Evaluating the Uncertainty of DTI Parameters at 1.5, 3.0 and 7.0 Tesla

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Introduction

The introduction of ultra high field MRI scanners operating at field strengths above 3T has shown imaging of the human brain at an increased signal to noise ratio (SNR)[1,2]. However, increased field strengths substantially shorten T2 and T2* times[3] and causes larger image distortions and signal dropouts due to global magnetic susceptibility related artifacts. Previous investigations[4] have shown the gain in SNR for diffusion tensor imaging (DTI) at 7T, even at long echo times. However, it was not investigated whether this increased SNR translates to improved precision and accuracy for DTI sequences. The aim of this study is to compare DTI at 1.5T, 3T and 7T in the same volunteers using a data driven approach that uses clinically relevant DTI scans and observes resulting uncertainties in the DTI metrics. We investigated potential differences between these field strengths in terms of the precision in fractional anisotropy (FA) and the precision of the primary eigenvector of the diffusion tensor. Regional averages from nine volunteers, measured at each field strength, were compared. For this, three regions of interest (ROIs) were selected: sections of the corpus callosum, cortico-spinal tract and cingulum bundles. The benefits in terms of precision of performing DTI at 7T are shown.

Materials and methods

DTI data was collected on three Philips Achieva MRI scanners, operating at 1.5, 3 and 7 Tesla. Nine volunteers were scanned on all three scanners using a diffusion weighted spin echo sequence with an echo planar imaging readout (EPI factor 47). Data were acquired at a resolution of 2 mm isotropic resolution covering a field of view of 224×224×98 mm in 49 slices. As the hardware is not identical on all three scanners, the diffusion, repetition, read-out and echo times differ slightly per scanner. The scanner dependent parameters are shown in table 1. Diffusion measurements consisted of 1 image at b = 0 s/mm^2 and 32 directions at b = 1000 s/mm^2. Also, a noise acquisition was performed by adding an extra diffusion direction without RF and gradients. This allows for mapping of the standard deviation of the noise from the coil elements and the SENSE parallel imaging reconstruction profile. DTI processing was conducted using ExploreDTI[5] and included eddy current correction, brain masking, tensor estimation using weighted linear least squares optimization with an anisotropic covariance matrix and determination of uncertainties of the DTI parameters using a wild bootstrap method[6]. Finally, full brain tractography was performed using a streamline algorithm, tracking pathways with a minimum FA of 0.2 and maximum angles of 20°. Fiber pathways were selected and segmented in between two manually placed masked on color coded FA images. Segments of the corpus callosum (CC), the cortico spinal tract (CST) and cingulum bundles (CNG) were selected for further analysis (figure 1). The uncertainty in FA is expressed as the standard deviation of the FA found in 1000 bootstrap repetitions. Likewise, uncertainty in the primary eigenvector is expressed as the standard deviation of the bootstrapped orientations relative to the mean orientation, also known as the cone of uncertainty[7].

Results and Discussion

The relative SNR increase for the three scanners was found to be 1 : 2.1 : 3.2 for 1.5T, 3T and 7T respectively, averaged over all subjects and ROIs. The data acquired at 7T benefits from the increased field strength as well as the increased number of receiver coil elements. This study does not discriminate between these two effects. Figure 2 shows the group averages for the uncertainties in FA and primary eigenvector. The boxplots show the distributions of the values for the three different field strengths, grouped per ROI. A clear decrease in uncertainty for both DTI metrics can be observed. To further illustrate this, figure 3 shows the uncertainty in the primary eigenvector, as visualized by the cones of uncertainty. For the same location in the brain, a reduction of the uncertainty of the primary eigenvector can be observed. This effect is a direct result of the increase in SNR, and shows the gain of scanning at higher field strengths and with improved receiver coils.

Conclusions

In this study it is observed that by imaging at 7 Tesla while utilizing a 16 channel head coil, a gain in SNR is achieved, even with long echo-time sequences such as diffusion weighted acquisitions. As a result, the DTI-based metrics of FA and primary eigenvector improve significantly. This improves the usability of these measures, both in fiber tracking applications in a single subject, and in reporting of group averages.

References

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***Table 1:** Details of scanning parameters*

FIELD (Tesla)	1.5	3.0	7.0
TR (ms)	9 837	8 384	11 268
TE (ms)	65	51	71
BW phase (Hz)	21	29.7	29.6
BW read (Hz)	2101	2969	2555
Δ (ms)	32	25.1	35.2
δ (ms)	17.5	13.3	23.8
Scan duration	6'04"	5'10"	6'56"
Coil elements	8	8	16

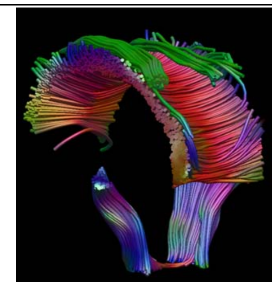

Figure 1: 3D view of regions of interest based on segments of selected fiber trajectories.

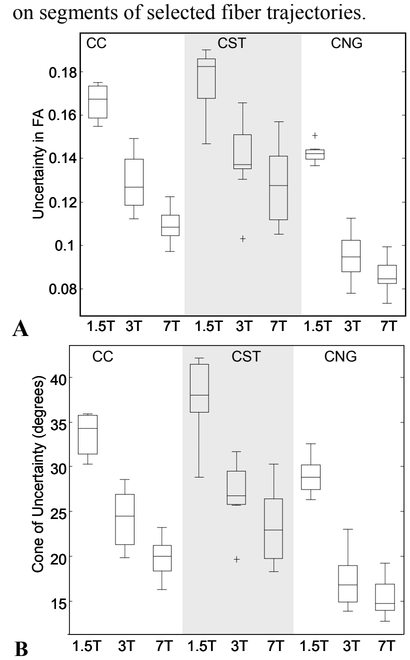

Figure 2: Group averages of 9 volunteers for three ROIs, scanned at three field strengths each, for three parameters, A: uncertainty in FA, B: Cones of Uncertainty.

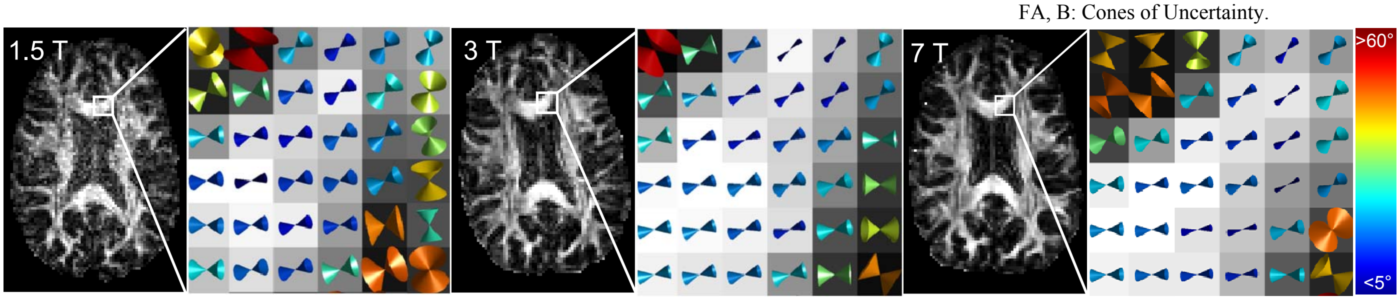

Figure 3: Cones of Uncertainty in a single subject on three field strengths, showing the uncertainty in the primary eigenvector for a section of the corpus callosum.