B_1-Insensitive SSFSE using Adiabatic Preparation of the Echo Train

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Introduction: Fast Spin Echo (FSE) or Rapid Acquisition with Relaxation Enhancement (RARE) is a widely used clinical sequence for T2-weighted imaging. A sub-second version of this sequence acquired in a single shot with half-Fourier (SSFSE or HASTE) is routinely used to reduce motion sensitivity and is a key technique for MRCP evaluations (1,2). The SSFSE sequence starts with a 90° excitation pulse, followed by a train of refocusing pulses. Although 180° refocusing pulses are often ideal, lower refocusing pulses are employed to reduce power deposition and may be further reduced when B_1 throughout the body is not uniform. B_1 non uniformity is particularly problematic at high field strengths of 3T or greater because the dielectric and resistive properties of the body itself alter the uniformity of the RF fields in the tissue (3).

The magnetization during a train of constant refocusing flip angles can be described by a pseudo-steady state (PSS) solution of the Bloch equations (4). While high signal can be maintained by establishing PSS for refocusing flip angles less than 180°, reduced B_1 amplitude can result in an imperfect 90° pulse that does not adequately prepare the PSS. In this work, we consider an adiabatic approach to prepare the PSS and demonstrate improved robustness to B_1 inhomogeneities via simulation and *in vivo* results.

Theory: A standard 90° excitation pulse can be viewed as preparation pulse that places the magnetization in the 180° PSS, which can then be transitioned to lower angle PSS by varying the refocusing flip angles (4,5). Here, we consider an alternative preparation that places the magnetization in the 0° PSS, a solution in which the z-magnetization is a square wave function of the phase shift, ϕ, between the refocusing pulses (equation). Once placed in the 0° steady state, the magnetization can be efficiently transitioned to a higher flip angle PSS by gradual increasing of the refocusing flip angle. In order to generate this square wave longitudinal magnetization while maintaining B_1-insensitivity, we apply a pulsed version of the hyperbolic secant (HS) pulse that is adiabatic (insensitive to B_1 variation) (6,7) with 21 pulses. The time and area of the gradients between the pulses of the HS preparation must be half those between the pulses of the SSFSE echo train and the phase modulation must be set to achieve a symmetric square wave.

$$M_t = iM_0\left(1+\left(\frac{\sin\alpha\sin\left(\frac{\phi}{2}\right)}{(1-\cos\alpha)}\right)^2\right)^{-\frac{1}{2}} \qquad M_z = -i\left(\frac{\sin\alpha\sin\left(\frac{\phi}{2}\right)}{(1-\cos\alpha)}\right)M_t$$

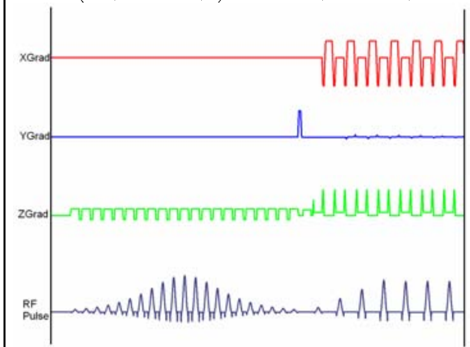

Fig. 1. 90° excitation pulse of a standard SSFSE sequence is replaced by a train of 21 RF pulses to prepare the magnetization to be at 0° pseudo-steady state.

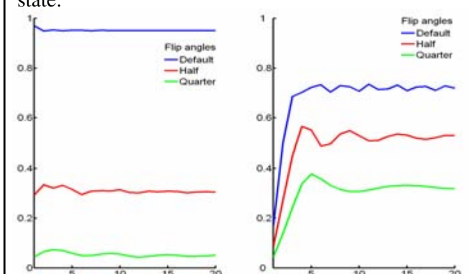

Fig. 2. Simulated results for the first 20 echoes of standard SSFSE sequence (left) and the adiabatic preparation sequence (right) at different RF pulse strengths.

Materials and Methods: The sequence (Fig. 1) was implemented on a 3T Excite scanner (GE Healthcare). Simulations of echo amplitude were performed using MATLAB software previously reported (8). The abdomens of five volunteers were scanned using both the standard and the new B_1-insensitive SSFSE sequence. To emphasize the nonuniform B_1 effect, the manufacturer recommended dielectric pad for improving B_1 uniformity (3) was not employed. The scanning parameters for both sequences were: TE = 80 ms, BW = ± 83.33 kHz, Nx = 256, Ny = 192, Δz = 5 mm, spacing = 5 mm and Nslices = 15-30 based upon the breath-hold duration. To eliminate signal loss due to cardiac-induced motion in the left lobe of the liver observed during preliminary experiments, the sequences were cardiac triggered using peripheral gating, with images acquired at 2 or 3 R-R intervals.

Results: Simulations (Fig. 2) indicated that the adiabatic preparation followed by ramping up of refocusing flip angles, restores approximately 70% of the signal in the regions of full B_1. When the B1 was reduced to half and one quarter, to simulate regions of attenuated B_1, the signal was lower with the standard SSFSE sequence than with the adiabatic preparation sequence. Volunteer studies (Fig. 3) demonstrated marked signal loss in the anterior abdomen (arrow) with the standard sequence (A, C), but uniform signal throughout the corresponding axial slice acquired with the adiabatic preparation sequence (B, D).

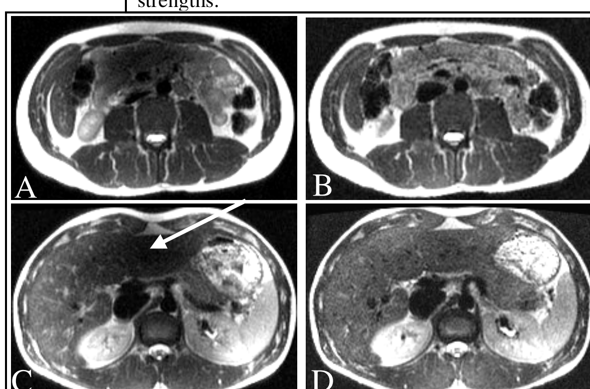

Fig. 3. Volunteer studies using standard SSFSE (A, C); adiabatic preparation SSFSE (B,D)

Discussion: The adiabatic PSS preparation approach preserved signal uniformity and image quality in the presence of inhomogeneous B_1. While SNR was reduced by 30% in regions of full B_1, increased SNR was seen in areas of reduced B_1. Improved preparation and transition ramps may achieve closer to the SNR of standard SSFSE in the full B_1 regions. This sequence may serve to improve the clinical reliability of body imaging at 3T and may also increase image quality at 1.5T in patients with abdominal fluid accumulation that perturbs the normal B_1 distribution.

Reference: 1) Semelka RC et. al., JMRI 1996, 6: 698-699. 2) Miyazaki T, et al. AJR. 1996, 166: 1297-1303. 3) Schmitt M et. al., ISMRM 2004, 12: 197. 4) Alsop DC, MRM 1997, 37: 176-184. 5) Hennig J et al., MRM 2003, 49: 527-535. 6) Silver MS et al., Physical Review A 1985, 31: 2753-55. 7) Conolly S et al., MRM 1992, 24:302-313. 8) Busse RF et al. MRM 2006 55:1030-1037.