Blood flow simulations in models of the pulmonary bifurcation to facilitate treatment of adults with congenital heart disease

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Tetralogy of Fallot (ToF) is the most common cyanotic congenital heart disease, for which patients require surgical intervention at a very young age. Although these patients have long survival rates, they are at risk of chronic complications and frequently require re-operations with the most common being pulmonary valve replacement (PVR). However, the decision for surgical intervention is currently based on clinical indications and the right timing for PVR remains ambiguous [1,2]. The overall objective of this work is to identify a computational metric that will help assess the right timing for surgical intervention in adults with repaired tetralogy of Fallot. This current study concerns a preliminary computational analysis of blood flow in simplified geometries of the pulmonary bifurcation. The focus lies on the effect of geometric and haemodynamic parameters on the wall shear stress patterns around the pulmonary bifurcation.

Different models of the pulmonary bifurcation were created with varied angles and origins of the branches, representing normal and diseased cases. Blood flow simulations were performed based on steady and incompressible flow, governed by the Newtonian Navier-Stokes equations. Physiological vessel dimensions and boundary conditions were applied in all models and different Reynolds numbers were tested.

Blood flow in the pulmonary bifurcation is strongly dependent on geometric and haemodynamic conditions. An increase in the angle of the pulmonary branches cannot be directly correlated with increased regions of recirculation zones downstream of the junction, but more extended regions were observed for higher Reynolds numbers. The origin of the branches also appeared to influence flow separation and recirculation, for the same branching angle. Changes in velocities and shear stresses developed on the vessels walls were observed for each model. Evaluation of these parameters can provide an insight into the underlying flow mechanisms of more complex 3D geometries. Future work will involve the reconstruction of 3D patient-specific geometries from medical images of adult patients with repaired tetralogy of Fallot, pre- and post- operatively. Time-dependent effects will also be tested. These results contribute towards the identification of new reliable approaches for the assessment of PVR and may help towards better medical care.

Acknowledgments

This work is supported in part from the University of Strathclyde Research Studentship Scheme (SRSS) Research Excellence Awards (REA), Project No 1208 and the European Union's Horizon 2020 research and innovation programme, under the Marie Skłodowska-Curie grant agreement No 749185.

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