Practical crossing fiber imaging with combined DTI datasets and generalized reconstruction algorithm

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Abstract We present a clinically feasible imaging scheme that combines two DTI datasets to obtain a high angular resolution reconstruction of crossing fibers. The scheme was designed based on a paradigm that sampled q-space points with equally distributed q-space interval, similar to the approach of diffusion spectrum imaging (DSI) [1] and hybrid diffusion imaging [2]. The obtained images were reconstructed by generalized q-space imaging (GQI) method [3], which is a dataset independent q-space imaging technique that can be applied to any balanced diffusion sampling scheme. To evaluate the proposed scheme, the reconstructed result was compared with the high angular resolution diffusion imaging (HARDI) sampling scheme of q-ball imaging (QBI) [4]. The comparison showed that the proposed scheme correctly discerned crossing fiber in the three-way crossing regions passed by corticospinal tract, corpus callosum, and superior longitudinal fascicules. This result also suggested that the proposed scheme could obtain time efficient and high-resolution images by using a combination of highly available DTI sampling schemes.

Introduction Several advanced diffusion methods, such as model-free q-space imaging methods or model-based ADC analysis, have been proposed as the alternative methods to DTI [1][4]. However, most of the methods require long scanning time and customized b-tables or pulse sequences, which make it hard to use those methods for clinical purpose. In this abstract, we propose a clinically feasible scheme that uses built-in DTI scanning sequences to obtain high angular resolution images that are reconstructed by GQI method.

Theory The proposed DTI combination scheme consists of two independent DTI datasets that form an outer shell and an inner shell in q-space. Moreover, these two shells share the same average q-space interval; simultaneously, the interval is also equal to the q-space distance between the shells. Following this design paradigm, the sampling number of each shell is in proportion to its b-value, and the difference of the b-value of these two datasets also is tuned to match the same q-space interval. This proposed scheme is similar to the grid sampling scheme used in DSI, but the arrangement combines two spheres instead. The scheme is also similar to hybrid diffusion imaging that combines multiple shells in q-space; however, hybrid diffusion image does not require that the q-space interval of every shell be uniform. GQI is used as the reconstruction method for this scheme. GQI is a q-space imaging method based on the sinc function relation between the q-space signal and orientation distribution function.

$$\psi(\hat{\mathbf{u}}) = \mathbf{Z}\sum_{\forall\bar{\mathbf{q}}} \mathbf{S}_{\Delta}(\bar{\mathbf{q}})\mathrm{sinc}(\mathbf{L}\cdot\hat{\mathbf{u}}\cdot\bar{\mathbf{q}})$$

, where S(**q**) is the MR signal with gradient direction **q**, **L** the sampling distance in PDF space, and **Z** the normalization term.

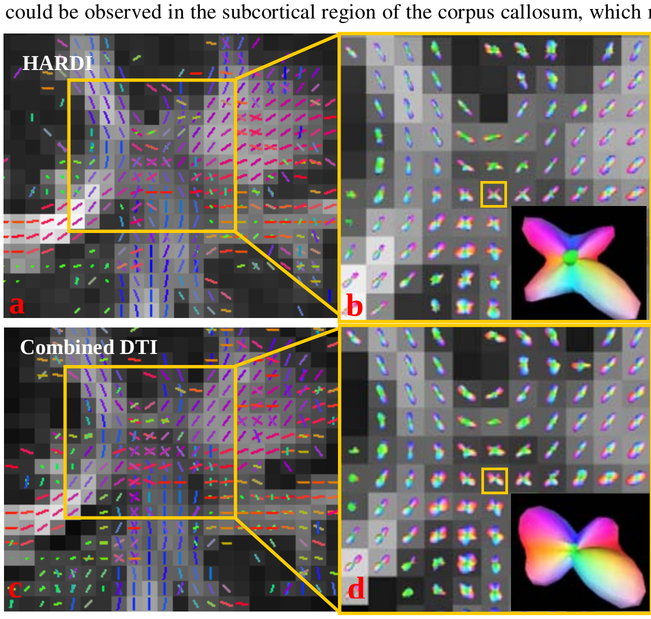
Materials and Method A 25-year-old healthy volunteer was scanned on a Siemens 3T TIM scanner by using a 12-channel head coil and single-shot echo planar imaging sequence with parameters listed in table 1. Two DTI datasets were obtained by the built-in DTI pulse sequence, while the HARDI scan was done by a customized b-table. The spatial parameters such as field of view, voxel size, matrix size, slice thickness, and slice number were identical in both datasets. The two DTI datasets were reconstructed by QGI with sampling length 40μm, and the HARDI was analyzed by a spherical harmonics based QBI [5]. The fiber directions were determined by searching for the local maximums on the reconstructed ODFs.

Table 1. Summery of the scanning parameters

	field of view	voxel size	matrix size	slice thickness	slice number
DTI 1 DTI 2 HARDI	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	averag e	scanning time
DTI 1	5500	101	1500	30	1	3 min
DTI 2	6300	121	3000	64	1	7 min
HARDI	7200	133	4000	253	1	30 min

Results The result of the reconstructed images is presented in Fig. 1, which is the coronal view of the three-way crossing region passed by corticospinal tract, corpus callosum, and superior fasciculus. In Fig. 1a and Fig. 1c, the fiber directions are illustrated by orientation colored. The directions demonstrated the consistency of the major fiber presentation between these two schemes, and the crossing regions could both be identified. However, the difference between the directions of minor fibers could be observed in the subcortical region of the corpus callosum, which may be due to the insufficient resolving power of the DTI datasets. The reconstructed ODFs are presented on Fig. 1b and Fig. 1d. The ODFs of both methods also showed consistent presentation; however, the ODFs generated from HARDI were sharper and more discernible, suggesting a clue to explain the difference in discerning some minor fibers.



Discussion and Conclusion The reconstructed result of the proposed scheme showed consistent fiber presentation as HARDI reconstructed by QBI. Although the proposed combination scheme may not be as accurate as the HARDI dataset, the scheme has several advantages. First of all, the scheme can be used to resolve most of the prominent crossing areas without redesigning the b-table or pulse sequence. Since DTI pulse sequence is widely available on most clinical MRI machines, this feature makes the proposed scheme a handy and flexible one. Moreover, the short scanning time of the scheme renders it highly feasible for participants intolerant of long scanning time. Still, though not demonstrated in this study, the scheme is possible to avoid crowding the sampling points and to better characterize the diffusion displacement.

Reference [1] Wedeen et al. MRM 54:1377,2005 [2] Wu et al. NeuroImage 36:617, 2007 [3] Yeh et al. submitted to ISMRM, 2009 [4] Tuch MRM 52:1358, 2004 [5] Descoteaux et al. MRM 58:497, 2007

FIG. 1. Coronal views focusing on three way crossing regions of corticospinal tract, copurs calosum, and superior longitudinal fasciculus. The fiber directions (a) and ODFs (b) obtained by reconstruction of the HARDI data. The fiber directions (c) and ODFs (d) obtained from the proposed combination scheme of two DTI datasets and generalized reconstruction algorithm.