Improved Multi-Exponential T2 Imaging of Myelin

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INTRODUCTION/THEORY

Neural tissue is known to exhibit multi-exponential T_2 relaxation (MET_2) behavior, which is believed to reflect separate micro-anatomical water compartments in slow exchange. In particular, myelin-associated water is one such compartment and exhibits a characteristic short T_2 value. Using multi-echo imaging, it is possible to measure MET_2 decay functions and decompose them into a so-called T_2 spectrum, from which myelin content can, in principle, be calculated (1). However, accurate computation of the T_2 spectrum, particularly myelin T_2 domain (≈ 10 ms), is hampered by the rapidly decaying signal and the relatively long first echo time typically possible with imaging (also, ≈ 10 ms). One potential method of improving short-T_2 content measurement stems from the realization that in many situations, the irreversible rate of transverse relaxation (i.e., R_2) of myelin water is significantly larger than the reversible rate (R_2'). Thus, by sampling the origin of k-space at the onset of the acquisition period, rather than in the middle, the short-T_2 component signal will be increased. For example, by replacing the echo-planar k-space trajectory used in the *RATE* imaging sequence (2) with a *spiral* trajectory, the sampling of k = 0 will shift by half the total acquisition window, as depicted in Fig. 1. In this case, the observed transverse magnetization at the n^{th} echo is then

$$M_{\perp}(n) = M_{\perp}(0)\exp(-2n\tau R_2)\exp(\Phi(R_2 - R_2')) \qquad [1]$$

Based on reports of R_2 (3) and R_2^* (4) in rat brain, we estimate that R_2' at 4.7T is not greater than ≈ 20 s^{-1} given normal, manual linear shimming. Thus, in nerve, an echo shift of Φ = 4 ms will decrease signal of the long T_2 component (R_2 ≈ 10 s^{-1}) by approximately 6%. However, the same shift will increase the signal from the short T_2 component (myelin, R_2 ≈ 100 s^{-1}) by approximately 35%. We hypothesize that such an approach can by used to increase the accuracy with which a multi-echo imaging acquisition can be used to estimate myelin content.

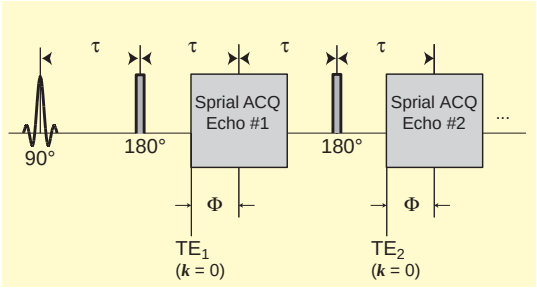

Fig 1. Acquisition period timings for a spiral-RATE sequence. Echo times (TE_n) are defined by the time between excitation (center of 90° pulse) and the time at which the origin of k-space (***k*** = 0) is sampled. Spins are maximally refocused at t = $2n\tau$, as defined by the RF pulse spacing. The difference between TE and the refocused time is defined by Φ.

METHODS/MATERIALS

A computer model was created in MATLAB to simulate MET_2 decay curves with additive noise, as measured using the sequence depicted in Fig. 1, and automatically generate and analyze subsequent T_2 spectra. All simulations run thus far have used three components with signal fractions/T_2s of 0.19/12 ms, 0.47/33 ms, 0.34/105 ms (taken from (3)), and 48 echoes with 12 ms inter-echo spacing. R_2' and SNR were varied between 0 and 100 s^{-1} and 50 and 1000, respectively. For each of 1000 noise realizations, the MET_2 data with transformed into a T_2 spectrum using a NNLS fitting (which accounted for Φ) and smoothed with a non-minimum energy constraint (5). These T_2 spectra were then inputted into a third MATLAB program, written to distinguish and characterize each spectral component. Several metrics were recorded from each spectrum, including number of components identified, their signal amplitude and mean T_2.

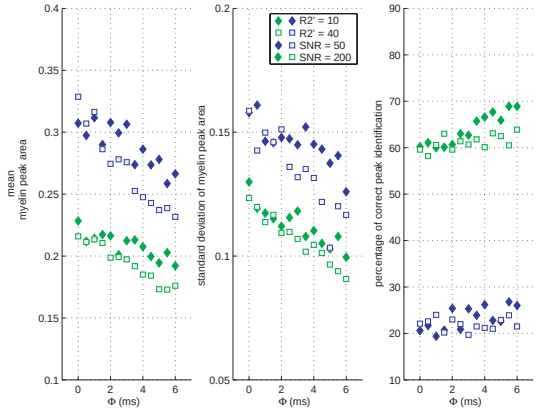

Fig 2. (left) mean myelin component signal amplitude vs echo shift (Φ), at two SNRs and two R_2's. (center) Standard deviation across trials of the mean myelin component amplitudes plotted on the left. (right) The percentage of trials from which the correct number (3) of T_2 spectral components was identified, plotted vs. echo shift (Φ).

RESULTS/DISCUSSION

Figure 2 shows, plotted vs. echo shift Φ, the mean and standard deviation of myelin component spectral amplitudes, as well as percentage trials in which the correct number of T_2 components was found, for a selection of the data. It is apparent from this figure that all three metrics show and improvement with echo shift. At very low SNR (50), the very low percentage of accurately identifying three components makes the reduced bias and uncertainty in myelin component area of limited value. Similarly, at very high SNR (1000, not shown) all three metrics were good without echo-shifting, so improvements were modest. However, in the intermediate range of SNRs, significant improvements are apparent in accurate component count and myelin component metrics are evident, even for R_2' = 40 s^{-1}. Further simulations will be necessary to more clearly define the useful SNR domain for this modified pulse sequence, and will also be used to analyze additional modifications, such as collecting some additional k-space data prior to the first refocusing pulse.

1. MacKay et al. *Magn Reson Med* 31, 673 (1994). **2.** Does and Gore, *J Magn Reson* 147,116 (2000). **3.** Does and Gore, *Magn Reson Med* 47, 274 (2002). **4.** Zywicke et al. *Ann Neurol* 52,102 (2002). **5.** Whittall and MacKay, J. Magn Reson 84,134 (1989).

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