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Blood Flow Simulations in the Aortic Arch in relation to Haemodynamic Wall Shear Stress and Obesity-induced Vascular Changes

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Introduction

The aorta is the largest artery in the human body, with a complex geometry and flow dynamics. Locations of arterial curvature and bifurcation are known to be prone to endothelial dysfunction, one of the early biological markers for atherosclerotic lesions that underlie most cardiovascular diseases [1]-[2]. However, the influence of local anatomical and haemodynamic factors, such as wall shear stress (WSS), on lesion development is not well established [3]. This is particularly relevant to conditions of obesity, which is believed to accelerate the initiation and progression of vascular changes, and may be associated with vascular remodelling, inducing increased vessel diameters and wall thickness [4]. In this study, we hypothesize normal and obesity-altered arterial conditions to investigate the effect of a range of anatomical and flow parameters on the haemodynamic environment. To that end, we utilised 3D computational fluid dynamic (CFD) modelling methods; such methods have become an essential tool in the study of cardiovascular diseases and can be indirectly incorporated into clinical practice by improving our understanding of the underlying mechanisms of such diseases.

Methods

Simplified three-dimensional aortic arch geometries were created using the ANSA pre-processor (BETA CAE Systems), while numerical simulations were performed with the open source platform OpenFOAM®, using physiological parameters adopted from the literature [5]. Preliminary results consider both steady and time-dependent (pulsatile) flow for the solution of the incompressible Newtonian Navier-Stokes equations. The boundary conditions studied include different inlet profiles with both steady and pulsatile flow. Computational fluid dynamic analysis focussed on the variance of flow parameters, specifically velocity, pressure, and wall shear stress, for the different boundary conditions.

Results & Discussion

The results demonstrate the importance of normal and obesity-altered arterial conditions for aortic arch models. The branch flow splits in both steady-state and unsteady calculations influence the shear stresses developed on the aortic wall. Time-dependent metrics such as the time-averaged wall shear stress (TAWSS) and oscillatory shear index (OSI), indicate locations of disturbed flow.

Conclusion

In this work, simulations were conducted on simplified aortic arch configurations for various boundary conditions that could quantify the impact of such parameters and find associations with early signs of vascular changes in obese patients. The future direction of this work is to improve the accuracy of the simulations by implementing more complex boundary conditions, namely the windkessel model to account for the resistance and capacitance of peripheral arteries. The investigation will then be extended to patient-specific aortic models to confirm the results of this work.

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