Fat Suppression with Low SAR for SE EPI fMRI at 7T

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Introduction: Functional imaging studies at 7 Tesla have given encouraging results, with increased CNR and stronger BOLD contrast [1]. However, a remaining problem at such field strengths is the increased specific absorption rate (SAR). A possible solution would be the omission or the modification of the RF pulses used in the imaging sequence. The SAR for gradient-echo EPI at 7 Tesla can be reduced significantly by omitting the fat suppression pulse, since at the optimal echo time for BOLD weighting (~25 ms) the signal from subcutaneous fat has already decayed [2]. T2* of the tissue region outside the scull at 7 Tesla is about 10 ms [2]. However, the T2 of fat is closer to 65 ms [3] so that for a spin-echo (SE) BOLD EPI acquisition, where the fat signal is refocussed, the fat saturation pulse cannot easily be omitted. Here we describe a simple method to remove the fat signal, by increasing the duration of the refocussing pulse to approximately the T2* value of fat, which has the additional virtue of reducing the SAR by a factor of 2.

Materials and methods: All experiments were performed on a 7T whole-body MR scanner (MAGNETOM 7T, Siemens Healthcare Sector, Erlangen, Germany). An 8-element phased array head coil (RAPID Biomedical, Rimpar, Germany) was used. Five healthy volunteers were included in the study after obtaining their informed consent. Several SE EPI sequences with variable durations of the sinc-shaped excitation and refocussing pulses were designed. The durations of the excitation pulse were chosen as 2.56 ms, 3.84 ms, 5.12 ms, 6.40 ms, and 7.68 ms. The durations of the refocussing pulses were 3.84 ms, 5.12 ms, 6.40 ms, 7.68 ms, 8.96 ms, 10.24 ms, 11.52 ms, 12.80 ms, 14.08 ms, and 15.36 ms. To verify the temporal robustness of the method, twenty image volumes were obtained with each of these modified sequences at a repetition time of 2 seconds. The voxel sizes of the volumes were varied between 1 mm^3 and 27 mm^3. For the most SAR intensive version, which used an excitation pulse of 2.56 ms, refocussing pulse of 3.84 ms, together with a fat saturation pulse, the maximum number of slices allowed by the SAR monitor was determined. This number was then used for each of the other acquisitions. Furthermore, for every subject a T2* map of the volume covered was acquired, using a fully flow compensated spoiled gradient echo sequence with seven different echo times. Finally, for one subject seven SE EPI volumes were obtained at different echo times with the sequence having the shortest refocussing pulse and no fat saturation pulse in order to generate a T2 map showing clearly the fat signal artefact. Several regions of interest in different slices were taken to assess variability across the head.

Results and Discussion: The T2 map indicated a value of 75±10 ms for the regions outside the brain where artefacts could be seen matching the published value for subcutaneous fat at 7 Tesla [3]. The difference between the T2* and T2 values of scalp fat probably arises from the rapid change of susceptibility between bone and air. The increase in the refocussing pulse duration obviously increases the minimum achievable echo time, but since for spin-echo BOLD contrast the optimal TE is about 55 ms [1], this is not a problem at low spatial resolution. For higher resolution acquisitions, in order to provide time for the longer refocussing pulse, partial Fourier acquisition or/and parallel imaging techniques can be used. Among those tested, the refocussing pulse duration necessary for suppression of the fat signal to the noise level for three of the five subjects was 10.24 ms. For the two other subjects the necessary duration for complete elimination of the fat artefact was even shorter and amounted to 8.96 ms. These values agree well with the T2* values of scalp fat determined in each of the subjects.

Fig. 1 shows SE EPI images with 3 mm isotropic resolution obtained at identical slice positions in a single subject with the same excitation pulse duration of 2.56 ms. The images in Fig. 1a and Fig. 1b were acquired with and without fat suppression, respectively, using refocussing pulse duration of 3.84 ms. As shown in Fig. 1c, a refocussing pulse duration of 10.24 ms is enough to eliminate the fat signal artefact without a fat saturation pulse. In Fig. 1d it is verified that using a fat suppression pulse in addition to the 10.24 ms refocussing pulse does not improve the cancellation of the fat signal. Additionally, comparison of figures 1a and 1c indicates that lengthening the refocussing pulse duration does not result in reduced overall image quality. Increasing the duration of the refocussing pulse still further did not show a measurable improvement in the fat suppression achieved, but was clearly helpful in decreasing the overall SAR of the sequence. This decrease was also produced by lengthening the excitation pulse, which had no effect on fat suppression. Of course, longer RF pulses entail longer minimum echo times that favours using the excitation pulse with the shortest duration. The reduced SAR values immediately transform into an increased number of slices that can be acquired per second. For a sequence with a 2.56 ms excitation pulse, 3.84 ms refocussing pulse, and the standard fat saturation pulse, 3.3 slices per second can be acquired. By comparison, a sequence with 10.24 ms refocussing pulse duration, no fat saturation pulse, and the same excitation pulse allowed 7.2 slices per second to be acquired, an improvement of over 200%. These values are typical, but can vary across subjects depending on coil loading.

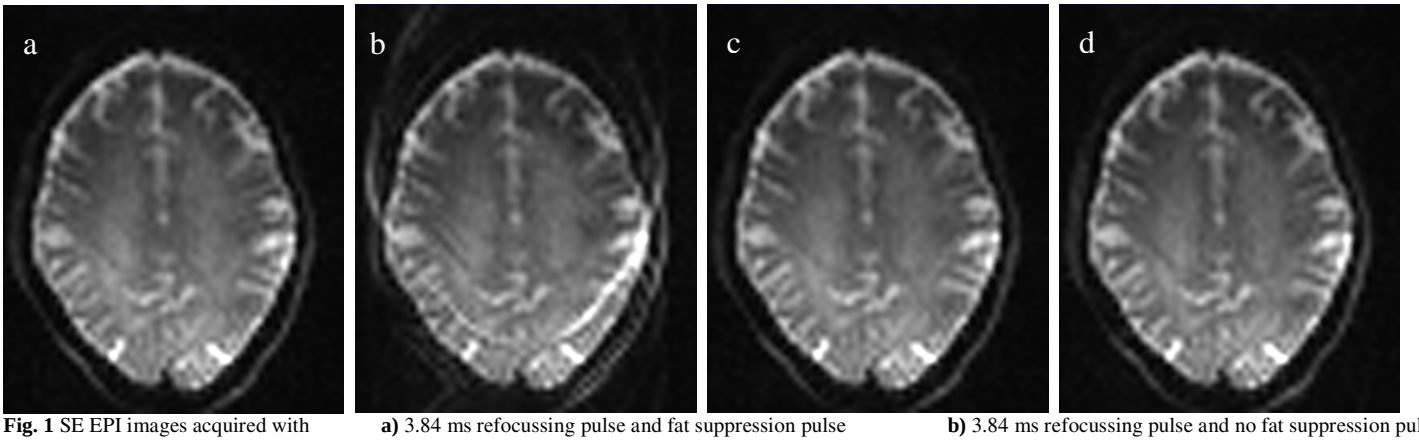

Fig. 1 SE EPI images acquired with **a)** 3.84 ms refocussing pulse and fat suppression pulse **b)** 3.84 ms refocussing pulse and no fat suppression pulse **c)** 10.24 ms refocussing pulse and no fat suppression pulse **d)** 10.24 ms refocussing pulse and fat suppression pulse

Conclusion: Fat suppression can be achieved by lengthening the refocussing pulse to approximately the T2* of scalp fat. Replication across five subjects indicates the general applicability of this method for spin-echo EPI functional studies at 7 Tesla. Furthermore, the proposed method has the advantage of reducing SAR in two ways - by eliminating the need for a fat saturation pulse and by decreasing the amplitude of the SAR intensive 180 degree pulse. This results in doubled brain volume coverage for the same repetition time.

References: [1] Yacoub E et al, Magn Reson Med. 2003;49:655-64 [2] Speck O et al, MAGMA 2008; 21:73-86 [3] Ren J et al, J Lipid Res. 2008; 49:2055-62