Highly Accelerated 4D MR Flow Measurements in Congenital Heart Disease

Daniel Giese[1,2], Gerald Greil[1], Tobias Schaeffter[1], and Sebastian Kozerke[1,2]

[1]*Division of Imaging Sciences and Biomedical Engineering, King's College London, London, United Kingdom,* [2]*Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland*

Introduction:

Time-resolved 3D MRI with phase contrast velocity encoding in all three dimensions (4D Flow MRI) has been shown promising for studying cardiac and vascular pathologies. The assessment of congenital heart disease (CHD) has demonstrated to benefit from 4D Flow MRI [1] as retrospective reformatting of flow planes in complex anatomies can be performed. However the long acquisition times required for a fully sampled dataset with appropriate spatio-temporal resolution [2] still limits wide-spread clinical use. Spatio-temporal acceleration techniques have been successfully applied to reduce scan time [3-4] in 2D flow applications. However, temporal blurring and residual folding artifacts have been found to limit the applicable range of undersampling factors in practice. Recently k-t Principal Component Analysis (k-t PCA) has been proposed to address these limitations [5] and it was shown previously that net acceleration factors on the order of 7-10 are achievable in 2D [6] and 4D Flow MRI [7].

The present study investigates the clinical potential use of accelerated 4D Flow MRI in patients with CHD. Flow volumes were compared to fully sampled 2D Flow MRI, the current gold standard, in different vessels of interest. Particle tracking was performed for qualitative analysis of flow patterns.

Methods:

k-t undersampled 4D Flow MRI with a nominal acceleration factor of 8 was performed in 4 patients with CHD. Scan times were in the order of 5 minutes excluding navigator gating efficiency. The scan geometry was chosen to cover the heart and great vessels within the thorax (Table 1). Undersampled 4D Flow MRI scans were reconstructed using *k*-t PCA in combination with a sparsifying transform between all four flow encoded segments similar to [7]. Phase offsets were corrected using linear regression through the phase of static tissue [8]. 4D-Flow MRI was then analyzed using dedicated software (GTFlow, Gyrotools LLC, Switzerland) allowing multiplanar reformatting. Particle traces were analyzed in the main pulmonary artery of (patient #1), in the ascending aorta (patient #2) and in the modified Blalock-Taussig (BT) shunt connecting the innominate artery and the bifurcation of the pulmonary arteries (patient #3 and #4).

Results:

Figure 1 shows flow curves through different vessels of interests in all four patients measured with the fully sampled 2D and undersampled 4D Flow MR. Good agreement was found without any noticeable temporal blurring. An analysis of all 9 flow values in all 4 patients yielded a mean deviation of -5.9 +- 7.8% in volumes. Figure 2 displays particle trace screenshots of two patients with flow abnormalities: Patient #1 with Tetralogy of Fallot post repair shows increased main pulmonary artery flow with strong retrograde flow due to pulmonary valve incompetence, whereas in patient # 3 circular flow from the shunt into the right pulmonary artery is observed. Furthermore reduced blood flow into the left pulmonary artery is noted.

Discussion:

The presented initial results of an ongoing study demonstrate the feasibility using k-t PCA accelerated 4D Flow MRI in clinical routine of CHD patients. Good agreement in flow rates and volumes were found compared to the results from 2D Flow MRI in accordance to the literature [9].

References:

[1]Valverde.JACC,2011;58 [2]Markl.JCMR.2011;13
[3]Baltes.MRM.2005;54 [4]Jung.JMRI.2008;28
[5]Pedersen.MRM.2009;62 [6]GieseISMRM2010;72
[7]Knobloch.ISMRM.2010;67 [8]Walker.JMRI.1993;3
[9]Carlsson.JCMR2011;13

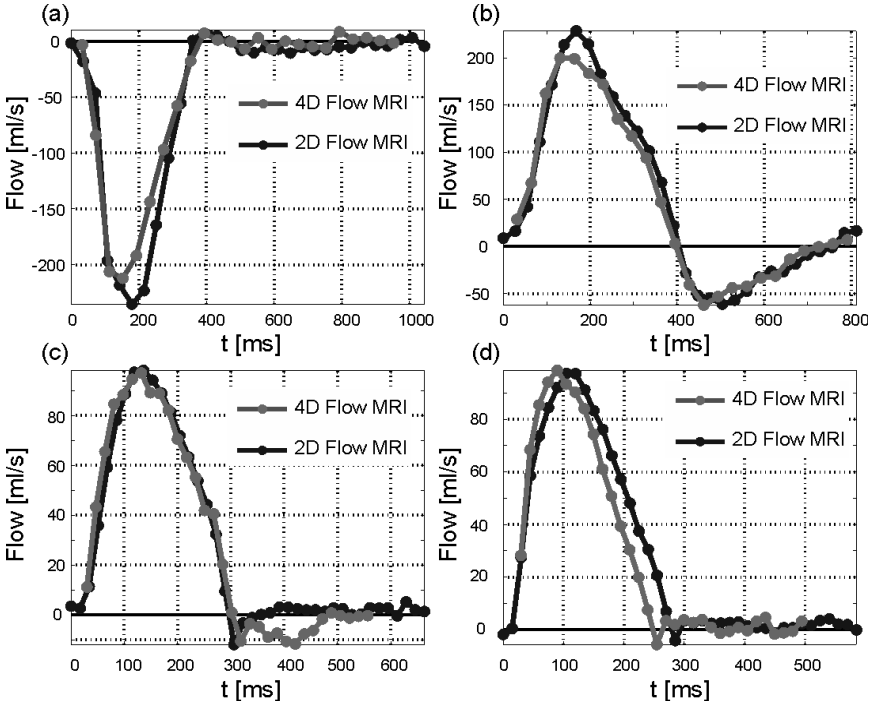

Figure 1: Comparison of flow profiles for 2D Flow and accelerated 4D Flow imaging for the descending aorta (Patient 2; a), the right pulmonary artery (Patient 1; b), the ascending aorta (Patient 3; c) and ascending aorta (Patient 4 d).

Patient	CHD Type	Age	Scan Resolution [mm^3]	#Phases	FOV [mm3]	GA
1	Tetralogy of Fallot	29 y	2.5x2.5x2.5	24	280x250x100	No
2	Marfan's Syndrome	18 y	2.5x2.5x2.5	24	280x250x100	No
3	HLHS	5 m	2.5x2.5x2.5	32	200x140x70	Yes
4	PA with IVS	7 m	1.67x1.67x2	32	160x160x58	Yes

Table 1: Patient and scan details (HLHS: Hypoplastic Left Heart Syndrome Norwood 1 procedure; PA with IVS: Pulmonary Atresia with Intact Ventricular Septum, GA: General Anesthesia)

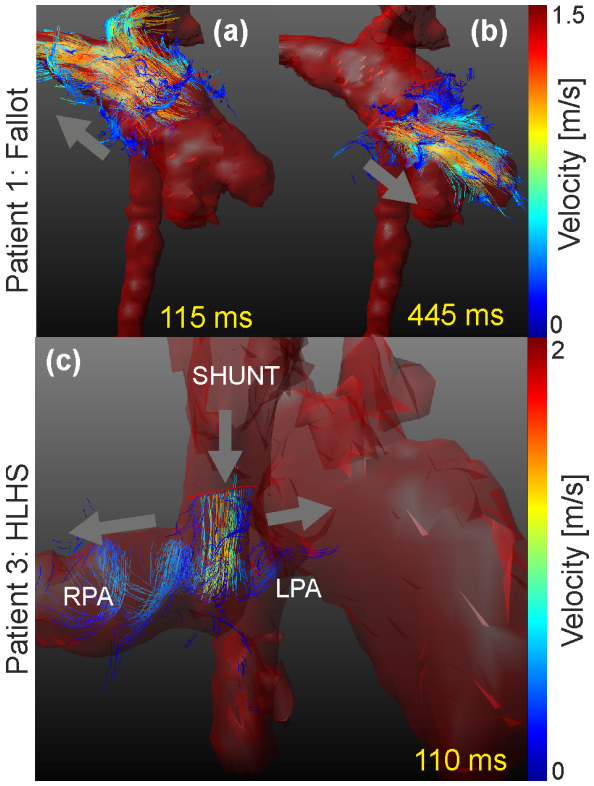

Figure 2: (a) and (b) show particle traces in patient 1. In (a), particles were released from the depicted red contour during systole, demonstrating antegrade flow. Abnormal retrograde flow is demonstrated in (b) where particles were released in early diastole. (c) shows a screenshot of patient 3 with the shunt connecting the innominate artery to the bifurcation of the pulmonary arteries. Particles were released during systole. Circular flow entering the right pulmonary artery (RPA) is seen. Furthermore, the flow entering the RPA is visibly higher than the flow entering the left pulmonary artery (LPA). The large gray arrows depict the main flow directions.