Water and Metabolite Proton T1 and T2 Relaxation in Rat Brain In Vivo

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Introduction - Magnetic fields strengths for *in vivo* MRI and MRS have seen a steady increase, currently up to 9.4 T for humans and >14 T for animals. This drive has largely been fuelled by the linear increase in signal-to-noise (SNR) ratio and spectral resolution with increasing field strength. However, T_1 and T_2 relaxation parameters play an important role in the actual SNR and resolution, but are often ignored when discussing high field NMR. While the field-dependent trends for T_1 and T_2 relaxation have been qualitatively established, here we present a comprehensive and quantitative measurement of T_1 and T_2 relaxation of water and metabolites in rat brain under identical experimental conditions at three high magnetic field strengths (4.0 T, 9.4 T and 11.7 T). Besides establishing the contribution of relaxation on sensitivity and resolution, this data will also be valuable for determining optimal image T_1/T_2 contrast, establishing optimal acquisition parameters for quantitative MRS and determining optimal inversion delays for macromolecule detection or suppression.

Methods - All experiments were performed on Bruker consoles interfaced to 4.0 T Bruker, 9.4 T Magnex or 11.74 T Magnex magnets. RF transmission and reception were performed with 14 mm surface coils tuned to the proton frequency. Water T_1 and T_2 relaxation was measured by acquiring eight T_1-weighted inversion recovery and eight T_2-weighted spin-echo EPI images (128 x 128 over 2.56 cm) over 24 slices (0.5 mm). Proton MR spectra were acquired with a LASER sequence (75 uL). Metabolite and macromolecule T_1 relaxation times were measured at TE = 12.5 ms and 100 ms, respectively, by acquiring 16 T_1-weighted inversion recovery spectra. T_2 relaxation times were measured from 16 T_2-weighted spin-echo spectra (TE = 12.5 – 450 ms).

Results - Fig. 1A shows a T_2-weighted MRI together with a calculated T_2 map obtained at 9.4 T. Fig. 1B shows a single T_1-weighted MR spectrum obtained at 9.4 T (long TE for metabolites (left) and short TE for macromolecules (right)). Water T_1 and T_2 relaxation times were determined in nine distinct cerebral structures, while metabolite/macromolecule T_1 and T_2 relaxation times were determined for ten and seven resonances, respectively. Fig. 2 shows a summary of metabolite/macromolecule T_2 relaxation time data at different fields. For all brain regions the water T_1 shows a significant increase with field strength (on average from 1253 ms (4T) to 2018 ms (11.7 T)), while the water T_2 decreased in all regions (on average from 66 ms (4T) to 35 ms (11.7 T)). Metabolite T_1 and T_2 relaxation showed similar, but less pronounced trends. The macromolecule T_1 closely followed the relative water T_1 differences.

Discussion - Here we have presented a comprehensive and quantitative measurement of water, metabolite and macromolecule relaxation parameters under identical experimental conditions at three different field strengths. While an increase in SNR is often a prime reason to move to higher field strengths, the linear increase with magnetic field strength is, at least for anatomical T_1/T_2-based images of water, largely canceled by the prolonged T_1 and shortened T_2. Functional MRI based on BOLD-contrast will still greatly benefit from higher fields. Furthermore, MRS is also better at higher fields since the SNR and the spectral resolution increase (T_2* does not decrease linearly with field). These increases will lead to improved quantification of low-concentration metabolites, like gamma-amino-butyric acid (GABA). The variations in metabolite and macromolecule T_1 relaxation, as well as their convergence at higher field strengths, argues for more sophisticated approaches to selectively observe macromolecules.