Pulmonary Artery 4D Flow MRI in Normal Volunteers and Pulmonary Hypertension

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Introduction: Pulmonary arterial hypertension (PAH) is a pathological condition of the pulmonary artery (PA), which can lead to right ventricular failure and subsequent death due to an increase of vascular resistance [1]. Since this is a progressive condition, it is of critical importance to diagnose and monitor the patients regularly. PAH routine assessment consists of echocardiogram and right heart catheterization [2]. Considering the subjectivity of former and the invasiveness of the latter, there have been studies trying to find a new method for evaluation of PAH patients. MRI can be an appropriate alternative for the current methods, since it is a less subjective and noninvasive way of vessel evaluation. Among different methods of MR, 4D flow MRI is a new and promising method for pulmonary artery evaluation providing full spatial and temporal coverage of pulmonary hemodynamics.

Methods: This HIPAA compliant study was approved by our IRB. Six volunteers (age = 32.7 ± 9.2, 2 females, 4 males) and 3 patients with PAH (age = 59 ± 9.5, 2 females, 1 male, no contrast agent administered) were studied prospectively at our institute. The ejection fraction was within normal range for both volunteers (58% ±6) and patients (67%±2). Pulmonary valve insufficiency was not present except in patient 3 with mild insufficiency of pulmonary valve.
All measurements were performed at a 1.5T MR system (ESPREE Scanner Siemens, Germany). In all subjects 2D CINE SSFP images in standard orientation were acquired. Subsequently, pulmonary blood flow velocities were measured using ECG synchronized 4D flow MRI with free breathing with navigator respiration control. Data were acquired in an oblique coronal 3D volume covering the right ventricular flow tract, pulmonary trunk (TP) and the left and right PA branches (rPB, lPB). Imaging parameters were as follows: spatial resolution = 2.2 mm x 2.9 mm x 2.5 mm, TE/TR= 2.6 ms/5 ms, temporal resolution = 40 ms, flip angle = 15, 3-directional velocity encoding with venc = 150 cm/s). All volunteers received contrast agent (Ablavar, Lantheus, USA) before the 4D flow data were acquired. However, the patient's MRIs were performed without contrast agent.
The data processing was performed using in-house [4] software (Matlab, The Mathworks, USA) to correct for eddy currents, Maxwell terms and velocity aliasing and to derive a 3D PC angiogram from the 4D flow data. Pulmonary 3D blood flow was visualized (EnSight, CEI, USA) with time resolved 3D pathlines emitted from 3 planes located perpendicular to vessel wall at the level of pulmonary trunk, the right PA and the left PA (figures 1 and 2). Images were scored based on the presence of retrograde, vortex and helix flow (none, mild, pronounced).

Results: In one patient 3D blood flow could only be visualized in the pulmonary trunk due to incomplete coverage of the left and right pulmonary branches. Exemplary results of the 3D flow visualization during systole and diastole in one normal volunteer is shown in figure 1 and in all three patients in figure 2. All volunteers and patients had a mild level of retrograde flow at all three planes (for patient 3 only 1 plane). Helical flow was observed during diastole in the right PA in 3 volunteers and in 2 patients. Compared to volunteers, marked vortex flow was present in 2 patients in the TP during systole (patient 3) and diastole (patient 2) and in the left PA in one patient during diastole (table 1 and figure 2).

Discussion: The results of this pilot study demonstrate the feasibility of 4D flow MRI for the comprehensive assessment of pulmonary flow characteristics and the ability to detect changes in PA flow compared to normal controls. The presence of additional vortical flow in PAH confirms findings of a previous study based on multi-slice 3D phase contrast MRI [3]. Noticeably, patients with similar clinical presentation (normal, EF, LV-function and pulmonary valve) showed markedly different pulmonary 3D flow patterns indicating the potential of the methods to detect changes in pulmonary hemodynamics that may permit an improved characterization of the individual PAH severity.

Limitations: The results are not representative due to the small cohort of only 6 volunteers and 3 patients.

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[2] Swift et al., Eur Radiol. 2011 Oct 13., [3] Bock et al, Proc ISMRM 2007, [4] Reiter et al., Circ Cardiovasc Imaging. 2008;1:23-30

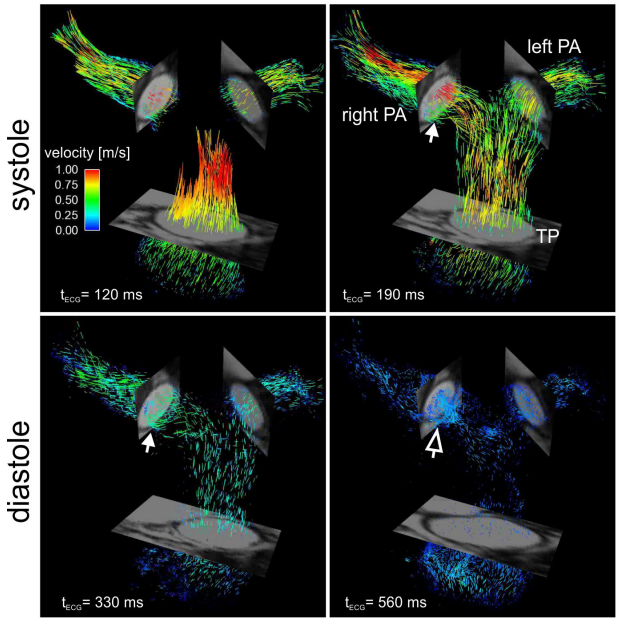

Fig. 1: 3D blood flow visualization in the pulmonary system based on time-resolved 3D path limes in abnormal volunteers. Systolic pulmonary outflow with high blood flow velocities (red color) is followed by lower diastolic flow with mild helix flow (solid white arrows) and mild retrograde flow (open white arrow) in the right PA.

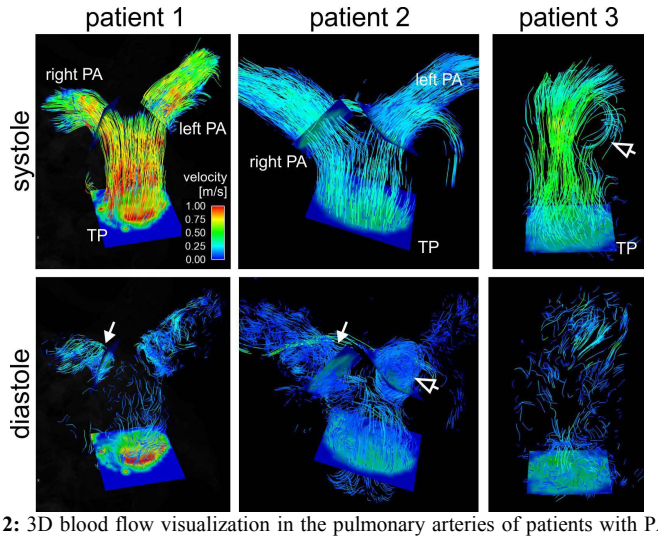

Fig. 2: 3D blood flow visualization in the pulmonary arteries of patients with PAH. Note the high variability of peak velocities between patients 1 and 2 despite similar EF and absence of valve insufficiency in both. Patients 2 and 3 demonstrated marked vortex flow in the pulmonary trunk. Additionally, patient 2 had vortex flow in the left PA (open white arrows). Similar to volunteers, mild helix flow was seen in 2 patients in the right PA (open white arrow).

Table 1: Results image grading.

	volunteers		PAH Patients	
Anatomical locations	Helical Flow	Vortical Flow	Helical Flow	Vortical Flow
Pulmonary Trunk	-	1	-	2
Right Pulmonary Artery	3	-	2	-
Left Pulmonary Artery	-	-	-	1