Quantitative Comparison of Fiber Properties from DTI, HARDI and Light Microscopy

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Introduction Previously, we developed methods for making a direct comparison of fiber orientation measured using DTI and light microscopy of tissue sections of the same brains. We showed that there was good agreement between the principal direction of tensors and that of myelin stained fibers [1]. In this study, we extended the methodology to perform quantitative analysis of fiber orientation and coherence based on DTI, HARDI, and light microscopy.

Methods Three major datasets of an owl monkey were acquired: DT-MRI, blockface photographs, and high resolution light micrographs. Diffusion images were obtained on a 9.4T Varian scanner using a multi-slice, pulsed gradient spin echo sequence (b=xxx, yyy diffusion encoding directions, zzz isotropic resolution), as described previously [1]. From the diffusion MRI dataset, tensors and fiber orientation distribution (FOD) functions were obtained. The FOD for each voxel was calculated using the FORECAST model [2] through the 4th order, with negative peak regularization [3]. Diffusion data were registered with light micrographs using blockface photographs as an intermediate step and both rigid [4] and nonrigid transformations calculated by the Adaptive Bases Algorithm (ABA) [5]. Spatial correspondence was improved using FA to micrograph registration in the final step. The tensors were appropriately reoriented within the micrograph space using the preservation of principal direction (PPD) algorithm [6], and the spherical harmonic components of the FOD were rotated using the method of Su *et al* [7]. The angular distribution of myelinated fibers was calculated using a Fourier domain filtering approach [8] and was displayed as a rose plot.

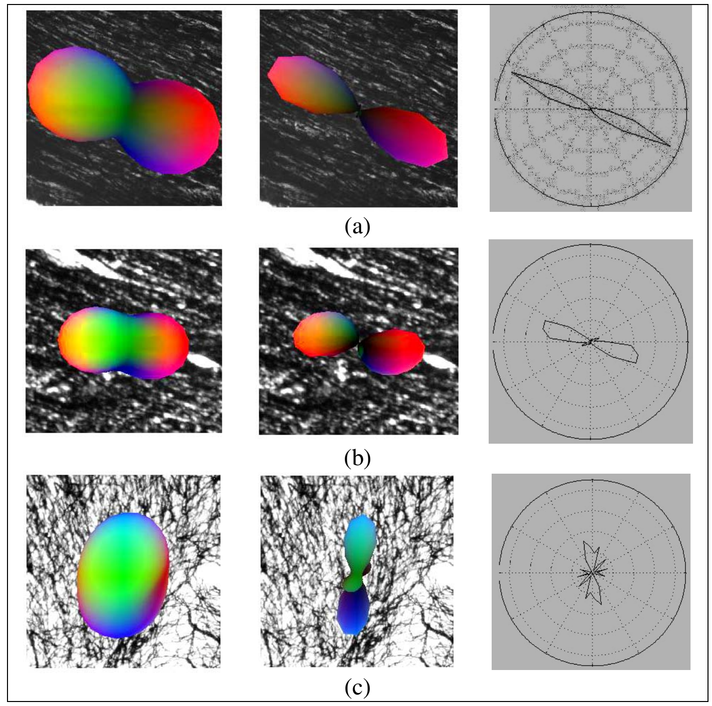

Figure 1. Fiber orientation comparison between tensors (left column), FODs (middle column), and rose plots of myelinated fibers (right column).

Results As shown in Figure 1, there was good correspondence between the orientations of the tensors, FORECAST FODs, and myelin stained fibers. Both tensors and FODs were able to identify the orientation of the fibers in the micrographs within less than 10 degrees (the limit of accuracy of the rose plot data, Fig. 2). As shown in Fig. 1, as the fibers become less coherent, tensors become more isotropic. It is also shown in Figure 1(c) that the FOD was able to resolve more complex fiber architecture. The shape of the FOD from FORECAST is comparable to that of the corresponding rose plot. A linear relationship between fractional anisotropy (FA) and the angular dispersion of myelin stained fibers (here measured as the standard deviation of the fiber orientation distribution) was also observed, as shown in Figure 3.

Conclusion In this study, diffusion parameters from DTI and HARDI were acquired for quantitative data analysis and comparison with fiber measurements from light microscopy. Both tensors and FODs were able to identify fiber orientation; the FOD was able to resolve more complex fiber structures while the tensors became isotropic. The linear relationship between FA and the standard deviation of fiber angles showed that FA provides a measurement of fiber divergence, as expected [9].

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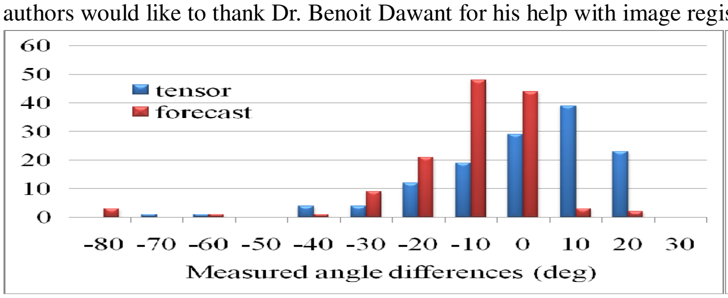

Figure 2. Histogram of measured differences between the tensor and micrograph (blue) and between the FORECAST FOD and micrograph (red) estimates of fiber orientation.

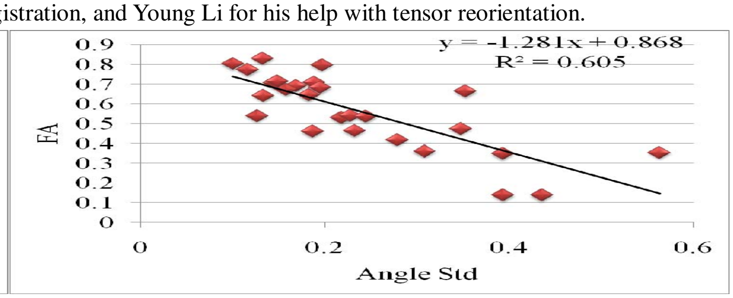

Figure 3. FA vs. standard deviation of fiber orientation measurements of micrograph

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