Modelling of a tibial bone-knee implant assembly in order to analyse its mechanical behaviour

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Abstract. Orthopaedic implants have a relatively long yet limited lifespan, but sometimes problems occur after a relatively short time, making it necessary to have the original implant replaced by a new one [1-3]. This intervention, which is called revision surgery, is more difficult than the initial surgical procedure, as the prosthesis is attached to the bone tissue, and by removing the initial implant, the surgeon will also remove part of the bone it is attached to [4]. This is why it would be really helpful for the surgeon to be familiar, before performing the first surgery, with how the implanted bone [5] behaves in the long run, depending on the type of implant, the patients characteristics and the illnesses they may suffer from [6], in order to customise the choice of the implant as best as they can so as to avoid or delay as much as possible the revision surgery [7-9]. For this purpose, the virtual model of the tibial bone and the virtual model of the implant are performed, the bone-implant assembly is created, and, finally, the finite element analysis is performed on the resulting assembly in order to determine its behaviour over time. The purpose of this paper is to show how the cemented tibial bone – knee implant assembly is made.

1. Introduction
In order to provide medical staff with information on the long-term behaviour of an implanted bone, the virtual model of the tibial bone-knee implant assembly is made with a view to being subjected to a finite element analysis.

Since the bone has a complex and irregular shape and is difficult to model, first we performed a 3D bone scanning using the 3D ExaScan portable scanner and then we processed the resulting model using the CATIA software, as shown in figure 1. However, we could not use this virtual bone model to perform the finite element analysis as, because of the large number of surfaces it comprised, it would have been necessary for us to divide it into several parts and assign different material properties to each one. Nevertheless, we used the scan model to create the virtual model through classic modelling techniques.

Thus, we sequentially sectioned the model resulted from scanning, took the curves from each section and imported them into a new drawing, took three representative bone points and we used them as guiding curves and, with the Loft command in SolidWorks, we developed the virtual model of the full body tibial bone [9]. Since the bone does not have identical material properties over its entire length, it is necessary for us to model all the regions that make up the bone, in order to assign distinct material properties to each one. A long bone (such as the tibia) consists of a compact bone tissue...
(outer shell), a medullary cavity in the middle, and a block of spongy substance (spongy bone tissue) surrounded by a layer of compact substance at each of the two ends (proximal epiphysis and distal epiphysis) [10, 11].

Figure 1. The 3D surface of the tibial bone, obtained by scanning (a) raw scanning, (b) processed scan in CATIA [9].

In view of the above, we will divide the resulting 3D model in 3 pieces, as seen in figure 2:
- the outer shell (to which we will assign compact / cortical bone-specific properties)
- the proximal epiphysis (to which we will assign spongy bone-specific properties)
- the distal epiphysis (to which we will assign same spongy bone-specific properties)

Figure 2. Proximal epiphysis, outer shell, and distal epiphysis.

The knee implant may be fastened to the tibial bone either by pressing (press fit method) or by cementation. We decided to use cementation as a fastening method. For this purpose, it was necessary for us to model the material used for fastening, which is the cement. The cement must be placed between the metallic tibial component of the knee implant and the proximal epiphysis of the tibial bone.

2. Modeling the cement cylinder between the proximal epiphysis and the metallic tibial component

In order to build the tibia-knee implant assembly, the proximal epiphysis must be processed (by drilling a hole into it) to enable the insertion of the metallic tibial component. Since we will model the cemented version, we will place the bonding cement between the Proximal Epiphysis and the Metallic Tibial Component. The bonding cement is shaped as a cylinder that fits on the metallic tibial component and takes its shape. The cement and the tibial component are inserted into the proximal epiphysis. To do this, we will proceed as follows:
Step I - we will create a part named Full Body Cement (which follows the shape of the tibial component) and we will use it to drill (process) the proximal epiphysis.

Step II - we will drill the Full Body Cement part (the hole will follow the shape of the tibial component) in order to create a part named Hollow Cement, into which we will later insert the tibial component.

Step I: Creating the Full Body Cement part and Processing the Proximal Epiphysis

To create the virtual model of the Full Body Cement, we extracted the sketches from the metallic tibial component. Using the Offset Entities command and setting the offset distance to 1 mm, we doubled the shape to get a larger extraction of the material, in order to fill it with the hollow cement part that will be created later, figure 3. We created guide curves and fixed them using the “Pierce” command. With the “Loft” command, we selected the two sketches and the three guide curves, and created the Full Body Cement part.

With the Full Body Cement part, we will process the proximal epiphysis part. Activating the “Insert - Features - Move/Copy” command, we select the object to be moved (Full Body Cement) and, using the constraints as shown in figure 4, we assemble it into the Proximate epiphysis part for processing.

The next step consists in activating and using the “Insert-Features-Intersect” command to extract the material (so as to be able to perform the processing). With the “Insert-Features-Intersect” command, we select the two parts, and check the first option – “Create intersecting regions”. Clicking the “Intersect” button and selecting “Cap planar openings on surfaces”, the program enables the selection of the regions we want to exclude. We unselect the region we want to exclude (region 1) and keep only the part that will be saved as Processed Proximity Epiphysis, figure 5.

Step II. Processing (drilling) the Full Body Cement part so it can accommodate the metallic tibial component. We will name the resulting drilled component Hollow Cement part.

With the “Insert – Part” command, we placed the Metallic Tibial Component part into the Full Body Cement part. We will use the “Insert - Features - Move / Copy” command, which at a later moment will enable us to select the constraints or mates.

By activating the “Move / Copy” command, we select the object to be moved (Tibial Component), and with the help of the constraints, we fit it into the Full Body Cement part in order to be processed, with the “Insert-Features-Combine” command. With this command activated, we selected “Subtract” as type of operation, we selected the main body (the Full Body Cement part), then we selected the body to be combined into it and extracted, namely the Tibial Component. Using the “Subtract” command, we obtained the processed Cement (Hollow Cement) part, figure 6.
Figure 4. Selecting constraints.

Figure 5. Result of Intersect command.
3. Making the tibia-knee implant assembly
In order to obtain the virtual model of the implant-fitted tibial bone, we open a new file for the entire assembly and use the “Insert component” command and the ‘axis-axis’, ‘plane-plane’, ‘plane-axis’, ‘coincidence’, ‘tangency’, and ‘distance’ constraints. First we bring in the Outer shell, then we add the Distal epiphysis, then the processed Proximal epiphysis, then the Cement, and in the end the Metallic Tibial Component. The polyethylene insert and the metallic femoral component are placed over it (figure 7).

4. Conclusions, future research directions

Figure 6. Result of the Subtract command.

Figure 7. Tibial bone-knee implant assembly.
Once the virtual model is created in Solid Works, it can be assigned customized parameters (sizes, material properties, varus - valgus deformities), depending on the patient [12]. We assembled the knee implant onto the tibial bone and we fastened it with the cement we modelled, with a view to performing the finite element analysis of the assembly, which will be subjected to various static and dynamic loads (human body weight when standing, walking, running etc.). This numerical simulation of the bone-implant behaviour is helpful for the optimal choice of the shape and size of the implant, depending on the patient’s characteristics [9, 13].

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