Modeling of cardiac hemodynamics: from the left atrium to the simulation of the entire organ

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Abstract

Mathematical models of the heart hemodynamics play a crucial role in advancing our understanding of both physiological and pathological conditions, including the assessment of thrombotic risks and valvular diseases. In this talk, we present a novel computational framework for simulating the hemodynamics of the human heart. The talk is structured as a journey, starting with the modeling of the left atrium in both physiological and pathological conditions, and ending with the simulation of the entire human heart, taking into account the primary factors that impact cardiac hemodynamics. Our model consists of the incompressible Navier-Stokes equations expressed in an Arbitrary Lagrangian Eulerian framework [1] and cardiac valves are modeled through the Resistive Immersed Implicit Surface method [2, 3]. We account for the transitional blood flow regime by means of the Variational Multiscale - Large Eddy Simulation method [4], which we found to be important especially when coarse meshes are employed [5]. We simulate the left atrium in idealized and patient-specific conditions and we quantitatively assess the hemodynamic consequences that atrial fibrillation has on cardiac hemodynamics. Our results demonstrate a significant increase in blood stasis and consequent thrombotic risk, particularly in the left atrial appendage [6]. For modeling the entire organ, we use a whole heart electromechanical model [7] as a driver to move the cardiac chambers in the fluid dynamics problem. Furthermore, we also couple this multiphysics system to the remaining circulation described by a 0D closed-loop model. We solve the multiphysics and geometric multiscale system through a segregated algorithm [8]. To evaluate the effectiveness of our computational model, we first simulate a physiological scenario, obtaining quantities of interest that fall within clinically relevant physiological ranges. Additionally, we use our model to investigate the hemodynamic consequences of electrical abnormalities on the heart, such as the Left Bundle Branch Block, as detailed in [9].

References

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