Towards whole-brain quantitative T_1 mapping at 3.0T for imaging Hippocampal Sclerosis

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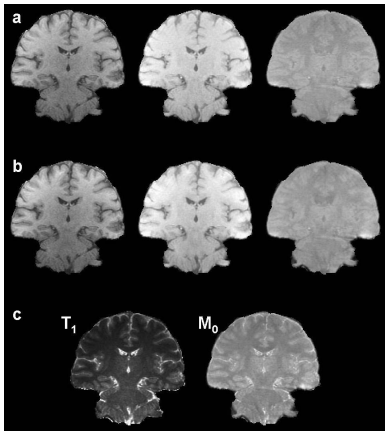
Introduction: The T_1 relaxation time of normal tissue is related to macromolecule concentration, water binding and water content (1), resulting in tissue contrast due to the particular composition of different tissue types. Changes in T_1 resulting from pathology alter this tissue contrast. In general increased water content causes an increase in the T_1 relaxation time in biological tissue. For example in the brain, oedema or inflammation may cause an increase in T_1, e.g. around tumours or in acute inflammatory Multiple Sclerosis (MS) lesions, or in chronic MS lesions, probably as a result of demyelination, axonal loss and increased water content.

Hippocampal Sclerosis (HS) is the most common pathological condition underlying intractable temporal lobe epilepsy and following surgery approximately 70% of patients become seizure free. Pathological changes occurring in HS include cell loss and astrogliosis (2). HS can be identified via MR imaging; in particular increased signal intensity on T_2-weighted images is a feature of HS as is hippocampal atrophy (3, 4, 5). Quantification of T_2 can also enable bilateral HS to be detected (5) and may also identify dual pathology (2), or identify abnormalities in patients with otherwise normal conventional MRI. Abnormal signal intensity has also been observed on T_1-weighted images in HS patients, and was shown to demonstrate bilateral abnormalities better than T_2-weighted imaging but abnormalities in hippocampal T_2 signal tend to lateralise better (6). T_1 measurement may, however, provide complementary information to T_2 mapping in HS.

In order to measure T_1, the magnetisation must be perturbed and the observation of the rate of recovery of longitudinal magnetisation towards the equilibrium state is used to obtain the T_1 value. The 'gold standard' of T_1 measurement is inversion recovery-based, with signal data acquired at different inversion times to allow fitting of the model to experimental data to obtain a T_1 value. However it is time consuming to wait for longitudinal recovery between inversion pulses, therefore faster methods have been developed. T_1 measurements are sensitive to RF pulse amplitude errors (caused by errors in the pre-scan procedure or transmit non-uniformity), therefore robust calibration of the B_1 field is also necessary. The T_1 weighting in a spoiled gradient echo (SPGR) sequence depends on the flip angle (α) and repetition time TR, therefore by varying one of these, and modelling the T_1 recovery, T_1 can be estimated. Two-point methods based on this concept have previously successfully been used to measure T_1 (7,8) . This study aimed to establish the normal variation in a 3D, whole-brain, three-point implementation of this method at 3.0T with a view to applying the technique in HS.

Figure 1: Raw T_1-weighted data (a), corrected T_1 data (b) & T_1(left) and M_0 (right) maps (c) for a single subject



Methods: 3 fast 3D SPGRs (TR/TE=6.2/2.8 ms, flip angles=15º, 7º, 3º, 88 2mm thick slices, acquisition matrix=256x192, FOV=24x18cm^2) were acquired coronally in order to calculate a T_1 map. 19 healthy controls (9 female, 10 male, age range 22-70 (mean age 44.2yrs, SD 13.0yrs)) were scanned on a 3.0T GE Signa Excite system (General Electrics, Milwaukee, WI, USA). 2 3D fast recovery FSE (TR/TE=300/24.3 ms, ETL=12, FAs=60º, 120º, matrix=64x64) sequences for B_1 mapping via the double angle method [9]. B_1 mapping data were co-registered to each of the 3 T_1-weighted images (10), 3 B_1 maps were calculated, and the signal intensity in each of the T_1-weighted images was corrected using the 3 B_1 maps. The corrected images were then co-registered, and linear regression was performed on a pixel-by-pixel basis to yield M_0 and T_1maps. Examples of raw and corrected T_1 images and the resultant $T_1$and M_0 maps for a single subject are given in figure 1. In each subject 20 regions of interest (ROIs) (10 right (R), 10 left (L) on 10 different image slices) were drawn in frontal and temporal white matter (WM) regions, the thalamus (6 ROIs R/L) and hippocampus on the first T_1-weighted volume.

Results: Mean T_1 values in right and left ROIs and all ROIs for the control group as a whole are given in the table, with standard deviations (SDs) in brackets. Intra-subject coefficients of variation (CVs) were uniformly low (~2-8%) for all subjects (data not shown). Female T_1values were longer than male T_1 values in all brain regions studied but were only found to be significantly different in the thalamus and frontal white matter. This is thought to be due to differing neuronal densities between males and females. Some right-left differences were also observed; in frontal and temporal white matter (WM) left hemisphere white matter T_1 values were lower, the reverse was true in the thalamus and no significant difference was observed in the hippocampus.

Table 1: Mean ROI T_1 values for all control subjects

Brain region	Mean T_1 (ms) (± SD)	Mean L T_1 (ms) (± SD)	Mean R T_1 (ms) (± SD)
Temporal WM	798.0 (± 53.2)	788.4 (± 56.6)	807.6 (± 47.9)
Frontal WM	733.4 (± 59.0)	718.8 (± 55.3)	748.0 (± 60.2)
Hippocampus	1566.0 (± 99.6)	1567.8 (± 111.6)	1564.1 (± 86.2)
Thalamus	1113.6 (± 94.6)	1183.0 (± 64.9)	1044.2 (± 63.6)

Measured T_1 values were compared with literature; Wansapura *et al* [11] measured an average WM T_1 value of 832 (±10) ms and an average grey matter (GM) T_1value of 1331 (±13) ms in 19 controls using a single slice saturation recovery method. Ethofer *et al* [12] used ^{1}H-MRS (PRESS) used to study the T_1 of different metabolites in the brain in 8 healthy controls and measured a T_1 in fronto-parietal WM of1060 (±60) ms, and a T_1 in the thalamus of 1150 (± 80) ms. Deoni [13] used a method very similar to ours to measure T_1 in 3 subjects but acquired an additional inversion-prepared SPGR in order to fit for the flip angle in addition to T_1. He measured a T_1 in WM of ~1100ms, and in the thalamus of ~1500ms. Clare & Jezzard [14] measured T_1in 8 subjects using a multi-slice inversion-recovery method, with single shot gradient echo EPI readout. They measured T_1 to be 860 (±20) ms in centrum semiovale WM and 1060 (±40) ms in the thalamus. There is variation in the T_1 measurements made using all of these methods, which can be attributed to differences in the methods used, whether B_1 correction was performed and the B_1correction method used, different numbers, location and sizes of regions of interest studied, and also differences between the subject groups studied.

Discussion: Measured T_1 values are consistent with those previously observed at 3.0T for control white and grey matter. Inter- and intra-subject CVs are low in all brain locations although results are not as precise as for some previous studies at 1.5T (15) and 3.0T (11-14). The technique shows good potential for fast quantitative T_1 imaging of the brain at 3.0T which could have many applications including imaging the hippocampus. Future work might include studying other brain locations, a VBM-type analysis to allow investigation of L-R asymmetry, investigation of different B_1 mapping techniques to facilitate better correction of B_1 errors and optimisation of the T_1 mapping acquisition parameters (flip angles) e.g. using Monte Carlo methods to minimise the SDs in T_1 measurements.

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