Diffusional Kurtosis Approximation of the Orientation Distribution Function in the Human Brain

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Introduction: The Orientation Distribution Function (ODF) has been used in conjunction with Q-ball imaging techniques (1, 2) to depict the directionality of the diffusion distribution peaks in complex biological tissues such as white matter. A clear advantage of the ODF is that it can resolve complex fiber configuration in a model independent manner. In this abstract we investigate an alternative method of calculating the ODF (3) based on a mathematical relationship between the ODF and the diffusional kurtosis (DK) and demonstrate its application to resolve multiple fiber configurations in the human brain. DK imaging requires only a relatively limited number of diffusion measurements and, for the brain, *b* values no higher than 2500 s/mm^2, thus offering increased efficiency and improved SNR compared to other ODF techniques.

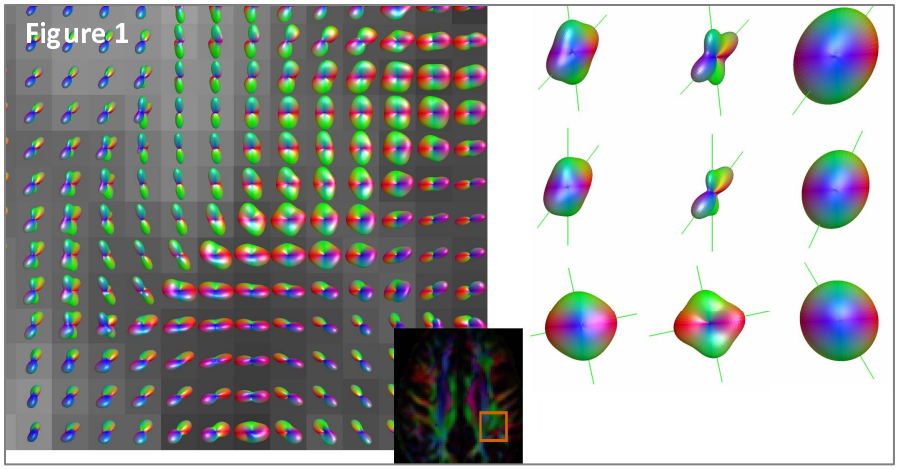
Theory: The ODF can be estimated as a function of the diffusion and kurtosis coefficients (3) and can be decomposed into two components representing the Gaussian and non-Gaussian (NG) diffusion contributions, respectively:

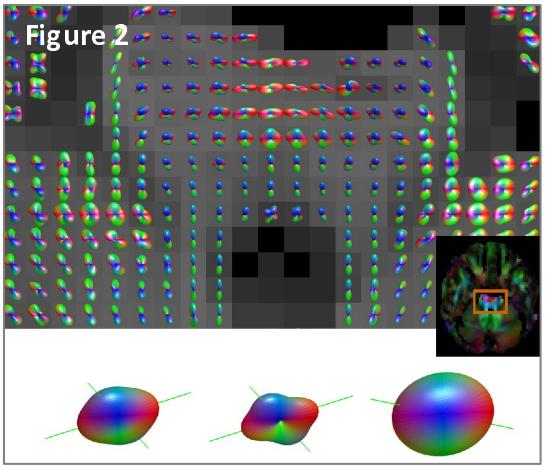
$$\psi(\hat{\mathbf{z}}) \approx \psi_{\mathrm{DK}}(\hat{\mathbf{z}}) = \frac{6\pi}{MD}\int_0^{2\pi} d\varphi \frac{3+K(\theta,\varphi)}{D(\theta,\varphi)} = \frac{6\pi}{MD}\int_0^{2\pi} d\varphi \frac{3}{D(\theta,\varphi)} + \frac{6\pi}{MD}\int_0^{2\pi} d\varphi \frac{K(\theta,\varphi)}{D(\theta,\varphi)} = \psi_{\text{G-DK}}(\hat{\mathbf{n}}) + \psi_{\text{NG-DK}}(\hat{\mathbf{n}})$$

where $D(\theta,\varphi)$ and $K(\theta,\varphi)$ represents the diffusion and the kurtosis coefficients, *MD* is the mean diffusivity, and the integration occurs along the equator perpendicular to $\hat{\mathbf{z}}$ direction (i.e., $\theta = \pi/2$). $D(\theta,\varphi)$ and $K(\theta,\varphi)$ are functions of the diffusion and kurtosis tensors, respectively (4).

Methods: Imaging experiments were conducted on a 3T Trio MR system (Siemens) for six healthy volunteers. DW images were acquired for 30 gradient directions and six *b* values (from 0 to 2500 s/mm^2) using a refocused-spin-echo EPI sequence. The in-plane resolution was 2mm×2mm and the slice thickness 2-4 mm. *Image data processing:* The DW images were first corrected for motion and spatially smoothed using SPM. The diffusion and kurtosis tensors were subsequently calculated similar to (5). The non-Gaussian (NG), Gaussian, and total ODFs were calculated at each voxel using the DK approximation using both absolute values and a 0 to 1 rescaled min-max version (1). The ODF surfaces were superimposed onto mean kurtosis maps (4) and were color-coded using the typical *xyz* to RGB mapping.

Results: The absolute and min-max normalized DK-ODF maps and the corresponding DT-ODF maps were derived for several brain regions where complex fiber architecture is present. Similar results were obtained for all subjects. In general, the NG-ODF in combination with the min-max normalization appeared to give the best visualization of the component diffusivity peaks. The fiber orientations resolved using the DK approximation appeared to be consistent with known anatomy. As expected, the complex fiber architecture was not apparent on the DT-ODF maps. Representative results of the scaled NG-ODF maps are shown in Figure 1 for a region situated at the interface of superior longitudinal fasciculus with corona radiata and the transverse arcuate fibers and in Figure 2 for a brainstem region. The magnified non-scaled NG-ODF, scaled NG-ODF, and DT-ODF (left to right) and the corresponding peak directions are shown for representative voxels from each figure.





Conclusion: The DK approximation of the ODF is a promising and potentially very efficient method for characterizing complex fiber architectures in the human brain. Future studies will focus on optimizing the DKI acquisition and comparing the DK-ODF approximation with other ODF methods.

References: 1. Tuch DS. MRM 2004;52:1358. **2.** Hess CP, et al. MRM 2006;56:104-117. **3.** Jensen JH et al., ISMRM, 2006, Berlin, p. 1476. **4.** Jensen JH, Helpern JA, Ramani et al. MRM 2005;53:1432. **5** Lu H, Jensen JH, et al. NMR Biomed 2006;19:236.