ASSESSMENT AND QUANTIFICATION OF AORTIC STENOSIS HEMODYNAMICS WITH 4D FLOW: COMPARISON WITH DOPPLER ECHOCARDIOGRAPHY

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Introduction: Phase Contrast MRI is widely used to noninvasively measure blood velocity and flow, in vivo.[1] 4D flow MRI can derive all three velocity components within a 3D imaged volume in a single acquisition resulting in shorter total scan times compared to 3D flow imaging which requires separate 3D scans for each flow direction[2]. The velocity field can then be used to obtain flow pattern, wall shear stress, vascular compliance, blood pressure, and other hemodynamic information. Doppler echocardiography with color flow mapping is currently the predominant approach for quantification of valvular disease. But existence of air, bone, or surgical scar presents impediments to accurate evaluation. Additionally, Doppler flow imaging can only derive components of velocities in the direction of insonification. As with Ultrasound, MRI has the capability to perform both structural and functional imaging; i.e., it can image the anatomy as well as velocity and flow which can be used to derive pressures in the setting of valvular stenosis[3]. Compared to ultrasound however, the direction of velocity can be measured in all 3D directions, and is not limited to being toward or away from the transducer. The advantages of Doppler US are its availability and real-time scan capabilities.

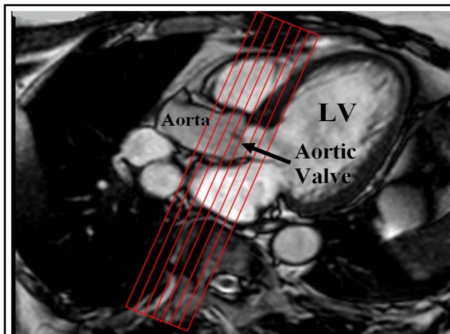

Figure 1: Out Flow track view in a patient with Aortic stenosis. Red lines show location of imaging volume.

Material and methods: The protocol was approved by the local institutional review board and all patients gave informed consent. Following IRB approval, 6 volunteers with a history of mild to moderate aortic stenosis (AS) were recruited and scanned with both Doppler echocardiography and 4D flow MRI, back-to-back and on the same day. 4D MRI data were acquired in two separate acquisition techniques, conventional Cartesian and Ultra short TE (UTE) radial. A stack of stars trajectory was used to collect the 3D volume with the UTE scheme[4] 4D Flow MRI was visualized with GTFlow (GyroTools, Zurich, Switzerland), and hemodynamic parameters were measured. Pressure gradient was calculated by adopting the modified Bernoulli equation ($\Delta P=4V^2$).

MR Imaging: MR imaging was performed on a Philips Achieva 1.5T scanner (Philips Healthcare, Best, NL) using a 5 element phased-array thoracic RF coil. To measure the velocities, a 4D turbo gradient echo sequence was utilized. With a scan time of about 3 minutes a respiratory navigator was required for overcoming motion artifacts through tracking the liver-lung border. The 3D imaging volume was located parallel to Aortic valve and perpendicular to Aorta covering about 2 cm proximal and 3 cm distal to the valve in order to visualize the jet distal to the valve. For the conventional 4D flow acquisitions, scan parameters were as follows: FOV = 230*230 (varies by patient size) volume thickness = 5cm, TR = 6.3–6.9 ms, TE = 3ms, temporal resolution = 50-55 ms, tip angle = 6°, Venc = 400 cm/s for all 3 directions, in plane resolutions = 1*1 mm, slice thickness = 5mm, and number of cardiac phases = 16. For 4D UTE flow, all parameters were identical other than TE = 1.15 and TR = 4.6 ms. In order to reduce scan time, a k-space sampling density of 75% was adopted. Additionally, to correct for phase errors and RF inhomogeneity, a static phantom was scanned and the result was used to perform phase correction on the 4D UTE data.

Results: Table 1 compares aortic valve peak velocity, time of peak velocity, ejection time, and peak systolic pressure gradient in 6 patients. Figure 2 demonstrates visualizations of different velocity components by 4D flow MRI.

Discussion and Conclusions: In this abstract, we have reported initial results of using 4D flow in assessment of AS in patients with mild to moderately severity. Results show good agreement between both 4D flow and Doppler ultrasound methods. However in 4D flow, low temporal resolution may lead to underestimation of peak velocities. Additional issues include total scan times, longer than 10 minutes due to reduced scan efficiency resulting from use of a respiratory navigator. As may be seen from the table, the peak velocities in the set of volunteers studied to date is not very high. Nevertheless, 4D UTE flow appears to have more significant correlation with US in patients with peak gradient > 40 mm Hg where more significant spin dephasing may be present. .

References: **1.** N. J. Pelc, et al., *Magn Reson Q,* vol. 10, pp. 125-47, Sep 1994. **2.** M. Markl, et al., *J Magn Reson Imaging,* vol. 36, pp. 1015-36, Nov 2012. **3.** S. D. Caruthers, et al., Circulation, vol. 108, pp. 2236-2243, Nov 2003. **4.** M. Kadbi, et al., Proc. *ISMRM* 21: 67, Apr 2013.

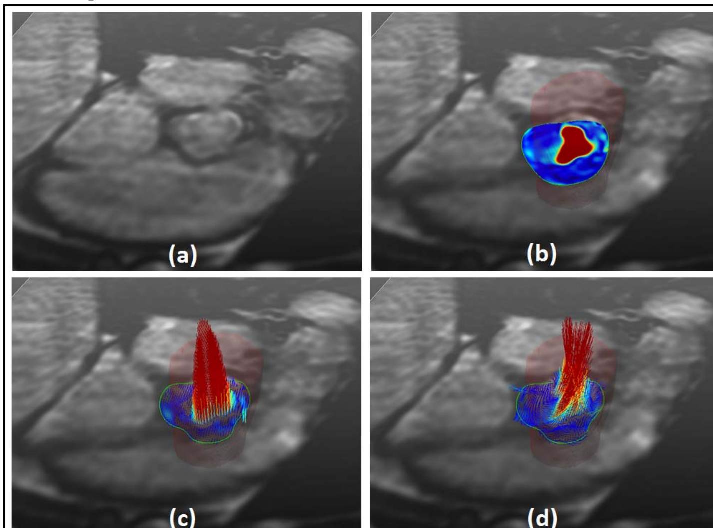

Figure 2: Visualizing the aortic valve and flow. (a) Middle slice in the imaging volume. (b) Color overlay of velocity on the magnitude image. (c) Through plane, and (d) 3D velocity field on magnitude image.

Patient number	1			2			3			4			5			6		
Modality	US	4DC MR	4DUTE MR	US	4DC MR	4DUTE MR	US	4DC MR	4DUTE MR	US	4DC MR	4DUTE MR	US	4DC MR	4DUTE MR	US	4DC MR	4DUTE MR
AVpeak velocity (m/s)	2.77	2.70	2.90	3.59	3.10	3.25	2.65	2.70	2.40	2.55	2.80	2.70	2.46	2.68	2.72	3.28	2.89	3.21
Peak time (ms)	60	41	82	85	110	102	135	150	150	77	60	110	100	110	110	100	95	110
AV Eject time (ms)	260	230	240	350	350	360	340	400	380	310	320	320	380	380	370	340	380	380
AV peak gradient (mmHg)	31	29	34	52	38	42	28	29	23	26	31	29	24	29	30	43	33	41

Table 1: Comparison of derived hemodynamic parameters between Doppler US (US), Conventional 4D flow (4DC MR) and 4D UTE flow (4DUTE MR) through the aortic valve (AV). Note that in determining the peak and ejection times from 4DC MR, temporal interpolation of the flow waveform was used.