Phase Contrast MRI with Flow Compensation View Sharing (FCVS)

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Introduction: Phase-contrast MRI (PC-MRI) is a well-established technique for quantification of blood velocity and volume. PC-MRI for cardiovascular applications requires a cardiac phase-resolved acquisition with adequate spatial and temporal resolution, which often results in relatively long acquisition times. In a typical PC-MRI exam, Flow Compensated (FC) and Flow Encoded (FE) data are acquired in an interleaved fashion as shown in Fig. 1a. However, in certain PC-MRI applications, such as the assessment of volumetric blood flow in the Common Carotid Arteries (CCA), FC images are not expected to change significantly over time due to limited physiological motion and background phase changes [1]. Hence, we propose a technique to accelerate PC-MRI that uses sliding window view sharing [2] of the FC data (FCVS) to improve both the temporal resolution and temporal footprint. Prospective *in vivo* studies were performed to evaluate the accuracy of peak velocity and volumetric flow measurements using the proposed FCVS technique.

Methods: In our approach, the FC data is sampled much less frequently than the FE data. In the example shown in Fig. 1b, a FC k-space line is acquired after every five FE lines and hence the FC data is under-sampled by a rate R_{FC}=6. To compensate for the under-sampled FC data, a sliding window view-sharing pattern (with 3 frames before and 2 frames after) is used to synthesize a composite FC frame for each corresponding FE frame. Due to the need for FC data acquisition, the FE data is slightly under-sampled at (R_{FC}-1)/R_{FC}=1.2 and this is overcome by using standard TGRAPPA [3]. In our proposed method, a longer temporal footprint is used to reconstruct FC images due to view sharing. However, this enables a shorter temporal footprint for each FE phase, which contains the desired flow information.

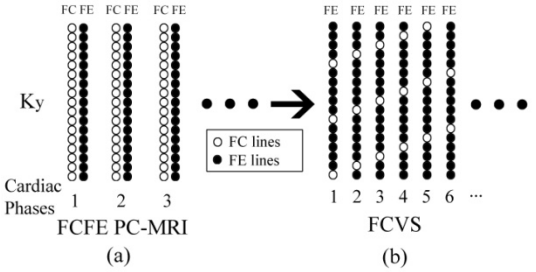

Fig. 1. The data acquisition scheme of (a) the standard FCFE PC-MRI and (b) the proposed FCVS approach.

Six volunteers (N=6) were recruited for a prospective *in vivo* study and scanned on 1.5T scanner (Siemens, Avanto, Erlangen, Germany) with six-channel coils (a 16-element head-neck coil combination with six active coil channels), using both standard FCFE PC-MRI sequence and the proposed FCVS sequence. Both sequences were implemented with through-plane velocity encoding (VENC=110cm/s), 30° flip angle, 260 Hz/Pixel readout bandwidth, TE_{min}=5.22-6.22 ms, TR_{min}=8.5-9.7 ms, 256x256 acquired matrix, 170x170 - 200x200 mm^2 FOV, and 5 mm slice thickness. Four data sets were acquired in each volunteer: 1) FCVS with 4 lines per k-space segment; 2) Standard FCFE with 2 lines per k-space segment; 3) FCVS with 2 lines per k-space segment; and 4) Standard FCFE with 1 line per k-space segment. ROIs within the CCAs were subsequently chosen for each subject to measure the change in the FC data phase over the cardiac cycle on a pixel-by-pixel basis in order to test our hypothesis that FC data phase does not change significantly over time in the CCA. ROIs for the left and right CCA were drawn for each volunteer and used to compare peak velocity and total volumetric flow between two sequential acquisitions. All scans were acquired during free breathing with retrospective ECG gating.

Results: The FC signal phase for a randomly selected pixel within the ROI of a volunteer's CCA was stable over the cardiac cycle (Fig. 2, mean/±SD: -2.51/±0.065 rad). An example of a healthy volunteer's peak velocity measurements are shown in Fig. 3. The 34ms-temporal-resolution (2 lines per k-space segment) FCFE scan failed to capture the maximum peak velocity at around 90ms into the cardiac cycle. The 17ms-temporal-resolution (2 lines per k-space segment) FCVS scan provided similar peak velocity values (FCFE: 88.6cm/s vs FCVS: 91.6cm/s) as the 17ms-temporal-resolution (1 line per k-space segment) FCFE scan albeit at almost half of the total acquisition time (FCVS: 106s vs FCFE: 214s). A Bland-Altman plot of total 24 volumetric flow values (left and right CCA in the six volunteers with 17ms and 34ms temporal resolutions) measured by FCVS and standard FCFE PC-MRI are shown in Fig. 4. The bias was 0.05 mL and the 95% confidence interval was [-0.25, 0.35] mL. The bias error in volumetric flow quantification was ≤1.3%.

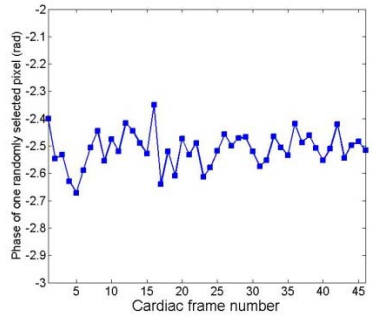

Fig. 2. The FC signal phase as a function of the cardiac frames for a randomly selected pixel within the CCA.

Conclusion: FCVS can accelerate PC-MRI acquisitions while maintaining flow and velocity measurement accuracy for applications where there is no significant temporal variation in the phase of the FC data.

References: 1. Offerman E., et. al. ISMRM 20. 2012. p4434 2. Lin H., et. al. ISMRM 15. 2007. p249 3. Breuer, F., et. al. MRM, 2005, 53: 981-985

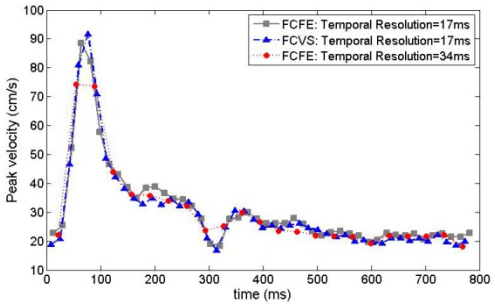

Fig. 3. Peak velocity waveforms from the standard FCFE PC-MRI (gray curve) with 17ms-temporal-resolution, FCVS (blue curve) with 17ms-temporal-resolution, standard FCFE PC-MRI (red curve) with 34ms-temporal-resolution. The FCVS results are highly correlated with the measurements from standard FCFE PC-MRI at the same temporal resolution but 2x faster. The standard FCFE PC-MRI fails to capture the peak velocity at approximately 90 ms or the transient dip at 320 ms when its temporal resolution is halved to match the total acquisition time of FCVS.

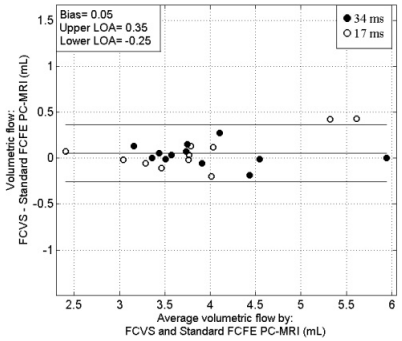

Fig. 4. The Bland-Altman plot of total volumetric flow measurements between standard FCFE PC-MRI and FCVS with two different temporal resolutions (17ms and 34ms) in the left and right CCA in six volunteers for a total 24 flow measurement. LOA: limits of agreement, interval between upper an lower LOA is also known as 95%-CIs