Pressure Gradient Measurement in the Coronary Artery Using View-Shared (VS) 4D PC-MRI: Towards Noninvasive Quantification of Fractional Flow Reserve

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TARGET AUDIENCE: For clinicians in diagnosing the functional significance of coronary stenosis before percutaneous coronary intervention (PCI) treatments.

INTRODUCTION: Fractional flow reserve (FFR) is the gold standard to evaluate the functional significance of an intermediate coronary stenosis through measurement of pressure drop across stenosis[1]. However, an inherent drawback is the ionizing radiation, rendering this method an invasive procedure. 4D Phase-contrast (PC)-MRI has been exploited to measure the pressure gradient in the cardiac chambers[2], aorta[3], and renal[4] arteries. This study aims to investigate the feasibility of quantifying the pressure gradient at a proximal segment of the coronary arteries by utilizing a view-sharing (VS) 4D PC-MRI technique, which in turn will allow for the derivation of FFR associated with stenosis.

METHODS: In our previous work, we have validated the feasibility of 4D PC-MRI to detect changes in pressure difference (ΔP) at various diameters in a phantom study, illustrated in ***Fig.1***[5]. To translate this technique to the coronary artery, cardiac and respiratory motions are the two major concerns. To minimize these motion-induced errors, the acquisition window is limited to the mid-diastole (quiescent) and end-expiration phase by using ECG-triggering and navigator-gating. The sequence measures the 3D velocity vector fields through a cross-sectional 3D acquisition with at least two cardiac phases, in conjunction with the Navier-Stokes (NS) equations[2] to calculate the pressure gradient within the vessel segment of interest. Thus, the total acquisition time per cardiac cycle can lie outside of the quiescent phase, causing inaccurate velocity measurements due to motion. To ameliorate these errors, a view sharing (VS) technique was implemented to further restrict the acquisition time within the quiescent phase. As illustrated in ***Fig.2***, instead of an "$A_1B_1A_2B_2$" configuration in k-space, B_1 in the peripheral k-space is shared between two phases where B_2 is neglected. The VS4D PC-MRI technique was first tested in the femoral arteries (static and small caliber) to assess its accuracy in velocity quantification. Nine phases were collected, where only two phases (phase 4&5), with velocities closest to peak coronary flow, were analyzed. Imaging parameters for the femoral arteries consisted of: cross-sectional 2D acquisition with three velocity encodings (VENC=80z, 40x, 40y cm/s), FA=15°, cardiac phase=9 (72.24ms/phase), spatial resolution=1.2x1.2mm^2. VS4D PC-MRI was then tested in the coronaries of 3 volunteers on the proximal left anterior descending (LAD) or left main (LM). Imaging parameters for coronary studies were: cross-sectional 3D acquisition (VENC=60z, 35x, 35y cm/s), FA=15°, cardiac phase=2 (71.44ms/phase) coinciding with the quiescent period, spatial resolution = 0.72x0.72x2.0mm^3 and TA=10-18mins. All scans were performed on a 3T system (MAGNETOM Verio, Siemens).

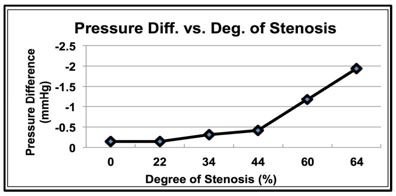

Fig.1: Flow phantom (Gd-doped water, Q=250mL/min, D_{max}=4.8mm) with varying diameters, simulating variation in degrees of stenosis[5].

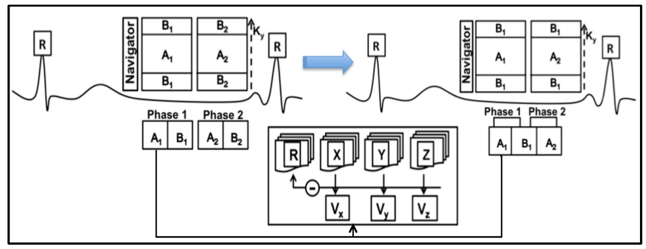

Fig.2: Conventional 4D PC-MR (left) to View Sharing (VS) 4D PC-MR.

RESULTS: *Femoral artery study*: A percent error of 5.18% was seen for velocity measurements before (solid blue) and after (dashed red) VS at phases 4 and 5 (***Fig.3***). It is important to note that all parameters were kept similar to coronary acquisition to maintain consistent temporal resolution and only velocity measurements in the z-direction is analyzed and shown. *Coronary artery study*: The central 6 contiguous slices were analyzed per volunteer. Data acquisition is confined where phase 1 starts at the beginning of the quiescent period, making phase 2 more prone to motion-induced errors depending on the total length of the quiescent period, which may vary between volunteers. ***Fig.4*** compares the flow compensated (reference) images of the second cardiac phase between conventional and VS 4D PC-MRI technique for one volunteer. The same data acquisitions were used between the two techniques. We can see a slight improvement of image quality at the coronary in the flow compensated images when using VS; the reduction in image quality using conventional 4D PC-MRI images might be due to the short quiescent phase (approx.100ms) of the volunteer, which lead phase 2 to partially lie outside of the quiescent phase, causing motion-induced errors; this was observed in 2/3 of the volunteers. ΔP values between slices 2 and 5 for the three volunteers are 0.0573, -0.0045, 0.0204 mmHg and 0.1723, -0.0073, 0.0293 mmHg for conventional and VS 4D PC-MRI, respectively.

CONCLUSION: A VS4D PC-MRI technique was developed to accommodate coronary flow velocity quantification. The test on the femoral artery demonstrated that the technique could yield accurate velocity measurements. Translating the technique to the coronary arteries, we have shown that narrowing the acquisition window within the quiescent phase can potentially reduce cardiac and respiratory motion-induced errors. Furthermore, healthy volunteers showed a near zero pressure gradient across the coronary arteries, as expected. Future studies will inspect the pressure gradient in stenosed coronary arteries of animals and patients, where the FFR index can be calculated for clinical diagnosis. Moreover, technical improvements in temporal and spatial resolutions are warranted.

REFERENCES: [1] Tonino, et al. *NEJM* 2009; 360: 213-24. [2] Thompson, et al. *MRM* 2003; 49.6:1056-1066. [3] Tyszka, et al. *JMRI* 2000; 12.2: 321-329. [4] Bley, et al. *Radiology* 2011; 261.1: 266-273. [5] Fan, et al. *MRA* 25th. (2013): 86.

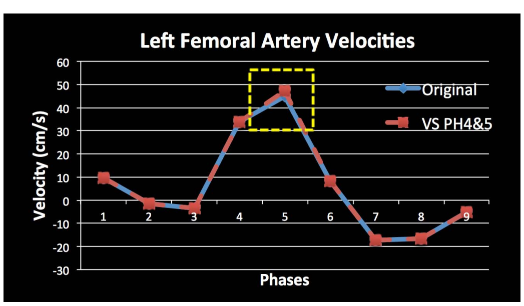

Fig.3: Velocity measurement of the left femoral artery before (solid blue) and after (dashed red) view sharing between phases 4 and 5.

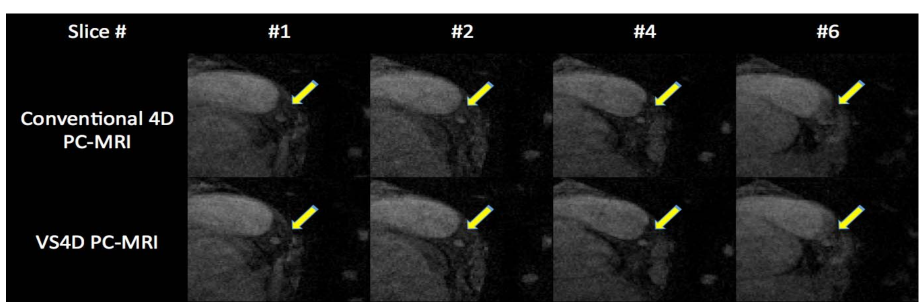

Fig.4: Conventional versus view sharing 4D PC-MRI during phase 2. Slices 1, 2, 4, and 6 of the flow compensated (reference) images are shown. Slices 1,2 and 6 clearly illustrate an improvement in image quality at the coronaries using the VS4D PC-MRI compared to conventional.