One-Shot Fourier Velocity Encoding with Higher Spatial Resolution

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INTRODUCTION: The accurate measurement of velocity distribution is important in diagnosing cardiovascular diseases. MR Doppler [1-3] is an MRI counterpart of Doppler ultrasound, which resolves velocity distribution in both space and velocity in real-time. While the velocity characteristics are generally more important, the spatial characteristics are also important in evaluating pathologic conditions where flow velocity can vary rapidly such as LV outflow velocity estimation and AV area calculation. We suggest a new approach in designing 1D readout waveforms achieving higher spatial resolution by traversing k-space in a more efficient way.

THEORY: Conventionally, we first decide velocity FOV (FOV_v) and this determines the basic bipolar gradient waveform. Then, we control the velocity resolution (Δv) by adjusting the number of bipolar lobes achieving a reasonable readout time so that constant velocity assumption is not violated. For a given trajectory, there is a trade-off between velocity & spatial resolution and, since the velocity resolution is of more interest, we normally choose higher velocity resolution at the cost of lower spatial resolution as in Figure 1a. But, we can achieve higher spatial resolution without increasing readout time by using different bipolar gradient waveforms. Each bipolar corresponds to one spoke in k-space. The conventional method sets the 0th momentum (M_0) zero and this leads to using limited part of acquired k-space due to its asymmetric shape around k-space center. By permitting M_0 variation to tweak the bowtie trajectory, we can achieve higher spatial resolution as Figure 1b. It practically doesn't increase the readout time for our application as long as the 1st momentum (M_1) remains the same, since the minimum time heavily depends on M_1.

under constant velocity assumption [1-3]

$$k_z(t) = \frac{\gamma}{2\pi}\int_0^t G_z(\tau)d\tau = \frac{\gamma}{2\pi}M_0(t), \quad k_v(t) = \frac{\gamma}{2\pi}\int_0^t \tau G_z(\tau)d\tau = \frac{\gamma}{2\pi}M_1(t)$$

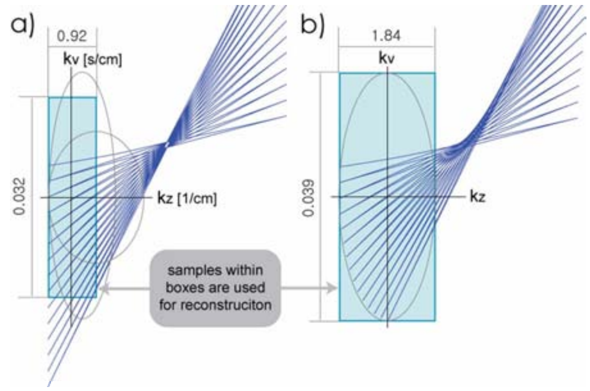

Figure 1. k-space trajectories (v_{max} = 2m/s, 16ms readout)
(a) rectangular coverage (b) ellipsoidal coverage

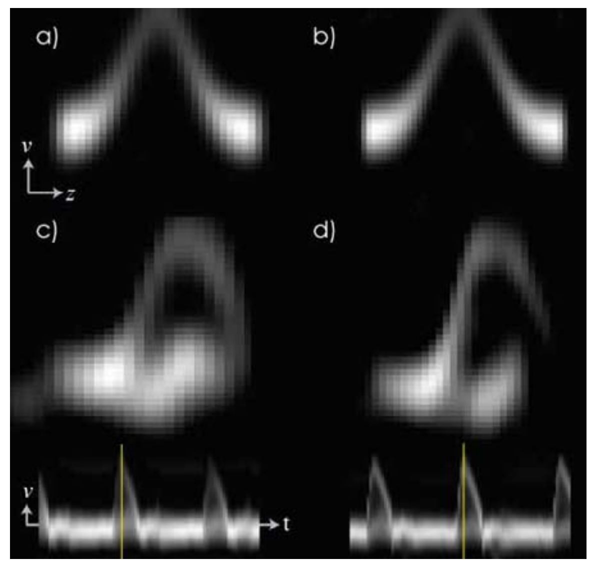

Figure 2. Comparison of simulation and in vivo images
(a,b) simulated flow of Gaussian shape (v = 0.5 ~ 2m/s, FOV_z = 20cm) (c,d) in vivo images in v, z at systole (yellow bars)
(a,c) reconstructed with rectangular k-space (b,d) reconstructed with with ellipsoidal k-space
[Note: same waveforms used as in Figure 1]

METHODS: To achieve an isotropic resolution, the left end of k-space trajectory follows quadratic path by having different M_0 for each bipolar and then whole trajectory is shifted to the left using prewinder bipolar as in the conventional method. The resultant elliptical k-space coverage is a reasonable choice considering k-space windowing to reduce Gibbs ringing. Designs were constrained by gradients of 40 mT/m maximum amplitude and 150 T/m/s maximum slew rate (GE 1.5T Signa scanner). Waveforms of 16ms readout with 2m/s FOV_v were used for simulation and in vivo imaging at the aortic valve using a real-time system [4]. The k-space data were gridded and multiplied by Hamming window while applying homodyne partial k-space reconstruction.

RESULTS AND DISCUSSION: Simple Gaussian flow pattern was used for simulation and in vivo images were acquired at the aortic valve. We observed 2 times higher spatial resolution without losing velocity resolution with new method in both simulation and in-vivo results as in Figure 2.

In the high-acceleration region, the constant velocity assumption breaks down, and this is reflected as signal dephasing. Thus, once we have a long readout, it's inevitable to have blurring and signal loss. The best way to avoid this is to acquire data in a short enough time so that velocity of spins changes little over the course of readout, which sacrifices FOV_v and Δv. This can be overcome by adopting variable-density [5] or echo-shifted multi-shot [6] approaches which shorten readout time and our method can be combined with these techniques for further improvement.

References

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