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Utilizing optimization techniques to build a patient-specific 1D arterial network for single ventricle patients

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Abstract:
Hypoplastic left heart syndrome (HLHS) is a congenital heart disease that affects about 1,025 infants in the US each year. HLHS patients are born with an underdeveloped aorta and left heart, receiving a series of three surgeries to create a univentricular circulatory system called the Fontan circuit. Patients typically survive into early adulthood but suffer from reduced cardiac output leading to insufficient cerebral and gut perfusion. Currently, clinical imaging data of the neck and chest vasculature is used to assess patients, but it is difficult to use imaging data to assess deficiencies outside of the imaged region. Data from patients used in this paper include three-dimensional, magnetic resonance angiograms (MRA), time-resolved phase-contrast cardiac magnetic resonance images (4D-MRI), and sphygmomanometer blood pressure measurements. The 4D-MRI images provide detailed insight into velocity and flow in vessels within the imaged region, but they cannot predict flow in the rest of the body, nor do they provide values of blood pressure. This study combines MRA, 4D-MRI, and pressure data with a 1D fluid dynamics model to predict hemodynamics in the aorta and the peripheral vessels, including the cerebral and gut vasculature. A novel method of using Bayesian change points along the vessel radii to define the location of junction points within the vessels was developed in this study. Optimization techniques are used to tune the model to flow data from 7 different vessel locations and pressure data from one location to each of the eight patients; four HLHS patients and four age/size/sex matched control patients. Our control patients are double outlet right ventricle patients (DORV) who also have a Fontan circuit, but have not undergone aortic reconstruction. Once tuned to data obtained from the imaged region, pressure and flow predictions are generated beyond the imaged region to compare hemodynamic function of the disease and control patients. Results demonstrate the HLHS patients has hypertensive pressures in the brain as well as reduced flow to the gut. Wave-intensity analysis suggests the HLHS patients has an irregular circulatory function during light upright exercise conditions and that predicted wall-shear stresses are lower than normal.