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Fluid-structure interaction simulation of flow-mediated dilation of a straight arterial conduit

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Introduction

Flow-mediated dilation (FMD) is a key non-invasive clinical assessment of endothelial dysfunction, an indicator of early atherosclerosis and cardiovascular diseases. FMD involves the measurement of an artery dilation, e.g. of the brachial, radial, femoral, or popliteal artery, induced by transient hyperaemia, following a temporary ischemic occlusion of a distal arterial segment. Such transient conditions, however, may also involve changes in the wall shear stress (WSS), blood pressure, and wall stiffness which have not been clearly established in relation to early vascular changes. This work aims to clarify the role of these flow-related mechanisms by investigating the haemodynamic environment of a straight arterial conduit with compliant walls during FMD.

Methods

By implementing a strongly-coupled fluid-structure interaction (FSI) solver within the open-source OpenFOAM-extend library [1], the arterial vessel was modelled as a quarter cylinder with an in-vivo measured hyperaemic inflow condition (by [2]). The FSI solver follows a partitioned approach with separated solvers for fluid and structure, and an implicit coupling method between fluid and solid, with interface values being passed from one solver to the other. The solution of the fluid flow is based on the finite volume method (FVM), while the solid is solved by a Lagrangian FVM solver. The mesh motion for both the fluid and the solid, due to the interface displacement, is updated at every timestep using a dynamic mesh solver in OpenFOAM based on the Laplace equation discretisation. Prior examples of FSI simulations in OpenFOAM and the foam-extend project have demonstrated its use for cardiovascular flows [3].

Results & Discussion

The results demonstrate the diameter change during FMD, while haemodynamic shear stresses and pressure values are also analysed. Current results are being used for correlating the displacement of the arterial walls and the prescribed in-vivo inlet velocity.

Conclusion

The methodology has been established for subsequent simulations. Future work will investigate the FMD in idealised and anatomically-correct bifurcated arterial models with prescribed ischemic occlusion of the distal branching arteries. It will also include the investigation of further haemodynamic metrics, such as the time-averaged wall shear stress, the oscillatory shear index, and the transverse WSS, in comparison with in-vivo data.

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