Robust $T_1$-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 and for myelin imaging. Accurate, whole-brain, high-resolution $T_1$ maps have been obtained in monkeys at 7 T in a clinically relevant time, from 3 MP-RAGE images with carefully selected inversion times (Ti). 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 MP-RAGE sequence with 1D-centric ($k_r$) ordering. We also implemented a 2D-centric ($k_r$-$k_z$) phase encode ordering scheme (radial fanbeam, or 2D-RFB) 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 MP-RAGE scans with optimally selected Tls (= 150, 1280, 4000 ms). One k-space segment was acquired after each inversion pulse (inversion pulse spacing $T_S = T_I + N*TR + TD$, using $N=180-240$ readouts, each at small flip angle ($a = 5^\circ$) and short TR ($= 7.7$ ms), with other parameters as in Table 1. $T_S$ was held constant for the different Tls by altering the final delay $TD$; this removes dependence on $M_0$, $T_1$, and $B_1$ and allows rapid $T_1$ estimation based on a simple lookup table. 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 of MnCl2 in 0.9 % saline solution, to provide $T_1$ values expected at 7 T in the 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 of MnCl2 in 0.9 % saline solution, to provide $T_1$ values expected at 7 T in the MR950 7 T scanner (GE Healthcare, Waukesha WI USA) with a 32-channel head coil (Nova Medical, Wilmington, MA USA).

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 ($r = +0.98$), 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).

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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