Fast Dynamic Fourier Velocity Encoding using *k-t* BLAST

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INTRODUCTION Fourier Velocity Encoding (FVE) (1) is a powerful alternative to standard phase contrast (PC) measurements, especially for characterizing heterogeneous velocity distributions. The practical applicability of FVE is, however, limited by a very long acquisition time associated with encoding an extra dimension in *k*-space. Several techniques have been suggested for accelerating FVE, but they usually accelerate at the expense of either spatial (2) or velocity resolution (3). In this study, we propose a *k-t* BLAST (4) based approach for accelerating time-resolved FVE.

THEORY, MATERIALS AND METHODS FVE data from a phantom experiment are shown in Fig. 1. The upper row shows an image of the phantom on the left and time-resolved velocity spectra at low (diastole, middle) and high (systole, right) flow rates. The bottom row shows renderings of the signals in *x-v-t* space and the corresponding signals in *x-v-f* space. The latter is obtained by applying an inverse Fourier transform along time *t*. By transforming the data to *x-v-f* space (lower right), signals become more concentrated in localized regions, indicating that the data are correlated in velocity, space, and time. This can be exploited to accelerate the acquisition by utilizing the unoccupied regions in *x-v-f* space more efficiently. Specifically, the acquisition can be accelerated through undersampling of the reciprocal k_x-k_v-*t* space, which introduces aliasing in *x-v-f* space. The introduced aliasing is then removed with the help of prior knowledge acquired in a training stage of the acquisition as described in (4).This undersampling and aliasing is illustrated in Fig. 2 for a 4-fold acceleration of the acquisition. The upper row in Fig. 2 shows the sampling patterns for a fully sampled, an accelerated, and a training acquisition. The second row shows the resulting signal distributions in *x-v-f* space. Notice the aliasing in the accelerated case. The prior knowledge (training data) is a low spatial- and velocity-resolution acquisition used to learn signal distribution in *x-v-f* space. To validate the method, FVE data were acquired in a pulsatile flow phantom and from the common carotid artery of two healthy volunteers. Parameters were: resolution 0.9-1.4 mm², slice thickness 8 mm, 16 velocity encoding steps, 32 time frames, TE 5.6 ms, TR 8.5 ms, flip angle 15°, v_{max} 100-130 cm/s. Fully sampled FVE datasets were acquired and reconstructed using only a subset of the data to simulate 5-fold and 8-fold acceleration. Training datasets consisted of 9 central profiles (in both velocity and spatial directions) of the fully sampled data. The reconstructions from incomplete data were then compared to those from the fully sampled data.

RESULTS The accelerated reconstructed velocity spectra agree well the reconstructions from the fully sampled data. Figure 3 illustrates the quantitative comparison between the accelerated and non-accelerated cases for the *in vitro* experiments. It is seen that the peak velocity detection capabilities of the FVE sequence is preserved in the accelerated cases. The volume flow curves appear similar, but there is a mild tendency of temporal blurring in the accelerated cases (arrows). Fig. 4 shows similar results for the two *in vivo* cases. Even at 8-fold acceleration, the peak systolic velocities are accurately detected.

CONCLUSION A novel method for accelerating FVE acquisitions has been presented. Using this method, it is possible to accelerate FVE to acquisition speeds that are comparable to a standard phase contrast scan. The acceleration is gained without compromising spatial or velocity resolution, and the overall shape of the reconstructed velocity spectra is generally well preserved in the accelerated images.

REFERENCES 1. Moran PR. Magn Reson Imag 1982. 1(4):197-203; 2. Galea D et al. Med Phys 2002. 29 (8):1719-1728; 3. Bittoun J et al. Magn Reson Med 1993. 29 (5):674-680; 4. Tsao J et al. Magn Reson Med 2003. 50 (5):1031-1042

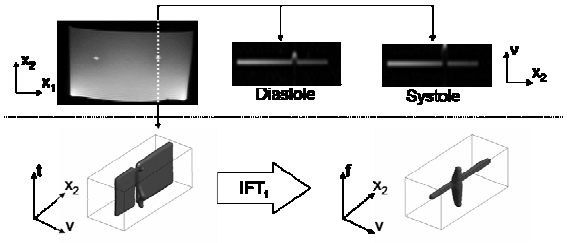

Figure 1. Typical FVE data.

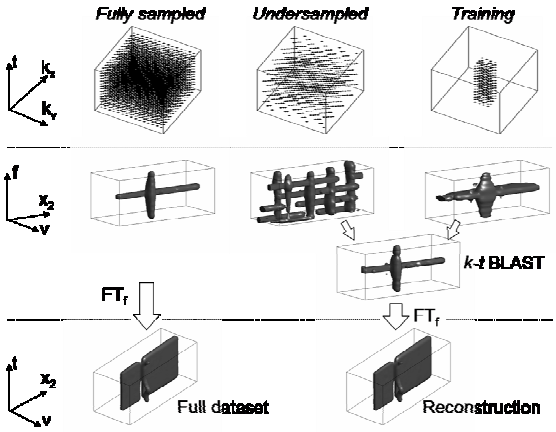

Figure 2. Undersampling and reconstruction process.

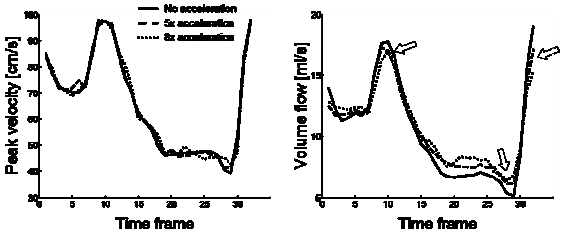

Figure 3. Quantitative *in vitro* results.

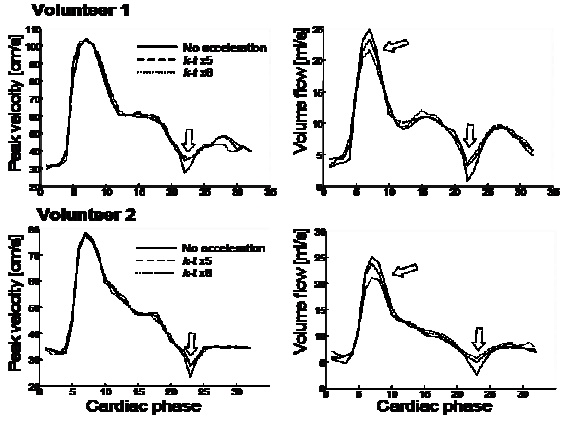

Figure 4. Quantitative *in vivo* results