BOOSTING THE ANGULAR RESOLUTION OF Q-SPACE IMAGING METHODS BY DIFFUSION ODF DECONVOLUTION

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Introduction Several deconvolution methods have been proposed to increase the angular resolution of HARDI or QBI [1][2]. However, there is no deconvolution method directly applied to diffusion ODF without resorting to spherical decomposition. In this study, we developed a deconvolution method that could be directly applied to diffusion ODF, thus extending its applicability to other q-space methods such as DSI and generalized q-space imaging (GQI) [3]. Moreover, this proposed method attempts to minimize the isotropic background effect, which was reported to degrade the result of spherical deconvolution [4]. To test the performance of the proposed method, it was applied to QBI, DSI, and GQI to present the fiber ODFs. Also, the fiber ODFs in gray matter was also presented to demonstrate its resistance to the isotropic background effect.

Methods The proposed method first estimates the single fiber diffusion ODF, which is then normalized and used as the deconvolution kernel. The relation between single fiber diffusion ODF **Ψs** and overall diffusion ODF $\boldsymbol{\Psi}_\mathbf{d}$ can be formulated as follows:

$$\psi_d = f_0\psi_0 + \sum f_i R_i \psi_s \quad (1)$$

where f_i is the volume fraction, **Ri** the rotation matrix, and $\boldsymbol{\Psi}_\mathbf{0}$ the isotropic background with the volume fraction of f_0. Before deconvolution, the isotropic component of the diffusion ODF is temporarily extracted so that the effect of isotropic background could be minimized. We used the minimum value of the diffusion ODF min($\boldsymbol{\Psi}_\mathbf{d}$) as an approximation to the isotropic component $f_0\boldsymbol{\Psi}_\mathbf{0}$. Then Eq. (1) can be formulated as the convolution form.

$$\psi_d - \min(\psi_d) \approx \psi_f \otimes \psi_s \quad (2)$$

The fiber ODF **Ψf** can be estimated through deconvolution with Tikhonov's regularization. After the deconvolution, the extracted isotropic component is added back to reflect the partial volume condition, resulting in the overall fiber ODF **Ψf** * as $\psi_f{}^* = (1-f_0)\psi_f + f_0\psi_1$.

Methods A 29-year-old healthy volunteer was scanned on a Siemens 3T TIM scanner by using a 12-channel head coil and single-shot echo planar imaging sequence with parameters listed in table 1. Under the same spatial parameters, diffusion weighted images were acquired by three different q-space sampling schemes: one-shell, grid, two-shell, which were further reconstructed by QBI, DSI, and GQI, respectively. For each method, the reconstructed diffusion ODFs received further deconvolution to obtain the fiber ODFs.

Table 1. Summery of the scanning parameters

	field of view	voxel size	matrix size	slice thickness	slice number
One-shell Grid Two-shell	240mm x 240mm	2.5 mm x 2.5 mm	96 x 96	2.5 mm	40 (no gap)

	TR (ms)	TE (ms)	b-value (s/mm^2)	gradient direction	scanning time
One-shell	7200	133	4000	253	30 min
Grid	7200	144	5000	203	25 min
Two-shell	5500	101	1500	30	10 min
	6300	121	3000	64	

Results The diffusion and fiber ODFs of QBI, DSI, and GQI were shown in Fig1, where the slice is located in the centrum semiovale, a region where corticospinal tract, corpus callosum, and superior longitudinal fasciculus (SLF) cross each other. For all three q-space methods, the diffusion ODFs presented coarser contours whereas fiber ODF presented sharper ones. The zoom-in images in axial view showed that the fiber ODFs clearly delineated the directions of callosal fibers aligned horizontally, and those of SLF aligned vertically. The most obvious sharpening effect was observed in GQI, which had the coarsest contours in diffusion ODFs since the scanning time was only 10 minutes. The fiber ODFs of DSI in gray matter is further illustrated in Fig. 2, where the dull ODF contours in gray matter correctly reflected the isotropic background condition. This suggested that the proposed method could avoid showing false fibers in such condition.

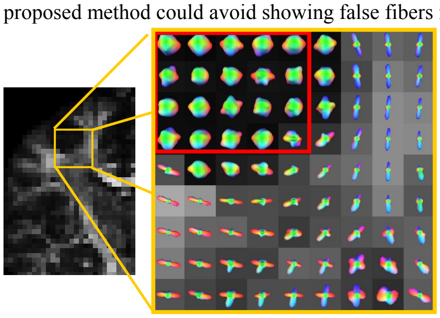

Fig2. The fiber ODFs of DSI in gray matter (red). The isotropic background condition did not degrade the ODF.

Discussion We demonstrated that the proposed deconvolution method could estimate fiber ODFs from diffusion ODFs reconstructed by QBI, DSI, and GQI. The fiber ODFs obtained by the proposed method presented sharper contour, suggesting better angular resolution. The isotropic background effect in gray matter could also be modeled. Both advantages may facilitate fiber tracking, especially for tracking methods that require a high angular resolution reconstruction method robust to noise and isotropic diffusion condition. Further study is still needed to investigate the improvement of angular resolution quantitatively.

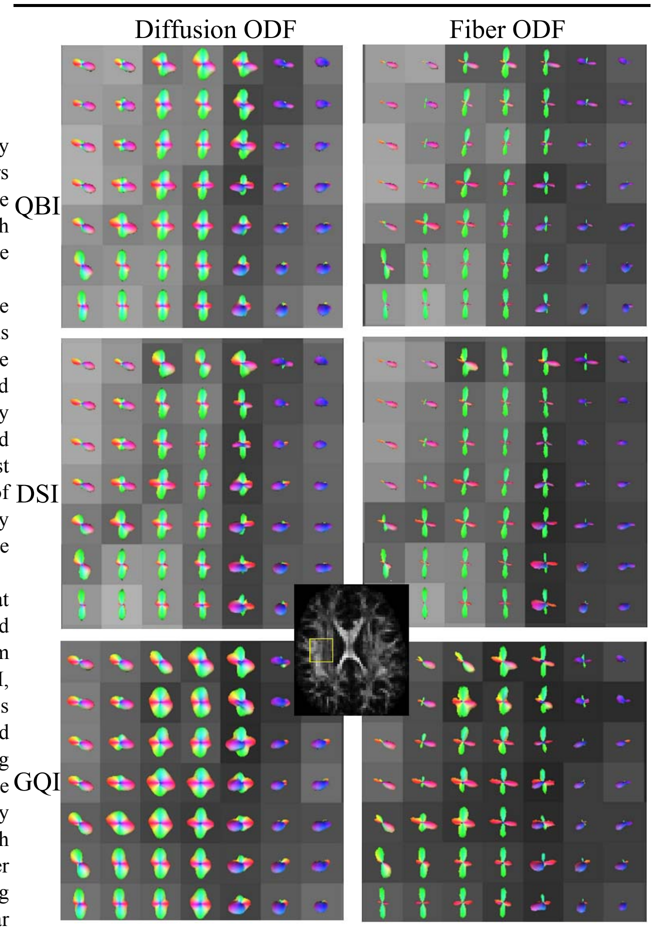

Fig1. The diffusion ODFs of QBI, DSI, GQI and their fiber ODFs obtained by the proposed deconvolution method. The fiber ODFs of all three methods present sharper contours, suggesting a better angular resolution.

Reference[1] Tournier et al. Neuroimage, 23:1176-85, 2004. [2] Descoteaux et al. IEEE TMI 28:269-86, 2009. [3] Yeh et al. ISMRM, 2009 [4] Dell'acqua et al. Neuroimage, 2009.