Signal and Contrast Optimized Inversion Prepared Imaging

A. Kir[1,2], and A. B. McMillan[1]
[1]Magnetic Resonance Research Center, Diagnostic Radiology and Nuclear Medicine, University of Maryland School of Medicine, Baltimore, MD, United States,
[2]Electrical Engineering and Computer Science, University of Maryland Baltimore County, Baltimore, MD, United States

Introduction: Rapid three-dimensional (3-D) inversion-prepared gradient echo imaging sequences are widely used to provide high-contrast anatomical brain images for various clinical and research purposes. In previous studies, optimizations of the contrast between gray matter (GM) and white matter (WM) were performed based on the assumption of ideal radio-frequency (RF) spoiling[1]. In this work, we propose a simulation approach using the extended phase graph (EPG) formalism[2] which takes into account the residual transverse magnetization to give a more accurate calculation and provide a base for protocol optimization.

Methods: Here we used the EPG to simulate the signal evolution of a magnetization-prepared 3D spoiled gradient echo sequence (MP-RAGE)[3]. The longitudinal and transverse magnetization can be described by $H(n,\varphi)=\sum_{k=-\infty}^{\infty} h_k(n)e^{ik\varphi}$ and $F(n,\varphi)=\sum_{k=-\infty}^{\infty} f_k(n)e^{ik\varphi}$, where h_k and f_k are the expansion coefficients, and n is an index for the RF pulse train. The EPG provides us an algorithm to update the coefficients during signal evolution to simulate imaging of GM and WM using 1-D phase encoding. To demonstrate the improvement of the proposed approach over others based on ideal RF spoiling, we performed both phantom and *in vivo* brain imaging experiments on a Siemens Tim Trio 3T MR scanner. The validity and accuracy of the approach were verified by comparing simulated and experimental results.

Phantom Study: Phantoms were prepared using Omniscan injection (GE Healthcare). Three vials with gadodiamide concentrations of 0.041, 0.059, and 0.076 mol/L, labeled as phantoms A, B, and C, respectively, with relaxation parameters of (T1, T2) = (210 ms, 201 ms), (165 ms, 156 ms), (120 ms, 104 ms). The T1 and T2 values were measured using standard inversion recovery sequences with multiple inversion times (TI) and spin-echo multi-contrast sequences. The phantoms were scanned using sets of arbitrary flip angle (α), TI, and delay time (TD) values as shown in Table 1. Deviations of the estimated contrast ratios from the measured contrast ratios were evaluated as error percentage, $|\ CR_{EXP} / CR_{SIM} - 1\ | \times 100\%$, where CR_{EXP} and CR_{SIM} are the contrast ratios between different vials obtained from imaging experiments and simulation, respectively.

	(α,TI,TD)=(10º,0.67s,0.50s)		(α,TI,TD)=(12º,0.67s,0.50s)	
	EPG	**Ideal**	**EPG**	**Ideal**
B vs A	0.85%	2.63%	0.59%	3.46%
C vs A	2.22%	6.36%	0.33%	6.03%

Table 1: Error percentage of EPG and ideal spoiling for two scans

In Vivo Brain Study: Relaxation parameters and relative proton densities, ($T1_G$, $T2_G$) = (1500 ms, 103 ms), ($T1_W$, $T2_W$) = (800 ms, 85 ms), and (PD_G, PD_W) = (1, 0.92) in frontal WM and parasagittal GM were obtained prior to performing imaging on a healthy volunteer. These measured relaxation parameter values are similar to previously reported values of the same brain regions[4]. Using these parameters, we simulated the gray to white matter contrast ratio (GWCR) and normalized gray matter signal intensity (NGSI) using the manufacturer's default sequence parameter values for MP-RAGE (α, TI, TD, TE, TR, BW, matrix, FOV) = (9º, 320 ms, 820 ms, 3 ms, 7.1 ms, 240 Hz/pixel, 240x256x160, 240x256x192 mm). We then used our simulation to adjust α, TI, and TD using a full-domain search to find optimized protocols meeting GWCR and NGSI criteria with the shortest total scan time. GWCR was fixed to be 2 or greater (compared with 1.88 from the default protocol). NGSI was restricted to be greater than a specified level (0.012, 0.015, 0.018, and 0.020). The estimated $GWCR_{EPG}$ and $GWCR_{IDL}$ (calculated by the EPG and ideal RF spoiling approaches, respectively) were compared to the experimental results.

NGSI	**>.012**	**>.015**	**>.018**	**>.020**	**Def=.023**
SNR	32.7	39.3	46.0	46.6	53.6
$GWCR_{EXP}$	2.267	2.110	2.060	2.063	1.928
$GWCR_{EPG}$	2.276	2.057	2.004	2.002	1.887
$GWCR_{IDL}$	2.022	3.610	6.282	11.866	4.622
α(°)	7	8	8	8	9
TI/TD (ms)	100/500	100/500	150/520	270/710	320/ 820
Acq.Time (m:ss)	7:03	7:03	7:20	8:34	9:13

Table 2: Corresponding experimental measurements and simulation metrics for each scan that has the specified NGSI. The far right column is the manufacturer's default protocol.

Results and Discussion: The phantom study shows that the measured CR's between vials are in very close agreement with our simulated results. The EPG simulation with error percentage below 3% (Table 1) is more accurate than a simulation based on the ideal RF spoiling assumption. For the *in vivo* brain study, the measured GWCR between GM and WM (approximate ROI's shown in red in Figure 1) were also well-predicted by our simulation. $GWCR_{EPG}$ performed better than $GWCR_{IDL}$ (Table 2). SNR of the *in vivo* images was predicted within 5% by appropriate scaling of NGSI (for coil and other system dependent factors). The images in Figure 1 show that our optimization method provides image quality comparable to the manufacturer's default protocol with contrast ratios and signal-to-noise ratios that are predicted by our simulations. Compared to the default protocol, the optimized sequences are shorter by 24%, 24%, 20%, and 7% for Images 1-4, respectively, with similar image quality

Conclusion: It has been demonstrated that the proposed optimization technique provides an accurate prediction of contrast between two tissues, as well as a reasonable prediction of SNR, for MP-RAGE imaging for a set of arbitrary sequence parameter values. Consequently, both image contrast and SNR can be optimized by proper adjustment of α, TI, and TD. Thus, based on the proposed work, we can perform highly optimized imaging in any tissue with our choice of optimization objective for specified contrast, SNR, and/or imaging time.

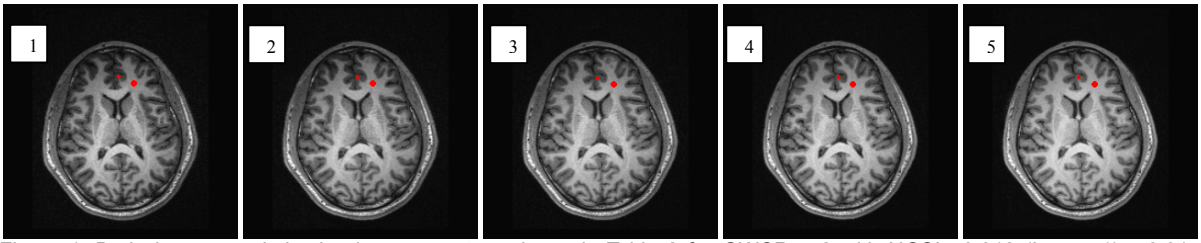

Figure 1: Brain images optimized using parameters shown in Table 2 for GWCR > 2 with NGSI >0.012 (Image 1), >0.015 (Image 2), >0.018 (Image 3), >0.020 (Image 4). Image 5 is the default protocol with NGSI = 0.023. Image quality is comparable to the default protocol with signal and contrast levels predicted by our simulation. Images are equivalently windowed.

References: [1] Deichmann et al, *NeuroImage* 12:112-127 (2000). [2] Stöcker et al, *MRM* 56:824-834 (2006). [3] Sobol et al, *JMRI* 6:384-398 (1996). [4] Wansapura et al, *JMRI* 9:531-538 (1999).