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Hemodynamics in the pulmonary bifurcation: Effect of geometry and boundary conditions

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Introduction

Pulmonary regurgitation [1] and obstruction in the left pulmonary artery [2], the most common complications affecting adult patients with repaired tetralogy of Fallot, are known to lead to right ventricular dilatation and dysfunction. Long-term pulmonary stenosis is also hypothesized to lead to abnormal lung development and elevated pulmonary vascular resistance [3]. Pulmonary valve replacement is deemed necessary in these patients, but the optimal timing to perform the surgery is still ambiguous [1]. The aim of this study is to numerically investigate the blood flow development in the pulmonary bifurcation of adult patients with congenital heart defects. In this work, we present results from a parametric analysis, where the effect of geometry (branch angle, origin, branch obstruction) and boundary conditions (unsteady flow, Reynolds number, pressure difference at the outlets, and non-Newtonian models) were examined.

Methods

Blood flow simulations were performed in simplified models of the pulmonary bifurcation, using a validated finite volume scheme in OpenFOAM®. Physiological and pathological conditions were assumed and local velocities, wall shear stress values, velocity and pressure distributions were evaluated. The fluid was considered incompressible and governed by the Newtonian Navier-Stokes equations. The Power Law, Cross-Power Law, the Casson, and the Bird-Carreau non-Newtonian models were also investigated.

Results & Discussion

Blood flow in the pulmonary bifurcation is highly dependent on the local geometrical characteristics and the boundary conditions assumed. Flow separation increases with the branching angle, the branch origin, and stenosis. Branch obstruction and boundary conditions have, further, a significant effect on velocities and shear stresses developed on the vessel wall. The presence of peripheral stenosis and pressure difference at the branch outlets affects significantly the flow splits in the daughter branches. Finally, pressure ratios are considered to provide a good indication of flow discrepancies between the different cases tested. Evaluation of the results on more complex 3D anatomically-correct geometries is necessary. Future work will involve reconstruction of patient-specific models using CT and MRI data from adult patients with congenital heart diseases. More realistic boundary conditions will also be considered, including the pulsatile nature of blood flow and Windkessel models at the branch outlets to account for peripheral resistance.

Conclusion

Computational fluid dynamics tools have been utilised in this study to investigate the effect of a range of different geometrical characteristics and boundary conditions. The main findings of this study concern a new effect of the branch origin, and a notable branch flow split analysis under conditions of peripheral stenosis and pressure difference in the branch outlets.

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