Fluid-Structure interaction applied to blood flow simulations.

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ABSTRACT:

A coupled fluid-structure interaction model has being developed in order to study the vessel deformation and blood flow. This paper presents a methodology from which smooth surface are obtained directly form segmented data obtained from DICOM images. An integrated solution for segmentation-meshing-analysis is also implemented based on the GiD platform.

1INTRODUCTION

Computed Tomography (CT), sometimes called CAT scan, uses special x-ray equipment to obtain image data from different angles around the body, and then uses computer processing of the information to show a cross-section of body tissues and organs. It can show different types of tissue—lung, bone, soft tissue and blood vessels—with great clarity. Using specialized equipment and expertise to create and interpret CT scans of the body, radiologists can more easily diagnose problems such as cancers, cardiovascular disease, infectious disease, trauma and musculoskeletal disorders (Fasel 1998, Goldin et al. 2000).

A CT examination often requires the use of different contrast materials to enhance the visibility of certain tissues or blood vessels (Marmion & Deutsch 1996). Because it provides detailed, cross-sectional views of all types of tissue, CT is one of the best tools for studying the chest and abdomen, becoming a very useful tool in preventive medicine.

CT imaging can also be used to extract the geometry of the organs and tissues for computer analysis via segmentation of the DICOM image (Digital Imaging and Communications in Medicine). After performing the segmentation, a discretization of the domain is required for computer simulation. Generating a mesh for Finite Element simulations from a segmented image can be cumbersome due to the complicated geometry. To overcome this problem, methodologies which make direct use of the segmented data (voxel geometry) has been proposed (Heidenreich 2006). However, eventhough they result useful for electrophysiologic simulations, the non-smooth nature of the surface pose serious problems in solid mechanics and fluid-structure interaction simulations. Therefore, methodologies which provide smooth surface of the organs and tissues from biomedical images are desirable for computer simulations.

This paper presents a methodology from which smooth surface are obtained directly form segmented data obtained from DICOM images. In what follows the methodology and the algorithm are described. The last section presents two applications of the methodology in a human heart and in a coronary artery used for fluid-structure simulations.

2METHODS

2.1*CT image segmentation*

The objective of the image segmentation is to find and to identify objects with certain characteristics form the rest of the image. The data segmentation will allow to visualize and to extract the part of the volume of interest. One of most widely used techniques is the grey thresholding segmentation. It is possibly the simplest and most direct method. The selection of the grey thresholds defining the object of interest is usually interactive, even though some alternative techniques have been proposed to determine it in an automatic way. These threshold can be defined in either a local or global data set, and sometimes, over a three-dimensional data set.

In most applications, threshold segmentation is accompanied by manual segmentation which requires the physician expertise. Figure 1 shows a segmentation of a human heart.

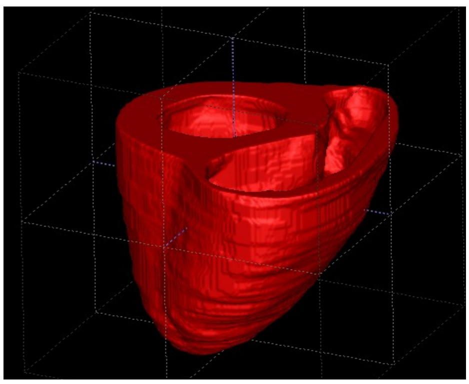

Figure 1. Segmented Human Heart

2.2*Meshing algorithm*

The development of finite element simulations in medicine, molecular biology and engineering has increased the need for quality finite element meshes.

In this work we have implemented the following methods to generate the finite element mesh to be used in the analysis stage:

1. Dual contouring
2. Marching cubes
3. Advancing front
4. Volume preserving laplacian smooth

3RESULTS

3.1*Human Heart*

In this example, a MRI image of a human heart has been segmented and a boundary mesh generated for the epicardial and endocardial surfaces. Figure 2 show the boundary mesh for the ventricles. The voxel image used as input correspond to the segmentation shown in Figure 1.

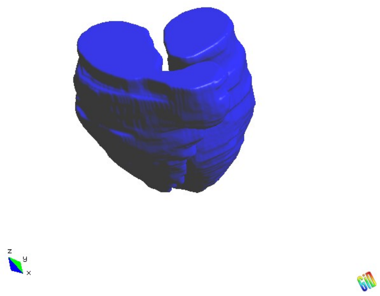

Figure 2. Boundary mesh for the right and left ventricles of the human heart

The resulting boundary mesh is quite smooth and can be decimated further to reduce the size of the resulting model without altering the topology

3.2*Femoral Artery*

This example considers an example of a human femoral bifurcation. In this case, a boundary mesh is generated from which two independent meshes are obtained, one for the solid artery wall and a volume mesh for the fluid to be used in fluid structure interaction computations.

Figure 4 shows the boundary mesh obtained after applying the algorithm, and Figure 5 and Figure 6 show the solid mesh for the arterial wall and the volume mesh for the fluid respectively. The solid mesh for the arterial wall has been generated by extruding the surface mesh.

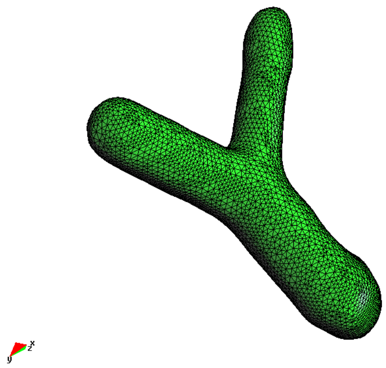

Figure 4. Boundary mesh obtained from the vtk file.

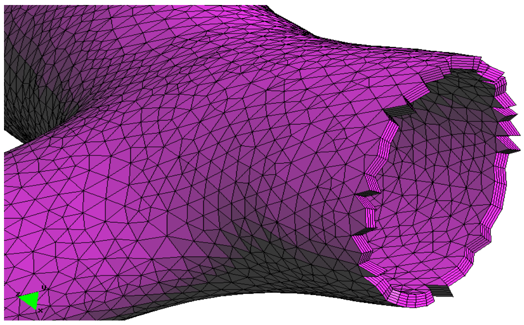

Figure 5. Solid mesh for the arterial wall.

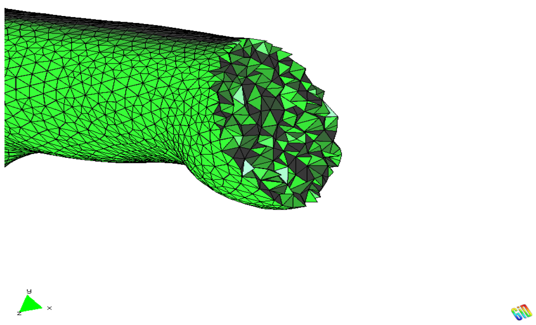

Figure 6. Volume mesh for the fluid.

4CONCLUSIONS

The results show the viability of applying the presented methodology to generate computational finite element meshes from segmentation files obtained from medical images. This tool opens new possibilities for patient specific biomechanical applications.

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