Improved Radial Spoiled Gradient Echo Imaging with Randomized RF Phases and Gradient Moments

W. Lin[1], and H. K. Song[1]

[1]Department of Radiology, University of Pennsylvania, Philadelphia, PA, United States

Introduction

Radiofrequency (RF) spoiling is the most established spoiling method for gradient echo imaging. It is based on a quadratic variation of RF (and receiver) phase angles in successive TRs, coupled with a constant gradient moment at the end of each TR period to create a range of resonance offset angles within each imaging voxel (1). However, it was recognized that RF spoiling yields non-ideal steady state signal intensities, particularly at larger flip angles and T_1/TR ratios, leading to significant quantification errors (2-3). For example, a recent variable flip angle gradient echo imaging study reported systematic T_1 measurement errors of 20-50% due to non-ideal RF spoiling as implemented by three major MR scanner manufacturers (3).

In this work, a novel spoiling scheme is proposed, based on applying random gradient moments and RF phases to achieve ideal average signal intensity, in conjunction with the radial acquisition scheme to suppress artifacts caused by TR-to-TR signal fluctuations. The proposed method achieves ideal spoiling within a wide range of flip angles (0^0-90^0) and repetition times (5-3000 ms). Simulation and phantom experiments demonstrate the superior performance of the proposed random spoiling scheme over conventional RF spoiling.

Methods

Bloch equation simulations were carried out to compare conventional RF spoiling with several random spoiling schemes, including random RF phase, random gradient moments with different maximal amplitudes, and a combination of both, at various T_1/TR and T_2/TR ratios in the range of 1-200 and flip angles in the range of 0-90^0.

Phantom experiments were further carried out to compare conventional RF spoiling with a spoiling scheme with random gradient moments and RF phase, on a 1.5T Siemens (Erlangen, Germany) Sonata MR scanner with maximum gradient amplitude of 26mT/m. The phantom contains 1.25 g $NiSO_4 \cdot (H_2O)_6$ and 5g NaCl per 1000 g H_2O. A standard RF-spoiled 3D gradient echo (FLASH) sequence was modified into a hybrid radial sequence with phase-encode in the slice direction. 3D gradient echo radial images, one with standard RF spoiling (phase increment $\phi=117^0$) and a second with proposed random spoiling, were acquired with flip angles $\alpha=10^0$ - 90^0 in 10^0 increments at TR = 15 and 4.3 ms.

Results and Discussions

Simulation results show that conventional RF spoiling results in a steady state that is different from the ideal spoiling condition (**Fig. 1a**). In contrast, a combination of random RF phase and gradient moment (with intra-voxel phase dispersion in the range of [20π, 40π]) results in a transverse signal slightly oscillating randomly around the ideally spoiled signal (**Fig. 1b).** Using just random RF phase or random gradient moment alone results in deviations of the average signal from the ideal level. Although the proposed random spoiling scheme introduces signal fluctuation (10-35%) among different TR's which can lead to artifacts for Cartesian imaging (**Fig. 2a**), radial imaging is more immune to such view-to-view signal intensity variations (**Fig. 2b**), due to the over-sampling in the central k-space region and the effective signal averaging during the image reconstruction process. Additional noise (streaks) introduced by random spoiling is less than 1% of the peak signal in the radial image.

Figure 3 shows simulation results comparing the ratio of the average signal to the ideal level at various T_1/TR and flip angles. For conventional RF spoiling, signal levels start to deviate significantly (up to 30%) from ideal spoiling condition when T_1/TR>5 or flip angle $\alpha>5^0$, due to the contributions from refocused coherence pathways. In contrast, with the proposed random spoiling, the average signal level never deviates from the ideal spoiling condition by more than 5% in the entire range of T_1/TR (1-200) and flip angles (0-90^0). Similar results were observed for various T_2/TR ratios in the range of 1-200. **Figure 4** shows the simulation and phantom experiment results, again showing that random spoiling gives more ideally spoiled signal over conventional RF spoiling.

When compared to a previously proposed spoiling method [4] which use a very large *fixed* gradient moment (~350 mT·ms/m, 150 cycles per cm) at the end of each TR (leading to minimum TRs of 20-30 ms), the proposed method allows fast imaging with TR < 5ms. In addition, there is no need for a large diffusion coefficient, which may not be valid in all tissues of interest. In conclusion, the proposed random spoiling method achieves ideal spoiling within a wide range of T_1, T_2, TR and flip angles. It is anticipated that the method will significantly improve the accuracy of quantitative MR methods based on T_1-weighted radial gradient echo imaging, such as dynamic contrast enhanced (DCE) MRI of tumor perfusion [5].

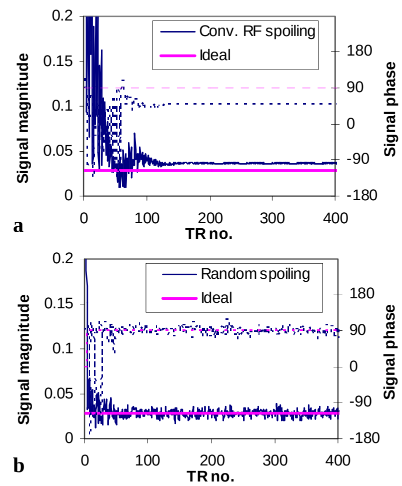

Fig. 1 Transverse magnetization after each RF excitation for (a) conventional RF spoiling (phase increment value $\phi=117^0$) and (b) random spoiling, showing both magnitude (solid curves) and phase (dashed curves). Simulation parameters: T_1/TR = 60, T_2/TR = 40, flip angle $\alpha=60^0$.

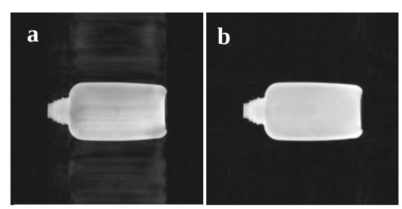

Fig. 2 Cartesian (a) and radial (b) images acquired with the proposed random spoiling.

References

[1] Zur Y, et al. *MRM* 1991;21: 251–263. [2] Denolin V, et al. *MRM* 2005; 54: 937–954. [3] Yarnykh VL. *Proc. ISMRM* 2007; 1796. [4] Yarnykh VL. *Proc. ISMRM* 2008; 234. [5] Lin W, et al. *MRM* 2008; 60; 1135-1146.

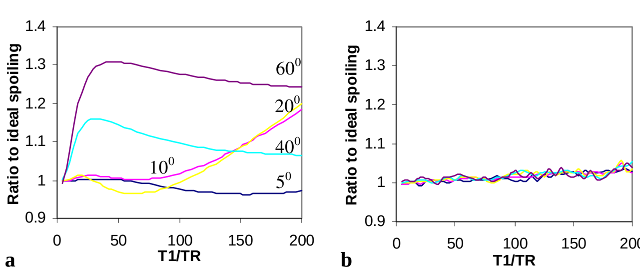

Fig. 3 Voxel signal ratio to ideal spoiling condition for conventional RF spoiling (a) and proposed random spoiling (b). T_1/T_2=2. Both plots contain flip angles of 5^0, 10^0, 20^0, 40^0 and 60^0.

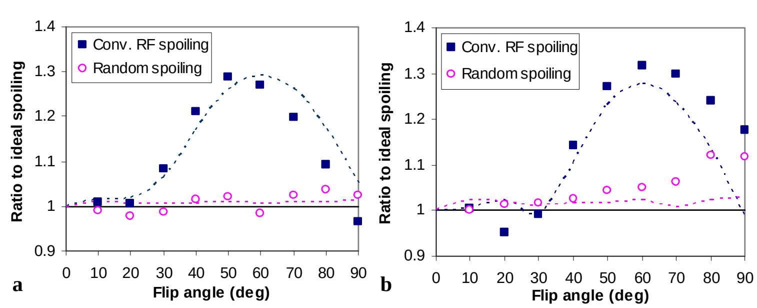

Fig. 4 Simulated (dashed lines) and measured (points) signal ratio to the ideal spoiling condition, for conventional RF and random spoiling. T_1=300 ms, T_2=260 ms. (a) TR = 15 ms. (b) TR = 4.3 ms.