Fibre-to-field dependency of T1 relaxation time in human white matter at 3T

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Introduction

Anisotropic NMR properties are well known *in vivo*, yet not fully understood [1], There has been much recent interest in the anisotropy of coherence lifetime and T2 in the white matter (WM) [2,3]. Spin-echo coherence lifetime has been shown to be anisotropic in the human WM and explained in terms of translational diffusion through inhomogeneous magnetic fields created by mesoscopic susceptibility differences [3]. The angular dependence of coherence lifetime anisotropy is such that T2 in WM follows a $\sin^4 \theta$ dependency and is shortest at fibre-to-field angle $\theta = 90^o$. In the present study we have examined a potential relationship between T1 relaxation time and θ in human WM at 3T.

Methods

10 healthy participants were recruited for this study (5 female, age range 23 to 33). All participants gave informed consent, and ethical approval was granted by the University of Bristol Faculty of Science Research Ethics Committee. A Siemens Magnetom Skyra 3T system equipped with a 32-channel head coil, 2-channel parallel transmit body coil, was used: (a) a 3D T_1-weighted MPRAGE, (b) 2D multi-band DTI with 60 diffusion sensitising gradient directions (axial, 1.88x1.88x1.98 mm^3), and (c) a set of 3 MP2RAGE scans (sagittal, 1.25x1.25x1.25 mm^3, TE 1.69 ms, total TR 1850 ms, TFL readout TR 4 ms, α 8°. A 10 ms hyperbolic secant pulse was used as the inversion pulse. The 6 TIs were 200, 300, 600, 900, 1200, and 1500 ms.

Diffusion tensor images were computed using FSL version 5.06 (https://fsl.fmrib.ox.ac.uk/fsl/). A single effective diffusion tensor was assumed for each voxel. T1 and S0 maps were fitted in Matlab (Mathworks, Natick, MA, USA) using one flip angle for the MP2RAGE data sets and assuming a single T1 time per voxel. Anisotropy of T1 was assessed using the method previously applied to anisotropy of coherence lifetime published [3] to provide a heuristic demonstration as a surface plot of T1 as a function of FA and the angle θ (between the principal direction of diffusion and B_0). In this method, FA and θ are bin-ranged to create 2D bins of constant dimensions. All T1 observations falling into a bin are averaged. A surface plot may be thereby produced. Data are required in a common space, chosen for each participant as that of their DTI data, re-sampled to 1 mm isotropic resolution. Relationship between θ and S0 was determined in a similar fashion as for T1 anisotropy.

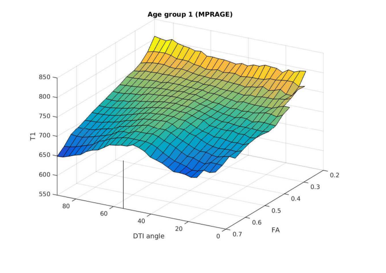

Fig. 1. Surface plot for FA, fibre-to-field angle and T1 in WM. Vertical bar marks the magic angle

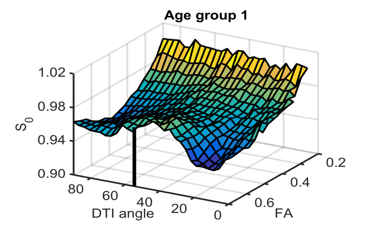

Fig. 2. Surface plot for FA, fibre-to-field angle and S0. Vertical bar marks the magic angle.

Results

Fig 1 shows the T1 on surface plots as a function of θ and FA of translational diffusion in the second dimension for all WM voxels. It is evident that the T1 angular dependence is present only at high FA, diminishing as FA reduces, with a near-flat T1 profile for FA < 0.3. The peak T1 at around 55^o is approximately 8% longer than at 0^o. S0 plot shows (Fig. 2) that the normalised S0 signal intensity was elevated by 2-3% t in θ range of $50\text{-}60^o$ for voxel with FA >0.4.

Discussion and conclusions

We have observed what appears to be a “magic angle” effect in the T1 of the human WM at 3T, with T1 maximised around the magic angle of 54.7°. It is difficult to assign with confidence a single mechanism for T1 anisotropy, though there are several candidates. Evidently T1 anisotropy is linked to microstructure of WM, because it is present only in WM with FA > 0.3 with θ close to the magic angle. It also remains to be determined whether the effect is a direct observation of water protons, or protons of some other molecular species, or an exchange-mediated effect. The proton density (a proxy of MR-visible water) was observed to possess a similar angular dependency of S0 in voxels with FA>0.4 in WM globally. However, T1 and S0 are derived from the same fits of TI series and are interrelated potentially gaining contributions from other factors, such as dipolar couplings and/or immobile protons. Nevertheless, a working hypothesis that elevated MR-visible water content underpins the observed angular dependency of T1 warrants further exploration.

References

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Acknowledgements

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