Imaging myelin in vivo; comparison of the T_2 distribution at 1.5T and 3.0T

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Introduction: It has long been a goal of MRI to accurately quantify myelin in vivo. From T_2 decay curves obtained using a multi-echo Carr-Purcell-Meiboom-Gill (CPMG) imaging sequence, the relative contributions from water in different environments can be resolved, in particular the water trapped between the myelin bilayers. The ratio of myelin associated water to total water provides a quantitative measure of the myelin water fraction [1]. However, this technique requires a high signal-to-noise ratio (SNR) for accurate extraction of the multi-exponential components [2]. The goal of this study was to investigate the effects on SNR and in vivo T_2 properties obtained with the multi-echo CPMG imaging sequence at a higher magnetic field strength; specifically, we compared multi-echo T_2 measurements at 1.5T and 3.0T.

Methods: *MRI Experiments:* MRI measurements were performed on 10 healthy volunteers (mean age: 22.8 years; range: 19-29 years) on both a GE Signa 1.5T system and a Philips Intera 3.0T system. On both systems, T_2 relaxation measurements were acquired for a single transverse slice through the base of the genu and splenium of the corpus callosum using a 32-echo CPMG sequence (BW=±32kHz, TR=3000ms, 256x128 matrix, 10ms echo spacing, slice thickness=5cm, FOV=22cm, 4 NEX)[3].

Data Analysis: T_2 decay curves were analyzed with a regularized non-negative least squares (NNLS) method using 120 input relaxation times spaced logarithmically from 15ms to 2s [4]. Both χ^2 and solution roughness were minimized such that χ^2 fell between 1.02 and 1.025 times the minimum χ^2 from the non-regularized least-squares solution. The peak assigned to myelin water was defined as having $15ms<T_2<50ms$ for data obtained at 1.5T and $15ms<T_2<25ms$ at 3.0T, and the intra/extracellular (IE) water peak was defined as having $50ms<T_2<300ms$ and $25ms<T_2<300ms$ for 1.5T and 3.0T respectively. The shift of the T_2 boundaries for both myelin and IE water at the higher field strength is due to shortening of T_2 values in brain as a result of the presence of iron; boundary values were determined by examining the T_2 distributions to establish where the IE peak began. The myelin water fraction (MWF) (the ratio between myelin water peak area to total signal in the T_2 distribution), geometric mean T_2 (analogous to the amplitude-weighted mean on a logarithmic scale) for the IE peak, and peak width (analogous to variance on a logarithmic scale) for the IE peak, were calculated for several regions of interest (ROIs). The fit-to-noise ratio (FNR) was defined as the theoretical amplitude at TE=0ms divided by the standard deviation of the residuals of the fit, normalized by the square root of the number of pixels in the ROI. The SNR was calculated as the TE=0ms intensity divided by the standard deviation of the signal from air in the background after dividing by 0.66 to obtain the Gaussian-noise standard deviation.

Results: MWF maps are shown in Figure 1 for one volunteer at 1.5T and 3.0T. While the images show good qualitative agreement, the image at 3.0T shows higher intensities in posterior white matter (WM) and in gray matter (GM) regions. Figure 2 illustrates the MWFs in several brain structures averaged across the 10 volunteers. While the MWFs are strongly correlated between 1.5T and 3.0T (slope of 0.95, R^2=0.87, $p<0.00005$) and agree with literature values [1], they are considerably higher in GM at 3.0T when compared to 1.5T. As can be seen in Table 1, the SNR increased significantly at 3.0T; however, the FNR decreased, primarily due to the first point of the decay curve having a consistent, large residual. Table 2 contains results for the IE peak; the geometric mean T_2 decreased by an average of 33% in WM and 37% in GM at 3.0T, and the IE peak at 3.0T widened by an average of 61% in WM and 165% in GM.

Discussion: The increased MWF measured in GM was also observed by Oh et al [5], who hypothesized that it could be due to poor performance of the 180° refocusing trains at the edge of the transmit/receive head coil. However, the increased MWFs were not only observed in the cortex but in GM regions throughout the slice. Another explanation could be local B_1 effects due to the iron content distribution, which is higher in GM than in WM as illustrated by the effect on geometric mean T_2 and peak width. Alternately, it could be attributed to the change in FNR, which is also generally associated with B_1 inhomogeneity.

Conclusion: Measuring the myelin water fraction at 3.0T is feasible, with results that agree with 1.5T and literature values [1,6]. The benefit of increased SNR is offset by the adverse effects of B_1 inhomogeneities.

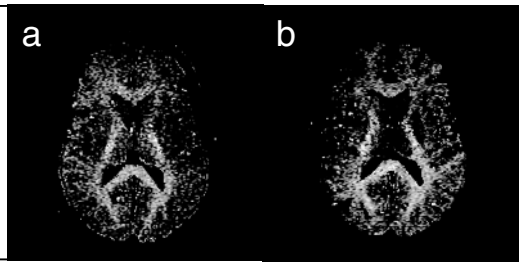

Figure 1: Myelin water fraction maps at (a) 1.5T and (b) 3.0T.

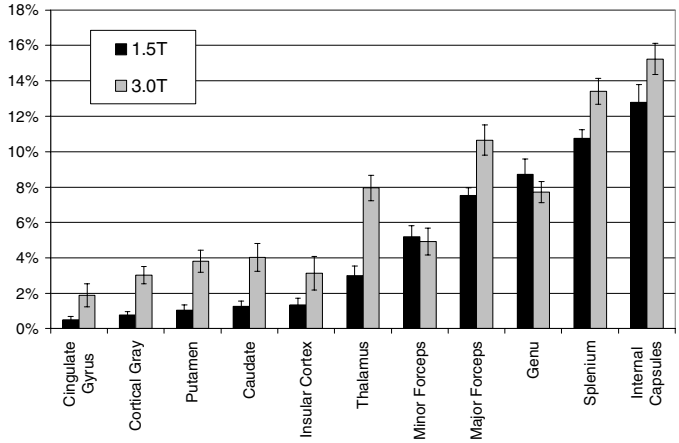

Figure 2: MWFs (%) for 6 GM and 5 WM structures averaged over the 10 volunteers. The error bars indicate standard error.

	1.5T		3.0T	
	FNR	SNR	FNR	SNR
Cingulate Gyrus	121 (6)	88 (7)	97 (12)	152 (16)
Cortical Gray	84 (5)	81 (7)	52 (5)	133 (14)
Putamen	75 (8)	92 (7)	40 (4)	169 (18)
Caudate	94 (6)	92 (7)	47 (5)	166 (19)
Insular Cortex	78 (5)	87 (7)	63 (7)	158 (17)
Thalamus	61 (4)	89 (7)	39 (4)	168 (17)
Minor Forceps	69 (4)	80 (6)	54 (9)	138 (15)
Major Forceps	73 (5)	78 (6)	29 (4)	138 (14)
Genu	102 (7)	81 (6)	63 (7)	150 (16)
Splenium	83 (5)	80 (6)	46 (6)	150 (15)
Internal Capsules	76 (5)	82 (6)	48 (6)	156 (16)

Table 1: FNR and SNR (standard error) averaged over the 10 volunteers.

	1.5T		3.0T	
	Geometric mean T_2	Peak Width	Geometric mean T_2	Peak Width
Cingulate Gyrus	95.7 (0.8)	0.026 (0.006)	71.3 (1.2)	0.070 (0.014)
Cortical Gray	88.7 (0.6)	0.014 (0.003)	66.7 (0.9)	0.070 (0.011)
Putamen	78.6 (0.3)	0.013 (0.008)	56.1 (0.7)	0.015 (0.006)
Caudate	84.6 (0.4)	0.014 (0.020)	62.7 (0.8)	0.038 (0.009)
Insular Cortex	96.0 (1.2)	0.027 (0.013)	68.2 (1.2)	0.051 (0.013)
Thalamus	79.7 (0.4)	0.008 (0.002)	58.6 (0.8)	0.022 (0.006)
Minor Forceps	76.5 (0.4)	0.028 (0.006)	59.0 (0.8)	0.056 (0.012)
Major Forceps	85.8 (0.5)	0.030 (0.007)	66.0 (1.0)	0.059 (0.012)
Genu	73.5 (0.4)	0.034 (0.005)	57.9 (0.7)	0.070 (0.012)
Splenium	88.7 (1.1)	0.077 (0.011)	64.5 (1.2)	0.081 (0.015)
Internal Capsules	89.5 (1.1)	0.087 (0.014)	64.0 (1.2)	0.089 (0.012)

Table 2: Geometric mean T_2 and peak width (standard error) of the IE peak.

References:

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Acknowledgments: Sincere thanks to our volunteers, technologists, the Canadian Institutes of Health Research, and the Multiple Sclerosis Society of Canada.