Multiple Kernel Spherical Deconvolution

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INTRODUCTION

Diffusion Tensor Imaging (DTI) provides sensitive and reproducible measures of fiber integrity, although it is unable to resolve crossing fibers. High Angular Resolution Diffusion Imaging (HARDI) methods can resolve crossing fibers, but do not provide estimates of the intrinsic anisotropy in each fiber, and hence have very limited ability to assess the integrity of individual fibers. For example, conventional spherical deconvolution [1] assumes that all fibers have the same intrinsic diffusivities. 'Model free' methods, such as diffusion spectrum imaging (DSI) [2] and Q-ball imaging (QBI) [3], estimate the probability density function for displacements, but do not attempt to disambiguate fiber coherence and intrinsic fiber diffusion properties. In this work, we propose an approach that resolves crossing fibers and estimates the intrinsic diffusion properties of each fiber. Multiple kernels are used in spherical deconvolution and multiple shells in q-space are sampled in order to estimate the kernel for each resolvable fiber in a voxel. The result is a fiber orientation distribution (FOD) function and kernel estimate for each resolvable fiber. These can be used to distinguish changes in fiber coherence from changes in intrinsic fiber diffusion anisotropy, and potentially provide more accurate analysis of the properties of fiber pathways in the brain.

METHODS

Theory: The procedure has three basic steps. First, the anisotropic part of the diffusion weighted (DW) signal is decomposed into contributions from each fiber compartment. For n_f fibers, this is accomplished by splitting the signal into n_f components with the maximum degree of axial symmetry. Axial symmetry is measured using a spherical harmonic decomposition (SHD) of the signal. Nonlinear optimization is used to find the orientations of n_f axes (one for each fiber compartment) around which signal components have the greatest axial symmetry. Next, the radial diffusivity in each fiber compartment is estimated by fitting the decay of the fiber-specific signal as a function of b value. For this step, we use a theoretical model of how the SHD of the signal from a compartment depends on radial diffusivity and b value [4]. Finally, the decay of the isotropic part of the total signal as a function of b value is used to fit for the compartment volume fractions, using the estimated radial diffusivities found in the second step and the same theoretical model.

In-vivo experiment: HARDI images of a healthy volunteer were acquired on a 3T Philips scanner. Three DWI scans with 2.5 mm^3 isotropic voxels were taken at b = 1000, 2000, 3000 s/mm^2 respectively. Each scan consists of 60 diffusion-sensitizing directions evenly distributed on a unit sphere (scan time 11:10). Six non-diffusion weighted images were acquired for averaging. Eddy current correction and inter-scan registration were done simultaneously by affine registration[5]. The signal intensity scale was normalized to the non-DW image before the multiple kernel spherical deconvolution analysis. Fig. 2 shows the results of the multiple kernel analysis in a two compartment case. Fourth order terms in the signal SHD were used to identify the directions along which the fiber axes are aligned, where the iterative spherical deconvolution (iSD) algorithm [6] was used to obtain an initial seed for the nonlinear search.

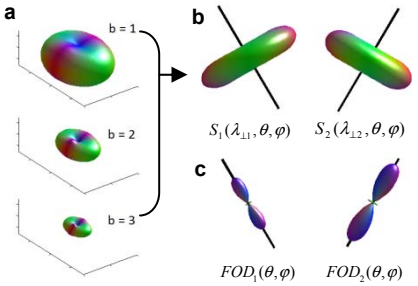

Fig.1. Simulation results. (a) Three shells of q-space were sampled, b values are in units of 10^3 s/mm^2; (b) SH coefficients of the three signal profiles were used to estimate fiber orientations and split signals belonging to individual compartments, allowing for multiple kernels; (c) using SH components of different orders, radial diffusivities and volume fractions of each fiber were estimated, and FOD's were reconstructed.

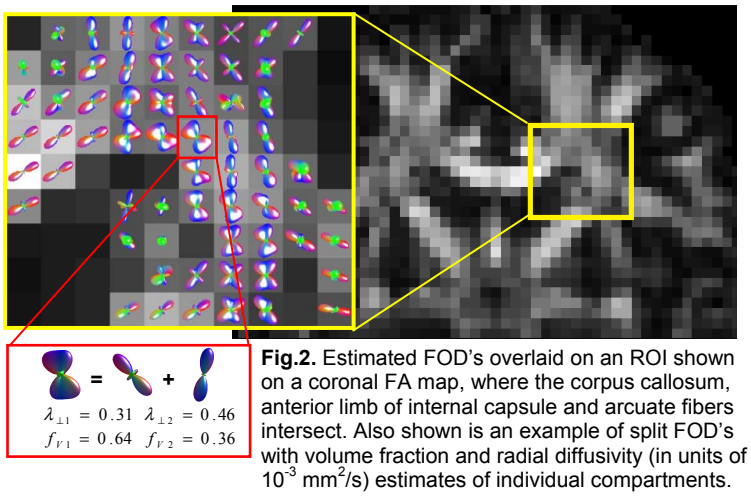

Fig.2. Estimated FOD's overlaid on an ROI shown on a coronal FA map, where the corpus callosum, anterior limb of internal capsule and arcuate fibers intersect. Also shown is an example of split FOD's with volume fraction and radial diffusivity (in units of 10^{-3} mm^2/s) estimates of individual compartments.

RESULTS

Results of a noise-free simulation were shown in Fig. 1 for illustrative purposes. In the in-vivo example (Fig. 2), the FOD's were overlaid on a coronal FA map within an ROI, where three major fiber bundles cross. The FOD's were only calculated where FA is greater than 0.2. An example of split FOD's with volume fraction and radial diffusivity estimates of individual fibers is also displayed.

CONCLUSION AND DISCUSSION

The multiple kernel spherical deconvolution approach is able to resolve crossing fibers, and the orientation estimates are consistent with iSD results (not shown). Further, the method provides estimates of radial diffusivity in each fiber. A limitation of this work remains in the assumption of a common mean diffusivity in the fiber compartments.

REFERENCES

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