

The optimization of B1 insensitive T1 weighted MP2RAGE sequence at high field.

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Target audience: high field users

Purpose: At high magnetic field (≥ 7 T), large spatial B1 inhomogeneities cause non-uniform signal intensity across an image volume. This artifact causes a large bias in T1 weighted 3D MPRAGE images [1]. To overcome the image bias due to B1 inhomogeneity, several approaches have been proposed [2, 3]. MP2RAGE has shown the potential to minimize B1 variation in T1-weighted images by using two GRE acquisitions with different flip angles after the inversion pulse [3]. A previous study showed that a long TR (>8 s) would provide high signal to noise ratio (SNR) and contrast to noise ratio (CNR) in MP2RAGE by providing the large dynamic contrast range for inversion recovery. However, this leads to a relatively long scan time. In this study, we optimize MP2RAGE parameters with different TR values to generate T1 weighted contrast at 7T with 10% image non-uniformity in brain tissues. A healthy subject was scanned with the optimized parameters with different TRs at 7T. Brain segmentation was conducted using acquired MP2RAGE images and the results were compared.

Methods: A simulation was conducted using a modified version of ref. [3,5]. Flip angles were varied from 1° to 12° , and time gap between RFs, τ , was fixed at 6ms. Z- directional 2nd phase encoding (PE) during gradient refocusing echo (GRE) acquisition ($N_z = 176$) was assumed so that the duration of each acquisition is 1056ms. TI1, and TI2 were varied in 100ms steps within a fixed TR (from 4s to 8s with a step of 0.5s). MP2RAGE contrast was simulated with T1 range from 500ms to 5000ms, and T1 of white matter (WM), gray matter (GM) and cerebral spinal fluid (CSF) were roughly assumed with 1, 2, and 4.5s [6]. Contrast to noise ratio (CNR) per unit time (divided by the root of TR) between WM and GM (CNR_{WG}), and GM and CSF (CNR_{GC}) were calculated [3]. B1 inhomogeneity of $\pm 40\%$ at 7T was simulated [3] and it was assumed that the only actual flip angle is determined by B1 homogeneity (e.g. actual FA = B1 efficiency \times input flip angle). Signal offset was calculated as $|MP2RAGE_{100\pm 40\% B1 \text{ efficiency}} - MP2RAGE_{100\% B1 \text{ efficiency}}| / (MP2RAGE_{WM} - MP2RAGE_{CSF})$. The optimized parameters for MP2RAGE within a fixed TR were chosen: 1) Screening the parameter sets that generate within $\pm 10\%$ of offset in WM and GM, and $MP2RAGE_{WM} > MP2RAGE_{GM} > MP2RAGE_{CSF}$ and 4) Maximizing CNR_{WG} .

The following MR parameters are commonly used at 7T in MP2RAGE; FOV=192 \times 192mm², matrix=192 \times 192 \times 176, voxel size isotropic 1mm³, $\alpha_1/\alpha_2/\tau = 4^\circ/3^\circ/6$ ms, bandwidth = 300 Hz per voxel. Three different TR values ($=4.0$, 5.0 , 6.0 , and 7.3 s) and different TIS were used (See Tab 1.) Parallel imaging (GRAPPA factor =2, reference lines = 32) was used to reduce the scan time as 7:26, 9:17, 11:08, and 13:02 for TR 4.0s, 5.0s, 6.0s and 7.3s, respectively. A healthy subject was scanned at 7T (MAGNETOM 7T, Siemens AG, Erlangen, Germany) with a 32 channel coil (Nova Medical, Wilmington, USA) using MP2RAGE with the optimized parameters, described in Tab 1. Brain segmentation was performed using Freesurfer [7].

Result

Simulation (Optimization): The optimized parameters of MP2RAGE with different TR are shown in Tab. 1. Tab 1 shows that CNR per unit time is improved as TR is increased. It is also observed that CNR_{WG} is maximized with TR=7.3s. Fig 1. plotted the relation between maximum CNR and TR. As shown, CNR_{GC} is improved by 75% from TR=4s to 5s, and the increases of CNR_{WG} is reduced with 2% or less from TR= 6s.

In-vivo: Fig 2. shows the representative MP2RAGE image and enlarged area to include WM, GM and CSF. It is observed that there is no visual difference in MP2RAGE images with different TR values. All images display claustrum with distinct contrast. Fig 3. demonstrates examples of brain segmentation using MP2RAGE with different TRs. The ratios of total volumes of WM, subcortical GM and GM with TR=4s to TR=7.3s are 1.03, 1.04 and 0.99, respectively.

Discussion: This study was conducted to answer the question: *what is the minimum TR for MP2RAGE to generate reasonable T1 weighted contrast among brain tissues?* However, due to the many factors involved in generating this contrast, some assumptions had to be made, e.g. not only the criteria to define the optimal parameters but also the hard-/soft-ware settings. For the same reason, it is not surprising that the resulting optimized parameters of MP2RAGE are different with ones in ref. [3]. In the experimental setting examined here, aTR of 4s generates reasonably good contrast in brain tissue, and results in good segmentation of WM and GM.

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Reference

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Fixed TR up to (s)	Optimized parameters				CNR_{WG} (a.u)	CNR_{GC} (a.u)	Sig offset(%)	
	TI1 (s)	TI2 (s)	α_1 ($^\circ$)	α_2 ($^\circ$)			WM	GM
4.0	4.0	1.0	3.5	3	0.46	0.20	2	10
4.5	4.3	1.0	3.8	3	0.50	0.24	2	10
5.0	5.0	1.1	3.3	4	0.53	0.42	1	10
5.5	5.5	1.1	3.9	4	0.58	0.42	1	10
6.0	6.0	1.1	4.2	4	0.60	0.45	1	9
6.5	6.5	1.1	4.2	4	0.61	0.50	1	8
7.0	7.0	1.1	4.2	4	0.62	0.52	1	8
7.5	7.3	1.1	4.2	4	0.62	0.52	1	8

Tab1. The optimized parameters of MP2RAGE. Maximum signal offset is shown from $\pm 40\%$ of B1 efficiency.

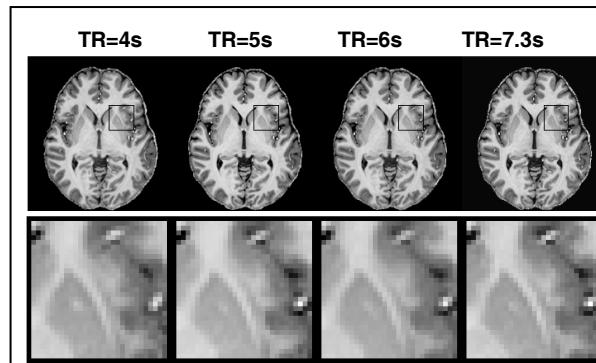


Fig 2. Representative MP2RAGE images and enlarged area with different TR. Since dynamic ranges of MP2RAGE contrast with different TRs vary, image are re-scaled with $(MP2RAGE - MP2RAGE_{GM}) / (MP2RAGE_{WM-GM})$ and displayed from -1 (black) to 1.5 (white).

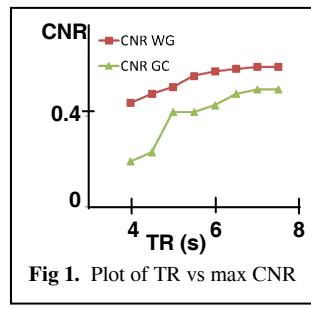


Fig 1. Plot of TR vs max CNR

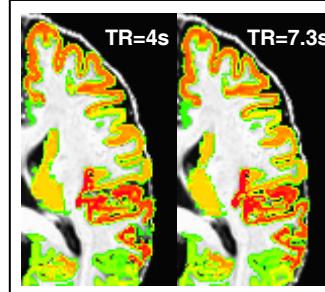


Fig 3. Example of brain segmentation result using MP2RAGE images with different TR.