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Immersed Boundary Finite Element Hyperelastic Heart Model

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Cardiovascular fluid and solid mechanics play crucial roles in various types of disease. Mathematical modeling provides a means with which to interrogate these systems, by enabling non invasive computational experimentation and surgical planning. These insights may translate into improved clinical care for patients impacted by cardiovascular problems.

In this work, we describe a computational model of the human heart incorporating the great vessels and the four valves. The heart and vessel geometries are segmented from computed tomography data; heart valves are represented by idealized geometrical models. The heart tissue is modeled as a viscoelastic material: the hyperelastic transversely isotropic Guccione's constitutive law is used to describe the elastic behavior of the heart wall, while the viscosity is inherited from a permeating viscous fluid. The anisotropy fields are determined using Poisson interpolation techniques to qualitatively match anatomical muscle bundles so that the fiber vector field corresponds to the orientation of the cardiomyocytes. Realistic models for the aorta and pulmonary artery, modeled as viscoelastic neo–Hookean materials, provide physiological outflow geometries for the left and right sides of the heart respectively. Fluid-structure interaction is performed via immersed–boundary spreading and restriction operators. Therefore, the solid model for the heart is immersed in a fluid model for the blood. We assume that the blood can be described by the incompressible Navier–Stokes equations. A Lagrangian finite element approximation is used for the solid mechanics, while a finite difference MAC scheme is employed for discretizing the fluid equations. erelastic fiber reinforced solid, with the fiber vector field corresponding to the orientation of the myocytes. Viscoelasticity in the solid model is provided by the underlying fluid. The aortic and pulmonary valves are also modeled as fiber reinforced solids, and the mitral and tricuspid valves are described by resistive surfaces. Fiber fields are determined using Poisson interpolation techniques to qualitatively match anatomical muscle bundles. Realistic models for the aorta and pulmonary artery, modeled as viscoelastic neohookean materials, provide physiological outflow geometries for the left and right sides of the heart respectively. The overall model geometry is derived from cardiac MRI data.

The solid model for the heart is immersed in a fluid model for the blood, given by the incompressible Navier–Stokes equations. A Lagrangian finite element approximation is used for the solid mechanics, while a finite difference MAC scheme is employed for discretizing the fluid equations. Interaction between the solid and fluid are performed via immersed–boundary type spreading and restriction operators.

This model provides a baseline description of cardiac hemodynamics for various computational experiments. We plan to systematically study the impact of different medical devices on the heart as well as the effect of different pericardial boundary conditions on active contraction dynamics.

REFERENCES

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