Noise-induced bias in low-direction diffusion tensor MRI: Replication of Monte-Carlo simulation with in-vivo scans

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Introduction

Clinical neuroimaging studies involving diffusion tensor MRI (DTI) require precise estimation of diffusion properties for statistical analysis. Tensor derived measures such as fractional anisotropy (FA) and trace are often analyzed for hypothesis testing. Given the limited scanning time typically available for studies, careful selection of scanning protocols and processing methods is essential for accurate and precise measurements. Analysis of the effect of MR noise on tensor derived measures has shown a negative bias in FA when the principal eigenvector of tensor is aligned with a gradient direction [1][2][3]. This bias can lead to a correlation between FA and tensor orientation in protocols with low numbers of gradient directions. We extend the results of simulation experiments by showing evidence of predicted anisotropy bias in in-vivo data.

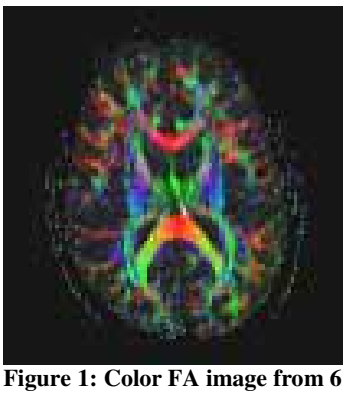

Figure 1: Color FA image from 6 direction scan

Materials and Methods

Simulation of the effect of Rician noise in diffusion weighted images was implemented by applying the Stejskal-Tanner equation to a known tensor and adding Rician noise to the predicted intensities. Three gradient schemes with approximately equivalent scanning time were considered. One repetition of 60 gradient directions, 3 repetitions of 21 gradient directions, and 10 repetitions of 6 gradient directions were simulated. Tensors with a known FA value were simulated with the principal diffusion direction aligned and unaligned with a gradient direction. Tensors were simulated with a trace of $2.1*10^{-3}$ mm^2/s, b-value of 1000 s/mm^2, baseline 265 intensity units, and sigma 27 intensity units. Several FA values were simulated, and one example for FA=0.6 is shown in Figure 2. The choice of the baseline signal and sigma were obtained from ML estimation of rician noise parameters from test data.

In-vivo scans of a healthy adult volunteer were acquired to replicate the simulation experiments. The baseline image of each scan was rigidly aligned to the 60 direction baseline. The 21 and 6 direction scans were averaged across repetitions. A white matter mask was created via registration of a tissue classification map obtained from structural image segmentation. Within the white matter segmentation, the alignment of a tensor to the gradient directions was computed by the angle between the estimated principal diffusion directions with each gradient direction in the 6 direction scan. Voxels within $\pi/16$ radians of aligned with a gradient and those within $\pi/16$ of being unaligned were segmented into two groups, and the labels were applied to each image.

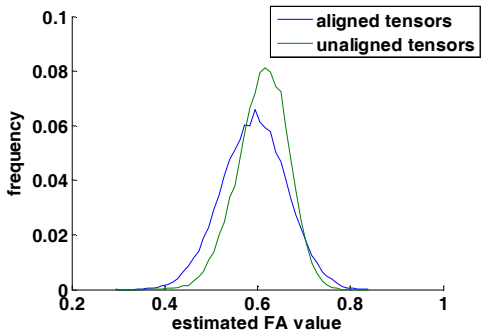

Figure 2: Monte Carlo simulation of the estimated FA from tensors with true FA=0.6 aligned and unaligned with gradients in 6 direction protocol

Results

Results from the simulation, show a negative bias in the FA value for tensors aligned with the gradient direction versus unaligned as well as substantial variability due to noise. Figure 3 shows a comparison of histograms of FA values for the aligned and unaligned voxels in the in-vivo scans. The histograms show a difference in mean FA of .046 between the aligned and unaligned groups in the 6 direction scan with a 95% confidence interval between .052 and .040, the 21 direction scan has difference of .026 with confidence interval between 0.032 and 0.020, and the 60 direction scan has a difference of .015 with 95% confidence interval between .021 and .0081.

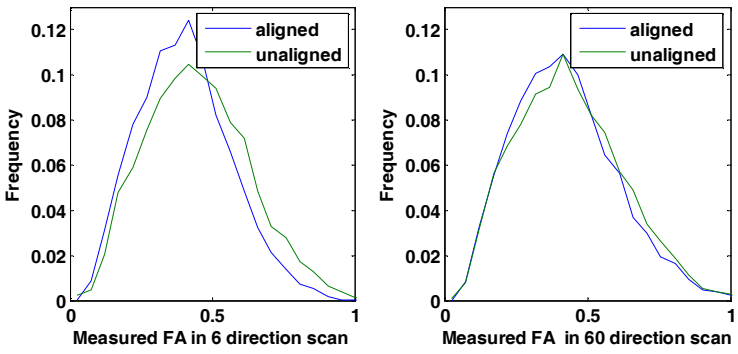

Figure 3: Histograms of measured FA in aligned and unaligned masks for 6 direction and 60 direction scans

Discussion

The simulation results predict a bias of anisotropy measures due to MR noise in protocols with few gradient directions as well as substantial variability due to MR noise. The in-vivo results support the predictions of simulation by showing a decrease in the correlation between FA and tensor orientation as the number of gradient directions increases.

References

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