BLOOD DYNAMICS IN THE LEFT HEART TO ASSESS TURBULENCE FOR MITRAL REGURGITATION: A COMPUTATIONAL STUDY BASED ON MULTI-SERIES CINE-MR IMAGES

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Introduction

Mitral valve regurgitation (MVR) is a condition leading to a formation of a regurgitant jet in the left atrium during the systolic phase due to an incomplete closure of the mitral valve leaflets. The formation of the regurgitant jet may give rise to: i) turbulent atrial flow leading to hemolysis in the atrium and ii) washing out of stagnant blood in the atrium preventing the formation of thrombi.

In this respect, computational methods represent a non-invasive way to better understand the left heart physio-pathology and to predict the outcomes of surgical interventions. Among different models, we focus on Computational Fluid Dynamics (CFD) with imposed motion, where the displacement of the left heart (LH) internal wall surfaces (left atrium, left ventricle and aortic root) and valves is provided from kinetic medical images.

The aim of this work is to perform a fully patient-specific image-based CFD simulation with imposed motion of the whole heartbeat on a healthy subject and, for the first time, on patient with MVR to compare, between the subjects, the occurrence of turbulence, risk of hemolysis and thrombi formation. To do this, we reconstruct the geometry and displacement of the left heart internal wall surfaces and valves from multi-series cine-MRI images.

Methods

To reconstruct the geometry and displacement of the LH internal wall surfaces, we combine two different reconstruction techniques used for the left ventricle and for the left atrium and aortic root, respectively.

Concerning the valves, we reconstruct the patient-specific mitral valve in its fully open and fully closed configuration by using the method proposed in [1]. For the aortic valve, instead, we deform a template geometry to match its annulus with the annulus detected from the cine-MRI images.

For CFD, we consider the Navier-Stokes equations in the Arbitrary Lagrangian-Eulerian framework with a LES model for transition to turbulence [2] and a resistive method to manage the valve dynamics [3] that has been modeled in an on-off modality, where the reconstructed leaflets opened and closed instantaneously according to the pressure drop across the valve and the flow rate through the valve plane, respectively.

Results

In Figure 1, we report the velocity standard deviation (SD) at a representative time instant of the systolic phase for the healthy scenario H (left) and for the regurgitant patient R (right). We notice that the regurgitant jet in the MVR case leads to a larger amount of transition to turbulence especially in the left atrium resulting also in a higher risk of formation of hemolysis. Moreover, we observe that MVR promotes a more complete washout of stagnant flows in the left atrium during the systolic phase and in the left ventricle apex during diastole. Our results are supported by the validation with echo color Doppler velocity measures in the healthy subject and by a qualitative comparison with a cine-MRI flow pattern in the MVR case highlighting a good agreement and thus the ability of our method to give clinically significant information.

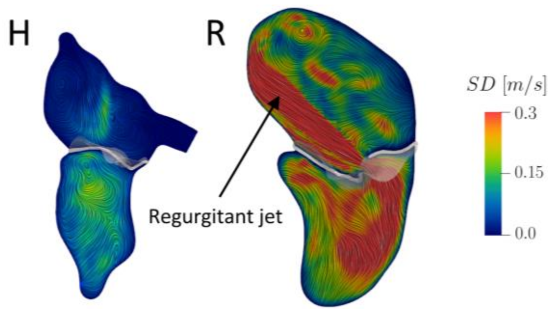

Figure 1:velocity standard deviation (SD) at a representative time instant for H (left) and R (right).

References

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2. Nicoud, F. et al, Physiscs of Fluids, 2011.
3. Fedele, M. et al, Biomechanics and Modeling in Mechanobiology, 2017.