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Quantitative blood flow analysis of aorto-pulmonary collaterals by 3D-flow Phase-Contrast Magnetic Resonance Imaging in patients with single ventricle physiology

Valverde I.(1,2), Nordmeyer S.(3), Crelier G.(4), Kuehne T.(3), Beerbaum P.(1,2)
Imaging Sciences. King's College London, London, United Kingdom(1); St. Thomas & Guy's Hospitals. Evelina Children Hospital. London. United Kingdom (2);Unit of Cardiovascular Imaging. German Heart Institute. Berlin. Germany (3);Institute for Biomedical Engineering, ETH and University of Zurich, Zurich, Switzerland(4);

INTRODUCTION: Aorto-pulmonary collaterals (APCs) have been associated with increased morbidity in patients after single ventricle circulation palliation surgery. Diagnosis by invasive angiography is qualitative only. Whilst cardiovascular magnetic resonance (CMR) using two-dimensional time-resolved flow (**2D-flow**) at multiple sites has been shown to successfully quantify APC flow; disadvantages however include complexity requiring very experienced CMR operators, and potential for slice malposition and hence inaccurate flow quantification. CMR three-dimensional time-resolved flow (**3D-flow**) might be an elegant solution to this problem.
MATERIALS: Twenty patients were included in this two-centre prospective study to quantify APCs flow, 10 with previous hemi-Fontan surgery (2.5±1 years, mean±standard deviation) and 10 with Fontan surgery completion (14±6 years). Five 2D-flow acquisitions were performed in the aorta, superior and inferior vein cava, right and left pulmonary arteries to serve as gold-standard. They were compared with flow results from a single whole-heart 3D-flow acquisition. In each patient, the 2D flow planes were registered into the 3D flow volume data set to allow accurate alignment of all 5 positions.
RESULTS: 3D-flow and 2D-flow results showed good agreement in all investigated vessels (Bland-Altman, mean difference 1.1 ml, limits of agreement -7.1 to 9.3 ml). Single 3D-MR-flow was faster and easier compared with the five 2D-flow measurements (12:14 min of 3D-MR-flow vs. 12:58 min for 2D-flow scan-time plus another ~5 min of 2D planning,$p<0.05$).
On the basis of this validation, to investigate the APCs flow we compared the pulmonary inflow via branch pulmonary artery supply with pulmonary outflow via all pulmonary veins. It revealed a significant increase in the lung perfusion due to the APCs of 6±10 ml in the hemi-Fontan and 9±15 ml in the Fontan group ($p<0.05$,Figure1).
The pulmonary to systemic ratio (Qp:Qs) including the APCs (hemi-Fontan 0.8:1, Fontan 1.23:1) was significant different than without including the APCs (hemi-Fontan 0.46:1, Fontan 0.79:1) ($p<0.05$,Table1).
CONCLUSION: Single 3D-flow is accurate compared with multiple-site 2D-MR-flow, but easier to plan, faster to scan and provides further flow information from additional sites. This allows to reliably quantify APC flow in patients with single-ventricle physiology. The method has potential to become clinically valuable in routine clinical follow-up.

	Qp:Qs without APCs (Q_{PA}:Q_{AO})	Qp:Qs with APCs (Q_{PVR}:Q_{SVR})	p value
Hemi-Fontan	0.46 : 1	0.80 :1	0.01
Fontan	0.79 :1	1.23 :1	<0.01

Table 1. Pulmonary to systemic ratio (Qp:Qs). Q_{PA}: Flow pulmonary artery. Q_{AO}: Flow aorta. Q_{PVR}: Flow pulmonary venous return. Q_{SVR}: Flow systemic venous return.

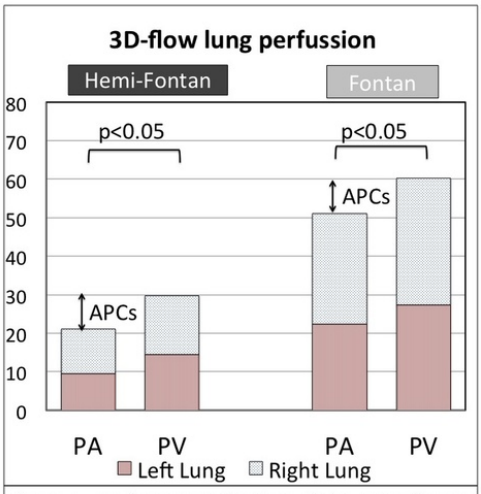

Figure 1. 3D-flow quantification of the APCs flow in the hemi-Fontan and Fontan groups. The net balance between the pulmonary venous return (PV) and the pulmonary artery (PA) supply can be calculated to obtain the APCs (ml/beat).