T2-Snapshots imaging with simultaneous multislice TESS acquisition

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Target audience. Physicists and physicians interested in T_2 quantification methods.

Purpose. Single slice transverse relaxation (T_2) mapping with triple echo steady state (TESS) was recently introduced to mitigate the intrinsic motion sensitivity that generally accompanies all unbalanced steady state methods[1]. TESS-T_2 is not only free of the typical T_1/T_2 bias common to all mono-parametric steady state methods, but also shows a high insensitivity to B_1-field inhomogeneities. As a result, TESS-T_2 imaging was demonstrated to be feasible and accurate in the brain from low to ultra-high fields. However, a large number of averages were required to provide a reasonable signal-to-noise ratio (SNR) for precise T_2 calculation, resulting in relatively long acquisition times of about 30 sec / slice. To this end, we extended the single slice TESS approach by a Hadamard-encoding scheme[2] for simultaneous multislice excitation (hTESS) yielding improved SNR while at the same time reducing the overall scan time per slice.

Methods. A four-slice Hadamard excitation scheme (with an interslice spacing of 10 mm) was implemented for a 2D-TESS sequence (hTESS). With this method, four slices are acquired simultaneously requiring four measurements (repetitions) with different RF pulses. The individual slices are then reconstructed online from linear combinations of the acquired images.

Axial TESS scans were performed in vivo and in vitro at 3T (Siemens MAGNETOM Prisma) with a 20-channel head coil. TESS imaging was further modified to include water saturation (WS) pre-pulses (with variable flip angles) to mitigate pulsation-related phase inconsistencies from the cerebrospinal fluid (CSF). TESS imaging parameters were: TE/TR of 5.8/11.6 ms, 200 Hz/px bandwidth, 4 mm slice thickness, 210 × 210 mm^2 field-of-view (FOV) yielding 1.1 × 1.1 mm^2 in plane-resolution (matrix size: 192 × 192). The flip angle (FA) was set to 25° and the RF pulse length to 4 ms in order to provide a maximum number of samples in the pulse envelope (8000). Eight averages were taken for the single slice TESS method, while for the hTESS, three averages were used; yielding a total acquisition time of 27 s / slice for TESS, and 10 s / slice for hTESS.

Results. Generally, the CSF signal decreases with increasing flip angle of the WS pre-pulse, but flattens for FA ~ 90° - 120° (not shown). Observed T_2 values as a function of the WS FA are shown in Fig. 2 for an in vitro experiment, as well as for in vivo scans for the regions of interest (ROIs) marked in Fig. 1. Interestingly, there is no observable effect on the T_2 estimate with TESS derived either in the steady state (WS FA = 0°) or in the transient state (WS FA > 0°). T_2 results for a four-slice Hadamard TESS acquisition with WS (FA ~ 120°) in comparison to a single slice TESS-T_2 scan are summarized in Table 1. Differences of up to 3% in the T_2 values are observed. However, these deviations are not found to be significant (p values > 0.12 for all selected ROIs). Finally, a representative set of four simultaneously acquired axial T_2 slices with hTESS is presented in Figure 3. Visually, no cross-talk between the individual slices is observed demonstrating proper Hadamard encoding.

Discussion and Conclusion. Simultaneous multislice TESS T_2 mapping proved to be robust and accurate in the human brain at 3T. Furthermore, the scan times per slice could be shortened by about three times compared to single slice TESS imaging yielding about 10 sec per slice for a typical clinically relevant inplane resolution of 1 x 1 mm^2. As a result, the proposed technique has the potential to provide full brain T_2 coverage in about 4 – 5 minutes. Pre-saturation of the water signal turned out to be crucial in order to remove residual CSF phase inconsistencies from the Hadamard encoding scheme, such that TESS imaging was performed in the transient rather than in the steady state; however, this was shown not to impair the accuracy of the T_2 estimation. In conclusion, simultaneous multislice TESS imaging provides a fast and robust framework that can be used for accurate snapshot-like T_2 mapping of brain pathologies, as well as full brain T_2 relaxometry within clinically acceptable scan times.

References. [1] Heule R et al., NMR Biomed2014;27:1037-1045; [2] Müller S, MRM 1988;6:364-371.

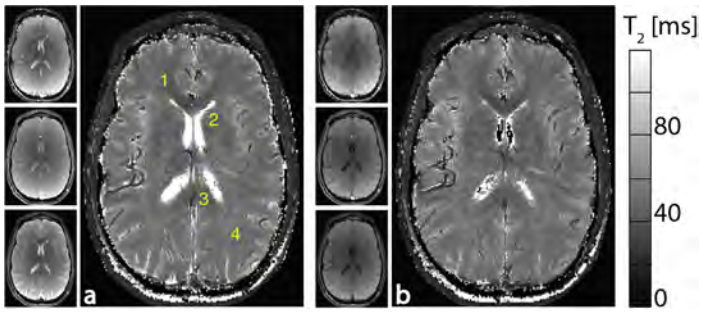

Figure 1. *In vivo single slice 2D-TESS T_2 relaxometry of the human brain at 3T without (a) and with presaturation (b) of the CSF signal (WS FA=120°). In the lateral columns, corresponding F_1, F_0 and F_{-1} base images are shown. Four ROIs are indicated in (a).*

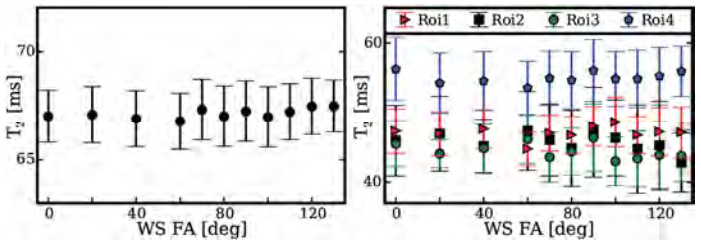

Figure 2. *TESS-T_2 measured as a function of the WS FA (left) in a manganese-doped spherical phantom (0.125 mM $MnCl_2$ in H_2O) and (right) in the human brain (for the selected ROIs shown in Figure 1a).*

Brain Tissue	TESS T_2 [ms]	hTESS-WS T_2 [ms]	Difference [%]
Frontal white matter (1)	47.4±3.2	47.5±2.7	0.2
Caudate nucleus (2)	46.0±5.1	45.5±3.8	-1.3
Corpus callosum (3)	45.5±3.4	46.9±3.9	3.1
Occipital white matter (4)	56.3±4.5	55.0±4.4	-2.3

Table 1. *T_2 data and relative difference for the selected ROIs indicated in Figure 1a using TESS single slice excitation and simultaneous four-slice Hadamard excitation (WS FA=120°).*

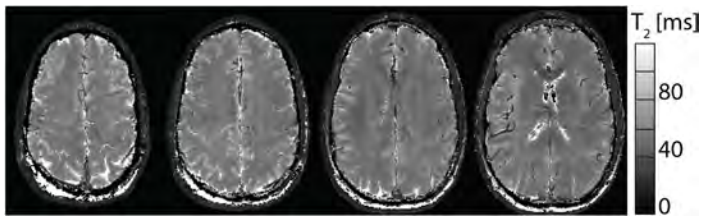

Figure 3. *Representative brain T_2 maps using four-slice Hadamard TESS (WS FA=120°). Scan time: 10 sec / slice; 1.1 x 1.1 mm^2.*