Measuring T_2 and T_2' in the brain at 1.5T, 3T and 7T using a hybrid gradient echo-spin echo sequence and EPI

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Aim: To develop an accurate, straightforward method of measuring T_2 and T_2' in the brain, and to report results at 1.5, 3 and 7T. The method used is the gradient echo-spin echo (GESE) sequence, variants of which have been reported in the past[1-4]. T_2 results have been compared to those obtained using the spin echo EPI sequence.

The GESE Sequence: The sequence consists of a series of M gradient echoes (GE) (i.e. similar to an EPI readout gradient) superimposed on a spin echo (SE) (fig. 1). This is repeated N times, where N is the number of phase encoding steps, with a phase encoding gradient applied before the start of the readout. (In practice this was implanted using 'EPI test mode' on a Philips scanner). The signal obtained at each gradient echo is modelled as[2]

$$S(t) = S_0 \exp - \left([t/T_2] + [|t - \tau|/T_2'] \right)$$

and fitted using the Powell algorithm[5] to give T_2 and T_2'. Here τ is the time between the first and central echo and t=0 is the time of the first echo. This sequence is insensitive to RF pulse errors since errors in either of the pulse flip angles will cause equal attenuation of all the echoes, leading to a simple reduction in SNR. It is also insensitive to T_1 saturation (weighting) since the time between the refocusing pulse and next 90° pulse is constant.

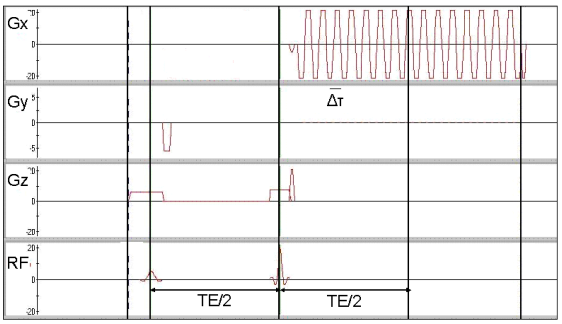

Figure 1: GESE sequence used to measure T_2 and T_2'

Method: 4 subjects (aged 24-44 years) were scanned with local Ethics Committee approval using GESE and SE-EPI sequences, on Philips Achieva 1.5, 3 and 7T MRI scanners with a SENSE head coil (SENSE factor = 2). For the GESE sequence, imaging parameters were 256x256 (RFOV 80%) matrix, 1x1x3 mm voxel size, single slice, TR=2s. Other parameters were 7T: $\Delta\tau$=1.43ms, M=25, total time=3mins; 3T: $\Delta\tau$=1.43ms, M=31, total time=3mins; 1.5T: $\Delta\tau$=1.54ms, M=31, total time=8mins. For the SE-EPI sequence, a single slice was acquired in a single shot (voxel size 1.5x1.5x1.5mm) at 12 TEs (7T: 30-85ms; 3T: 55-120ms; 1.5T: 90-200ms) and TR>5T_1. On a separate occasion, high resolution SE-EPI measurements were made at 7T with 1x1x3 mm voxel size and 64x64 FOV using 8 TEs (42-150ms). The GESE data was fitted using the method described above and the EPI data fitted using a linear log fit, taking account of the effect of noise at long echo times. The SE-EPI and GESE data were used to measure T_2 in occipital (back) and frontal grey (GM) and white matter (WM).

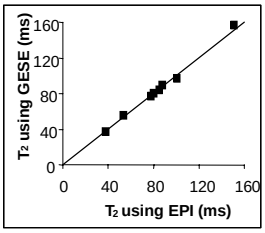

Figure 2: T_2 calibration curve comparing GESE and EPI (identity line shown)

T_2 Calibration: 2 spherical phantoms, divided into quadrants, and containing NaCl and 8 different concentrations of agar gel and Gadolinium ions were scanned at 7T using GESE and the same single shot SE-EPI sequence used *in vivo*, which is insensitive to RF pulse errors and T_1 saturation.

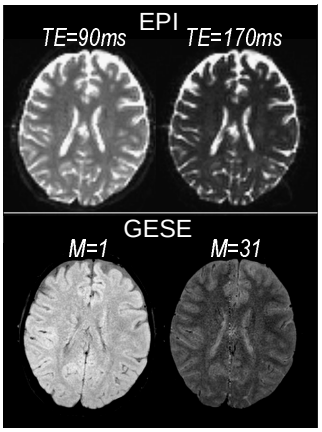

Figure 3: 1.5T images for a single volunteer using EPI and GESE.

Results: The T_2 calibration curve for the GESE sequence is shown in fig. 2; similar results were obtained for other pulse sequence timings. Fig. 3 shows varying T_2 weighted images from the SE-EPI and GESE sequences at 1.5T from a single volunteer. Table 1 shows T_2 values for WM and GM using SE-EPI and GESE. It was observed that GM/WM contrast in T_2 maps was lost at the back of the head in all subjects at 7T, due to an apparent drop in GM T_2. The T_2 values obtained using the high resolution EPI sequence and different echo time GESE sequences agreed with those obtained using the standard SE-EPI and GESE sequences (to within the std. dev. quoted). The T_2' values obtained with GESE are shown in table 2.

Discussion: Under clinical imaging conditions standard gel phantoms exhibit monoexponential T_2 with minimal diffusion effects and the GESE and SE-EPI results are in excellent agreement.

T_2 is a difficult parameter to measure or even define in vivo because:
(i) Most tissues exhibit multiexponential decay and voxels can contain components with very different T_2s so that if data is fitted to an apparent single exponential decay, the fitted T_2 depends on the echo times used and the T_1, T_2 or T_2* weighting of the imaging sequence.
(ii) Transverse decay rate is enhanced by diffusion in any local field inhomogeneities (e.g. around venous vessels or iron deposits). This can be mitigated using multiecho sequences with short interpulse spacing, but such sequences are often affected by errors due to RF pulse inhomogeneities.

Table 1	1.5T		3T		7T	
	GESE	EPI	GESE	EPI	GESE	EPI
GM front	87 ± 4	96 ± 6	76 ± 2	72 ± 2	47 ± 11	48 ± 4
GM back	80 ± 2	84 ± 6	68 ± 6	63 ± 2	46 ± 8	39 ± 2
WM	80 ± 1	94 ± 5	71 ± 2	77 ± 4	47 ± 2	50 ± 3

Table 1: Measured GM and WM T_2 (in ms) using GESE and EPI (mean ± inter-subject std. dev.). **Table 2**: Measured GM and WM T_2' (in ms) using GESE (mean ± inter-subject std. dev.)

Table 2	1.5T	3T	7T
GM front	1578 ± 243	685 ± 241	283 ± 272
GM back	1198 ± 252	492 ± 102	129 ± 73
WM	2051 ± 625	648 ± 215	236 ± 59

Consequently there is great variability in the T_2 values reported in the literature. GESE and SE-EPI are insensitive to RF pulse errors and have long echo times making them more sensitive to longer T_2 components and any local field inhomogeneities. Our single echo GESE and EPI results generally agree well, except for a tendancy for EPI to measure longer T_2s than GESE in the WM, which would be expected due to the increased T_2* weighting in EPI compared to GESE (fig. 3), and the CSF contribution to WM. Our T_2 results also compare well with results reported in the literature using similar imaging modules[7,8]. The loss of GM/WM contrast in the occipital lobe of the T_2 maps has been previously reported[7,8], and has been attributed to increased iron content in the occipital lobe. This explanation would be consistent with the change in T_2' between different regions of GM reported in table 2. Inter-subject variability is less in WM which may be due to variable iron content in GM, but intra-subject variability will now be assessed to confirm this. The apparent sensitivity of this T_2 measurement to iron content suggests that future work should study the variations in T_2 and T_2' in deep grey structures with age and in Parkinsons's disease[4]. As implemented, GESE had a lower SNR than EPI; however the EPI images are very distorted in parts of the brain at 7T. Future work will optimize the SNR in the measured T_2 and T_2' in GESE in terms of TR TE, M and $\Delta\tau$, and will investigate the imaging readout module used on the results.

References: 1. DL Thomas *et al.* Neuroimage **15**, 992-1002 (2002) 2. KA Miszhiel *et al.* MRI. **15**, 1113-9 (1997) 3. H An & W Lin. J. Ce. Blood Flow Met. **20**, 1225-36 (2000) 4. JM Graham *et al.* Brain, **123**, 2423 (2000) 5. WH Press *et al.* Num. Rec. in C (2nd Ed.) 6. H Dahnke & T Schaeffter **53**, 1202-6, (2005) 7. J Zhou *et al.* MRM. **46**, 401-6 (2001) 8. R Bartha *et al.* MRM **47**, 742-50 (2002). *This work was funded by the MRC and EPSRC.*