Robust multicomponent T2 imaging in the brain at 3 T using least squares fitting in the presence of RF inhomogenities

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Introduction: Multicomponent T_2 imaging of the brain can distinguish the presence of water within the myelin layers, the intra/extracellular space, and CSF, hence allowing the production of a myelin water fraction map, which is of interest for many applications [1][2][3][4]. A 3D CPMG spin-echo sequence [3] is capable of acquiring multiple echo images from which it is possible to generate T_2 spectrum images, such as from myelin water, intra/extra-cellular water, and CSF, by using the non-negative least squares (NNLS) method [1][2]. However, at 3 T, RF inhomogeneity causes the CPMG refocusing pulse to deviate from the ideal 180°, leading not only to reduced spin-echo signals, but also to signal from stimulated echoes introduced from the second echo onwards [5], which cause errors in estimates in short T_2 components obtained using NNLS. An acquisition method using alternating polarity and decaying amplitude spoiling gradients has been proposed to reduce the stimulated echo signal [6], but this is not generally available on clinical scanners. A least squares fitting method that takes into account stimulated echoes has been proposed to acquire *mono*-exponential T_2 maps in brain at 4.7 T [5]. Here we present a method of using least squares fitting to obtain *multiple* exponential T_2 spectrum images that accounts for stimulated echoes from the brain at 3 T.

Methods and Results: Experiments were conducted on a Philips 3 T Achieva. We use a 3D CPMG turbo-spin-echo sequence [3] with 32 echoes and echo spacing 10 ms, nominal refocusing angle 165°, and a TR of 1200 ms, FOV of 240x202 mm^2, matrix size 256x192, 8 4 mm slices. The total acquisition time is 20 minutes. Fig. 1 shows signals from two regions in brain, where the stimulated echo signal effect is evident as a relatively low signal in the first echo. This leads to a poor estimate of the short T_2 (myelin) component image using NNLS, as shown in Fig.2.

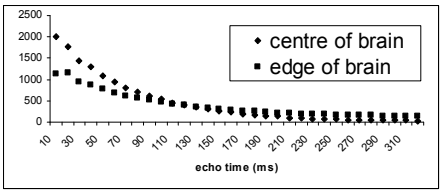

Fig.1. Echo signals from 2 regions in the brain, stimulated echo effect is evident due to the non-180° refocusing pulses.

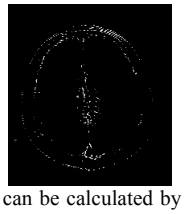

Fig.2. The shortest component (T_2 = 10 ms) of T_2 spectrum image, generated using NNLS, which fails to obtain any meaningful values due to the stimulated echo problem.

It has been proposed [5], that the multiple echo signals of different T_2s and rephasing angles can be calculated by an extended phase graph [7]. As we use a 3D data acquisition, the slice profile problem discussed in [5] is largely avoided. Therefore using the method described in [7] without considering slice profile or T_1 effects [5], we simulated normalised echo signals according to the experimental conditions for different T_2s and rephasing angles as $S_i(T_2(\mathbf{x}), \Phi(\mathbf{x}))$, where Φ is the true rephasing angle at position $\mathbf{x}$ in the brain and i is the echo number index. The total signal is modelled as the sum of different T_2 components as $M_i(\mathbf{x}) = \Sigma A_j(\mathbf{x}) * S_i(T_{2j}(\mathbf{x}), \Phi(\mathbf{x}))$ (Eq. 1), where A_j is the proportion factor for T_{2j}, and the summation over index j, the T_2 components of the brain. We have observed from [1][2][3] and our data that there are 4 detectable T_2 components in the healthy brain with values at approximately: T_2 = 10 ms for myelin water, T_2 = 60 ms for intracellular water, T_2 = 90 ms for extracellular water and T_2 = 1000 ms for CSF respectively. We therefore set j from 1 to 4, with T_2 values are fixed at these values, respectively. Also we assign a parameter λ to represent the B_1 efficiency, so that $\Phi(\mathbf{x}) = \lambda(\mathbf{x}) * \Phi_0$, where Φ_0 is the nominal angle of the rephasing pulse, 165° in our case. Then there are 5 unknown parameters in (1): A_1, A_2, A_3, A_4 and λ, which can be determined by least squares fitting for each voxel in the brain.

Fig.3 shows the fitted data along with the experimental data for the two regions of brain as shown in Fig.1. Fig.4 shows the T_2 spectrum images of the 4 fitted components. Fig.5 is the fitting errors and Fig.6 shows fitted λ map along with a B_1 map from the brain.

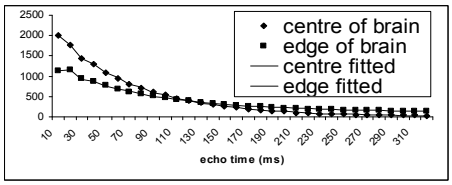

Fig.3. Excellent fitting results achieved of the signals in Fig.1 using our proposed method.

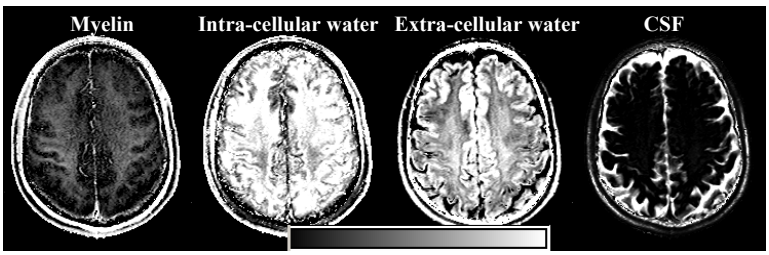

Fig.4. T2 component ratio images of brain generated using our method. From left to right: myelin water with T_2 = 10 ms, intracellular water with T_2 = 60 ms, extracellular water with T_2 = 90 ms, and CSF with T_2 = 1000 ms, all displayed with a scale of 0 to 0.5.

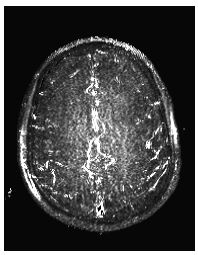

Fig.5. Map of fitting errors.

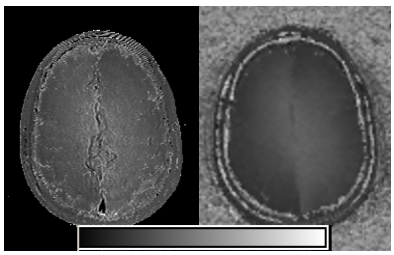

Fig.6. Left: fitted λ map, Right: a B_1 map of the same slice, all displayed with a scale of 0 to 1.25

Discussion: We have demonstrated that our proposed method is able to distinguish four T_2 components in the normal brain that demonstrate the expected spatial distributions of myelin water, intracellular water, extracellular water and CSF (Fig.4). It does so in the presence of variable RF amplitudes that cause stimulated echo contamination of the CPMG signal and in doing so also provides an estimate of the B_1 efficiency across the brain (Fig.5). A limitation of our approach is that we assume four pools of fixed T_2 in the calculation. However, as four pools are generally described for the brain, this seems a reasonable assumption, and. our method can be thought of as being equivalent to a reduction in the number of T_2 components being investigated in a NNLS study, as proposed in [8]. Future work will explore the sensitivity of our method to expected changes in the amplitudes of each component in the presence of pathology.

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Reference: [1] Mackay *et al,* (1994) MRM. 31:673**.** [2] Whittall *et al*, (1997) MRM, 37: 34-43**.** [3] Mädler *et al*, (2008) MRI, 26: 874-888**.** [4] Deoni *et al*, (2008) MRM, 60:1372-1387. [5]Lebel *et al*, (2010) MRM, 64: 1005-1014**.** [6] Poon *et al*. (1992) JMRI, 2:541-553**.** [7] Hennig, (1988), JMR, 78: 397-407**.** [8] Vavasour *et al,* (2000) MRM, 44: 860-866.