Comparison of Fat Suppression Methods for Functional and Diffusion Studies Using SE EPI at 7T

D. Ivanov[1], **M. Streicher**[1], **A. Schäfer**[1], **and R. Turner**[1]
[1]Department of Neurophysics, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

Introduction: MR imaging at ultra-high field strengths has given encouraging results for high resolution functional and diffusion-weighted brain image acquisition. For both applications, single-shot echo-planar imaging (EPI) is often used, because it acquires entire slices in a fraction of a second and thus avoids distributed artifacts associated with head motion. However, EPI acquisitions are sensitive to chemical shift artifacts which appear in the phase-encoding direction. These are usually mitigated by including a fat suppression module before the excitation pulse. Other methods include an inversion pulse [1], or a spectrally selective saturation pulse [2]. These fat suppression methods require additional RF pulses, thus increasing the specific absorption rate (SAR) which is highly undesirable at high fields. Moreover, fat saturation pulses generate magnetization transfer contrast (MTC) in multi-slice imaging, which reduces the remaining water tissue signal [3]. In addition, at high field strengths the increased inhomogeneities in B_1 and B_0 fields may cause incomplete suppression of the fat signal. It is evident that methods which do not require additional RF pulses for fat suppression have a distinct advantage. One such technique is the slice-select gradient reversal approach, which utilizes slice-select gradients of equal magnitude and opposite polarity during the excitation and refocussing pulses [4]. More recently, a new method has been developed which uses sufficiently different slice-select gradient amplitudes for the excitation and refocussing RF pulses [5]. The unequal gradient (UG) method can be implemented by increasing the duration of the excitation or the refocussing pulse, the latter giving greater SAR reduction at a cost of slight increase in the minimum echo time. We investigated the comparative SNR and robustness of the UG method, the use of fat saturation pulses, and the gradient reversal method.

Materials and methods: Experiments were performed on a 7T whole-body MR scanner (MAGNETOM 7T, Siemens Healthcare Sector, Erlangen, Germany). A 24-element phased array coil (NOVA Medical Inc, Wilmington MA, USA) was used for imaging. Two healthy volunteers were included in the study, after their informed consent was obtained. SE EPI sequences were designed and implemented which allowed the durations of excitation and refocussing pulses to be variable, the magnitudes of their accompanying gradients to vary correspondingly, and their polarity to be reversible. The bandwidth-time product was kept constant and chosen to be the same for both pulses (5.22), so that increasing the pulse duration resulted in decreasing its bandwidth, and thus its associated slice-select gradient, while maintaining the same slice thickness and profile. The refocussing pulse was surrounded by crusher gradients in all 3 spatial directions. Pulse sequences with the following RF pulse combinations were designed and implemented (duration of excitation pulse / refocussing pulse, in ms): 2.56 / 2.56, 2.56 / 3.84, 2.56 / 6.4, 3.84 / 2.56, 3.84 / 3.84, 6.4 / 2.56, 6.4 / 6.4. Scanning was performed with all of these parameter combinations, including gradient reversal, using 3 mm x 3 mm in-plane resolution and 3, 2 and 1 mm slice thickness, totalling 42 acquisitions. In addition, every acquisition was done twice with the vendor-provided fat saturation switched on and off. A single volume was acquired with each of these variants. The shim volume remained the same throughout the experiment. The echo time was set at 55 ms – the smallest possible for the sequence in which both excitation and refocussing pulses had 6.4 ms duration. TR was set to 20 s, to eliminate any T1 effects and allow whole brain coverage for the scans with 3 and 2 mm slice thickness without exceeding the SAR limit. The individual scans for every slice thickness were coregistered using SPM5 to the first volume acquired to eliminate effects of inter-scan motion. Then all the scans with 1 and 2 mm slice thickness were coregistered to the 3 mm scans and resampled to 3 mm isotropic resolution. This allowed voxel-wise correspondence between the images to estimate the effect on water signal SNR of gradient reversal with increasing slice-select gradients. The resulting images were subtracted pair-wise.

Results and Discussion: All of the fat suppression methods tested achieved complete cancellation of the subcutaneous fat signal. When both slice-select gradients were in the same direction, the volumes obtained by averaging three adjacent slices of 1 mm thickness always showed a 2-3 % higher SNR than the volumes acquired with 3 mm slice thickness. This was especially true for sequences with short RF pulse durations and strong slice-select gradients. By contrast, images obtained using the gradient reversal method had lower overall SNR when three 1 mm thick slices were averaged, as compared with one 3 mm thick slice. This was exacerbated by increasing the difference in slice-select and refocussing gradient amplitudes. Here, inhomogeneity in B_0 causes an opposite bending of the slice between slice-excitation and refocussing, which results in loss of signal. Table 1 shows typical SNR improvement in percent achieved by the UG method [5] (2.56 ms excitation pulse and 6.4 ms refocussing pulse) over a well-shimmed region, as compared with use of a fat-sat RF pulse and with the gradient reversal method. The UG method provides excellent fat suppression and reduction of SAR by 50 % compared with the vendor provided fat-sat sequence (with 2.56 ms excitation and 3.84 ms refocussing pulse). The UG acquisition also gives higher SNR than any sequence using gradient reversal, for all slice thicknesses. The UG method incurs some signal loss when very long RF pulses are used, with correspondingly weak slice-select gradients. Here the slices are significantly bent in regions of severe field B_0 inhomogeneity, and the refocussed slice has a different bending from the slice excited, so that overlap is no longer complete. We have shown, however, that substantially greater signal losses occur using the gradient reversal method, for the same RF pulse durations, because then the slices excited and refocussed will be distorted in opposite directions, and thus have still less overlap.

	excitation / refocussing pulse duration in ms				
	2.56 / 3.84	2.56 / 2.56	2.56 / 6.4	6.4 / 6.4	6.4 / 6.4
slice thickness	fat saturation	gradient reversal	gradient reversal	fat saturation	gradient reversal
3 mm	4.8%	1.28%	1.7%	4.8%	2.3%
1 mm	3.2%	5.9%	4.6%	0.1%	15.1%

Table 1 *Typical SNR improvement measured for the unequal gradient fat suppression method compared with use of a fat saturation RF pulse and of the gradient reversal method. All other sequence parameters were kept the same.*

Conclusion: At higher field strength, the increased SAR and inhomogeneities in B_0 and B_1 fields make effective fat suppression more difficult. The UG method for fat suppression, which uses different slice-select gradient amplitudes and durations for the excitation and refocussing pulses, allows not only a substantial reduction of SAR, but also proves to be insensitive to B_1 inhomogeneities and more robust against B_0 inhomogeneities, as compared with the gradient reversal method. These features make it especially suitable for high-field applications, and applicable for fat suppression in any body region.

References: [1] Bydder GM et al, J Comput Assist Tomogr 1985; 9: 659-675; [2] Haase, A et al, Phys Med Biol 1985; 30: 341-344; [3] Shin W et al, Magn Reson Med 2009; 62: 520-526; [4] Volk A et al, J Magn Reson 1987; 71: 168-174; [5] Ivanov, D et al, Proc Intl Soc Mag Reson Med 2009, 17: # 1547.