FAST B1-INSENSITIVE T2 RELAXOMETRY OF THE HUMAN BRAIN AT HIGH TO ULTRA-HIGH FIELDS

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Target audience. Physicists and physicians interested in robust and fast T_2 relaxometry of the human brain at high to ultra-high field strengths.

Purpose. Quantitative imaging poses many challenges at high to ultra-high fields. Among them are prominent transmit field (B_1) inhomogeneities that degrade image quality. A rapid 2D technique is suggested for high to ultra-high field T_2 quantification of human brain tissues that is highly insensitive to B_1 field variations.

Methods. The derived method relies on a variant of the 3D triple echo steady-state (TESS) sequence that has recently been proposed for fast quantification of T_1 and T_2 in a single scan (1). As reported by the authors, TESS-T_1 is affected by B_1 field inhomogeneity but TESS-T_2 relaxometry revealed to be highly B_1-insensitive, making it particularly suited for ultra-high field applications. A rapid 2D TESS sequence is investigated offering considerably reduced motion sensitivity compared to 3D acquisitions and thus being applicable to nonrigid targets such as the brain. The three signal modes, i.e. the lowest order SSFP-FID (F_0), the lowest order SSFP-echo (F_{-1}), and a higher-order SSFP-FID (F_1) are acquired within three consecutive TRs (see Fig. 1). This sequence setup ensures short TR as well as short TE and hence reduces susceptibility- and T_2*-related issues. To quantify T_2 from the three modes, the approach described in Ref. (1) is adopted. It is based on exploiting the dependencies on relaxation of the SSFP signals (analytical expressions for the different modes can be found e.g. in Ref. (2)) and using their ratios for fast relaxometry within an iterative search. Here, this method is extended to 2D imaging by incorporating RF slice profile effects into the relaxation times calculation. For small flip angles α, the slice profile is well approximated by the flip angle profile $\alpha(\Delta\omega)$ ($\Delta\omega$: Larmor frequency offset). The signal amplitudes $F_{1,0,-1}$ are then replaced by the sum over $F_{1,0,-1}(\alpha_i)$ for i=1,...,N (N: number of samples). By this means, TESS-T_2 quantification becomes largely independent of the RF pulse shape. In this study, simple SINC pulses with a time-bandwidth product of 2 are used. 2D TESS-T_2 relaxometry of the human brain is evaluated in vitro and in vivo at 3 T, and the feasibility of ultra-high field TESS-T_2 quantification is demonstrated at 7 T and 9.4 T.

Results. Excellent agreement between slice profile corrected 2D TESS-T_2 measurements and reference single-echo spin echo data is found in vitro at 3 T for four manganese-doped aqueous probes. Derived TESS-T_2 values with reference SE-T_2 values given in brackets are: 173.4 ± 2.2 ms (173.6 ± 0.7 ms), 72.4 ± 0.7 ms (71.7 ± 0.2 ms), 33.0 ± 0.2 ms (32.7 ± 0.1 ms), and 18.3 ± 0.1 ms (18.2 ± 0.1 ms) for 0.05 mM, 0.125 mM, 0.25 mM, and 0.5 mM $MnCl_2$ in H_2O respectively. The robustness of the proposed 2D technique to B_1 field errors is shown for human brain scans at 3 T by detuning the RF reference amplitude at the MR scanner (see Fig. 2 and Table 1). Finally, 2D TESS-T_2 relaxometry proves to be feasible and reliable in the human brain at 7 T and 9.4 T (see Fig. 3). T_2 values assessed for frontal white matter in the left brain hemisphere are: 23 ± 2 ms / 28 ± 2 ms at 7 T (left / right slice in Fig. 3a) and 20 ± 2 ms / 25 ± 2 ms at 9.4 T (left / right slice in Fig. 3b). Even though prominent B_1 field heterogeneities are present at ultra-high fields, the obtained T_2 maps show no B_1 degradations.

Discussion. Rapid SSFP relaxometry techniques generally suffer from their sensitivity to flip angle errors caused by B_1 field inhomogeneity. To the best of our knowledge, TESS-T_2 relaxometry is the first suggested SSFP-based method that overcomes this drawback without need for corrective strategies, just exhibiting an intrinsic highly B_1-insensitive behavior. In this work, the motion sensitivity of 3D-TESS initially proposed in Ref. (1) is tackled by a rapid 2D approach. 2D TESS imaging offers accurate and robust T_2 quantification even in the presence of substantial B_1 field errors as has been demonstrated within the scope of this study for high to ultra-high field imaging of the human brain.

Conclusion. The results accentuate the potential of TESS-T_2 to act as valuable measure for early diagnosis and progression monitoring of brain diseases in high-resolution 2D acquisitions at high to ultra-high fields.

References. 1. Heule R, Ganter C, Bieri O. Triple echo steady-state (TESS) relaxometry. Magn Reson Med 2013;doi:10.1002/mrm.24659. **2.** Hänicke W, Vogel HU. Magn Reson Med 2003;49(4):771-775.

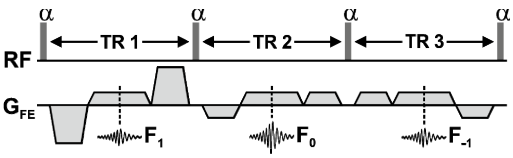

Figure 1: Triple echo steady state (TESS) sequence optimized for 2D imaging at high to ultra-high fields. The three echoes (F_1, F_0, and F_{-1}) are acquired within three consecutive TRs.

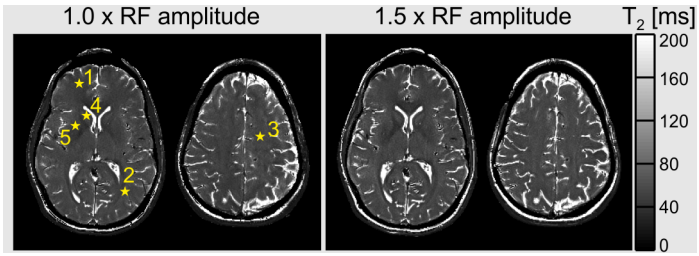

Figure 2: In vivo 2D TESS-T_2 relaxometry of the human brain at 3 T. The robustness of TESS-T_2 to B_1 field errors is demonstrated for two axial slices by detuning the transmitter reference amplitude at the MR scanner. Results are shown for scans at 1.0 times (left) and 1.5 times (right) the nominal amplitude. For selected ROIs (numbered stars), T_2 values are summarized in Table 1.

Brain Tissue		TESS-T_2 [ms]		SE-T_2 [ms]	
		RF amplitude multiplication factor			
		1.0	1.5	1.0	1.5
WM	Frontal white matter (1)	47 ± 3	49 ± 4	48 ± 2	48 ± 2
	Occipital white matter (2)	56 ± 5	57 ± 6	62 ± 3	56 ± 3
	Centrum semiovale (3)	53 ± 5	55 ± 6	52 ± 3	47 ± 4
GM	Caudate nucleus head (4)	46 ± 4	49 ± 8	48 ± 3	42 ± 4
	Putamen (5)	53 ± 5	57 ± 6	63 ± 3	55 ± 4

Table 1: 2D TESS-T_2 relaxometry data of the human brain at 3 T for selected ROIs in white matter (WM) and gray matter (GM) as indicated in Fig. 2 (numbers in brackets refer to the corresponding ROI). Reference SE-T_2 values are derived based on five single-echo SE scans using a nonlinear least-squares fit with echo times of 20, 40, …, 100 ms.

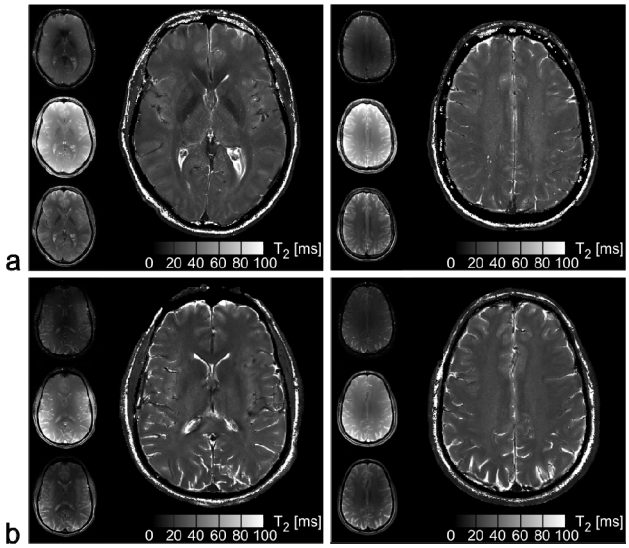

*Figure 3: Ultra-high field 2D TESS-T_2 mapping for two axial slice positions at (**a**) 7 T and (**b**) 9.4 T. For each slice, the three acquired base signal modes are shown on the left (F_1, F_0, and F_{-1} from top to bottom).*