Characterizing longitudinal relaxation in bovine brain white matter ex vivo

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Introduction & Purpose: Accurate measurement of longitudinal relaxation, T_1, in white matter has crucial implications for myelin water imaging using multi component T_2 relaxation. For example, to better understand magnetization exchange in white matter we need to understand the longitudinal relaxation behavior in white matter. If exchange is fast on the T_1 timescale, the exchange may also be relatively fast on the T_2 timescale. The main goal of this research was to investigate whether white matter T_1 relaxation in brain is a mono-exponential or a multi-exponential phenomenon.

Methods: White matter tissue samples (0.1 mL) were cut from fresh bovine brain and placed in a 4.7 T NMR spectrometer. The experiments were carried at 37° C. The NMR experiments involved an initial inversion pulse followed by either a free induction decay (FID) or a CPMG data collection. A 'hard' inversion pulse (2.4 μs) was employed for which both non-aqueous and water protons received a 180° rotation. For the IR-FID, data was collected for 98 inversion times, TI. The first 20 TIs were collected with 0.4 μs spacing, and the rest were collected by a geometric factor of 1.1 and the last TI was at 9.3 s. For the IR-CPMG, we collected 49 TI 's starting from 5 ms and ending at 7.69 s, increasing by a geometric factor of 2.2. We collected 160 echoes out to a TE time of 320 ms. In order to separate the aqueous signal from the solid signal in the FID curves, a straight line was fitted to the data for times from 250 μs to 0.8 ms. Then the intercept of this line with the vertical axis was calculated and assumed to be the intercept of the aqueous signal. This aqueous signal was then subtracted from the intercept of the total signal at t=0 in order to find the contribution of the non-aqueous signal to the total FID signal. The Inversion Recovery-CPMG data was analyzed using a Non Negative Least Squares (NNLS) approach (1). First the IR-CPMG data from the shortest (5 ms) and the longest (7.69s) TI 's were analyzed for the T_2 distribution and shown to be composed of two major peaks corresponding to myelin water and intra/extracellular water plus an additional T_2 peak at long T_2 times. Subsequently, all 49 IR-CPMG curves were fitted to two fixed T_2 components (corresponding to those measured from the shortest and longest TI times) plus an additional floating long T_2 component, hypothesized to be residual extracellular water.

Results: Fitting the FID data to the exponential functions revealed that the composite aqueous signal possessed a mono-exponential behavior with amplitude A_{aq} = 6025 (100 %) and T_{1aq} = 1341 ms. Signal from the non-aqueous pools, on the other hand, was best fitted by two T_1 components with amplitudes: A_{1NA} = 211 (23 %), A_{2NA} = 703 (77 %), associated with T_{1NA1} = 110 ms and T_{1NA2} = 703 ms respectively. However, from the CPMG data, the myelin water component (Figure 1A) had a T_1 of 0.50 ms and the intra/extra cellular component had a T_1 of 1.47 s.

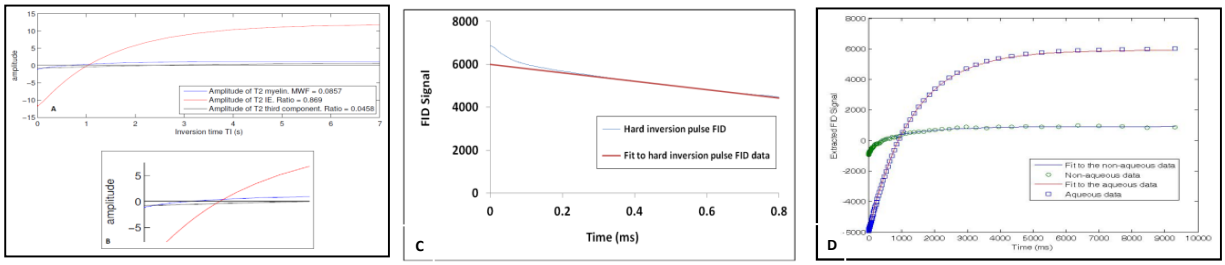

Figure 1. (A) The amplitudes of each of the water pools are shown as a function of inversion time TI. (B) gives a zoomed view on the zero crossing of each component. (C) FID of bovine brain sample at long TI after the hard inversion pulse. A straight line (red line) was fitted to the data at times 0.25 ms < t < 0.8 ms. (D) Fit to the experimental hard inversion pulse FID data from the aqueous and non-aqueous pool.

Discussion & Conclusion: The findings of this study clearly demonstrate two component T_1 relaxation in bovine brain white matter measured in an ex vivo setting. It is interesting that when the two water components were added together, they appeared as a single component.

References

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