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VIRTUAL COMPARATIVE STUDY ON THE USE OF NAILS AT THE FIXATION OF TIBIAL FRACTURES USING FINITE ELEMENT METHOD

G. Buciu[1], D.L. Popa [1], D. Grecu[1], D. Niculescu[1], R. Nemes[1]
[1] University of Medicine and Pharmacy Craiova, Faculty of General Medicine, Craiova, ROMANIA,
buciugabriel@ yahoo.com, popadragoslaurentiu@yahoo.com, grecudan@ortopezi.ro,
niculescudragos@yahoo.com, nemesraducu@yahoo.com

Abstract: *Tibial shaft fractures are the more frequent fractures of lower limb. For this purpose was used a CAD parametric software which permits to define models with a high degree of difficulty. First, were defined the main bone components as tibia using CT images. These images were transferred to AutoCAD where the outer and inner contours of the bone were approximate to polygonal lines composed by many segments. These contours were transferred to SolidWorks where, step by step, and section by section, was defined the virtual tibia. At the first time the tibia was complete and, after that, was divided in 2, 3 or more components to simulate different types of fractures. Using the direct measurement method were generated the virtual metallic components as nail and orthopedic screws. All these virtual components were combined to obtain four cases of tibia fractures studies. The virtual models were exported to a software for kinematical and FEA simulation. Using similar initial parameters for each studied case (as total force and torque) were obtained dynamic maps of stress, strain and displacement. These results were analyzed and compared and, in the final, were extracted important conclusions.*
Keywords: *tibial fracture, virtual bones, biomechanics, CAD, FEA*

1. INTRODUCTION

Tibial shaft fractures are the second most common after distal radius fractures and the more frequent fractures of lower limb, their frequency is 15-20% of all fractures in adults.
Fractures of the shaft of the tibia cannot be treated by following a simple set of rules.
By its very location, the tibia is exposed to frequent injury; it is the most commonly fractured long bone. Because one third of the tibial surface is subcutaneous throughout most of its length, open fractures are more common in the tibia than in any other major long bone.
Furthermore, the blood supply to the tibia is more precarious than that of bones enclosed by heavy muscles. High-energy tibial fractures may be associated with compartment syndrome or neural or vascular injury.
The presence of hinge joints at the knee and the ankle allows no adjustment for rotary deformity after fracture, and thus special care is necessary during reduction to correct such deformity.
Delayed union, nonunion, and infection are relatively common complications of tibial shaft fractures [1].

2. THREE-DIMENSIONAL MODELING OF THE BONE COMPONENTS FOR THE KNEE HUMAN JOINT

To obtain tomographic imaging of the bone components were used two main bones of the human knee: tibia and femur. The experiment was conducted using CT installed at County Hospital Emergency of Craiova.
To further define the three-dimensional models of bone was used a fixed reference as an plastic rod whose dimensions were measured. Also, this plastic bar was subsequently used for tomographic image scaling and bringing them to the natural size [2], [3].
Tomography machine allows to obtain images in DicomWorks format, a specialized software for obtaining images and their management.

Were obtained 4 folders with a total of 143 images grouped by areas of computer tomography scans. In Figure 2 were shown six images of the tibia.

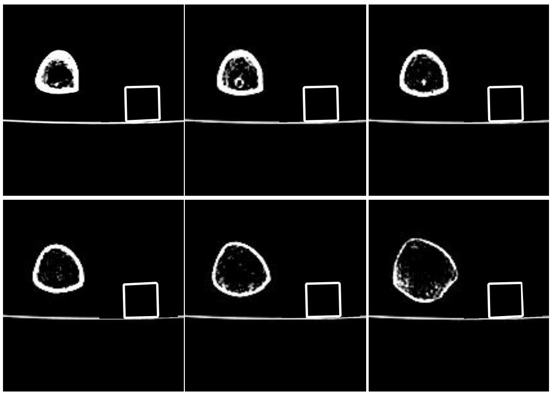

Figure 2: Six tomographic images of tibia

Cross-sectional fixed mark appears in cross section in the tomographical image (Figure 3.).

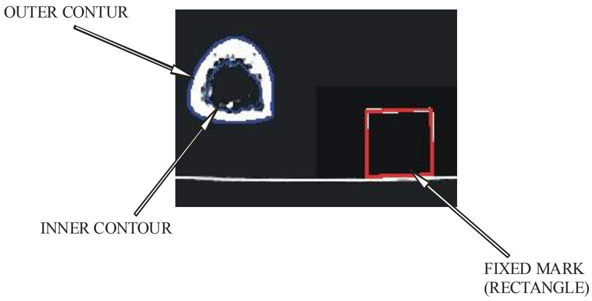

Figure 3: Tibia nearby the fixed mark in cross section

To obtain tomographic images we used a scanning scheme shown in Figure 4 based on the use of parallel planes placed at 1 mm distance for bone extremities and 3 mm medial areas [4].

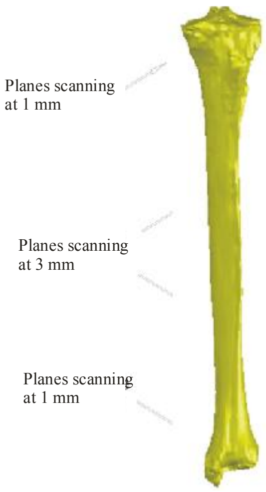

Figure 4: Tomography scheme used for tibia

Images taken by computer tomography in Dicomworks format were exported and converted to Windows Bitmap files, and they were organized in separate folders considering the areas highlighted in scanning scheme. These images compatible with most Windows-based files were loaded one-by-one in AutoCAD. The computer aided design software allows defining two-dimensional non-parametric models.
First, the images were loaded into the program to determine the scale at which they were performed by computer tomography. For each tomography image contains a fixed benchmark and comparing the size of the actual image size was determined the scale of these images were loaded into AutoCAD, so the images appear at natural scale 1: 1. For the begining, over loaded image in Autocad and properly scaled to size were drawn the inner and the

outer contours of the bone and a square with sides of 20 mm corresponding to section bar used as a fixed reference point (Figure 4). These contours were transferred successively into a three-dimensional parametric design software - Solidworks (Figure 5). In this program were initially defined several parallel planes at a distance of 1 mm or 3 mm, according to the tomographical used scheme [4].

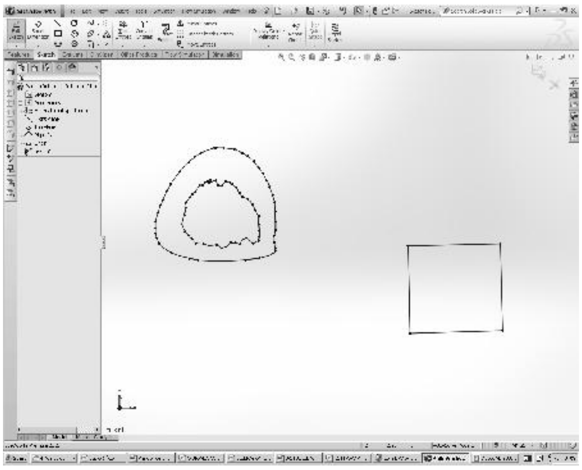

Figure 5: The contours transferred in SolidWorks

This operation of defining and transfering of the contours in Solidworks was repeated for each CT scan image. To obtain a parametric solid were "unified" outer and inner contours in a loft-type form (Figure 6).

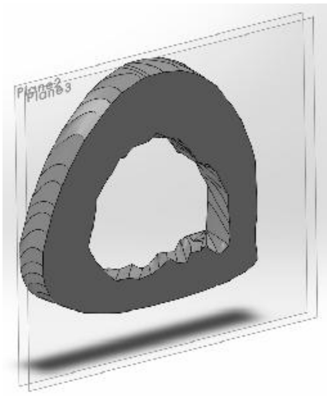

Figure 6: Segment of virtual tibia

Repeating these steps were obtained the tibia and femur models shown in Figure 7.

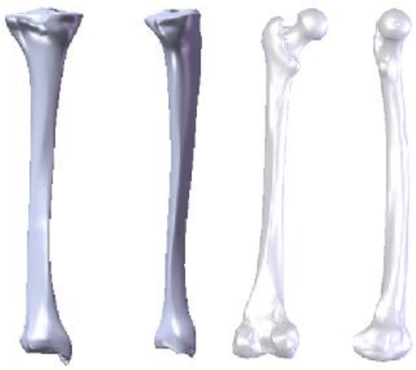

Figure 7: The final model of tibia (4 views)

In SolidWorks were defined similarly, metal components used in fixation of fractured tibia. In Figure 8 are presented a rigid nail, a flexible nail and an orthopedic screw obtained by direct measurement and observation.

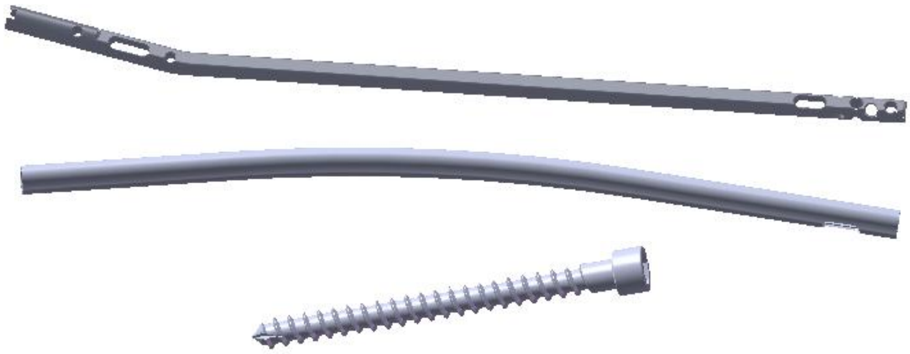

Figure 8: Metallic components used for tibial fixation

3. RECOMPOSING HUMAN WALKING AND MAIN KINEMATICS PARAMETERS USING IMAGE ANALYSIS METHOD

To recompose a human walking kinematics analysis program for the begining was filmed a human subject during the stepping cycle. Obviously, several cycles were filmed, and we selected the stepping cycle complete and relevant. The subject was filmed providing special conditions:
- Subject stepping cycles performed on a straight lane
- On a wall parallel to the direction of travel, were glued parts whose dimensions are known;
- Position of the camera in 3D coordinates are known;
- Human locomotion system joints (hip, knee, ankle) were put out by landmarks;
- Complete movement cycle was reported at a fixed reference point located at the bottom right of the wall using AutoCAD (Figure 9).

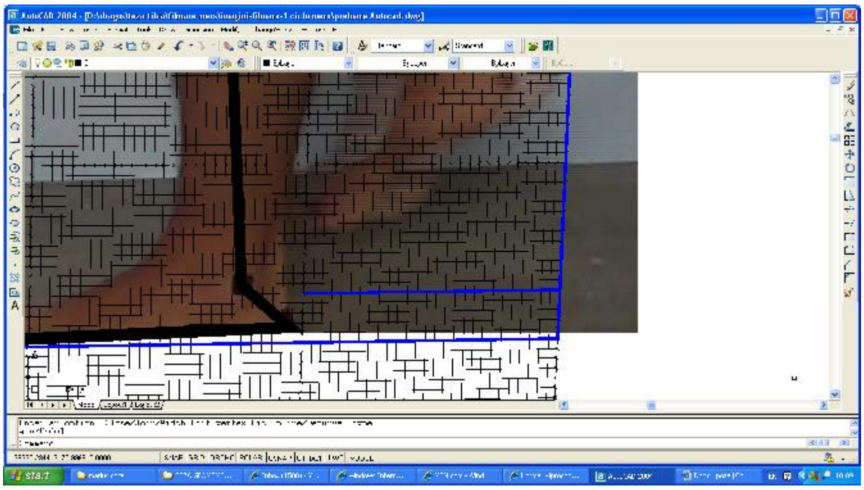

Figure 9: The position of the origin of the fixed coordinate system

Every frame of the walking cycle movie was analyzed, every joint was measured and after several calculus were determined the angular mathematical fuctions for the human joints (hip, knee and ankle). These functions were the initial transposed to a biomechanical model of the human lower limbs. After several speciffic operations was obtained the kinematic simulation. In Figure 10 were presented the main frames of the kinematic simulation, similar in [5].

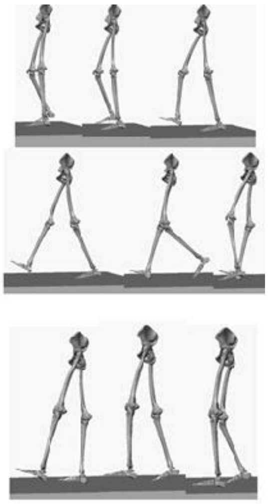

Figure 10: Main walking simulation frames

Also, the kinematic software gives important data as the forces and torques which have the action on the tibia bone. These evolution vs time of force and torque were applied on the two ends of tibia in several situation of fixation using tibial nail. In the next figures were presented stress maps obtained by FEA analysis applied on different types of tibial fracture.

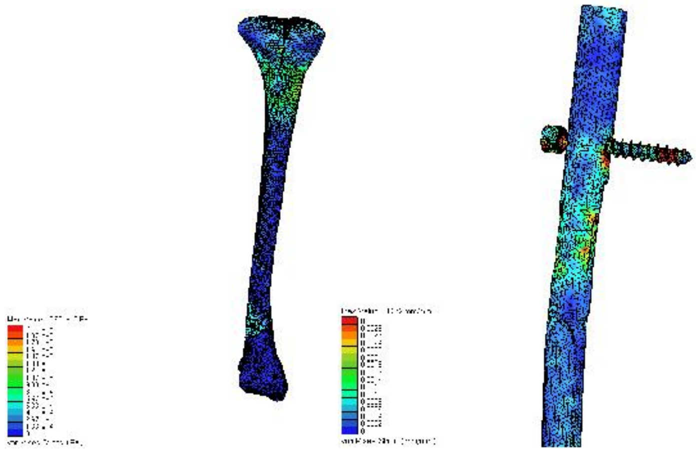

Figure 11: Stress and strain maps in the case of cominutive fractures.

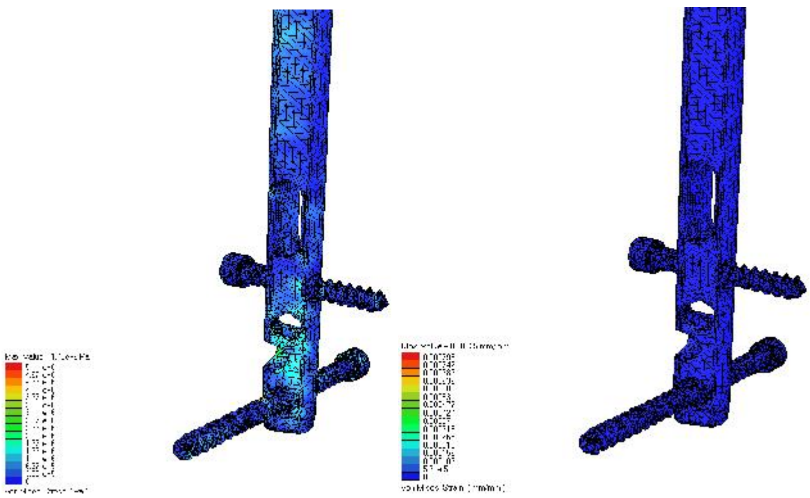

Figure 12: „Butterfly wing" tibial fracture stress and displacement maps

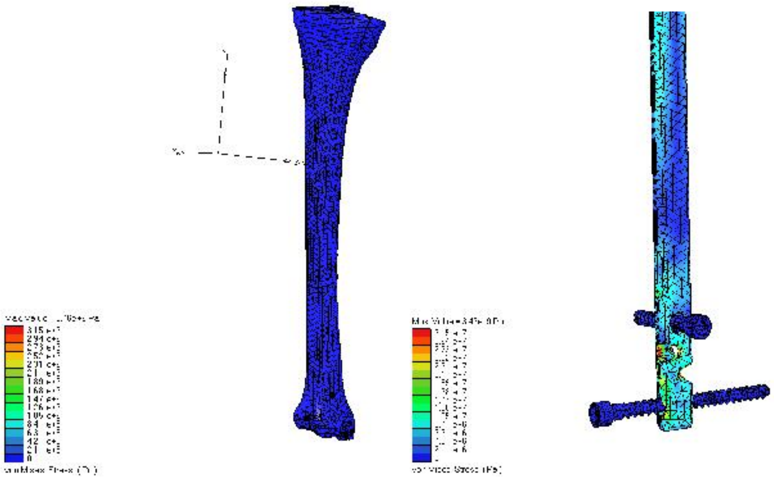

Figure 13: Common tibial fracture stress maps.

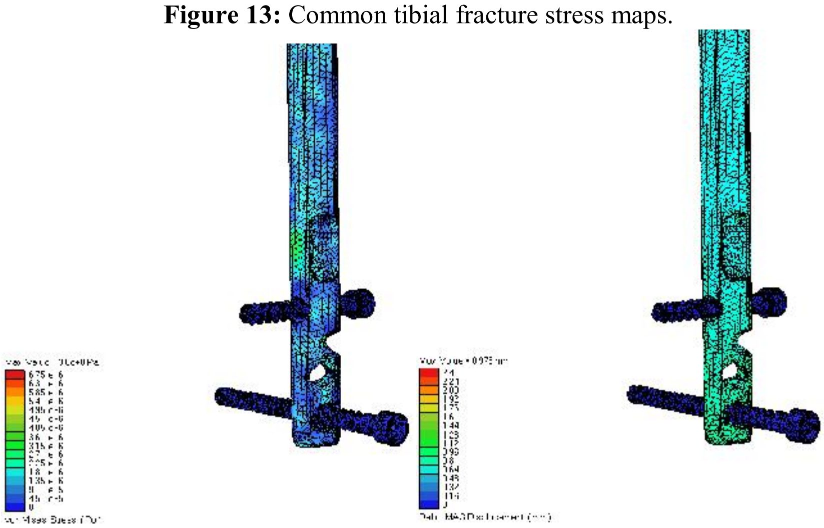

Figure 14: Double tibial fracture stress and displacement maps

4. CONCLUSIONS

Analyzing the dynamic stress, strain and displacement maps were extracted next conclusions:
- a complete analysis suppose a complex study including many converging simulations;
- an entire and complete analysis can not be possible without CAD, FEA and kinematic software;
- these analysis open the way to the virtual prototyping for the new types of tibial nails, orthopedic screws, plates and any other metallic components used for bone fixation;
- in the all tibial fractures cases studied and analyzed the maximal stress was disposed on tibial nail and screws;
- a combined study supposed a cooperation between many field researchers as engineering and medical specialist.

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