Fast two-dimensional relaxometric characterisation of brain tissue in vivo: is T1 relaxation multi-component?

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Introduction
Multi-component T2 relaxation has been observed from several neural tissues, including 3-component relaxation in the white matter of the human brain [1], and interpreted as a sign of microanatomical compartmentation. Interestingly, in most cases T1 relaxation was found to be well described by a single exponential and the fact has been explained by intercompartment exchange which is fast on the time scale of longitudinal relaxation, but intermediate or slow for transverse relaxation. However, two-dimensional methods which measure both the spin-lattice and, for example, the spin-spin relaxation, provide an additional dimension for resolving the heterogeneity of the whole spin system, and can facilitate the separation of multiple components in the T1 decay if they exist. This has, indeed, been observed for the trigeminal nerve, but not for white matter in the rat brain, possibly due to insufficient resolution and partial volume effects [2]. Since truly two-dimensional methods for correlated relaxometry are time consuming and usually restricted to a single or a few slices, we propose here the use of a fast whole brain 3D imaging method which allows one to investigate the presence of multiexponential T1 relaxation by correlating it with simultaneous T2* relaxation.

Materials and methods
T1 mapping was performed on a 3T whole-body scanner (Siemens Trio) equipped with a 40mT/m whole-body gradient coil, using a two-point method similar to the one described in [3,4]. Briefly, two 3D multiple-echo gradient echo data sets were acquired with the same TR=50ms and different flip angles $\alpha1$=10deg and $\alpha2$=50deg, optimised to give the highest accuracy of T1 determination. Two probes with known T1 were placed in the FOV for calibration. Other parameters were: FOV 256x192, matrix 256x192, 1mm slices, 128 slices/slab; iPAT=2; TA=10min/scan. Twelve echoes were acquired for each measurement, with echo times ranging between TE_1=2.58ms and TE_{12}=46.5ms, spaced equidistantly with ΔTE=4ms. The RF field of the transmit body coil (BC) was measured using the 3D actual flip angle imaging proposed by Yarnykh [5]. The RF calibration contributes an additional 7 minutes to the total measurement time. For each echo time TE, the T1 maps were calculated using the Ernst formula for the signal intensities corresponding to (TR,$\alpha1$,TE) and (TR, $\alpha2$,TE), where $\alpha1$ and $\alpha2$ are the effective flip angles determined with AFI. Data from two female volunteers, aged 24 and 26 were evaluated. The data were averaged using a sliding window 2 voxels wide in each dimension, to increase SNR and the precision of the 2-point mapping method. The dependence of T1 on TE was evaluated on a pixel by pixel basis. In order to avoid the confounding effect of low SNR on the T1 mapping, only the first 8 of the 12 echoes were included in the evaluation. The 8-point distribution T1(TE) in each pixel was described by its mean and SD and by a linear fit $T_1=m*TE+n$. To characterise the dependence of T_1 on echo time, maps of the SD(T1)/mean(T1) and of the parameters of the linear fit (slope *m* and intercept *n*) were calculated.

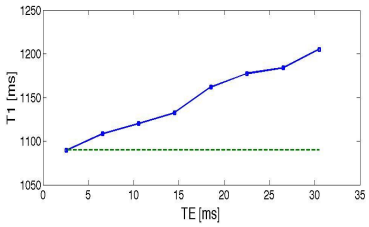
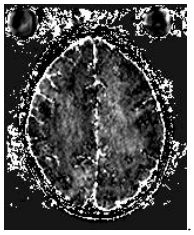
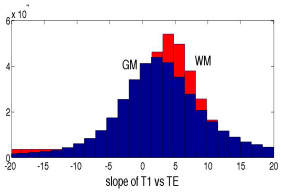
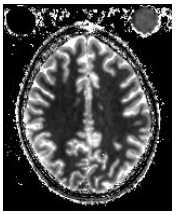


Figure 1







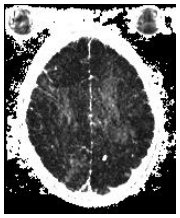


Fig. 2: a) slope *m* b) histogram of *m* for WM and GM c) intercept *n* d) SD/mean

Results
Figure 1 shows the observed behaviour of T1 with echo time for a representative ROI placed in the genu of the corpus callosum (blue) and its expected behaviour (green), according to the signal equation for a spoiled GRE sequence. In figure 2, different ways of describing the behaviour of T1 with TE on a pixel by pixel basis are presented. The map of the linear coefficient is shown in Fig. 2a, the intercept in Fig. 2c and the SD/mean(T1) in Fig. 2d. The brain tissue was segmented into white matter (WM), grey matter (GM) and CSF based on T1 values and the properties of each type of tissue were investigated separately. The distribution of slopes for GM, shown in Fig. 2b has a mean value of 1.8 and FWHM of 15.5, the distribution of values for the WM a mean of 4.0 and FWHM of 8.1.

Discussion and conclusions
An important aspect of the 2-point mapping procedure is that the echo-time dependence of the signal cancels out in the expression used to calculate T1 [3-5]. There is, therefore, no explicit dependence of T1 on TE, but the accuracy of the method is expected to depend to a certain extent on SNR, when all other parameters are fixed. However, a variation of T1 with TE was present in the data, as depicted in Fig. 1 for a selected ROI and in Fig 2a,c,d for voxels from a representative slice. In figs. 2a (scale -20 to 20) and 2d (scale 0 to 0.2), the white matter region is seen to display a higher and positive slope and a higher relative T1 variation than the grey matter. The intercept of the linear fir, shown in Fig. 2c (scale 0 to 3500ms), has values which are very close to those of T1 at the shortest measured echo time, but a slightly higher spread in the WM values. The mean value of the slope for the WM over the whole brain is different from zero (within one SD) and positive. Regions where SNR is known to degrade fast due to pronounced T2* effects show predominantly a negative slope (data not shown). Since the T2* of white and grey matter at 3T is on average the same [8], the difference in the mean slope between WM and GM, seen in Fig. 2b, is most probably not due to differences in the change of SNR due to T2* decay.

We will assume now that several distinct water components with distinct T1 and T2/T2* relaxation properties contribute to the observed signal S(TR,α,TE), since such components have already been detected in the T2 decay [1]. If a common T1 is established in all compartments by fast exchange (on the time scale of the longitudinal relaxation), the observed T1 will not depend on TE. This holds even if the contribution of each compartment to the observed signal is changing with TE due to T2/T2* decay. If, however, the short-T2 compartment is characterised by a distinct, and short, T1 value, the decreasing contribution of this short-lived component to the observed signal will give rise to an increase of the observed T1 with TE. In conclusion, the variation of T1 with echo time provides indication for the presence of multi-component T1 relaxation in the brain white matter. While SNR plays an important role in the accuracy of T1 mapping with the two-point method, a numerical investigation of the effect (data not shown) shows that the observed variation in T1 with TE is unlikely to be due to SNR alone. With proper modelling of the multiple water compartments which are present in the brain, the observed variation of T1 with echo time might provide a useful way of estimating, for example, the myelin water fraction from high resolution 3D data which are acquired in a clinically acceptable time.

References
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