Hybrid diffusion imaging for complex diffusion characterization

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Background

Complex diffusion behavior in brain tissue has been studied with different approaches including diffusion spectrum imaging (DSI) [1,2], q-ball imaging (QBI) [3], high angular resolution diffusion imaging (HARDI) [4,5], and diffusion model fitting [6]. Unlike QBI and HARDI, which measure diffusivities for a spherical shell in q-space, the DSI experiment samples the full q-space and provides the most complete description of complex diffusion through the probability density function (PDF) of the water displacement. The diffusion behavior can be characterized using several measures of the PDF. The directional density information can be described by the orientation distribution function (ODF), which is the radial integral of the PDF. In this study, a novel hybrid diffusion imaging (HYDI) method, which samples the q-space non-uniformly on concentric shells, was investigated. For HYDI, the angular resolution was increased with the level of DW. HYDI was compared against DSI and QBI. For comparison, DTI was also estimated using the subset of the HYDI data with low DW.

Materials and Methods

Diffusion-weighted MR images of two healthy volunteers were acquired on a 3T GE SIGNA using a SS-SE-EPI sequence. Three experiments were performed including HYDI, DSI and QBI with otherwise identical imaging parameters at the same anatomical location. Specific parameters were coronal, TR/TE = 1000/94 ms, matrix size of 64x64, FOV of 20 cm and one slice with 5mm thickness. The imaging time was around 6 min for each method. Table 1 describes the encoding for HYDI, DSI and QBI. The HYDI q-space sampling consisted of three concentric shells of antipodal icosahedral encoding directions. Because the DTI model works relatively well for b < 1500 s/mm^2, low DW data was estimated from the 12 directions, which are commonly used in DTI experiments. The higher angular sampling resolution for larger b-values may be used to characterize complex diffusion behavior. The geometric mean of signals from the antipodal directions was used to eliminate the diffusion effects of background and imaging gradients. The nonuniform HYDI q-space sampling was regridded onto a 9x9x9 Cartesian lattice, the HYDI-PDF was Fourier reconstructed [2] and normalized by the total PDF volume in each voxel. Maps of the zero displacement and the FWHM were estimated from the PDF. The ODF was obtained by radial integrals of the PDF. For QBI, the ODF was reconstructed using Funk-Radon transform of the q-space diffusion signal [3].

Table 1 Diffusion parameters for HYDI, DSI and QBI

Method	Ne	G (G/cm)	delta (ms)	q_{max} (mm^{-1})	$\Delta\theta$ (°)	Δq_r (mm^{-1})	b_{max} (s/mm^2)
HYDI	1	0	34.2	0			0
	2x6=12	2.3	34.2	33.54		33.54	1492.34
	2x46=92	3.25	34.2	47.40	22.27±1.07	13.86	2998.84
	2x81=162	3.98	34.2	58.04	16.90±0.93	16.65	4482.35
DSI	257	3.98	34.2	57.96		14.49	4482.35
QBI	252	3.98	29.4	49.82	13.68±0.75		2998.84

Results and Discussion

The DTI ellipsoids and ODF glyphs for HYDI, DSI and QBI in a region of centrum semioval are shown in Fig. 1. The ODF maps appear similar for DSI, QBI and HYDI, including the depiction of crossing fiber regions. The PDF measures of FWHM for both DSI and HYDI are shown in Figure 2. The similarity of these maps demonstrates that HYDI approaches are promising, although the exact shell configuration and diffusion weightings of the shells can be optimized further. In the futuer, we will examine reducing the number of encodings in each shell to evaluate HYDI acquisitions in more clinically feasible acquisition times.

References

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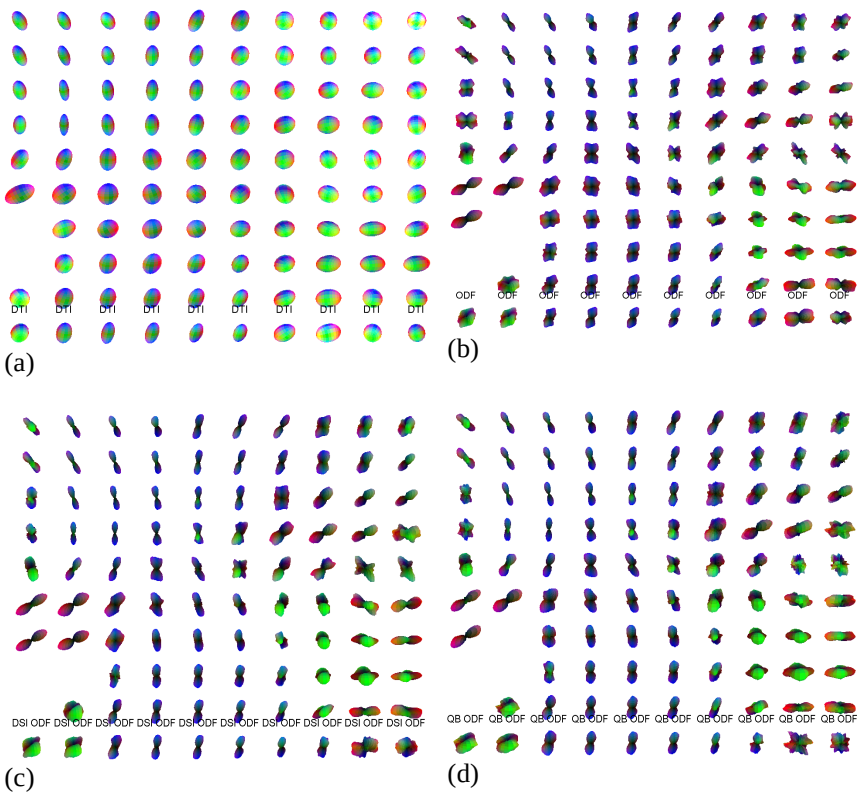

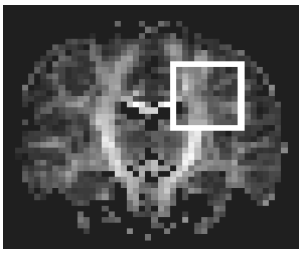

FIG. 1 (left) The directional measures: (a) DTI ellipsoids, ODF glyphs for (b) HYDI, (c) DSI and (d) QBI. The colors denote red/left-right, green/anterior-posterior, and blue/superior-inferior. (e). The corresponding ROI in FA map.

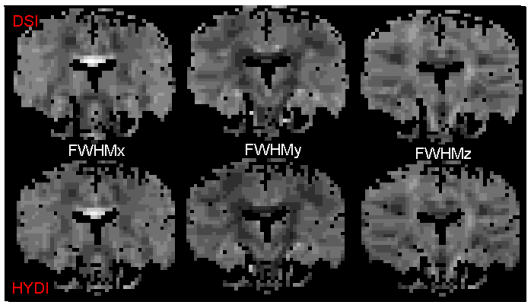

FIG. 2 (upper) The PDF measures of FWHM for both DSI (upper row) and HYDI (lower row).