4D flow assessment of pulmonary artery flow and wall shear stress in adult pulmonary hypertension: results from two institutions

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Target audience: Those with interest in cardiopulmonary physiology, pulmonary arterial hypertension, and 4D Flow MRI

Purpose: Pulmonary hypertension (PH) is associated with substantial morbidity and mortality [1]. The disease is characterized by a stiffening of the pulmonary arteries (PA) and an increase in pulmonary artery pressure (PAP). The aims of this two-center study were (1) to determine if PA flow and WSS can be reliably measured using two different four-dimensional flow-sensitive (4D Flow) MRI techniques (radial and Cartesian k-space sampling) and (2) to characterize differences in PA hemodynamics between healthy and PH subjects.

Methods: Healthy volunteers (n=19; 14M, 38.6±13.3y) and subjects with PH (n=17; 6M, 56.7±9.9y) were recruited at two sites according to an IRB-approved protocol. Presence and severity of PH was determined with right heart catheterization (mPAP=44.5±17.0mmHg, PVR=491±236dyn•s/cm^5). At Site 1 (n=19; 10PH), 4D Flow MRI was performed with a Cartesian acquisition (Siemens scanners, TR/TE=4.8-6.6/2.3-3.4ms, FA=7-15°, FOV=340-400x200-300mm, VENC=150-400cm/s) [2]. At Site 2 (n=17; 7PH), 4D Flow MRI was performed with a three-dimensional radially undersampled acquisition (GE scanners, PC-VIPR, TR/TE=6.1-8.9/2.1-3.2ms, FA=10-14°, FOV=320x320x220mm, VENC=75-150cm/s) [3]. Two-dimensional cutplanes in the main pulmonary artery (MPA), right pulmonary artery (RPA), and left pulmonary artery (LPA) (Fig. 1) were generated interactively from the 4D Flow MRI datasets using Ensight (CEI, Apex, NC) and exported for quantitative analysis in homebuilt Matlab software (The Mathworks, Natick, MA) [2]. Two blinded, independent observers, one at each institution, analyzed all 4D Flow MRI datasets from both institutions. MPA, RPA, and LPA peak systolic velocity (PSV), peak flow (Qmax), total flow (Qnet), and regional WSS were recorded for each study. Statistical analysis included assessment of inter-observer variability, inter-site differences, and differences in hemodynamic parameters between healthy volunteers and subjects with PH.

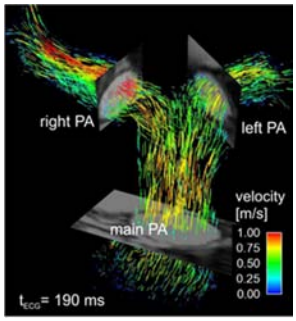

Figure 1. Particle traces in central pulmonary arteries showing location of cutplane placement.

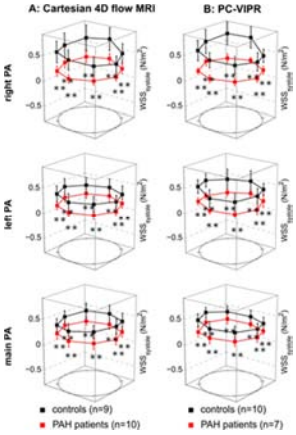

Figure 2. Regional WSS derived from Cartesian 4D Flow MRI (A) and PC VIPR (B) data. The individual plots show the WSS distribution in normal controls compared to patients with PH.

Results and Discussion: *Cartesian vs. radial:* MPA, RPA, and LPA flow data are summarized in the Table. Differences between inter-site groups may be attributed to individual physiologic flow differences, since the same subjects were not examined at both sites. *PH vs. healthy volunteers:* All measured flow parameters were significantly lower ($p<0.05$) in PH subjects than in healthy volunteers (Table and Fig. 2). *Inter-observer variability:* Mean differences in flow and WSS measurements between the two observers for all 36 subjects were 0.07 m/s, -0.02 L/sec, and -0.005 L/cycle for PSV, Qmax, and Qnet (Fig. 3), respectively, and 0.04 N/m^2 for WSS.

Conclusions: 4D Flow MRI can be used to reliably assess differences in pulmonary artery hemodynamics in patients with PH. Flow and WSS measurements in healthy and PH volunteer cohorts were similar whether obtained using either Cartesian- or radial-based 4D Flow MRI acquisitions with minimal inter-observer variability.

References: [1] D'Alonzo GE, et al. Ann Intern Med 1991;115:343. [2] Stalder AF, et al. Mag Reson Med 2008;60:1218. [3] Gu T, et al. AJNR Am J Neuroradiol 2005;26:743.

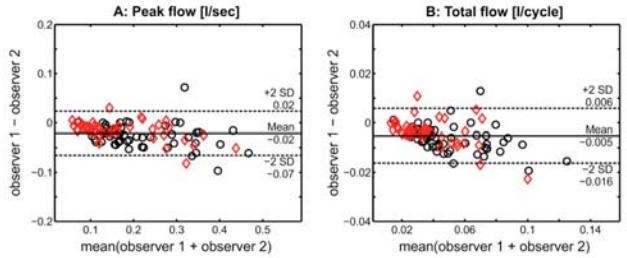

Figure 3. Inter-observer variability for (A) Qmax and (B) Qnet.

Table. Summary of PSV, Qmax and Q net in healthy volunteers and PH subjects. *, P<0.05 for site-to-site differences. **, P<0.05 for PH-Control differences.

	Healthy volunteers			PH		
Qnet (mL/cycle)	Site 1	Site 2	Combined	Site 1	Site 2	Combined
MPA	68±13	88±20*	79±19	53±12	55±30	54±20**
LPA	29±8	42±10*	36±11	21±5	23±9	22±7**
RPA	33±6	48±11*	41±12	26±7	26±7	26±10**
Qmax (mL/s)						
MPA	313±74	358±64	337±71	270±40	285±109	276±74**
LPA	136±40	168±29	153±37	96±15	95±32	95±23**
RPA	151±39	189±31*	171±39	128±25	120±50	125±36**
PSV (cm/s)						
MPA	84±13	84±11	84±12	57±13	82±25*	67±22**
LPA	77±18	79±16	78±17	35±12	62±19*	26±20**
RPA	93±18	84±16	88±17	44±15	65±20*	53±20**