# Efficient Velocity Mapping by Accelerated Acquisition of Phase Reference Data

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**Introduction:** Velocity measurement based on phase-contrast magnetic resonance imaging (PC-MRI) [1] is firmly established as a valuable technique to assess hemodynamics in a variety of clinical applications [2]. The conventional phase-velocity measurement requires the acquisition of two separate and complete k-space datasets with different flow sensitivity. Two methods are commonly used; one acquiring datasets with equal and opposite velocity sensitivity, and the other acquiring velocity-encoded and velocity-compensated phase reference data. Complex subtraction of the two datasets is applied to compensate for residual non-zero phase due to effects other than velocity. Both approaches double the amount of data required relative to other MRI sequences. Thus, velocity mapping requires extended scan times to achieve reasonable spatial and temporal resolution, reducing the performance of breath-hold and real-time flow quantification techniques, and making three-dimensional acquisition impractical. We hypothesize that the residual phase effects are slowly varying in both space and time, and thus the spatial and/or temporal resolution of the phase reference data can be significantly reduced without affecting the accuracy of the resultant velocity map. The current work aims to test this hypothesis by reconstructing phase-velocity images with reduced spatial resolution and temporal view-sharing applied to the phase-reference data to improve image acquisition efficiency.

**Methods:** In this study, a conventional spoiled gradient echo PC-MRI sequence was implemented on a 1.5 T Avanto system (Siemens Medical Solutions, Erlangen, Germany) with 12-channel surface coil array and electrocardiography signal gating. Flow measurement with through-plane velocity-encoding was performed in a region of interest including both tricuspid inflow and pulmonary outflow in three normal, healthy volunteers. Image acquisition parameters were as follow: TE/TR = 4.3/7.7 ms, flip angle = 15°, FOV = 340 mm × 253 mm, acquisition matrix = 192 × 94, venc = 120 cm/s. We evaluated two approaches for phase-reference data reduction in PC-MRI. First, we examined the use of a reduced spatial resolution phase reference, utilizing only the lower spatial-frequency portion (50% or 33% of full k-space) of the phase-reference data. A smooth roll-off of the remaining k-space data was used to suppress Gibbs ringing artifact [3]. To reduce the phase reference temporal resolution, full k-space phase-reference data was generated by sharing data with earlier and later cardiac phases. In the case of acceleration rate equal to 3, the phase-reference k-space was filled using data from current (1/3), previous (1/3) and next (1/3) cardiac phases. Temporal view-sharing by factors of 3 and 7 were tested. In all reconstructions, full temporal and spatial resolution of the velocity-encoded data were maintained; these acceleration methods were only applied to the phase reference data.

**Results:** Illustrative magnitude and phase PC-MRI images with conventional data acquisition and full phase reference are shown in Fig. 1a and b with the ROI shown in red and green, respectively. Fig. 1c and d demonstrate similar phase information including 50% (c) and 33% (d) of central phase-reference k-space lines for phase reconstruction. Figure 2a shows separately the flow velocity during the cardiac cycle in a single volunteer measured with 100% (diamonds ♦), 50% (squares ■) and 33% (triangles ▲) data. Note the excellent correspondence between the three velocity curves despite the significantly reduced phase reference spatial resolution. The Root-Mean-Square error (RMS) comparison (Table 1) shows good agreement between different spatial resolution conditions compared to conventional PC-MRI acquisition.

In Fig. 2e and f, example phase-velocity images at temporal view-sharing acceleration factors of 3 (e) and 7 (f) are shown. Flow velocity curves comparing full temporal resolution (diamonds ♦), sharing factor of 3 (squares ■) and factor of 7 (triangles ▲) are shown in Figure 2b. Phase information appears to be equivalent despite significant reduction in phase reference temporal resolution. Note that the curves in Figure 2a and b are significantly overlapping except for the first velocity measurement point that was reconstructed by sharing phase-reference data from the later cardiac phases. To investigate the accuracy of velocity measurements, the RMS error was calculated between the velocity curves obtained using each of the acceleration techniques and the conventional technique, for each of the three volunteers. Insignificant average RMS errors (0.059 cm/sec for 50% spatial-resolution reduction, 0.144 cm/sec for 33% spatial-resolution reduction, 1.047 cm/sec for temporal view-sharing acceleration factor of 3 and 1.198 cm/sec for temporal view-sharing acceleration factor of 7) were obtained in all cases.

**Discussion:** In this study, a new method to improve the efficiency of PC-MRI by reducing the spatial or temporal resolution of the phase reference data is presented. The accuracy of two approaches were compared to the standard, full phase-reference method for cardiac valve velocity measurement in healthy volunteers. This study suggests that appropriate phase-reference data reduction can accelerate acquisition time for velocity measurement without any significant loss of velocity measurement accuracy. This new method is compatible with the use of parallel acquisition techniques, which could further increase scan efficiency. In conclusion, appropriate spatial resolution reduction and temporal view-sharing for phase-reference data allows us to maintain quantitative flow measurement accuracy while significantly reducing data acquisition requirements. This method can be used to improve the spatial and temporal resolution of breath-hold and real-time PC-MRI techniques, and reduce the lengthy scan times of three-dimensional data acquisitions.

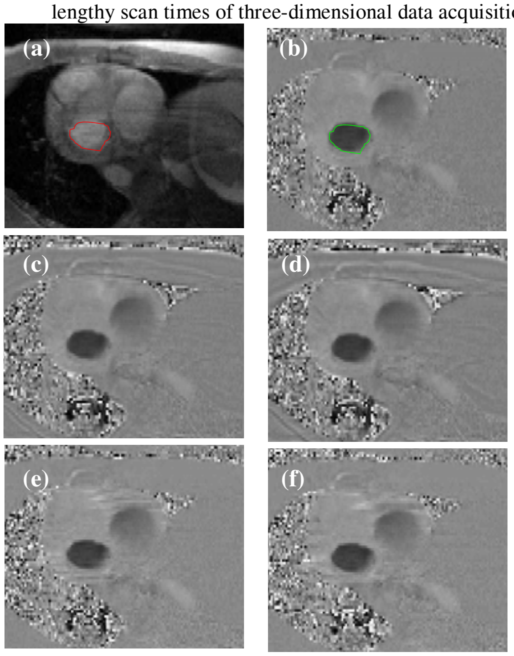


Figure 1. Single frames of MR images reconstructed showing magnitude image (a) with full phase-reference k-space data, and phase-velocity images with (b) full phase-reference k-space data, (c) 50% phase-reference k-space data, (d) 33% phase-reference k-space data, (e) temporal view-sharing acceleration factor of 3, and (f) temporal view-sharing acceleration factor of 7.

**References:** [1] Bryant, DJ. et al, J Comput Assist Tomogr 1984; 8:588-593
[2] Powell, AJ. et al., Pediatr Cardiol. 2000; 21:47-58
[3] Szarf, G. et al, J of Magn Reson. Imaging, 2006; 42-49

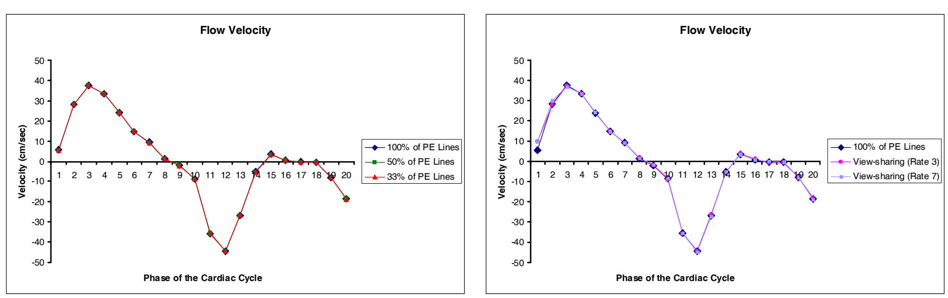


Figure 2. Comparison of flow velocity versus phase of the cardiac cycle for the three normal volunteers obtained from (a) spatial resolution reduction of phase-reference, and (b) temporal view-sharing methods of phase-reference data acceleration.

| Subject | RMS (100% vs. 50%) | RMS (100% vs. 33%) | RMS (View-sharing Rate 3) | RMS (View-sharing Rate 7) |
|---|---|---|---|---|
| A | 0.051876 cm/sec | 0.142621 cm/sec | 0.912569 cm/sec | 1.019946 cm/sec |
| B | 0.078892 cm/sec | 0.176379 cm/sec | 1.343498 cm/sec | 1.559643 cm/sec |
| C | 0.046863 cm/sec | 0.115117 cm/sec | 0.884723 cm/sec | 1.013574 cm/sec |

Table 1 Root-Mean-Square error (RMS) of the PC-MRI measurements with respect to the conventional reference-phase flow quantification.