Breath-held highly-accelerated 2D Fourier-velocity encoded MRI using compressed sensing

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Introduction: Accurate measurement of blood velocities in complex flow conditions can improve the diagnosis and characterization of a variety of pathologies such as cardiac valvular disease or arterial stenosis [1-2]. Phase-contrast MRI provides an average of the velocity distribution in each voxel in a specific direction but is unable to determine accurately details of the velocity distribution, such as peak flow velocity. ECG-gated, Fourier-velocity-encoded (FVE) M-mode MRI has been shown to provide a fast, non-invasive measure of blood velocity distributions [3]. Extension of this technique to two velocity dimensions allows better characterization of complex flow, at the cost of substantially increased scan times [4]. Unlike in conventional MRI, parallel imaging methods cannot be used for FVE imaging to accelerate the scan. In previous work [4], a compressed sensing (CS) algorithm was used on synthetically undersampled data to demonstrate scan-time reductions up to fivefold. We have now developed a new CS technique that takes advantage of sparsity in the velocity domain rather than in a transform domain (e.g. wavelets), and runs 3 orders of magnitude faster while yielding improved image quality.

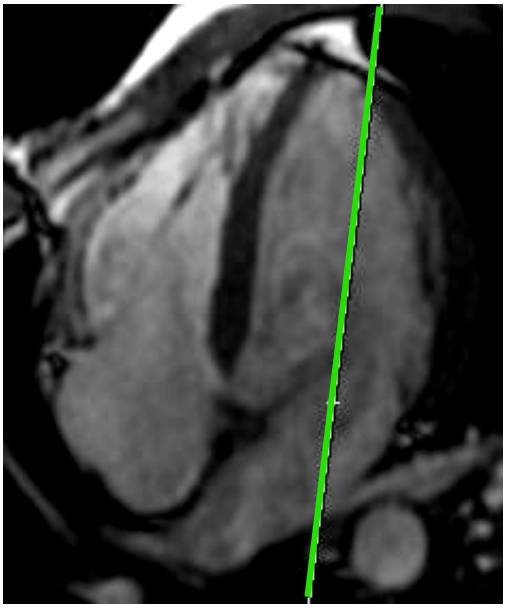

Figure 1. Four-chamber view of the heart showing position of the M-mode pencil through the mitral valve.

Methods: All data were acquired on a 1.5 T GE CVi system using an 8-element cardiac phased-array coil. Following localization (Fig. 1) of the mitral valve, 2D FVE M-mode MRI was performed with a VENC of 80 cm/s. A 2 cm pencil of spins was excited through the valve with a 12-turn spiral excitation followed by a readout along the pencil axis. An incremented pair of bipolar flow-encoding gradient pulses was applied along two chosen axes prior to readout, yielding a dataset with 16 vx-encodes × 16 vy-encodes × 160 readout points (half-echo) × 32 cardiac phases. Under-sampled datasets were also acquired with acceleration factors of R=4 (64 total encoding steps) and R=6 (42 total encoding steps). The R=1 and R=4 were acquired with respiratory gating, while the R=6 case was acquired in a single breath-hold. A uniform random distribution with Nyquist sampled center was chosen for the velocity encoding steps, with no samples in the corners (Fig. 2b). We adapted to this problem a reconstruction scheme [5] that provides exceptional computational performance by enforcing sparsity directly in velocity space, without any transform, wavelet or otherwise.

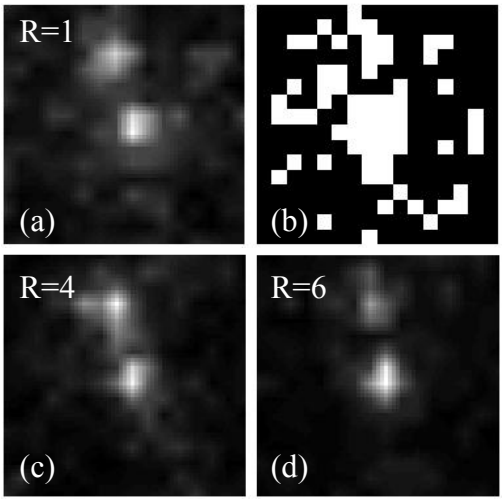

Figure 2. Frame 29 of 32 of the 2D velocity distribution movie, at a location along the pencil near the mitral valve. The y direction is velocity along the green line (across the valve), while the x direction is velocity perpendicular to the valve. a) fully sampled data, (b) random sampling pattern for R=4, and data under-sampled by a factor of 4 (c) and 6 (d), and reconstructed using CS.

Results and Discussion: Figure 1 shows the location of the M-mode pencil through the mitral valve. FVE was applied in two directions: along the pencil axis, and orthogonal to the pencil. In Fig. 2a, a 2D-velocity distribution is shown from a location on the pencil near the valve, in the 29th frame of the movie. Fig. 2b shows the sampling pattern chosen for the R=4 under-sampled acquisition. The same velocity distribution as in Fig. 2a is reconstructed from the under-sampled datasets (R=4 in Fig. 2c and R=6 in Fig. 2d), using CS. In this case, the quality of the reconstruction is significantly improved relative to a conventional soft-thresholding reconstruction and computational performance is 1400x faster. The accelerated velocity images closely match the flow patterns as seen in the fully sampled image. Background noise reduction is also apparent in the accelerated images because of the inherent denoising properties of the reconstruction algorithm. The efficiency of the respiratory trigger is 30%, therefore the total scan time reduction from respiratory triggered R=1 acquisition to breath-held R=6 is 20-fold. We are now extending the present work to 3D FVE. Due to the higher dimensional encoding, we expect to be able to increase the acceleration factor even further, bringing such a time-consuming scan closer to clinical practice.

References: 1) Isaaz K, et al. J. Am. Soc. Echocardiogr., 2003:16;965 - 974. 2) Yamamoto T, et al. Arterioscler, Thromb, and Vasc Biol. 1996;16:172-177. 3) Hardy CJ et al. Magn Reson Med. 1996; 35:814-819. 4) L. Marinelli et al. Proc. 17th ISMRM, 2827 (2009). 5) D. Donoho et al. Tech. Report, preprint, Stanford University (2006).