High-resolution, high-SNR velocity maps reconstructed from low-resolution Fourier velocity encoded MRI data

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Introduction: Fourier velocity encoding (FVE)[1] provides considerably higher SNR than phase contrast (PC), due to its higher dimensionality and larger voxel sizes. FVE is also robust to partial voluming, as it measures the velocity distribution of the spins within each voxel. FVE data are typically acquired with low spatial resolution, due to scan-time restrictions associated with its higher dimensionality. FVE provides the velocity distribution associated with a large voxel, but does not directly provides a velocity map. This work proposes a method to derive velocity maps with high spatial resolution from low-resolution FVE data.

FVE signal model: If spiral acquisitions are used to encode the spatial k-space, than the FVE spatial-velocity distribution, $s(x,y,v)$, may be modeled as:

$$s(x,y,v) = \left[m(x,y)\cdot \mathrm{sinc}\left(\frac{v-v_o(x,y)}{\Delta v}\right)\right] * \mathrm{jinc}\left(\frac{\sqrt{x^2+y^2}}{\Delta r}\right), \qquad (1)$$

where $m(x,y)$ and $v_o(x,y)$ are spin-density and velocity maps, and Δv and Δr are FVE's spatial and velocity resolutions, respectively[2]. Spiral FVE's k-space coverage consists of a stack-of-spirals in k_x-k_y-k_v[3]. Therefore, **sinc(*v*)** and **jinc(*r*)** are the blurring kernels associated with the rectangular and circular coverages in k_v and k_x-k_y, respectively.

Estimating the velocity map: The spatial blurring effects of the jinc($r/\Delta r$) kernel are reduced using the deconvolution algorithm recently proposed by Krishnan and Fergus[4], and we obtain:

$$\tilde{s}(x,y,v) \approx m(x,y)\cdot \mathrm{sinc}\left(\frac{v-v_o(x,y)}{\Delta v}\right). \qquad (2)$$

If a high-resolution spin-density map, $\widetilde{m}(x,y)$, is available (e.g., acquired in a separate scan), the velocity v_o associated with a given pixel (x_o,y_o) may be estimated from $\tilde{s}(x,y,v)$ as:

$$\tilde{v}(x_o,y_o) = \arg\min_{v_o} \left\| \frac{\tilde{s}(x_o,y_o,v)}{\widetilde{m}(x_o,y_o)} - \mathrm{sinc}\left(\frac{v-v_o}{\Delta v}\right)\right\|_2. \qquad (3)$$

Proof of concept: **Experiment 1:** Simulated FVE data with 1 mm spatial resolution was derived — using equation (1) — from a numerical phantom: a parabolic velocity map, with 0.33 mm spatial resolution and $m(x,y) = 1$. Then, the proposed approach was used estimate the original velocity map. **Experiment 2:** Simulated FVE data with 1 mm spatial resolution was derived from the through-plane velocity and spin-density maps, measured with 0.33 mm spatial resolution, at the carotid bifurcation of a carotid flow phantom (Phantoms by Design, Inc.). A CINE gradient-echo 2DFT PC sequence (0.33 mm res., 10 NEX, 80 cm/s Venc) was used. The PC spin-density map was used as $\widetilde{m}(x,y)$, as the proposed approach was used estimate the original velocity map from the simulated FVE.

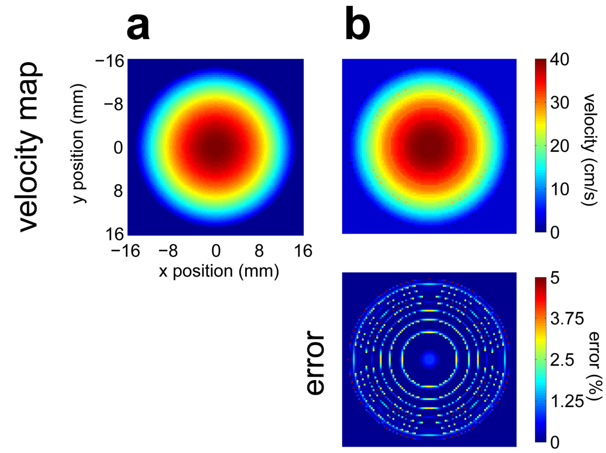

Fig.1: Experiment using a parabolic flow numerical phantom: (a) reference velocity map; (b) velocity map estimated from the simulated low-resolution FVE data, and associated error percentages.

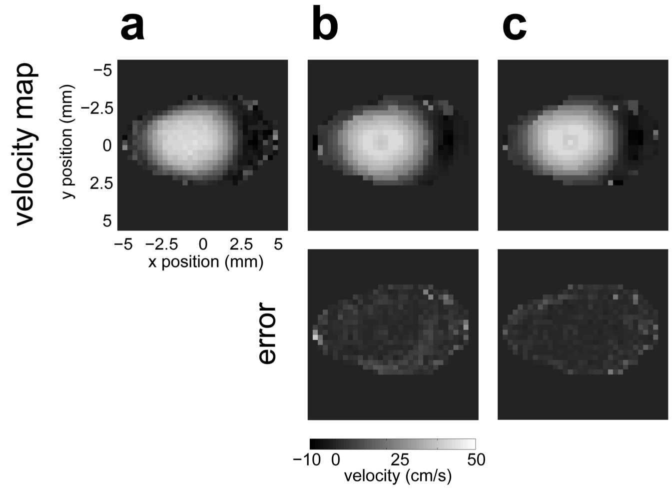

Fig.2: Experiment using a pulsatile carotid flow phantom: (a) reference PC velocity map, measured at the phantom's bifurcation; (b) velocity map estimated from the simulated low-resolution FVE data, without spatial deconvolution (and associated error percentages); and (c) velocity map estimated from the simulated low-resolution FVE data, with spatial deconvolution (and associated error percentages).

Results and discussion: **Experiment 1:** The velocity map estimated from the simulated low-resolution FVE data was accurate within 3% for the vast majority of the pixels (Fig. 1). This is a very important result, as carotid flow distant to the bifurcation — which is typically used as input and output profiles in computational fluid dynamics (CFD) simulations — is typically approximately parabolic. This means that FVE may be used for modeling CFD simulations of carotid flow, instead of PC. The latter has issues with low SNR and partial volume effects, which are overcome by FVE. **Experiment 2:** The maps estimated from the simulated low-resolution FVE data are very similar (qualitatively) to the reference map (Fig. 2). The error images show that the map obtained using spatial deconvolution (Fig. 2c) was more accurate than the one obtained without spatial deconvolution (Fig. 2b). These good results are also important, as the velocity profile measured at the carotid bifurcation may be used for improving CFD simulation quality[5]. This means that FVE may potentially be used also for driving CFD simulations, with considerably higher SNR and robustness to partial voluming.

Conclusion: We proposed a method for deriving high-resolution velocity maps from low-resolution FVE measurements. The results showed that it is possible to obtain reasonably accurate velocities maps from the FVE distributions. This suggests that FVE may potentially be used for driving CFD simulations of carotid flow[5], with considerably higher SNR and robustness to partial voluming than PC MRI.

References: [1] Moran PR. MRI 1:197, 1982. [2] Carvalho JLA, et al. MRM 63:1537, 2010. [3] Carvalho JLA and Nayak KS. MRM 57:639, 2007. [4] Krishnan D and Fergus R. Proc 24th NIPS, 2009. [5] Nielsen J-F and Nayak KS. Proc ISMRM 17: 3858, 2009.