Accelerated spiral Fourier velocity encoded MRI using SPIRiT parallel imaging

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Introduction: Fourier velocity encoding (FVE) [1] is useful in the assessment of valvular disease [2], as it eliminates partial volume effects that may cause loss of diagnostic information in phase-contrast imaging [3]. FVE has also been proposed as a method for measuring wall shear rate in the carotid arteries [4,5]. Although the scan-time of 2DFT FVE is prohibitively long for clinical use, the spiral FVE method [2] shows promise, as it is substantially faster. The scan time in FVE can be significantly reduced using temporal acceleration [6]. The temporal resolution of temporally-accelerated spiral FVE can be improved if spatial aliasing due to temporal undersampling is reduced. This may be achieved using parallel imaging. We investigate the use of the iterative self-consistent parallel imaging reconstruction (SPIRiT) method [7] to accelerate the acquisition of spiral FVE.

Spiral FVE: The pulse sequence consists of slice-selective excitation, a velocity-encoding bipolar gradient along z, a 4 ms spiral readout, and spoiler and refocusing gradients [2]. The acquired data consist of a temporally-resolved stack-of-spirals in k_x-k_y-k_v space [2]. A non-Cartesian inverse Fourier transform along k_x-k_y, followed by a Cartesian inverse Fourier transform along k_v, produces the spatio-temporal-velocity distribution, $m(x,y,v,t)$.

SPIRiT: The iterative self-consistent parallel imaging reconstruction (SPIRiT) approach [7] is an autocalibrated coil-by-coil parallel imaging reconstruction method, based on self-consistency.

Data acquisition: Spiral FVE scans were performed on a GE Signa 3T EXCITE HD system (40 mT/m, 150 T/m/s), using a 4-channel carotid coil. Scan parameters: 1.4×1.4×5 mm^3 spatial resolution over a 16 cm FOV, 5 cm/s velocity resolution over a 240 cm/s FOV, 12 ms temporal resolution. Scan time was 146 seconds (256 heartbeats at 105 bpm).

Methods: Parallel imaging acceleration was evaluated using 2-fold and 4-fold spatially-undersampled datasets, obtained from the fully-sampled spiral FVE dataset. The undersampled data was reconstructed using two techniques: sum-of-squares using NUFFT [8,9], and image-domain SPIRiT [7,10]. Results were compared with the fully-sampled sum-of-squares result.

Results: A qualitative evaluation of the SPIRiT results shows good results for 2-fold acceleration, in both spatial domain (Fig. 1) and time-velocity domain (Fig. 2). Poor results were obtained with 4-fold acceleration (see Fig. 1). In the velocity distributions, aliasing due to spatial undersampling typically results in increased signal at v = 0 cm/s, since the majority of the aliasing signal is associated with static material. The results in Fig. 2 show that 2-fold accelerated SPIRiT was able to completely remove aliasing artifacts (see error images). This is an important result, as we intend to use SPIRiT to reduce spatial aliasing and hence improve the temporal resolution of temporally-accelerated spiral FVE [6]. A quantitative evaluation is presented in Table 1. The SPIRiT results are consistently better (higher signal-to-error ratio) than those obtained with sum-of-squares reconstruction, in both spatial and time-velocity domain. With 2-fold acceleration, SPIRiT achieved signal-to-error ratios higher than 10 dB for all evaluated voxels.

Conclusions: We have demonstrated 2-fold acceleration of spiral FVE using SPIRiT parallel imaging. In future works, we will use SPIRiT to reduce spatial aliasing in temporally-accelerated spiral FVE [6]. This will enable the use of a less-selective UNFOLD filter, which will improve temporal resolution for high velocities.

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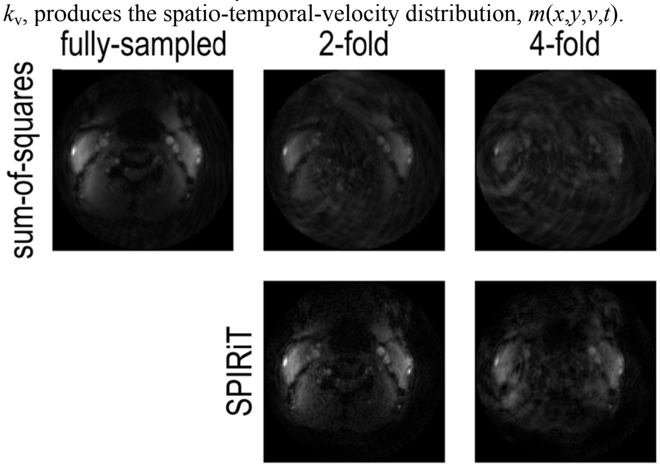

Fig. 1: Magnitude axial images of the neck obtained using sum-of-squares (top row) and SPIRiT (bottom row), with different acceleration factors. These were reconstructed from $M(k_x,k_y,k_v,t)$ for k_v = 0 and t = 0.

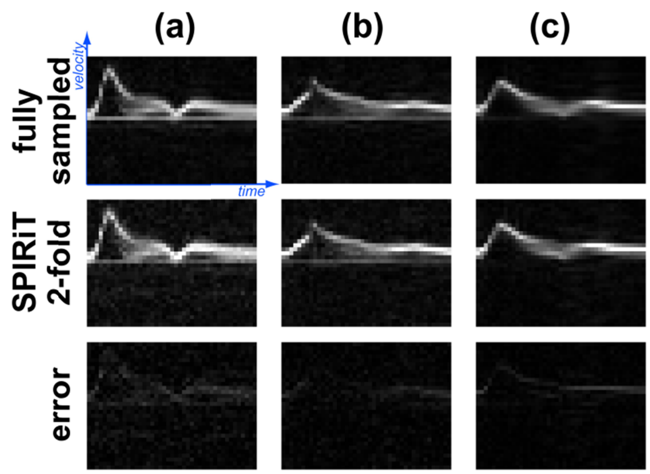

Fig.2: Time-velocity distributions from select voxels, reconstructed using 2-fold accelerated SPIRiT (center row), in comparison with the fully-sampled reference (top row): (a) right external carotid artery; (b) right internal carotid artery; and (c) left carotid bifurcation.

Table 1: Signal-to-error ratio (in dB) for 2-fold and 4-fold accelerated results, in comparison with the fully-sampled reference.

	spatial images	right ext. carotid artery	right int. carotid artery	left carotid bifurcation
sum-of-squares 2×	7.9	9.7	8.1	9.7
SPIRiT 2×	14.4	10.3	13.1	12.5
sum-of-squares 4×	4.7	4.9	4.2	5.3
SPIRiT 4×	10.1	6.6	7.7	7.5