Noninvasive Pressure Measurement in Patients with Congenital Heart Disease using 4D Phase Contrast MRI

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Background: In clinical routine, invasive catheter pressure measurements are considered the gold standard for quantifying pressure gradients, whether in valvular stenosis, aortic stenosis or renal artery stenosis, in order to assess the hemodynamic significance of a narrowed segment. Pressure gradients can also be estimated noninvasively from Doppler ultrasound (US) or 2D phase contrast (PC) MRI using a simplified Bernoulli equation [1]. However, thoracic US measurements are not always possible, results can be user dependent and error prone, and do not provide information regarding temporal and spatial variations of pressure gradients. 4D PC MRI with dynamic, three-directional velocity encoding can be used to derive the spatial and temporal distribution of pressure gradients [2] as well as other hemodynamic parameters (Fig. 1) and good quality angiograms. In recent work, we have shown that these pressure measurements correlate well with invasive catheter based measurements in the carotid, iliac, and renal arteries [2,3]. This study investigates the feasibility of non-invasively quantifying the stenosis grade and pressure differences in congenital heart disease, specifically in patients with aortic coarctation (CoA) and pulmonary artery stenosis (PAS) with a radially undersampled 4D PC-MRI sequence.

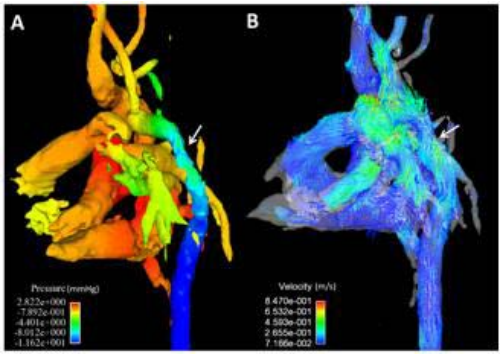

Figure 1: Pressure (A) and velocity maps (B) measured in a nine week old patient patient with an AoC using PC VIPR. The location of the coarctation is indicated by the white arrow.

METHODS: Seven subjects (5M, 2F, mean age 22.7 years) with CoA and six subjects (3M, 3F, mean age 7.2 years) with PAS were enrolled according to an IRB, HIPAA-compliant protocol. Three CoA patients were imaged before repair and four after. Data from transthoracic echocardiography (TTE) was also available in all CoA and four PAS patients to derive estimates of pressure gradients.

MRI: All patients were scanned on clinical 1.5T and 3T systems. Contrast-enhanced (CE)-MRA was performed as part of the routine clinical MRI. Volumetric, time-resolved PC MRI data with 3-directional velocity encoding were acquired with dual-echo PC VIPR [4] and respiratory and retrospective cardiac gating: 1.25mm^3 isotropic spatial resolution, BW=125 kHz, TR 6.2ms, volume: 32cm x 32 cm x 20 cm, 12,000 dual echoes, scan time= ~13 min, V_{enc} = 160 cm/s, reconstructed with 15-20 time frames per R-R interval.

Analysis: The anatomical severity of the ACoarc and PAS was quantified from CE-MR angiograms and PC VIPR complex difference images. In CoA patients, the percent stenosis was defined from double-oblique vessel diameter measurements proximal to and at the area of greatest narrowing. In PAS patients, the percent stenosis was defined from measurements at the widest and narrowest areas in the vessel. Anatomical measurements made from PC VIPR and CE-MRA data sets were compared in all patients. PC VIPR pressure gradients were derived using an iterative method based on the Navier-Stokes equation [5]. PC VIPR 3D visualizations and vessel diameter measurements were accomplished in EnSight (CEI, Apex, NC). CE MRA vessel measurements were done using Vitrea (Vital Image, Minnetonka, MN).

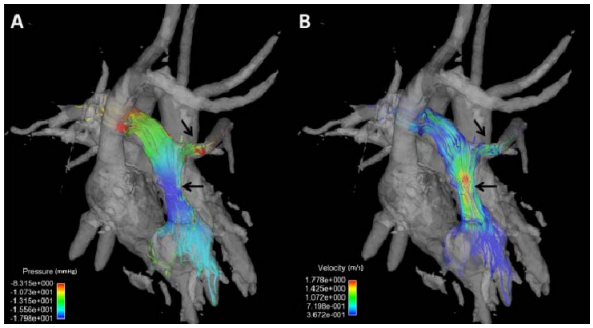

Figure 2: Pressure (A) and velocity (B) maps measured in a 3 year old patient with narrowing in the MPA and LPA. The locations of these stenoses are indicated by the black arrows.

RESULTS: In both sets of patients, excellent correlation was found between CE-MRA and PC VIPR vessel measurements (R^2> 0.88). In patients with pulmonary artery stenosis, PC VIPR underestimated vessel size compared to CE-MRA by about 15%.

The results for pressure measurements made with PC VIPR and Doppler US and stenosis grades measured with CE-MRA are shown in Table 1.

	Stenosis Vessel	Time Between Ultrasound and MRI	PC VIPR Pressure (mmHg)	Ultrasound Pressure (mmHg)	Percent Stenosis (CE-MRA)
Coarctation No Repair	Aorta	7 days	16.3	42**	28.3
	Aorta	5 months	32.3	33.8	10
	Aorta	6 days	16.3	23.4	5.9
Coarctation Post Repair	Aorta	17 months	5.5	0*	23.8
	Aorta	1 month	6.6	0*	20.2
	Aorta	3 months	26.6	35.1	15.3
	Aorta	2 years	-1.6	0*	15.6
PA Stenosis	RPA/LPA	13 days	2.97/1.85	1.69/1.35	6/53.1
	MPA	4 months	57.46	44.35	18.7
	MPA/LPA	1 month	7.27/9.9	21.2/36	33/44.9
	LPA	3 months	13.8	19	16.1

*Measurements not done because aorta measurements were wtihin a normal range
**Ultrasound report stated this measurement likely over-estimates pressure

Table 1: Peak pressure differences measured across vessel narrowing and associated exam dates with PC VIPR and Doppler ultrasound.

CONCLUSIONS: This feasibility study demonstrates the utility of 4D PC VIPR for quantifying vessel anatomy and 4D pressure gradients in both the aorta and pulmonary arteries. In the aorta, PC VIPR pressure measurements were found to be lower than compared with Doppler ultrasound, similar to recent results in the literature [6]. In PAS patients, larger differences were seen between PC VIPR and US. These differences are not entirely understood but could be due to the small vessel sizes imaged in this very young patient cohort. Discrepancies in the pressure measurements could also arise from US errors and insufficiencies with the Bernoulli approximation. In the pulmonary system, PC VIPR vessel diameter measurements were somewhat lower than those measured with CE MRA, possibly due to reduced vessel contrast. In both patient populations, pressure measurements appeared to be fairly well correlated with the percent stenosis measurements. However, in the pulmonary arteries, PC VIPR pressure measurements correlated less well with the degree of stenosis as assessed with anatomical measurements.

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