Reproducibility of Phase-Contrast MRI in the Coronary Artery: Towards Noninvasive Pressure Gradient Measurement and Quantification of Fractional Flow Reserve

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TARGET AUDIENCE: For clinicians and scientists who are interested in noninvasive evaluation of the functional significance of coronary artery stenotic lesions before percutaneous coronary intervention (PCI) treatments.

PURPOSE: Fractional Flow Reserve (FFR) is an invasive diagnostic tool used to determine the functional severity of an intermediate coronary stenosis by measuring the pressure drop across the lesion via coronary catheterization[1]. Due to potential risks, side effects, and radiation exposure associated with invasive cardiac catheterization, the feasibility of noninvasive pressure gradient (ΔP) measurement using phase-contrast (PC)-MRI is explored in this study. Noninvasive ΔP measurements using PC-MRI has been attempted in the aorta, carotid, and renal arteries[2-4]. The purpose of this study is to assess the reproducibility of PC-MRI and noninvasive ΔP calculations in the coronary artery to establish the robustness of noninvasive FFR measurement using MRI.

METHODS: 2D PC-MRI was used to acquire two-cardiac-phase data at mid-diastole and end-expiration via ECG-triggering and navigator-gating, respectively, on 3T MAGNETOM Verio (Siemens). K-space phase-encoding ordering is designed to allow offline view sharing[5], which is applied in cases where the data acquisition window exceeds the quiescent period (~100ms). The sequence measures the velocity fields in three orthogonal directions (v_x, v_y, v_z) of a single cross-section per acquisition and 4-5 consecutive slices were obtained in the proximal LAD. Reproducibility was assessed with two repeat scans on 8 healthy subjects. VENC was 30-45 cm/s for each flow encoding direction, which was determined from a VENC scout scan. The Navier-Stokes (NS) equations were used to derive ΔP from the velocity vector field data[6]. In addition, a flow phantom (gadolinium-doped water flow at 300 mL/min in a silicone tubing of 4.8 mm ID) with a stenosis of 40% narrowing over a length of 5 mm (VENC=130z30xy cm/s) was likewise tested for reproducibility. Imaging parameters were: in-plane resolution = 0.58-0.67mm, slice thickness = 3.2 mm, flip angle = 15°, temporal resolution = 65-71 ms/phase with the first phase strictly coinciding with the quiescent period, scan time = 1-3 min per slice. Maximum and averaged velocities at each slice in all three orthogonal directions and the ΔP between each adjacent slices obtained from both scans were statistically compared via intra-class correlation (ICC).

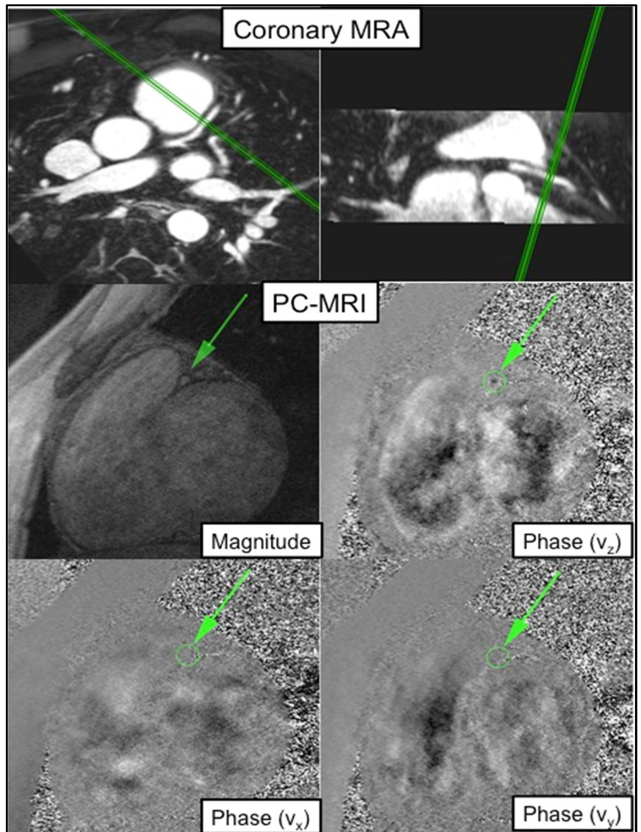

Figure 1. Coronary MRA and PC-MRI (magnitude, phase images of all 3 orthogonal directions) example images for one healthy subject.

RESULTS: Volunteer studies: averaged maximum through-plane velocity over all healthy volunteers was 17.8±4.6 cm/s. A total of 37 cross-sectional slices for each encoding direction were acquired from all subjects. For velocity measurements, excellent correlations were seen in the through-plane maximum velocities (v_z), with ICCs of 0.94/0.96 and slightly lower in v_x and v_y with ICCs of 0.77/0.88 and 0.86/0.70 as shown in Table 1. for cardiac phases 1 and 2, respectively. Similar results were also observed in the averaged velocities for the three encoding directions. For ΔPs, ICC was 0.44 with an average of 0.3670±0.42 mmHg among all subjects. Phantom studies: stenosis with 40% narrowing showed excellent correlations in all velocity directions and ΔPs (table 1).

DISCUSSION / CONCLUSION: Our preliminary results suggest that the noninvasive quantification of flow velocities and ΔPs are reproducible in the coronary arteries, demonstrating the robustness and feasibility of the 2D PC-MRI technique. Although high correlation was observed in the velocity values, moderate correlation in the ΔP values was observed partially due to low ΔP in normal coronary arteries. It also suggests that further technical improvements in terms of spatial, temporal resolutions and reduction of noise are needed to further improve reproducibility. Patient studies are underway to determine the ΔP and FFR thresholds between healthy and patient populations.

Table 1. Intra-Class Correlation (ICC) between two scans.

	Velocity Encoding	Averaged Velocity		Maximum Velocity		Pressure Gradient (ΔP)
		Phase 1	Phase 2	Phase 1	Phase 2	
Volunteers N = 8	Z	0.948	0.926	0.936	0.958	r = 0.442 p<0.05
	X	0.535	0.570	0.767	0.880	
	Y	0.720	0.722	0.858	0.696	
Phantom	Z	0.992		0.988		r = 0.768 p<0.05
	X	0.918		0.934		
	Y	0.979		0.969		

REFERENCES: [1] Pijls et al. NEJM.1996;334(26):1703-8. [2]Bock et al. MRM. 2011;66:1079-88. [3]Lum et al. Radiology. 2007;245(3):751-60. [4]Bley et al. Radiology. 2011;261(1):266-73. [5]Deng et al. ISMRM 2014; [6]Yang et al. MRM. 1996;36:520-6.