Accelerated Spiral Fourier Velocity Encoding using UNFOLD and Partial Fourier Reconstruction

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Introduction: In phase contrast MRI, scan time can be reduced by sacrificing temporal and spatial resolution, but data inconsistency and partial-volume effects can lead to the loss of diagnostic information [1,2]. Fourier velocity encoding (FVE) eliminates partial-volume problems, but requires longer scan time [3]. We recently demonstrated slice-selective FVE with single-shot spiral acquisitions that fully resolves velocity distributions with 52 ms–19 cm/s time-velocity resolution in an 8-heartbeat breath-hold [4]. Under-sampling of FVE data causes blurring and ghosting, which can be corrected by filtering the aliased signals (UNFOLD), but this requires some sort of pulsatility removal (flattening) [5]. In this work, we improve the temporal resolution of spiral FVE to 13 ms using a similar approach, and propose two new flattening methods that are effective even when a distribution of velocities exists (flow jets). We also show 60% velocity resolution improvement using partial Fourier [6]. Experiments were performed on a GE Signa Excite HD 3T scanner.

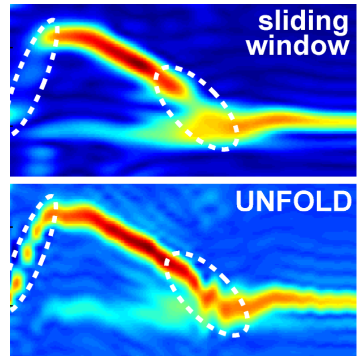

Fig. 1: Aortic valve flow corrected with UNFOLD.

Acceleration using UNFOLD: We acquired fully sampled spiral FVE datasets with 13 ms temporal resolution, from a flow phantom and from healthy volunteers, in 30-second acquisitions. Under-sampled datasets were then generated by discarding 75% of acquired data. Temporal filtering was applied, and flattening was performed using peak-tracking [5] and two new approaches.

In the first approach, the first two heartbeats acquire the two central lines of k_v-t, with maximum temporal resolution. A phase-contrast measurement is obtained from these lines, and is used as reference for flattening. The acquisition time previously used for these k_v levels is used to increase the sampling rate for the neighboring levels.

In the second approach, the k_v-t sampling scheme is changed so that alternating but continuous portions of k_v are acquired every TR. From the central portions, unaliased (but blurred) velocity distributions are reconstructed and used as reference for flattening. Blurring is reduced by phase-corrected conjugate synthesis [6]. Only temporal frames containing central portions were used, and the average velocity was then calculated.

In the healthy aortic valve flow profile (Fig. 1), the most important benefit of pre-processed UNFOLD is the ability to resolve the acceleration at the beginning of systole and at the closing of the valve (circled).

Peak-tracking fails when a distribution of velocities is present (Fig. 2). In an experiment using a flow phantom with such a distribution, the phase-contrast reference approach is more accurate. The unaliased reference approach has similar performance, but shows ringing artifacts.

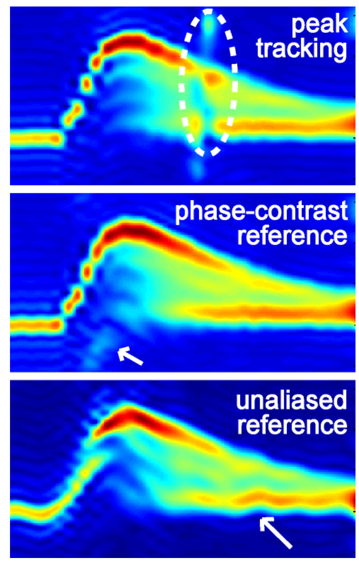

Fig. 2: Flattening methods for UNFOLD (phantom).

Acceleration using partial Fourier: Feasibility was evaluated in healthy volunteer and patient studies, by discarding up to 47% of acquired data, and then using homodyne reconstruction [6]. Velocity resolution was increased by 60% in a 5-heartbeat aortic stenosis study using homodyne reconstruction (Fig. 3), as it can be verified from the narrower lines.

Conclusions: In spiral FVE imaging, UNFOLD and partial Fourier can each be used to reduce scan time by a factor of up to 4 and 1.9 respectively, as demonstrated in our studies of flow phantoms and normal and abnormal aortic flow. This translates to shorter breath-holds and/or improved time-velocity resolution. We are currently working on ways of combining these two techniques.

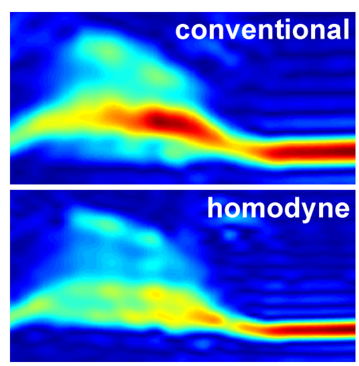

Fig. 3: Partial Fourier reconstruction (patient with aortic stenosis).

References: [1] Clarke GD, et al. JMRI 6:733, 1996. [2] Tang C, et al. JMRI 3:377, 1993. [3] Moran PR. MRI 1:197, 1982. [4] Carvalho JLA, et al. Proc ISMRM 14:1906, 2006. [5] Macgowan CK, et al. Proc ISMRM 14:872, 2006. [6] Noll DC, et al. IEEE TMI 10:154, 1991.