Relaxation Measurements in Brain tissue at field strengths between 0.35T and 9.4T

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Introduction: The main magnetic field strength used in MRI experiments has increased dramatically over the past few decades, fundamentally affecting many biochemical and biophysical tissue parameters determining image contrast, such as relaxation. For the understanding of the underlying mechanisms, reliable relaxation data is required, ideally derived by robust bias-free relaxometry methods from the same subjects over a large range of field strengths.

Methods: Two healthy volunteers were enrolled in this study. The scans were performed at magnetic field strengths (B_0) ranging from low field 0.35T to clinical fields of 1.5T, 3T, and up to ultra-high field of 7T, and 9.4T. Basic spin-echo (SE)-based relaxometry methods were used to sample the T1 recovery and T2 decay curves at the various field strengths not only to mitigate to the best of our knowledge any possible sequence-related bias in the derived T1 or T2 time, but also due to their general availability on all the systems and their overall robustness on hardware imperfections, such as transmit field errors. To this end, T1 scans were performed with inversion-recovery (IR) turbo spin echo (TSE) protocols (TE = 12ms, TR = 15000ms, matrix size = 256 x 192, voxel size = 2.0 x 1.0 x 5.0 mm^3, turbo factor = 7, scan time 3 min 47 s). Three axial slices were acquired (10mm gap), oriented parallel to the anterior and posterior corpus callosum to include deep white and gray matter structures. The IR curve was sampled with six consecutive inversion times (TI = 50, 100, 200, 500, 2000, and 4000ms). T2 measurements were acquired based on a single echo SE protocols only (TR = 3000ms, matrix size = 256 x 192, voxel size = 2.0 x 1.0 x 5.0 mm^3, scan time of 4 min 53s) to mitigate stimulated echo contributions. Three slices were acquired (10mm gap) using flow compensation in the slice direction, but essentially positioned identical to the T1 acquisition. The T2 decay curve was sampled based on six consecutive TEs (10, 25, 50, 90, 150, and 250ms). The overall protocol was completed within 1hour.
T1 and T2 relaxometry maps were generated pixelwise using a nonlinear least squares fitting routine from Matlab (The Math Works Inc., Natick, MA, USA) based on a single-exponential signal model for both T1 and T2:

$$S = S_0 \cdot (1 - b \times \exp(-TI/T_1)) \quad [1]$$

$$S = S_0 \cdot \exp(-TE/T_2) \quad [2]$$

Ten regions of interest (ROI) were defined within the derived T1 and T2 maps, four ROIs in white mater (frontal WM, occipital WM, temporal WM, and parietal WM), four ROIs in gray mater (frontal cortex, occipital cortex, temporal cortex, and parietal cortex), one ROI in the putamen, and one ROI in the thalamus.
The dependence of T1 on B0 was evaluated according to [(2)]:

$$T_1(B_0) = A \times {B_0}^{\beta} \quad [3]$$

where B_0 is the magnetic field strength, A and β are free parameters.

Results and Discussion: Sample T1 and T2 maps are shown in Figure 1 as a function of the main field strength. For some selected structures, corresponding T1 and T2 values are summarized in Table 1. As expected, relaxation times depend sensitively on the main magnetic field and decreases with B0 for T2, but increases for T1. The B_0 dependence of the T1 is further analyzed in Figure 2, where the solid lines represent fits of the data to Eq.(3). With increasing field strength, the dynamic dephasing also increases due to increased susceptibility, which will cause the decrease of T2 [(3)].

Conclusion: In this study, robust and reliable T1 and T2 relaxation times were derived over more than one order of magnitude in the main magnetic field for two healthy subjects to provide normative relaxometry data in gray and white matter.

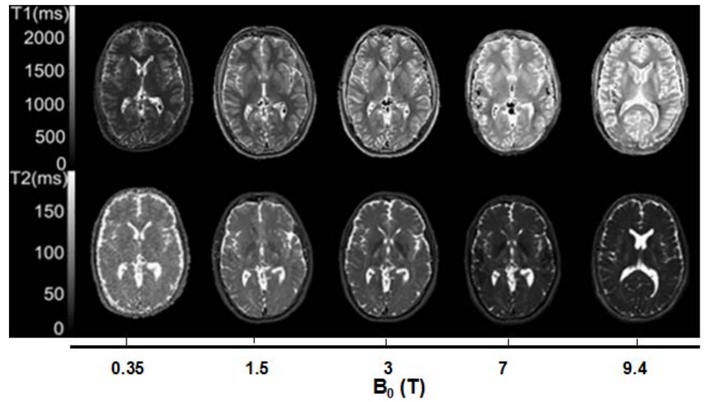

Figure 1: Sample axial T1 and T2 maps as a function of the main magnetic field strength derived from a pixelwise fit of the inversion recovery T1 and T2 decay data of one volunteer to Eqs. [1] and [2], respectively.

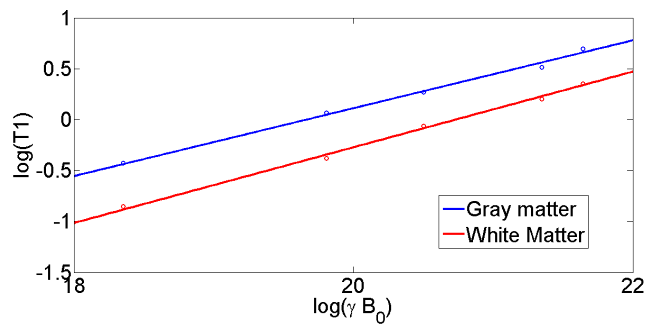

Figure 2: Analysis of the B_0 dependence of the mean gray (blue circles) and white (red circles) matter T1 values. The solid line shows a fit with estimated β values for gray and white matter of 0.3334 and 0.3717, respectively.

Main Magnetic field strength (T)	Average GM		Average WM	
	T1 (ms)	T2 (ms)	T1 (ms)	T2 (ms)
0.35	653±46	94±8	427±24	84±11
1.5	1072±77	90±5	685±26	72±4
3	1310±110	71±5	939±68	62±2
7	1670±70	43±3	1222±58	37±3
9.4	2002±105	35±3	1425±48	29±2

Table 1: Average T1 and T2 values for gray and white matter as observed at various field strengths.

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