Rapid Cardiovascular Flow Quantitation Using Slice-Selective Spiral Fourier Velocity Encoding

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Introduction: Accurate flow quantitation is important for the evaluation of many cardiovascular conditions. Phase contrast [1] has problems with partial voluming when flow is highly localized and/or turbulent. Fourier Velocity Encoding (FVE) [2] avoids such problems by resolving the full velocity distribution within each voxel. We propose the use of FVE with single-shot spiral readouts and slice selective excitation to acquire fully localized velocity distributions in a short breath-hold. Scan plane prescription is done using classic protocols, and a semi-automatic algorithm is used for in-plane localization. We were able to acquire time and spatially-resolved aortic valve velocity distributions with 26 ms temporal resolution and 25 cm/s velocity resolution in a single 12-second breath-hold. For measuring carotid flow, longer scan-time was used to achieve higher spatial resolution. The method was tested on phantoms and volunteers, and the results were compared with Doppler ultrasound.

Methods: Experiments were performed on a GE Signa 3T system, with gradients capable of 40 mT/m amplitude and 150 T/m/s slew rate. The pulse sequence is shown in Fig. 1. Slice thickness is 5 mm, and through plane flow encoding was implemented using a large bipolar pulse that was scaled to achieve different k_V encodings. For the readout, uniform density spirals [3] were used. In the heart, we used a single-shot 8.1 ms readout, achieving 7 mm resolution over a 25 cm FOV. In the neck, we used a 4-interleave 7.6 ms readout, achieving 2.5 mm resolution over a 20 cm FOV.

Acquisitions were prospectively ECG-triggered, and the k_V encodes were segmented across multiple heartbeats. During each RR interval, 2 k_V encodes are repeatedly acquired, resulting in many cardiac phases [4]. The true temporal resolution is thus 2•TR, but velocity histograms were reconstructed every TR using a sliding window (Fig. 2). Temporal resolution can be improved by acquiring only one k_V level per heartbeat. Velocity resolution is limited by the breath-hold duration (typically 8-16 seconds).

Each FVE dataset is a stack-of-spirals in k_x,k_y,k_V space (Fig. 3). During reconstruction, a 2D image is obtained for each k_V level by gridding [5] and inverse Fourier transform, converting the acquired data $S(k_x,k_y,k_V,t)$ to $S(x,y,k_V,t)$. A region of interest in the x,y plane is defined and the best pixel is automatically chosen based on the energy at high velocities. The $S(k_V,t)$ dataset is inverse Fourier transformed into $S(v,t)$, the time-velocity histogram. Initial tests were performed on two flow-phantoms designed by PBD Inc., and then in volunteers, aiming at quantifying flow through the common carotid artery and the aortic valve. Doppler ultrasound was used as a "gold standard" in all experiments.

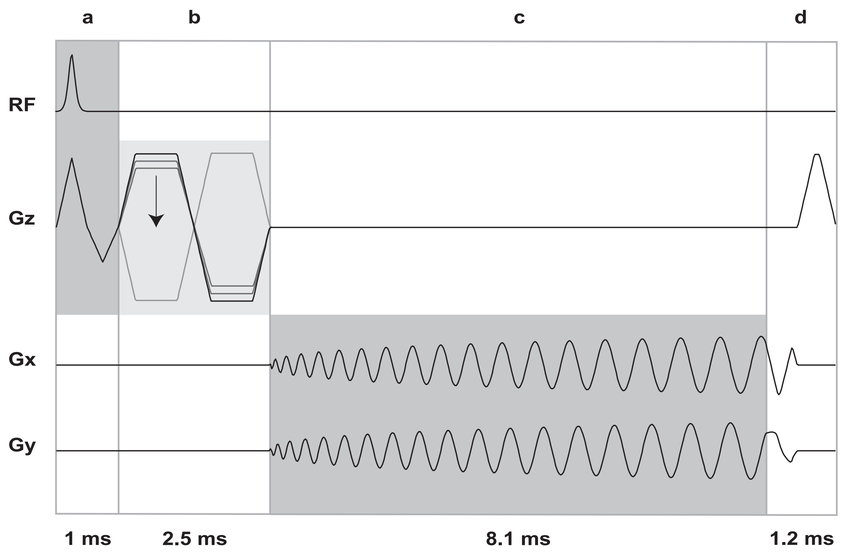

Figure 1: Pulse sequence consists of (a) slice selective excitation, (b) velocity encoding bipolar gradient, (c) spiral readout, and (d) refocusing and spoiler gradients.

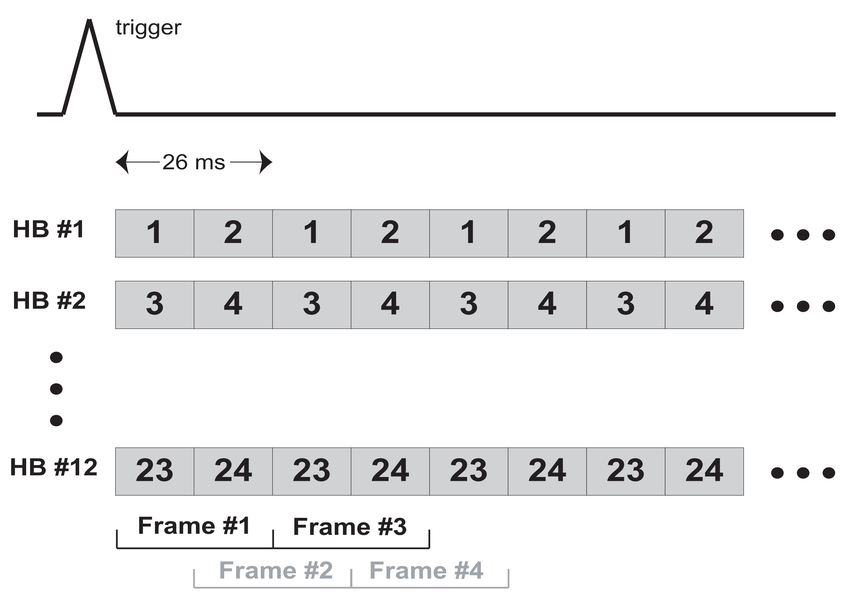

Figure 2: Acquisition timing during a 12-heartbeat breath-hold. Each box represents the acquisition of one k_V level, during one imaging TR. A sliding window reconstruction is used to produce a new image every TR.

Results and Discussion: The MRI measured time-velocity histograms show excellent agreement with Doppler ultrasound. The peak velocity and the shape of the time-velocity curve from phantoms and normal subjects were comparable to those acquired with ultrasound (Fig. 4). Qualitatively best results were achieved using 24 k_V encodes and 600 cm/s velocity FOV (or 400 cm/s for carotid flow). The most noticeable artifacts were ghosting along the velocity axis, due to k_V segmentation. This can be avoided by acquiring only one k_V level per heartbeat.

Conclusions: We've demonstrated fully localized cardiac FVE in a 12-second breath-hold, with temporal and velocity resolutions comparable to Doppler ultrasound. ROI localization is semi-automatic, and the sequence can also be used at the carotids. Preliminary patient results show that this technique can accurately measure flow distributions in stenotic jets, detecting multiple velocities within a voxel (Fig. 5). The proposed method may be useful for accurate quantitation of abnormal valvular flow and congenital flow defects.

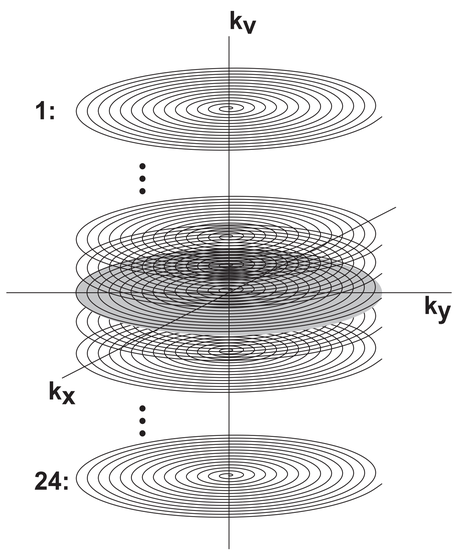

Figure 3: The dataset corresponding to each temporal frame is a stack-of-spirals in k_x,k_y,k_V space. Each spiral acquisition corresponds to a different k_V encode.

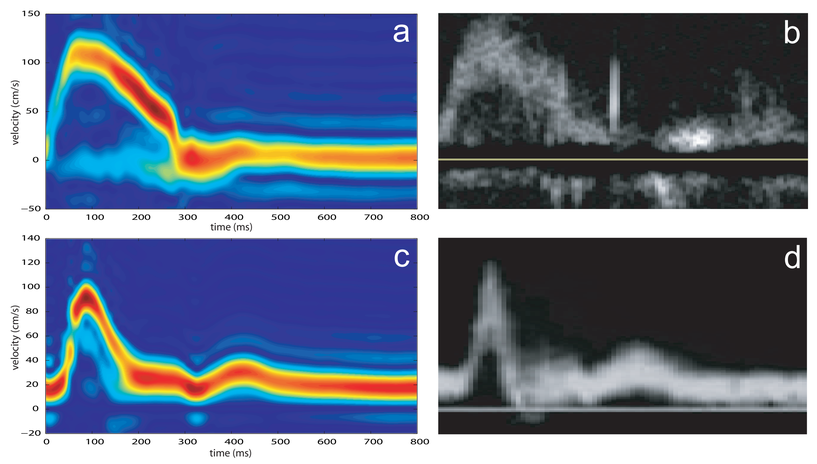

Figure 4: Time-velocity flow histograms from the aortic valve, (a) Spiral FVE, (b) Doppler ultrasound, and from the common carotid artery, (c) Spiral FVE, (d) Doppler ultrasound.

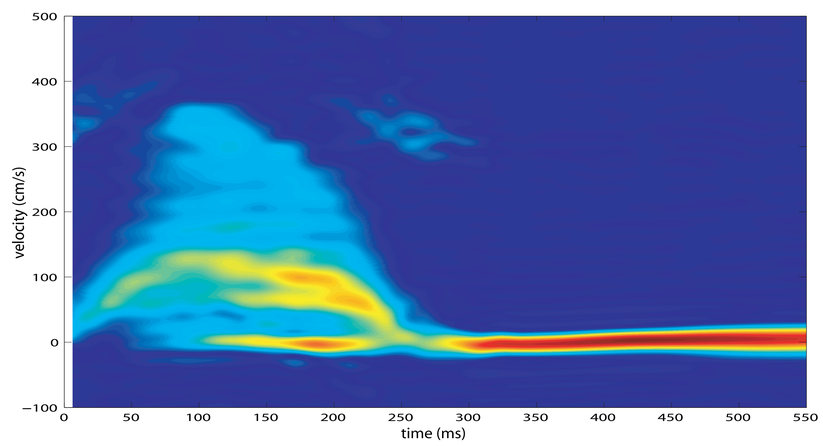

Figure 5: Time-velocity flow histogram from a patient with aortic stenosis. The proposed method detects multiple velocities within a voxel, and the high-speed flow jet is clearly visible.

References:

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