Efficient Multi-Slice Fast Spin Echo Imaging with Reduced Flip Angles at High Field

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Introduction: Fast spin echo (FSE), also known as RARE and TSE, is a prevalent imaging sequence with numerous applications. High contrast images can be obtained rapidly with minimal sensitivity to static field heterogeneities. Human MRI systems exceeding 3.0 T have potential for rapid or high resolution imaging; however, severe RF power deposition forbids successive high flip angle RF pulses, essentially precluding traditional FSE with 180° refocusing pulses at high field strengths. Recently, it was shown that high resolution FSE images can be obtained at 4.7 T using a specific parameter set [1, 2]. While an excellent proof of principle, this approach is unsuitable to applications requiring short echo spacings and long echo trains, such as HASTE, and may not reduce RF power sufficiently at even higher field strengths. Recent works at 7 T have demonstrated high resolution FSE but with very limited slice coverage due to SAR restraints [3, 4]. Reduced and variable refocusing flip angle echo trains have been shown, at clinical field strengths, to provide substantial RF power savings, maintain high signal levels, and provide longer effective T_2 values [5]. In this work, we investigate the use of reduced and variable flip angles at 4.7 T for efficient (ie: no excess delay time for RF power mitigation) multi-slice imaging. We explore the inherent magnetization transfer (MT) effect from multi-slice imaging at reduced refocusing angles and we demonstrate both very rapid and very high resolution images of the human brain.

Methods: Images were obtained from a 4.7 T Varian Unity Inova whole-body imaging system. Maximum gradient strength was 3.5 G/cm with 300 μs rise time. We employed a 27 cm birdcage RF coil (XL Resonance, Canada) for transmit and a closely coupled 4-element array coil (PulseTeq, United Kingdom) for signal reception. The MT effect as a function of refocusing flip angle was assessed from the signal intensity ratio between multi-slice (17 slices, 2 cm gap around central slice only), Ims, and single-slice, Iss, images (1x1x5 mm^3, ETL=8, ESP=12 ms). HASTE images (1x1x5 mm^3, ETL=109, ESP=5.5 ms, TE=49.5 ms) were obtained in 600 ms/slice with a refocusing train that was smoothly ramped down to 55° over the first four pulses. A stack of 30 high resolution images (0.4x0.4x1 mm^3, ETL=8, ESP=20.5 ms, TE=41 ms, TR=6.1 s) was obtained with a train of 100° pulses in 6:30. The first refocusing pulse was set to 140° to increase signal intensity and reduce oscillations. HASTE and high resolution images were obtained with very high duty cycles; gradient events occupied 92% and 88% of the total time respectively. Short term average RF power remained below 3 W/kg with the exception of the MT experiment, whose 5 minute RF power remained below 3 W/kg.

Results and Discussion: As shown in Fig. 1, MT significantly affects tissue contrast with multi-slice FSE at 4.7 T. With 180° flip angles, white matter is attenuated by up to 25%; gray matter by 15%. The MT effect is reduced at lower refocusing flip angles with less than 5% signal change below 60°. With low flip angles, more gradual signal decay permits unconventionally long echo trains yielding high quality single shot images, as shown in Fig. 2. Reduced refocusing angles are equally applicable to high resolution imaging as depicted in Fig. 3 where voxel volumes of 0.17 mm^3 are achievable in multi-slice mode.

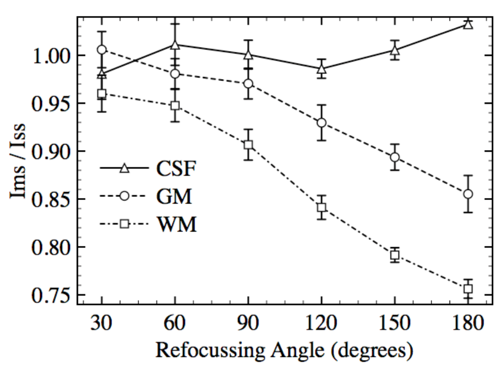

Figure 1: Ratio of multi-slice to single-slice signal intensity showing MT effect in cerebrospinal fluid (CSF), gray matter (GM) and white matter (WM) at various refocusing flip angles.

Figure 2: Sagittal HASTE image acquired with an ETL=109 and 55° refocusing pulses in 600 ms.

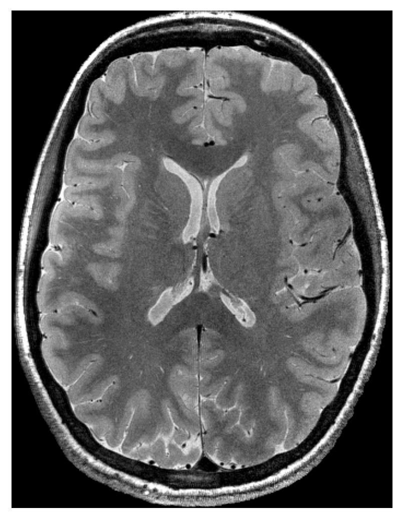

Figure 3: High resolution (0.4 x 0.4 x 1 mm^3) axial image drawn from a 30 slice data set acquired with 100° refocusing pulses in 6 min, 30 sec.

Conclusion: A variety of exceptional FSE based images can be obtained at high field. RF power is readily mitigated via reduced and variable flip angle refocusing trains, an approach with many benefits and few penalties. Tissue contrast varies with refocusing angle due, in part, to a strong MT effect at high flip angles. Very low flip angles are ideal for long echo train imaging due to longer effective T_2 values; applications include HASTE and 3D configurations (not shown). High signal return combined with reduced signal decay at low flip angles permits high resolution multi-slice imaging. We anticipate this approach applies equally well at 7 T.

References: **[1]** De Vita, E. et al., (2003) Br J Radiol 76(909) 631-637. **[2]** Thomas, D. L. et al., (2004) Magn Reson Med 51(6) 1254-1264. **[3]** Sanchez Panchuelo, R. M. et al., (2007) Proc. ISMRM. 15 2054. **[4]** Theysohn, J. M. et al., (2007) Proc. ISMRM. 15 2060. **[5]** Alsop, D. C., (1997) Magn Reson Med 37(2) 176-184.