10-Minute High-Resolution Whole-Brain T_1 Mapping: A Comparison of Three Candidate Methods

James A. Rioux[1], Ives R. Levesque[1,2], Manojkumar Saranathan[1], and Brian K. Rutt[1]

[1]*Radiology, Stanford University, Stanford, CA, United States,* [2]*Medical Physics, Oncology, and RI-MUHC, McGill University, Montreal, QC, Canada*

Target Audience: Researchers and clinicians interested in fast, high-resolution T_1 mapping of whole organs (e.g. whole-brain), particularly at high field strengths.

Purpose: Accurate T_1 maps can now be obtained with three MPRAGE images with suitably chosen inversion times (TI)[1], or two MP2RAGE images obtained during a single interleaved acquisition.[2,3] Such methods could enable high-resolution T_1 mapping in clinically relevant scan times, i.e. on the order of 10 minutes, allowing for better visualization and classification of deep-brain structures. Due to their robustness to B_1 heterogeneity, these MPRAGE-based methods are particularly attractive for high field applications. In this work, we compare three candidate sequences at 7T: 3-TI MPRAGE as described by Liu *et al.*[1], MP2RAGE as described by Marques *et al.*[2,3], and MP3RAGE, a modification of MP2RAGE first proposed by Hung *et al.*[4] that allows collection of a third image without increasing scan time. This experimental comparison of T_1 accuracy and precision will inform the choice of method for future development and clinical implementation.

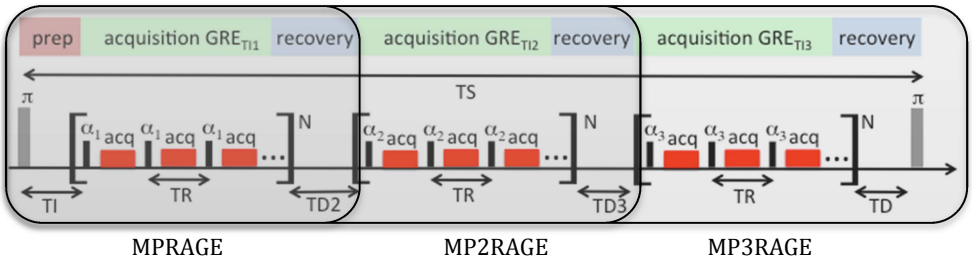

Figure 1. Pulse sequence schematic for MPRAGE-based T_1 mapping methods. MPRAGE acquires an image segment at time TI after inversion with a train of N pulses of flip angle α_i. 3-TI MPRAGE requires three acquisitions with varying TI but constant TS. MP2RAGE re-acquires the same segment before the next inversion pulse, after a delay TD2 (effective inversion time TI2=TI+N*TR+TD2). MP3RAGE adds a third acquisition of the segment (effective inversion time TI3=TI2+N*TR+TD3.

Methods: One to three images are acquired following each inversion pulse, as shown in Figure 1, with each acquisition collecting the same single k-space segment during the TS interval. For the 3-TI MPRAGE method, TS is fixed by altering the final delay TD for each TI; this ensures that all three images have a simple dependence on T_1 that allows a straightforward lookup instead of a least-squares fit, and which removes any dependence on M_0, T_2* or B_1 effects.[1] A similar lookup is used for MP2RAGE and MP3RAGE using appropriate combinations of the acquired images.[2] These lookups were done without additional B_1 correction, and in forming the lookup table the inversion pulse efficiency was set to -0.85 (empirically determined to produce best accuracy). All methods were implemented with a 2D centric (radial fan-beam[5]) phase encode ordering that reduces scan time by omitting k-space corners, allows for flexible k_y-k_z undersampling, and also improves B_1 insensitivity in the MP2RAGE and MP3RAGE images (data not shown).

Parameter	3-TI MPRAGE	MP2RAGE	MP3RAGE
TS (ms)	6000	7500	7500
TI (ms)	150/1280/4000	1000/3300	700/2200/4000
α (deg)	5	5/4	5/4/5
N	240	200	200
TR (ms)	7.7	7.7	7.4
BW (kHz)	25	25	27.78
ARC factor	3x2	2x1	2x1
Scan time	3:18 x 3 = 9:54	10:00	10:00

Table 1. Sequence parameters for candidate methods.

All images were obtained using a GE Discovery MR950 7T scanner (GE Healthcare, Waukesha WI) with a Nova 2chTx / 32chRx head coil (Nova Medical, Wilmington, MA). Two healthy volunteers (1M/1F, age 33 years) were scanned according to IRB requirements. Parameters for the MPRAGE-based methods are listed in Table 1. A reference T_1 map was acquired with a single-slice IR-FSE sequence, ETL=8, TR=6000ms, TI=50, 200, 600, 1500 and 4000ms, with T_1 determined by a reduced-dimension non-linear least-squares fit.[6] Scan time was kept constant at 10min for the three different MPRAGE methods and for the IR-FSE reference, with 1mm isotropic resolution in all cases.

Results: The single slice reference T_1 map from one volunteer is shown in Fig. 2a, along with T_1 maps from the corresponding slice of the whole-brain 3-TI MPRAGE (Fig. 2b), MP2RAGE (Fig. 2c) and MP3RAGE (Fig. 2d) scans. ROIs used for comparison are highlighted in green. The overall quality of the T_1 maps is similar, with MP2RAGE having an overall T_1-to-Noise-Ratio (T_1NR) advantage, which we calculate as the average of (ROI mean)/(ROI std.dev.) across all ROIs (see Table 2). In terms of accuracy compared to the reference map, computed as the average absolute % error from the reference, 3-TI MPRAGE has the best performance, followed by MP3RAGE.

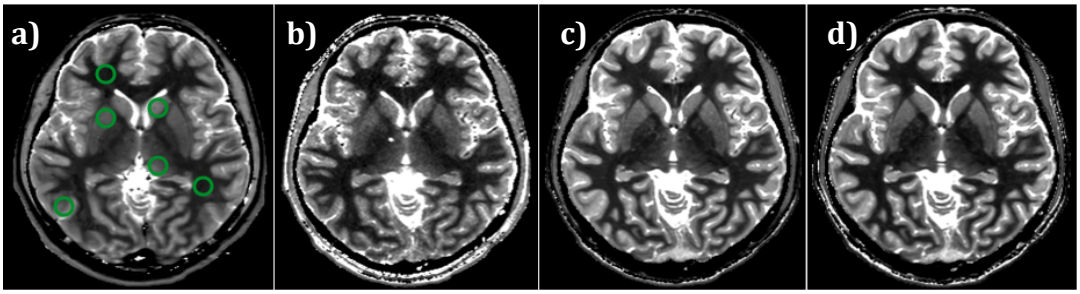

Figure 2. T_1 maps produced by (a) IR-FSE single-slice reference, (b) 3-TI MPRAGE, (c) MP2RAGE, (d) MP3RAGE.

Method	T_1NR	%Error
IR-FSE	30 +/- 10	N/A
3xMPRAGE	16 +/- 5	1.3 +/- 1
MP2RAGE	32 +/- 16	4 +/- 2
MP3RAGE	24 +/- 10	2 +/- 1.7

Table 2. T_1-to-Noise Ratio and percent error from reference T_1 map for each candidate method, based on ROIs highlighted in green on Figure 2a.

Discussion and Conclusions: MP2RAGE has the highest T_1NR of the three methods compared, but the lowest accuracy, likely due to residual B_1 effects. A separate B_1 correction is possible but this adds to scan time and reconstruction complexity. The reduced T_1NR of 3-TI MPRAGE is caused by the shorter segment time and increased undersampling necessary to achieve a 10-minute scan (since MP2RAGE and MP3RAGE acquire all images within a single TS, less acceleration is needed for the same scan time). Our implementation of MP3RAGE is a promising compromise that offers higher T_1NR than 3-TI and lower relative error than MP2RAGE.

References: [1] Liu et.al., *NeuroImage* **56** pp.1154–1163 (2011) [2] Marques et.al., *NeuroImage* 49 (2010). [3] Marques and Gruetter, *PLoS ONE* 8:7 (2013). [4] Hung et.al., Proc. ISMRM #2353 (2013). [5] Saranathan and Glockner, *JMRI* doi:10.1002/jmri.24113 (2013). [6] Barral et.al.,*MRM* **64** pp.1057-1067 (2010).

Acknowledgements: Research support from NIH (P41 EB015891, 1U54 A151459, 1P50 A114747), GE Healthcare, and the Richard M. Lucas Foundation.