Multidimensional Visualization of Hemodynamic Data

Michelle Borkin[1], Simone Melchionna[1,2,5], Charles Feldman[3,4], Efthimios Kaxiras[1,2] & Hanspeter Pfister[1]

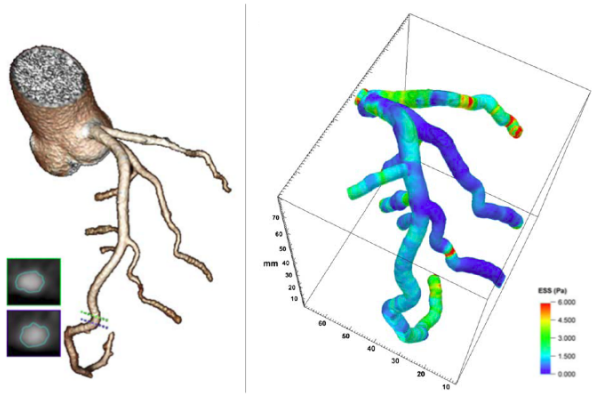
[1]School of Engineering and Applied Sciences, Harvard Univ. [2]Physics Department, Harvard Univ. [3]Harvard Medical School [4]Brigham & Women's Hospital [5]Italian National Research Council

Summary

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.

The Multiscale Hemodynamics Project

This project 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. With the simulation, aspects of blood flow that can not be measured directly, including local velocity patterns and shear stress, can be studied. Of particular interest is endothelial shear stress (ESS) which has been associated with sites of atherosclerotic lesion formation and rapid disease progression in the coronary arteries. 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.



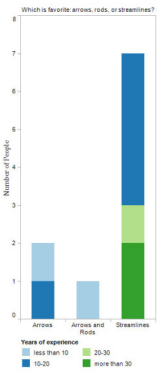
Left: Isosurface of a patient's left coronary artery. The CT data was segmented (sample cross sections shown) and visualized in Vitrea. **Right:** Surface representation in Vislt of the same left coronary artery with color mapped to endothelial shear stress (ESS), a known indicator of atherosclerotic lesions and rapid disease progression in the coronary arteries.

For more information, go to:

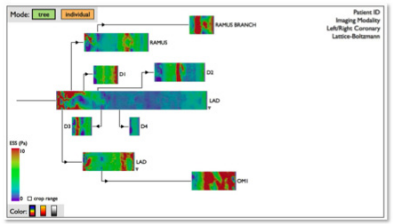
http://hemo.seas.harvard.edu

User Study

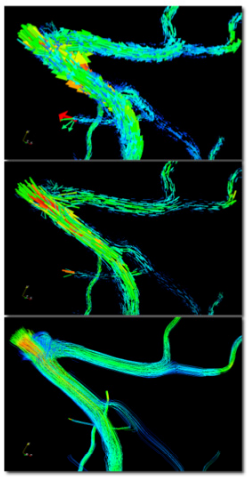
As part of the motivation to develop visualizations specifically targeted for the medical audience interpreting the simulation output, a user study was conducted to evaluate the effectiveness of various display techniques and to determine the best methods for interacting with the data. Based on the survey 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. The tree diagram was well received with users saying that seeing all of the data laid-out together (3D models always have part of the artery tree occluded) and being able to compare multiple trees is extremely beneficial.

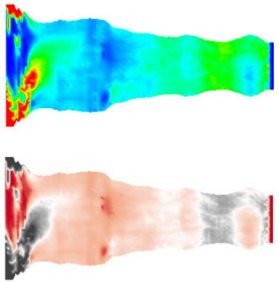


Left: Graph of preferred flow visualization styles as a function of experience. Those who liked streamlines compared them to fluid dynamic result visualizations, a traditional depiction versus more contemporary computer glyph visualizations.



Above: Design sketch of an interactive 2D visualization tool (see HemoVis section for final outcome). The user study participants had never seen the coronary arteries represented as tree diagrams before, and found the concept extremely useful.





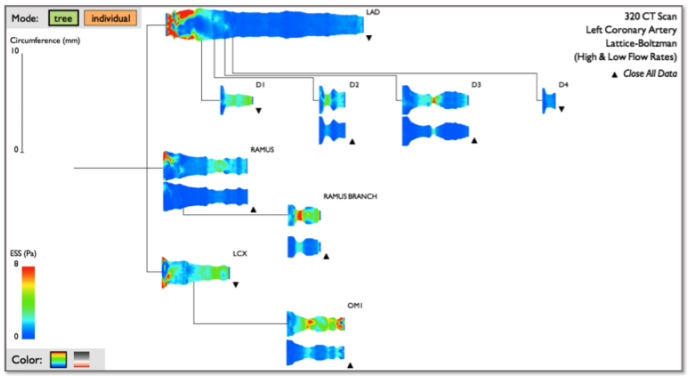
Above: Cylindrical projection, in which the width represents arterial circumference, of a patient's LCX coronary artery. Participants preferred this to other 2D projections. *Top:* The rainbow color map, traditionally used in the medical literature, has blue indicating dangerous low ESS. *Bottom:* Alternative color map based on user study responses in which red indicates dangerous low ESS values.

Above: *Top:* Blood flow represented with 3D arrow glyphs. The size and color indicate velocity magnitude, and arrow orientation flow direction. *Middle:* Same as top, but rod glyphs are used instead. *Bottom:* Blood flow represented as streamlines, the study participants' preferred representation due to aesthetics and intuitive interpretation, in which color indicates velocity magnitude.

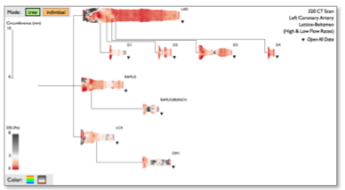
HemoVis

HemoVis is an interactive 2D visualization tool developed for viewing the Multiscale Hemodynamics simulation output. It was created using Processing. Based on the user study, the 2D ESS maps were changed (see original sketch to the left) from the traditional square cylindrical projection to the alternative centerline maps, and the tree ordering was altered to be more anatomically correct. 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 displayed on the left. In the alternate "individual" mode, only one artery is displayed at a time allowing the user to take care in studying particular arteries in high resolution. 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.

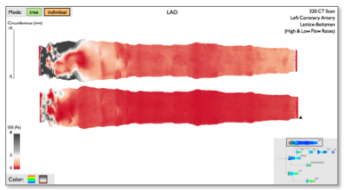
HemoVis is available at http://www.seas.harvard.edu/~borkin/HemoVis/



Above: Screenshot of HemoVis in the "tree" mode displaying ESS for a patient's left coronary artery. The data displayed represents a high flow rate (e.g. a person exercising) and for those with a flipped triangle additionally low flow rate data (e.g. a person at rest).



Above: Screenshot of HemoVis in "tree" mode with the second tree's worth of data closed, and the diverging rainbow-alternative color palette loaded.



Above: Screenshot of HemoVis in the "individual" mode displaying the LAD artery with both low and high flow rate data sets displayed. The user is able to navigate the artery tree in the lower right corner.

Michelle Borkin

michelle_borkin@harvard.edu

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