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MODELING AND ANALYSIS OF A TOTAL KNEE PROSTHESIS

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Abstract: *Total knee arthroplasty is one of the most commonly performed procedures in the field of adult reconstructive surgery and the number of procedures continues to increase. [1]*
This paper proposes a model of total knee prosthesis. The prosthesis geometry is established based on 3D reconstruction of CT images. Using Mimics and Magics software, 3D solid models of the tibia and femur are obtained. The designed prosthesis has two main metallic components (femoral and tibial component) and an intermediate plastic component. Thus, the space between the two metal inserts is filled with high density polyethylene which is resistant to wear but decreases the amount of friction between the two metal plates.
The mechanical behavior of the proposed prosthesis is studied based on numerical analysis, using ANSYS software. The stress and strain distributions are determined.
Keywords: *total knee prostheis, 3D modeling, numerical analysis,*

1. INTRODUCTION

The goal of knee replacement is to relieve pain, improve the life quality, and maintain the knee function. Knee arthoplasty is a surgical procedure in which parts of the knee joint that have been damaged, usually by a form of arthritis, are replaced with an appropriate prosthesis. Many sizes of knee prostheses are available on the market, so it is generally possible to have an implant which fits perfectly to the patient bones.
The knee joint is a sliding joint on a cylindrical surface. During walking, at the flexion- extension movement, the tibial bone rotates around the femur towards forward. The kinematics of the knee is very complex due to the shape of the contact surfaces and especially due the positioning of ligaments and muscles.
For designing of a knee prosthesis we can use the dimensions presented in the domain literature, as well as the dimensions obtained with the help of images from CT.

2. DESIGN AND MATERIALS

The dimensions and geometry of the prosthetic given have been set based on the reconstruction of the CT images. The superior part of the prosthesis has the shapes of the femoral condyles, following in detail their shape. Replacing the surface has the advantage of minimum loss of bone mass. The prosthesis stability is maintained by lateral ligaments stability and integrity.
After setting the dimensions the prosthesis should be modeled, with help of the Solid Edge V19 software.
To begin the procedure the *Part* module must be run. In the initial window the *Sketch* option is selected, then the plan in which the base of the implant must be placed. After developing the base of the implant (figure 2.1) we must come back to the Part module.
The *Extrude* option must be choose next, which allows thickness to the plane figure to be created. After executing this command a solid figure shaped in figure 2.2 is obtained.

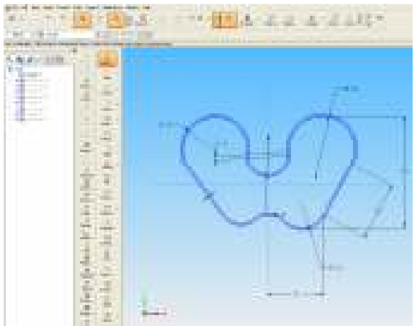

Figure 2.1: Developing the base of the implant

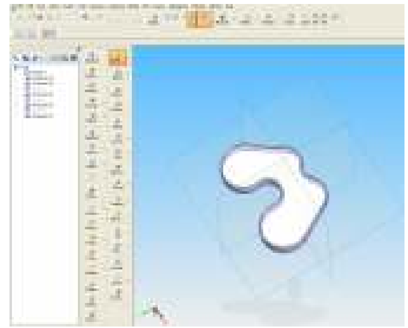

Figure 2.2: The base of the implant-the final piece

The femoral part is shaped like an encampment which fits exactly on the femoral side after it has been adjusted. In each medial femoral condyle a body of few centimeters will be implant.

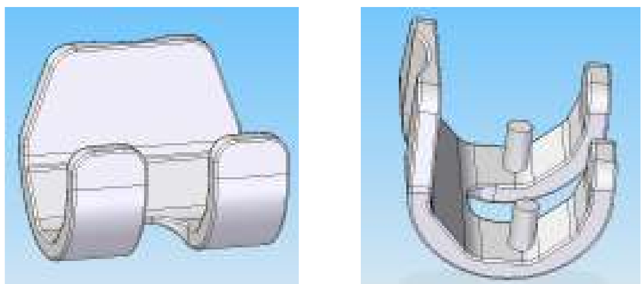

Figure 2.3: Femoral component of the total knee prosthesis

A highly conforming femoral surface geometry minimizes the possibility of excessive linear wear or fracture of the polythene through local overloading. At the same time, a freely moving interface between the tibial baseplate and the polythene bearing dissipates much of the torque on the tibial component. The aim is to achieve stable long-term fixation with minimal generation of polythene wear debris and related bone lysis [2]

The tibial part has a flat form tied to a stem which fits over the tibial plateau. On this implant a part made of a plastic material with high friction endurance must be placed, a part of high density polyethylene. This has a cavity as a joint.

With help of the *Boolean* command, the appropriate shape has been given to the component of polyethylene.

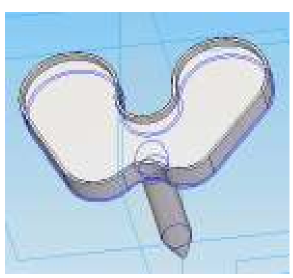

Figure 2.4: Thibial component

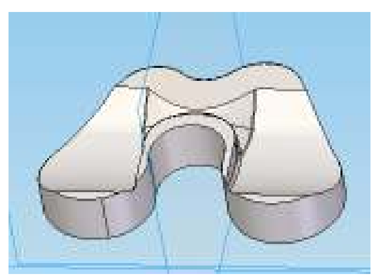

Figure 2.5: The polyethylene component

The stem which will fasten the implant into the tibial bone, has a conic shape, especially towards the top which will be introduced into the tibial bone, this representing the bond between the tibia and the part of the implant fixed on the tibial plateau.

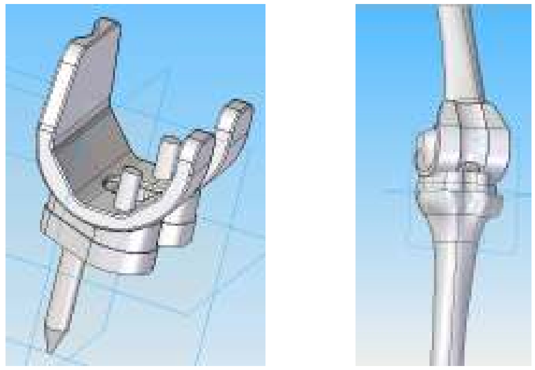

Figure 2.6: Designed total knee prosthesis

The material used is titanium grade 2, especially on the parts implanted into the bone, because of its advantageous properties: biocompatibility, low thermal conductibility, low density, corrosive resistance.
The intermediate part of the implant, which connects the fixed piece on the tibial plateau and the one fixed on the femur is made of high density polyethylene. This reacts like a buffer between the 2 titanium parts. This part is made out of polyethylene not to allow the metal on metal friction.
Polyethylene wear and biological reaction to its particles by the surrounding tissues can induce osteolysis; that is the major reason for failure of a total joint arthroplasty. In the knee joint, the implant should gain mobility and stability with respect to the normal kinematics, avoiding peaks of stress on the polyethylene surface and constraint forces on the tibial component. [3]

3. NUMERICAL ANALYSIS AND RESULTS

Next fallowing the 3D model design was the static structural analysis on the 3D assembly which was imported from SolidWorks to Ansys Workbench environment.
The mechanical behavior of the proposed prosthesis is studied based on numerical analysis. The working phases and the corespondent figures are presented below. The fixed support was considered on the inferior side of the tibial bone in the position shown in the figure 3.1. The force was considered in the XY plane, splited in two components with the values of 400N on each axis, having its origin on the femoral head (figure 3.2). After meshing (figure 3.3 and 3.4) a number of 12026 nodes and 5670 elements were obtain. The discretization was implict generated by the software with no other intervention.

Figure 3.1: Fixed support

Figure 3.2: Force positioning

Figure 3.3: Meshing

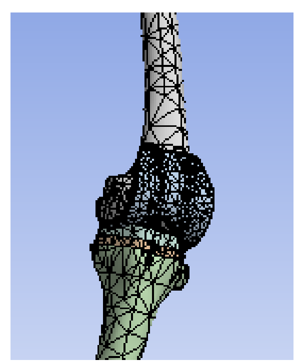

Figure 3.4: Meshing detailed

The deformations on Y and Z axis together with the equivalent stress are presented in the figures 3.5, 3.6 and 3.7.

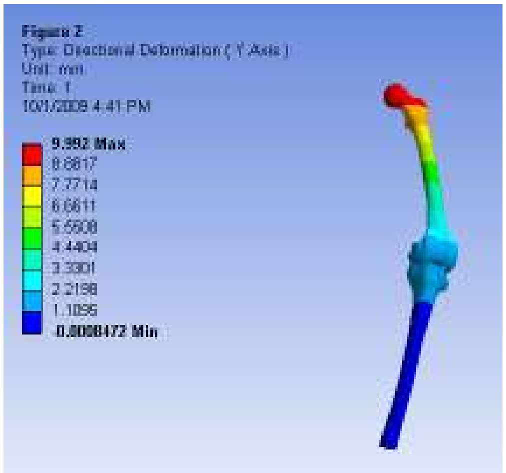

Figure 3.5: Deformation on Y axis

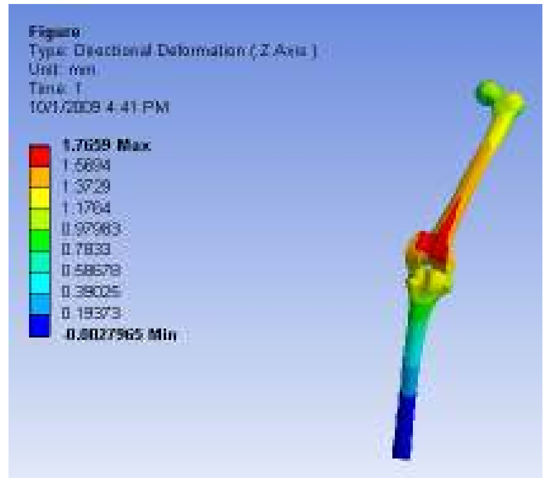

Figure 3.6: Deformation on Z axis

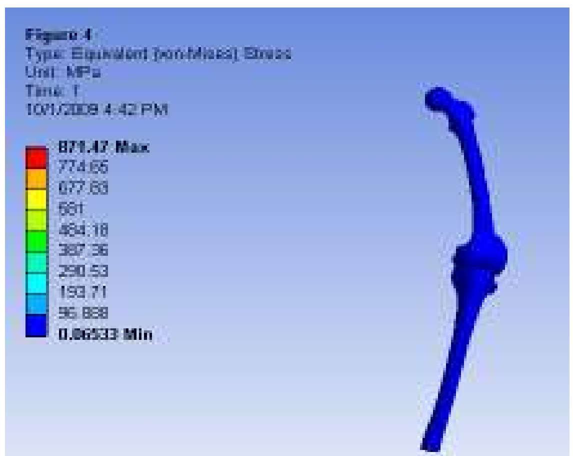

Figure 3.7: Equivalent stress

3. CONCLUSION

An anatomicaly functional model of the human knee joint has been succesfully created.
The directional deformations obtained on the Y and Z axis, coresponding to the components of the active force are included in normal anatomical intervals.
The equivalent stress reaches its extreme value on the femoral head and not on the implanted area, which explains the high intensity of the stress in that location.

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