

# Sensitivity of Modulated Refocusing Flip Angle Single-Shot Fast Spin Echo to Impulsive Cardiac-Like Motion

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**Target Audience:** Scientists and physicians interested in fast body imaging and modulated flip angle techniques.

**Purpose:** To characterize the sensitivity of a modulated refocusing flip angle single-shot fast spin echo to impulsive, cardiac-like motion.

**Background:** Single-Shot Fast Spin Echo (SSFSE) is an attractive alternative to conventional 2D FSE when imaging speed and robustness to motion are desired, as in pediatric and breath-held abdominal imaging. Due to long echo trains and high flip-angle refocusing pulses, the imaging speed (i.e. repetition time) of SSFSE remains limited by high specific absorption rate (SAR). It is possible to achieve waveform-limited minimum TRs with refocusing flip angle modulation<sup>1</sup>, which reduces SAR considerably, though lower refocusing flip angles are less robust to motion. This inherent motion-sensitivity can be problematic in SSFSE of the liver, for example, where intermittent signal loss may occur due to cardiac motion<sup>2</sup> (Figure 4a).

**Materials & Methods:** All experiments were performed on a 3T whole-body MRI scanner (MR750, GE Healthcare, Waukesha, WI). A modulated refocusing flip angle SSFSE sequence was developed, where the refocusing flip angle profile was parameterized, as in [1], with an initial flip angle of 130°, varying  $f_{min}$ , and with  $f_{cen}$  and  $f_{end}$  fixed at 100° and 45°, respectively. Using a pneumatic actuator (Resoundant, Inc., Rochester, MN), a cardiac-like mechanical impulse (Fig 1a) was introduced into a liver-mimicking PVC-rubber phantom (Fig 1b) during a multi-phase, modulated refocusing flip angle SSFSE image acquisition. The arrival time of this cardiac-like impulse was delayed by a single echo-spacing for each iteration of the multi-phase acquisition, ranging from the first RF pulse in the echo train, to the central, low-order phase encoding view, and repeated for minimum refocusing flip angles ( $f_{min}$ ) ranging from 20° to 130°. Corresponding motion-free images were also collected for comparison. Other acquisition parameters were as follows: TR/TE<sub>effective</sub> 1000/100 ms, 35-cm FOV, 5-mm slice, 384x224 matrix, 1.5x acceleration factor (ARC, GE Healthcare, Waukesha, WI), ±83.3 kHz receive bandwidth, 4.8 ms echo-spacing. The total signal in each image acquired during motion was normalized by the total signal in its corresponding motion-free image. Additionally, our findings were corroborated *in vivo* under IRB guidance with similar imaging parameters.

**Results & Discussion:** Figure 2 contains example stationary and moving phantom images for  $f_{min}$  values of 20°, 70°, 90°, and 130°, for a representative impulse arrival time near  $f_{min}$ , illustrating increasing signal loss for lower refocusing flip angles. Figure 3a is a plot of the total signal in the motion-corrupted phantom image versus its stationary counterpart as a function of  $f_{min}$ , again, for a representative impulse arrival time near the minimum flip angle, illustrating accelerating signal loss for decreasing refocusing flip angles. Figure 3b contains the complete results of the experiment in terms of percent signal loss versus  $f_{min}$  and impulse arrival time. These results demonstrate that certain modulated refocusing flip angle schemes with SSFSE exhibit increased sensitivity to motion occurring during the low flip-angle regions at or before low-order phase encoding. This signal loss increases nonlinearly for decreasing values of  $f_{min}$ . Imaging with lower values of  $f_{min}$  also requires a longer actual TE (i.e. low-order phase encode position), to produce equivalent image contrast, leading to a secondary reason for higher motion sensitivity, which is a longer dwell time at lower flip angles, and therefore a higher likelihood of unfavorable overlap with the cardiac cycle. Figure 4 contains the results of a coronal liver acquisition for  $f_{min}$  values of 20° and 90°, demonstrating improved robustness to cardiac motion for higher values of  $f_{min}$ , in support of phantom results.

**Conclusions:** We have demonstrated the need for careful selection of the refocusing scheme for SSFSE during acquisitions with motion. Images acquired with modulated refocusing flip angle SSFSE exhibit signal loss when motion occurs concurrently with low refocusing flip angles at or before acquisition of low-order phase encoding views. Refocusing flip angle profiles optimized for other anatomies, such as the brain, therefore, may not be optimal for abdominal imaging. The robustness of the modulated SSFSE technique can be largely preserved, however, by limiting the minimum refocusing flip angle used for abdominal imaging. Further steps to avoid unfavorable overlap of the modulated SSFSE acquisition and the cardiac cycle, such as cardiac gating and shorter TEs, may also prove to be beneficial.

**References:** 1) Busse RF, Brau AC, Vu A, et al. Magn Reson Med. 2008 Sep;60(3):640-9. 2) Madhuranthakam AJ, Busse RF, Brittain JH, et al. Proc. Intl. Soc. Mag. Reson. Med. 15 (2007), #2523.

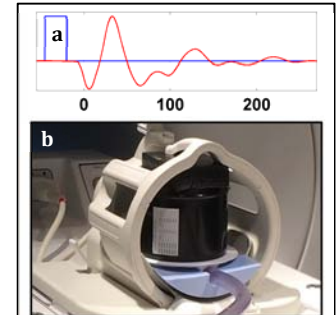
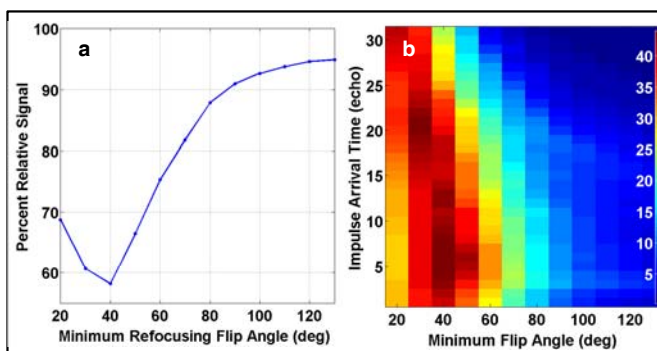
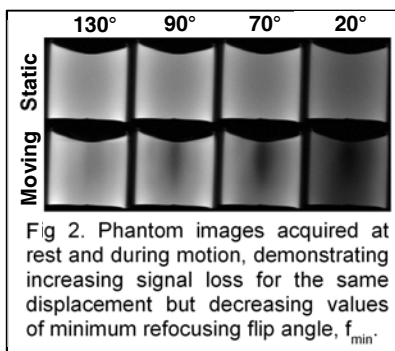


Fig 1. Experimental setup. a) Normalized amplitude of 25-ms square impulse and cardiac-like displacement response vs. time (ms). b) Pneumatic actuator, PVC-rubber phantom, and 8-channel coil.

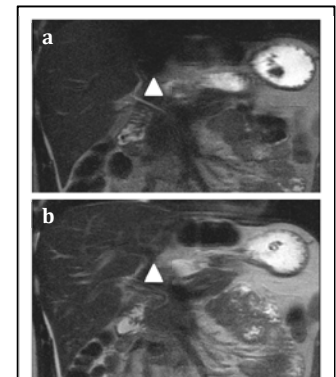


Fig 4. *In vivo* results for  $f_{min}$  values of a) 20° and b) 90°, with improved robustness to cardiac motion.

Figure 3. Each data point is a measure of total phantom image signal during motion relative to its stationary counterpart. a) Relative signal (%) vs.  $f_{min}$  for a representative impulse arrival time. b) Relative signal loss (%) vs.  $f_{min}$  and all impulse arrival times, demonstrating increasing signal loss for lower values of  $f_{min}$  and decreasing robustness for longer dwell times at low refocusing flip angles.