Optimisation of the combined gradient echo/spin echo (GESE) sequence for the measurement of T_2 at 7.0 T

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The combined gradient echo/spin echo (GESE) sequence has been used to measure T_2 and T_2* simultaneously in the brain at 7T in both healthy volunteers and patients[1,2]. GESE is particularly useful at 7T as it is insensitive to RF pulse errors since errors in either of the pulse flip angles will cause constant attenuation of all the echoes, leading to a simple reduction in SNR, and it has a low SAR. It is also insensitive to T_1 saturation (weighting) since the time between the refocusing pulse and next 90° pulse is constant. Other groups have used variants of this sequence in the past at lower field[3-6].

Aims: To determine the best approach for fitting GESE data, and to optimise the acquisition parameters for SNR in the measured T_2 and T_2' in terms of TE, M and ΔT.

Optimization

GESE consists of a series of M gradient echoes (GE) (i.e. an EPI readout gradient) superimposed on a spin echo (SE) (figure 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). Figure 2 shows typical T_2 maps obtained using this sequence. Two methods for calculating the relaxation parameters were investigated:

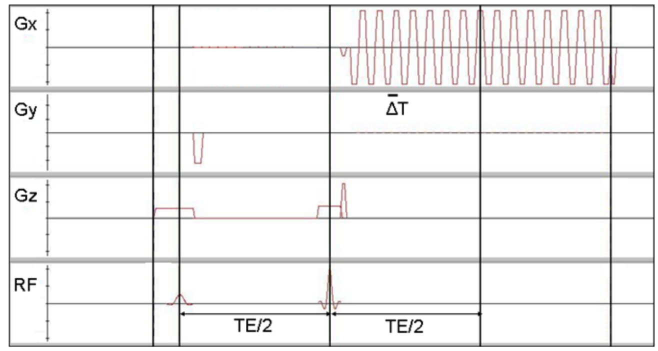

Figure 1: GESE sequence used to measure T_2

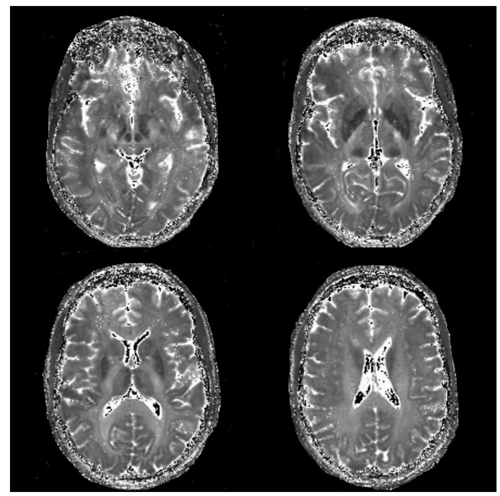

Figure 2: Example T_2 maps obtained using GESE

Method A: The signal obtained at each gradient echo is modelled as[4]

$$S(t) = S_0 \exp - \left(\frac{TE + i\Delta T}{T_2} + \frac{|i\Delta T|}{T_2'} \right) \qquad \text{(eq. 1)}$$

where ΔT = gradient echo spacing (fig. 1) and i = -½(M+1), -½M, ..., 0, ..., ½M, ½(M+1), and fitted using the Powell algorithm[7] to give T_2, T_2' and S_0. Errors in fitted T_2 values were calculated using a covariance matrix method[7].

Method B: The relationship between the symmetric gradient echoes at time nΔT before (S_-) and after (S_+) the spin echo at TE, (n < M/2) is given by[3]

$$\frac{1}{T_2} = \ln\left(\frac{S_{-n}}{S_{+n}}\right) \Big/ 2n\Delta T \qquad \text{(eq. 2)}$$

so that a linear fit of $\ln(S_{-n}/S_{+n})$ against 2nΔT will yield a value of T_2. This value can then be used to correct the rising and falling edges of the echo train and the data can be used to measure T_2* from both sides of the echo as well. Errors in fitted T_2 values were calculated using standard analytical error analysis.

Method

To compare the results from methods A and B, the error in T_2 (σ) was calculated for each method for different numbers of gradient echoes (M) and ΔT for TE= 50ms. Subsequently the maximum allowed value of ΔT for a given TE and M was used since the preliminary calculations showed this to yield the lowest error in T_2 as expected. Using method A, the echo time was optimised for different values of M, and the value of M was optimized for different values of TE. For the calculations, a 1% random gaussian noise was assumed but this was scaled for the bandwidth of the readout. The following values were assumed from pilot results at 7T: T_2 = 50 ms, T_2' = 250 ms with S_0 = 1.

Results

Figure 3 shows the comparison between the errors obtained in the fitted T_2 values from methods A and B. They are in excellent agreement for high values of M, but deviate more at lower values of M, with method B giving the lower errors. They show that the maximum achievable value of ΔT for a given TE and M should be used. Figure 4 shows the variation of the error in T_2 with TE (using method A). Figure 5 shows the effect of increasing the number of gradient echoes (M) on the error obtained in T_2 for different values of TE (using method A).

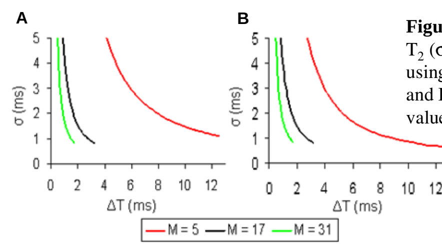

Figure 3: Error in T_2 (σ) obtained using method A and B for different values of M.

Discussion

The two methods agree well for fitting T_2 when the data is over determined (large M), but method B gives better results when the data is less well determined, which is expected since method B is analytical. However since the optimum fit occurred at large M (where the fits gave the same results), and since method A also gives the value of T_2', method A was used in the subsequent optimizations. The optimum TE was found to be relatively independent of the number of gradient echoes and was 56 ms for the T_2/T_2' combination used here (T_2/T_2' = 50/250 ms). The error in T_2 increased at small M, but for M>10 there was little benefit of further increasing M (figure 5), and the effect of ΔT on image quality would become more important. Future work will consider the effect of different T_2/T_2' combinations on the optimum sequence parameters. In conclusion GESE gives precise T_2 maps in a reasonable imaging time at 7T, and to measure T_2/T_2' combinations typical at 7T (in the ratio 1:5), TE should be set to 1.12 T_2 and the number of readout pulses should be greater than 15.

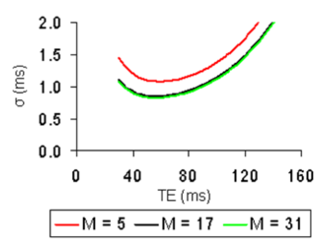

Figure 4: Effect of increasing TE on the error in T_2 (s) obtained at different values of M.

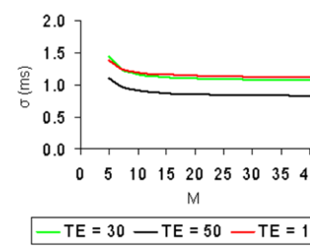

Figure 5: Effect of increasing M on the error in T_2 (σ) obtained at different TEs.

References

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