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Recent Advances in Multi-Modal Experimental and Computational Investigations of Cardiovascular Flows

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Extended Abstract

We present a comprehensive overview of our recent research activities, which focus on combined multi-modal experimental and numerical studies in advanced mathematical modelling of cardiovascular blood flows, [1], [2].. First, we introduce various experimental techniques used to validate flow in a left heart ventricle model. This model is constructed from transparent organic silicone (PDMS), with its geometry derived from a statistical shape model (SSM) based on a large cohort of 150 patient-specific CT scans, and incorporates biological mitral valves, [3-6].

Here, we will focus on the comparative assessments of the clinical techniques (magnetic resonance imaging, MRI [5]; ultrasound measurements, US [4]) and current state-of-the-art optical particle image velocimetry (PIV) [3,6]. The major novelty includes the evaluation of a complete 4D velocity field in great detail, as well as the important blood flow-based biomarkers (e.g. wall shear stress, WSS; oscillatory shear index, OSI, etc.).

In addition to experimental studies, we introduce a recently developed computational fluid dynamics (CFD) approach suitable for moving geometries, [7-10]. The finite-volume based numerical approach solves the full set of governing transport equations (mass and momentum) for a non-Newtonian working fluid, with dynamic numerical mesh deformations represented by a novel morphing approach based on radial basis functions (RBF), [9], [10]. This method closely mimics the experimental studies, capturing cardiac cycle variations in left ventricle shape and the synchronized opening and closing of heart valves. We present detailed comparisons of the velocity field and its derivatives (e.g., vorticity, wall shear stress) obtained from various experimental techniques and numerical simulations.

Finally, we discuss the potential of MRI-based numerical simulations to provide detailed insights into patient-specific valve failure and its impact on the local dynamics of blood flow within the left ventricle. This information can be used to further improve current synergetic clinical tools for the early diagnosis of patient-specific heart failure.

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