Computational Modeling and Simulation of Heart Failure

Cardiovascular diseases (CVDs) such as stroke, heart failure, and sudden cardiac death have been the leading causes of death in the United States and other developed countries for more than a century, and these diseases are now the leading causes of death worldwide. From the beginning of the 20th century, there has been a large increase in death due to CVDs, and this increase is increasingly driven by the increase in occurrence of CVDs in low-to-middle-income populations. The direct and indirect costs that the United States alone is estimated to have spent on CVDs in 2010 is $315.4 billion [1].

Computational modeling is a promising approach to improve patient outcomes and reduce costs in treating CVDs. For instance, computer models can be used for patient selection and treatment planning in designing patient-specific therapies and developing medical devices. One example is treatment for left ventricular dyssynchrony (LVD), which leads to heart failure (HF). One of the more effective HF treatments for patients with LVD is cardiac resynchronization therapy (CRT) or biventricular pacing. CRT is a highly invasive and expensive procedure, however, and although it is highly effective in ~65% of patients, ~35% of patients are non-responsive to CRT. One possible way to reduce the risk and cost of CRT for patients is the use of non-invasive cardiac magnetic resonance (CMR) images of the left ventricle (LV) in studying the hearts of the patients [2]. However, the resolution and the accuracy of this method on patients need validation. So my goal for this summer is to develop LV models using real image data and physiological data usable for developing computational methods to enable dynamic cardiovascular modeling and simulation. This will allow us to study the effects of mechanical LVD on the LV function, and could lead to improved selection criteria for determining which patients should receive CRT.

The primary software to be used in the project is the Immersed Boundary Method with Adaptive Mesh Refinement (IBAMR) code developed by Dr. Griffith at UNC Chapel Hill, which allows us to simulate the fluid-structure interaction (FSI) of an elastic or viscoelastic structure immersed in viscous fluid. Simulating CRT will require incorporating a description of electromechanical coupling, which will require models very similar to those discussed in the BD2K Neuromechanics module.

This project will also leverage a strong and growing collaboration between Dr. Griffith's research group and Dr. Thomas Caranasos, Assistant Professor of Surgery in the Division of Cardiothoracic Surgery at UNC School of Medicine. Dr. Caranasos is already working with Dr. Griffith's group on modeling the dynamics of the aorta, with a primary focus on understanding aortic dissection. He is also now the surgical directory of UNC's heart failure program, and through this clinical role, he will be able to provide access to substantial patient data needed to develop predictive computational models of HF and treatments for HF.

The connection between medical imaging and cardiovascular modeling is extremely well aligned with my previous experience at LBNL, where I worked on the medical imaging of the cardiovascular system. I also took BD2K modules on Nueromechanics, studying various electromechanical models, and Predictive Models for High-Dimensional Data Analysis, as well as BCB 715 module, which gave me some basic tools on approaching my problem.

If funded, we will seek to involve an expert in medical image analysis such as Marc Niethammer from UNC Computer Science in the project.

References: [1] Go AS et al. *Circulation.* 2014;129:e28-e292. [2] Delgado, V and Bax, J *Circ: Cardiovascular Imaging*, 2015;8:e003985