THE EFFECT OF THE KURTOSIS ON THE ACCURACY OF DIFFUSION TENSOR BASED FIBER TRACTOGRAPHY

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Introduction

Diffusion kurtosis imaging (DKI) (1) can provide a more complete picture of the diffusion characteristics than diffusion tensor imaging (DTI) (2) in the sense that it can also quantify the degree to which the diffusion is non-Gaussian. However, DKI requires the acquisition of additional diffusion-weighted images (DWIs) at higher b-values. It was previously shown that typical DTI measures, such as fractional anisotropy (FA), can be estimated more accurately with DKI than with DTI (3). In this work, we studied the *orientation information* of the second-rank diffusion tensor (DT), estimated either with DTI or DKI from real DWI data. More specifically, we investigated DT based tractography results obtained from (i) the conventional DTI and (ii) the DKI approach using the same DWI acquisition. Our results demonstrate that, in addition to the theoretically expected decrease in precision of DT estimators for DKI compared to DTI (4), there are clear differences in terms of accuracy for the reconstructed pathways between DTI and DKI.

Methods

Data acquisition and post-processing:

The DWI data set was acquired from a healthy volunteer (female, 25 y) on a 3T Philips Achieva MR scanner using an eight-channel head coil and a single-shot spin echo EPI sequence with the following parameters: 60 diffusion-weighted images with *b*-values of 1200 s/mm^2 and 2500 s/mm^2 with the gradient directions uniformly distributed over the sphere (5); 1 non-diffusion-weighted (b = 0 s/mm^2) image (NEX = 6); 70 contiguous slices (no gap), slice thickness = 2 mm; acquisition matrix of 112 x 112, reconstructed to 128 x 128 matrix size with a field-of-view of 224 x 224 mm^2 (acquired voxel size = 2 x 2 x 2 mm^3, reconstructed voxel size = 1.75 x 1.75 x 2 mm^3); TR/TE = 10265/107 ms. The diffusion tensor was estimated with a weighted linear least squares approach after correcting for subject motion and eddy current induced geometric distortions (6) with *ExploreDTI* (7). Deterministic and probabilistic tractography experiments were performed as described in Basser et al. (8) and Jones DK (9), respectively.

Diffusion Tensors from DTI and DKI:

The DT was estimated using its relationship with the signal attenuation both in the conventional DTI framework ($\mathbf{D}_{DTI}$), and in the DKI approach ($\mathbf{D}_{DKI}$):

$$S_{\mathbf{g}} = S_0 e^{-b_{\mathbf{g}} \mathbf{g}^T \mathbf{D}_{DTI} \mathbf{g}} \quad \text{and} \quad S_{\mathbf{g}} = S_0 e^{-b_{\mathbf{g}} \mathbf{g}^T \mathbf{D}_{DKI} \mathbf{g} + \frac{1}{6}(b_{\mathbf{g}})^2 \left(\frac{1}{3}\sum_{i=1}^{3} D_{ii,DKI}\right) \sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{3}\sum_{l=1}^{3} g_i g_j g_k g_l W_{ijkl}},$$

with $S_{\mathbf{g}}$ the diffusion-weighted signal along gradient direction $\mathbf{g} = [g_1\ g_2\ g_3]^T$, S_0 the b = 0 s/mm^2 image, $b_{\mathbf{g}}$ the diffusion weighting along direction $\mathbf{g}$, and W_{ijkl} the kurtosis tensor elements. Note that $\mathbf{D}_{DTI}$ was estimated from only S_0 and the b = 1200 s/mm^2 DWIs.

Results

Fig. 1 shows the first eigenvector ($\mathbf{e}_1$) color-encoded FA maps for (a) $\mathbf{D}_{DTI}$ and (b) $\mathbf{D}_{DKI}$ showcasing the decreased precision (noisier DT estimates) with DKI. The difference in orientation of $\mathbf{e}_1$ can be appreciated in Fig. 1(c), where the angle α between $\mathbf{e}_{1,DTI}$ and $\mathbf{e}_{1,DKI}$ is shown. The systematic deviation (bias) in the orientation of $\mathbf{e}_1$ between $\mathbf{D}_{DTI}$ and $\mathbf{D}_{DKI}$ can be observed in Fig. 1(d): there is clearly not a random orientation difference between $\mathbf{e}_{1,DTI}$ and $\mathbf{e}_{1,DKI}$. With tractography, this difference in accuracy of $\mathbf{e}_1$ can be observed more clearly as errors accumulate along the fiber trajectory. Figs. 2 (part of the genu of the corpus callosum) and 3 (motor pathways) demonstrate this effect for deterministic and probabilistic examples, respectively.

Discussion & conclusion

With DKI sequences becoming clinically feasible, there is an increasing interest in combining tractography based segmentations with DKI measures (e.g., kurtosis anisotropy and the mean/axial/radial kurtosis) as these kurtosis parameters may be useful to investigate microstructural properties of white matter structures or provide new insights into specific neuropathologies (10). It was not clear, however, whether the DT estimated with DKI would provide the same *orientation information* as the DT derived from conventional DTI. In this work, we have clearly shown with real diffusion MRI data that orientation differences do exist between DTI and DKI. More specifically, our tractography results indicate the existence of a systematic deviation of the reconstructed fiber trajectories between DTI and DKI. Given that DKI is a more *accurate* model, we believe that the architectural configuration of the DKI based fiber pathways is more *accurate* than the corresponding DTI based configuration.

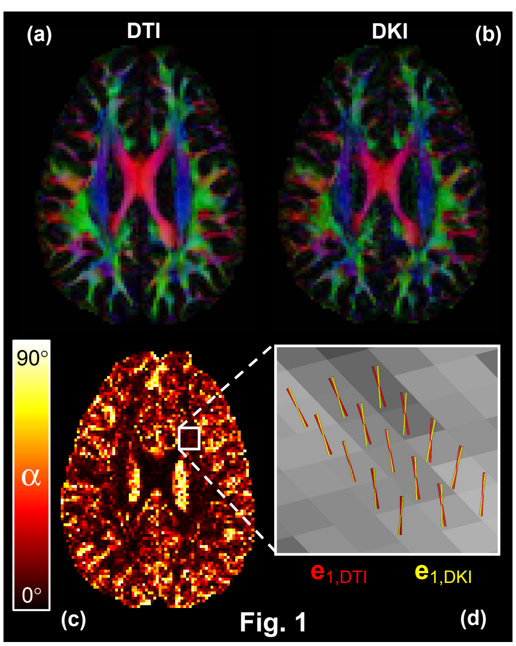

Fig. 1

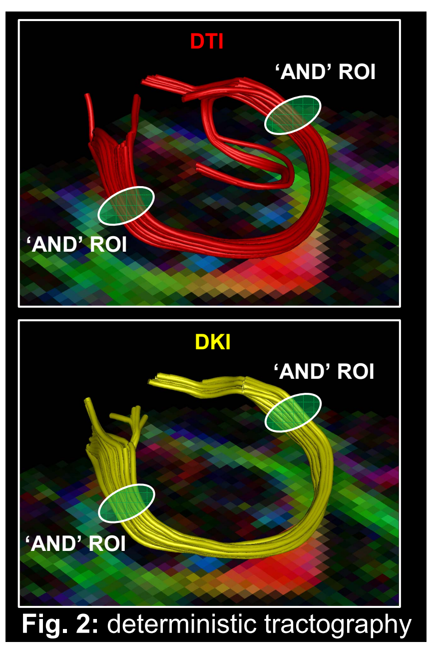

Fig. 2: deterministic tractography

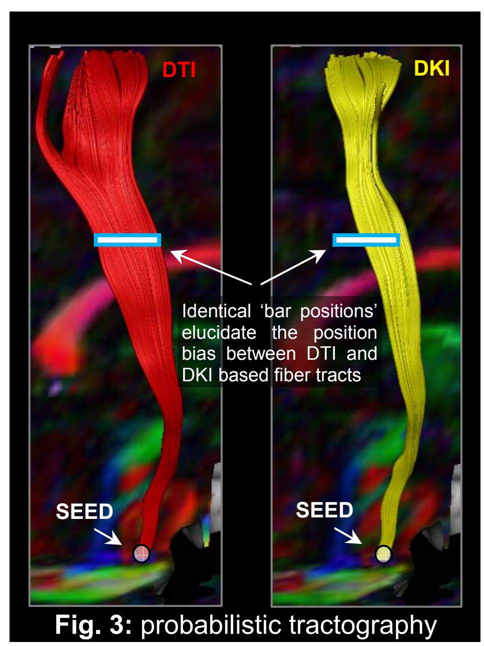

Fig. 3: probabilistic tractography

References

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