Characterizing DTI Image Quality and the Efficacy of Dyadic Sorting with a Capillary Phantom

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Introduction

Diffusion tensor imaging (DTI) is an MRI-based technique used in clinical research to map white matter fiber trajectories in the brain. As this technique evolves into one that will enhance diagnosis and evaluation for a number of neurological conditions (1), methods for characterizing systematic uncertainty need to be developed. It is *theoretically* well-documented that ROI-averaged metrics of DTI (e.g., tensor eigenvalues) exhibit a systematic bias that depends on the signal-to-noise (SNR) ratio in an image (2). In MR applications where SNR is spatially dependent (e.g., SENSE), this bias can mimic pathology. In this project, we use a capillary phantom (e.g., 3) to characterize *empirically* the noise-dependent bias in DTI data, and to observe the corrective effect of using dyadic sorting of tensor components (2). Capillary phantoms imaged during clinical procedures are suggested as a tool for monitoring uncertainty within each image.

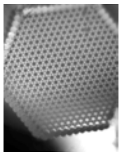

Figure 1: Hexagonal array.

Methods

Two phantoms were constructed for testing, using water-filled arrays of glass capillary fibers from Schott Glass (Figure 1). The hexagonal cross section allows for larger "macro-arrays" to be constructed from close-packing these arrays. The first phantom, used to study the effect of SNR on DTI eigenvalues, was constructed with three macro-arrays, each with a different capillary diameter (i.d.~23, 48, and 82 μm). Each macro-array was inserted into glass vials filled with undoped water, which were placed in a water-filled polypropylene container. The second phantom, used to investigate the relationship between ROI size and eigenvalue correction, consisted of thirteen arrays bound into a macro-array (capillary i.d.~23 μm) in a water-filled tube lightly doped with $CuSO_4$.

The first phantom was scanned using a GE Excite HD 3.0T MRI scanner, using an eight-channel phased-array head coil. An axial high-resolution FSPGR 3D image was acquired (voxel size=0.23mm ×0.23mm×1mm) to verify regions of interest (ROI). Seventeen axial DTI series were acquired with TR values in the range 2-8 sec, using an EPI sequence (TE=78.5msec; FOV=180mm; slice thickness=3mm; 12 diffusion gradient directions; b=1000s mm^{-2}; Acq. Matrix=256×256). In this manner, the undoped water signal intensity was modulated via T1 contrast to yield five different SNR values. Averaging selected series together resulted in eight unique SNR values. Macro-array ROIs and free water ROIs were defined using the b=0 reference images. Capillary SNR values on average are ~50% of free water SNR values; due to the variability of signal within the small ROIs, capillary SNR values are reported here as 50% of the mean SNR value for free water. The second phantom was scanned sagitally with a Bruker BioSpin 7T MRI scanner using an high-resolution spin-echo sequence (TR=500msec; TE=18.4msec; FOV=17.0mm; slice thickness=0.066mm; 12 diffusion gradient directions; 2 b-values=340,540 s mm^{-2}; Acq. Matrix=96×96).

The tensor eigenvalues, eigenvectors, and fractional anisotropy (FA) were calculated using Matlab (Mathworks Inc., Natwick, MA) software. Sorting of eigenvector-eigenvalue dyadic pairs (2) was implemented by calculating average eigenvalues and eigenvectors in an ROI as per Basser, et al.(2).

Results

Figure 2 illustrates the dependence of eigenvalues on SNR within each ROI. The largest tensor eigenvalue should be equal for all ROIs, corresponding to the apparent diffusion coefficient (ADC) for free water. Furthermore, the smallest two eigenvalues should be equivalent, corresponding to radially-restricted diffusion within the capillaries. Sorting of dyadic pairs (middle row of Figure 2) results in moderate corrections, although the SNR dependence is still noticeable. A small ROI, such as that used for the small i.d. array (# pixels ~ 20), demonstrates the least change after sorting (2). Figure 3 shows the amount of correction within one array as a function of ROI size (here, SNR~25). Considering the mean eigenvalues sorted within the whole array to represent 100% accuracy (# pixels~2800), the precision of the correction after sorting as well as the accuracy of the correction depends on the ROI size, as expected. The mean FA accurately represents the actual FA for ROIs of ~50 pixels or more, given this SNR value.

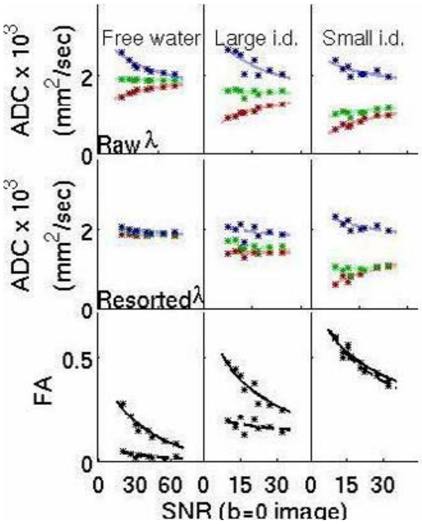

Figure 2: λ and FA values after resorting, as a function of SNR, for capillary arrays and for free water. The solid line represents raw values, and the dashed line indicates post-sorted values.

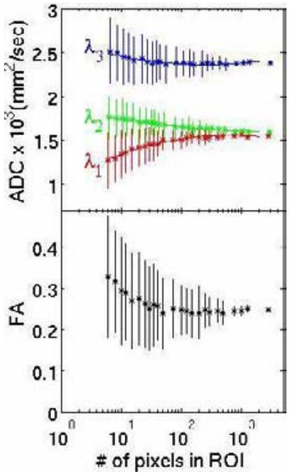

Figure 3: λ and FA values after resorting, as a function of ROI size.

Discussion

These results demonstrate that dyadic sorting can improve the accuracy of DTI eigenvalues, based on prior knowledge of capillary geometry. Success is limited at lower SNR values and smaller ROIs.

References

1) Hagmann P., et al. 2003. Neuroimage 19: 545
2) Basser PJ, et al. 2000. Magn. Reson. Med. 44: 41
3) Yanasak NE, et al. 2006 Magn. Reson. Imag. In press.