Fully-Coupled Fluid-Structure Interaction (FSI) Simulations of Heart Valve-Left Ventricle Dynamics

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Abstract: Fluid–structure interaction (FSI) is a common phenomenon in biological systems. FSI problems of practical interest, such as fish/mammalian swimming, insect/bird flight, and human cardiac blood flow and respiration often involve multiple 3D immersed bodies with complex geometries undergoing very large structural displacements, and inducing very complex flow phenomena. Simulation of heart valve FSI is a technically challenging problem due to the large deformation of the valve leaflets through the cardiac fluid domain in the atrium and ventricular chambers.

Recently, we developed a FSI computational framework [1] for modeling patient-specific left heart (LH) dynamics using smoothed particle hydrodynamics (SPH) for the blood flow, and non-linear anisotropic finite element analysis for heart valve tissues. SPH is a meshless, statistical method that relies on sampling neighboring particles to calculate fluid field variables. SPH's mesh-free and Lagrangian nature makes it particular suitable for numerical problems where there are 1) moving boundaries and 2) large deformations, which are the conditions seen in heart valve FSI applications.

In this presentation, I will explain under which scenarios that heart valve FSI simulations are needed, and give a few examples of our FSI applications. Briefly, we utilized the SPH-FE based, fully-coupled FSI modeling techniques to investigate the pathological LH dynamics under primary and secondary mitral regurgitation (MR) conditions [2], and examine the underlying biomechanics of various minimally-invasive mitral valve (MV) repair techniques. The FSI model was also used to investigate the impact of transcatheter aortic valve replacement (TAVR) on LH dynamics under bicuspid aortic valve (BAV) stenosis and concomitant significant MR [3].

Keywords: Fluid structure interaction simulation; heart valve biomechanics; left ventricle biomechanics

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