Improved Accuracy in T_1 mapping and Flip Angle Correction with Random Spoiling in Radial Gradient Echo Imaging

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Introduction

Due to its high imaging speed and SNR efficiency, spoiled gradient echo imaging plays an important role in many quantitative MR methods. For example, a variable flip angle (VFA) method [1] is now widely used for in vivo T_1 mapping due to its time efficiency and large 3D anatomical coverage. Recently, an actual flip-angle imaging (AFI) technique [2], which utilizes two interleaved spoiled gradient echo acquisitions with different TRs, has been proposed for rapid mapping of transmitted radiofrequency field B_1. B_1 mapping has become increasingly important due to the growing availability of high-field clinical and research scanners operating at 3T and higher.

Critical to the accuracy of these quantitative methods based on spoiled gradient echo imaging is the complete spoiling of the transverse magnetization at the end of each TR. However, it was recently recognized that conventional RF spoiling yields non-ideal steady state signal intensities, particularly at larger flip angles and T_1/TR ratios, leading to significant quantification errors [3-4]. The purpose of this work is to propose an alternative spoiling scheme based on random gradient moment and RF phase, and to compare the performance of the proposed spoiling scheme with conventional RF spoiling for T_1 mapping and flip angle correction.

Theory

In conventional RF spoiling, the RF phase is often set to be a quadratic function of TR number. A constant gradient moment is also applied at the end of each TR period to create a range of resonance offset angles within each imaging voxel. This scheme leads to a steady state that is generally different from the ideal spoiling condition (**Fig. 1a**). In the proposed random spoiling scheme, both the RF phase and the gradient moments at the end of each TR are randomized (with intra-voxel phase dispersion in the range of $[20\pi, 40\pi]$). Although this leads to slight TR-to-TR variations of the signal in each voxel, the average voxel signal intensity matches the ideally spoiled condition at a wide range of T_1/TR ratios and flip-angles (**Fig. 1b**). As the signal variations can cause ghosting artifacts in conventional Cartesian imaging, radial acquisition could be utilized to suppress these artifacts, taking advantage of the averaging effect of oversampling in central k-space. It was found that using either random RF phase or random gradient moment alone results in higher deviation of the average signal from ideal levels.

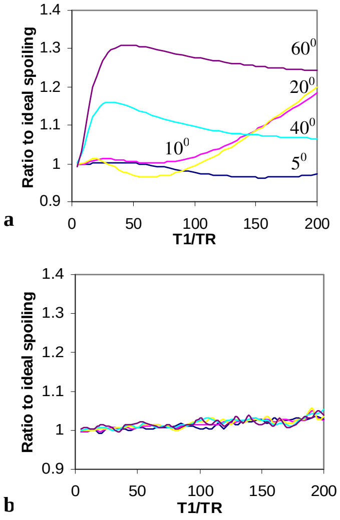

Fig. 1 Ratio of the actual voxel signal to ideally spoiled signal level in conventional RF spoiling (a) and proposed random spoiling (b). T_1/T_2=2. Different curves correspond to different flip angles.

Methods

Phantom experiments were conducted on a 1.5T Siemens (Erlangen, Germany) MR scanner to evaluate T_1 and B_1 mapping performance of conventional RF spoiling and the proposed random spoiling methods, using a 3D gradient echo (FLASH) sequence modified to acquire radial data in the k_x-k_y plane. For the first experiment, a phantom consisting of six tubes with the following gadolinium concentrations was constructed: 3.0, 1.5, 1.0, 0.5, 0.3 mM (T_1 ranging between 80-800 ms). Radial images were acquired with the following flip angles: $\alpha = 3^0, 10^0, 20^0$ and 40^0. The signal intensity S was then fitted to the following equation to determine the T_1's: $S/\sin\alpha = E_1 S/\tan\alpha + M_0(1-E_1)$, where M_0 is the equilibrium magnetization and the $E_1 = \exp(-TR/T_1)$. The true T_1 values were determined with a separate set of inversion recovery measurements (TR = 3s; TI = 0, 23, 60, 100, 150, 200, 350, 500, 800, 1200 ms). .

A second experiment was performed on a larger phantom (~36 cm in length) to demonstrate the effectiveness of our strategy in the presence of large B_1 variations. The T_1 mapping procedure was the same as the previous experiment, while the flip angle mapping procedure was carried out using the AFI technique (2). In AFI, two interleaved TRs (TR_1 and TR_2) with the same flip angle are used to establish an alternating steady state. It was shown that when $TR_1 < TR_2 << T_1$, the signal ratio of two interleaved acquisition $r = S_2/S_1$ becomes independent of T_1, and the actual flip angle can be then determined from this ratio as: $\alpha = \arccos[(rn-1)/(n-r)]$, where $n = TR_2/TR_1$. In our experiment, n = 4 and flip angle α=60^0. A calibration factor was then computed as the ratio of the true flip angle α to the prescribed flip angle. This calibration factor was subsequently used to adjust the flip angle α used in the T_1 fitting.

Results and Discussions

Figure 2 shows the T_1 mapping results from the gadolinium phantom. While the T_1 measurement error values were consistently less than 3% with the proposed random spoiling scheme, it increases up to 15.7% for the tube with a small T_1 (~80 ms) with conventional RF spoiling. For the larger phantom, inhomogeneous B_1 fields near both ends of the phantom causes large T_1 errors when no flip angle correction is applied (**Fig. 3a**). When the AFI flip angle correction was performed with conventional RF spoiling, there is still significant residual T_1 variations within the homogeneous phantom due to suboptimal spoiling (**Fig. 3b**). In particular, the edge of the phantom shows significantly underestimated T_1 values. When AFI correction was performed with random spoiling (**Fig. 3c**), the resulting T_1 map becomes homogeneous throughout the phantom, including the edges. Comparison of the T_1 profile (**Fig. 3d**) confirms the superior performance of the random spoiling over conventional RF spoiling, in achieving flip angle correction and accurate T_1 mapping.

In conclusion, the proposed random spoiling scheme achieved more accurate T_1 measurement and flip angle correction than conventional RF spoiling. An important application where the proposed technique may be particularly useful is in dynamic contrast enhanced imaging applications where T_1 maps are required to compute tissue perfusion while the use of undersampled radial imaging may be beneficial to enhance temporal resolution [5].

References [1] Cheng HM, et al. *MRM* 2006; 55: 566-574. [2] Yarnykh VL. *MRM* 2007; 57: 192-200. [3] Denolin V, et al. *MRM* 2005; 54: 937–954. [4] Yarnykh VL. *Proc. ISMRM* 2007; 1796. [5] Lin W, et al. *MRM* 2008; 60; 1135-1146.

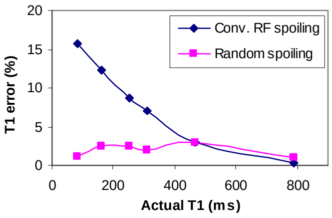

Fig. 2 Comparison of T_1 measurement error of two spoiling methods.

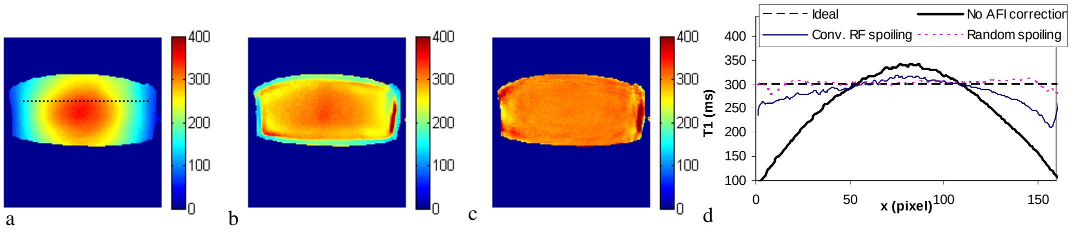

Fig. 3 T_1 map (in ms) before (a) and after AFI correction with conv. RF spoiling (b) and the proposed random spoiling (c). (d) T_1 profiles along the dashed line shown in (a). Ideal T_1 value was determined from a separate IR experiment.