Real Time Phase Contrast MRI With Radial K-space Sampling With Golden Angle Ratio and Block Wise Low Rank Constraint

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Purpose: Phase contrast (PC) MRI is a clinically useful modality for assessment of hemodynamics associated with pathophysiology. The main hurdle to widespread use of PC is its low data acquisition efficiency, especially for cardiovascular applications. We sought perform numerical simulation experiments to identify the maximal acceleration rate for real-time PC MRI, using compressed sensing [1] with block-wise low rank (BWLR) constraint [2-3] as the vehicle to drive data acceleration. The long-term of this project is to develop real-time PC MRI [4] for clinical application, including pediatric PC MRI.

Methods: We acquired fully sampled PC MRI acquisitions in 5 patients at 3T (Siemens, Verio), for both mitral and aortic valve planes. The relevant imaging parameters include: spatial resolution = 3 x 3 mm, slice thickness = 8 mm, TE/TR = 1/3.3ms, flip angle = 20^0, venc between [150,250] m/s (through-plane). All simulation was conducted using MATLAB (Mathworks, USA). We then retrospectively undersampled the k-space data with radial k-space sampling with gold angle ratio [5], with number of rays ranging from 4, 6, and 8, which correspond to temporal resolution of 26.4, 39.6, and 52.8 ms, respectively (i.e., real-time PC MRI). The undersampled data were reconstruction using hybrid BWLR reconstruction, where BWLR was the primary constraint (normalized regularization weight = 0.005) and temporal total variation is the secondary constraint (normalized regularization weight =0.00025). Regularization weights were tuned based on visual inspection of flow, where the objective is to achieve a good balance between data consistency and artifact/blurring suppression, as previously described [6]. Region of interest (ROI) was drawn manually around the mitral and aortic valves. The same ROIs were used for fully sampled and retrospectively undersampled data. For image analysis, the agreement in resulting peak velocities was analyzed using the Bland-Altman analysis.

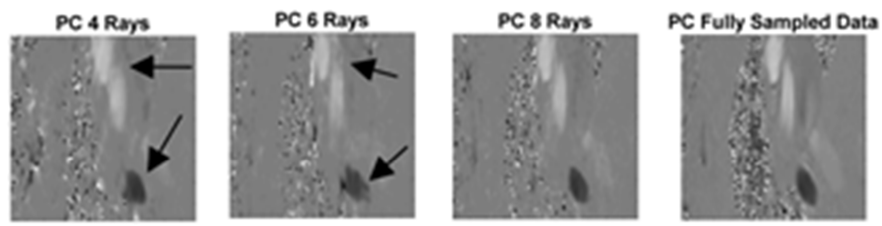

Fig. 1. PC images in the mitral valve plane reconstructed using different number of radial rays. Arrows point to areas where there is significant loss of the phase spatial resolution. Significant phase information blurring is observed for reconstructions using 4 and 6 radial rays.

Table 1. Bland-Altman statistics on peak velocity curves. Fully sampled data (control) versus undersampled.

Number of Rays	Mean Diff	Upper Limit	Lower Limit
4	-3.5	26.3	-33.3
6	-4.9	21.3	-31.2
8	0.4	12.9	-12.1

Results: Figure 1 shows representative PC images of a patient, comparing fully sampled and retrospectively undersampled data with 4, 6, and 8 k-space rays. Using 4 and 6 rays produced visually apparent phase errors compared to the fully sampled results. Reconstructions with rays 8 rays suppressed phase errors as shown. According to the Bland-Altman analysis, the mean difference, as well as the confidence intervals, in peak velocity decreases from 4 rays to 8 rays (Table 1; 5 patients, 10 cardiac planes).

Discussion: This numerical simulation shows that real-time PC MRI is feasible with radial k-space undersampling with golden angle ratio (8 rays, temporal resolution = 52.8 ms) and hybrid BWLR constrained reconstruction. A future study is warranted to implement the pulse sequence with radial k-space undersampling with golden angle ratio and to test its performance in patients with disease.

References: **[1]** Lustig, M, et al. MRM 2007;58:1182-1195. **[2]** Chen X, et al. MRM. 2014 Oct;72(4):1028-38. **[3]** Trzasko J, 2011 ISMRM Proceedings p. 4371. **[4]** Joseph AA et al. JMRI 2014; 40:206-213. **[5]** Winkelmann S., et al. IEEE Trans Med Imaging. 2007 Jan;26(1):68-76. **[6]** Feng L, et al. MRM. 2013 Jul; 70(1):64-74.

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