Mathematical modeling of cardiac valves by a resistive method in physiological and pathological conditions

Ivan Fumagalli

MOX - Department of Mathematics, Politecnico di Milano, piazza L. da Vinci 32, 20133 Milan, Italy
e-mail: `ivan.fumagalli@polimi.it`

In the computational modeling of cardiac hemodynamics, the fluid domain is subject to complex deformations and topological changes, due to the contraction/relaxation of the heart and the opening/closing of the valves. Because of this, several unfitted methods for Computational Fluid Dynamics (CFD) have been proposed, to prevent mesh distortion and the possible need for remeshing. The Resistive Immersed Implicit Surface (RIIS) method [1] belongs to this category, and its effectiveness and computational efficiency have been proven in different clinical applications [2, 3].

In this talk, we present recent developments in the use of the RIIS method for modeling the physiological and pathological dynamics of cardiac valves. We will display its suitability and computational efficiency both for CFD with prescribed boundary kinematics, with anatomy and displacements reconstructed from clinical images, and in the case of Fluid-Structure Interaction (FSI) between the blood flow and the valves. In the CFD settings, we discuss the issue – widely acknowledged, but little addressed – of properly defining the ventricular pressure during the isovolumetric phases of the heartbeat, when all valves are closed. To solve this issue, we introduce an Augmented version of the RIIS method (ARIIS) [5], extending the one proposed in [6] to the case of a mesh not conforming to the valve. In terms of FSI, we present an original lumped-parameter model for the structural mechanics of the valve leaflets, coupled with 3D CFD via the RIIS method [4]. Applications of this model to the cases of native and prosthetic valves will be presented. The numerical results were obtained by the open-source `life`$^{\text{x}}$`-cfd` module of the `life`$^{\text{x}}$ parallel finite element library developed in the iHEART group [7].

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