Investigating the impact of wall distensibility on aortic flow using a network-based approach

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***Abstract*— The impact of aortic wall distensibility on spatiotemporal coherence of large-scale flow patterns was investigated by applying a network-based approach to CFD models under the rigid-wall assumption and to distensible models based on a Radial Basis Functions (RBF) mesh morphing technique. The findings of the study suggest that the similarity of velocity time-histories along the cardiac cycle is only moderately affected by the aortic wall distensibility.**

***Keywords*—Aorta, Computational fluid dynamics, Radial basis functions, Mesh morphing, Network science.**

I. Introduction

To contribute to the assessment of the impact of uncertainties associated with the rigid-wall assumption in computational hemodynamics models of the aorta, this study aims at investigating the effects of wall distensibility on the spatiotemporal coherence of the aortic flow on a dataset of three personalized CFD models of healthy human thoracic aorta. To do so, a network-based approach [1] was applied to CFD data from the rigid-wall simulation and from the distensible simulation where the patient-specific aortic wall motion was reproduced using a recently proposed RBF mesh morphing technique [2]. For each model, the correlation between the patient-specific inlet flow rate waveform and the axial velocity waveforms obtained from the simulations at each node of the computational grid was used to build a *"one-to-all"* network [1].

II. Methods

Using ECG-gated CT images, aortic geometries were reconstructed at different phases of cardiac cycle. The shape deformation of the ascending aorta (AAo) geometry along the cardiac cycle was obtained following three steps [2]: (1) calculation of the RBF solution targeting the position of the aorta geometry with respect to its baseline configuration (at 0% phase of cardiac cycle), for each of the selected phases, (2) calculation of the RBF incremental solution to reshape the aorta geometry over the cardiac cycle, and (3) coupling of the transient RBF solution with the CFD simulation. Simulations for the rigid and deformable cases were performed using the finite volume method to solve the discretized Navier-Stokes equations on tetrahedral meshes, assuming blood as Newtonian. Further details on the simulation setup are reported elsewhere [2].

The flow rate waveform $Q(t)$ at the AAo inlet (Figure 1) and the axial velocity component waveforms $V_{\mathrm{ax}}(t)$ calculated at each node of the computational grid were used to build networks. Pearson correlation coefficients $\mathrm{R}_i^{V_{\mathrm{ax}}}$ were computed between $V_{\mathrm{ax}}(t)$ waveforms in the rigid and deformable geometries, for each node *i*. The spatiotemporal similarity of $Q(t)$ waveform with the large-scale aortic flow was evaluated building a *"one-to-all"* network [1] for the rigid and deformable case, respectively. The network nodes corresponded to the center of mass of the AAo inlet section (where $Q(t)$ is defined) and to all the nodes of the computational grid. The link between the inlet node and each node *i* was weighted by the correlation coefficient $\mathrm{R}_i^{Q-V_{\mathrm{ax}}}$ between $Q(t)$ and $V_{\mathrm{ax}}(t)$ at that node.

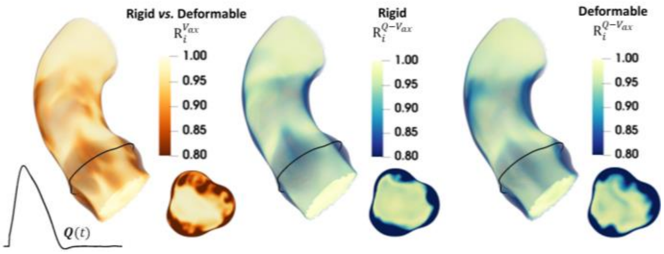

Fig. 1. $\mathrm{R}_i^{V_{\mathrm{ax}}}$ and $\mathrm{R}_i^{Q-V_{\mathrm{ax}}}$ volumetric maps for one representative aortic model. The patient-specific inlet flow rate waveform $Q(t)$ is also displayed, as well as a cross-sectional view of the aortic root.

III. Results And Discussion

The $\mathrm{R}_i^{V_{\mathrm{ax}}}$ volumetric map (an explanatory case is presented in Figure 1) highlighted a very high similarity in the intravascular axial flow waveforms between the rigid and distensible case (median=0.97, IQR=0.07). A moderate loss in similarity ($\mathrm{R}_i^{V_{\mathrm{ax}}}$<0.80, Figure 1) was bounded in the near-wall regions of the aortic root and of the mid AAo. Consistently, the degree of dynamical similarity between $Q(t)$ and $V_{\mathrm{ax}}(t)$ waveforms in the deformable aorta is comparable to that in the rigid model, as emerged from the $\mathrm{R}_i^{Q-V_{\mathrm{ax}}}$ maps (Figure 1): in both rigid and deformable models, $Q(t)$ waveform markedly shapes the dynamics of axial flow in the bulk of the vessel, while it has a minor impact on the aortic root and AAo inner wall hemodynamics.

IV. Conclusion

The presented results suggest that, compared to the distensible models, the rigid-wall assumption preserves the large-scale aortic flow patterns in terms of similarity between $Q(t)$ and $V_{\mathrm{ax}}(t)$ waveform shapes.

References

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