Implementation of SE and GE SIR-EPI at 7 T using Fast Switching Gradients and Parallel Imaging

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Introduction
For fMRI studies the higher field strength of 7T provides increased BOLD contrast and higher SNR for possibly higher spatial resolution. Accelerated image acquisitions, which can result in affordable reduced sensitivity, are often used at high fields to reduce acquisition times, gradient heating, and SAR. The application of SE EPI has greater limitations because of increased SAR due to the 180^O RF refocusing pulse used for each slice which can quickly become excessive with whole brain coverage at 7T, limiting the number of slices and/or the repetition time. The Simultaneous Image Refocusing (SIR) EPI (1) pulse sequence refocuses signals from multiple images in each echo. SIR used for SE EPI would reduce the SAR limitations in whole brain coverage as it would require a fraction of the number of refocusing pulses. This comes at the expense of larger readout times compared to a conventional single refocused slice, but with fewer gradient switches during the EPI readout. SIR has been demonstrated at 3T, however, its successful implementation at 7T requires sufficient gradient strength and slew rate as well as concurrent parallel imaging to keep the readout times short with respect to the shorter T2* at high fields. The purpose of this work is to evaluate SIR EPI for GE and SE based brain imaging at 7T.

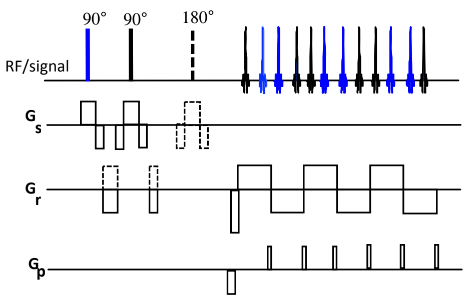

Fig 1. SIR EPI showing hatched pulses and RF for SE SIR EPI

Methods
A 7T whole body scanner (Siemens console) with a head gradient insert (Siemens AC84) with settings limiting Gmax to 80mT/m at slew rate 333mT/m/ms and a 16 channel head coil. Four subjects were studied under institutional guidelines. SIR EPI sequences initially apply two or more 90^O RF excitation pulses with frequency offset to excite signal in multiple image planes, then applies Gr dephasing pulses between and after the excitation pulses to separate the signal from different slices onto different timed positions on the switched readout gradient. This produces several times more echoes in the total echo train that are separated into the respective k-spaces of each slice for 2D FT image reconstruction. In this preliminary implementation 4.3ms between the excitation pulses occurred whereas the center of k-space, ko, was positioned on the same read period with maximum 2.2ms to 4.3ms displacement from the Hahn SE time, resulting in a small T2* effect in a fraction of the slices. This effect could be eliminated by shifting ko of each slice with Gp pulses to their respective HSE times but this was not applied in these preliminary experiments.

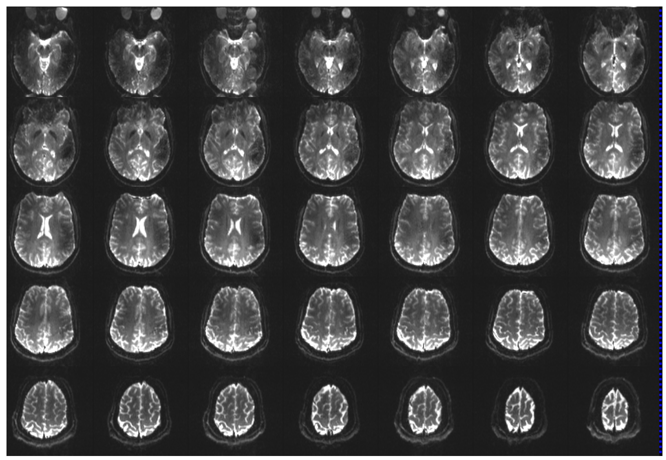
Fig 2. SIR-2 SE EPI of whole brain.

Results
Comparisons were made between conventional GE EPI and SE EPI to SIR sequences with attempts to hold image parameters and sequences parameters similar, but with different allowed bandwidths. For GE imaging for both SIR and non-SIR sequences, TE/17.4ms, TR/2000ms, 44-45 slices, image matrix: 96x96, voxel resolution: 2mm isotropic, partial Fourier:6/8ths, and a phase encode parallel imaging reduction factor R of 4. For SE EPI, SE SIR-2 and SE SIR-3, 50-51 slices, TE/50ms and R=3. The EPI bandwidths were: (GE/SE): 3064/2895, SIR-2 2004/1735, SIR-3 2004/1735 (all in Hz/pixel). The measured SNR (mean tissue/air) in the GE images was 21.2, 29.4, and 12.6 and in SE images was 15.9, 24.5, 8.75 for EPI, SIR-2 and SIR-3, respectively. There was a measured 100% reduction in SAR using SIR-2 SE EPI compared to SE EPI. There was increased distortion in the SIR images in regions of susceptibility as determined by their longer echo trains and greater echo spacing; 0.42ms for GE and SE EPI compared to 0.84ms for SIR-2 and SIR-3, however, the parallel imaging greatly reduced these effects. The overall image quality of SIR-2 was comparable to conventional SE, whereas SIR-3 suffered from occasional spiking artifacts in these preliminary scans. The SIR-2 GE EPI with R=4 was acquired at isotropic 1.5 mm resolution Fig 4. to evaluate higher resolution and had SNR of 14.4. The image quality overall was not dissimilar to conventional EPI images.

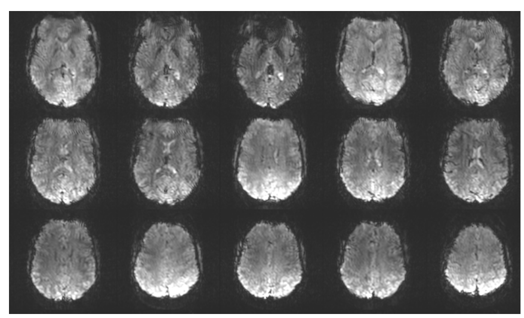
Fig 3. SIR-3 GE EPI 15 of 45 slices.

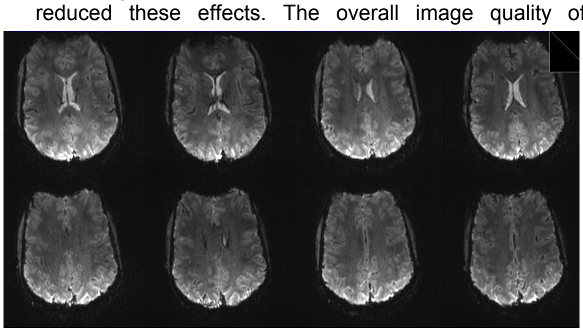
Fig 4. SIR-2 GE EPI 1.5 mm isotropic resolution.

Conclusion:
We demonstrated here that with the combination of fast switching gradients and parallel imaging afforded at high magnetic fields, SE and GE SIR EPI can be effectively implemented to reduce acquisition times and SAR with minimal losses in image quality and SNR at 7T. The use of SIR should be highly valuable for fMRI and diffusion acquisitions at high fields that require reduced repetition and acquisition times, which are often limited. **References**: 1) Feinberg et al, MRM 2002, Jul;48(1):1-5.; **Acknowledgement**: R44NS063537, R01EB000331, P41-RR008079, P30 NS057091, The Keck Foundation, The MIND Institute