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Towards predictive modeling of patient-specific Glenn-to-Fontan conversions: boundary conditions and design issues.

Single-ventricle defects are a class of congenital heart diseases that leave the child with only one operational pump, requiring the systemic and the pulmonary circulations to be placed in series through several operations performed during young childhood. The last procedure (the Fontan palliation) artificially connects both venae cavae to the pulmonary arteries, which improves oxygeneration of the baby at the cost of blood flowing passively into the lungs. Numerical simulations may be used to investigate the nature of the flow and its connection to post-operative failures and sources of morbidity. However they heavily rely on boundary condition prescription. We present our recent work on predictive patient-specific modeling of the Glenn-to-Fontan conversion. Three-dimensional patient-specific preoperative models are developed based on clinical data. Results include a sensitivity analysis of several hemodynamics factors to the input data. In addition, previous studies have demonstrated that the geometry plays an important role in Fontan hemodynamics. A novel Y-shaped design was recently proposed to improve upon traditional designs, and results showed promising hemodynamics. In this study, we show how geometry and boundary conditions affect the performance of these virtual surgical designs. In particular, we investigate if and how the inferior vena cava flow (which contains an important biological hepatic factor) can be optimally distributed amoung both lungs. Finally, we present a multiscale (three-dimensional to reduced model of the entire circulation) predictive framework for this Glenn-to-Fontan conversion, which provides a means to relate global response to local changes in geometry and hemodynamics in the circulatory system. Results illustrate that the local graft geometry plays essentially no role in the workload on the heart. While the offset and Y-graft designs result in reduced energy loss, this does not appear to have any significant impact on the cardiac dynamics. This result suggests that future work should focus not just on energy loss, but on other clinical relevant parameters, such as hepatic flow distribution.