Acceleration of spiral Fourier velocity encoded MRI using 3D SPIRiT

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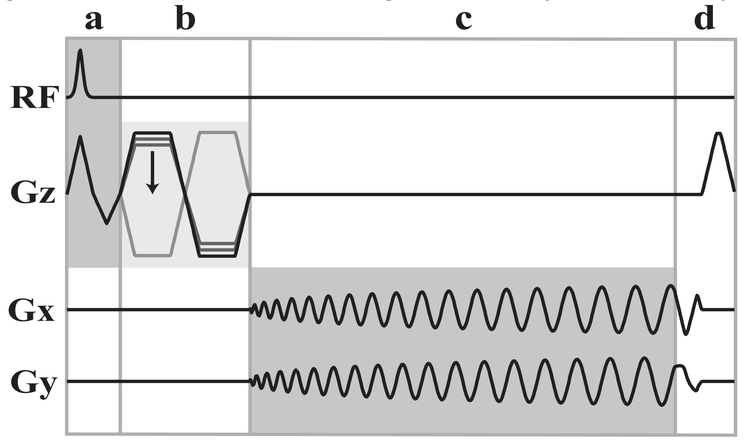
Introduction

Fourier velocity encoded (FVE) MRI [1] is useful in the assessment of vascular and valvar stenosis [2] and intravascular wall shear stress [3,4], as it eliminates partial volume effects that may cause loss of diagnostic information in more conventional phase-contrast MRI [5]. However, FVE MRI has not been adopted for any routine clinical applications, primarily because scan-time is prohibitively long.

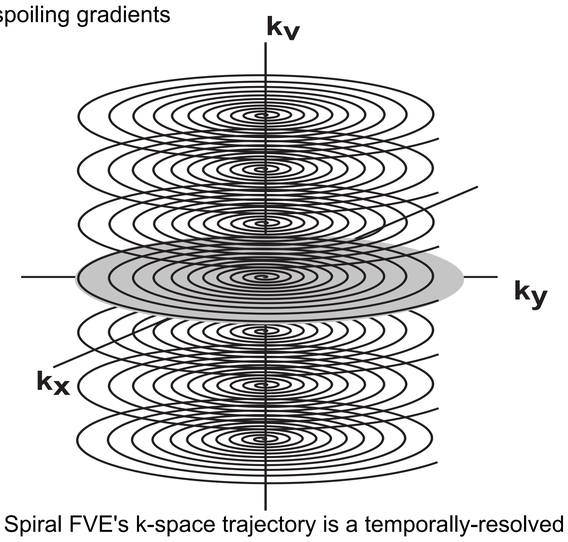
Scan-time in FVE can be significantly reduced using temporal acceleration [6], and temporal resolution can be improved using parallel imaging [7-9]. 2D Image-domain SPIRiT has been previously used for acceleration of spiral FVE without temporal acceleration [7,8].

Theory

Spiral FVE: Acquisition is performed using spiral trajectories in k_x-k_y for spatial encoding, and bipolar gradients for phase-encoding the velocity dimension (k_v).



Pulse sequence: (a) slice excitation; (b) velocity encoding; (c) spiral read-out; (d) spoiling gradients



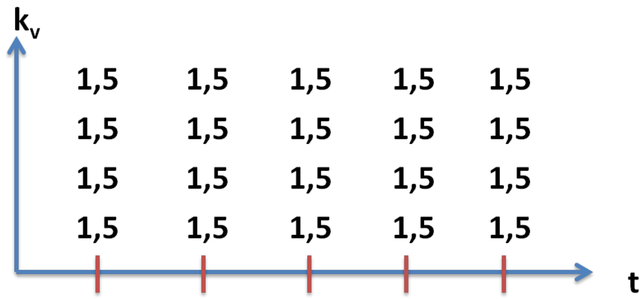
Spiral FVE's k-space trajectory is a temporally-resolved stack-of-spirals in kx-ky-kv [3].

SPIRiT: The iterative self-consistent parallel imaging reconstruction (SPIRiT) approach [10] is an autocalibrated coil-by-coil parallel imaging reconstruction method, based on self-consistency.

Methods

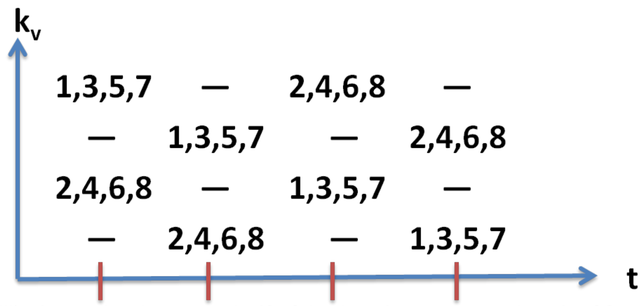
Imaging: Data were acquired on a GE Signa 3T EXCITE HD system (40 mT/m, 150 T/m/s), using a 4-channel carotid coil. Scan parameters: 1.4 x 1.4 x 5 mm^3 spatial resolution, 16 cm field of view (FOV), eight 4-ms variable density spirals, 5 cm/s velocity resolution, 240 cm/s velocity FOV, 12 ms temporal resolution, and scan time 146 seconds (256 heartbeats at 105 bpm).

Evaluation: Parallel imaging acceleration was evaluated using 4-fold retrospective undersampling of the spiral FVE datasets. Temporal undersampling was performed using three different view-ordering schemes presented below:

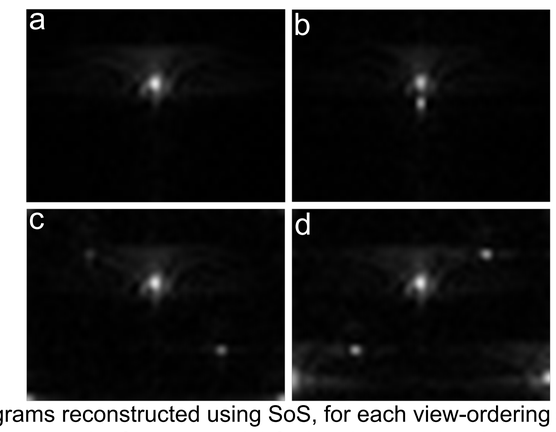


(i) acquiring only the 1st and 5th spiral interleaves in each k_v-t coordinate [7,8];

(ii) alternating interleaves pairs between k_v levels and cardiac phases;



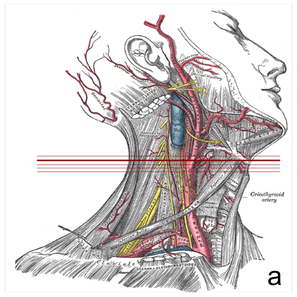
(iii) alternating between half of the interleaves or no interleaf for each k_v-t coordinate [6].



V-f diagrams reconstructed using SoS, for each view-ordering scheme: (a) fully sampled reference; and 4-fold undersampling data according to (b) scheme (i); (c) scheme (ii); and (d) scheme (iii).

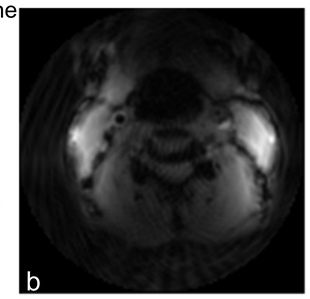
Results

Reconstruction: Undersampled data was reconstructed using three approaches: sum-of-squares (SoS) [11], 2D image-domain SPIRiT [7,8,10], and 3D image-domain SPIRiT [12]. The fully sampled SoS result was used as reference.



(a) The strongest line on the image indicates the anatomical position of the reconstructed slice.

(b) Fully-sampled reconstructed spatial image. It is possible to identify the left carotid bifurcation, the right internal and external carotid arteries.



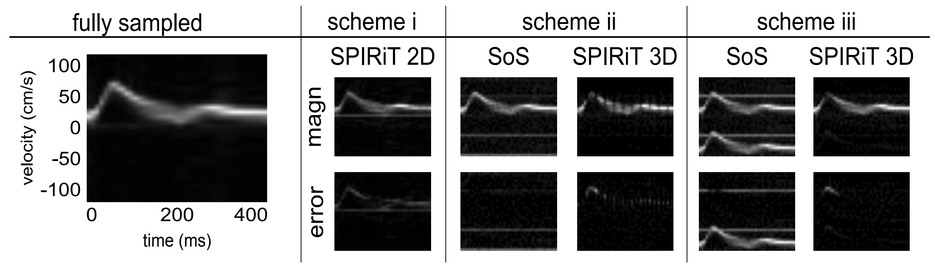


Figure: Time-velocity distributions from the left carotid bifurcation of a healthy volunteer, obtained from 4-fold temporally-undersampled data (right), and from the fully-sampled data (left). The undersampled data were obtained using the three view-ordering schemes (i-iii) and reconstructed using sum-of-squares (SoS), and 2D and 3D SPIRiT (right, top row). The bottom row shows the residual error for each result.

Table: Signal-to-error ratio (in dB) for 4-fold undersampled results, with respect to the fully-sampled reference.

View Order	Recon Technique	Right ECA	Right ICA	Left Bifurcation
i	2D SPIRiT	6.6	7.7	7.5
ii	sum-of-squares	-3.6	0.4	5.0
	3D SPIRiT	8.0	10.5	11.3
iii	sum-of-squares	-0.9	-0.5	-0.9
	3D SPIRiT	8.6	12.9	12.7

Discussion & Future Work

We have demonstrated the potential for 4-fold acceleration of spiral FVE using retrospective undersampling and 3D SPIRiT reconstruction. Results may be further improved using a temporal implementation of SPIRiT (analogous to TGRAPPA [13]), and/or pseudo-random selection of spiral interleaves for each k_V-t coordinate, which would result in incoherent aliasing artifacts in *v-t* space; and/$_1$ norm regularization factor [10]. This general approach also needs to be evaluated prospectively.

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References: [1] Moran PR. MRI 1:197, 1982. [2] Carvalho JLA et al. MRM 57:639, 2007. [3] Carvalho JLA et al. MRM 63:1357, 2010. [4] Frayne R et al. MRM 34:378, 1995. [5] Tang C et al. JMRI 3:377, 1993. [6] Carvalho JLA et al. ISMRM 15:588, 2007. [7] Lyra-Leite DM et al. ISMRM 20:1189. [8] Lyra-Leite DM et al. EMBC 34:416, 2012. [9] Steeden et al. MRM 67:1538, 2012. [10] Lustig M et al. MRM 64:457, 2010. [11] Roemer PB et al. MRM 16:192, 1990. [12] Shin et al. JCMR 14:250, 2012. [13] Breuer FA et al. MRM 53:981, 2005.