The Fontan circulation is a result of the last (third stage) surgical procedure to correct a single ventricle congenital cardiac disorder in children. Although the Fontan circulation has been successfully established in surgeries over the years, it is flawed and can lead in certain cases to premature death. The main cause of this failure is due to increased pulmonary vascular resistance due to loss pulse pressure and blood flow. In healthy circulations, the heart pumps directly to the lungs, whereas single ventricle patients must use a single sided heart to supply blood to the rest of the body before the lungs. Improvements to the Fontan circulation have been proposed, but they require extensive care or external devices. We propose a "Self-Powered" Fontan circulation that will inject energy into the pulmonary system by adding an injection jet shunt (IJS) directly from the heart. The IJS will provide the pulse pressure, blood flow, and entrainment that the pulmonary vascular system needs to function at a healthy level. The difference between a healthy and sick Fontan circulation is 3-5 mmHg in the inferior vena cava (IVC). The goal of the IJS is to cause this 3-5 mmHg pressure drop in the IVC. In the analysis of the Fontan, ascertaining energy losses due to flow jet impingements and flow mixing is critical. Moreover, in order to better understand surgical alternatives it is important to have a robust multi-scale 0D-3D computational fluid dynamics (CFD) analysis tool that permits investigation of surgical alternatives in a virtual physics-based environment. To this end, an open loop lumped parameter model (LPM) is tightly coupled at the time step level with a full 3D CFD model. Using this model scheme, the Fontan test section is no longer being modeled by the LPM and therefore not limited by the 0D nature of the vascular resistance, capacitance, and inertia bed model. The CFD is able to take over at the area of interest which accounts for flow directionality and momentum transfer that the LPM is unable to capture. To efficiently calculate optimal IJS configurations, a closed loop steady state model was created to solve a simplified Fontan circulation in 3D. Two models were created with several different optimized configurations, a synthetic model and a patient-specific model. Patient data are used to tune the LPM and provide corresponding pulsatile boundary conditions to the tightly coupled multi-scale model. The configurations for both models include changes in the IJS nozzle diameter and IJS placement which is compared to a baseline model with no IJS. Both models suggest that the IJS helps to decrease IVC pressure while adding pulse pressure and blood flow to the pulmonary system.

IJS: injection jet shunt, IVC: inferior vena cava, CFD: computational fluid dynamics, LPM: lumped parameter model

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The public is welcome to attend.