Novel high-resolution model of cardiac mechanics

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Finite element modeling is a key tool to analyze experimental and clinical observations of ventricular mechanics. However, existing published modeling approaches are limited in the number of degrees of freedom (DOF) and hence cannot be applied to high spatial resolution finite element meshes. The talk presents new methods to solve a model of the ventricular contraction based on very large meshes. In our approach, passive cardiac tissue is modeled as hyperelestic, incompressible material with orthotropic properties, and mixed pressure-displacement finite elements are used to enforce incompressibility. Active stress is represented in the model with force dependence on length and velocity of muscle shortening. The ventricles are coupled to a lumped circulatory model. The model equations are solved with an implicit numerical scheme with an iterative method (Flexible GMRES) for the solution of the linearized system of equations. A non-linear preconditioner to the Flexible GMRES is based on the Schur complement factorization with the Schur complement approximated by least-squares commutators and sparse approximate inverse. The matrix block corresponding to the displacement variables is preconditioned by hybrid geometric-algebraic multigrid with the K-cycle and sparse approximate inverse as a smoother at the first level. The solver performance is demonstrated on high-resolution hex-dominant meshes, including geometry reconstructed from human ventricles (~1.7 M DOF) and canine infarcted ventricles (~0.5 M DOF). The ability to solve these models represents as advancement in the field to higher spatial resolution than previously possible.