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Cardiac electro-fluid-mechanics in health and disease

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The heart is a coupled electro-fluid-mechanical system that acts to pump blood to the tissues of the body. The contraction of the heart muscle is stimulated by electrical impulses that actively propagate within the tissue, and these impulses in turn are coordinated by a specialized fast-conduction system that acts to ensure the effective contraction of the heart.

The immersed boundary (IB) method [1] is an approach to modeling fluid-structure interaction that we use to simulate cardiac mechanics and fluid dynamics [2−4]. The IB approach to fluid-structure interaction describes the momentum, viscosity, and incompressibility of the coupled fluid-structure system in Eulerian form, and describes the deformation and elasticity of the immersed structure in Lagrangian form. Coupling between Eulerian and Lagrangian variables is mediated by integral transforms with Dirac delta function kernels. When discretized, these singular delta function kernels are replaced by regularized delta functions that permit the use of non-conforming Eulerian and Lagrangian spatial discretizations, and thereby enable simulations involving very large deformations. Moreover, because the Lagrangian structures move according to a common, continuous velocity field, the IB method implicitly handles contact between structures. These features of the IB method enable the simulation of the dynamics of the cardiac valves throughout the entire cardiac cycle.

We have been working to extend our models of cardiac fluid-structure interaction to incorporate descriptions of cardiac electrophysiology and excitation-contraction coupling. This talk will describe progress towards the development of such models of cardiac electro-fluid-mechanics, using both models of the healthy heart as well as models of heart failure. We also shall present recent high-resolution simulations of cardiac fluid-structure interaction that indicate that we are able to resolve the details of the flow field within the heart, especially the relatively high-speed flows in the vicinity of the outflow tracts.

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