses increased with the increase of the axial load there was not a valuable change in XY planar stress. Noticeably the XZ stress was greater than YZ stress and both were much greater than XY stress in all axial loading values (Fig. 7). The directional shear stress analysis revealed that while the shear stress in Y direction did not change, it is increased in Z direction and much apparently increased in X direction with the increase of the load. The shear stress in X direction was much greater than that in Y and Z direction, figure 6 and 8.

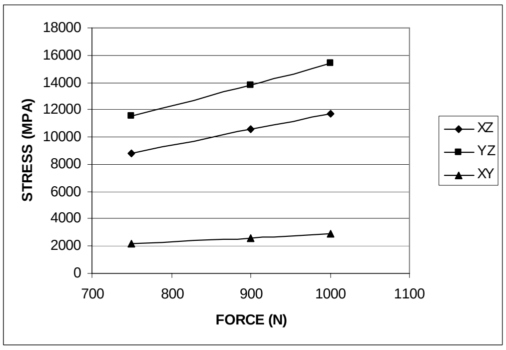

Figure 5. Planar compressive stress analysis of tibia under axial compression loading

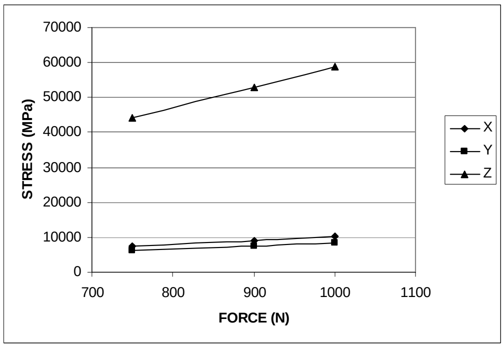

Figure 6. Shear stresses on the tibia under axial compression loading.

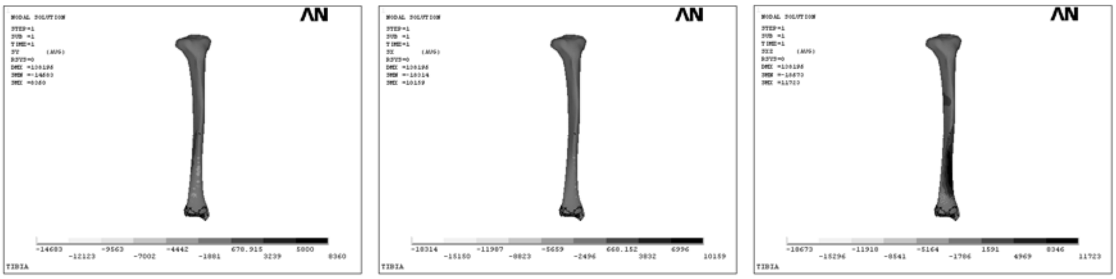

Figure 7. Planar compressive stresses on XY, YZ and XZ direction of the tibia, respectively

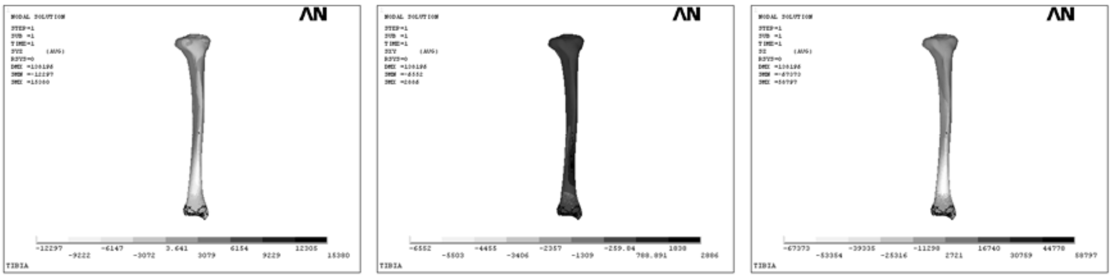

Figure 8. Shear stresses on X,Y and Z direction of the tibia, respectively

4. CONCLUSION

- Von Mises stress on the tibia naturally increased with increasing axial loading.
- The biggest planar compressive stress was observed on the XZ plane.
- The biggest directional shear stress was observed on the X direction.
- Directional compressive stresses on the tibia vary. There was not a significant change in the stresses in both Y and Z directions as the axial compressive load was increased.
- As can be clearly observed from images shown in figure 4,7 and 8, the Von Mises stress, the directional and planar shear stresses increased as gone toward the tibia's distal apex, and reached to a maximum value at the narrowest cross-section of tibia, where most of the fractures do occur in practice. Indeed, this weak bony area is much supported by the muscle tissue in real life, and so makes it strong enough.

In this perspective this work is important in understanding the behavior or tibia exposed to dynamical forces, and this study may also be helpful in specifying the implant materials that need to have well adaptation to the implanted tissue. However for elucidation of such implants further works are required.

5. REFERENCES

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