Robust B_1-Insensitive Whole-Brain T_1 Mapping with 3-TI MP-RAGE: Validation and Acquisition Strategy

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Target audience: Researchers, clinicians, and neuroscientists interested in robust volumetric high-resolution T_1 mapping.

Purpose: Fast T_1 mapping is potentially useful for segmentation of brain structures[1,2] and for myelin imaging[3]. Accurate, whole-brain, high-resolution T_1 maps have been obtained in monkeys at 7 T in a clinically relevant time, from 3 MPRAGE images with carefully selected inversion times (TI)[4]. This approach, which we will refer to as 3-TI-MP T_1 mapping, is free from B_1 heterogeneity effects, a particularly attractive feature for high field (≥ 3 T) applications. We implemented 3-TI-MP for human imaging at 7 T based on a MPRAGE sequence with 1D-centric (k_z) ordering. We also implemented a 2D-centric (k_y-k_z) phase encode ordering scheme (radial fanbeam, or 2D-RFB[5]) to improve scan efficiency. In this work, we validated the method, and compared the accuracy and blur of the 3-TI-MP method for different k-space ordering and parallel imaging factors.

Methods: 3-TI-MP data were acquired using 3 serial MPRAGE scans with optimally selected TIs (= 150, 1280, 4000 ms). One k-space segment was acquired after each inversion pulse (inversion pulse spacing TS = TI + N*TR + TD), using N=180-240 readouts, each at small flip angle (α = 5°) and short TR (= 7.7 ms), with other parameters as in Table 1. TS was held constant for the different TIs by altering the final delay TD; this removes dependence on M_0, T_2*, and B_1 and allows rapid T_1 estimation based on a simple lookup table[4]. All data were collected using a GE Discovery MR950 7 T scanner (GE Healthcare, Waukesha WI USA) with a 32-channel head coil (Nova Medical, Wilmington, MA USA). Data were collected in a multi-compartment phantom constructed using a range concentrations of $MnCl_2$ in 0.9 % saline solution, to provide T_1 values expected at 7 T in human brain (roughly 1000-5000 ms), and one peanut oil compartment. Three male volunteers (A, B, and C; ages 35, 35, and 31) were scanned each with a different k-space-ordering variant of the protocol, after providing informed consent. For all experiments, a reference T_1 map was acquired with a single-slice IR-FSE sequence, using four TIs (= 200, 600, 1500, 4000 ms), and freely available T_1 estimation software[6] that takes into account RF pulse imperfections and finite TR (= 5000 ms). 3-TI-MP T_1 lookups were performed offline without additional B_1 correction using either 1) scanner-reconstructed magnitude data with polarity restoration[6] or 2) coil-wise complex raw data as recommended by Liu *et al.*[4]

Table 1. Selected sequence parameters for 3-TI-MP: k-space ordering, readout train length (N), ARC acceleration factor, and scan time per TI

Parameter	PHANTOM	Vol. A	Vol. B	Vol. C
k-space ordering	1D-centric; 2D-RFB	1D-centric	1D-centric	2D-RFB
N	1D: 200; 2D: 240	180	200	240
ARC factor	no ARC	no ARC	2.5×1	3×1
Scan time	48:00; 36:00	33:00	21:00	10:30

Results: T_1 estimation based on magnitude-data with polarity restoration was simple to compute and generally correct in white matter, but led to large errors in long-T_1 regions such as cortical grey matter near cerebrospinal fluid (data not shown), and for this reason was subsequently abandoned. The reference and coil-wise-complex 3-TI-MP T_1 maps agreed well in the phantom (*linear regression*: $T_{1,MPRAGE} = 0.97*T_{1,REF} + 66$ ms, $r = +0.98$), and 2D-RFB ordering produced better quality T_1 maps than 1D-centric, as seen in Fig. 1. In volunteers, the correspondence of reference and 3-TI-MP T_1 maps was very good ($r \geq +0.78$), and 2D-RFB resulted in maps with lower spatial variability (COV range=4-9% for 2D-RFB vs. 6-9% for 1D-centric) in a shorter scan time (Fig. 2).

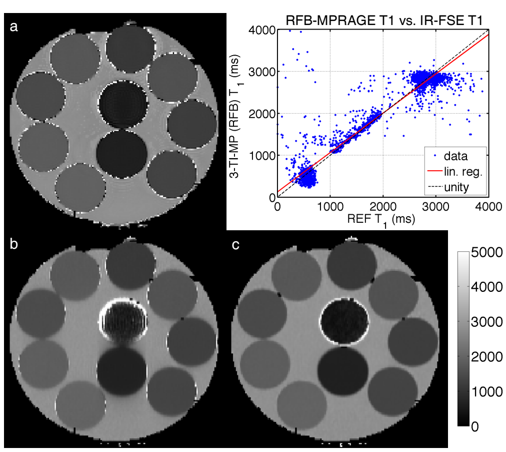

Figure 1. Axial phantom T_1 maps from IR-FSE (a), and 3-TI-MP with 1D centric ordering (b) and 2D-RFB ordering (c). 3-TI-MP maps are reformatted in the axial plane to show blur. Note the reduced blur and better quality in (c). Upper right: 3-TI-MP T_1 from (c) is plotted vs. the reference T_1.

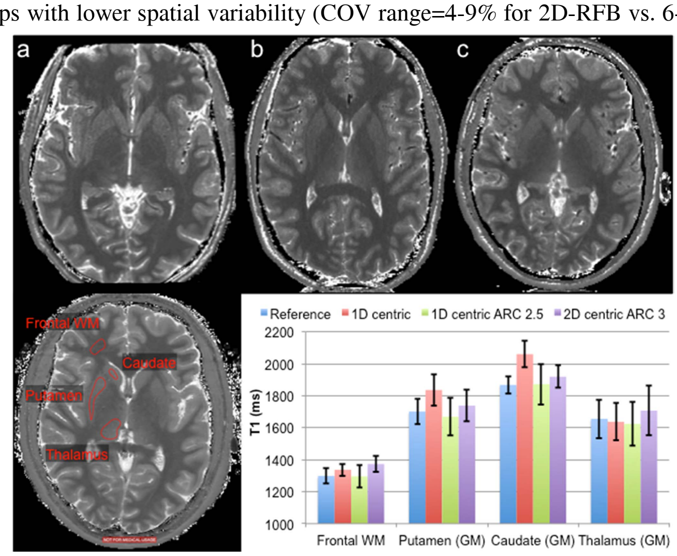

Figure 2. T_1 maps obtained using variants of 3-TI-MP: fully sampled 1D-centric (a), 1D-centric with ARC 2.5×1 (b), and 2D-RFB with ARC 3×1 (c). Bottom: T_1 values (mean ± std. dev.) in 4 manual ROIs (shown on left). Note the high quality of the 2D-RFB map in (c), and small variation in ROI T_1 values for the variant compared to 1D-centric with ARC 2.5.

Discussion and Conclusions: This experimental demonstration of B_1-insensitive 3-TI-MP whole-brain T_1 mapping at 7 T, validated against a reference technique in phantoms and *in vivo* human volunteers, demonstrates high accuracy and precision, and holds promise for future research and clinical applications. The proposed 2D-RFB k-space ordering scheme decouples readout train length from the slice dimension, extending the readout train and allowing for 2D acceleration, and reducing spatial blur in the k_z direction without any use of k-space filtering.

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