Rapid quantitation of cardiovascular flow using slice-selective Fourier velocity encoding with spiral readouts

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Cardiovascular conditions such as valvular disease, coronary artery stenosis, and atherosclerosis, affect millions of Americans. Blood flow measurement is critical in the assessment of cardiovascular disease. This work proposes spiral Fourier velocity encoding (spiral FVE), a method for rapid measurement of cardiovascular blood flow using magnetic resonance imaging (MRI).

This method is capable of measuring the time-velocity distribution in cardiovascular blood flow in 10 seconds. The main advantage of spiral FVE over other approaches is the fact that measurements are fully localized in 3D space. Therefore, the method is capable of spatially separating static tissue from flowing blood in different vessels. Also, multiple flows can be measured in a single acquisition. The proposed method is capable of detecting and quantifying flow jets due to aortic stenosis or regurgitation. It may also be uniquely useful in applications such as measuring the pressure drop in coronary arteries, and evaluating wall-shear stress in the carotids.

Original contributions of this work include:
– A method for rapid MR flow imaging (Figs. 1 and 2);
– An algorithm for automatic localization of flow;
– Pratical implementation for measuring blood flow through the aortic valve (heart) and carotid arteries (neck) (Fig. 3);
– Optimal view-ordering schemes for aortic and carotid flow, respectively (not shown);
– Demonstration in healthy volunteers and patients;
– Validation against Doppler ultrasound, the current non-invasive “gold standard” (Fig. 4);
– 40% reduction in acquisition time using partial Fourier (Fig. 5).

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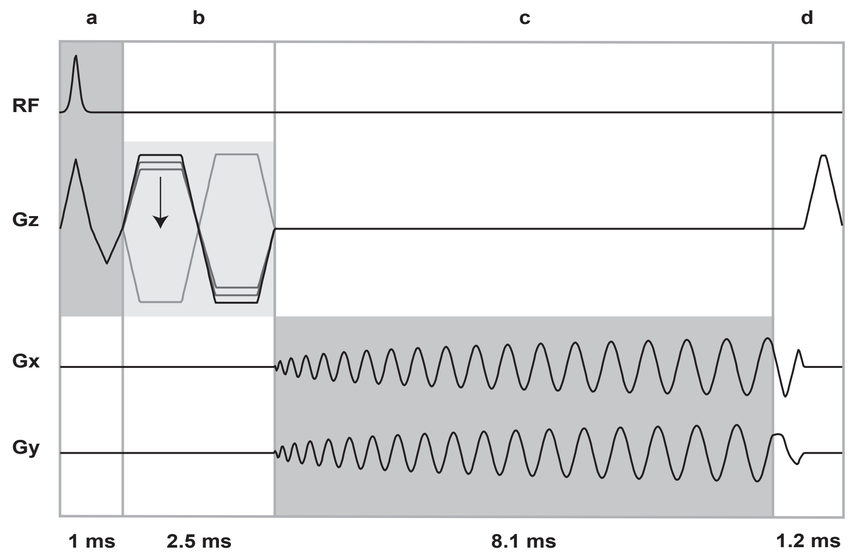

Fig. 1: Spiral FVE pulse sequence. It consists of (a) slice selective excitation, (b) velocity encoding bipolar gradient, (c) spiral readout, and (d) refocusing and spoiler gradients.

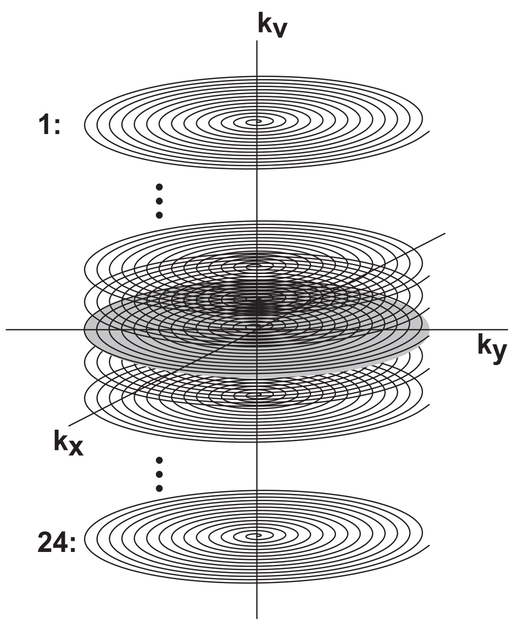

Fig. 2: Fourier domain “k-space” sampling scheme. The dataset corresponding to each temporal frame is a stack- of-spirals in k_x,k_y,k_v space. The bipolar gradient phase-encodes in k_v, while each spiral readout acquires one “platter” in k_x,k_y. The 3D inverse Fourier transform of this data represents the signal distribution in x,y,v.

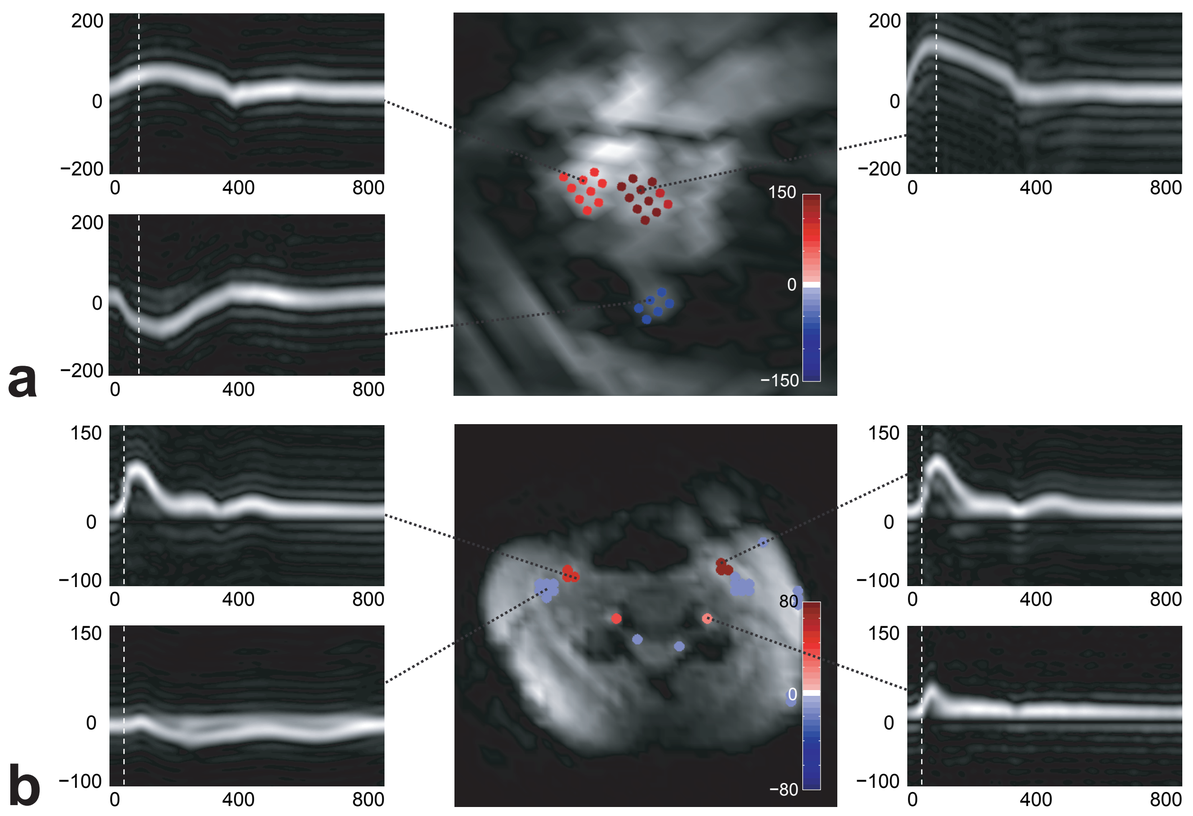

Fig. 3: Multiple flow distributions are obtained from a single cardiac (a) and neck (b) dataset. Red and blue dots indicate voxels where ascending and descending blood flow was detected, respectively. Flow distributions are shown for voxels automatically selected from clinically relevant vessels.

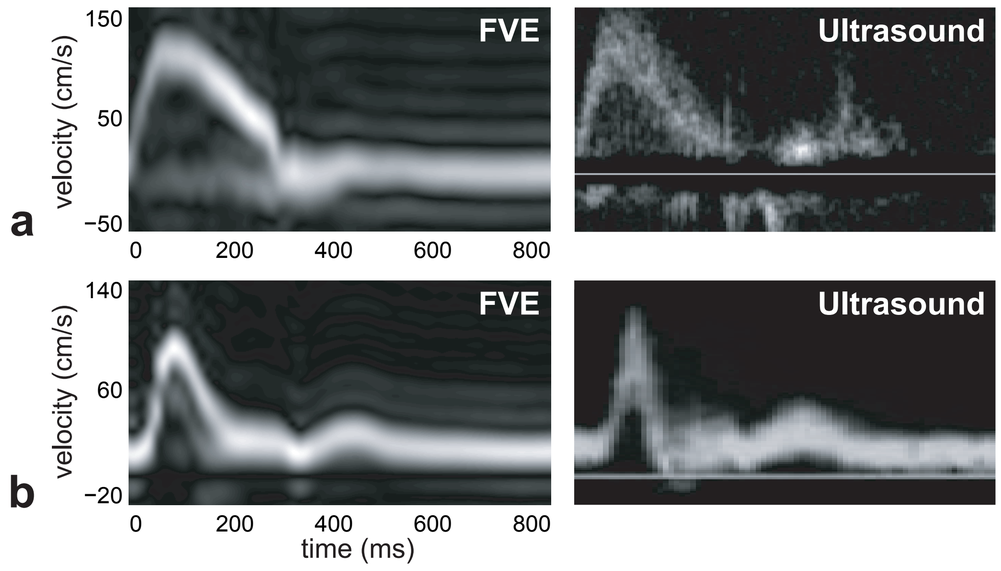

Fig. 4: Comparison of the spiral FVE method with Doppler ultrasound, in healthy volunteers: (a) aortic valve and (b) carotid artery. Peak velocity and time-velocity waveforms are in good agreement with the current non-invasive “gold standard”.

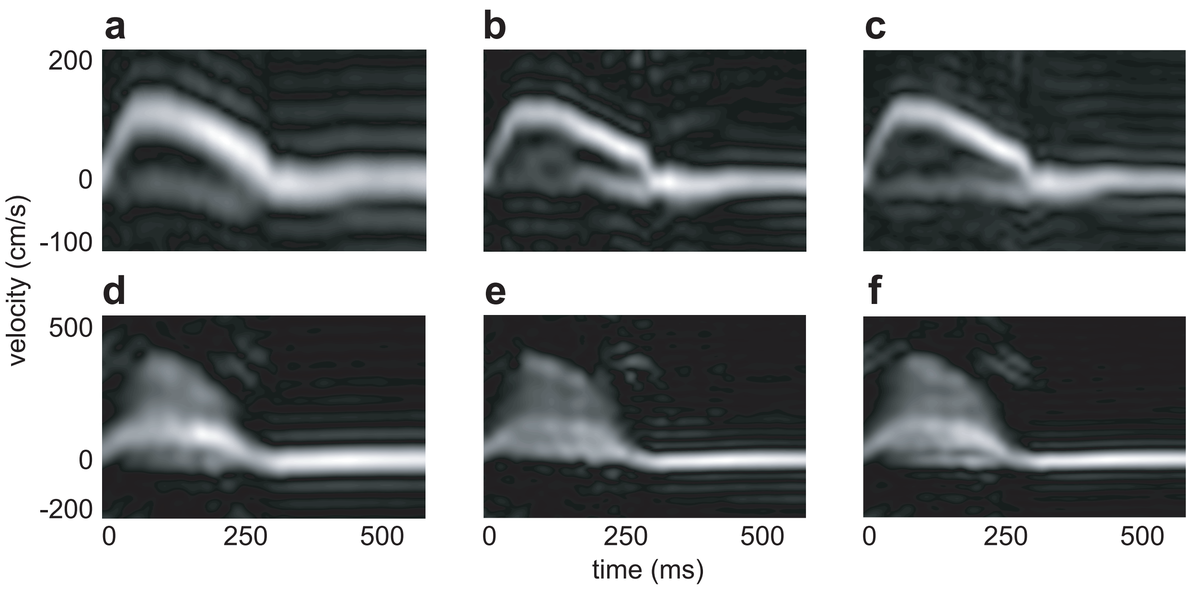

Fig. 5: Evaluation of partial Fourier reconstruction along k_v, in aortic valve studies of a healthy volunteer (a-c) and a patient with aortic stenosis (d-f). Homodyne reconstruction performed well in both healthy volunteer (b) and patient (e) studies, improving the velocity resolution by 71% and 60%, respectively. Full k-space distributions with the same number of k_v samples are shown for comparison (a,d), as well as the fully-sampled datasets (c,f). Note the high-speed jet with a wide distribution of velocities in the patient data.