CFD AND CSM MODELS OF THE ASCENDING THORACIC AORTA ANEURYSM WITH PATIENT SPECIFIC WALL DISPLACEMENT

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Introduction

The Ascending Aneurysmal Thoracic Aorta (ATAA) is a persistent enlargement of the aorta caused mainly by ageing or genetics. The European Society of Cardiology defines an ATAA as an aortic diameter increase of 50%. Surgery is advised if this diameter is higher than the 55mm cut-off. Nevertheless, 60% of individuals with aortic dissections before reaching the surgical limit experienced aortic failure. A new method is required to implement the geometric criterion, and it is believed that computational fluid dynamics (CFD) and computational solid mechanics (CSM) analyses can provide the solution. The application of these techniques frequently ignores the ATAA wall motion brought on by heartbeat and hemodynamics. Fluid-structure interaction (FSI) may be an option, but the time needed for each numerical solution is a limitation. In this study, SimVascular [2], an open-source program specialising in cardiovascular CFD, CSM, and FSI models, is utilised to examine the impacts.

Methods

The geometric model was developed in SimVascular using the SV MITK Segmentation for the first instance of Computed Tomography Angiography (CTA). This segmentation method is used for the wall deformation calculation for 20 equally spaced acquisitions throughout a cardiac cycle. After this first step, a Python script was implemented to translate all segmented geometric models into a wall displacement using the best centreline match. Both PyVista [3] and VMTK libraries were used. As boundary conditions, the wall deformation was used in CFD and CSM numerical models.

In the CFD model, the flow inlet condition was derived from the 4D-flow MRI and imposed downstream of the aortic valve. The outlet was defined as a three-element Windkessel model, also known as the RCR model, to simulate patient-specific arterial pressure. The blood was reduced to a Newtonian fluid with density of 1.06 g/cm^3 and viscosity of 0.04 Pa.s. A laminar incompressible flow was taken into consideration for the Navier-Stokes equation solution.

In the CSM model, the Neo-Hookean hyperelastic model was used to describe the ATAA mechanical properties. The numerical parameters imposed are described in Valente et al. [4].

Results

The CFD model, complemented with the patient-specific wall deformation as a boundary condition, allows for a good agreement of patient-specific hemodynamics and wall shear stress compared to a 4D MRI. The CSM, on the other hand, can calculate the wall mechanical behaviour and translate the displacement measured as wall stress to characterize wall load.

Discussion

The CFD and FEA models and the patient-specific wall deformation ensure an excellent agreement compared with in-vivo data extracted from 4D MRI. Furthermore, these results of both models allow for replicating an FSI model result with significantly less computational time.

References

1. A. Mourato, R. Valente, M. Brito, J. Xavier et. al., “Computational modelling and simulation of fluid structure interaction in aortic aneurysms: a systematic review and discussion of the clinical potential”, Appl. Sci., Vol. 12, nº 16, 1-38, 2022.
2. Sullivan et al., (2019). PyVista: 3D plotting and mesh analysis through a streamlined interface for the Visualization Toolkit (VTK). Journal of Open Source Software, 4(37), 1450, https://doi.org/10.21105/joss.01450
3. A. Updegrove, N.M. Wilson, J. Merkow, H. Lan, L., et al. “SimVascular: an open source pipeline for cardiovascular simulation”, Ann. Biomed. Eng., Vol. 45, nº 3, 525-541, 2017.
4. R. Valente, A. Mourato, M. Brito, J. Xavier et. al.,” Fluid–Structure Interaction Modeling of Ascending Thoracic Aortic Aneurysms in SimVascular”, Biomechanics, Vol. 2, nº 2, 189-204, 2022.

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