

MODELLING THE TIBIAL BONE USING CAD TECHNIQUES, STARTING FROM THE 3D SCAN MODEL

Mihai-Constantin Balasa¹, Simona Mihai², Viviana Filip³, Alexis-Daniel Negrea⁴, Gheorghita Tomescu⁵

¹Macartney Hydraulics A/S, DK-7620 Lemvig, Denmark

²Valahia University of Targoviste, Institute of Multidisciplinary Research for Science and Technology, 130004, Targoviste, Romania

³Valahia University of Targoviste, Doctoral School of Engineering Sciences, 130105, Targoviste, Romania

⁴Valahia University of Targoviste, Faculty of Material Engineering and Mechanics, 130004, Targoviste, Romania

⁵University Politehnica of Bucharest, Faculty of Mechanical Engineering and Mechatronics, 060042, Romania
mihai.simona@yahoo.com

Abstract: To improve the long-term quality of life for patients with major joint problems, choosing an orthopedic implant based on patient particularities is essential. In this sense, numerical modeling of the bone and implant is useful, assembling them and simulating the behavior of this ensemble over time, taking into account the most accurate features of the bone, such as varus - valgus deformities, osteoporotic diseases, etc. The need to use CAD 3D modeling techniques thus appeared. Because bone is irregularly shaped, consisting of more complex 3D surfaces it is difficult to build in Solid Works. That's why, to build it, we started from the virtual 3D scan model with the ExaScan scanner. Once the virtual model has been obtained through CAD techniques, it will be adapted to the patient's particularities (dimensions, bone mass, eventual deformities, etc.). The objective of this paper is numerical modeling of the tibial bone using CAD techniques, starting from the virtual model obtained by 3D scanning.

Keywords: Tibial Bone, Knee Implant, Virtual Model, 3D Scanning, CAD Techniques.

1. Introduction

Knee prosthesis is the surgical procedure by which the affected knee cartilage and the bones are removed and replaced with an implant which allows for natural movements of the knee joint (primary surgery) [1, 2]. Although implants have a relatively long life, but limited, sometimes problems occur after a relatively short time and an intervention should be performed to replace the original prosthesis with another prosthesis [3].

This surgery, called revision surgery, is more difficult than the primary surgery because the prosthesis is fixed in the bone tissue, and the surgeon, by removing the initial implant, will also remove some of the bone in which it is fixed [4]. Therefore, it would be of great use if before performing the primary surgery, the surgeon would know how the implanted bone behave [5], depending on the type of implant, the particularities and affections of the patient [6], in order to personalize the best possible the implant for the patient and to avoid or postpone the revision surgery as much as possible [7, 8].

The aim of our work is to achieve the virtual model of the tibial bone, which we then use for finite element analysis of the knee implant bone assembly in order to determine its behavior over time.

2. Working Method and Resources Used

We created the virtual model of a tibial bone 320mm long, with a cortical bone thickness of 0.8mm (at the extremities toward the knees and toward the ankle) and 4mm (in the middle).

First, we performed the scanning of the real tibial bone (Fig. 1 **Error! Reference source not found.**) with an ExaScan 3D scanner [9] and obtained a complex 3D surface, Figure 2, which we converted into a solid body. The result of scanning has a very good fidelity due to the large number of surfaces / meshes obtained [9]. But this very multitude of surfaces has created difficulties in the finite element analysis of the tibial-knee implant assembly.



Figure 1: Tibia, real bone

This is why we decided to achieve the virtual model of the tibial bone using CAD modeling techniques in Solid Works [10, 11].

But this is very difficult due to the complexity of the shape of the tibial bone (many irregular surfaces

with complex profile). In order to succeed, we used the surface obtained by 3D scanning, processed in CATIA (Fig. 2b) [9], which we named reference model.

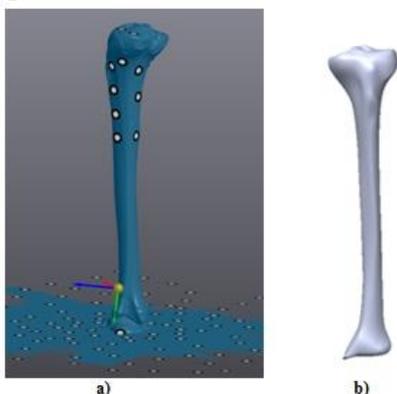


Figure 2: The 3D surface of the tibial bone, obtained by scanning a) raw scanning, b) processed scan in CATIA.

The use of the reference model greatly facilitates the shaping of the tibial bone. In the following, we will use the model in work term for the virtual model that we want to achieve.

The steps are:

Step 1

We established the tibial bone axes for both the reference model and the model in work, to work in correspondence (Fig. 3).

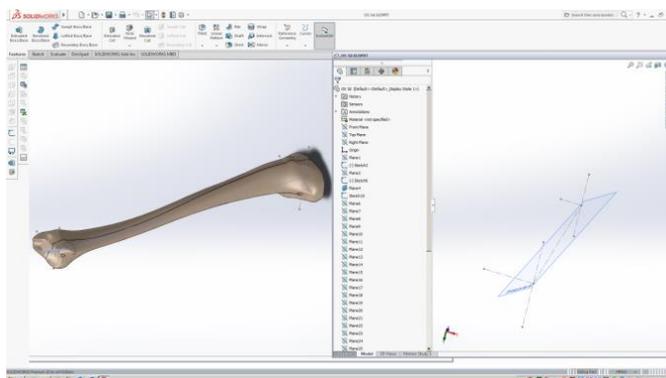


Figure 3: Choosing plans and work axes (reference model on the left, model in work on the right).

Step 2

We cut the reference model with parallel planes with a distance of 10 mm in between (transverse slices). A contour resulted in each section plane. We created a sketch in each plane, in which using a Spline command, Figure 4, we drew a curved overlay

on the contour previously obtained. This built curve was extracted and taken with the Copy command in the corresponding plane of the model in work and the action was repeated for each section plane (Fig. 4).

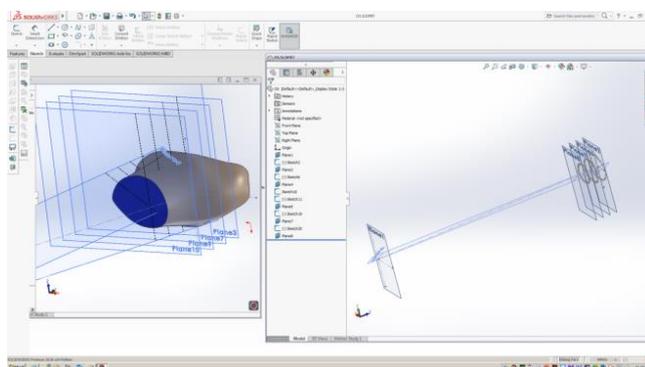


Figure 4: The processing of the tibia contour in successive plans from the reference model (left side) and its implementation in the model in work (right side).

For a better accuracy when taking these curves which define the bone profile at the proximal end of the tibia, the plans with which we cut the reference model were created at a smaller distance, namely 5 mm (Fig. 5).

We mention that we performed the slicing of the reference model without the end of the tibial bone, as they are not necessary for the bone knee implant assembly.

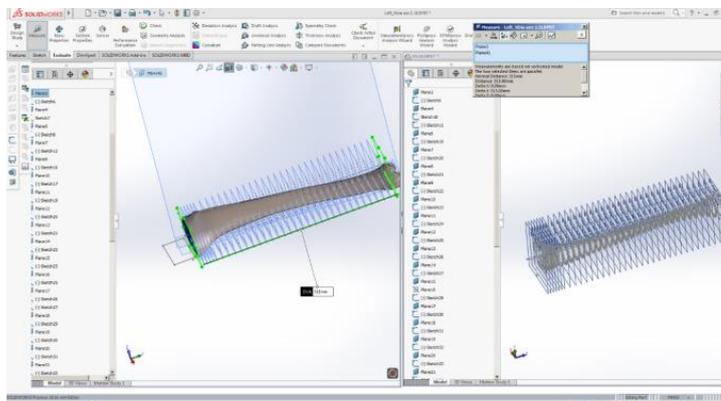


Figure 5: Slicing with parallel planes (reference model on the left, model in work on the right).

Step 3

Slicing with parallel planes (reference model on the left, model in work on the right) the Loft

command with which we will build the bone in the model in work (fig.6).

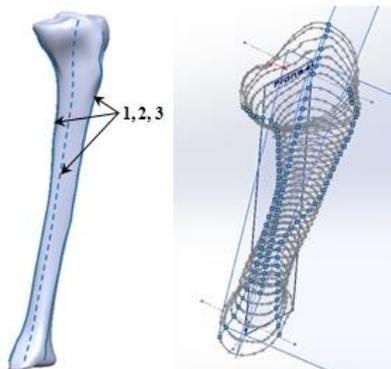


Figure 6: The three representative curves defining the tibial surface (reference model on the left, model in work on the right).

In the reference model we opened a sketch for each of the three curves and using Spline we drew, overlapping guiding lines over the 3 curves. Using the Copy command, each guiding line was transferred to the model in work, and then, with the

Pierce command, we made the guidance line intersect each contour curve in the parallel planes previously described (Fig. 7). We repeated the process for each guidance line.

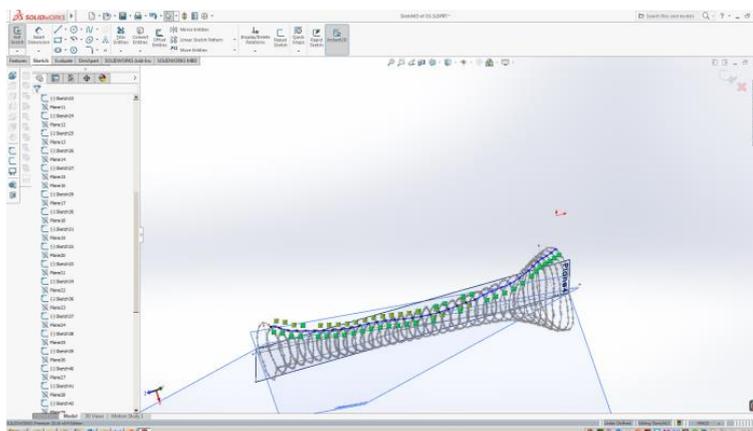


Figure 7: Modeling guide lines and fixing them on contour curves

Step 4

We created the 3D modeling of the bone using the Loft command by selecting all the contour curves and the three guiding lines (Fig. 8).

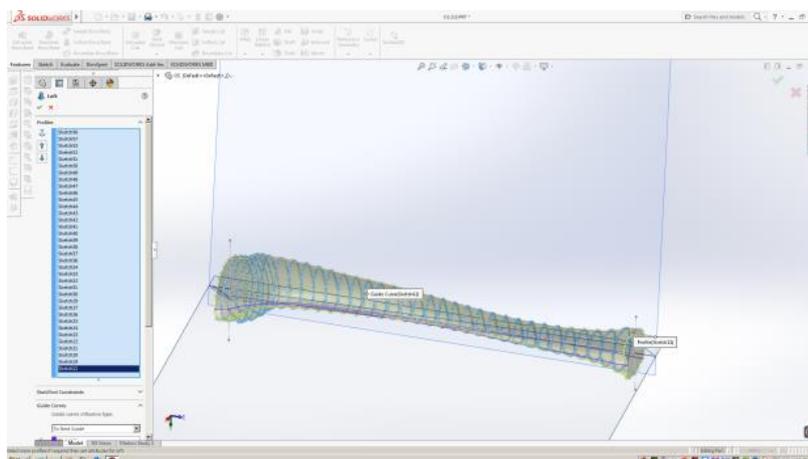


Figure 8: Obtaining the 3D model

To this point we achieved the tibial bone as a solid body (full). In order to perform the finite element analysis, it is necessary to assign distinct material properties to the bone [12], depending on the bone area, taking into account the following aspects (Fig. 9): long bones (such as the tibia) are made up of a

compact bone shell, they have a medullary canal in the center, and at the two extremities (proximal epiphysis and distal epiphysis) they have a block of spongy substance, surrounded by a layer of the compact substance [13, 14].

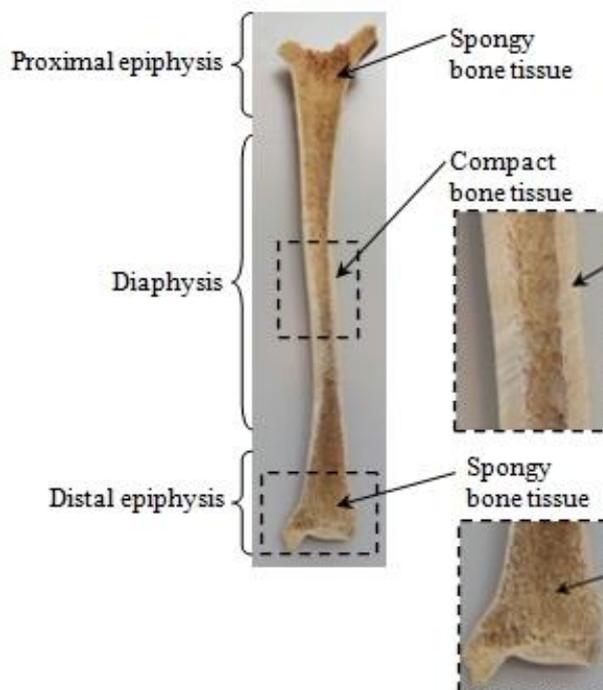


Figure 9 Tibial bone structure

For this, we will divide the obtained 3D model in three parts (Fig. 9): the shell (to which we attribute the compact / cortical bone properties), the proximal part and the distal part (to which we attribute the properties of the spongy bone).

In order to model the first part (shell), in each sketch (in each plane with which the bone was

sliced), the contour curves (Fig. 10) was doubled with the Offset command, thus obtaining the required thickness of the compact bone (0.8 mm in proximal and distal epiphysis and 4 mm in diaphysis).

Then, using the Loft Cut command, the virtual model of the shell was obtained (Fig. 12a).

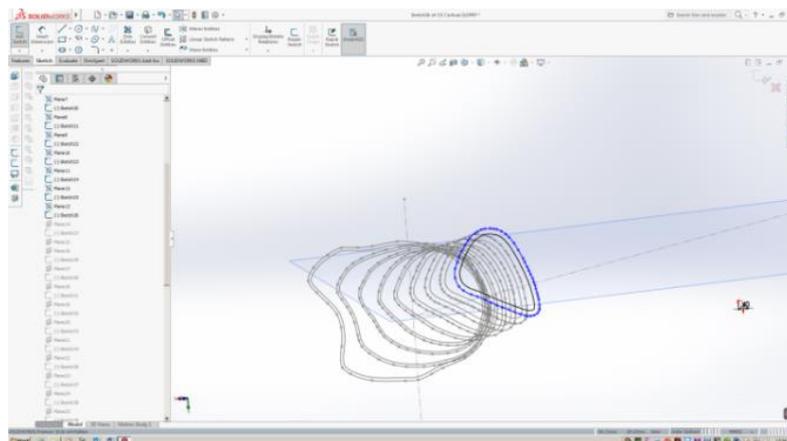


Figure 10: The doubling of the contour curves with the purpose of building the shell

To model the second and third part (the proximal and distal side), we use the sketches built for the outer layer and to build offset guides parallel to those used in the shell construction with the Offset command.

Also using the contour curves and with the Pierce command, we make the constraint that the guiding lines intersect each inner contour curve (Fig. 11).

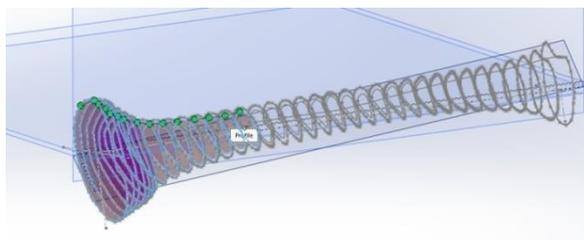


Figure 11: Fixing the guiding lines on contour curves

Using the Loft command, we generate a solid that has the shape of the tibial bone but with a lower thickness (the coating has been removed). The 3D model obtained is saved twice, thus obtaining two identical models. In the first model, at a distance of 100 mm from the end of the knee, we drew a

sectional plan and used the Cut-Extrude command to retain only the proximal part, Fig. 12b. In the second model, at a distance of 100 mm from the end of the ankle, we draw a cutting plane and used the command Cut-Extrude to retain only the distal Fig. 12c.

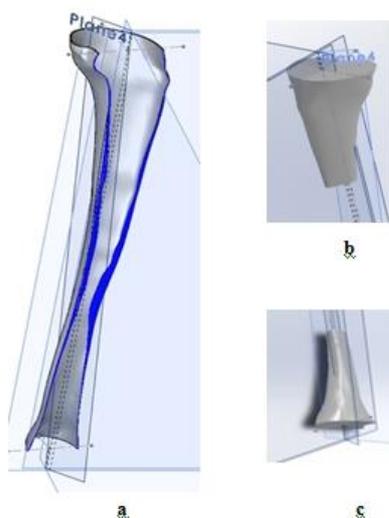


Figure 12: The shell (a), the proximal part (b), the distal part (c)

In order to obtain the virtual model of the tibial bone, we assemble the proximal and the distal part in this shell, Fig. 13.

In this way, we can assign materials with distinct properties to the three parts.

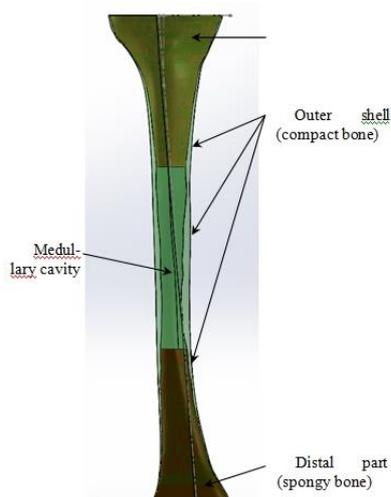


Figure 13: Assembling of the three parts of the virtual model

3. Conclusions. Future Research Directions

In this paper we have developed the virtual model of the tibial bone using CAD techniques, which was for us to carry out the finite element analysis of the tibial knee implant assembly in the future. Tibial bone modeling in Solid Works was not an easy task due to irregular shaped surfaces that make up the bone. That's why we started from the virtual 3D model [9], through Reverse Engineering techniques. Since the bone does not have the same material properties over its entire length [5], we have created three parts: the shell (which will receive the properties of the compact / cortical bone), the proximal part and the distal part (which will receive the properties of the spongy bone), and through the assembly the virtual model of the tibia was created.

Once the virtual model is built in Solid Works, it will be customizable (dimensions, material properties, eventual deformities) depending on the patient. In the future, we plan to place the cemented tibial plate on the tibial virtual model and perform the finite element analysis of this ensemble, which we subject to static stresses (weight of human subject in orthostatic position) and dynamic (walking, running). We will analyze both the situation in which the tibial plate is without extension, and the situation in which it has extensions of different lengths and thicknesses [15], which are standardized in the profile catalogs.

We will also analyze the situation where the tibial bone has deformations of the varus-valgus type (in which case we apply rotational moments to the finite element analysis) and the situation in which the bone is affected by different degrees of osteoporosis

(in which case modify bone density). This numerical simulation of bone-implant behavior is useful for the optimal choice of the shape and size of the implant [16,17,18], depending on the patient's particularities.

References

- [1] Cofaru I., Summary of the PhD Thesis, Researches regarding the biomechanics of the axial deviations of the human lower member and the development of the correspondent surgical devices, (2013).
- [2] Cristea Șt., Prundeanu A., Groseanu Fl. and Gărtone D., The Role of Arthroscopy in Mini-Invasive Treatment of Tibial Plateau Fractures, Chapter from the book Modern Arthroscopy, pp. 225–236, (2011).
- [3] Mihai S., Filip V., New design concept for reducing torque wear on implant, Applied Mechanics and Materials, Vol. 658, pp. 453–458, (2014).
- [4] Mihai S., Filip V., Vladescu M., Contributions to the improvement of the tribological behaviour of hip implant joints, Journal of Science and Arts, ISSN 1844-9581, Year 16, No. 2(35), pp. 177–184, (2016).
- [5] Nicolescu C.M., Bumbac M., Mihai S., Gheboianu A.I., Balasa M.C., Filip V., Cuculici S., Cristea S., Pantu C., X-RAY diffraction and nanoindentation characterization of bone tissue affected by severe osteoarthritis, Journal of Science and Arts, ISSN: 1844 – 9581, Year 18, No. 1(42), pp. 265–274, (2018).
- [6] Mihai S., Filip V., Studies on explanted orthopedic implants, The Scientific Bulletin of VALAHIA University – MATERIALS and MECHANICS – Nr. 8 (11), ISSN: 1844-1076; pp. 149–152, (2013).
- [7] Mihai S., Constructive concepts for reducing wear caused by the friction torque of hip implants, International Journal of Research in Engineering and Technology, Volume 2, pp.289–295, (2013).
- [8] Mihai S., Filip V., Simulator for testing the friction torque of the femoral head of a hip prosthesis, Bulletin of the Transilvania University of Brașov, Vol. 8 (57) No. 2, Series I: Engineering Sciences ISSN 2065-2119, pp 145–150, (2015).
- [9] Balasa M.C., Cuculici Ș., Panțu C., Mihai S., Negrea A.D., Zdrafcu M.O., Leț D.D., Filip V., Cristea Ș., Using 3D scanning techniques in orthopedic systems modeling, The Scientific Bulletin of VALAHIA University MATERIALS and MECHANICS –Vol. 15, No. 13, pp. 41–47, (2017).
- [10] Mihai S., Filip V., 3D modeling and performing of orthopedic implants by material deposition rapid prototyping, Romanian Review Precision Mechanics, Optics & Mechatronics / ISSN 1584-5982, nr.41, pp.128–131, (2012).
- [11] Mihai S., Orthopaedic implants and prostheses. Conventional and unconventional

- processing technologies, International Conference on Architecture, Civil & Mechanical Engineering (ICACME'2012), ISBN: 978-93-82242-15-4, pp.132–136, (2012).
- [12] Mihai S., Filip V., Aspects of orthopedic implants and prostheses. Materials. Processing technologies, The Scientific Bulletin of VALAHIA University – MATERIALS and MECHANICS – Nr. 7 (year 10), ISSN: 1844-1076, pp.101–106, (2012).
- [13] Cintra F. F., Yepéz A. K., Rasga M. G. S., Abagge M., Alencar P. G. C., Tibial component in revision of total knee arthroplasty: Compararison between cement and hybrid fixation, Sociada de Brasileira de Ortopedia e Traumatologia, V46(5), pp. 585–590, (2011).
- [14] Williams A., Logan M., Understanding Tibio-Femoral motion, The Knee, Volume 11, pp. 81–88,(2004).
- [15] Robalo T., Analysis of bone remodeling in the tibia after total knee prosthesis, Instituto Superior Tecnico – Universidade Tecnica de Lisboa, (2011).
- [16] Badita L.L., Gheorghe G., Orthopaedic Prosthetic Systems Topographically Characterized at Nanometric Scale, Advanced Materials Research, vol 837, pp. 675–681,(2014).
- [17] Florescu V., Căpitanu L., Bădiță L. L., Filip V., A Novel Engineering Spherical Bearing, with Potential Application for a Hip Implant, Journal of Mechanics Engineering and Automation (JMEA), ISSN 2159-5275, Volume 6, Number 5, pp. 217–226,(2016).
- [18] Florescu V., Capitanu L., Badita L.L., Filip V., A surprising tribological validation: metal on metal total hip prosthesis with rolling friction, International Journal of Application or Innovation in Engineering & Management (IJAIEEM) , ISSN 2319 – 4847, Volume 5, Issue 7, pp. 025–038, (2016).