Shape models and filters for the diffusion orientation distribution

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Introduction

High angular resolution diffusion imaging (HARDI) is one of the novel methods for estimating the distributions of multiple fiber directions within a single voxel [1]. In the original HARDI approach, the spherical harmonic decomposition (SHD) of the diffusivity profile is used to estimate the angular distribution of measured diffusivities, D_{app}. However fiber directions do not necessarily correspond to the peaks of the measured diffusivity profile [2]. The orientation distribution function (ODF), which allows model-independent estimation of the probability to find the orientation of the ensemble-average spin displacement, is estimated through the diffusion spectrum imaging (DSI) or q-ball imaging (QBI) methods [3]. The aim of this study is to develop a robust feature extraction and filtering method for the ODF to reconstruct the most significant fiber components in the presence of noise.

Methods

Brain diffusion MR acquisition for QBI experiment was performed on a healthy volunteer with a 3T SIGNA LX scanner (GEMS, Waukesha, WI) using a pulsed gradient spin echo EPI sequence. A single coronal slice with $3x3x5mm^3$ resolution was used. The sequence parameters were TR/TE/Δ/δ=1000/80/40.4/29.4ms, g_{max}=40mT/m, b=2998.84s/mm^2, and q_{max}=49.82mm^{-1}. The q-space sampling points were 252 vertices of a 5 fold-tessellated icosahedral sphere. The ODF was reconstructed using the Funk-Radon transform and then radially projected [3]. The spherical harmonic (SH) components of the ODF and the apparent diffusion (D_{app}) profiles were estimated using the spherical harmonic transform (SHT) to order l_{max}=6. The coefficients were determined by direct computation of $c_{l,m} = \int_0^{2\pi}\int_0^{\pi} f(\theta,\varphi) Y_{l,m}^{*}(\theta,\varphi)\sin\theta d\theta d\varphi$ [4]. The complexities of the ODFs and D_{app} profiles were characterized by the order of the SHD. The parametric boundary of the model was represented by a truncated SH series. The SHs of odd orders, which represent artifacts, were eliminated from reconstruction. Reconstructed ODFs were displayed as 3D polar surfaces and were compared with the original ODFs and D_{apps}.

Results

In general, the SHD appeared to fit the ODF data (Fig. 1) much better than the D_{app} profile data (not shown) especially for the l≥4 harmonic orders. The map of the isotropic spherical harmonic component (l=0) in D_{app} profile was identical to the ADC map of the single tensor model [1], whereas the l=0 order of the ODF SHD appeared to be hyperintense in regions of diffusion anisotropy (white matter – see Fig. 1). The angular features of both the D_{app} profiles and ODFs were reliably fitted and parametrized with SHD. For the SHD of the ODF (Fig. 1) the l=2 order corresponded to cylindrically symmetric prolate displacements (e.g., dominated by single fiber group), whereas the l=4, 6 indicated regions of greater complexity (e.g., multiple fiber groups). Truncation of the higher order (l>6) and the odd order SH components significantly reduced asymmetric and irregular features of the estimated D_{app} and ODF surface profiles, while preserving the surface features that are believed to correspond to underlying diffusion complexity (D_{app} profile) and fiber distributions (ODF) (Fig. 2).

Discussion

The orders of the ODF SHD represent a shape basis for characterizing orientational distribution of diffusion displacement. Signals in higher order SH components indicate regions of greater diffusion complexity (e.g., crossing white matter fibers). The present method effectively filtered the ODF surface by reducing irregularities while maintaining the overall shape distribution of the ODF. This technique may be used to improve fiber tractography in crossing white matter structures by modeling the complex topology of the fiber orientations with noise reduction. The approach may be used with both DSI and QBI acquisition methods.

References

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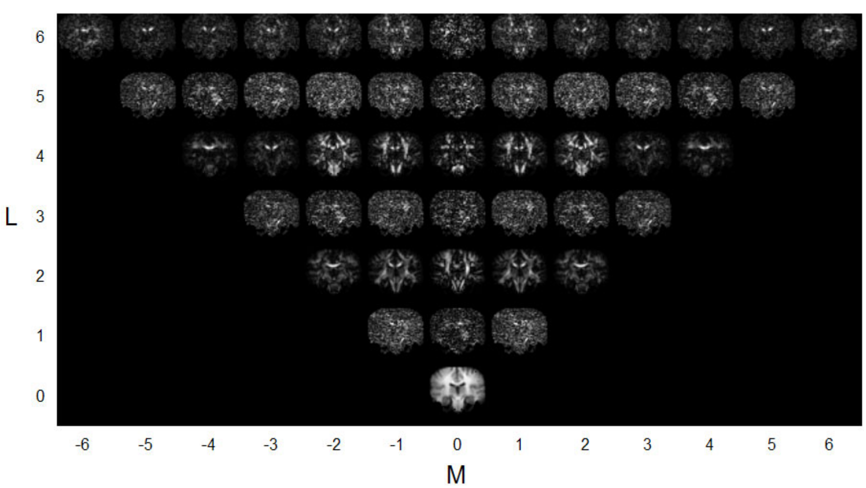

Fig. 1. SH components of the ODF estimated from QBI experiment (l_{max}=6). The odd orders (l=1, 3, 5) represent artifacts. Images were scaled independently for display.

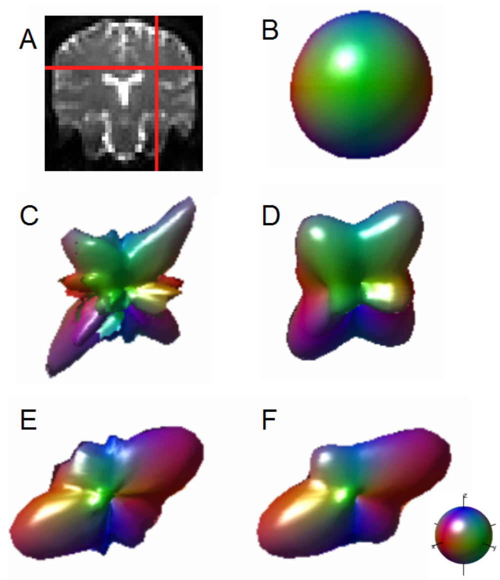

Fig. 2. Single voxel ROI from the centrum semiovale (A), the DT ellipsoid (B), and the surface reconstructions of the original and the SHD reconstruction (odd l orders removed) pairs : D_{app} profile (C, D), QBI ODF (E, F), Surface plots were color-coded according to the orientation in the lab frame.