

NEW CAD TECHNIQUES USED FOR VIRTUAL BONE MODELS APPLIED IN ORTHOPEDICS

Abstract: The paper presents some methods used to create and analyze human virtual bones. The cooperation between medical research team and the engineer research group give important tools for medical devices or implants design. To re-create anatomical 3D models it was used a CAD software which permits to define complex models. First, there were defined the "hard" parts as the main bone components and "soft" parts as ligaments or menisci using CT images. Also, using CAD methods, were created virtual models of human joints. In the last decade, a new concept called rapid prototyping, physical coating or without solid pre-form manufacturing, has become very popular.

Key words: computer graphics, orthopedics, virtual bones, rapid prototyping, virtual prototyping.

1. INTRODUCTION

The subject of this paper is the result of the cooperation between scientists working in different fields, which have the ability to develop methods and information technologies to solve difficult problems given the complexity of the scientific objective. Using computer aided design (CAD), complex medical devices and geometry transfer software, can be developed virtual models of the human skeleton including the main muscle groups, bone joints ligaments and menisci [6].

Also, on virtual models can be studied main types of movements such as walking, leg flexion, pronation, extension and supination for upper limbs or lateral bending (left - right) motion flexion - extension of the spine neck and skull. Using these virtual models can be analyzed pathological situations, surgical or post - surgical or can be tested different types of implants or innovative prostheses [1].

2. THE CAD METHODS BASED ON CT OR MRI SCAN IMAGES

2.1 CT or MRI scan operations

To obtain CT images of bone components were used main bones of the human knee, elbow and cervical spine joints, taken from cadavers, or were used CT images made on living subjects. In the Figure 1 were presented CT images obtained in the pelvis area obtained from four different patients.

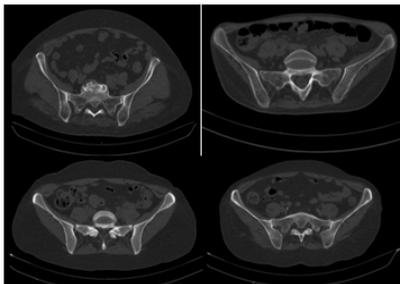


Fig. 1 Four CT images obtained in pelvis area.

The experiment was conducted using CT and MRI devices installed at Emergency County Hospital Craiova.

Tomography machine allows the user to obtain images in DicomWorks format, specialized software for CT or MRI images and their management.

2.2 Computational methods and techniques used to obtain bone models

In the last time we used the next methods to determine the virtual models of the human bones:

- A method based on planes reconstruction of the CT planes in a virtual environment. The CT images were inserted in these planes and were drawn the outer and inner contours of the bone. Finally, the bone was modelled using 3D shapes as Loft or Cut Loft for inner geometry. This method was effective for 3D reconstruction of long bones.
- A method based on software as InVesalius or Mimics which transforms the 2D CT images in 3D geometries. But, the results are files in .stl formats. To obtain a solid geometry of the bone, the software can transfer planar curves for inner and outer contours. In the final, these curves can be unified using Loft or Cut Loft shapes.
- Another method based on InVesalius or Mimics which can directly transfer the surfaces geometries of the bones. But, in the most cases, these geometries must be patched and after that, the outer and inner surfaces can be filled with solids.
- A method which combine all these methods. In many cases, on specific areas of the virtual bone can be applied one of the method explained before.

These virtual bones can be finished using other CAD techniques based on different software.

2.2.1 The first software method used for virtual bones [3,11]

These images, compatible with the most Windows-based files, were loaded, one-by-one, in AutoCAD. The computer aided design software allows defining two-dimensional non-parametric models. First, the images were loaded into the software to determine the geometric scale made by computer tomography. Because each CT image contains a fixed benchmark (a plastic rod with square section with sides of 20 mm) comparing the square on the images with real section was determined the scale of these images and these were loaded into AutoCAD, so images appear to the natural scale 1: 1. For

the beginning, over loaded image in AutoCAD and properly scaled to the natural size, were drawn inner and outer contours of the bone and a square with sides of 20 mm corresponding to bar section used as a fixed reference (Figure 2) [3,11].

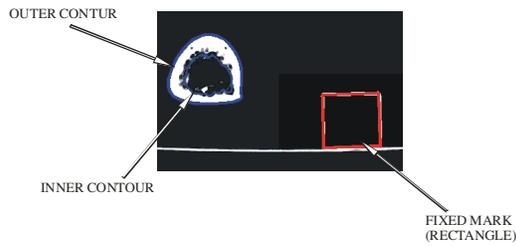


Fig. 2 The 2D elements drawn in AutoCAD over the imported CT image [3,11].

These contours were transferred successively into a three-dimensional parametric design software as SolidWorks, used in engineering (Figure 3). In this software, were, initially defined, several parallel planes at a distance of 1 mm or 3 mm, according to the scheme used for CT operation [3,11].



Fig. 3 The 2D elements drawn imported in SolidWorks [3].

This operation, of defining the contours and transfer to SolidWorks, was repeated for each CT scan. In Figure 4.a are shown, for example, three sections transferred to different planes. To obtain a parametric solid were "unified" the outer contours in a loft type form (Figure 4.b.).

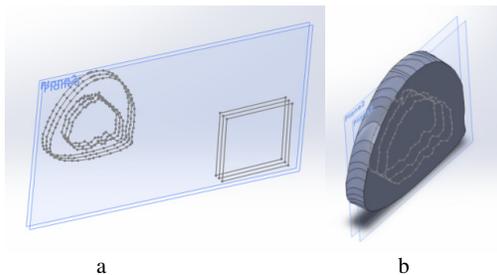


Fig. 4 The 2D elements drawn in AutoCAD and imported in SolidWorks [11].

To generate the inner channel of the virtual bone were used the three inner sections and a feature like CUT-LOFT type [11]. The result of this operation is shown in Figure 5.



Fig. 5 The virtual tibia segment re-composed in SolidWorks [3,11].

Using similar operations in that virtual parametric software, were defined femur, tibia, fibula, humerus, ulna and radius bones. In Figure 6 were presented the models of these bones [3].



Fig. 6 The virtual bones obtained using first method [3,6].

2.2.2 The second software method used for virtual bones [3,11]

This method is based on software as InVesalius or Mimics, which transforms the 2D CT images in 3D geometries.

InVesalius is a free software built in collaboration with academic community. It generates 3D medical imaging reconstruction based on a sequence of 2D DICOM files acquired with CT or MRI equipments, providing several visualization tools [14].

In the Figure 7 was presented the user interface of InVesalius after loading DICOM CT files made on a living subject in the pelvis area. Also, the software define the images in axial, coronal and sagittal planes. Usual, the software can generate very easy 3D surfaces in .stl format.

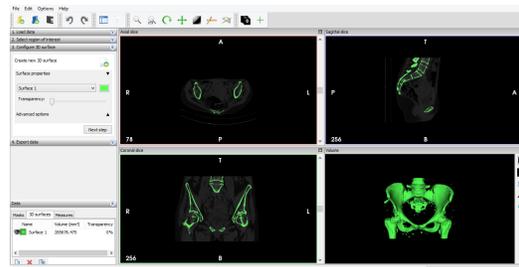


Fig. 7 The user interface of InVesalius.

The results (in .stl format) can be loaded in CAD software as SolidWorks. For the pelvis bones the imported geometry looks like in Figure 8.



Fig. 8 The .stl geometry imported in SolidWorks.

This type of model cannot be measured, modified, but can be 3D printed. To generate a valid geometry with solid shapes, from InVesalius or Mimics, we must to obtain the inner and outer contours in parallel planes. This kind of model, made on pelvis area, can be loaded in SolidWorks (Figure 9). Some algorithms for curves are detailed in [9,10].

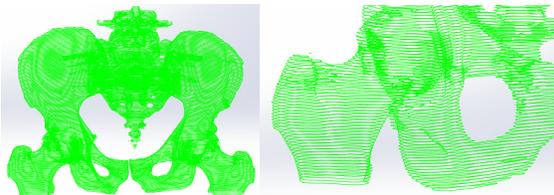


Fig. 9 The main curves imported in SolidWorks.

These curves can be unified using Loft shape. In the Figure 10 was presented a part of the femur bone made by defining curves.

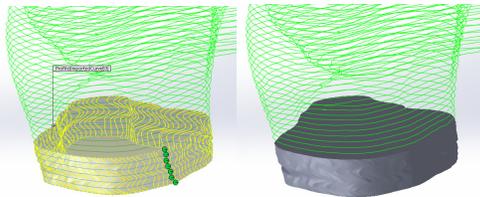


Fig. 10 The Loft applied on curves for the femur bone.

2.2.3 The third software method used for virtual bones [3,9]

This method is based on InVesalius or Mimics which can directly transfer the surface geometries of the bones to CAD software. Often, the surfaces are broken and it must be use a defining command as Fill Surface. In the Figure 11 was presented a broken surface before and after filling operation (added surfaces are in dark gray).

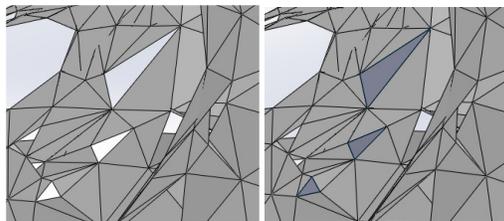


Fig. 11 A broken surface before and after filling operation.

After all the holes were filled the surfaces can be filled with solids. In Figure 12 was presented a geometry of pelvis after the solid filling operation.

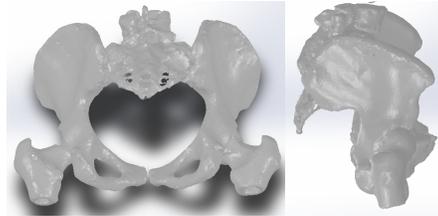


Fig. 12 Virtual solid bones obtained by using third method (different views).

2.2.4 The fourth software method used for virtual bones [3,11]

This method combine all the previous methods. In many cases on specific areas of the virtual bone can be applied one of the method explained before. Also, this method can use other software as Geomagic for SolidWorks. This software can works on .stl models using *Wrap*, *Remesh* and other specific operations which can transform entire mesh structure. Also, the software has powerful shape recognitions tools, almost of them can transform .stl surfaces into primitive solids. As an example, in the Figure 13 was shown how the *Freeform* recognition tool works on a virtual pelvis surface.

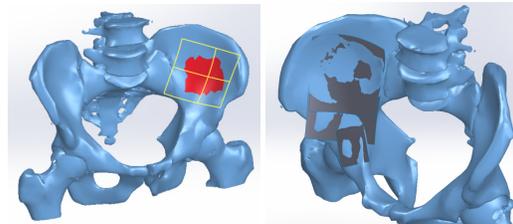


Fig. 13 A Freeform recognition tool applied on a pelvis surface.

3. VIRTUAL MODELS OF THE MAIN HUMAN BONES, LIGAMENTS AND MUSCLES

Using the methods previous presented, in the virtual parametric software were defined many bone models as humerus, ulna, radius, pelvis bones, C1-C7 vertebrae, cervical spine and human head-neck system and “soft” components as muscles attached on virtual elbow bones, menisci or ligaments (some of them are shown in Figure 14) [6,12].

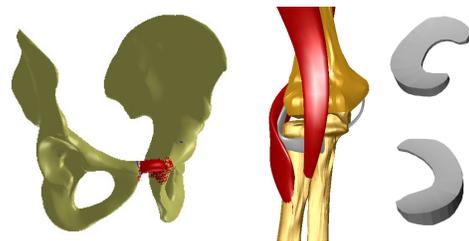


Fig. 14 Pelvis bones. The virtual models of the main muscles of the elbow joint, knee menisci, ligaments [6,7,8,12].

4. CONCLUSIONS

The behavior of the virtual human joints can give the important informations, which can be used in the fields

of robotics, medicine sciences and medical robotics. Also, on these virtual joints can be attached virtual prosthetic elements for virtual post-surgery simulations [2,4]. The obtained models were completed with the mass properties and the virtual bones had, in that moment, the same inertial characteristics as the real bones. Additionally, can be obtained different diagrams for analysis and discussions. Similar models and analysis were developed in [5], applied only on mechanical systems.

Using these methods, on the virtual lower leg joints can be attached virtual prosthetic elements for virtual post-surgery simulations. The simulation software permits the obtaining of some kinematical, statically or dynamical results in a short time with a high precision. Thus, it can obtain the position, velocity and acceleration variation vs time for any biomechanical system. It can be obtained the forces in joints, which could require an ample calculus or special equipment, permit the obtaining of some important parameters, which define the entire kinematical behavior. In conclusion, the studied virtual bones can be used as prototype model for the studies regarding elbow, knee, head-neck system with applications in medical research.

Also, were developed many types of kinematic and FEA simulations made on different assemblies composed by bones and metallic components to determine the virtual behaviour and to test implants and prosthetic elements and techniques presented in [13]. Using rapid prototyping method these prosthetic components can be 3D printed and analyzed.

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