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]. A limitation of this technique is that to date it has only allowed the measurement of one component of the velocity distribution at a time. In situations where a large component of the velocity is not along the pencil "beam" direction, significant information on the blood-flow velocity distribution can be lost. In a separate contribution to this conference [4] some of the authors have developed a new pulse sequence to address the shortcomings of the above mentioned methods to probe higher dimensional velocity distributions, namely a 2D FVE M-mode MRI pulse sequence. Unfortunately with the addition of the second velocity encoding direction, scan times become much longer and the number of velocity encoding steps has to be reduced. Unlike in conventional MRI, parallel imaging methods cannot be used for FVE imaging to shorten the scan time or achieve the desired velocity resolution. We have instead developed a compressed sensing technique to accelerate 2D FVE imaging, which utilizes the inherent sparsity of the blood velocity distributions in the heart.

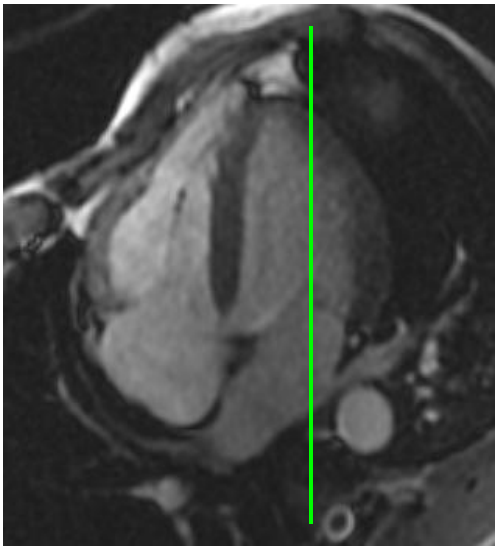

Figure 1. Four-chamber view of the heart showing position of the M-mode pencil through the mitral valve.

Methods: To test the concept, a fully sampled 2D FVE M-mode dataset was first obtained. 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 64 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 × 256 readout points × 32 cardiac phases.

The velocity encodings were then pseudo-randomly down-sampled by various factors, and a compressed-sensing reconstruction [5] was performed on the data.

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 5th frame of the movie. This same distribution is shown after random under-sampling by a factor of x2 (Fig. 2b), x4 (Fig. 2c), and x5 (Fig. 2d), after a compressed sensing reconstruction is applied. The accelerated velocity images faithfully reflect the flow patterns as seen in the fully sampled image.

The main drawback of the 2D FVE M-mode pulse sequence is the long scan time needed to acquire the full 2D velocity distribution. To keep scan times under ten minutes one is forced to reduce the total number of velocity encoding steps (related to maximum resolved velocity) or the maximum applied bipolar gradients (related to the resolution of the velocity distribution). Compressed sensing should allow us to reduce the number of velocity encoding steps by a factor of 4 or more, achieving higher velocity resolution without increasing scan times.

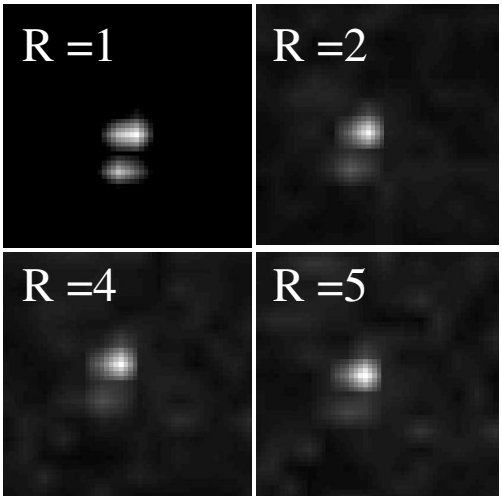

Figure 2. Frame 5 of 32 of the 2D velocity distribution movie, from a location on the pencil near the mitral valve. The y direction is velocity along the cylinder beam (across the mitral valve), while the x direction is velocity perpendicular to the valve. a) fully sampled data, and data under-sampled by a factor of 2 (b), 4 (c), and 5 (d), and reconstructed using compressed sensing.

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