Comparison of Diffusional Kurtosis Imaging (DKI) and Diffusion Spectrum Imaging (DSI) for White Matter Fiber Tractography

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TARGET AUDIENCE

Diffusional kurtosis imaging (DKI) is an increasingly utilized diffusion magnetic resonance imaging (dMRI) technique to quantify properties of tissue microstructure and investigate changes that occur in numerous disease states as well as with normal development and aging.[1] This study will benefit those who use DKI and wish to perform white matter (WM) fiber tractography (FT) to visualize specific WM tracts or investigate neural connectivity.

PURPOSE

The closed form solution of the DKI approximation of the diffusion orientation distribution function (dODF) has recently been derived, enabling efficient implementation of DKI-based WM FT.[2] However, the accuracy of the DKI dODF has not been comprehensively assessed. In this study, using the dODF reconstructed from diffusion spectrum imaging (DSI)[3] as a reference, we aimed to quantitatively compare the dODFs reconstructed from DKI and diffusion tensor imaging (DTI).[2] Finally, their effects on WM FT were also qualitatively examined.

METHODS

Both DSI and DKI datasets were acquired for a single subject on a 3T MRI system with a maximum gradient strength of 45 mT/m and a maximum single direction slew rate of 200 mT/m-ms (Tim Trio, Siemens, Erlangen, Germany), using a twice-refocused balanced spin-echo diffusion echo-planer imaging pulse sequence with fat suppression. Acquisition parameters for both sequences were: voxel size = 2.7 × 2.7 × 2.7 mm^3, matrix = 82 × 82, number of slices = 45, bandwidth = 1356 Hz/Px, and a 32 channel head coil with GRAPPA and adaptive combine coil combine mode. Additional parameters for the DSI sequence were TR/TE = 8300/151 ms and a total of 515 diffusion encoding gradient directions with a maximum b-value of 6000 s/mm^2,[4] resulting in a total acquisition time of 71.7 minutes, and for the DKI sequence, TR/TE = 6100/102 ms, 64 diffusion encoding gradient directions at b-values of 1000 s/mm^2 and 2000 s/mm^2, and a total of 20 independent acquisitions with no diffusion weighting, resulting in a total acquisition time of 15.6 minutes. DTI data were also analyzed using the 0 and 1000 s/mm^2 b-value images from the DKI dataset. The DSI dODF was calculated using DSI Studio (http://dsi-studio.labsolver.org/). The DKI and DTI dODFs as well as all other analyses were calculated using in-house software written in MATLAB (MATLAB 7.0, The Mathworks, Natick, MA, USA). For the DKI and DSI dODFs, all local maxima pairs were detected using the quasi-Newton method, and angular differences were calculated between the global maxima pair of the DSI dODF and the nearest orientation predicted by the DKI and DTI dODFs. The directions corresponding to the DTI ODF maxima are identical to the principle diffusion tensor eigenvector directions.[2] Regions-of-interest (ROIs) with crossing fibers were defined as regions with multiple fiber bundle orientations detected with DSI with quantitative fractional anisotropy[5] values greater than 0.15. WM ROIs were segmented from the DKI dataset in regions with both the mean kurtosis > 0.9 and mean diffusivity < 1.5 mm^2/s.[2] WM FT was performed using the FACT algorithm with 100,000 randomly generated seed points, fractional anisotropy threshold = 0.15, and a minimum track length of 20 mm. WM fiber tracts were visualized with TrackVis (http://trackvis.org/).

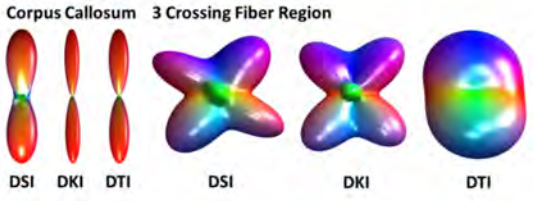

Figure 1. Example dODFs from regions with one predominant fiber bundle orientation, such as the corpus callosum, as well as a region where DSI identifies 3 fiber bundle orientations.

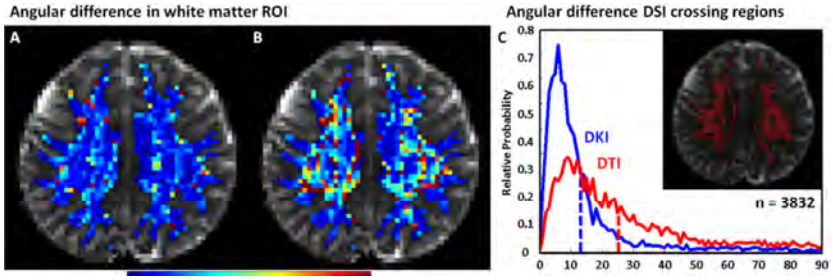

Figure 2. Angular difference in the WM ROI for DKI (A) and DTI (B). (C) Angular difference histogram for all voxels in which DSI detects multiple fiber bundle orientations for DKI (blue) and DTI (red), where the dashed line is the mean angular difference.

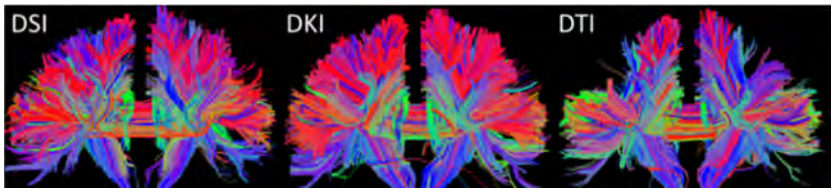

Figure 3. WM FT examples where a single, transverse slice filter has been added to emphasize the ability of DSI and DKI to track through crossing fiber regions that occur throughout the brain. DTI can only identify one predominant fiber bundle orientation in each voxel which affects the fiber tracts identified.

RESULTS

Example dODFs in a region with a single-fiber orientation (corpus callosum) as well as in a region with multiple-fiber orientations are shown in Figure 1. The dODFs of DKI and DTI are similar to the DSI dODF in single-fiber orientation, whereas only the DKI dODF is similar to the DSI dODF for multiple-fiber orientations. As shown in Figure 2, the DKI dODF has lower angular differences throughout the WM compared to DTI, and in crossing fiber regions the average angular differences for the DKI and DTI dODFs are 13.2 and 25.3 degrees, respectively. As shown in Figure 3, DKI-based WM FT is qualitatively more similar to DSI-based WM FT than is DTI-based WM FT.

DISCUSSION & CONCLUSION

In this study, we have demonstrated that the DKI dODF can resolve WM crossing fibers and has an angular accuracy comparable to the DSI dODF. Both DKI and DTI are capable of mapping the single predominant orientation, but the angular accuracy of DTI decreases substantially in complex fiber orientations due to its theoretical limitation under the assumption of Gaussian diffusion. Since the DSI dataset was acquired independently of the DKI/DTI datasets, the effects of noise, as well as systematic differences intrinsic to the methods, may contribute to the observed angular differences. Additional studies that account for noise effects are needed to obtain a more definitive assessment of the intrinsic differences between the different dODFs. With a shorter typical scan time than DSI, DKI is potentially more suitable for a variety of clinical applications. Further, DKI-based WM FT and associated quantitative indices may help improve our understanding of neural connectivity in normal and pathological states.

REFERENCES

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