Stimulated echo compensation enables accurate transverse relaxometry with short echo train multi-echo spin echo imaging.

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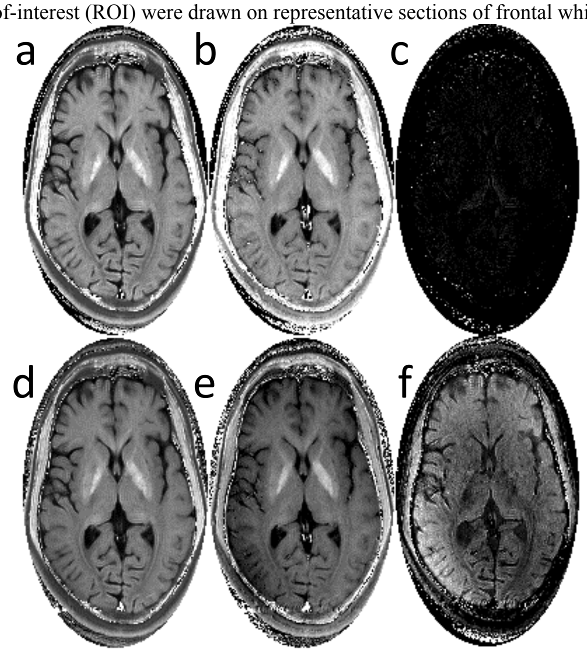
Introduction: Transverse relaxation (T_2) weighting is used in almost all clinical MRI exams. In certain cases, T_2 quantification would provide additional clinical value. For example, in multiple sclerosis, shortened T_2 times in grey matter are indicative of iron accumulation and appear to correlate with disease severity [1,2]. T_2 measurements are typically performed with a multi-echo spin echo sequence [3]. However, accurate measurement of T2 times in this manner is generally cumbersome, requiring long echo trains and carefully crafted refocusing pulses to ensure perfect spin echo behaviour. This method can be prohibitive at high magnetic fields due to RF heating requirements of the many refocusing pulses, and the breakdown of spin echo refocusing due to heterogeneous RF fields both across and within the slice of interest. In order to overcome the non-uniform RF field, Lebel [4] recently introduced and validated a fitting model which includes stimulated echoes to permit relaxometry in heterogeneous transmit fields requiring only knowledge of the RF pulse profiles used for excitation and refocusing. Unlike white matter, grey matter typically has a single component in its T_2 spectrum and may not require a large number of echoes to quantitate its relaxation time. The purpose of this study is to investigate the possibility of extending the value of this stimulated echo fit to overcome the significant RF heating limitation at high field by using substantially shortened echo trains to enable reductions in RF heating, or alternatively increases in the slice coverage, for the investigation of T2 fitting of grey matter in human brain.

Methods: Two-dimensional multi-echo spin echo images of the human head were obtained in single and multi-slice mode on a Varian Inova 4.7 T whole-body system. Maximum gradient strength was 60 mT/m with a slew rate of 120 T/m/s. Transverse relaxation maps of the human brain were obtained from 10 healthy subjects (four male, six female; mean age: 29±2 years) all of whom gave written informed consent in accordance with institutional protocols. Excitation and refocusing angles were prescribed at 90° and 180° respectively with the refocusing pulse slice profile 1.75, 3 or 5 times wider than excitation. The typical scan parameters were: 4000 ms TR, 10 ms echo spacing, 20 echo train length, 4 mm slice thickness, 8 mm slice gap, 1 or 2 slices, 50 kHz receiver bandwidth, and 256 x 145 imaging matrix. Acquisition time was 5.2 min per image set with phase partial Fourier. Slice coverage and echo train length were then varied under constant RF power deposition. Images were fit on a pixel-by-pixel basis with the stimulated echo compensation model and a standard exponential model for different numbers of consecutive echoes. Bilateral regions-of-interest (ROI) were drawn on representative sections of frontal white matter (WM), putamen, globus pallidus, and caudate nucleus.



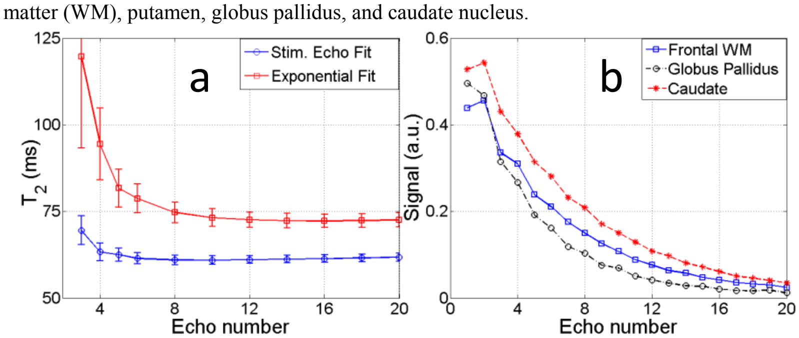


Fig. 2. (a) Variation of the measured relaxation time T_2 in the caudate nucleus (average of 10 healthy volunteers) with different number of echoes using the exponential and stimulated echo compensation fits. Error bars indicate the standard deviations. (b) Signal decay from one volunteer for three territories. Increased amplitude of the second echo is often observed due to stimulated echo contribution.

Fig 1 (left). In-vivo R_2 maps at 4.7 T: top row, stimulated echo fit; bottom row, exponential fit. In (a,d) 20 echoes are used, while (b,e) only 4 echoes. Difference maps are shown in (c,f) with stimulated echo (c) showing minimal change. Intensity scale is from 2.5 to 30 s^{-1} in images (a,b,d,e) and 5 to 60 s^{-1} for difference images (c,f).

TABLE 1: Average *T_2 values in 10 subjects obtained via retrospective truncation of the echo train*

# of echoes	Frontal WM		Caudate		Putamen		Globus Pallidus	
	Stim	Exp	Stim	Exp	Stim	Exp	Stim	Exp
20	53.2±1.3	63.2±1.2	61.8±1.2	72.5±2.0	54.2±1.3	63.5±2.9	44.6±1.0	53.7±2.1
5	52.7±1.3	68.8±2.3	62.5±1.8	81.7±5.4	54.7±2.1	69.9±7.1	44.8±1.1	58.3±5.0
4	52.2±1.6	76.9±4.1	63.3±2.5	94.4±10.4	55.0±2.7	79.0±12.2	44.6±1.6	65.0±8.2
3	56.2±1.8	90.8±8.3	69.5±4.1	120±26.4	59.4±3.3	97.7±28.7	47.8±2.5	75.9±15.4

TABLE 2: *T_2 values for different number of slices and echoes using the stim fit.*

# of Slices	# of echoes	FWM	Cd.	Put.	GP
1	20	51.4	62.8	57.5	38.3
2	20	51.9	62.9	55.9	37.0
4	10	50.5	61.8	57.7	37.9
8	5	50.4	64.8	59.1	36.9

Results: Figure 1 contains typical R_2 maps (1/ T_2) obtained using 20 echoes (left column) and 4 echoes (middle column); the difference images (right column) suggest the stimulated echo fit (a-c) remains accurate despite drastic reduction in echo train length while the standard exponential fit (d-f) is dependent on the number of echoes in the fit. This dependence is further explored in Figure 2 where the population averaged T_2 for the caudate nucleus is shown for echo trains employing 3 to 20 echoes and fit using both stimulated echo compensation and exponential models. The stimulated echo compensating fit is robust at most echo train lengths; a large variation in T_2 is observed with the exponential fit. Similar results were obtained for other deep grey matter structures (Table 1), and for different relative refocusing/excitation widths (data not shown). Table 2 contains the average T_2 values using the stimulated echo compensating fit for a single slice (20 echoes, half RF power), 2 slices (20 echoes), 4 slices (10 echoes) and 8 slices (5 echoes). Consistent relaxation times are observed with short echo trains and increased slice coverage. This further suggests that magnetization transfer has a negligible effect when fitting a single relaxation component to grey matter.

Conclusion: Using stimulated echo compensation, substantial shortening of the echo train can be achieved for single component T_2 mapping. At 4.7 T, echo trains as short as 4 were able to produce results similar to 20 echoes, which is not possible with the standard exponential method. Stimulated echo compensation enables use of T_2 mapping at high magnetic field by compensating for RF field non-uniformity and enabling substantial echo reduction over standard exponential fitting to minimize RF heating, or maximize slice coverage for a given RF heating restraint.

References: **[1]** Lebel RM, Mult. Scler. 2011. **[2]** Schenck JF, NMR Biomed 2004. **[3]** Poon CS, MRI 1992. **[4]** Lebel RM, MRM 2010.