Measurement of T_1 and T_2 in the Cervical Spinal Cord at 3 Tesla

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Introduction

Knowledge of the relaxation time constants of different tissues allows optimization of image contrast. Human tissue relaxation parameters have been measured in the brain (1,2) and in blood (3) at 3T, but, to our best knowledge, no studies of the spinal cord have been published at any clinical field strength. The small size and motion of the spine hamper relaxation time measurements, so prior studies have often assumed that spinal cord white and gray matter relaxation mimics that of the brain, in spite of known histological differences between brain and spinal cord (4). This abstract reports relaxation time measurements of both gray (GM) and white matter (WM) in normal human cervical spinal cord and compares the results to literature brain GM and WM values.

Methods

Six healthy volunteers (3 male, 3 female; mean age 28.8 ± 5.6 years) provided, informed consent for this IRB approved study. Scans were performed on a Philips Intera 3T (Philips Medical Systems, Best, The Netherlands) MRI system with body coil excitation and two surface coils placed bilaterally about the neck for reception.

Longitudinal relaxation time constants (T_1) were measured using a double flip-angle experiment (5): angles = 15°, 60°, 3D spoiled gradient echo (TR/TE = 100 ms/ 10 ms; 10 axial slices of 4 mm thickness, centered at C3; nominal in-plane resolution = 0.64 mm x 0.74 mm; FOV 192 mm x 224 mm; EPI factor 3; SENSE factor 2.0; 2 averages; 2nd order shimming; scan time = 53 seconds per volume). The two images were co-registered using a six degree-of-freedom, rigid-body transformation. Absolute T_1 was calculated from:

$$T_1 = \frac{-TR}{\log\left(\frac{\sin(\alpha_2) - R\sin(\alpha_1)}{\cos(\alpha_1)\sin(\alpha_2) - R\cos(\alpha_2)\sin(\alpha_1)}\right)}$$

where $R=S(\alpha_1)/S(\alpha_2)$, the ratio of intensities at each flip angle (Fig 1b and c).

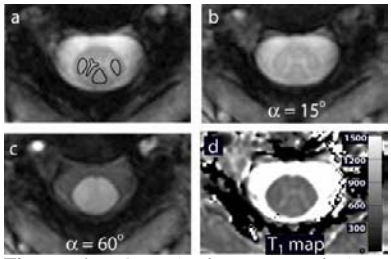

Figure 1 ROI selection (a), typical T_1 dataset (b,c) and calculated T_1 map (d).

Transverse relaxation time constants (T_2) were calculated using a sixteen-echo spin-echo sequence (TE = 10 ms – 160 ms). To account for imperfections in the 180° refocusing pulse and to eliminate stimulated echo contributions, the 8 even echoes were used for curve-fitting. A single 4 mm slice, centered at C3, was acquired (nominal in-plane resolution 0.9 mm x 0.8mm; FOV 190 mm x 224 mm; 2 averages; cardiac triggering; minimum TR 2.5 s or 3 cycles at 70 bpm; total scan time 4.5 – 5 min). T_2 was determined from a non-linear least squares fit of the signal decay curve to a mono-exponential model for each voxel using Matlab (The Mathworks, Natick, MA).

ROI selection and Data Analysis: Four ROIs were analyzed at C3 (Fig 1a): left and right lateral column WM, dorsal column WM, and dorsal horn GM. Relaxation times were compared between lateral/dorsal column and between white/gray matter using an unpaired t-test.

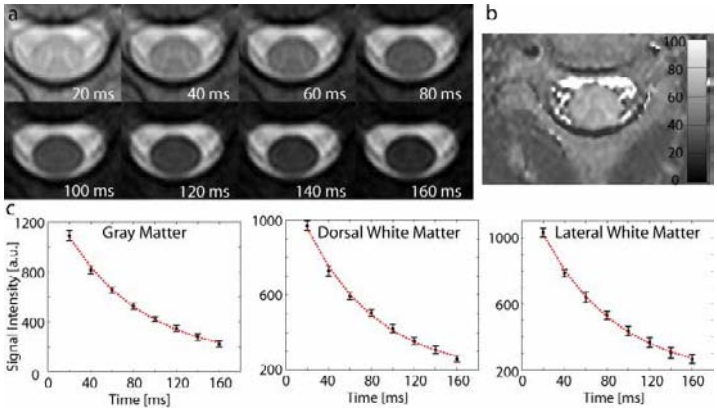

Figure 2 Typical T_2 dataset (a), calculated T_2 map (b) and fitted decay curves (c).

Results

Fig. 1 shows a representative T_1 data set and the calculated T_1 map. The low flip angle scan shows maximal intra-cord contrast while the higher flip angle shows much less. T_1 values are given in Table 1**.** GM and WM could be discriminated in all T_1 maps. Unpaired t-test showed a statistically significant difference between gray and white matter ($p = 0.006$), but difference between WM (dorsal vs lateral) was not significant ($p = 0.90$). T_2-weighted images in Fig 2 show appreciable GM/WM contrast at short echo times, which is lost at long echo times. The resulting T_2 map shows little GM/WM contrast, similar to brain, where most contrast in T_2w images is due to spin density, The small GM/WM difference is significant ($p = 0.02$, Table 1), while the dorsal-lateral WM is not different. ($p = 0.31$). Fig 2c shows the signal decay curves (mean +/- SD) for 3 ROIs: GM; dorsal column; and lateral column. Chi-squared goodness-of-fit analysis reveals extremely good agreement ($p = 0.85 – 0.91$, where a high p-value ($p > 0.05$) indicates reason to accept the null hypothesis that the observed values equal the fitted values).

	T_1 (ms)	T_2 (ms)
Lateral	752 ± 89	65 ± 4
Dorsal	745 ± 61	66 ± 4
GM	964 ± 130	69 ± 2

Table 1 Measured T_1 and T_2 values.

Discussion

For the first time longitudinal and transverse relaxation time constants are reported in the spinal cord *in vivo*. The values reported here should be useful in parameter optimization for clinical spine imaging at 3T, and should also be useful for quantitative assessment of metabolite concentrations by the MR spectroscopy water reference method and accurate fitting of magnetization transfer effects in the cord. Spinal cord white matter consists of very densely packed fiber bundles and, of the tissues in the brain, is most similar to dense white matter found in structures such as the internal capsule and corpus callosum (4). The T_1 and T_2 of the lateral and dorsal column white matter at the level of C3 fall within the range of reported values for callosal white matter (720 – 770 ms) (1,2). Spinal cord gray matter is similar to deep cerebral gray (basal ganglia and brain stem) matter and we observe that spinal cord gray matter relaxation times agree well with published values for the deep gray matter structures of the human brain (900-1100 ms) (1,2). Simulations using these relaxation times applied to the steady-state signal equations for spin echo and gradient echo reveal combinations of TR/TE that will yield the greatest contrast between tissue types. In particular, for spin echo, a short TE (≤ 60 ms) and a TR ~ 1500-2000 ms yield excellent intra-cord contrast, and a much longer TE (> 100 ms) yields good myelographic contrast. A similar finding is seen for the gradient echo (assuming a 90° flip angle): TR < 500 ms and TE as short as possible give greatest intra-cord contrast while TR > 2000 ms with short echo time yields great myelographic contrast.

References: 1.Wansapura JP, Holland SK et al. J Magn Reson Imaging 1999; 9(4):531-538. 2. Lu et al., JMRI 22: 13-22 (2005) 3. Lu H, Clingman C et al. Magn Reson Med 2004;52(3):679-682. 4. Kandel E, Schwartz JH, Jessell TM. Principles of Neural Science: McGraw-Hill Companies; 2000. 5: Bottomley P, Ouwerkerk R, Journal Magn Reson B 1994; 104: 159-167.

Grant Acknowledgement: NIH/NCRR (RR015241)