Characterizing cone of uncertainty in diffusion tensor MRI

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INTRODUCTION

Diffusion tensor MRI (DT-MRI) provides information on the orientation of fibers by modeling water diffusion with a 3x3 tensor. In the presence of image noise, however, perturbations are included in the diffusion tensor field that affect the accuracy of fiber tractography (1). Basser and Jones (2, 3) have described the uncertainty in orientation with a circular cone, the "cone of uncertainty" (COU). In this study, we have investigated whether the COU is circular and the effect of signal averaging on reducing the uncertainty using a nonparametric bootstrap method (4) and perturbation theory (2,1).

METHODS

The DT-MRI experiment is performed on a GE 3T scanner (dual spin echo EPI, six diffusion weighting directions, b=1000 s/mm^2, TE = 89 ms, TR=9 s, 128x128 image matrix, 30 slices, 2x2x4 mm voxels, 63 s scan time) with 37 repetitions. First, the image data were averaged and used to estimate the true orientation of the principal eigenvector, $\mathbf{v_1}$, in each voxel in an ROI (Fig. 1). Next, bootstrap sampling (with replacement) was used to select n_A acquisitions to average (n_A = 1 to 37), and the principal eigenvector was calculated for this sample. The process was repeated to obtain 200 estimates of the principal eigenvector (for each choice of n_A). Each of the 200 principal eigenvectors was projected onto the plane perpendicular to the 'true' $\mathbf{v_1}$ of the first step. A principal component (PC) analysis was used to analyze the distribution of projections in the plane to define the major and minor axes of the elliptic COU. The equality of the major and minor axes (the standard deviations of the PC's) is tested using the method of Bartlett (5), and cones are color coded by the p-values of the test. Mardia's multivariate normality test (6) was applied to the distribution, and the effect of DW signal averaging on the COUs was quantified.

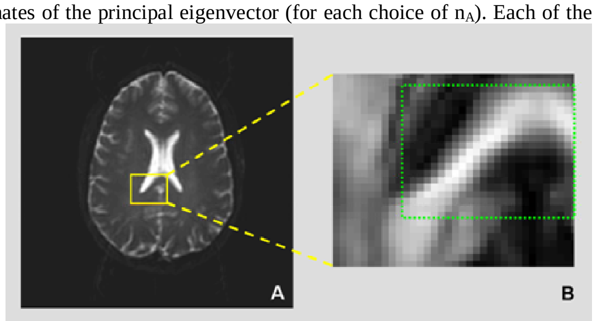

Figure 1. A T2-weighted image (A) with an ROI and its FA map (B) with green dot area for COU reconstructions.

RESULTS AND CONCLUSION

The COUs for voxels in the ROI of Figure 1 are shown in Figure 2 (for n_A = 37). Each cone is oriented along the local value of $\mathbf{v_1}$ and is color coded according to the p-value for equality of major and minor axes (e.g., circular cones are dark red). The cone angle is the standard deviation of the (diffusion) principal eigenvector in the corresponding plane. The distribution of uncertainty is multivariate normal for most voxels, and most of the cones are elliptic, although there are a few circular cones in high FA regions. Generally cone eccentricity increases at low fractional anisotropy (FA) and low SNR (i.e., less signal averaging). Figure 3 shows the uncertainty (cone angle, θ) for 37 signal averages and a range of FA values. Cone angles decrease with increased averaging and FA. At high SNR and/or high FA, perturbation theory agrees with the bootstrap analysis. In summary, the COU for fiber direction is mostly elliptic and the errors of the principal eigenvector for diffusion are normally distributed. This information can be used to make more realistic probabilistic algorithms for MR tractography and to evaluate the benefits of signal averaging for fiber path accuracy.

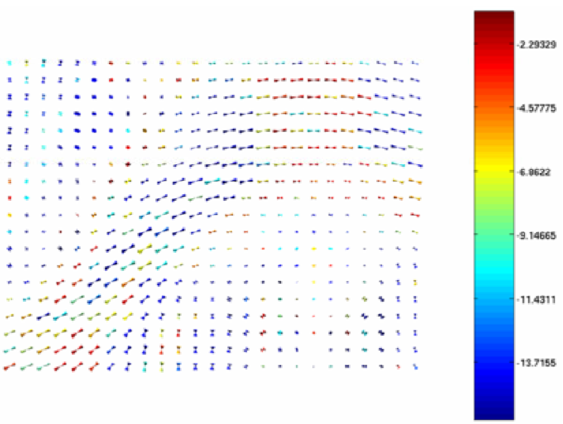

Figure 2. The COUs are colored with log 10 based p-values from low (blue) to high (red).

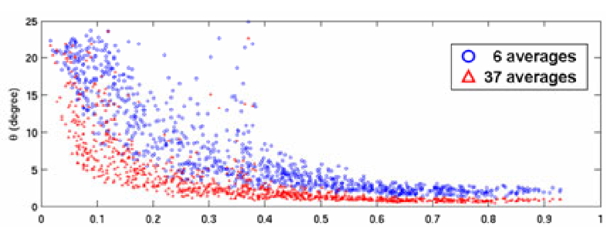

Figure 3. The uncertainty of cones along major axis for 6 (blue) and 37 (red) signal averages.

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