Flip angle modulation in single shot fast spin echo imaging greatly increases speed with little change in diagnostic image quality

Andreas M. Loening[1], Manojkumar Saranathan[1], Nichanan Ruangwattanapaisarn[2], Daniel V. Litwiller[3], Ann Shimakawa[3], and Shreyas S. Vasanawala[1]
[1]Dept. of Radiology, Stanford University School of Medicine, Stanford, CA, United States, [2]Faculty of Medicine, Ramathibodi Hospital, Mahidol University, Bangkok, Thailand, [3]GE Healthcare Global MR Applications and Workflow, Rochester, MN, Menlo Park, CA, United States

Target Audience: Physicians utilizing SSFSE sequences in abdominal MRI protocols, and researchers studying flip angle modulation in spin echo techniques.

Purpose: Single shot fast spin echo (SSFSE) sequences are often used in body MRI, especially when robustness to non-periodic motion such as irregular breathing or bowel peristalsis is important. In current implementations, the speed (minimum TR) at which SSFSE images can be acquired is limited by specific absorption rate (SAR). We investigated whether flip angle modulation could be used to decrease SAR/increase imaging speed without compromising image quality, by evaluating clinical SSFSE images acquired with and without flip angle modulation.

Methods: An algorithm similar to that used in 3D-FSE techniques like that described in [1] was utilized for computing an echo train with refocusing flip angle modulation. This sequence, referred to as variable refocusing flip-angle SSFSE (vrfSSFSE), is parameterized by 4 flip angle parameters: f_{init} (initial flip angle), f_{min} (initial angle to ramp down to), f_{lope} (angle at the center of k-space), f_{end} (ending flip angle). The flip angle over the course of the train modulated smoothly between these parameters. These four parameters were systematically varied on a volunteer to semi-empirically arrive on the following parameters: f_{max} 130, f_{min} 90, f_{lope} 100, and f_{last} 45 degrees (Fig 1).

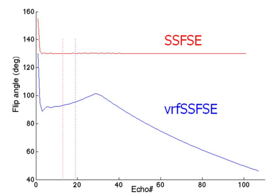

Fig 1: Flip angle train

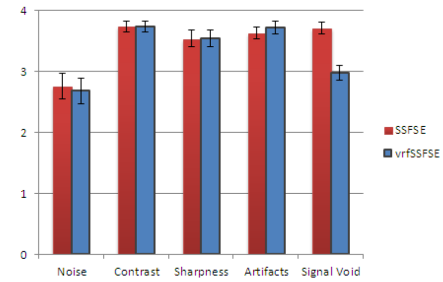

Fig 2: Results of grading various image features. Difference in signal void artifact along the left lobe of the liver was highly significant, other differences were not significant. Error bars are standard error.

With IRB approval and informed consent/assent, we recruited 9 consecutive adult and 16 consecutive pediatric patients referred for MRI evaluation. Each subject was scanned on a 3.0T MRI scanner (MR750, GE Healthcare, Waukesha, WI) with conventional SSFSE (constant refocusing flip angle of 130°) and vrfSSFSE with the following parameters: 32-channel torso or cardiac coil (choice optimized to patient size), ARC parallel imaging factor 3, half Fourier k-space filling with homodyne reconstruction, effective TE 100 ms, matrix 416 x 320 (in adults) or 416 x 288 (in children), and bandwidth ±50 kHz.

Field of view was optimized to each patient's anatomy (28-44 cm), but was identical between both sequences for a given subject. Both sets of images were graded in random order and blinded fashion by two radiologists on a 4 point scale for noise, contrast, sharpness, general artifacts, and cardiac motion related dephasing artifact. The null hypothesis of no significant difference in image quality between sequences was assessed with a Wilcoxon signed rank test, with two-tailed $p<0.05$ considered significant. Scan times were recorded.

Results/Discussion: Assessing different values of f_{init}, f_{min}, f_{lope}, and f_{end} in a volunteer, showed that significant decreases in TR (reflecting SAR reductions) could be readily achieved by decreasing flip angles towards the end of the echo train (decreasing f_{end}). To stabilize signal over the initial portion of the echo train and thereby reduce blurring, f_{min} was dropped to 90 and then slowly ramped up to 100 (f_{lope}). Further reductions in f_{min} lead to increasing intermittent dephasing artifacts over the left lobe of the liver due to cardiac motion, these became unacceptable below an f_{min} value of 50.

Average TR for adult cases was 1243 ms for SSFSE and 633 ms for vrfSSFSE. Average TR for pediatric cases was 1956 ms for SSFSE and 777 ms for vrfSSFSE. There was no statistically significant different in gradings for image noise, contrast, sharpness, and general artifacts (Fig 2, example images Fig 3). There was a significant difference in cardiac motion related dephasing artifact over the left liver lobe with vrfSSFSE (Fig 4).

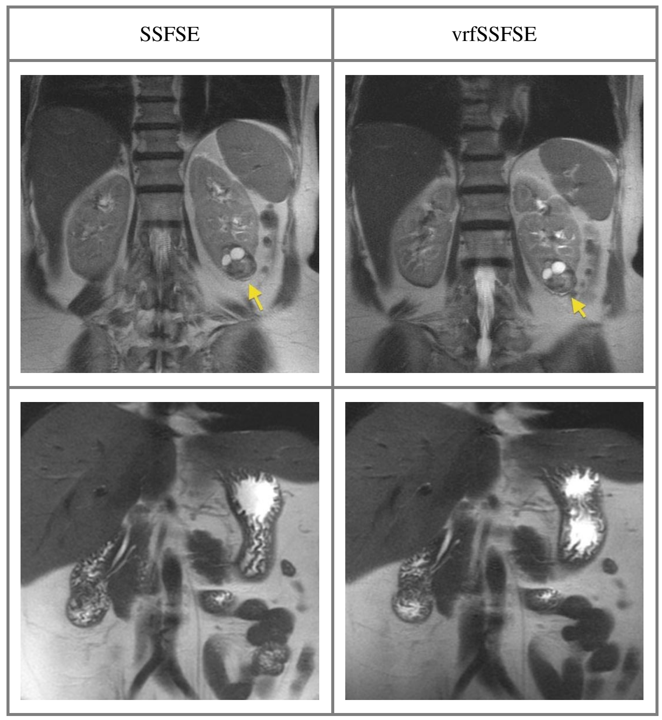

Fig 3: Representative comparison images. Left renal lesion is an RCC.

Conclusion: Refocusing flip angle modulation can increase the speed of SSFSE by ~100% in adults and ~150% in children with no appreciable loss in image quality aside from a slight increase in dephasing signal loss over the left lobe of the liver. This allows twice as many slices to be acquired in a single breath hold, and enables faster, less taxing abdominal scans with better registered images.

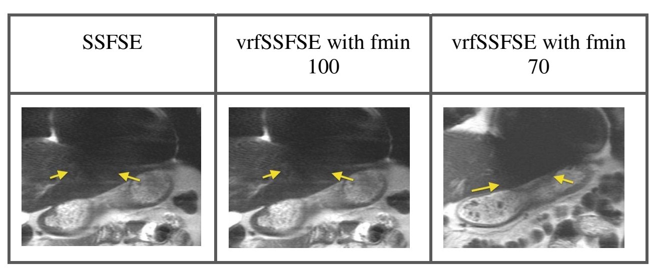

Fig 4: Cardiac related motion artifact. This artifact is intermittent and variable, depending on timing of acquisition with respect to cardiac

References:

[1] Busse RF, Brau AC, Vu A, et al. Effects of refocusing flip angle modulation and view ordering in 3D fast spin echo. Magn Reson Med. 2008 Sep;60(3):640-9.