Sensitivity of Low Flip Angle SSFSE of the Abdomen to Cardiac Motion

A. J. Madhuranthakam[1], R. F. Busse[2], J. H. Brittain[2], N. M. Rofsky[3], and D. C. Alsop[3]
[1]Global Applied Science Lab, GE Healthcare, Boston, MA, United States, [2]Global Applied Science Lab, GE Healthcare, Madison, WI, United States, [3]Department of Radiology, Beth Israel Deaconess Medical Center, Boston, MA, United States

Introduction: When spin-echo (SE) based techniques such as Rapid Acquisition with Relaxation Enhancement (RARE) are used at high-field strengths (3T and above), RF power becomes a critical constraint in the pulse sequence design. RF power deposited in the patient limits the minimum interval between successive acquisitions and thus the achievable spatial coverage in a given amount of time. This is particularly problematic for the acquisition of T2-weighted abdominal images, which uses SSFSE (or HASTE) to reduce motion sensitivity (1). Reducing the refocusing flip angle reduces the associated power deposition, however, lower refocusing sequences can suffer from signal loss in flowing or moving tissue. Here we investigate the effect of low refocusing flip angles on imaging of the abdomen.

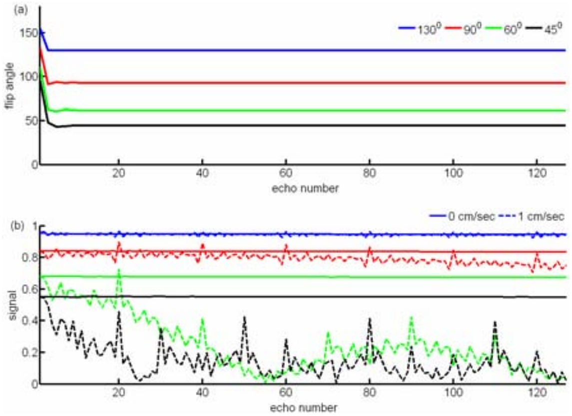

Fig. 1. (a) Flip angle trains to achieve PSS signal. (b) PSS signal for static materials (solid lines) and objects moving at 1 cm/sec (dashed lines) corresponding to the flip angle trains in (a).

Materials and Methods: For static tissue, it has been shown that using reduced flip angles in SSFSE need not compromise SNR (2). However, moving spins can be attenuated because the effective refocusing time for low flip angle trains is longer and hence phase shifts from flow can accumulate over a longer interval. Previous studies have shown that the variable refocusing flip angle trains for 3D-FSE acquisition are sensitive to CSF flow and cause signal loss in neurological images when reduced flip angles are used (3). In this study, the impact of reduced flip angle trains on intensity from vessels and abdominal tissue that is moving due to mechanical coupling to the heart (4) was assessed.

Four different flip angle trains were designed to achieve pseudo-steady state (PSS) asymptotic flip angles of 130°, 90°, 60°, and 45° (2), as shown in fig. 1a. The Extended Phase Graph (EPG) algorithm (5) was programmed using MATLAB (Mathworks) and modified to include phase accrual due to motion (3). Velocities on the order of 1.0 cm/sec (4), echo spacing of 4 ms, and 1 mm spatial resolution were used for simulations.

Volunteer experiments were performed using an SSFSE sequence with different refocusing flip angle trains. All data were acquired on a 3T Signa scanner (GE Healthcare). Typical imaging parameters included: TE = 80 ms, BW = ± 62.5 kHz, FOV = 34 × 24 cm^2, matrix = 256 × 192. To assess signal loss due to cardiac-induced liver motion the studies were also performed with peripheral gating. Experiments were performed with and without a dielectric pad placed on the abdomen to achieve a uniform B_1 throughout the body (6).

Results: Simulations show that for lower refocusing flip angles of 60° and 45°, 1 cm/sec motion causes strong signal attenuation (fig 1). Volunteer studies acquired with a 90° PSS flip angle train and no peripheral gating show signal loss in the left lobe of the liver (fig. 2a). Use of gating (acquisition delay of 400 ms) eliminated this tissue signal loss (fig. 2b). Figs.2c-d show similar left lobe results observed with a flip angle of 45° in a different volunteer. Note the obscuration of a caudate lobe cyst in fig. 2c, readily appreciated in fig. 2d (arrows). Also note that signal from liver vessels was strongly attenuated at the lower flip angles (fig. 2c and d). When a dielectric pad was not employed, reduced B_1 coupled with cardiac-induced liver motion in the superior left lobe caused signal loss even with higher nominal flip angles (130°) (fig. 2e). With peripheral gating, signal loss was observed only due to reduced B_1 (fig. 2f).

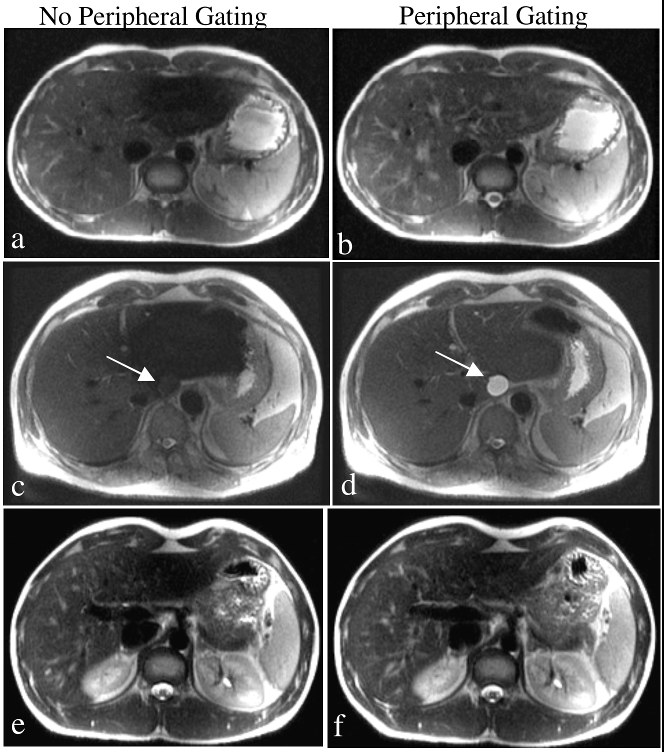

Fig. 2. Volunteer studies showing signal loss due to cardiac motion given a (a) 90° train and a (c) 45° train. (b, d) Signal loss is eliminated when the acquisition occurs 400ms after the peripheral gating trigger. (e) Image acquired using higher flip angle train (130°) also exhibits signal loss due to reduced B_1 coupled with cardiac-induced liver motion when dielectric pad is not used and (f) reduced signal loss using peripheral gating.

Discussion: At higher field strengths, it is desirable to use lower refocusing flip angles to reduce the RF power deposition. Lower flip angles cause attenuation of vascular signal and can cause signal loss in abdominal organs, especially the left lobe of the liver. While attenuated blood signal may be desirable to distinguish pathology from vessels, signal loss in tissue is unacceptable. The coincidental tendency towards reduced RF field strength in the same region can exacerbate the problem by further reducing the flip angle in this region. We have demonstrated, however, that low flip angle trains can be used at 3T to acquire abdominal images with greatly reduced signal loss when the data acquisition is synchronized to the cardiac cycle using peripheral gating. The feasibility of low flip angle SSFSE for abdominal imaging at high field offers additional flexibility in the optimization of imaging protocols.

Reference: 1) Semelka RC et. al., JMRI 1996, 6: 698-699. 2) Alsop DC, MRM 1997, 37: 176-184. 3) Busse RF. ISMRM 2006 14: 2430. 4) Kolen AF et. al., Phys. Med. Biol. 2004 49: 4187–4206. 5) Hennig J. Concepts in MR 1991 3: 125-143. 6) Schmitt M et. al., ISMRM 2004, 12: 197.