THE IMPACT OF 4D-FLOW MRI-DERIVED INLET CONDITIONS IN FLOW SIMULATIONS OF ANEURYSMAL TYPE-B AORTIC DISSECTION

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Introduction

The biological mechanisms driving the progression of Type-B Aortic Dissection (TBAD) are not yet well-understood. 87% of patients will experience aneurysmal dilatation of the false lumen (FL), for example, but current anatomical predictors of growth perform poorly. Better tools are needed to support clinicians in treatment planning and risk stratification. Haemodynamic analysis via 4D-Flow MRI (4DMR) and Computational Fluid Dynamics (CFD) may uncover quantities with greater predictive power than existing metrics, but such efforts are hindered by our limited understanding of the impact of modelling assumptions on simulation accuracy.

The impact of inlet conditions in TBAD simulations have been examined in terms of pressure, velocity, and Time-Averaged Wall Shear Stress (TAWSS)[1,2]. However, disturbed shear and helical flow have been consistently linked with aneurysmal growth; their sensitivity to inlet conditions in TBAD remains unreported. In this study, we simulated flow in a TBAD case exhibiting widespread FL dilatation using various commonly applied, patient-specific inlet velocity conditions. Comparing the gold-standard patient-specific 3D inlet velocity profile (3D IVP) from 4DMR against equivalent uniform and axial profiles, we assess their impact on these potentially predictive quantities.

Methodology

Computed Tomography Angiography (CTA) data and 4D-Flow MRI (4DMR) data were acquired from a 56yo chronic TBAD patient under ethical approval from the local institutional review board (ID: 2019-00556). The fluid domain was manually segmented from baseline CTA data and elastically registered to the 4DMR domain. Follow-up 4DMR at two years was used to assess FL dilatation. Four commonly used inlet velocity profiles (IVP), as shown in Fig. 1, were derived from 4DMR data and applied at the inlet: a three-component, three-dimensional (3D) IVP, flow-matched flat (F) and through-plane (TP) IVPs and a modified 3D IVP with a 25% increase in each velocity component (+25%) to assess the impact of 4DMR velocity underestimation in the ascending aorta[3]. Three-element Windkessel outlet boundary conditions were calibrated using flow rate data from 4DMR and a brachial pressure measurement. Transient, rigid-wall simulations were performed using ANSYS CFX (ANSYS Inc, PA, USA).

Results

The inlet velocity profile affected the strength and directionality of helical flow and distributions of wall shear stress (WSS) throughout the FL, as shown in Fig. 1. At the point of greatest FL dilatation (β), weak helicity coincided with high OSI and RRT. Relative to the 3D IVP, the F and TP inlet conditions affected OSI and RRT to a greater extent than TAWSS (up to 167% vs 17%). The +25% IVP, had a greater mean impact on all flow metrics than flow-matched (F & TP) IVPs.

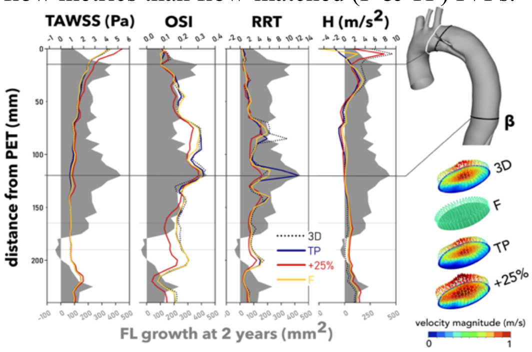

Figure 1: WSS and helicity (H) against FL growth years. Each IVP is shown at peak systole, bottom right.

Conclusions

Our results demonstrate that the precise distribution of inlet velocity affects helicity and disturbed shear throughout the FL. By scaling the gold-standard 3D IVP within the reported error of 4DMR measurements, mean differences in all WSS metrics were affected to a greater extent than amongst the flow-matched conditions. Thus, even 3D IVPs may not provide sufficient accuracy for future clinical application due to 4DMR imaging errors. Further efforts may be needed to minimize these errors within acceptable bounds for the purpose of future large-scale clinical simulation studies and subsequent clinical application.

Acknowledgements

We acknowledge support from WEISS (203145Z/16/Z), VIRTUOSO (NH/20/1/34706), PIONEER (EP/W00481X/1) and MEDICARE (BB/X005062/1).

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