

Poster: Multidimensional Visualization of Hemodynamic Data

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ABSTRACT

The Multiscale Hemodynamics Project is a collaboration of doctors, physicists, and computational scientists working together to model human blood flow through the coronary arteries. Having effective visualizations of the simulation's multidimensional output are vital for the quick and thorough evaluation by a cardiologist. A user study was conducted to evaluate the utility of various methods for both 3D scalar and vector representations. As a result of the study, HemoVis was developed to aid in the visualization and analysis of the endothelial shear stress (ESS) in a patient's coronary arteries. By identifying the areas of low ESS, cardiologists are able to determine the likely sites of atherosclerotic lesion formation and can take action to prevent further progression.

KEYWORDS: Hemodynamics, simulation visualization.

INDEX TERMS: J.2 [Physical Sciences and Engineering]: Physics; J.3 [Life and Medical Sciences]: Health; I.6.6 [Simulation and Modelling]: Simulation Output Analysis

1 INTRODUCTION

The Multiscale Hemodynamics Project [1] is a collaboration of doctors, physicists, and computational scientists working together to accurately model human blood flow through the coronary arteries. This pilot program acquires blood flow rates and 3D images of the human coronary system via 320 slice computed tomography and simulates detailed blood flow patterns within the coronary arteries with the Lattice-Boltzmann technique. The simulation, MUPHY [2] models blood flowing through a static geometry. With this model, aspects of blood flow that can not be measured directly, including local velocity patterns and shear stress, can be studied [3]. The ultimate goal of this project is to non-invasively detect regions of the coronary artery system that are at high risk for rapid progression in time to facilitate targeted local, prophylactic interventions.

A key physical quantity of medical interest is the endothelial shear stress (ESS) which has been associated with sites of atherosclerotic lesion formation and rapid progression in the coronary arteries [4]. These lesion sites have increased attraction to inflammatory cells and increased permeability to molecules such as LDL leading to the eventual build-up of high-risk plaque which could lead to a rupture possibly causing a heart attack. There is no way to directly measure ESS in a patient thus it must be inferred from hemodynamic computer simulations.

In the medical literature, ESS has been primarily depicted as either cylindrically projected maps for individual arteries in 2D or 3D surface of a single artery with ESS mapped to color.

Recently an entire coronary artery tree was depicted by the Hemodynamics Group in 3D (Figure 1). With this new data becoming available, there is a need for new visualization techniques thus exploring the possibilities and assessing their effectiveness is of great benefit for future work.

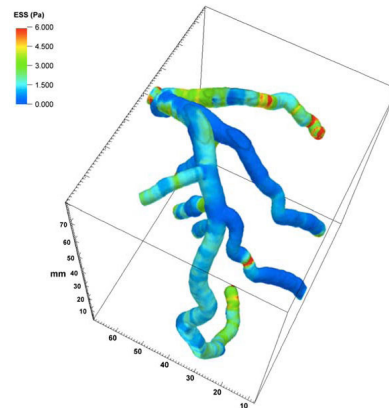


Figure 1. 3D surface representation of ESS mapped on a patient's left coronary artery (geometry from CT scan data). [3]

2 USER STUDY

As part of the motivation to develop visualizations specifically targeted for the medical audience interpreting the Hemodynamics simulation output, a user study was conducted to evaluate the effectiveness of various display techniques and to determine the best methods for interacting with the data. The user study participants included the various end users of the simulation output: both clinical doctors who will use the simulation output for specific patient diagnoses, and research doctors investigating the fundamental causes of heart disease. The ten users were presented with the same series of images covering 2D and 3D representations of ESS, and 3D representations of blood flow velocity.

Based on the survey responses, keeping the data as anatomically correct as possible is important both for ease of use for the doctors and for applicability of the data results directly to the patients. In evaluating 2D representations of ESS, when presented with a version of the cylindrical projection map where the height of the map is scaled with the arterial circumference, all participants said that it was better since it was able to give some geometric information. When asked whether a "centerline" version (height centered on x-axis) would be better, since it would more closely represent a cut-open artery, they all said "yes" (Figure 3).

In terms of 2D tree diagram representations of the coronary arteries, when presented with a draft sketch of a 2D interactive data tool (Figure 2) none of the participants had seen anything like it before. The visualization displays the branched artery system as a tree diagram where each "node" is a 2D representation of the artery. All except one interviewee responded that they really liked the tree view and thought seeing all of the data laid-out

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together was extremely beneficial (3D models always have part of the artery tree occluded). The two most commonly cited scenarios where a tree representation would be useful are for viewing a patient's data with the simulation adjusted to simulate a patient at rest and at heightened physical exertion (i.e. low and high flow rates), and for having multiple image acquisitions of a patient over time to view the progression of disease.

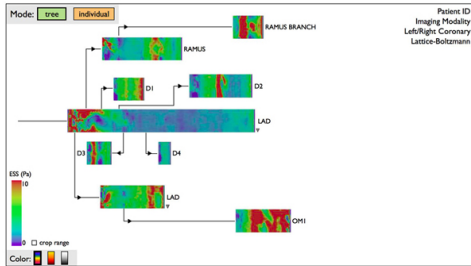


Figure 2. Original HemoVis design sketch.

To evaluate the best color map representations, each user was presented with seven different color maps encoding ESS on a 3D coronary tree model. The sample color maps included variations on the traditional rainbow scheme as well as a variety of diverging color maps that highlighted the highest and lowest ESS values. Most of the participants preferred the rainbow because that is what they are accustomed to viewing, but many also liked a black-and-white diverging scheme where the lower ESS values were highlighted in red effectively drawing their eyes to the highest risk areas (Figure 3).

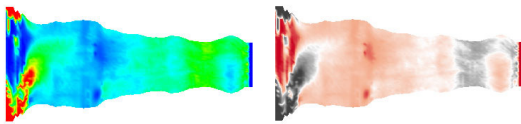


Figure 3. "Centerline" style cylindrical projection of a patient's LCX artery with rainbow (left) and diverging (right) color maps.

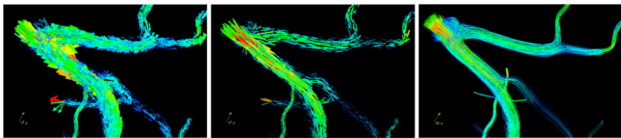


Figure 4. Sample flow visualizations: arrow glyphs (left), rod glyphs (middle), and streamlines (right).

Finally, for the analysis of 3D blood flow velocity patterns, a variety of representations were presented to study participants (Figure 4). Included were glyphs (both arrows and rods) where the color and size were mapped to the velocity magnitude and orientation, and streamlines where the color was mapped to either velocity or ESS value. The majority of user study participants preferred streamlines primarily due to their aesthetics and intuitive interpretation. When asked whether it was confusing to have a non-flow variable such as ESS mapped to streamline colors, half of the participants (primarily clinical doctors) found it confusing.

3 HEMOVIS

HemoVis is an interactive 2D visualization tool developed for viewing the Multiscale Hemodynamics simulation output [5]. It was created using Processing [6]. An initial sketch (Figure 2) was presented during the user study, and based on the feedback the

original design was altered (Figure 5): the 2D ESS maps were changed from the traditional square cylindrical projection to the alternative centerline maps, and the tree ordering was altered to be more anatomically correct based on user feedback.

In the "tree" mode, a tree diagram of the artery system is presented with each artery labeled with its anatomical name, color mapped to ESS, and color and size scales are displayed on the left. The upper right of the screen displays the relevant metadata for the particular data set. The user is able to simultaneously view additional simulation data sets for the same patient by selecting the small triangles. In the alternate "individual" mode, only one artery is displayed at a time allowing the user to take care at studying particular arteries in high resolution. In this mode there is also a small non-interactive version of the entire coronary tree in the lower right corner to help keep the displayed artery in context as well as be used to navigate the branches.

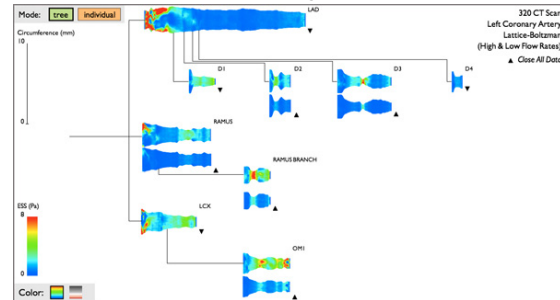


Figure 5. Final HemoVis visualization tool.

4 CONCLUSION AND FUTURE WORK

Based on feedback from the user study, we were able to gain insight into the most effective and useful visualization techniques for displaying and analyzing data from Multiscale Hemodynamics. Future improvements to HemoVis include the addition of a 3D navigation view, pulsatile flow data, 2D display of blood flow, and the ability to easily switch between or compare patient data sets. A follow-up user study would also be useful to effectively evaluate the use of HemoVis in the hospital and research settings.

5 ACKNOWLEDGEMENTS

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