Validation of an Improved Single Shot Flow Mapping Method

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Introduction

The most popular method of flow measurement by MRI is the phase contrast (PC) method [1], which requires multiple image acquisitions. Rapid single-shot flow mapping could be very valuable for monitoring flow in dynamic flow situations (e.g., pulsatile vascular flow, cardiac valvular regurgitation). As a variant of SS-PARSE (Single Shot Parameter Assessment by Retrieval from Signal Encoding) [2], V-SS-PARSE, a single shot imaging method has been developed to realize fast and straightforward flow quantification by solving an inverse problem [3]. Magnitude, phase and velocity information can be retrieved without any extra reference image acquisitions, as demonstrated by simulation and the preliminary phantom studies. A more robust signal model is described here that includes the local magnetization and its evolution during the signal, giving a more precise representation of the sampled signal. Therefore, relaxation rate and frequency maps are retrieved from this brief snapshot signal in addition to the magnitude and velocity maps. More importantly, velocity information could be reliably determined with the presence of the stationary background. Validation of this flow mapping technique was accomplished using the conventional phase contrast approach as a reference.

Method

With the bipolar velocity encoding gradient incorporated in the gradient waveform to provide velocity sensitive phase shifts, data is sampled in the (k, k_v, t) space and k_v is the gradient first moment. A rosette trajectory was chosen for image acquisition due to its excellent frequency selectivity and capability to perform data sampling within a short time period. All the unknown local parameters (static image signal M_{xy} that contains magnitude and background phase information, velocity v, relaxation rate R_2^*, and frequency ω) are assigned initial estimates of 0. Through the signal model:

$$S_e = \iint M_{xy} \exp(-i2\pi(k_v \cdot v)) \exp(-(R_2^*(x,y) + i\omega(x,y))t) \exp(-i2\pi(k_x \cdot x + k_y \cdot y))dxdy,$$

an estimated signal S_e is generated for the current parameter values, and compared with the measured signal S_0 by computing a sum square error cost. Using an iterative conjugate gradient search, these parameter estimates are updated and the estimated signal is recalculated to minimize the cost. When the fractional decrease of the cost from one iteration to the next is less than the threshold, the final estimates of M_{xy}, v, R_2^* and ω are obtained.

A phantom study was performed for through-plane flow measurement on a Varian 4.7-T vertical scanner. Velocity was calibrated with the "bucket-and-stopwatch" method and was measured with a PC technique to provide a reference. Laminar flow with mean velocity ranging from -25 to 25 cm/s, corresponding to a [-50, 50] cm/s peak velocity range, was measured. For both imaging methods, slice thickness was 2 mm with a 64×64 image resolution and a 12.8 cm field of view. Image acquisition time was 70 ms for V-SS-PARSE. The PC method employed here was a normal gradient echo sequence with TR/TE = 20/6.6 ms, leading to a 1280 ms data acquisition time for a single image and 2560 ms for two images for velocity computation. A single tube containing water ran down through an agar filled bottle, then back up, producing in the image plane a cross-section with downward (positive) flow and one with upward (negative) flow surrounded by stationary bottle.

Results

Retrieved magnitude and velocity maps show results comparable to those obtained from the PC method, even with the brief 70 ms acquisition in contrast to the 2560 ms used in PC (Fig.1). The bottle appears with lower signal in the magnitude map from PC because the agar in the bottle has shorter T2* than the water in the tube; in V-SS-PARSE, the decay factor is modeled separately from M_{xy}, so that the agar in the bottle and water in the tubes appear with similar intensity in the M_{xy} map. 3 pixels are picked out from the stationary part, positive flow and negative separately. The convergences of the magnitude and velocity estimates are shown throughout the iterations (Fig.1c and f). Despite the minor glitches observed in the computed velocity map within the bottle, the velocity measurements from V-SS-PARSE were consistent with the results from PC, yielding a correlation of r > 0.99. Both of them agreed with the actual flow values (Fig. 2). The relaxation rate and frequency maps were retrieved as well from this single shot image, providing additional information about the imaging subject.

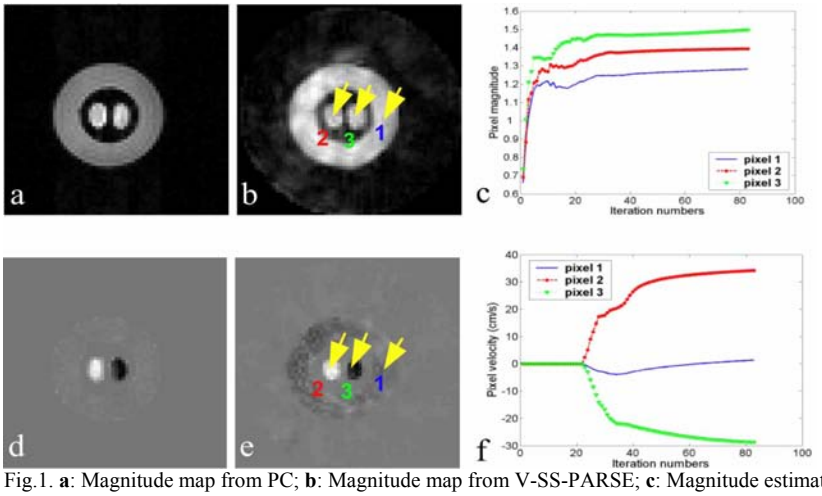

Fig.1. **a**: Magnitude map from PC; **b**: Magnitude map from V-SS-PARSE; **c**: Magnitude estimates from V-SS-PARSE evolve with the iterations; **d**: Velocity map from PC; **e**: Velocity map from V-SS-PARSE; **f**: Velocity estimates from V-SS-PARSE evolve with the iterations.

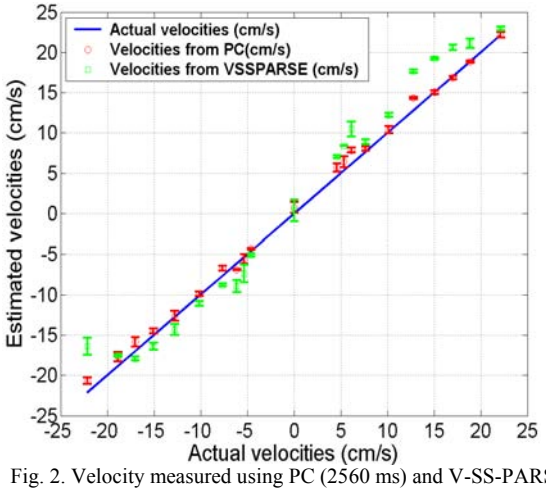

Fig. 2. Velocity measured using PC (2560 ms) and V-SS-PARSE (70 ms) with varied constant velocities calibrated by the "bucket-and-stopwatch" technique.

Discussion

A more robust model for flow mapping with single-shot image acquisition was developed and validated with phantom experiments. The retrieved velocity estimates are consistent with estimates from the conventional PC method while saving the necessity of acquiring an extra phase reference image. It is expected that *in vivo* studies will be carried out in the near future, and the technique may ultimately be applied to rapid flow quantification in clinical cardiovascular applications.

Acknowledgements

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References

1. Moran PR. Magn Reson Med 1982; 1:197-203.
2. Twieg DB. Magn Reson Med 2003;50:1043-1052.
3. Zuo J, Walsh EG, Deutsch G, Twieg DB. Magn Reson Med, in press.