Abnormal Right Heart Flow Patterns in Pulmonary Artery Hypertension Visualized with 4D Flow-Sensitive MRI

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Purpose: To evaluate flow patterns in the right atrium (RA), the right ventricle (RV), and the main, right, and left pulmonary arteries (MPA, RPA, and LPA, respectively) in patients with pulmonary arterial hypertension (PAH) using four-dimensional (4D), flow-sensitive phase-contrast (PC) MRI.

Background: PAH is a fatal disease characterized by a progressive increase in pulmonary vascular resistance (PVR) that ultimately leads to right ventricular failure [1]. PAH was once considered a very rare disease but the most recent evidence suggests that prevalence is 15 to 30 per million. The prognosis of PAH is quite poor with 15% mortality within one year, on modern therapy. Right ventricular (RV) function is a major determinant of functional capacity and prognosis in PAH patients. The relationship between the degree of pulmonary hypertension (specifically, mean pulmonary artery pressure - mPAP) and right heart failure are incompletely understood. 4D flow-sensitive PC MRI provides a means of evaluating intracardiac flow patterns which should allow for additional analysis of the interactions between the pulmonary circulation and RV function.

Methods: Five subjects (3F/2M, 48±12years) with PAH (4 WHO Group I and 1 WHO Group III; 2/5 on treatment at time of enrollement) were prospectively enrolled according to our IRB-approved and HIPAA-compliant protocol. Right heart catheterization, performed within one week of the cardiac MRI, was used to measure right ventricular end-diastolic (RVEDP), pulmonary artery (mPAP) and pulmonary capillary wedge (PCWP) pressures. MRI studies were performed on 3.0T clinical systems (GE Healthcare, Waukesha, WI). Right ventricular function was measured from contiguous, axial, ECG-gated steady-state free precession (SSFP) images heart (acquired spatial resolution = 1.4-1.6mm x 1.5-1.9mm, slice thickness = 7mm, TR = 3.1-3.2ms; TE = 1.1ms). Pulmonary artery distensibility (relative crossectional area change, RAC) was determined from time-resolved 2D PC acquisitions through the MPA (VENC = 150cm/s; acquired spatial resolution = 1.4-1.5mm x 2.2-2.7mm, slice thickness = 7mm, TR = 5.4-6.1ms; TE = 2.6-3.1ms). Quantification of RV function and PR were performed using CV Mass and Flow Analysis software package in an Advantage Workstation (version 4.2, GE Healtcare, Waukesha, WI). 4D flow-sensitive PC MRI was performed with a previously described, three-dimensional (3D) radially-undersampled PC trajectory, PC VIPR (Phase Contrast Vastly undersampled Isotropic Projection Reconstruction) [2] with the following parameters: VENC = 75-150cm/s; isotropic acquired spatial resolution = 1.25mm, TR = 6.3-8.9ms; TE = 2.2-3.0ms, scan time = 13.6-17.4min. The heart and thoracic vasculature were segmented using commercial image processing software (Mimics Materialise, Ann Arbor, MI) and stored in a format specific to the visualization software Ensight (CEI, Apex, NC). Particle emitter planes were placed in the superior vena cava, inferior vena cava, tricuspid valve, mid RV, MPA, RPA, and LPA. 3D streamline and particle trace visualizations were both reviewed in consensus by three readers with experience in cardiovascular imaging and flow analysis. Flow patterns were recorded with respect to their presence in the RA, RV, MPA, RPA and LPA. Results were compared with those from a normal healthy volunteer scanned with the same technique. Normal right heart flow patterns have been previously reported in the literature [3-5].

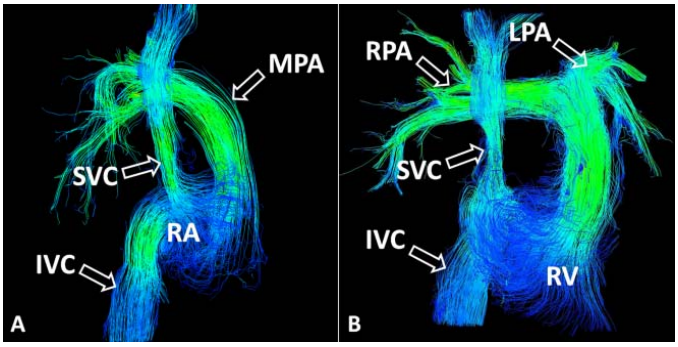

Figure 1. Normal healthy volunteer. RA filling occurs primarily during systole and smooth flow pattern are present in the MPA, RPA, and LPA

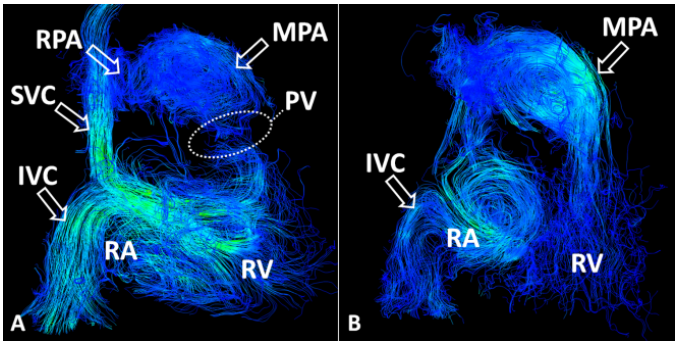

Figure 2. 45 year-old male with PAH secondary to scleroderma. (A) Streamlines during RV diastole, when the pulmonary valve (PV) is closed, show an increased number of vortices in the RV, MPA and RPA. In addition, flow through the SVC and IVC is greater than normal during RV diastole. (B) Streamlines during late RV systole reveal an abnormally directed vortex in the RA. A large vortex is also present in an aneurysmal MPA.

Results: RVEDP (13.6±7.2mmHg), mPAP (51.2±13.7mmHg), and PCWP (10.6±2.9mmHg) were elevated, consistent with PAH. MPA RAC (8.4±4.0%) was decreased compared to previously reported normal values. RVEDV (161.5±52.4mL) was elevated and RVEF (30.7±11.7%) was decreased. 4D flow-sensitive PC MRI data were successfully acquired in all subjects. The RA, RV, MPA, RPA and LPA flow patterns in the healthy volunteer were as expected based on previously reported normal patterns. Markedly abnormal flow patterns were observed in all PAH subjects. RA filling was abnormal in 4/5 PAH subjects with filling occurring primarily during RV systole in 3/5 and disorganized flow features in 4/5. Diastolic RV filling was abnormal in 3/5. Systolic RV flow patterns were normal in all PAH subjects. Tricuspid regurgitation was present in all PAH subjects. MPA flow was abnormal in all subjects, with antegrade flow along the anterior and cephalad surface of the MPA and a retrograde vortex directed toward the pulmonary valve. RPA and LPA flow patterns were also abnormal in all cases with decreased or disorganized flow during diastole.

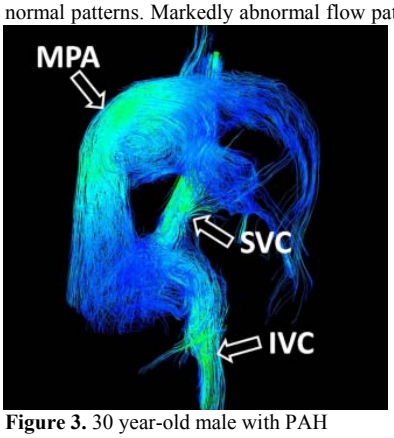

Figure 3. 30 year-old male with PAH secondary to congenital heart disease. Streamlines during RV systole show large vortex in aneurysmal MPA.

Summary: The flow patterns in the right heart and pulmonary arteries in patients with PAH are dramatically altered. The alterations in the RA filling may be partially explained by the presence of tricuspid regurgitation while the changes observed in RV diastole and MPA, RPA, and LPA flow are presumably related to the elevated RV pressures and PVR, respectively. This initial data already augments insights into hemodynamic alterations in PAH provided by Reiter, et al. using a multislab 2D approach. [4]. Obviously, PAH does affect the whole heart by altered hemodynamics. The use of 4D flow-sensitive PC MRI techniques to study these alterations in flow dynamics in the right heart may therefore provide a better understanding of the RV-PA coupling in patients with PAH hence play an important role in future diagnosis and follow-up of this detrimental disease.

References: [1] R. Naeije & S. Huez. Eur Heart J 2007; 9:H5-H9. [2] K.M. Johnson, et al. Magn Reson Med 2008, 60:1329-1336. [3] P. Kilner, et al. Nature 2000; 404:759-761. [4] G. Reiter, et al. Circ Cardiovasc Imaging 2008;1:23-30. [5] M. Markl, et al. Eur J Cardiothorac Surg 2010, *in press*.