Contrast Similarity between FA and T2* Studied in White Matter of the Human Brain at 3.0 and 7.0 T

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Introduction: High resolution T_2*-weighted MRI at 7T has recently been shown to be useful for studying white matter microstructures [1]. In this study, the orientation and field strength dependencer of R2* in white matter and its correlation with diffusion anisotropy were investigated in normal volunteers at 3 and 7T. Another goal of this investigation is to verify if the "magic angle" effect on MRI report previously [2] exists in white matter.

Methods: The experiments were conducted using a whole body GE Signa 3 and 7TT MRI systems equipped with Twin-Speed gradient sets. Signal receptions at 3 and 7T were performed using 16 and 24-channel whole-brain detector arrays (NOVA Medical Inc, MA) dedicated for brain imaging, respectively. DTI and highresolution R2* mapping were conducted at 3 and 7T in 6 and 3 normal volunteers, respectively. The 3T MRI protocol included the following: 1) Two repeated sets of R_2* mappings using a multiple echo GRE pulse sequence. The acquisition parameters were: FOV=24x18cm, 64 contiguous transverse slices of 1.5 mm thick, matrix size=512x384, TR=3s, flip angle 90°, TE was varied from 9.2 to 60ms, receiver bandwidth =32 kHz; 2). Four sets of repeated DTI measurements based on the single-shot SENSE EPI method. The acquisition parameters were: 64 contiguous axial slices of 1.5mm thick with locations coinciding with those of the R_2* measurements, in-plane resolution of 1.5x1.5 mm^2, TR=15s , b=1000s/mm^2, an optimized DTI scheme [3] with 3 T_2-weighted and 25 diffusion-weighted scans. The 7T MRI protocol was quite similar except for reducing the number of slices to 9 and adjusting TR/TE accordingly. In addition, the orientation dependence of R2* was performed in 8 subject at 7T by tilting their heads together with the RF coils relative to the main magnetic field. DTI data analysis included calculation of diffusion tensor elements, eigen parameters, and fractional anisotropy (FA). R_2* maps were extracted by pixel-wise fitting of an exponential function to the T_2*-weighted image intensities as a function of TE. For comparison, the extracted R_2* results were down sampled to 1.5x1.5x1.5mm^3 using a bicubic kernel to match the resolution of the DTI results. In order to detect the "magic angle" effect [2] the pixel R_2* values were plotted versus $|3\cos\theta^2 - 1|\cdot FA$, where θ is the orientation angle of the principle eigenvector with respect to B_0.

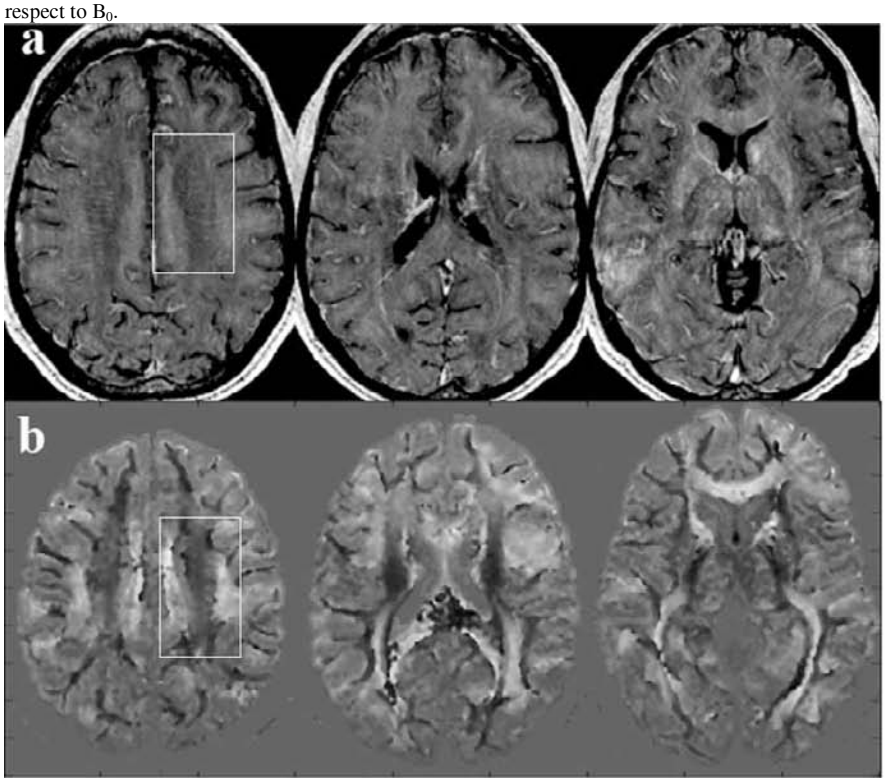

Fig. 1: R_2* maps (a) and snthesized DTI results $(3\cos\theta^2-1)\cdot FA$ (b) at the same slice locations.

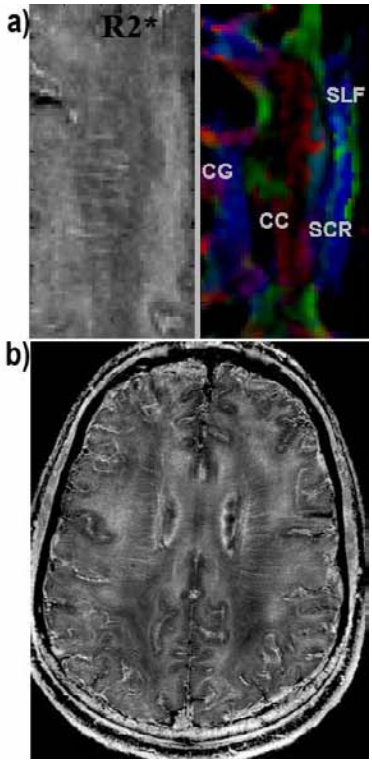

Fig. 2: Blow-up of the boxed aresa (a) and a 7T R_2* map (b).

Results: As shown in Figs. 1 and 2, R_2* results exhibit extensive heterogeneity within white matter as similarly observed earlier at 7T [1]. The T_2* contrast difference between adjacent fiber bundles can be observed in many parts of the brain. For example, the average R_2* values at 3T for cingulum (CG) and superior coronal radiata (SCR) are 19.9 and 15.8 s^{-1}, respectively. At 7T, the corresponding R_2* values for CG and SCR are 34.5 and 28.6 s^{-1}, respectively [1]. As the field strength is increased, the T2* contrast difference between different fiber bundles is enhanced.Tthe contrast heterogeneity in R_2* maps was overall quite consistent with that in the synthesized image of $|3(\cos\theta^2-1|\cdot FA$ (Fig. 1b). This can be better appreciated in Fig 2a which depicts the boxed region at higher amplification. In Fig. 2a, the fiber bundles with different orientations, as identified with DTI, are also shown in the RGB color scheme. These fibers were readily delineable in the corresponding R_2* map. In addition, the R_2* map also revealed some further vascular details as bright linear lines. The scatter plot of R_2* versus $|3\cos\theta^2-1|\cdot FA$ shows a triangle area with a lower linear boundary R_2*>5$|3\cos\theta^2-1|\cdot FA$. This indicates that the R_2* relaxation may be related to $|3\cos\theta^2-1|\cdot FA$. But the orientation dependence is not exclusive. Other factors, such as iron content and vasculature, can also significantly affect R2* relaxation. The direct measurement of R2* dependence on orientatoin of the head relative to B_0 at 7T shows some minor changes in R2* depending on the anatomic locations. This could also be caused by RF and field inhomogeniety. On the other hand, the measurements in fixed brain tissue specimen demonstrate definitely no orientation dependence of R2*.

Discussion: Taking advantage of the R2* contrast difference between different fiber bundles, it is e possible to use T_2*-weighted MRI for direct detection of white matter fiber bundles at much higher spatial resolution. Using a 8-channel array coil, we have recently achieved T_2* mapping results in the human brain with the resolution of 0.5x0.2x0.2 mm^3 at 7T, which is over two order magnitude smaller than that of the highest resolution in DTI. High resolution T_2*-weighted imaging is also less susceptible to motion and susceptibility artefacts than DTI. Preliminary results from chemial assay of fixed brain tissues indicate that iron contents in neighoring white matter fiber bundles are quite similar, whereas myelin stain results show that there is a good correspondence between the myelin content and T_2* contrast variations. It remains to be a quite intriguing question to pin point the underlying mechanisms of the observed T_2* heterogeneity in white matter.

Reference: [1] Li,T.Q. et al. *Neuroimage*, **32**:1032, 2006. [2] Chappell K.E. et al. AJNR 25:431,2004. [3] Skare, S. et al. *J. Magn. Reson* **147:**340 (2000).