SNR improvement of MP2RAGE from slice encoding acceleration.

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Target audience: high field users who are interested in high-resolution anatomical information.

Purpose: At high magnetic field (≥7T), large spatial B1 inhomogeneities invoke non-uniform signal intensity in images, including MPRAGE [1]. MP2RAGE can reduce B1 variation effects while generating T1 contrast using two image volumes with different inversion times [2,3]. Since the y-direction PE number (Ny) is directly proportional to the scan time in an MPRAGE style acquisition, a previous study proposed acceleration of the MP2RAGE acquisition in the k_y direction [3]. We hypothesize that z-direction PE (N_z) mainly determines optimizal T1 contrast due to the apparent T1 relaxation period during repetitive GRE acquisitions. A simulation is conducted to test N_z effects on contrast to noise ratio (CNR) in MP2RAGE. To vary or decrease N_z, we propose a new 2D acceleration paradigm comparable to MP2RAGE. A healthy subject was scanned using MP2RAGE with 1D and 2D accelerations, and the reconstructed images are compared.

Methods: The simulation was conducted based on ref. [3,4], with modified sequence parameters. Flip angles varied from 1° to 12 °, and time gap between RFs, τ is set to 6 ms. N_z varies from 80 to 180 in increments of 10. Assuming linear acquisition, TI1/TI2/TR varies in 100 ms increments, up to maximum TR=7s. Assuming T_1 of WM, GM and CSF at 7T, CNR per unit time between WM and GM (CNR_{WG}), and GM and CSF (CNR_{GC}) were calculated [3]. B_1 inhomogeneity of ±40% at 7T was simulated [3]. The optimized parameters for MP2RAGE were chosen: 1) Screening the parameter sets that generate within ±7% of offset in WM and GM with ±40% B1 inhomogeneity, 2) $MP2RAGE_{WM} > _{GM} > _{CSF}$ and 3) Maximizing the minimum between CNR_{WG} and CNR_{WG}.

Based on the simulation result, 4 scans were conducted using the following MR2RAGE parameters at 7T; voxel size/α1/α2/TI1/TI2/TR/acceleration/scan time = A) iso-1mm^3/3°/5°/0.9s/2.3s/6s/ R_Y=3/8:30; B) iso-1mm^3/5°/6°/1.0s/2.2s/5s/ R_Y=3& R_Z=2/7:05; C) iso-1mm^3/4°/8°/0.8s/1.7s/4s/ R_Y=3& R_Z=2/5:40; D) iso-1mm^3/4°/8°/0.6s/1.4s/3s/ R_Y=3& R_Z=2/4:15; E) iso-0.75mm^3/4°/6°/0.9s/2.4s/6s/ R_Y=3/10:36, and F) iso-0.75mm^3/6°/8°/1.0s/2.4s/6s/ R_Y=3, R_Z=2/10:36. Z directional partial Fourier (=6/8) is applied in E) and F).

GRAPPA reconstruction was used for cases A) and E). Due to the irregular undersampling pattern in 2D accelerated MP2RAGE, shown in Fig.1, SPIRiT is employed for the reconstruction of the cases B), C), D) and F) [5]. Any filtering is not applied during the image reconstruction.

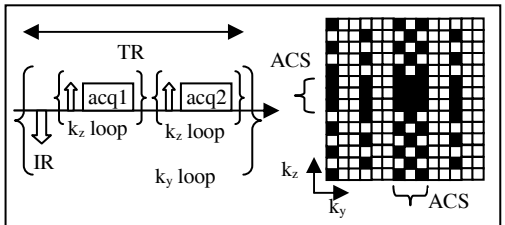

Fig 1. MP2RAGE sequence diagram and proposed accelerated acquisition paradigm (R = 3×2). Note that k_y and k_z accelerations determine scan time and T_1 contrast mainly in acq1 with a fixed TR.

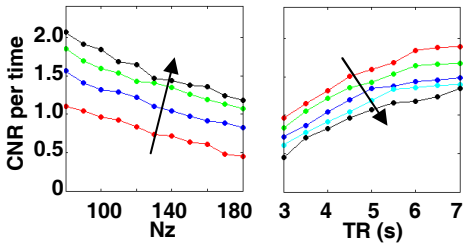

Fig 2. Plot of A) CNR vs N_z varying TR (3s to 7s) and B) CNR vs TR varying N_z (100 to 180). Arrow indicates the increasing TR in A) and N_z in B).

Result

Simulation: The dependence of unit-time CNR on N_z and TR is shown in Fig 2 and Tab1. The optimized tissue CNR increases as N_z decreases and TR increases. Tab. 1 shows CNR between tissue is improved by 56% with TR=6 s when N_z is decreased from 180 to 100. Even TR=4 with N_z=100 generates the similar range of CNR (not per time) as TR=6s with N_z=160.

In-vivo: Fig 3. shows the representative MP2RAGE images and enlarged areas with different combinations of N_z, acceleration and TR. No visual difference is observed in MP2RAGE images with TR from 6 to 3 s, shown in Fig3. Fig.4.shows that 2D accelerated MP2RAGE (Fig4.B) show the less noise in white matter than 1D accelerated MP2RAGE (Fig 4. A)

TR (s)	Optimized parameters Nz	α1 (°)	α2 (°)	TI1 (s)	TI2 (s)	CNR_{WG} per time (a.u)	CNR_{GC} per time (a.u)
3.0	100	4	8	0.6	1.4	1.39	0.96
4.0	100	4	8	0.8	1.7	1.44	1.37
5.0	100	5	6	1.0	2.2	1.59	1.64
6.0	100	6	8	1.0	2.4	1.84	1.86
6.0	180	3	5	0.9	2.3	1.18	1.18

Tab1. The optimized MP2RAGE parameters.

Discussion: Since apparent relaxation during the repetitive excitation ($1/T_1^* = 1/T_1 + \ln(\cos\alpha)/\tau$) is always shorter than intrinsic T_1, the small N_z allows for a larger flip angle while demonstrating similar relaxation contrast to an MP2RAGE with large N_z. For this reason, the MP2RAGE with small N_z would generate improved SNR due to the SNR gain from the larger flip angle, leading to increased SNR and CNR. We proposed z-direction accelated MP2RAGE to improve CNR, leading to acceleration of scan time under 5 mins with isotropic 1mm^3 voxel size, as shown in Fig3 and the improvement of SNR with the same voxel size to be comparable to 1D accelerated MP2RAGE, as shown in Fig 4.

Acknowledgements: This work was supported by the Imaging Institute, Cleveland Clinic. Author gratefully acknowledges technical support by Siemens Medical Solutions.

Reference: 1. Mugler and Brookeman, MRM,1990;15:152-157.2. Van de Moortele et al., Nueroimage, 2009;46:432-46. 3. Marques et al., Neuroimage, 2010;49:1271-81. 4. Deichman et al., Neuroimage,2000;12:112-27. 5. Lustig and Pauly, MRM, 2010;64(2):457-71

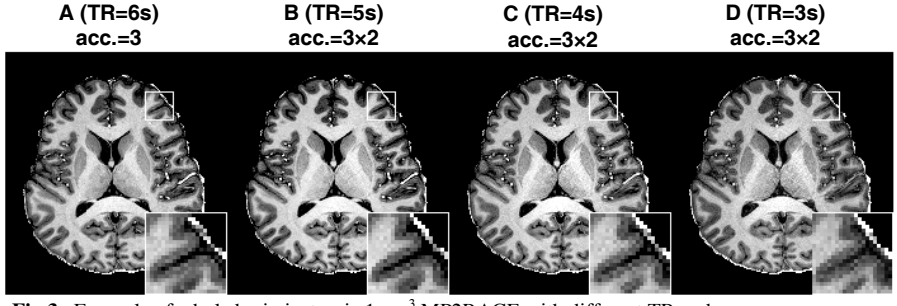

Fig 3. Example of whole brain isotropic 1mm^3 MP2RAGE with different TR and acc.

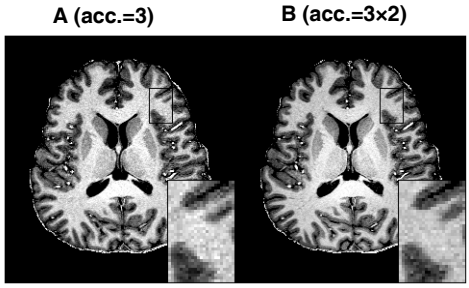

Fig 4. Example of isotropic 0.75mm^3 MP2RAGE