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GEOMETRICAL MODELS OF HUMAN BONES AND IMPLANTS, AND THEIR USAGE IN APPLICATION FOR PREOPERATIVE PLANNING IN ORTHOPEDICS

Abstract: Geometrically accurate and anatomically correct three-dimensional geometric model(s) of human bones (or bone sections) and implants are essential for successful preoperative planning in orthopedic surgery. Such models are often used in various software systems for the preparation and control of surgical interventions. In this paper, the process of models' creation and their usage in application for the preoperative planning in orthopedics are presented. Models are created by using reverse engineering techniques, CAD (CATIA) and 3D Content creation software (Blender). The application is web oriented, and developed with use of modern web technologies like HTML5 and WebGL. In relation to commercial and free software systems currently in use, this application has several advantages such as: implementation of adaptive geometrical models, the ability to work across multiple platforms, ease of installation and use, etc.

Key words: geometrical models, bones, application, web, preoperative planning

1. INTRODUCTION

In orthopedic surgery, but also in all other sub-branches of surgery, where there is need for preoperative planning or creation of customized implants (fixators), there is a specific requirement to know the exact geometrical model of the human bone. Therefore, it is very important to create geometry of the bone rapidly and accurately. Having such models, it is possible to build customized bone implants (fixators) using rapid prototyping technologies, or performing preoperative planning procedures in adequate applications.

The classification and analysis of 3D modeling methods for the creation of human bones geometrical models are presented in [1]. This paper describes the study and the development of a script for a commercial software package (3ds Max) able to reconfigure the template model (deformable by Free Form Deformation method - FFD) of a femur starting from two orthogonal images representing the specific patient's anatomy. Although this study provides an outstanding contribution to the research field, there are some drawbacks. First one is the semi-automatic image segmentation (X-ray images) which is always problematic due to previously known problems with the X-ray images (superposition, inaccurate patient positioning, artifacts, etc.). The parametric model presented in this paper is not limited to the input data from only one source, because parameter values can be acquired from any available medical imaging devices: CT, X-ray, MRI, ultrasound, etc. The second drawback is creation of the script for the application in only one software (3ds Max). The points model created by this method can be used in any 3D graphic application which works with cloud of points model(s).

The 3D reconstruction process which is based on anatomical properties is presented in [2]. The purpose of this study is to create a 3D model of human femur by using multiple X-ray images and anatomical properties

of the femur. For 3D reconstruction, firstly, the 2D shape and specific parameters of the bone are measured from X-ray images. Then, the corresponding CT model is modified as it follows: the axial scaling, shearing transformation and radial scaling. Findings presented in [1,2] are the basis for the development of method presented in this paper.

In [3], the authors are trying to create composite bone model with possible bone part adaptation and replacement from generic database of bone models. This is a useful approach when 3D scanning methods are available, but for 2D scanning methods more precise and patient-adapted models are required. In [4], the authors suggest application of standard bone fracture models database and its implementation in application for planning orthopedic operations. In [4] good example of preoperative procedures and techniques is presented.

2. THE GEOMETRIC MODELS CREATION PROCESS

The developed method contains three preparatory processes which must be performed in order to generate a valid geometrical model (surface, solid, parametric model) of the specific human bone, as presented in Fig. 1. The applied method for creating the human bone geometrical model is based on anatomical properties (anatomical model) and human bone morphology.

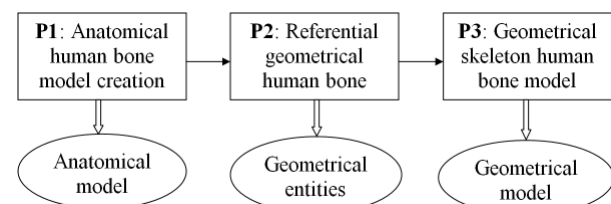


Fig.1 Preparatory processes for geometrical models creation

Anatomical bone model is, in its essence, a semantic (descriptive) model in which anatomical definitions are taken from medical sciences, and it defines terms referring to certain areas on geometrical bone model. In other words, the anatomical model can be described as a set of anatomical landmarks which are defined on each bone and well known in medicine.

In connection with that, the first step is semantic defining of anatomical areas on human bone, i.e. creation of anatomical bone model, as well as informing about basic bone morphology (P1).

After creating the anatomical model, creating of the basic model geometry is introduced. Initial preparatory processes are thoroughly presented in [5] and [6], demonstrating application of the following operations: Computer Tomography (CT) scanning part of the human body or dry samples (in this case femur); Preprocessing of raw data (scans) and its transformation into STL format; Importing the scanned model in STL format into CAD application (for example CATIA) and its further preprocessing; Cleaning the cloud of points; Tessellation and Healing the tessellated model. At the end of the preparatory processing processes, polygonal geometrical bone model is created.

The upper stated processes are so called preparatory processes for a very important procedure of referential geometry defining - RGEs (planes, lines, axis, points, and so) [6] which is defined on polygonal human bone model in accordance with its anatomical and morphological features. After defining RGEs (P2), follows the examination of polygonal bone model in order to create geometrical entities which will serve as base for creating the geometric model(s). Geometrical entities are mainly spline curves (B-spline) and are defined to follow bone geometry and topology the best way possible and all in accordance with anatomical bone model (P3). Spline curves defined on femur condyles are presented in Fig. 2.

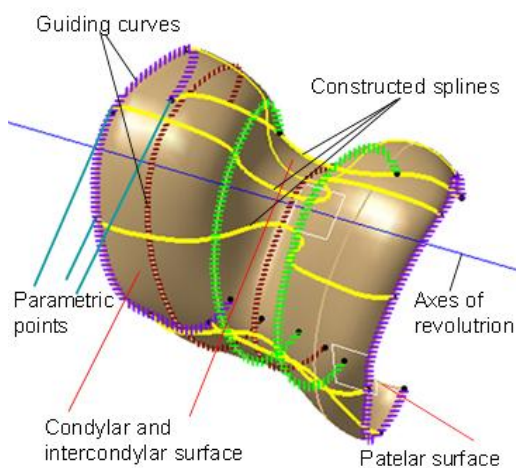


Fig. 2. Femur condyles surface model with defined spline curves and parametric points

These entities serve as the basis for the creation of adequate geometrical models. They can be used for the creation of:

- Geometrical points for the parametric bone model [6]

- Polygonal, Surface and Volume models [5,7]
- Finite Element Models [8],
- Geometrical models of human bones missing parts (due to bone illness or bone fractures).
- etc.

The parametric and polygonal models are used in web application, created by authors, for the preoperative planning in orthopedics. To provide further information, a brief description of the process of creating polygonal and parametric models of human bones will be presented.

The parametric model consists of a set of points whose coordinates are defined by parametric functions. This model can be regarded as a mathematically defined cloud of points model. Points are created at specific anatomical positions on spline curves defined in the P3 process (Fig. 2), as shown in [6].

Parametric functions are created for each point individually and they provide the dependency of points coordinates on pre-defined parameters. The parameters are, in most cases, morphometric measurements, and they are defined for each bone (femur, tibia, fibula) separately. Their values can be acquired from various medical images (CT, X-ray) by the use of classical (ruler) or computer software measuring techniques. An example of parameters defined on the femur polygonal model is shown in the Fig. 3.

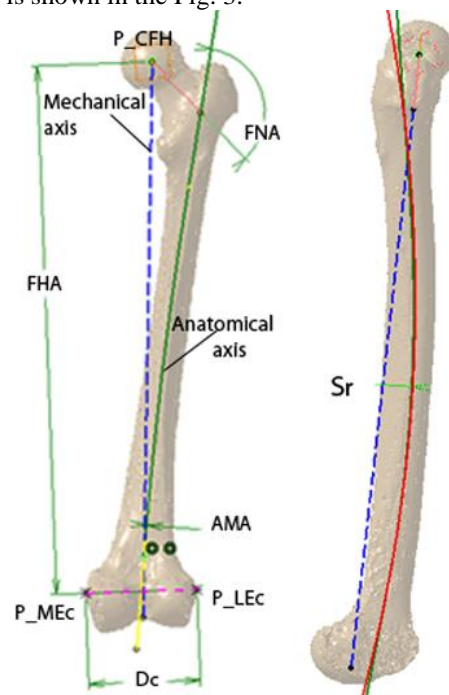


Fig. 3. Bone parameters defined on Femur polygonal model

Parameters are:

- FNA – Femoral Neck Angle
- FHA – Distance between P_CFH and line connecting P_MEc and P_LEc
- DC – Distance between P_MEc and P_LEc
- AMA – Angle between Anatomical and Mechanical Axis in Anterior Posterior view
- Sr – Shaft radius in Lateral-Medial view
- Femoral Head Radius - FHR

The polygonal model can be obtained in two general ways, and they are:

- by using the techniques presented in [5], which are based on the transformation of CT (DICOM) model into the polygonal model
- by using a parametric points model as input data to form a polygonal model by creating correctly connected triangles.

3. THE PROCESS OF CREATING MEDICAL FIXATOR SOLID MODEL

This paper describes a method for creating a geometric model of the tibia internal fixator by Mitkovic. Based on the fact that the bones are not shaped as typical geometrical forms, and that two identical bones do not exist in reality, there is a requirement to define optimal geometry of the fixator, which can be applied on more than just one tibia. The fixator by Mitkovic consists of two parts: distal and proximal, whose geometrical models are made separately and then connected in one whole model. The first step in creating a geometrical fixator model is to create the fixator's outer contour projection, perpendicular to tibia shaft tangential plane, on the tibia surface, Fig 4. Fixator's contour geometry was created on the basis of existing (real) fixator geometry and topology by Mitkovic.

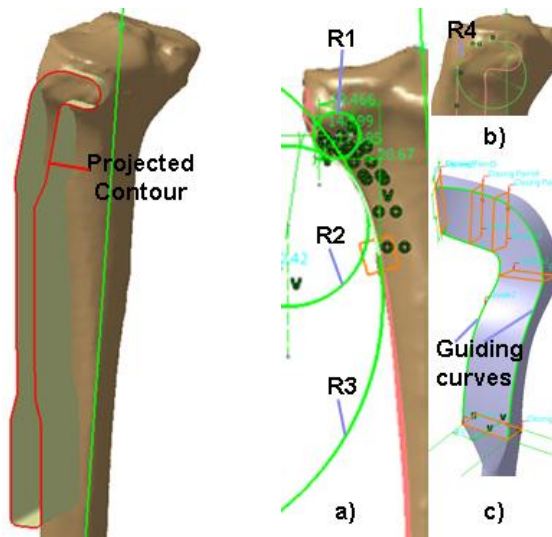


Fig. 4. Fixator contour projection Fig. 5. a,b) Constructed circles, c) Fixator volume model

A projection curve is used to create the proximal and distal curve guidelines and limitations for the design of optimal fixator geometrical model. The process of creating proximal part guiding curves consists of two individual steps: creating the outer (lateral) and inner (medial) circles with adequate radius values on the tibia model surface. The proximal part of guiding curves is created by cutting and connecting the created circles, Fig 5a,b. The fixator proximal part volume model is created by dragging the rectangle profile along the contour curves, Fig. 5c. The fixator distal part volume model is formed by extrusion of adequate profiles to

the merging point with the proximal model. The complete fixator solid model for the specific bone (patient) is created by merging proximal and distal part models.

In order to obtain optimal values of guiding curves radiuses (and thus fixing the model so it can be applied to a number of different patients) measurements on ten different tibia (patients age 20 to 55, male and female) were performed and mean values were obtained and presented in Table 1. Values given in Table 1 were used to create a guiding curve with mean radiuses values, which is used to create fixator volume model with optimal geometry.

Tibia	Radius R_1	Radius R_2	Radius R_3	Radius R_4
Mean Value	15.5969	26.1637	83.0417	17.9543

Table 1. Specific guiding curves radiuses mean values for ten different tibia bones

4. THE APPLICATION OF THE MODELS

Polygonal bone and fixator models are used in a web application for the preoperative planning in orthopedics. The application is based on the use of WebGL and HTML5 technologies, implemented through THREE3D open source engine. The application allows the transformation of basic models (rotation, translation, scaling), and pairing bone and fixator models in the appropriate assembly, Fig. 8.

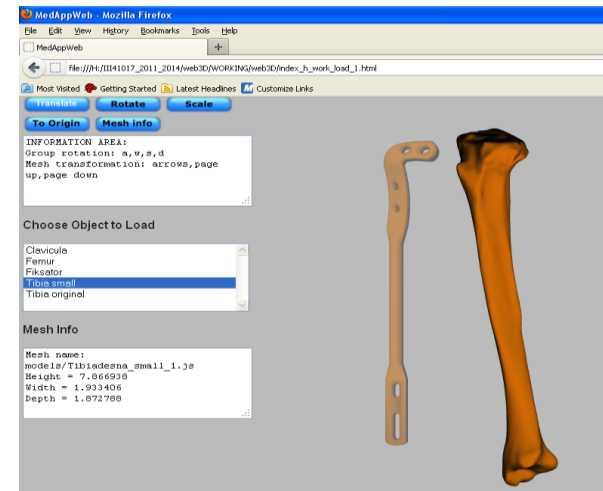


Fig. 8. Web application for the preoperative planning in orthopedics

In order to successfully apply the models in the application, it is necessary to previously perform the transformation processes, ie., to create the appropriate format of the model. Possible file formats are: .js in the form of JSON (JavaScript Object Notation), .3ds (3D Studio) .obj (Object), etc. In the current phase of development, JSON notation is used in applications (an example of entries for tibia model are presented in (1)). JSON data format allows data entry on: vertices, triangles, lights, normals, etc.. which completely defines the corresponding 3D model, and the scene

where the object model exists. JSON models are created on the basis of polygonal (STL) models in Blender software.

```
{ "vertices" : 71251,
  "faces" : 142498,
  "normals" : 71251,},
"materials": [ { }],
"vertices"=[-0.157411,1.041358,0.140951,...]
"normals"=[0.861171,0.032258,-0.507248,...]
```

5. CONCLUSION

Methods for creating human bone and fixators geometrical models are presented in this paper. Considering anatomical and morphological properties of the human bone, presented method(s) enables creation of more realistic, geometrically accurate and anatomically correct models as presented in [6,9,10]. The resulting model(s) of human bone(s) and fixators can be used for various purposes: preoperative planning in orthopedics (presented in this paper), learning processes, implant manufacturing, FEM analysis, etc.

In addition to the process of creating geometric models, their use in a web application for the preoperative planning in orthopedics is presented. The application enables basic geometric transformations of bone and implant models, such as : translation, rotation, scaling, zooming, etc., as well as the option to receive data on models (basic measurements, triangle quantity, and such), and to measure adequate distances on models, both individually and as part.

Further work in the research includes improving the method of creating a geometric model for the construction of better quality models in terms of accurate geometry and morphology, as well as creating models of a large number of implants (fixators) and bones (library of models). Regarding the application for preoperative planning, further focus is directed towards the improvement of the algorithm for managing the parametric model. Adequate algorithm will allow creation of patient bone geometrical models, solely on the basis of a number of predefined parameters whose values can be read (measured) from the input medical images.

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6. REFERENCES

- [1] Filippi, S., Motyl, B., Bandera, C.: *Analysis of existing methods for 3D modelling of femurs starting from two orthogonal images and development of a script for a commercial software package*, Computer methods and programs in biomedicine, 89, p.p. 76-82, 2008
- [2] Kyu Lee, M., Hyuk Lee, S., Kim, A., Youn, I., Soo Lee, T., Hur, N., Choi, K.: *The Study of Femoral*

3D Reconstruction Process Based on Anatomical Parameters Using a Numerical Method , Journal of Biomechanical Science and Engineering, 3, p.p. 443-451,2008

- [3] Matthews, F., Messmer, P., Raikov, V., Wanner, G., Jacob, A., Regazzoni, P., Egli, A.: *Patient-specific three-dimensional composite bone models for teaching and operation planning*, Journal of Digital Imaging, 22, p.p. 473-482, 2009
- [4] Sourina, O., Sourina, A., Howe, T.: *Virtual Orthopedic Surgery Training on Personal Computer*, International Journal of Information Technology, 6, p.p. 16-29, 2000
- [5] Stojkovic, M., Trajanovic, M., Vitkovic, N., Milovanovic, J., Arsic, S., Manic, M.: *Referential Geometrical Entities for Reverse Modeling of Geometry of Femur*, Proceedings of VIP IMAGE 2009, p.p. 189-194, Taylor & Francis Group, Porto, Portugal, 2009
- [6] Vitković, N., Trajanović, M., Milovanović, J., Korunović, N., Arsić, S., Ilić, D.: *The geometrical models of the human femur and its usage in application for preoperative planning in orthopedics*, ICIST 2011, Kopaonik, Serbia, 2011
- [7] Veselinovic, M., Vitkovic, N., Stevanovic, D., Trajanovic, M., Arsic, S., Milovanovic, J., Stojkovic, M.: *Study on creating human tibia geometrical models*, Proceedings of the 3rd International Conference on E-Health and Bioengineering - EHB, p.p. 195-198, Iași, Romania, 2011
- [8] Trajanović, M., Korunović, N., Milovanović, J., Vitković, N., Mitković, M.: *Application of computer models of mitković selfdynamizable internal fixator in rehabilitation of femur traumas*, FACTA UNIVERSITATIS Series: Mechanical Engineering, 8, p.p. 27 - 38, 2010
- [9] Vitković, N., Milovanović, J., Trajanović, M., Korunović, N., Stojković, M., Manić, M.: *Different Approaches for the Creation of Femur Anatomical Axis and Femur Shaft Geometrical Models*, Proceedings of ICPE 2011, ICPE 2011, Niš, Serbia, p.p. 351-354, 2011
- [10] Stojkovic, M., Milovanovic, J., Vitkovic, N., Trajanovic, M., Arsic, S., Mitkovic, M.: *Analysis of femoral trochanters morphology based on geometrical model*, Journal of Scientific and Industrial Research, 71, p.p. 210-216, 2012

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