

**Quantification of Blood Mixing in Patients with Fontan Circulation Using 4D Flow MRI**

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**Background:** Single ventricle physiology is one of the most severe forms of complex congenital heart disease. For treatment, patients undergo multiple surgeries to achieve Fontan circulation: systemic return from the inferior and superior vena cava (IVC, SVC) is routed directly to the right and left pulmonary arteries (RPA, LPA). Uneven distribution of blood from the caval to the pulmonary system has been suspected to influence patient outcome through the delivery of protein-rich venous return [1]. The aim of the study is to employ whole heart 4D flow MRI to visualize and quantify blood mixing in Fontan circulation.

**Methods:** Time-averaged 3D phase contrast angiograms (PC-MRAs) were calculated using 4D flow MRI data to provide the depiction of cardiovascular geometry. From PC-MRAs, three segmentation volumes were generated (1-Fontan segment, 2-IVC, 3-SVC) by user-guided segmentation techniques (Mimics, Belgium) to isolate velocity flow data in these segments. Particle trace pathlines were released from the IVC and SVC segments and the number of pathlines in each PA were collected and normalized over the total number of pathlines that reached either PA. In addition, SVC-IVC offsets were estimated by the distance between vessel centerpoints as a measure of Fontan geometry.

**Results:** While all patients had undergone Fontan surgery, their mixing results were shown to vary considerably. SVC flow was predominantly directed to the RPA in 4 patients, to the LPA in 3 patients and more evenly distributed (<20% difference) in the remaining 2 patients. Flow originating in the IVC was primarily directed toward the RPA in 6 patients, to the LPA in 2 patients and evenly distributed in one patient. Correlation analysis revealed a relationship between the asymmetry of flow distributions (% difference in pathline distributions to RPA and LPA) and SVC-IVC offsets (IVC:  $r=0.72$ ,  $p=0.03$ ; SVC:  $r=0.3$ ,  $p=0.43$ ).

**Conclusions:** Using 4D flow MRI, blood flow distribution was shown to vary between patients with Fontan circulation, indicating non-uniformity in the distribution of protein-rich hepatic blood carried in the IVC to the lungs and demonstrating the value of 4D flow MRI for the individual assessment of complex Fontan hemodynamics. Furthermore, the findings of this study indicated a statistically significant linear relationship between Fontan geometry and IVC flow distribution.

1. Shah MJ, et al. Ann Thorac Surg. 1997;63:960-963.