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MODELING OF THE HIP JOINT

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Abstract: This paper presents the results of the researches enterprised by the authors for the purpose of obtaining an adequate methodology for modeling of hip joint. We did that by using a 3D reconstruction software (Mimics) and a CAD software (SolidWorks). There are three major stages to obtain the final 3D model of the hip endoprosthesis. The first stage contains data acquisition of the detailed anatomical information using a computer tomography system. The second stage is for virtual modeling of the hip joint using a method which combines the imagine processing techniques and 3D computer graphics. The third stage is reserved for CAD modeling which allows to design the endoprosthesis by using the anthropometrical data.

Cuvinte cheie: arthroplasty, CAD modeling, endoprosthesis, medical imaging, hip joint.

1. Computer modeling with applications in biomechanics

The growth and the development of computer simulation has been rapid and its uses have extended from the entertainment media to the airline and automotive industries, military, different branches of science like medicine, engineering, physics and certainly to education.

To illustrate the potential that a combination of the knowledge from biology, engineering and computer graphics can have on the understanding of the development, maintenance and repair of the skeleton and on the clinical management of bone disease is the essence in the biomechanical research.

Biomechanics is the theory of how tissues, cells, muscles, bones, organs and the motion of them and their form and functions are regulated by basic mechanical proprieties.
A comparison with engineering may help us to understand the principles that presumably guide the evolution of bone strength. As in many sciences, the integration of experimental and analytical model is critical to gain and understanding of the skeletal response to mechanical factors.

Experiments provide insights and data, which can then be interpreted within the context of analytical frameworks. These investigations are greatly impacted by recent technological advances in imaging, computational mechanics, genetics and molecular biology. The integration of these techniques will provide important insight into skeletal development and disease.

In medical application, attention of researchers has now turned toward using combined 3D reconstruction and virtual environment technologies to train clinicians and to help surgeons plan patient-specific, complex procedures like plastic surgery, surgery for trauma from accidents and reconstruction surgery.

The 3D models are very useful in simulation of bone fractures and internal fixations with implants. These models are also important to understand how human musculoskeletal structures adapt to external forces disturbances. Because of the complexity of these structures and because not all the biological and anatomical data about them are known, there are many possibilities for how the system might work. Computational modeling techniques applied to the human body and skeleton provide a possibility to analyze without interference in the human body [1][2][4].

2. Virtual reconstruction of the hip joint and the design of the endoprosthesis

The proposed solution is based on a method witch combine the imagine processing techniques and 3D reconstruction with computer graphics. For these techniques it has been used a 3D reconstruction software (MIMICS). Mimics is a software suite that performs the segmentation of the anatomy through sophisticated three-dimensional selection and editing tools. Also this software can be used as an interface between CT scan and Rapid Prototyping installation and CAD software. The method adopted for visualization is the conversion of 2D image slice data, as gray value images. The resolution can vary from 0.2 to 1 mm. The program also generates high-resolution 3D renderings in different colors directly from the slice information, as shown in figure 1. Contrast enhancement can be carried out interactively to improve the model. The segmentation mask can be displayed in different colors on top of the image [2][4][6].

To obtain the virtual model of the hip joint is necessary to follow some major steps, steps that are enumerated downwards:

1. The first step is to import all processor data, which are represented by 2D thomographic slice. This process is done ascending from slice –523 to –359 (figure 1). In this case the segmentation of the interest area is made using a pitch of 1 mm.

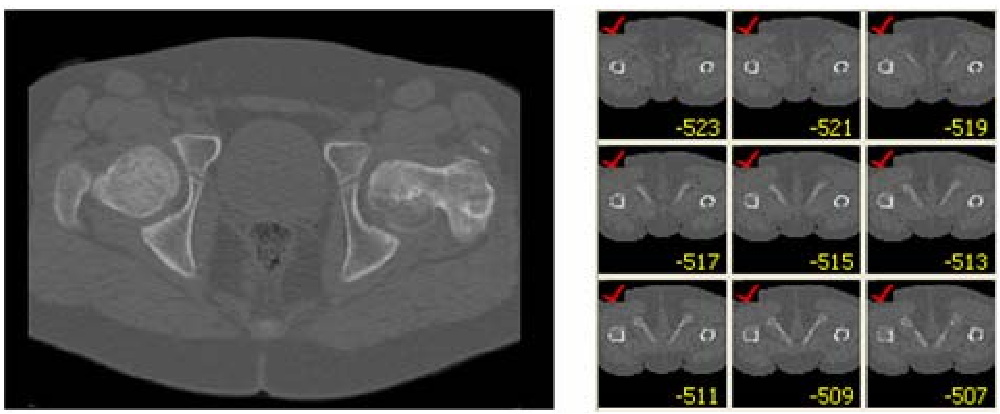

Fig. 1 ***The impute source represented by 2D thomographic slices.***

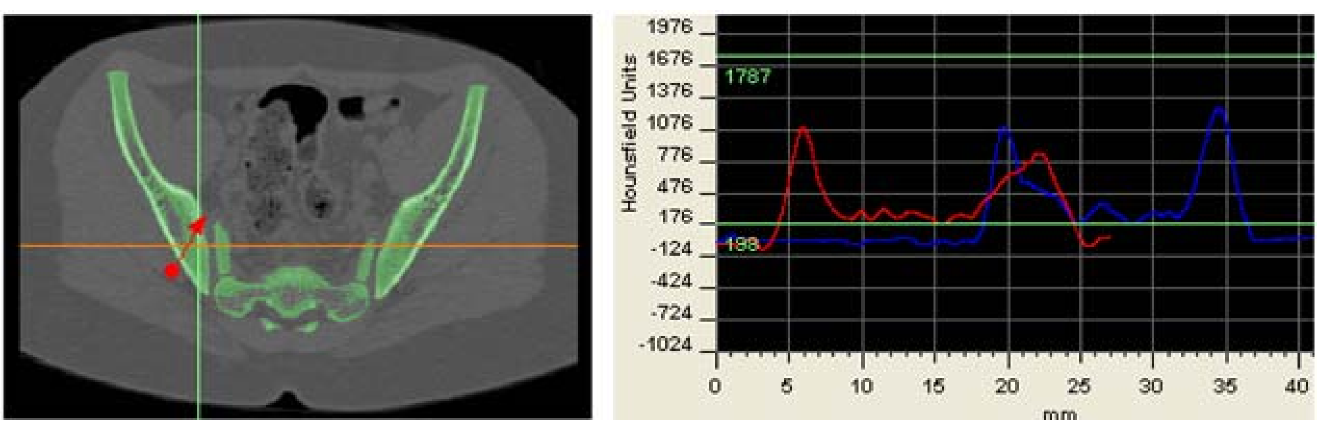

Fig. 2 The segmentation process used to separate the hard tissue (bone tissue) from soft tissue (muscles).

2. Thresholding means that the segmentation object (visualized by a colored mask) will contain only those pixels of the image with a value higher than or equal to the threshold value. Sometimes an upper and a lower threshold are needed; the segmentation mask contains all pixels between these two values. A low threshold value makes it possible to select the soft tissue of the scanned patient. With a high threshold, only the very dense parts remain selected. Using both an upper and a lower threshold is needed when the nerve channel needs to be selected. Defining a good threshold value also depends on the purpose of the model. The detection of bone tissue can be obtained by using the optimal gray value, established between minimum value of 198 and maximum value of 1787 Hounstield units (figure 2) [2].
3. 3D reconstruction of the hip joint (figure 3. a) and respectively 3D model of the femoral bone (figure 3. b).

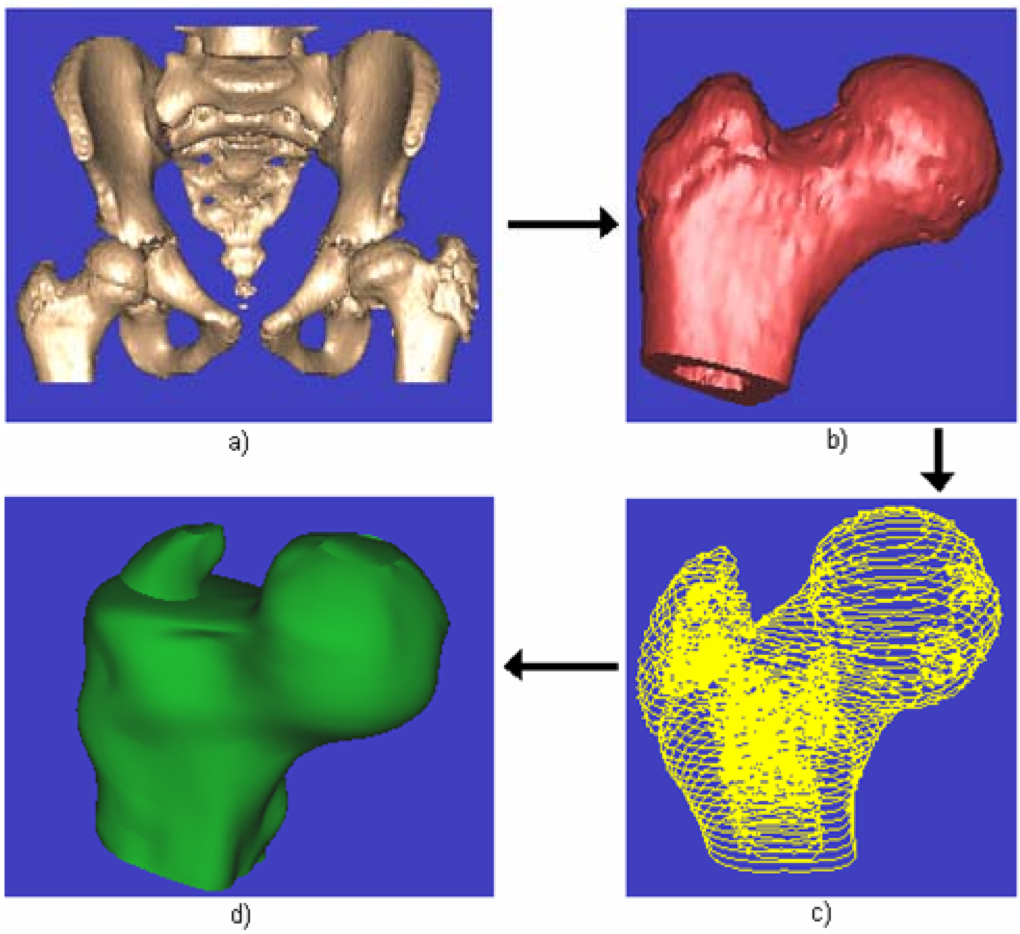

Fig. 3 a) Virtual model of the hip joint: b) virtual model of the femoral bone; c) determination of the polylines (contour lines); d) IGES model of the femoral bone.

The virtual model of femoral bone can be exported as IGES file to the CAD software where an endoprosthesis will be designed. The IGES model is described by a surface witch “wraps” and copy with fidelity all the irregular parts of the natural bone and it is taken as reference model for ulterior design of the prosthesis by CAD software (SolidWorks).

To obtain an IGES format of the anatomical part takes three stages [4]:

1. Determination of polylines resulting the outer contour of the bone (figure 3. c). In this case, the polyline is a continuous curve line that passes to all points of the model contour. The bone contour can be displayed 2D or 3D.
2. Checking and patching of contours determinated by polylines. The analysis can be affected by the influence of artifacts. The artifacts are some erroneous signals received during scanning time and they are produced by the metal implants witch are already in the human body. To remove all these errors, Mimics module has some editorial panel that can remove or add elements.
3. Obtaining of the IGES model (figure 3. d).

Fig. 4 Hip endoprosthesis designed in SolidWorks.

SolidWorks is a software package intended to design, analyze and fabricate by using the computer. The modules, which compound the SolidWorks package, permit the construction of geometrical models, the definition of complex ensembles, the generation of technical documentation of projects, etc.

The fundamental concept used by the SolidWorks package is the graphical block of construction (feature). The construction of hip endoprosthesis starts by defining a base graphical block (base feature).

This graphical block is the base for the next steps used to construct the rest of the model. The graphical blocks introduced ulterior depend of base graphical block by references. The final model of hip endoprosthesis (figure 4) is obtained by using some complex operations like: extrude, sweep, revolve, blend, cut, slot, etc. Another important characteristic of CAD software is the parameterizations of implant. This means that the form and the structure of model can be established and modified every moment. Every modification of these attributes (known as parameters) immediately is reflected in the geometrical model.

A very important characteristic that is used to design a prosthesis is the adaptation of the bone model in IGES format to the virtual model of the prosthesis, keeping in this way the anthropometrical data of the bone. This is possible by fading two models (red color model is IGES model of the femoral bone and the gray model is the virtual model of the endoprosthesis) (figure 5) [4].

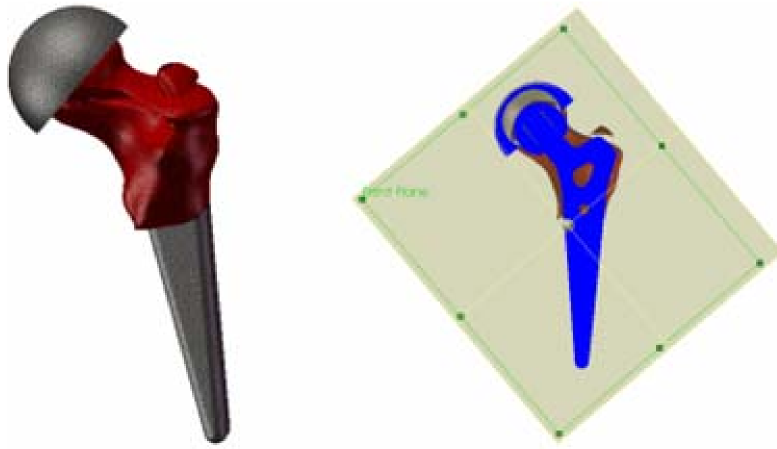

Fig. 5 ***a) The fading of two virtual models; b) the section of assembly formed from two models.***

Hip endoprosthesis, presented in figure 6, is a cemented implant used for hip arthroplasty, which consists of a femoral component and an acetabular component (figure 7).

The femoral stem is divided into head, neck and shaft. The femoral stem is made of Ti alloy or Co-Cr alloy (316L stainless steel was used earlier) and is fixed into a reamed medullary canal by cementation or press fitting. The femoral head is made of Co-Cr alloy, alumina or zirconia. Although Ti alloys head function well under clean articulation conditions, they have fallen into disuse because of their low wear resistance to third bodies (bone or cement particles). In this case the femoral components is made from Ti alloys.

The acetabular component generally consists of three components: acetabular cup made of Ti alloys, a component of ultra-high-molecular-weight polyethylene (UHMWPE) and a component of Co-Cr alloys that articulate to the femoral head [3].

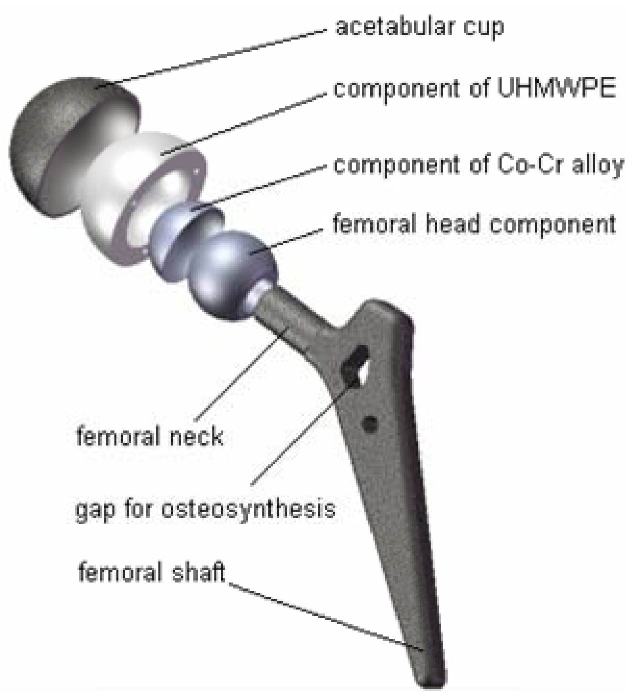

Fig. 7 The component elements of the hip endoprosthesis designed in SolidWorks.

Generally, the hip prosthesis can be monolithic when they consist of one part, or modular when they consist of two or more parts and require assembly during surgery. Monolithic components are often less expensive, and less prone to corrosion or disassembly. However, modular components allow customizing of the implant intraoperatively and during future revision surgeries [3].

3. Conclusions

The potential for computer graphics to contribute to biomechanics and medicine progress is promising. It is important that not only knowledge of the natural tissue is focuses on. Also controlling and modeling mechanical stimuli will be essential to develop appropriately engineered organs and how to integrate the function with the host.

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[6] www.materialise.com