Systematic Comparison of DTI at 7T and 3T: Assessment of FA for Different Acquisition Protocols and SNR in Healthy Subjects

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Introduction: Diffusion tensor imaging (DTI) has many promising clinical applications but is limited at ultra-high field. Higher field strengths increase SNR but are more prone to artifacts from B_0 and B_1 field inhomogeneity and shorter T_2*. There are several studies exploring the feasibility of 7T DTI [1-5]. In DTI applications, accurate measurement of fractional anisotropy (FA) is critical in assessment of white matter (WM) integrity and its microstructure. Recently, cross-site difference in bias level of DTI measurement was reported, in spite of that the measurement carried out by scanners and software were from the same vendor [6]. Further, each group has developed particular acquisition methods and scan parameters. Thus, FA will have certain range of measured values method-to-method as well as site-to-site. In this study, we explored the effect of different scan parameters on FA values in aging brain at 7T and 3T. In the study, we considered the voxel shape, the number of diffusion-weighting (DW) gradients, and voxel volume as well as FA sampling methods. In addition, we investigated DTI SNR and FA over a range of SENSE factor (R) systematically. As a trial, we explored high resolution DTI at 7T and 3T for comparison.

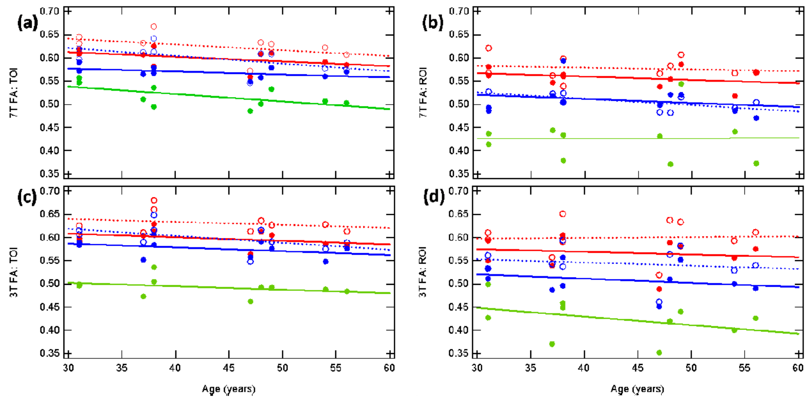

Fig.1. FA measurement dependency on voxel dimension, gradient scheme and sampling method: (a) 7T- TOI, (b) 7T-ROI, (c) 3T-TOI, and (d) 3T-ROI

Methods: Ten healthy (31-56y) subjects were recruited and underwent a series of DTI acquisitions at 7T and 3T Philips Achieva scanners with IRB approval. A 16-ch coil (NOVA Medical) for 7T and an 8-ch SENSE coil for 3T were used. R=2 was used for 3T while higher R=5 was used for 7T to compensate image distortion. Isotropic ($2\times2\times2mm^3$) and anisotropic voxel ($1.6\times1.6\times3.2mm^3$) dimensions were employed. Two gradient schemes (6, 15) were tested (b=0, 1000 s/mm^2, 3 averages for b=1000). An anisotropic voxel dimension ($2\times2.5\times5mm^3$) was also used with 6 gradient directions. Thus, total five sets of scan parameters were used. Mean FA was sampled in two ways. First, measurement was carried out using a ROI covering entire corpus callosum in the midsagittal plane. Next, mean FA across the entire fiber bundle through the same ROI was recorded. Collected DTI metrics were examined using analysis of covariance (ANCOVA) using SPSS (Version 16, SPSS, Chicago, IL) at the significance level $\alpha = 0.01$. We carried out a intra-individual DTI SNR study using a parameter set that is as identical as possible (TR/TE=10400/75ms, voxel=$2\times2\times2mm^3$, FOV=$240\times240mm^2$, 15 directions (b: 0 and 1000) at both 7T and 3T over a range of R (2 to 7). Two sequential scans were acquired with RF-on for the first and off for the second. SNR was determined as the ratio of signal in the RF-on images over the standard deviation in the RF-off image for 6 selected ROIs. Six selected anatomical regions were body, genu, splenium of corpus callosum, right post limb of internal capsule, subcortical white matter, and right thalamus. In-house code written in IDL (ITT, Boulder CO) was used for the SNR calculation. Then FA measurement was followed. In trial high resolution DTI, a parameter set of 1x1x2=2mm^3 voxel, 15 gradient directions, 2 b-values (0 and 1000) was tested over a range of R (3 to 6) at 7T and 3T.

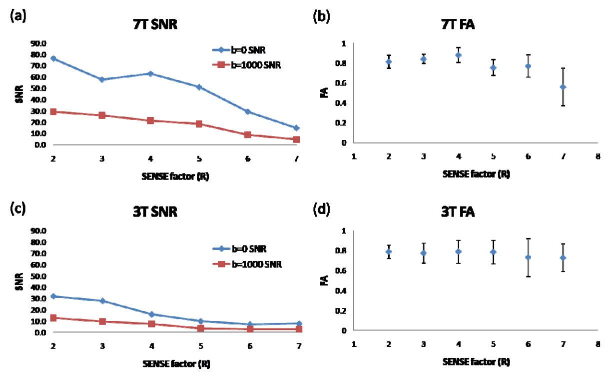

Fig. 2. SNR and FA for different Rs

Results: In the regression analysis of results from five parameter sets, we observed no significant difference in slopes ($p > 0.01$; $\alpha = 0.01$) and significant difference in offset ($p < 0.001$; $\alpha = 0.01$) between the regression lines. Larger anisotropic voxel apparently resulted in relatively low FA values (green closed circles in **Fig. 1.**). FA sampling methods seem to affect FA values (lower for ROI analysis) for both field strengths. Relatively, no obvious difference was measured between field strengths with using same sampling. Interestingly, in most cases, low directional resolution resulted in slightly higher FA values (dashed line). With the same gradient scheme, FA sampled from the isotropic voxels was higher. This result supports a previous report [7]. In a given condition, SNR values measured at 7T were much higher (**Fig.2. (a), (c)**) than 3T except for subcortical WM. Image distortion in the outer brain region was much significant at 7T. FA in each anatomical region was not significantly different between 7T and 3T (R up to 6). At 3T, even signal images appeared to be noise images with R larger than 5. The standard deviation of FA values clearly increased larger at 3T than at 7T as SNR decreased (**Fig.2 (b), (d)**). FA at 7T showed more (than 3T) variability among various anatomical regions (not shown here). In the trial high-resolution DTI, better results was achieved in color FA map in the central brain region (**Fig.3. (a)**). G-factor distribution across the selected ROIs was more homogeneous with 16-ch coil at 7T (not shown here).

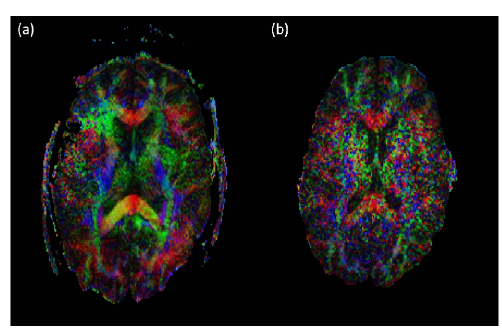

Fig. 3. Comparison of high-spatial resolution color FA maps: (a) 7T and (b) 3T. (R=4) 7T showed better DTI quality in the central brain region. **Note:** 16-ch coil was used for 7T and 8-ch coil for 3T

Discussions: Our study demonstrated that FA is significantly dependent on the voxel volume, voxel shape, and diffusion gradient scheme even within-site measurements. Therefore it would be useful to have a standardized set of acquisition parameters in DTI applications. It is essential to use higher SENSE factor to compensate image distortion at ultra high field. In this case, more numbers of channels in the coil would be beneficial. Decreased SNR (due to increased R) did not affect FA itself. However standard deviation of FA increased as SNR decreased. Hence, ultra high-field DTI would be better for accurate DTI measurement due to less standard deviation in FA. To the best of our knowledge, this (less standard deviation in FA at 7T) has not been reported yet at the time of this submission, although confirmation should be followed with results from an extended number of subjects.

References: [1] Metcalf et al. ISMRM 2007, 2180, [2] Morgan et al. ISMRM 2008, 1807, [3] Speck, ISMRM 2009, 1462, [4] Sigmund et al. ISMRM 2009, 169, [5] Polders, ISMRM09 1406, 2006, [6] Zhu et al. Proc. Intl. Soc. Mag. Reson. Med. 17 (2009), [7] Oouchi et al.AJNR (2007)