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ORIGINAL PAPER

The virtual model of the prosthetic tibial components

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Abstract

The paper presents a method of study and the steps to obtain the virtual tibial component of the human knee joint prosthesis. For that purpose CAD parametric software was used which allows the construction of a high definition model. The obtained 3D model was studied using the finite element method and the stress and displacements distribution was obtained for different solicitations of the prosthetic and non-prosthetic tibial component of the virtual knee joint.

Keywords**:** 3D virtual model, knee joint, tibial component, knee prosthesis.

Introduction

The knee joint is one of the most complexes in the human body, which makes studies extremely difficult to carry out even when analyses are obtained in static regime. However, there has been some worldwide research regarding the simulation and determination of mechanical parameters of the knee joint and of its components.

Well known are the studies of Moglo K, Bendjaballah MZ and Shirazi-Adl A [1–3] from the Biomechanics and Biomaterials Research Group, École Polytechnique de Montréal, who have developed several studies using programs of analysis with finite element in various situations (flexion, extension), as well as other attempts.

A non-linear 3D model of the knee joint in full extension has been developed using both computer-assisted tomography and a mesh generation algorithm. This work concentrates the response of the knee in flexion in order to obtain the behavior of the knee joint under physiological conditions. Defining the three-dimensional model has been accomplished starting from different sectioned obtained with a tomograph. Studies have been done in static regime using various attempts known in literature.

An interesting study has been made by Pioletti DP *et al.* [4], regarding theoretical constitutive laws for large deformations which appear in ligaments and tendons in the joint composition. In this study, a mathematical model has developed based on elastic and viscous potential, and the determined laws being valid in the domain of large deformations also satisfying the laws of thermodynamics. This way, it has been observed that three parameters are necessary (two for elasticity and one for viscosity) in order to determine a non-linear fort low-loading obtained for different loadings.

There has also been concluded a complete analysis with finite elements for modeling the viscoelastic conduct of ligaments and tendons in dynamic regime.

Wilson W *et al.* [5] have made a study regarding the development of arthrosis in joint. For this purpose, the researchers have made a model with finite elements of the human knee in which the cartilage layers have also been included.

An ample study was carried out through a programme of European financing in which a series of research institutes and universities took part, such as the German National Research Center for Information Technology, The University of Sheffield Medical School, Engineering Systems International, which achieved several three-dimensional models of the knee joint, implant studies and of simulating to impact.

There have also been published various studies regarding the knee joint by researchers [6–11]. Most of them are articles regarding the experience of prestigious collectives of orthopaedic surgeons of the Departments or Clinics of Hospitals known worldwide where it is presented the clinic experience and post-operator observations regarding total or partial arthroplasty of the knee joint, methods and techniques employed as well as types of prostheses used.

Conclusions come up regarding the efficiency of these techniques and prostheses and recommendations regarding subsequent surgical onsets.

Migaud H *et al.* [12] studied *in vivo* kinematics for four designs of knee prosthesis during level walking, stair climbing and non weight-bearing flexion-extension.

Uvehammer J [13] studied the influence of different designs of the joint area on tibial component fixation, kinematics and clinical outcome after a cemented total knee arthroplasty (TKA).

Compared with normal knees all prosthetic designs showed abnormal pattern of motion. The extent of this abnormality was influenced by the design of the joint area. A corresponding influence on the fixation of the tibial component could not be verified.

Li G *et al.* [14] have determined the three-dimensional tibiofemoral articular contact patterns of a posterior cruciate ligament-retaining total knee replacement during *in vivo* weight-bearing flexion.

While the minimum anteroposterior translation of the contact point on the medial side might be interpreted as a medial pivot rotation during knee flexion, the contact point did move in the mediolateral direction with flexion.

Werner F *et al.* [15] studied the knee prostheses of eight different designs were tested experimentally to determine the axial torque necessary to rotate the tibial component relative to the femoral component with the prosthesis positioned at or near full extension. The results represent transmitted torque as a function of axial rotation.

Soudry M *et al.* [16] showed that cruciate resection increases the shear forces and the rocking moments to the tibial components and that additional fixation means may be necessary to compensate. On the other hand, cruciate retention with low conformity gives higher contact forces, which may lead to more wear in the long term.

Parvizi J *et al.* [17] evaluated the long-term clinical and radiographic outcome of total knee arthroplasty in patients who had undergone a previous proximal tibial osteotomy and to identify the risk factors that may result in an inferior outcome.

Uvehammer J *et al.* [18] studied the kinetics of the knee in 20 patients (22 knees) 12 months after total knee arthroplasty (TKA), by using three-dimensional radiostereometry and film-exchanger techniques.

Eleven knees had a concave (constrained) tibial implant and 11 a posterior-stabilized prosthesis. In the posterior-stabilized knees there was less proximal and posterior displacement of the centre of the tibial plateau during extension from 45 to 15 degrees.

In [19] and [20] the generation of the three-dimensional model of the human knee joint was studied.

Theoretical considerations

A painful knee can severely affect the ability to lead a full active life. Over the last twenty-five years, major advancements in artificial knee replacement have improved the outcome of the surgery greatly.

Artificial knee replacement surgery is becoming more and more common as the population of the world begins to age. X-rays are helpful in the diagnosis and may not show changes typical of osteoarthritis. It is not always clear where the pain is coming from.

In Figure 1 were presented few pictures with normal and arthritic knee [2].

There are two major types of artificial knee replacements: cemented prosthesis and uncemented prosthesis. Both are still widely used. In many cases a combination of the two types are used.

The patellar (kneecap) portion of the prosthesis is commonly cemented into place. The choice to use a cemented or uncemented artificial knee is usually made by the surgeon based on the age, the lifestyle, and the surgeon experience.

Each prosthesis is made up of three parts:

- the tibial component replaces the top of the lower bone, the tibia;
- the femoral component replaces the two femoral condyles and the groove where the patella runs;
- the patellar component (kneecap portion) replaces the joint surface on the bottom of the patella that rubs against the femur in the femoral groove.

In Figure 2 were presented the main components of the knee prosthesis [2].

The tibial component is usually made up of two parts – a metal tarry that is attached directly to the bone and a plastic spacer that provides the bearing surface. The plastic used is very tough and very slick.

A special cutting jig is placed on the distal part of the femur. This jig is used to make sure that the bone is cut in the proper alignment to the leg’s original angles – even if the arthritis has made you bowlegged or knock-kneed. Another jig is used to cut several pieces of bone from the distal femur so that the artificial knee can replace the worm surfaces with a metal surface.

In Figure 3 was presented the surgical preparation for the femur and tibia.

The knee prosthesis must have the next properties:

- anatomic adaptation;
- integrated system / wide range;
- modularity and interchangeability;
- per-operative choice;
- bone preservation;
- alignment / ligamentary balance / gap equivalence / stability;
- reduced contact stress/low wear;
- precise and reliable instrumentation.

Material and methods

We used a type Richards knee prosthesis. The real model of the tibial prosthesis is presented in Figure 4.

The tibial prosthesis has two components: the metallic tibial component and the polyethylene tibial component.

The aim of this paper is to build the parameterised virtual model of the prosthesis, using SolidWorks, a CAD/CAE software.

The virtual model of metallic tibial component

1. We start from the sketch drawn in a default plane, represented in Figure 5.

2. Using the previous sketch and the Insert/Base/ Extrude command for a height $h = 3$ mm, applying the Fillet command for a radius $R = 3$ mm and applying a Shell shape for a height $h = 1$ mm, we obtain the model from Figure 6.

3. On the posterior plane was drawn a circle having the diameter $d = 6$ mm and by using the Cut-Extrude command, the model from Figure 7 was obtained.

4. On different faces of the model are drawn sketches respecting the imposed dimensions and a Cut-Extrude command is applied. The obtained model is presented in Figure 8.

Figure 1 – ***Normal and arthritic knee***

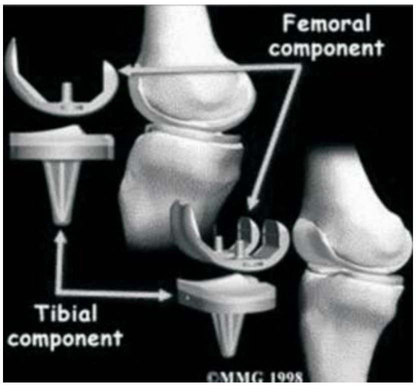

Figure 2 – ***The main components of the knee prosthesis***

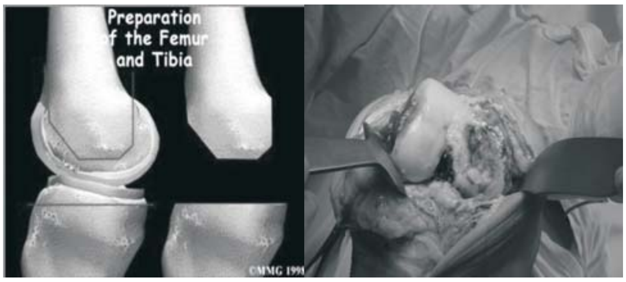

Figure 3 – ***The surgical preparation of the femur and tibia***

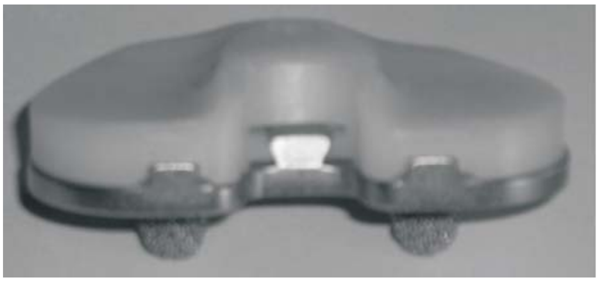

Figure 4 – ***The real tibial prosthesis component***

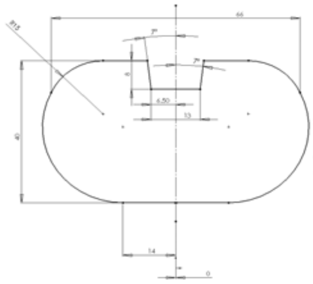

Figure 5 – ***The initial sketch drawn in a default plane***

Figure 6 – ***The base shape of the metallic tibial component***

Figure 7 – ***The obtained model after the Cut-Extrude command***

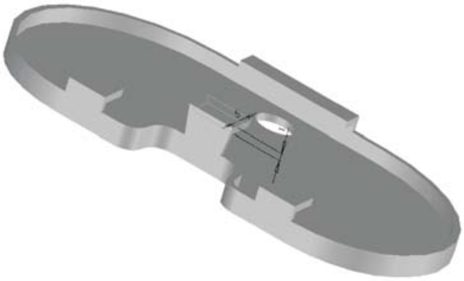

Figure 8 – ***The extruded shape realized on the bosaje***

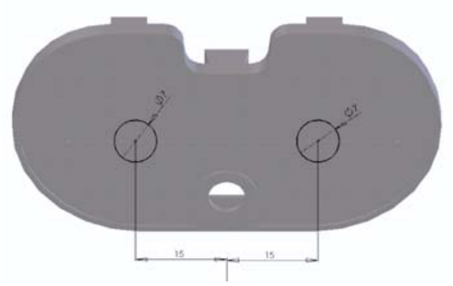

Figure 9 – ***The sketch drawn on the Plane 1***

Figure 10 – ***The Dome shapes***

Figure 11 – ***The final model of the tibial metallic component***

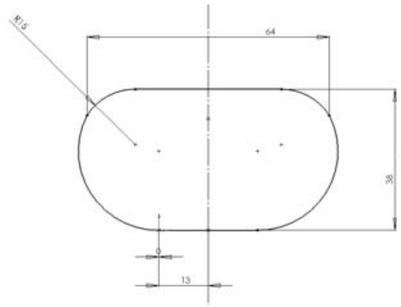

Figure 12 – ***The sketch drawn on a default plane***

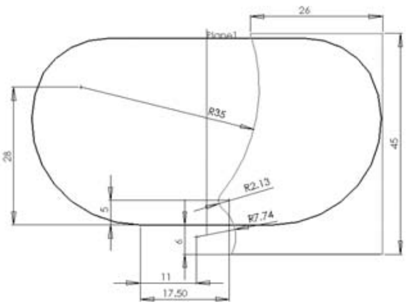

Figure 13 – ***The sketch realized on a face of the model***

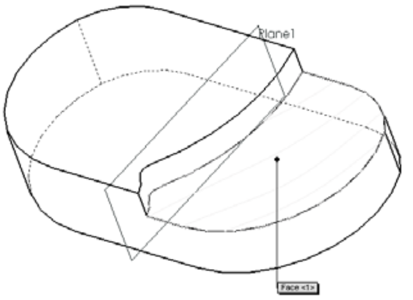

Figure 14 – ***The model after the Cut-Extrude command and the Dome shape***

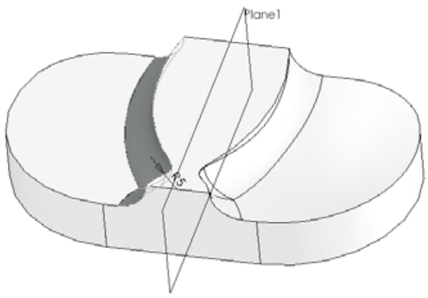

Figure 15 – ***The Fillet shape applied on the model***

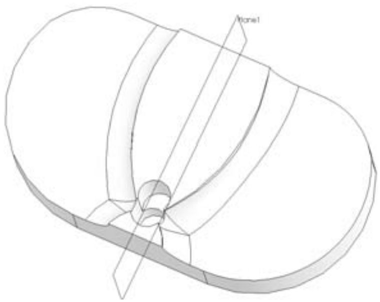

Figure 16 – ***The model obtained after the Cut-Extrude command***

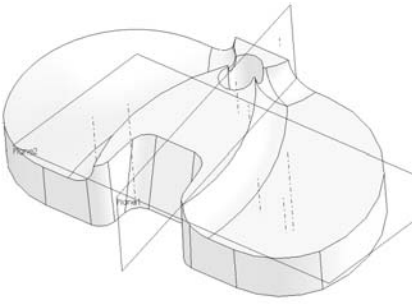

Figure 17 – ***The model obtained after the Fillet command***

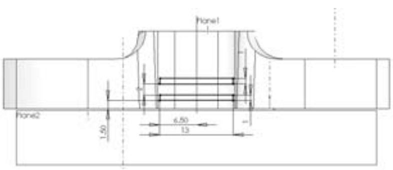

Figure 18 – ***Sketch realized on a lateral plane of the model***

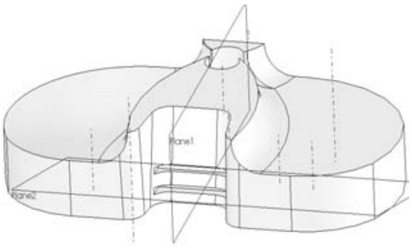

Figure 19 – ***Holes for catching***

Figure 20 – ***The final model of the tibial component***

Figure 21 – ***The two tibial components of the prosthesis***

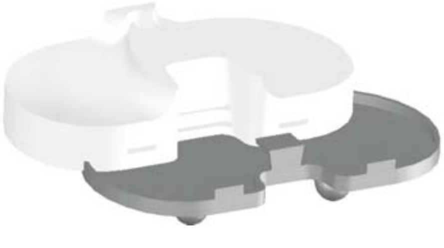

Figure 22 – ***The final model of the tibial component***

Figure 23 – ***The second constraint and the model obtained using the Mate command***

Figure 24 – ***The final model of the tibial knee prosthesis***

5. On the reference Plane, which angle is 33° the sketch from Figure 9 is drawn.

6. This sketch is used for obtaining the extruded shape. Two Dome shapes are defined (Figure 10).

In Figure 11 the final model of the metallic component is presented.

The virtual model of polyethylene tibial component

1. To realize the polyethylene tibial component was drawn an initial sketch in a default plane (Figure 12).

2. On a face of the obtained model, by applying the Extrude command, we realize the sketch from the Figure 13.

3. The Cut-Extrude command is used and on the plane face of the model was applied a Dome shape with a negative height h = -3 mm (Figure 14).

4. After successive applying of Filet commands and Mirror command, the model obtained is presented in Figure 15.

5. On the superior face of the model, different sketches are drawn and successive Cut-Extrude commands are applied. The model is presented in Figure 16.

7. In a defined plane was drawn the sketch used for Cut-Extrude command and the Fillet command is applied (Figure 17).

8. On a lateral plane of the model the sketch from Figure 18 is realized.

9. The previous sketch is used for defining a Cut Extrude shape and the obtained model is presented in Figure 19.

10. After similar several commands was obtained the final model of the tibial polyethylene component of the knee prosthesis (Figure 20).

Assembling of the tibial components

In the opened assembly module the two components of the prosthesis are imported (Figure 21).

Using the assembly module of the CAD software and several matting commands was obtained the final model of the tibial component (Figure 22).

Using the *Mate* command we obtain the second constraint and the model from the Figure 23.

The assembly is finalized using the last constraint, FACE-FACE between two pane faces of both the components (Figure 24).

Conclusions

We obtained the high fidelity virtual model of both components of the tibial prosthesis.

This model allows different solicitations. The obtained virtual model can be introduced inside a virtual knee joint and the biomechanics of the prosthetic knee joint can be studied.

The parameterized virtual model of the tibial prostheses allows different changes in shape, dimensions and other mechanical properties.

These changes lead to the optimization of the implant and of the biomechanics of the prosthetic knee.

The results obtained by means of optimization may definitely be used in the design of more resistant prosthetic implants which better respect the biomechanics of the knee joint.

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