A MESH MORPHING TOOL FOR MOVING BOUNDARIES CFD SIMULATIONS AND WALL STIFFNESS ESTIMATION OF THE AORTA

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Introduction

Computational Fluid Dynamics (CFDs) is a well-established technique to analyze blood flow of the thoracic aorta (TA) and its correlation with pathological conditions [1]. However, standard CFD simulations are based on the rigid wall hypothesis, so vessel structural properties are neglected. The mechanical behavior of the arterial tissue is an important indicator of the functional and structural changes within the vessel wall [2]. In this perspective, Fluid-Structure Interaction (FSI) simulations consider wall compliance, but demand extensive computational resources and additional information on the vessel wall difficult to be defined in-vivo. Recently, mesh morphing techniques are presented as promising tools to cope with the aorta wall changes [1, 3]. Nevertheless, they are limited to the ascending aorta and show some intrinsic discontinuities. The aim of this work is to develop and implement a new tool which employs mesh morphing techniques to set up moving boundaries CFD simulations for the assessment of the hemodynamics of the TA and estimate the aortic stiffness from in-vivo patient-specific images.

Methods

From ECG-gated CT images of five subjects we performed a segmentation process through a U-net deep neural network [4]. This allowed to reconstruct, for each patient, ten 3D models of the TA, corresponding to different phases of the cardiac cycle. Then, we applied an in-house non-rigid registration algorithm to morph the baseline mesh on the geometries of the other phases. Firstly, the morphed meshes, together with a spline interpolation, were used to obtain the TA wall displacement for the whole cardiac cycle. This displacement was included in the setup of a moving-boundary CFD simulation (CFD_{morph}) in Ansys Fluent® and used by the solver to handle the volume mesh. In addition to the developed procedure, we performed a standard CFD simulation (CFD_0) for the baseline configuration of the TA to compare hemodynamic results. Secondly, the meshes were employed in a workflow for the assessment of the aortic wall stress, strain and stiffness [5]. We evaluated the circumferential strain as the ratio between sectional contour lengths. The vessel wall behaviour was assumed as membranal and linearized under the physiological pressure load. Under these assumptions, the circumferential Young's modulus (E_θ) was obtained according to Laplace assumption and Hooke's law.

Results

The proposed tool replicated the TA patient-specific deformations and wall motion throughout the cardiac cycle, without significantly decreasing mesh quality. Velocity (v) distributions showed differences between the two simulation strategies (Figure 1a), as well as the main wall shear stress based hemodynamic parameters. Moreover, the CFD_{morph} was able to model flow waveform shift occurring along the aortic lumen. Finally, the presented method revealed heterogeneous stiffness distributions, with differences between ascending and descending districts (Figure 1b).

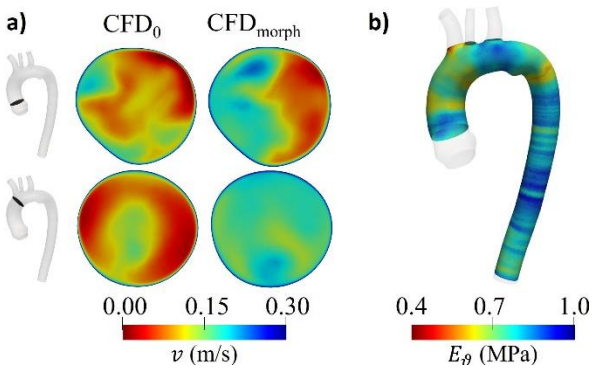

Figure 1: Velocity magnitude at different TA sections at maximum acceleration time (a) and E_θ distribution (b)

Discussion

The mesh morphing tool represents a worthwhile strategy for moving boundaries patient-specific CFD simulations, overcoming the main limitations of standard CFD and FSI approaches. Additionally, it is a valid method for the non-invasively local estimation of the aortic wall mechanical properties.

References

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