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USING MAGNETIC RESONANCE IMAGES TO CREATE 3D MODELS OF BONES FOR SUBSEQUENT NUMERICAL ANALYSIS

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ABSTRACT
This paper presents and explains the procedure for creating 3D models of human bones for subsequent numerical analysis. In particular, the models of tibia and femur are constructed from a number of magnetic resonance (MR) images using MIMICS software. The models are meshed and prepared for the numerical analysis of the contact problem between them. In addition, the procedure of producing real models using 3D printing (3DP) is also presented. The study shows a great potential of this approach not only for the analysis of the contact phenomena, but also in other biomechanics areas, such as for planning complex surgical procedures, design and manufacture of implants, and so on.
Keywords: magnetic resonance imaging (MRI), segmentation, meshing, numerical analysis, three dimensional printing.

1. INTRODUCTION
Over the last decade, considerable efforts have been put into both biomedical image processing and biomechanical modeling and computation. Computer imaging techniques have become an important diagnostic tool in the practice of modern medicine. These techniques include Computed Tomography (CT) or Magnetic Resonance Imaging (MRI), which use a sampling or data acquisition process to capture information about the internal anatomy of a living patient [1]. CT and MRI are based on different physical principles such that they produce vastly different image characteristics [2]. For example, CT can produce the distinct contours of bones, but it cannot show clear images of soft tissues. On the other hand, MRI shows good contrast between the organs and the other soft tissues, but it does not reveal the distinct contour of bones. Neither imaging technique can produce clear contours of both, the bone and the surrounding soft tissues, even though they provide complementary information. However, the advantage of MRI technique is that there is not radiation risk to the patient.
In order to obtain 3D models of bones, image based modeling involves two additional steps: (i) image processing using commercially available software, which would organize and process the region of interest (ROI) from the image, and (ii) three dimensional reconstruction (3DR) of the ROI to form voxels that describe the 3D shape of the model to be used for the further modeling, analysis or prototyping. Several studies have been reported in literature that used 3D reconstruction to help in a better understanding of anatomical functionality and morphological analysis [3-5]. The use of 3DR

can also be used in surgical assessment and planning of various bone pathologies that primarily include the hip and knee bone.

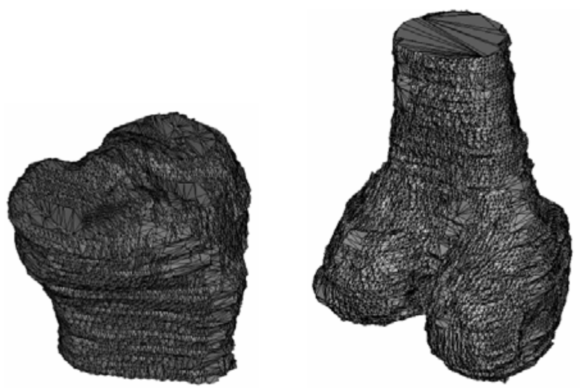
This paper presents and explains procedure used to obtain 3D models of proximal tibia and distal femur from MRI images. For this purpose image segmentation techniques, threshold and region growing, were employed. In order to get an adequate mesh for FEM analysis, MAGICS software was used. Numerical analysis of the contact problem between reconstructed models was performed in ABAQUS. Using Z-corp three dimensional inkjet printer, a real model was produced from reconstructed 3D models of bones.

2. THREE-DIMENSIONAL RECONSTRUCTION FROM MRI IMAGES

The region of study involved MRI images of the knee joint. In total 160 slice images were obtained in the sagittal, axial and coronal planes, with a thickness of 0,78 mm. Once loaded into the MIMICS, all images were properly registered and aligned for its orientations. Next, the regions of interest were identified and 3D voxel models of the bones were made. For the best capture of relevant information contained in the proximal tibia and distal femur, an appropriate threshold range was found. Using this threshold value, all pixels were grown to a color masks (M1,M2) and hence the segmentation process achieved by making use of region growing techniques available in the software. These color masks act as the input to the 3-D reconstruction process. The process is depicted in Figure 1.

a) MRI images are loaded into MIMICS

b) Region of Interest are indentified and given an appropriate differentiating color masks



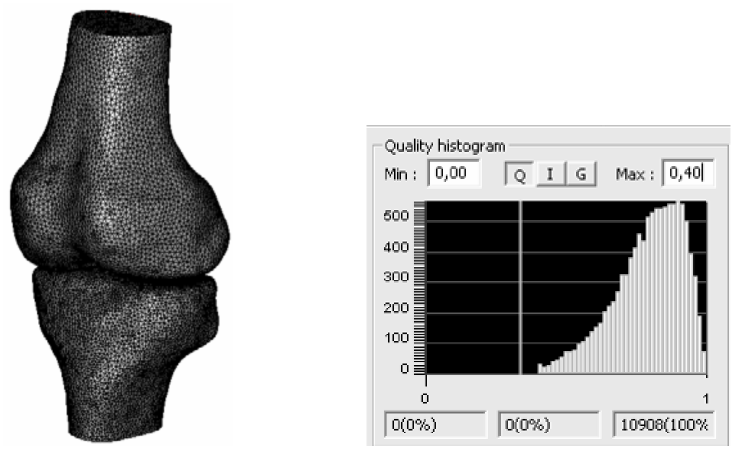
c) Three dimensional voxel reconstruction of the segmented images

Figure 1. Image Registration, 2-D segmentation, 3D reconstruction process

3. REMESHING

In order to improve the quality of the surface mesh produced in the last step, so that the preprocessor of an FEM package can build a tetrahedral mesh from them, the remeshing protocol had to be conducted. This protocol was based on applaying following steps: smoothing, normal triangle reduction, split-based automatic remeshing, and quality preserving triangle reduction [6].

The quality measurements are based on the properties that describe a triangle: base, length, height, A perfect mesh would consist of triangles that are all equilateral. Typically for FE analysis the Height/Base (N) quality parameter is used. To guarantee an adequate mesh for an FEA preprocessor the value of Height/Based parameter for all triangles should be above 0.4. Figure 2a depics the surface mesh of the reconstructed models at the end of the remeshing protocol. As shown in the quality histogram (Figure 2b), all triangles had the value of Height/Base parameter above 0.4.

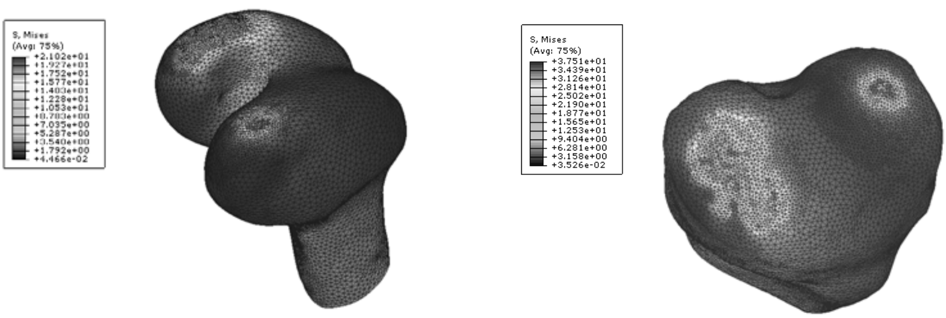


a) Final mesh *b) Height/Base quality histogram*

Figure 2. Surface remeshing

4. APPLICATION FOR NUMERICAL ANALYSIS

Reconstructed models were imported into ABAQUS software and the tetrahedral volume mesh was built. The model consisted of 373069 3D tetrahedral elements. In order to perform biomechanical analysis of the contact between reconstructed 3D models of bones, material for both tibia and femur was modeled as elastic, with modulus of elasticity of 12.7 GPa and Poisson's ration of 0.28. Boundary conditions and forces were applied according to ISO 14242-1.4 (the wear of Knee Joint standard). Numerical simulation was performed using ABAQUS software. Figures 3a and 3b show the results of the stress analysis in the contact region between femur and tibia.

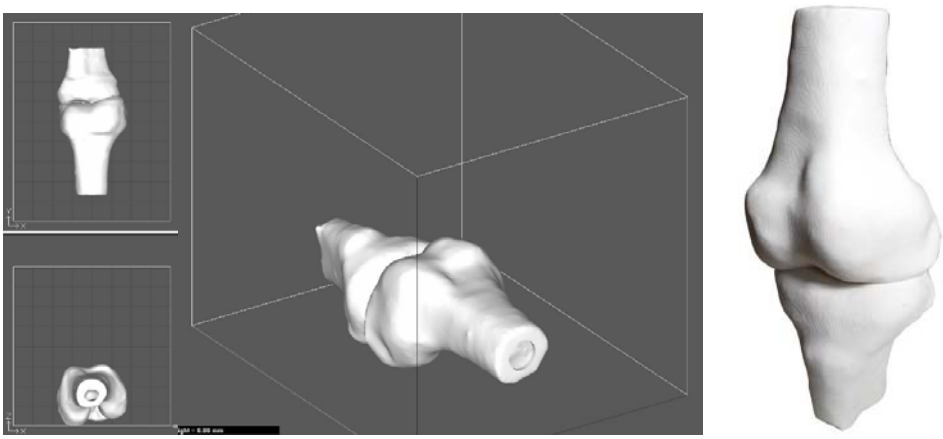


a) Stress distribution-femur *b) Stress distribution-tibia*

Figure 3. FEM analysis of the contact between Femur and Tibia

5. RAPID PROTOTYPING (RP) MODEL PRODUCTION

In order to make RP models of reconstructed 3D models, the technology of three dimensional printing [7] was employed. Obtained models in STL format were assembled in one model (Figure 4a) and printed on monochrome Z-CORP 310 MX printer. The final RP model of the knee joint obtained from MRI images is presented in Figure 4b.



a) Z-print virtual environment *b) RP model of the knee joint*

Figure 4. Three dimensional printing

6. CONCLUSION

The procedures presented in this paper focuses on converting MRI based images to 3D models of bones and their usage for subsequent numerical analysis and rapid prototyping applications. Numerical analysis can help in understanding of the biophysical property of the model under study. Various uses of rapid prototyping, especially 3DP technology, within surgical planning, simulation, training, production of models of hard tissue, prosthesis and implants, biomechanics, tissue engineering and many other cases open up a new great chapter in medical field.

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