Accelerated spiral Fourier velocity encoded imaging

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Introduction: Fourier velocity encoding (FVE) [1] is robust to partial-volume effects, which are known to cause loss of diagnostic information in phase-contrast imaging [2]. We previously demonstrated slice-selective FVE with single-shot spiral acquisitions that acquires time and spatially resolved aortic flow velocity distributions in a short breath-hold [3,4]. In this work, we aim to: improve the spatial resolution from 7 mm to 3.6 mm using a multi-interleaf acquisition; reduce off-resonance effects by shortening the readout duration from 8 ms to 4 ms; improve temporal resolution from 26 ms to 9 ms; and double the velocity field-of-view (v_{FOV}) to ±600 cm/s, while maintaining diagnostic velocity resolution (33 cm/s). Without acceleration, this would require a prohibitive 216-heartbeat acquisition. This was achieved in a 12-hearbeat acquisition (18-fold acceleration) using a combination of: variable-density spirals, *k-t* acceleration, and partial Fourier along the velocity dimension (k_v). *In vivo* validation is presented.

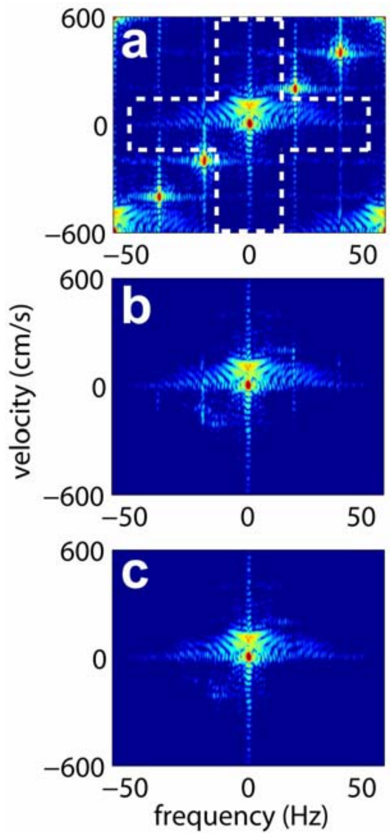

Fig. 1: Signal representation in *v-f* space. The undersampled data (a) is filtered using a 2D filter (dashed) that separates signal energy from aliasing (b). A notch filter removes the remaining aliasing energy (c).

Methods: In order to achieve 18-fold acceleration, several techniques were combined. Variable-density spiral readouts were used to reduce by a factor of 2 the number of interleaves required to achieve the desired spatial resolution. Temporal undersampling with a special view-ordering scheme was used in combination with a 2D filter in k_v-t space to reduce acquisition time by a factor of 6. Finally, partial Fourier acquisition along k_v was used to achieve an extra 1.5-fold reduction in scan time.

Variable-density spirals: The spatial field-of-view was varied linearly from 25 cm at the center of k_x,k_y to 6 cm at the periphery [5]. Gridding with a Kaiser-Bessel kernel was used, and a standard inverse 2D-DFT converts $S(k_x,k_y,k_v,t)$ to $S(x,y,k_v,t)$.

Region-of-interest prescription: Improved spatial resolution facilitated the prescription of regions-of-interest (ROIs). A color-flow video is produced from the spiral FVE data using only the two central k_v encoding levels and standard view-sharing. One or multiple ROIs are prescribed using this video, and $S(x,y,k_v,t)$ is converted to $S_{ROI}(k_v,t)$.

2D filter: While normal cardiac flow requires high temporal resolution due to pulsatility, it utilizes only a small portion of the v_{FOV}. Flow jets may fill the entire v_{FOV}, but generally have a much lower temporal-frequency bandwidth. A special view-ordering scheme is used to minimize the amount of overlap between signal and aliasing components in *v-f* space (Fig. 1a) [6]. A 2D filter in k_v-t space was designed such that velocities below ±150 cm/s retain 90% of the full bandwidth (the equivalent to a 9 ms temporal resolution), while velocities above ±150 cm/s retain a bandwith of ±15 Hz (33 ms) (dashed lines). This filters most of the aliasing energy, while preserving almost all signal energy (Fig. 1b). A zero-phase 1D notch filter is then applied along t to remove the remaining aliasing at $\pm\pi/3$ and $\pm 2\pi/3$ (Fig. 1c).

Partial k_v: Scan time is reduced by imaging only 24 velocity encoding levels (out of 36). The missing data is synthesized using homodyne reconstruction along k_v. This converts $S_{ROI}(k_v,t)$ to $S_{ROI}(v,t)$, the velocity distribution in the ROI.

Validation: *In vivo* data was acquired from a healthy volunteer in a 12-heartbeat breath-hold on a GE Signa Excite HD 3T scanner, and reconstructed using the approach described above. A scan plane perpendicular to the aortic valve was prescribed, and through-plane velocities were measured.

Results and Discussion: A comparison between distributions obtained with the accelerated approach and a reference dataset shows that the proposed method effectively preserves time-velocity resolution, with few visible artifacts (Fig. 2, arrow). The greatest benefits are the improved spatial resolution and reduced off-resonance effects, and the increased velocity field-of-view.

Conclusions: Slice-selective spiral Fourier velocity encoding is a new approach applied to the quantitation of flow jets, and allows the measurement of multiple flows from a single dataset, obtained in a 12-heartbeat breath-hold (Fig. 2). In this work, the spatial resolution was improved to 3.6 mm, the velocity field-of-view was doubled to ±600 cm/s, and the temporal resolution was improved to 9 ms. These improvements were made possible by combining variable-density sampling, partial Fourier reconstruction, and a novel *k-t* acceleration scheme, to achieve a total 18-fold acceleration. *In vivo* validation has been presented, with few visible artifacts. Patient validation is planned.

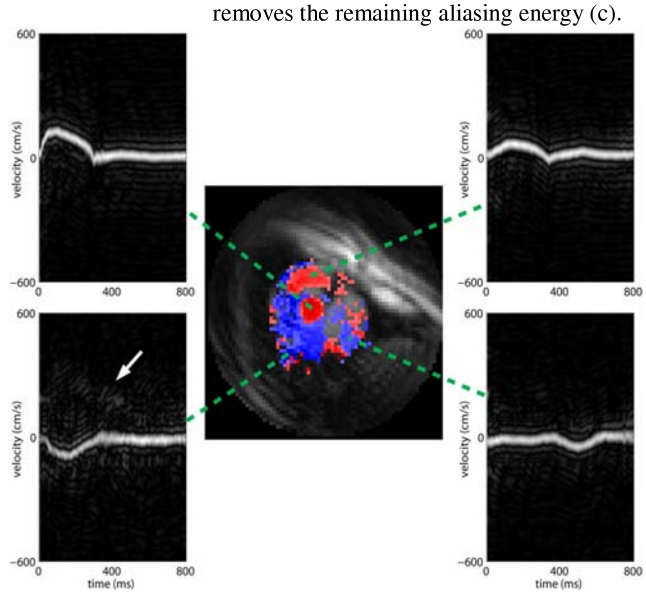

Fig. 2: Color-flow image and FVE histograms. These images were produced from the same dataset, acquired in a 12-heartbeat breath-hold. Few residual artifacts were observed (arrow).

References: [1] Moran PR. MRI 1:197, 1982. [2] Tang C, et al. JMRI 3:377, 1993. [3] Carvalho JLA, et al. Proc ISMRM 14:1906, 2006. [4] Carvalho JLA, et al. MRM (in press). [5] Tsai CM, et al. MRM 43:452, 2000. [6] Tsao J. MRM 47:202, 2002.