Fluid-Structure Interaction Simulation of Left Ventricular Blood Flow during the Systolic and Diastolic Phases

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This paper presents a study on the blood flow inside the left ventricle using one-way and two-ways loosely coupled fluid-structure interaction strategy. A parametric model for the geometry of the left ventricle and myocardium was developed as illustrated in Figure 1 and best fitted to a human left ventricle using published MR image data. A four-element Windkessel model [1] was developed and solved to introduce a pressure boundary condition to the aortic valve in the systolic phase. The Alexander model [2] was used to represent the left atrial flow on the mitral valve during the diastolic phase. The fluid-structure simulation algorithm starts at the systolic phase by applying an artificial force (actuation force) to the internal surface of the myocardium to contract the muscle. The displacement of the myocardium was calculated using a nonlinear finite element hyperelastic model and subsequently transferred to the fluid domain. The fluid mesh was moved accordingly using a spring analogy method and the Navier-Stokes equations were solved in laminar and Newtonian form with the new mesh using finite volume CFD method. In the next time step, the actuation force was increased to contract the muscle further and the same procedure was repeated for the fluid solution. In the diastolic phase, the actuation force was set to zero to allow the myocardium to relax. The Young's module of the muscle was adjusted to control the left ventricular volume. The distributions of pressure, transient velocity vectors as well as the vortex pattern shown in Figure 2 were analyzed showing good agreement with existing qualitative and quantitative data reported in the literature.