PATIENT-SPECIFIC MODELING OF BLOOD FLOW IN ARTERIES

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Hemodynamic factors including shear stress and pressure provide the stimuli for many acute and chronic changes in the vascular system and contribute to the initiation and progression of congenital heart diseases and acquired vascular diseases such as atherosclerosis and aneurysms. Furthermore, knowledge of hemodynamic variables is essential for properly assessing the severity of many vascular diseases and devising an appropriate therapeutic strategy.

While advances in cardiovascular imaging have provided unprecedented insight into vascular anatomy, noninvasive methods for quantifying physiologic variables are not as broadly applied, with the notable exceptions of phase contrast MRI and Doppler ultrasound. Yet, these imaging methods, no matter how advanced, can only provide data about the present state and do not provide a means to predict the outcome of an intervention or evaluate alternate prospective therapies. We have developed a computational framework for computing blood flow in anatomically relevant vascular anatomies with unprecedented realism. This framework includes methods for (i) creating subject-specific models of the vascular system from medical imaging data, (ii) specifying boundary conditions to account for the vasculature beyond the limits of imaging resolution, (iii) generating finite element meshes including anisotropy, adaptivity and boundary layers, (iv) assigning blood rheological and tissue mechanical properties, (v) simulating blood flow and vessel wall dynamics, and (vi) visualizing simulation results and extracting hemodynamic data. These methods have been applied to model blood flow and vessel wall dynamics in the aorta, the lower extremities, the cerebrovasculature, coronary and pulmonary arteries in children and adults. Such computational solutions of blood flow offer an opportunity to predict potential hemodynamic benefits of treatment strategies. An entirely new era in medicine could be created whereby doctors utilize simulation-based methods, initialized with patient-specific anatomic and physiologic data, to design improved treatments for individuals based on optimizing predicted outcomes. Furthermore, such methods have been applied to quantify hemodynamic conditions in animal models of human disease. Most recently, computational methods of blood flow and vessel wall dynamics have been coupled to growth and remodeling codes to simulate vascular adaptation in health and disease.

While significant progress in modeling blood flow and vessel wall dynamics has been made over the last decade, challenges remain. First, while three-dimensional anatomic data is readily available, physiologic (e.g. flow distribution, pressure, impedance spectra) and mechanical (e.g. vessel properties) input data are more difficult to obtain. Second, in vivo validation data is scarce and, as a result, theoretical methods development is greatly outpacing its experimental foundation. Third, state-of-the-art image-based modeling tools are only being used at a few elite research universities and institutions around the world due to the significant expertise required to produce meaningful results. Developing software systems for reliable patient-specific modeling of blood flow and vessel wall dynamics for biomedical researchers, clinicians and engineers who are not experts in biomedical computational science is a challenge for the future.