Origin of the Bright Signal in the Corticospinal Tract on T_2-weighted Images and Myelin Water Images.

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Introduction

The corticospinal tract (CST) can be identified on T_2-weighted MR images as an area of increased signal (brighter) intensity within the posterior limb of the internal capsule (PLIC) [1] and has longer T_2 times than areas that are immediately anterior to it in the PLIC when examined quantitatively with mono-exponential analysis [2]. The presence of large axons with thick myelin sheaths [1] may give rise to a difference in the CST's water T_2 behaviour. The T_2 decay curve from central nervous system tissue can be separated into several exponential components. In normal brain tissue, the T_2 decay curve has three main components, which arise from three distinguishable water environments: (1) a shorter component ($T_2 \sim 20$ms), designated as signal from the water trapped within the myelin layers (MW); (2) an intermediate component ($T_2 \sim 80$ms) where the signal arises from intra- and extra- cellular water (IE); and (3) a very long component ($T_2 > 2$s) from cerebrospinal fluid [3]. An additional long T_2 component (200ms < T_2 < 800ms) has been observed in the CST of healthy controls and in pathological white matter regions in patients with phenylkeonuria and multiple sclerosis [5,6]. A previous study using a 32-echo sequence examined the T_2 distribution and found higher myelin content and the IE peak shifted to longer T_2 times in the PLIC [3]. The purpose of this study was to examine the T_2 distribution of the CST in comparison to other white matter structures using quantitative multi-exponential T_2 analysis with a 48-echo sequence extended to a final echo of 1.120s to better characterize longer T_2 times [7].

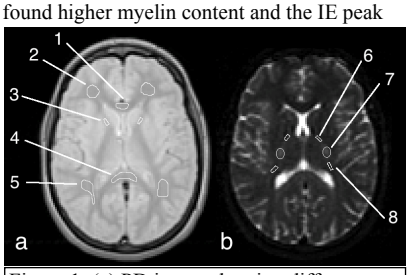

Figure 1: (a) PD image showing different ROIs 1) genu of CC, 2) minor forceps 3) AIC 4) splenium of CC and 5) major forceps. (b) Heavily T_2-weighted image TE=230ms 6) Anterior to CST 7) CST 8) Posterior to CST.

Methods

Subjects: Fourteen normal healthy subjects were examined (mean age=27years (range=19-34); 6 males and 8 females).
MR Imaging: Imaging was conducted at 1.5T (GE Echo Speed v.5.7 software). The MR protocol consisted of a localizer, proton density (PD)-weighted and T_2-weighted images (TR=2500ms,TE:30/80ms) and a modified Carr-Purcell-Meiboom-Gill (CPMG) T_2 relaxation sequence (48 echoes, 5mm thick axial image acquired through the base of the genu/splenium of the corpus callosum, TR=2.12-3.8s [7,8], echo spacing = 10ms (first 32 echoes),= 50ms (last 16 echoes), 128x128 matrix 4 averages).
Data Analysis: Regions of interest (ROIs) were drawn around different white matter structures (Figure 1). The T_2 decay curves were decomposed into an unspecified apriori number of exponentials using a non-negative least squares (NNLS) fitting algorithm using AnalyzeNNLS [9]. The myelin water fraction (MWF) was defined as the area under the MW peak divided by the total area under the T_2 distribution for each ROI; the lower limit for MWF estimation was 5ms and two MWF upper limits were used, 40ms and 25ms. The position of the IE peak was examined using the geometric mean T_2 (gmT_2), which is the mean T_2 on a logarithmic scale. All errors are reported as standard deviations. Student's t-test was used to test significant differences between the two MW ranges for each structure and Bonferroni corrected, $p < 0.003$ was considered to be significant.

Results

Figure 2 shows that the CST has a distinctly different T_2 distribution shape than other structures examined. The CST IE peak split into two separate peaks in 50% of the ROIs, which could imply two separate water environments. Figure 3a shows the MWF map (5-40ms) for one subject, with the CST appearing brighter compared to other white matter regions, suggesting a higher MWF. This finding for the CST however is no longer evident on the MWF map for 5-25ms (Figure 3b). Quantitatively, there was a general but slight decrease in MWF for most white matter structures for MWF obtained at 5-25ms compared to that at 5-40ms with significant differences observed for the CST ($p = 2.11 \times 10^{-6}$) and major forceps ($p = 0.0021$) (Table 1) and the contrast between the CST and other structures was no longer evident. Therefore, it appears that part of the IE peak overlaps with the region designated for MW and the MWF is consequently artificially increased.

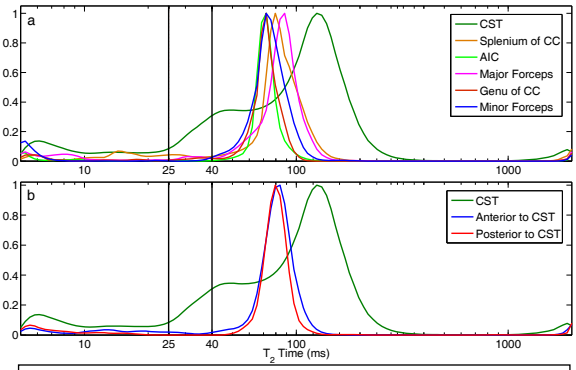

Figure 2: Normalized summation of T_2 distributions with vertical lines drawn at 25ms and 40ms to show MWF/gmT_2 limits comparing a) CST and other white matter structures and b) CST and areas anterior and posterior to CST

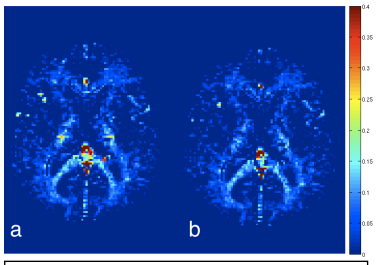

Figure 3: MWF maps for one subject with two different T2 ranges; a) 5-40ms and b) 5-25ms

Table 1: Changes in MWF for two different cutoffs in white matter structures

Structure	MWF (5-40ms)	MWF (5-25ms)	% MWF Change	p-value
CST	0.19(.05)	0.11(.04)	8.5	$\mathbf{2.11 \times 10^{-6}}$
Splenium of CC	0.14(.04)	0.11(.04)	3.5	0.061
Major Forceps	0.11(.04)	0.086(.02)	2.5	**0.0021**
Anterior to CST	0.11(.03)	0.095(.03)	1.7	0.010
Posterior to CST	0.098(.02)	0.096(.02)	0.1	0.32
Genu of CC	0.085(.03)	0.060(.03)	2.5	0.041
Minor Forceps	0.074(.02)	0.069(.02)	0.6	0.040
AIC	0.066(.02)	0.060(.03)	0.6	0.12

Discussion/Conclusion

We characterized the T_2 distribution of the CST using a 48-echo sequence extending to 1.120s . The CST peak is broadened compared to other structures, which may be the result of separation between the intracellular and extracellular water. We found the IE gmT_2 shifted to both higher T_2 times, causing the CST to appear bright on T_2-weighted images, and to lower T_2 times, causing an increase in MWF that is not caused by increased myelin density, an observation supported by earlier literature that found less dense myelin in the CST compared to areas anterior and posterior [1]. The presence of large clear spaces in the CST [1] may result in increased extracellular water, which would cause a difference in T_2 times between intracellular and extracellular water. Another possible explanation is restricted exchange across the myelin sheath in the CST, as thick myelin sheaths may restrict water diffusion resulting in separation of the intracellular and extracellular water environments.

References

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