T_2 Quantification Using Only T_2-weighted and Proton Density Weighted Fast Spin Echo Images

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INTRODUCTION: Clinical MRI exams often include proton density (PD) and T_2-weighted fast spin echo (FSE). It is common for T_2 to be calculated by applying an exponential fit to these two images. This method of T_2 measurement remains in persistent use in the clinic, despite recent demonstration of the failure of exponential fitting to produce accurate T_2's in the presence of non-180° RF refocusing [1]. Variation from 180° refocusing arises within the slice profile from standard 2D slice selection, within the imaging plane from RF interference, or simply from the purposeful prescription of smaller refocusing angles, as is common practice for FSE at 3.0 T, to minimize RF heating. Methods such as stimulated echo compensation (SEC) [1,2] overcome this RF limitation but have only been demonstrated using multi-echo spin echo sequences that require a substantial time penalty that is unacceptable in most clinical practice. Given that most modern scanners now collect an RF field map, it becomes possible to apply SEC to standard brain exams with no time penalty. *We present stimulated echo compensated T_2 mapping using only T_2-weighted and PD-weighted FSE images, enabling T_2 quantification without additional imaging time. We demonstrate the method in comparison to standard quantitative multi-echo spin echo approaches with application to subcortical human brain.*

METHODS:

Human brain imaging experiments were performed at 4.7 T. Eight axial single slice FSE images were acquired through iron-rich deep grey matter with varying effective TE (ETL = 8; effective TE = 10, 20, 30, 40, 50, 60, 70, 80 ms; echo spacing = 10 ms; prescribed excitation = 90°; refocusing = 180°; relative refocusing width = 1.75; matrix = 256 x 145; voxel size = 1 x 1.25 x 4 mm^3). Multi-echo spin echo (CPMG) images with geometry matched to FSE images were acquired through iron-rich deep grey matter (TR = 4 s; ETL = 20; TE = 10 to 200 ms; echo spacing = 10 ms; prescribed excitation = 90°; refocusing = 180°; relative refocusing width = 1.75).

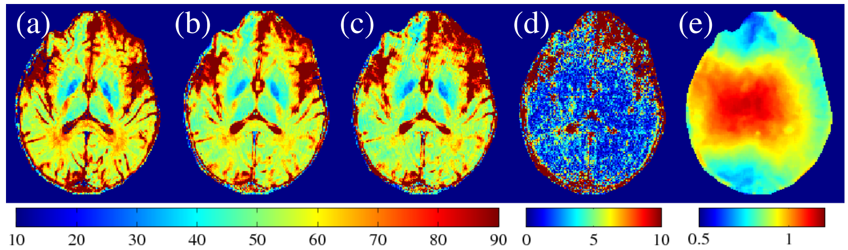

Figure 1: *T_2 maps (ms) computed using SEC on (a) full 20 echo CPMG, (b) eight FSE images (effective TE equally spaced from 10 – 80 ms), (c) two FSE images (effective TE = 10, 60 ms), (d) absolute difference of (b) and (c), (e) the corresponding normalized FA map.*

Flip angle (FA) maps were acquired using the double angle method [3] with a correction for slice profile (geometry and pulse shapes matched to multi-echo data, TR = 7 s; FA = 60°, 120°; effective TE = 43 ms). Normalized FA maps are expressed as a ratio of the FA achieved at the centre of the slice relative to the requested FA.

T_2 fitting was performed using fully simulated CPMG sequences to compensate for both spin echo and stimulated echo pathways. Slice selective RF pulses were simulated using the Shinnar-Le Roux algorithm [4], and relaxation between pulses was calculated according to Bloch equation solutions. Simulation parameters (TE, selective RF pulses, and spoiling) were matched to the experimental imaging sequence to calculate the theoretical signal at the respective TE for each image. Simulations of decay curves and all image processing were performed in MATLAB using custom in-house code. T_2 maps were computed with both the SEC method and standard exponential fit using different combinations of data: full CPMG, all eight FSE images, different pairs of FSE images (PD and different T_2-weighted images). The FA map was provided to the SEC fitting algorithm in each case.

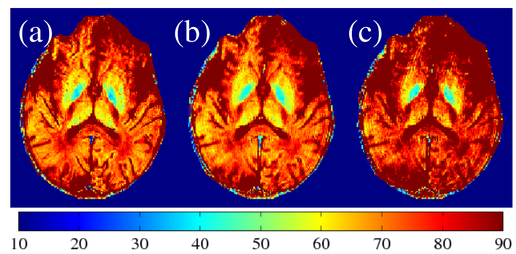

Figure 2: *T_2 maps (ms) computed using an exponential fit on (a) full 20 echo CPMG, (b) eight FSE images, (c) two FSE images (effective TE = 10, 60 ms).*

T_2 averages were calculated in regions of interest (ROI) drawn selecting iron rich grey matter (caudate, putamen, globus pallidus) and white matter territories (corpus callosum splenium, and optic radiation).

T2 (ms) from Various Structures Using Either SEC or Exponential Fit

Acquisition	Echo #	Globus pallidus				Caudate				Putamen				Optic Radiation				Splenium			
Type	used	SEC	±	exp	±	SEC	±	exp	±	SEC	±	exp	±	SEC	±	exp	±	SEC	±	exp	±
CPMG	1-20	31	4	41	4	55	3	68	3	48	4	60	5	65	3	80	4	63	5	79	6
FSE x 8	1-8	31	2	41	2	55	2	71	3	47	3	61	3	61	3	79	4	57	3	74	4
FSE x 2	1, 2	43	9	N/A		78	50	N/A		54	9	N/A		80	60	N/A		90	90	N/A	
FSE x 2	1, 3	32	3	48	5	55	5	100	14	46	3	78	8	54	4	100	10	53	6	100	20
FSE x 2	1, 4	31	2	48	4	54	3	94	8	46	3	77	7	58	4	100	10	54	5	97	13
FSE x 2	1, 5	33	3	43	4	56	3	79	5	48	3	66	5	60	3	86	6	57	4	84	8
FSE x 2	1, 6	31	3	43	4	54	3	77	5	46	3	65	4	61	4	90	8	55	4	82	7
FSE x 2	1, 7	33	3	42	4	58	3	76	5	49	4	63	5	63	4	84	6	59	4	79	6
FSE x 2	1, 8	29	3	41	4	53	3	74	4	45	3	63	5	59	3	84	5	57	4	80	6

Table 1: *ROI averaged T_2 fit values from one volunteer are reported. The uncertainty is the standard deviation within the ROI. Exponential fits using only echoes 1 and 2 were not performed because at high field this relationship is dominated by stimulated echos, and provides meaningless negative T_2 fit.*

RESULTS AND DISCUSSION: T_2 maps using SEC are shown in Fig 1. To provide a gold standard for comparison, the T_2 map from SEC fitting on full CPMG data is shown in Fig 1a. The T_2 map computed using SEC fitting on a PD-weighted (TE = 10 ms) and a T_2-weighted (TE = 60 ms) FSE image (Fig 1c) is found to be very similar to the map computed using 8 FSE images (TE = 10 – 80 ms; Fig 1b), as shown by the absolute difference map (Fig 1d). Both are found to have values close to the gold standard. Exponential fitting varies depending on TE used, and provides artificially long T_2's in all cases due to stimulated echoes (Fig 2 a-c).

T_2 values within various subcortical structures (see Table 1) are found to be reliable for certain combinations of FSE images when using the SEC method. Accuracy of T_2 fit values will depend on the effective TE of the FSE images, as the optimal TE choices will depend on the T_2. Performance is also reduced in areas of reduced FA (the FA map is shown in Fig 1e).

T_2 fitting used full Bloch simulations instead of the extended phase graph (EPG) algorithm, as implemented by Lebel [1]. In order to accurately fit for T_2 with only two points, FA must be independently measured. The EPG implementation of SEC underestimates FA to compensate for the overestimation of slice width in its slice profile approximation [1], and therefore providing FA may not be appropriate for that algorithm, unlike the full simulation used here.

CONCLUSIONS: In standard clinical exams that collect both PD and T_2-weighted FSE images, effective quantitative T_2 can be performed with stimulated echo compensation with no time penalty, provided a FA map is already available.

REFERENCES: 1. Lebel RM, Wilman AH. Magn Reson Med. 2010;64:1005–14. 2. Uddin MN, Lebel RM, Wilman AH. Magn Reson Med. 2013;70(5):1340–6. 3. Stollberger R, Wach P. Magn Reson Med. 1996;35:246–51. 4. Pauly J, Le Roux, P, Nishimura, D, Macovski, A. IEEE Trans Med Imag, 10(1):53–65, 1991.