A COMBINED CFD AND MESH MORPHING TECHNIQUE TO INVESTIGATE THORACIC AORTA HEMODYNAMICS

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Introduction

Thoracic aortic (TA) diseases are associated with high mortality rates [1] because of their silent nature, before acute events, and the lack of a screening program. Computational Fluid Dynamics (CFDs) represents a powerful tool for the study of blood flow and its relationship with pathophysiology of TA diseases [2, 3]. While standard CFD simulations affect the evaluation of hemodynamic parameters due to the rigid-wall assumption, Fluid-Structure Interaction (FSI) simulations have high computational times and need additional information on vessels wall that are difficult to be defined in-vivo. Recently, a strategy based on radial basis functions mesh morphing technique combined with transient simulations was presented [2, 4] to investigate TA hemodynamics. However, it was confined to the ascending aorta and it showed some intrinsic limitations.

This work aims to overcome these limitations and to develop and implement a new procedure (CFD_{morph}) that integrates CFD simulations and mesh morphing techniques to study the hemodynamics of the entire aorta, following the geometrical variations of the vessel throughout cardiac cycle.

Methods

Starting from ECG-gated CT images, TA 3D models of five subjects were reconstructed through segmentation with a U-net deep neural network for ten phases of cardiac cycle [5]. An in-house algorithm for mesh morphing was applied to build the surface mesh from each 3D model, maintaining the same number of nodes and connectivity of the baseline mesh (0% phase). A mesh nodes mapping of TA wall at each phase was employed in a spline interpolation process to gain the wall displacement for the whole cardiac cycle. Motion of TA boundaries was included in the CFD simulation and used by the solver to handle volume mesh. Regarding the boundary conditions, patient-specific flow velocities were set at the inlet and blood pressure were imposed at the four outlets by implementing a lumped 3 element Windkessel model. In addition to the developed procedure, a standard CFD simulation (CFD_0) for the 0% phase of TA has been performed to compare results in terms of fluid velocity and the main hemodynamic parameters. Ansys® Fluent® software was used for both the simulation strategies.

Results

The proposed approach allowed to cope with the TA patient-specific morphological variations and motion during the cardiac cycle, with no significant loss of mesh quality. Differences in terms of velocity distribution with respect to the CFD_0 were found (Figure 1). For the CFD_{morph} a time lag equal to 0.072 s was detected between the descending aorta flow rate waveform and the inlet flow profile. Discrepancies between the two simulation strategies were also found in the main wall shear stress (WSS) based hemodynamic parameters. The CFD_0 underestimated the surface areas with high oscillatory shear index and low time-averaged WSS.

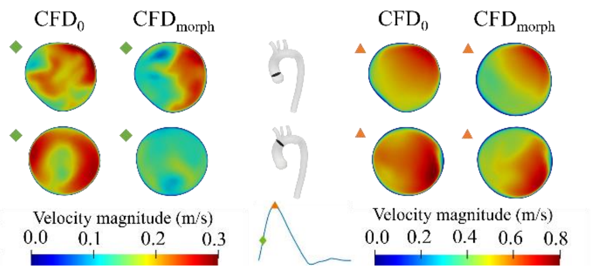

Figure 1: Velocity magnitude at different TA section and different times of cardiac cycle for the two simulation strategies (CFD_0 and CFD_{morph}).

Discussion

These findings show the impact of wall motion and aortic geometric variations during cardiac cycle on the assessment of TA hemodynamics. The combination of mesh morphing techniques and CFD simulations represents a powerful strategy to obtain motion-related patient-specific results, overcoming the main limitations of standard CFD and FSI approaches. A further analysis may also include pathological TA datasets.

References

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