MODELLING AORTIC FLOWS: IMPACT OF WALL DISPLACEMENTS ON LARGE-SCALE HEMODYNAMIC COHERENCE IN ASCENDING AORTA

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Introduction

The translation of Computational Fluid Dynamics (CFD) as supportive technology in clinics is hampered by the uncertainties affecting personalized blood flow simulations. The aorta is characterized by not negligible wall displacements [1], but the rigid-wall assumption is largely adopted. This represents a major source of uncertainty, as the real need for introducing aortic wall displacements in computational models is still debated. This study analyzes the impact of wall displacements on the large-scale flow structures in the healthy human ascending aorta (AAo). On three subject-specific models, two CFD simulations are performed: (1) assuming rigid walls, and (2) imposing personalized wall displacements through a moving-boundary method based on a radial basis functions (RBF) mesh morphing technique [2]. The impact of wall displacements on AAo large-scale hemodynamics is analyzed in terms of axial blood flow coherence (quantified applying a network approach [3]), secondary flows, and helical flow because of its physiological significance.

Methods

Aortic geometries were reconstructed at ten phases of the cardiac cycle from dynamic CT scans. On each analysed subject two modelling strategies were adopted: (1) a rigid-wall CFD simulation performed on the baseline geometry at 0% (late diastole) phase of cardiac cycle; (2) a CFD simulation imparting subject-specific aortic wall displacements applying an RBF mesh morphing on the reconstructed transient geometries [2]. Simulations for the rigid- and moving-wall 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 effect of the aortic wall displacements on axial flow coherence was investigated building *"one-to-all"* networks [3,4] for the rigid- and moving-wall aorta, measuring the similarity of blood axial velocity waveforms $V_{ax}(t)$ (representing the generic network nodes) in the AAo with the subject-specific blood flow rate waveform $Q(t)$ (representing the network's reference node) at the AAo inlet (Fig. 1). In each network, the link between the reference node and the *i-th* node was weighted by the correlation coefficient $R_{Q,i}$ between $Q(t)$ and $V_{ax,i}(t)$ at that node. The anatomical length of persistence of the $Q(t) - V_{ax}(t)$ correlation was quantified computing an ad-hoc network metric called *Average Weighted Curvilinear Distance* ($AWCD$) (Fig. 1) [4]. The impact of aortic wall displacements was also investigated in terms of secondary flow patterns and helical flow intensity and topology.

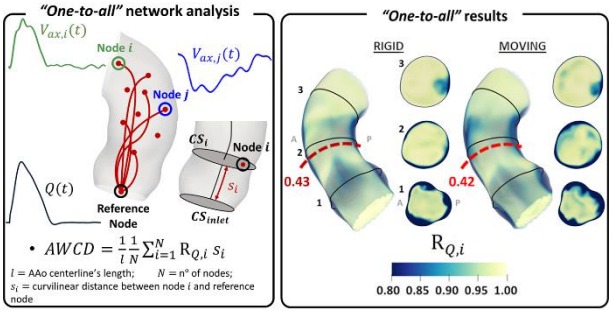

Figure 1: Overview of the "one-to-all" analysis. Left: network construction. Right: $R_{Q,i}$ volumetric maps with AWCD (red line) for one representative subject. Cross-sections along the AAo are also displayed.

Results and Discussion

Results from the *"one-to-all"* analysis are reported in Fig.1 for one explanatory subject. Notably, $R_{Q,i}$ volume maps of the rigid- and moving-wall aortas are very similar. In general, $Q(t)$ waveform markedly shapes $V_{ax}(t)$ waveforms independent of wall displacements ($R_{Q,i}$ median values above 0.95). The anatomical length $AWCD$ of axial flow coherence with the driving proximal $Q(t)$ waveform (Fig. 1) varies from the 42% to 45% of the total AAo length for all subjects, with a 4.4% maximum difference between rigid- and moving-wall models. Contrarily, wall motion impacts more markedly secondary flow patterns and helical flow topology, whereas cycle-average helicity intensity remains almost insensitive to aortic wall displacements.

Conclusion

We conclude that the rigid-wall simplification can be a valid assumption in CFD simulations of the aortic large-scale fluid structures, providing a reasonable hemodynamic description in the context of potential clinical practicality. This is particularly true when helical flow, an indicator of physiological significance in arteries [5], is analyzed.

References

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