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A Multi-Dimensional, Multi-Modality Approach to Optimise Perfusion in Vascular Stent-Grafts

Scott M. Black*[1], Craig. Maclean[2], Pauline. Hall Barrientos[3], Konstantinos. Ritos[4]

[1] Department of Biomedical Engineering, University of Strathclyde, Glasgow, UK,
scott.black.100@strath.ac.uk, asimina.kazakidi@strath.ac.uk
[2] Research and Development, Terumo Aortic, Glasgow, UK,
craig.maclean@terumoaortic.com
[3] Clinical Physics, Queen Elizabeth University Hospital, NHS Greater Glasgow & Clyde, Glasgow, UK, Pauline.HallBarrientos@ggc.scot.nhs.uk
[4] Department of Mechanical and Aerospace Engineering, Glasgow, UK,
Konstantinos.ritos@strath.ac.uk

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Vascular stent-grafts are commonly used to treat aortic pathologies including aneurysm and dissection. For treatment planning and long-term success, accurate understanding of aortic geometry and perfusion in patient-specific cases is vital. Therefore, the aim of this study was to create patient-specific computational fluid dynamics (CFD) models through a multi-modality, multi-dimensional approach to extract clinically relevant haemodynamic parameters from pre- and postoperative cases.

Three-dimensional (3D) aortae were reconstructed from four-dimensional flow-magnetic resonance imaging (4D Flow-MRI) and computed tomography (CT) images. The former employed a novel approach to generate and enhance vessel lumen contrast *post-hoc* via through-plane velocity at discrete, user defined cardiac time steps. Patient-specific, 3-element Windkessel model (3EWM) boundary conditions (BCs) were then generated from a reduced order, 0D-1D coupled model. Subsequently, these 3EWMs were coupled to each terminal branch of a 0D-3D CFD model, and an MRI-derived velocity profile was prescribed at the inlet.

4D Flow-MRI granted unparalleled visualisation and quantification of blood flow in healthy, diseased, and stented cases in both the true and false lumen. Further, segmentation and reconstruction of healthy and stented regions from 4D Flow-MRI images was validated against CT-derived models. However, CT images were required to segment the false lumen. Reduced order modelling permitted rapid optimization of the 3EWM BCs, while 0D-3D coupling captured pulse waveforms and enabled quantification of hemodynamic parameters which are clinically relevant for the prediction of in-stent thrombus formation. With multiple 3EWM BCs and stent-graft configurations, it was possible to perform a parametric analysis on a range of distal vasculature conditions and graft limb diameters on several stent-graft configurations.

Thus, aortic blood flow was investigated in a fully patient-specific, 0D-3D numerical framework, created from non-invasive measurements. This study was also a step towards the prediction of post-surgical branch perfusion and in-stent hemodynamics for custom stent-grafts.

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