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Effect of Windkessel Boundary Conditions on 3D Blood Flow Simulations in the Aortic Arch

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Abstract

Regions of the aortic arch affected by an aneurysm or dissection may require surgical intervention using synthetic vascular grafts, which requires a means of reperfusing the supra-aortic branch vessels. For the long-term success of an open surgical repair, it is crucial that the chosen graft configuration promotes physiological perfusion with an optimal division of flow through each branch, to reduce the risk of ischaemic neurologic and cardiac events. Further, abnormal wall shear stresses can induce thrombosis, post-dissection aneurysm formation, and focal intimal hyperplasia, contributing to graft failure[1]. It is clear, therefore, that enhanced understanding of perfusion is critical to improving clinical practice and patient outcomes. The aim of this study was to determine appropriate boundary conditions (BCs) to enable the prediction of flow splits and investigation of arterial haemodynamics in a patient-specific case.

Preliminary coupling and validation were performed on an adapted thoracoabdominal aortic model, provided by Dr A. Marsden (SimVascular, Stanford University). A patient-specific aortic arch was obtained through 4D magnetic resonance imaging (4D-MRI) was then reconstructed to create a computational model. This model was investigated via computational fluid dynamics (CFD) methods, within a coupled 3D-0D numerical framework in ANSYS Fluent®, utilising the three-element Windkessel model (3EWM) as a coupled function for the outlet BCs[2]. By tailoring the 3EWM parameters, simulation of a range of healthy and pathological downstream vascular conditions was possible. These BC's do not require any prior knowledge or specification of pressure or flow rate at the outlets and can be validated by phase contrast MRI.

It was possible to alter perfusion through the aortic branches by modifying the 3EWM parameters to achieve a physiologically representative flow split. When compared to zero pressure conditions, the 3EWM models have an insignificant effect on the computational performance, indicating they are computationally efficient BCs.

References

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