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The Stress Distribution Effects Comparisions of Fixed and Broken Fibula, a Finite Element Study

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Abstract: This study aimed to implement the Finite Element (FE) method to analyze and investigate the stress distribution effects of broken fibula on lower extremity under the body weight and moment. The congruent three-Dimensional (3D) solid models of lower extremity bones (tibia and fibula) were generated using the Computerized Tomography (CT) images. After modeling processes, 3D model was converted to FE model to apply the loading and the relevant boundary conditions to obtain the stress distribution on the tibial zone. It was obtained that the fibula had an important stress distribution role on tibia. Especially, according the all FE analysis fibula is an effective duty of load carrying capacity on distal side of tibia. These FEA suggested that the loading characteristics of the fibula should be taken into account in planning medical and surgical operations.

Key words: Stress distribution, finite element analysis, bio-modeling, computerized tomography, tibia, fibula

INTRODUCTION

Tibia is one of the most important structures for bearing body weight in the lower extremity system (Matheson *et al*., 1987; Giladi *et al*., 1985; Iwamoto and Takeda, 2003). Fibula is long and thin bone also part of lower extremity which situated lateral side of tibia. Tibia and fibula are almost the same size and fibula is placed distally. Therefore, upper end of fibula is located further down and fibula is not involved in knee joint structure. Distal and proximal fibula fractures are among the most common injuries seen and treated by foot and ankle surgeons. It has been shown that in literature when the distal fibula is involved, anatomic reduction and secure fixation of the lateral malleolus are of key importance to a good outcome (Hughes *et al*., 1979; Joy *et al*., 1974; Pettrone *et al*., 1983; Svend-Hansen *et al*., 1978; Yablon *et al*., 1977; Heim and Pfeiffer, 1988; Allgower, 1991). In contrast that when fracture became both tibia and fibula commonly only tibia fixed with plates. A question comes after what was the load bearing capacity of fibula and effects on tibia? In order to determine the load carrying capacity of fractured fibula by using non-surgical techniques played an important role on bone regularity on lower extremity. In this study, stress distribution effects of fibular fracture and effects on tibia was detailed and compared using with Finite Element Analysis (FEA).

MATERIALS AND METHODS

Modeling solid bone structures: In the field of medicine, computer-aided planning has frequently been used in recent years before surgical operations, conducted through such imaging techniques as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI). In this study, the main model was also modeled via CT images. CT images of the lower extremity bones were obtained from a female patient aged 33 using a Toshiba Aquilion CT scanner in the Department of Radiology of the Faculty of Medicine. CT images consist of parallel layers having a section range of 0.774 mm at the neutral position and a pixel resolution of 512×512. A 2551-layer shooting was carried out to develop the model used as reference. Images were recorded in the Digital Imaging and Communications in Medicine (DICOM) format. These images were then transferred to the MIMICS 12.11 program which is 3D image-processing software. In order to develop problematic surface details with reverse engineering software GEOMAGIC® was used (Fig. 1).

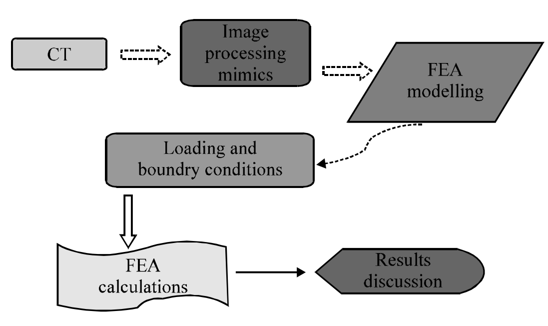

Fig. 1: Flow chart for 3D bone structures modeling

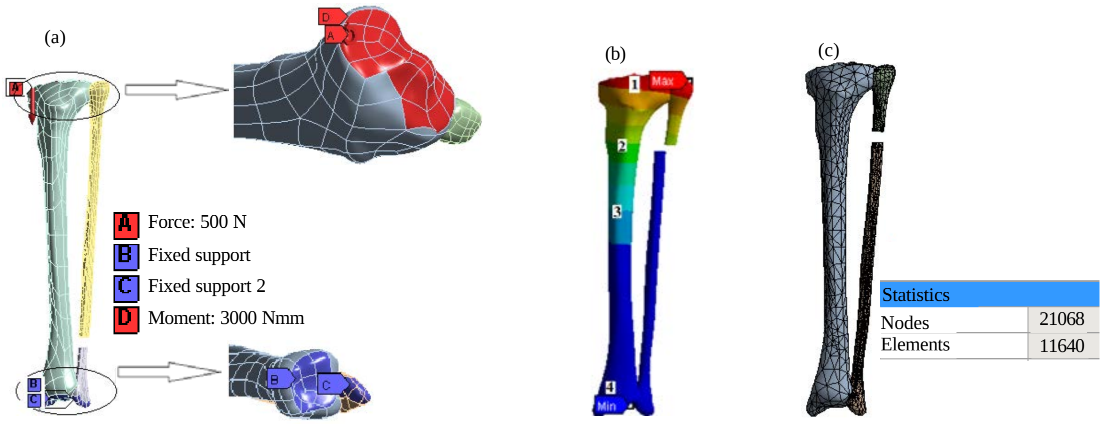

Fig. 2: Tibia-femur model for finite element analysis: a) Loading and boundary conditions; b) Selected zone points of tibia; c) Mash properties

Table 1: The isotropic material properties of bones (Pena *et al*., 2005)

Structure	Elastic modulus (E, Gpa)	Poisson's ratio (v)	Bulk modulus (Gpa)	Shear modulus (Gpa)
Tibia	17	0.3	14.167	6.538
Fibula	5	0.3	4.166	1.923

Broken and fixation models were completed digitally in the computer environment through the MIMICS program and all models were obtained. All bone structure 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 elements models were obtained by transferring them into the MIMICS Finite Elements Analysis (FEA) module content in Stereolithography (STL) format. The volumetric meshes were generated for the assembled biomodels. Finite element models were generated in MIMICS® and transferred to ANSYS® Workbench. The material properties in FEA was given in Table 1.

The stress distribution effects of fibula on tibia

Finite element model details: The effect of stress distribution in consequence of axial loading and torsion of fibula working together tibia as a structure was obtained with FEA. In order to carry out this calculation, congruent 3D Finite Element Model (FEM) of tibia and fibula constituted lower part of knee mechanism were used. The mechanical connection of fibula with tibia was described using model in MIMICS® transferred to ANSYS® Workbench and axial loading was applied with direction to mechanical load-bearing axis of lower extremity. Torsion were also applied as a rotation moment on mechanical axis of body in the same manner.

The load exerted on the foot bones changes depending on the movement of a human body and the standing position. The fact that the load exerted by the body is transferred through the hip and knee joints was taken into consideration to calculate the stress-carrying capacities of the elements forming the lower extremity. In the study, effective body force was 500 N and rotation moment for rotational analyses was 3000 N mm applied. The boundary conditions and loading position is shown in Fig. 2a. About 4 regions were selected on tibia for stress results comparisons (Fig. 2b).

About 10 node tetrahedral elements were used to form the mesh of the finite elements models. Computer-aided finite elements analysis aimed at comparing the stress distributions was carried out through ANSYS WB software. Mesh properties can be seen on Fig. 2c.

RESULTS AND DISCUSSION

The effects of body force which applied on the surface of tibia plateau that connected with cartilage were investigated. Under the same loading conditions, the effects of rotation moment on the intact model were analyzed. In this analysis, the effects of stress values caused by axial loading and rotation moments were evaluated on all models (fixed, proximal and distal fractured fibula). A comparisons were performed between intact fibula and fractured fibula models for evaluating existence functions of fibula when load bearing (Fig. 3 and 4a, b).

The results were obtained from finite element analysis method suggests that were successful in creating tibia and fibula also fractured fibula models that can reveal the characteristics of the bone without having bone samples. This femur model allows repeating different

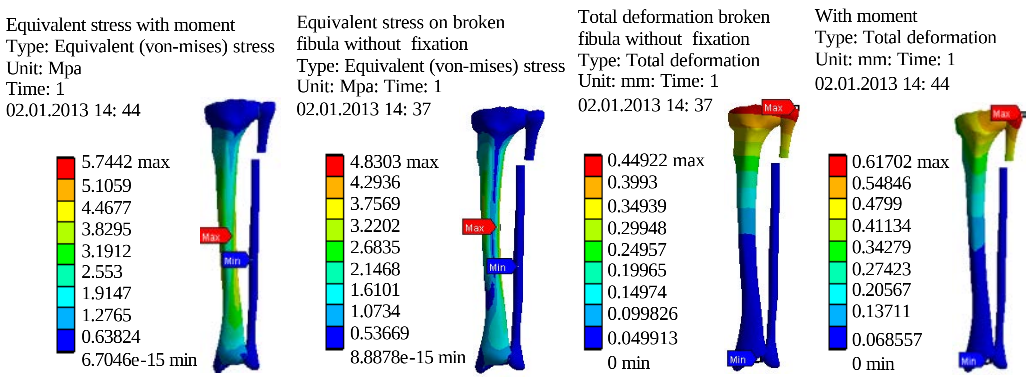

Fig. 3: The displacement and stress values of tibia with proximal fractured fibula (not fixed)

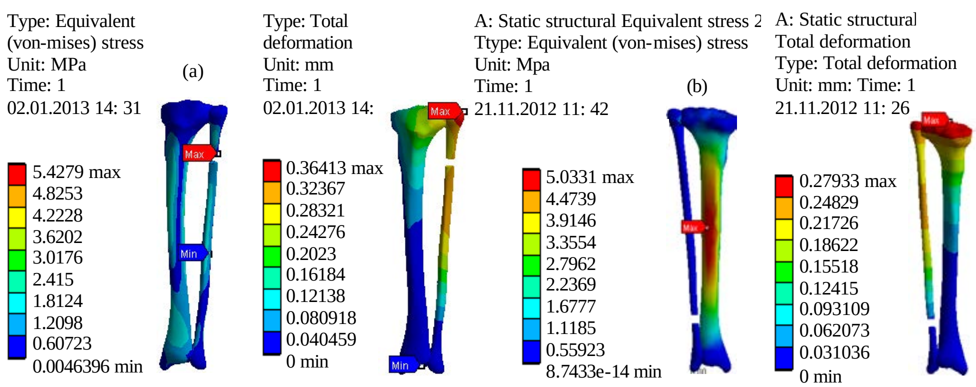

Fig. 4: The displacement and stress values of tibia with distal fractured fibula (fixed): a) Proximal fracture on fibula; b) Distal fracture on fibula

biomechanical methods at choice, as well as calculation of variations in the mechanical responses. Some factors that can influence the results of finite element analysis method are of great importance. One is that, the 3D structure of the bone in question should be generated separately for each model by computed tomography images. While creating the model, using as much as possible elements makes it more comparable to the true geometry (Comelekoglu *et al*., 2007). Another factor is to describe the characteristics of bone materials in a much more detailed, while denoting the direction and application point of the force more accurately (Comelekoglu *et al*., 2007).

The finite element analyzes results showed that there were stress distribution effects of fibula on tibia bone. The stress values acquired on four selected regions of tibia were given in Fig. 2b and 5a, b. Additionally, stress values decreased significantly on tibia with intact fibula, especially when rotation force was applied.

Total deformation values were evaluated with finite element analysis (Fig. 6). For these results fixed (intact) fibula had less deformation than the fracture ones.

The stress amounts of fourth region caused by rotation moments are illustrated as a graph in Fig. 5. It is

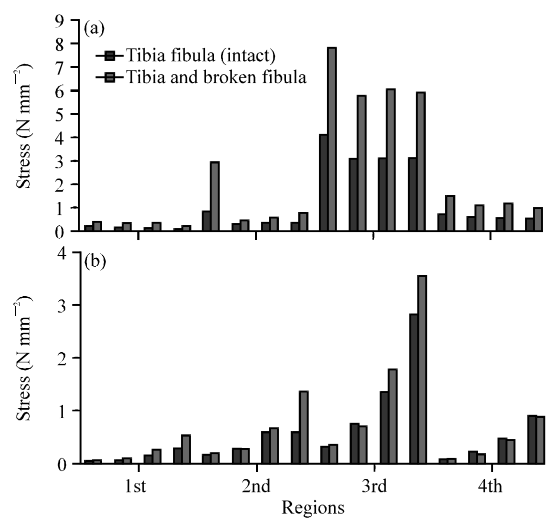

Fig. 5: Stress values for specific zones of tibia: a) Stress distribution on tibia under force applied; b) Stress distribution on tibia under moment applied

determined that the fixed model had less stress distribution than the broken fibula under the same

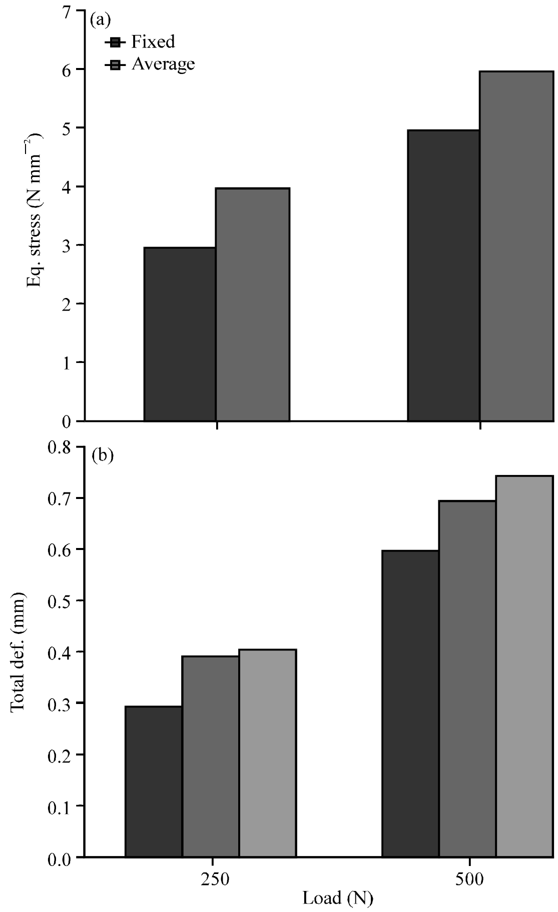

Fig. 6: Stress and deformations results

loading condition. As a result, it is pointed out that there is a function of fibula in load bearing.

CONCLUSION

It can be concluded that the fixation of fibula affected positively instead of all proximal and distal broken fibula. For this, fibula can be fixed in surgical operations for increasing load bearing capacity of tibia.

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