Novel sequence for accurate, multi-slice T2-rexometry with insensitivity to refocusing pulse profiles and reduced SAR

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Introduction: T2 has been found to be a sensitive indicator of conditions such as temporal lobe epilepsy and schizophrenia. Its acquisition in the clinical context is usually carried out with a multi-echo CMPG sequence. The method is disadvantaged however by limitations that are principally a result of the multiple refocusing 180° pulses in the sequence (1). Power deposition limits the number of slices that can be acquired. The accuracy of the T2 measurements are affected by stimulated echoes from the edges of the slice selective 180° pulses that modulate the measured T2. An apparent T2 measurement is therefore the result of such a study and this will likely deviate from the true T2. This report describes a novel rapid sequence for T2 relaxometry that enables accurate measurement of T2 with insensitivity to the refocusing pulse profile and with reduced SAR.

The sequence: The pulse sequence shown in Fig. 1 is based on a standard FSE multiple spin echo train of $90_x°$-$[180_y°]_{NE}$ pulses where *NE* is the desired number of echoes. With an incrementing phase encode pulse, T2-weighted images are produced at *NE* unique echo times. For multi-slicing, the sequence needs to be repeated for the desired number of times. In the new sequence, the slice selective 180° is replaced by a non-selective composite refocusing pulse, $[90_x°\text{-}180_y°\text{-}90_x°]$ (2). This pulse has improved robustness to B1 inhomogeneities. More significantly, the lack of a slice selection gradient across the refocusing profile results in a sequence that is unaffected by the source of stimulated echoes mentioned above (deviations of flip angle at slice edges). Stimulated echoes are thereby largely eliminated. The single 90° pulse of the standard sequence is replaced by the chosen number of slice-selective such excitation pulses $([90°]_{NS}$-$[180°]_{NE})$ where *NS* corresponds to the desired number of slices acquired in each pass. A modified read and slice gradient pattern (see Fig. 1) nulls the gradient moment at each echo readout. Each 90° pulse thereby induces a train of echoes at a particular slice position. The echo timings from each slice follow an asymmetric pattern around the refocusing pulses. The number of pulses in the sequence is smaller by a factor of $(NE+NS)/[(1+NE).NS]$ than those required for the standard approach and, therefore, the SAR is significantly reduced. With this implementation, the repetition time that follows each pass of the sequence is not used for multi-slice repetitions as in the standard sequence and rapid implementation is therefore facilitated. As a consequence of the non-selective refocusing, dummy acquisitions at the start of the acquisition are required for imaging with shortened TR. A crusher scheme in the slice direction was implemented for artefact elimination from any remaining unwanted coherence pathways (3). The novel sequence was termed FLATULAIT (**F**ast **L**ooping **A**symmetric **T**rain for m**UL**ti-slice **A**cquisition of B1-**I**nsensitive **T2**).

Methods: The sequence was implemented on a 3T GE LX scanner. For validation of the FLATULAIT sequence, a phantom experiment was performed using a phantom made up of four bottles with different T2 values. Multi-slice imaging was carried out with the FLAT sequence (128×64, 5 slices, TR=1sec, central TE=38 ms, 8×180° pulses, 1.5×3.1×5mm voxel, Tscan=64sec). Results were compared with a standard CPMG sequence (Tscan=192sec) and a slow single echo spin echo acquisition for a gold-standard measurement of T2 (Tscan>1hr). Regions-of-interest (ROIs) were drawn in the T2 bottles for comparison. To demonstrate the multi-slicing capabilities of the FLAT sequence, a 15 slice acquisition was performed using the same phantom (128×64, TR=1.7sec, central TE=50 ms, 8×180° pulses, Tscan=102sec). A human subject was also scanned with the 5 slice acquisition.

Results: Table 1 displays the results of the validation experiment. The FLATULAIT sequence performs nearly as well as the slow spin echo sequence in terms of accurate quantification. The T2 values obtained from the CPMG sequence are elevated in the phantoms with higher T2. This is the expected result of T1/T2-weighted stimulated echoes that will especially affect the early echoes but which can be reduced with manipulation of the sequence (4). Figure 2 shows a selection of the 15 T2 maps from the phantom FLATULAIT acquisition and the T2 maps from the human subject are shown in Fig. 3. The GM and WM T2 values from representative ROIs were 91±4 ms and 75±4 ms respectively.

Discussion & Conclusions: This report introduces a novel, rapid pulse sequence for T2 relaxometry with benefits of reduced SAR and optimized accuracy for multi-slice imaging. It is well known that non-selective 180° pulses are the only mean of accurate T2 quantification. However, this requirement usually conflicts with the needs of multi-slicing. The FLATULAIT sequence enables the use of these pulses but in combination with multi-slice selection. In addition, composite 180° pulses can be used for their benefits of B1-insensitivity. Any remaining stimulated echo effects are eliminated with a crusher scheme. The extra pulses in the train limit the minimal echo time but 2 (or more) passes of the sequence can be used. Rapid accurate T2 quantification with the shortened multi-slice pulse train can thereby be achieved with the additional benefit of reduced SAR. For a 15 slice acquisition, the sequence used approximately 16% of the pulses required by the standard technique which is obviously of significant benefit for for clinical T2 relaxometry.

Bottle	**1**	**2**	**3**	**4**
FLATULAIT (n=2)	37.2 ± 0.4	226.6 ± 4	168.7 ± 0.9	69.2 ± 0.3
CPMG (n=2)	48.8 ± 0.8	316.2 ± 4.8	190.4 ± 1.8	80.7 ± 1.3
spin echo T2 (n=1)	38	240	164	68

Table 1: Validation T2 results from the multi-T2 phantom

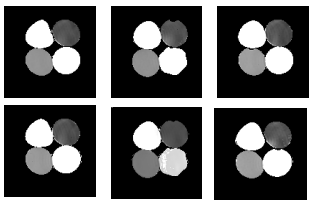

Fig. 2: Representative T2 maps from the 15 slice acquisition (Tscan=102sec)

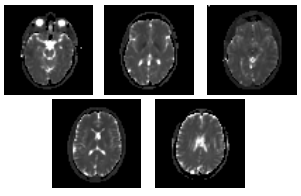

Fig. 3: Clinical T2 maps

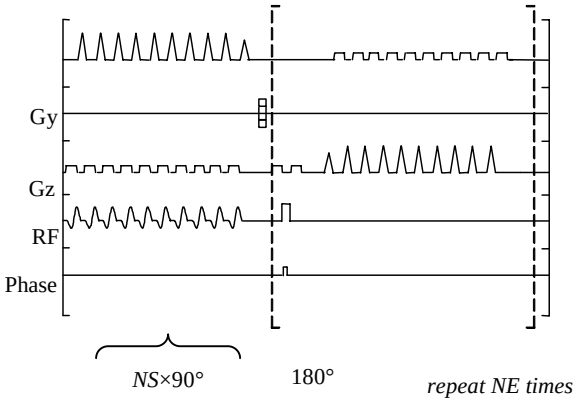

Fig. 1: The pulse sequence. *NS* is the desired number of slices; *NE* is the number of echoes

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