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Software Tools for Generating CFD Simulation Models of Blood Flow from CT Images, and for Postprocessing

D. Milašinović[*1], M. Ivanovic[1], H. Tengg-Kobligk[5,6], D. Böckler[4], N. Filipović[1,2,3]

[1] Bioengineering Research and Development Center – BioIRC, Kragujevac, Serbia
[2] Faculty of Mechanical Engineering, University of Kragujevac
[3] Harvard School of Public Health, Harvard University, USA
[4] Vascular and Endovascular Surgery Ruprecht-Karls University Heidelberg, Germany;
[5] Department of Radiology, German Cancer Research Center, Germany;
[6] The Ohio State University, Department of Radiology, Columbus, USA
* *Corresponding author*

Abstract

Modern medical image devices provide data which are suitable for computer modeling. Using the data from a multi-slice 64-CT scanner at German Cancer Research Center in Heidelberg, we developed a set of software tools for manipulating FE mesh as well as post-processing. In this work we employed raw data from the CT image device to create a 3D brick mesh of the aorta. The aorta image was taken from a patient that had an aorta aneurysm so we virtually removed it and created a corresponding 3D meshed model without the aneurism. Finite element calculation was performed for both geometrical models, for the aorta with and without aneurysm.

We also created a set of post-processing software tools for representation of the results. It is shown that the developed software tools are efficient regarding the post-processing time. This efficiency is very important for future diagnostic and modelling software.

Keywords: 3D modeling, CFD simulation, mesh, brick mesh, STL, post-processing

1. Introduction

Cardiovascular diseases are common and enormous efforts are needed in curing them. Diagnostics is very important in planning adequate interventions. Modern medical image devices provide data that can be used for 3D computer modeling, where geometrical modeling is the base for computational simulations.

Computer simulations can be very useful because we can simulate and modify physical (boundary) conditions and results (as shear stress, velocities and pressure distributions) without real interventions on a specific patient. This could open a new avenue in predictive medicine where we can help in predicting what could later happen in a particular organ of a specific patient.

Input data for this study is the aorta mesh in the .STL format from German Cancer Research Center in Heidelberg, obtained by a multi-slice 64-CT scanner. The aorta image was taken from a patient who had the aorta aneurysm. We used .STL mesh format to create a 3D brick mesh of the aorta to further proceed in finite element calculation. Our next step was to remove the aneurysm from the aorta (by modifying boundary surface mesh) and to create a new aorta mesh model using the same finite elements (3D brick). The calculation was performed on both models with the same input boundary conditions. For presentation of the results, we created a set of post-processing software.

2. Geometrical modeling

Firstly, we prepared the original .STL file (Fig. 1) for 3D meshing. Due to the threshold of medical image device, a number objects were present. We classified them into two categories:

a) objects that are independent

b) objects that are attached to the main object (aorta)

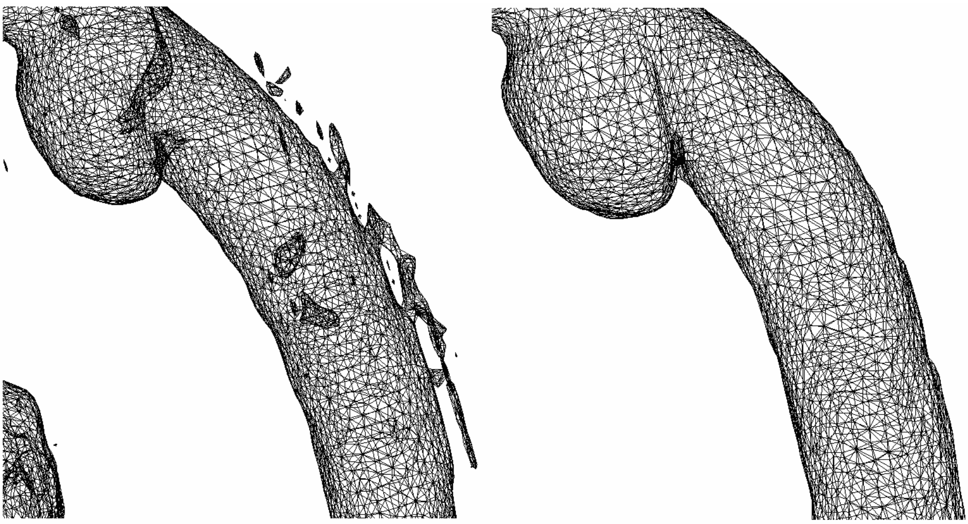

Fig. 1. Model .STL before and after removing unnecessary objects.

The first step in geometrical modeling was to remove independent external objects. We used (C.Geuzaine et al. 2008) for this procedure. In the process of removing the external objects that are attached to the main aorta we used software tools that we developed in C++. The input for this software is .STL surface triangle mesh with the hole, and the output is surface mesh without the hole. In our software we used COG (center of gravity) algorithm for patching the holes (D.Milašinović et al. 2008). After the removal of external objects we obtained a nice smooth surface of the main object - aorta (Fig. 1).

Due to different types of the attached objects, we developed several modules to perform the patching when there is one, two (or more holes in the model), because there were cases when the same object was attached to two or more branches to the main object -- thus after removing the object two or more holes also appeared. We used the same patching algorithm for this case for every hole independently. According to this procedure, each hole was firstly located and patched afterwards.

After completing the desired geometry for this aorta model, we proceeded to virtually remove the aneurysm. This removal was semi-automatic, because we manually set the connection nodes (Fig. 2).

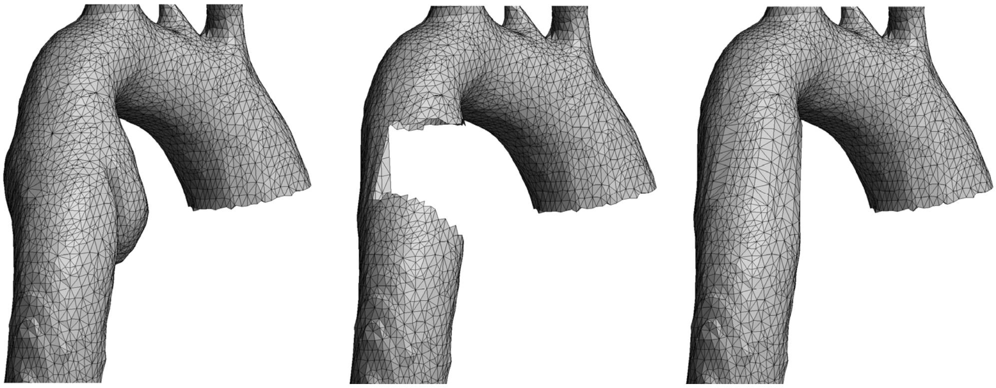

Fig. 2. Aneurism removal.

3. Mesh

After the surface mesh was generated, a 3D meshing was employed (Fig. 3). In order to have solution stability and accuracy in our finite element (FE) solver (D.Milašinović et al. 2008), we used 3D 8-node finite element for CFD analysis; therefore, a 3D 8 nodal "brick" mesh was developed. This procedure of the FE mesh generation was performed in two steps. First, we used a Tetgen software (Hang Si 2008) to create tetrahedrons from the surface triangles, and afterwards our re-mesh program was used to generate the 8 node 3D elements. In this re-meshing procedure we also used the COG algorithm, where each tetrahedron was split into four (D.Milašinović et al. 2008).

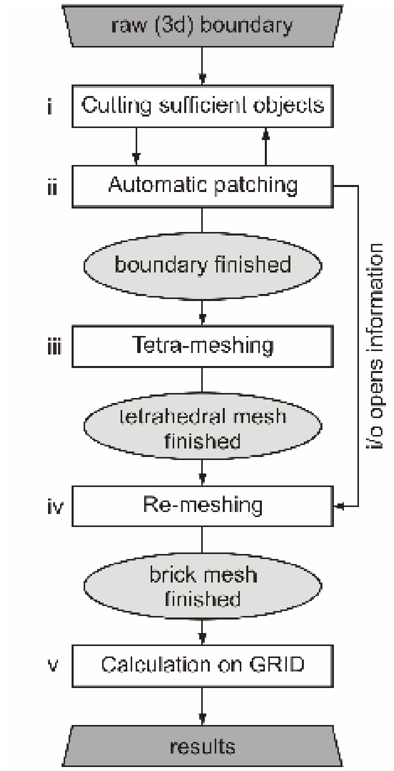

Fig. 3. The complete computational procedure.

After 3D meshing, the input boundary conditions were prescribed (e.g. input and output fluid velocity profiles), the FE calculation was performed. For both aorta models the mesh independence was reached at 350000 to 680000 finite elements.

4. Results

The calculation was executed on GRID, on 20 computational nodes. The calculation was performed for both aorta models. To create a user-friendly presentation of the results, we developed a set of post-processing software tools. Originally our PAK-F (M.Kojić et al. 1998) solver prints a UNV file format, and we used an in-home software for 3D drawings. In one FE model calculation 50 GB of data were written in a number of UNV files (usually one UNV file per time step). A problem with this UNV file is that all physical quantities are written in one file, and we found that the POS format is more useful for large models, so we created converters from the UNV to POS. The POS is also a standard post-processing format, where the POS prints one file for one physical quantity.

We created specific tools for various representations, as will be shown in the figures below. Velocity profiles for a peak systole phase for Case I (aorta with aneurysm) and Case II (aorta without aneurysm) at different cross-sections are presented in Figs. 4 and 5. Also, for diastole phase velocity profiles for both cases are shown in Figs. 6 and 7. The distribution of the wall shear stress magnitude along the aorta with branches, for both cases at the peak systolic and diastolic phase are presented in Figs. 8 and 9.

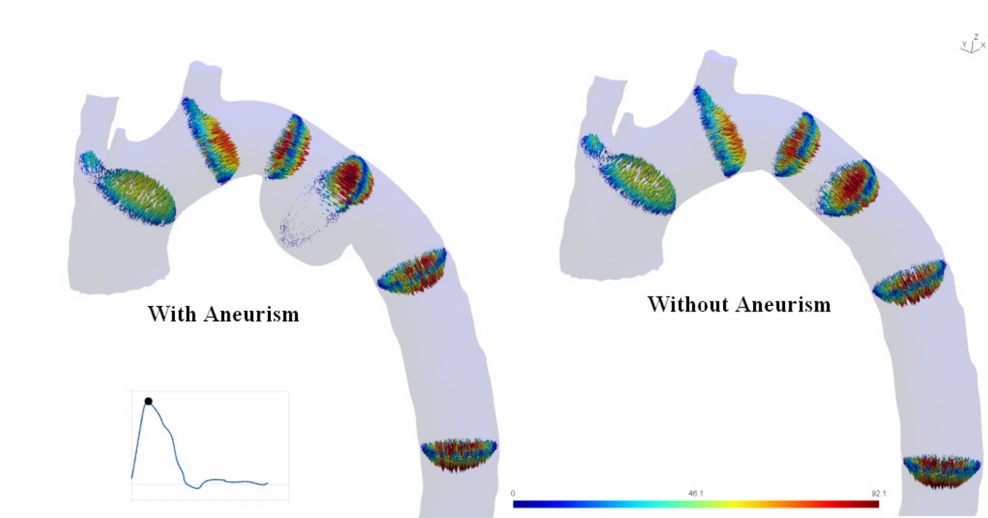

Fig. 4. Velocity profile for a peak systole phase for Case I (aorta with aneurysm) and Case II (aorta without aneurysm).

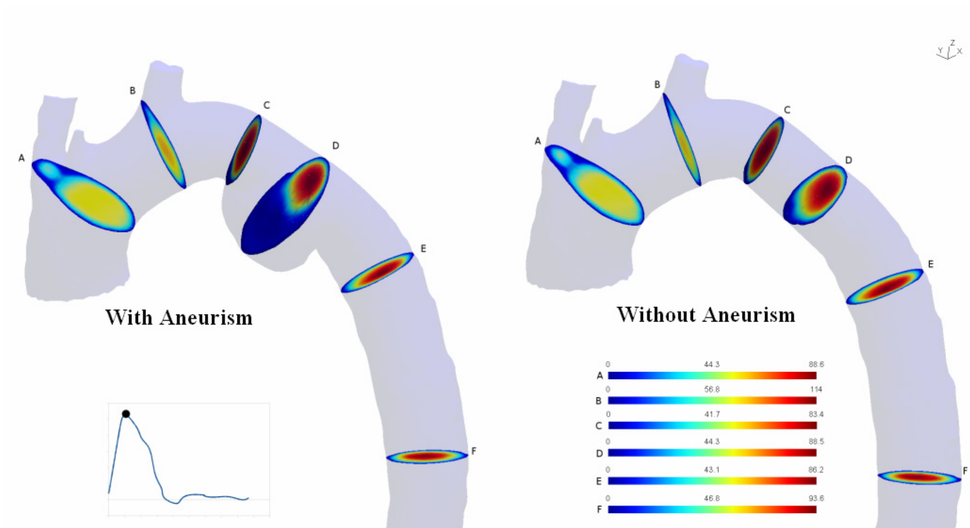

Fig. 5. Effective velocity distribution over cross-sections at different cross-sections for a peak systole phase for Case I (aorta with aneurysm) and Case II (aorta without aneurysm).

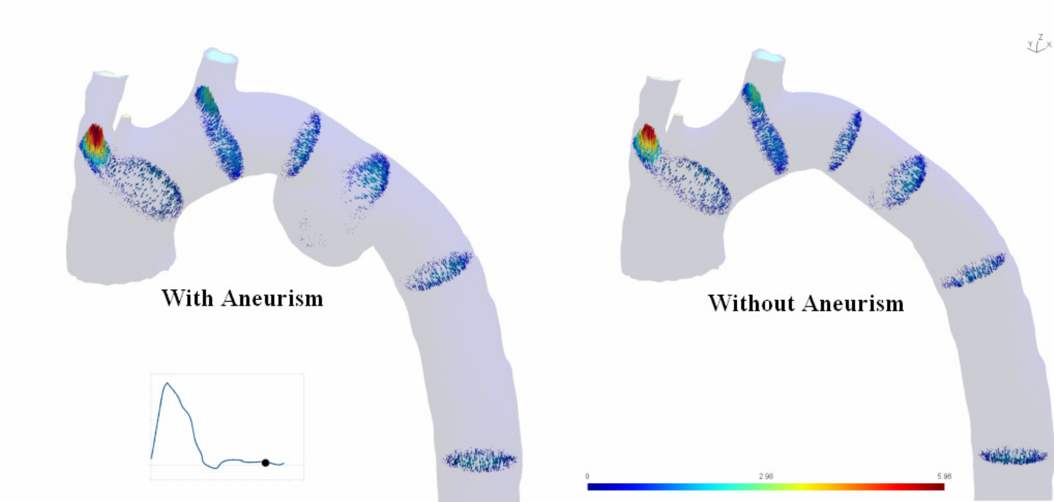

Fig. 6. Velocity profile for a diastole phase for Case I (aorta with aneurysm) and Case II (aorta without aneurysm).

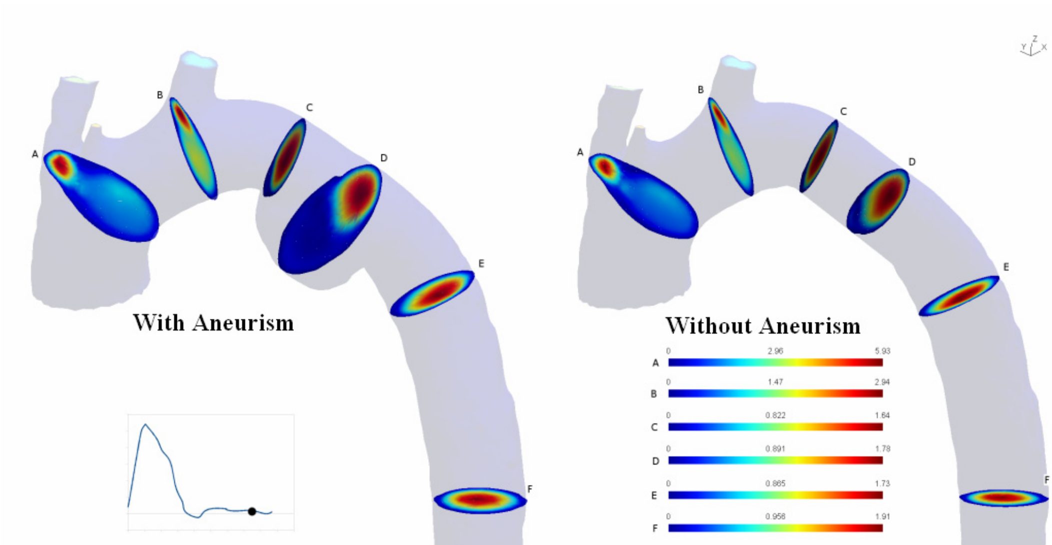

Fig. 7. Effective velocity distribution over cross-sections for a diastole phase for Case I (aorta with aneurysm) and Case II (aorta without aneurysm).

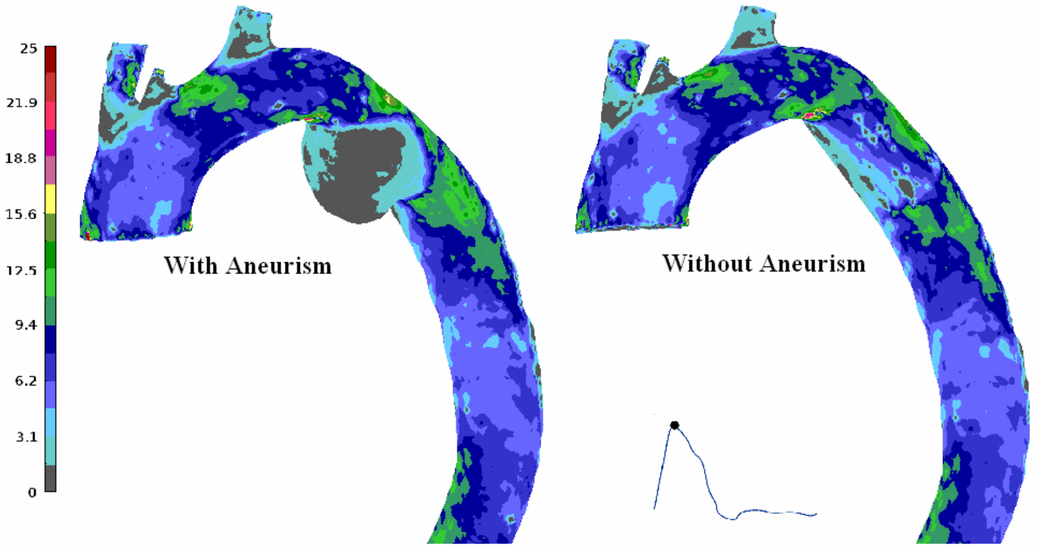

Fig. 8. Distribution of the wall shear stress magnitude along the aorta with branches, at the peak systolic flow for Case I (aorta with aneurysm) and Case II (aorta without aneurysm).

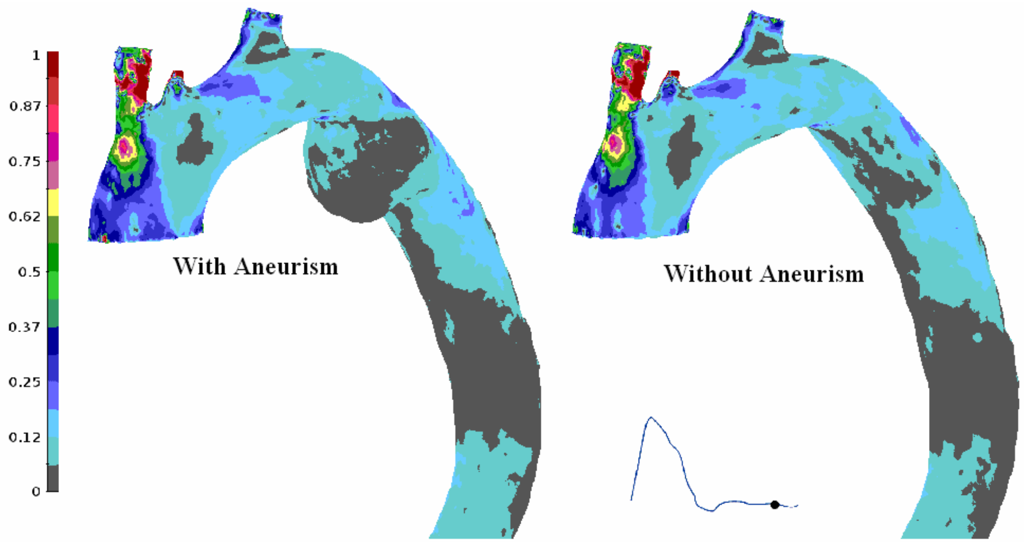

Fig. 9. Distribution of the wall shear stress magnitude along the aorta with branches, at the diastolic flow for Case I (aorta with aneurysm) and Case II (aorta without aneurysm).

5. Conclusion

Our main goal was to create a user-friendly system, which could be used by medical stuff in clinics. Realization of this project was only possible through a close cooperation with medical doctors. This approach of a multidisciplinary research (technical, natural and medical sciences and informatics) will lead to further fast development of computer simulation tools for general use in clinical investigations and practice.

Acknowledgments

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