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Fully Eulerian Finite Element Methodology for the Numerical Modeling of the Dynamics of Heart Valves

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Abstract : During the last decade, an increasing number of contributions have been made in the fields of scientific computing and numerical methodologies applied to the study of the hemodynamics in the heart. In contrast, the numerical aspects concerning the interaction of pulsatile blood flow with highly deformable thin leaflets have been much less explored. This coupled problem remains extremely challenging and numerical difficulties include e.g. the resolution of full Fluid-Structure Interaction problem with large deformations of extremely thin leaflets, substantial mesh deformations, high transvalvular pressure discontinuities, contact between leaflets. Although the Lagrangian description of the structural motion and strain measures is naturally used, many numerical complexities can arise when studying large deformations of thin structures. Eulerian approaches represent a promising alternative to readily model large deformations and handle contact issues. We present a fully Eulerian finite element methodology tailored for the simulation of pulsatile blood flow in the aorta and sinus of Valsalva interacting with highly deformable thin leaflets. Our method enables to use a fluid solver on a fixed mesh, whilst being able to easily model the mechanical properties of the valve. We introduce a semi-implicit time integration scheme based on a consistent NewtonRaphson linearization. A variant of the classical Newton method is introduced and guarantees a third-order convergence. High-fidelity computational geometries are built and simulations are performed under physiological conditions. We address in detail the main features of the proposed method, and we report several experiments with the aim of illustrating its accuracy and efficiency.

Keywords : eulerian, level set, newton, valve
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