A Multi-Scale Computational Fluid Dynamics Investigation of a Novel Hybrid Comprehensive Stage II Operation for Single Ventricle Circulation

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ABSTRACT

The hybrid comprehensive stage 2 (HCS2) operation is a novel palliation for a select subset of single ventricle patients with adequate antegrade aortic flow. It avoids dissection of the pulmonary arteries by introducing a stented intrapulmonary baffle and avoids reconstruction of the aortic arch by maintaining patency of the ductus arteriosus. This study aims to provide better insight on the post-operative hemodynamics of HCS2 patients.

A multi-scale Computational Fluid Dynamics (CFD) analysis of a synthetic, patient-derived HCS2 geometry based on unsteady laminar flow conditions and a non-Newtonian blood model is utilized to quantify the resultant hemodynamics. The 3-D CFD model is coupled to a 0-D lumped parameter model of the peripheral circulation that supplies the boundary conditions necessary to run the CFD analyses of the HCS2.

Based on clinical parameters suggesting the baffle related narrowing to be at minimum 10mm and the pressure gradient not surpassing 20mmHg, hemodynamic analysis reveals that for even a 7.23mm narrowing the average pressure drop is 0.53mmHg. A peak pressure drop of 2.96mmHg was computed across the investigated range of clearances of over the pulmonary baffle. Vortex shedding presents no concerns as the distance between the baffle and the aortic arch is much smaller compared to the length required for full vortices to form.

The study provides a range of main pulmonary artery geometries that, following multi-scale CFD analysis, present no concerns regarding excessive pressure gradients or vortex formation. Moreover, the model identifies locations of potentially problematic hemodynamics that could be mitigated by shape optimization of the reconstruction.

REFERENCES

