Accelerated DWI Using Simultaneous Image refocused EPI Optimized for Clinical Imaging

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Introduction

To reduce imaging times in clinical diffusion imaging, the simultaneous image refocusing (SIR) technique[1,2] can be utilized to acquire multiple slices in a single readout, thereby shortening the total scan time. With 2 simultaneously refocused echoes, an approximate acceleration factor of 1.5 can be achieved as compared to non-SIR imaging. Multiplexing the slices increases the efficiency of diffusion gradients, and enables whole brain diffusion imaging in a significantly shorter time. The penalty that one pays for encoding slices simultaneously is a longer readout time and longer TE. A longer readout and consequently longer echo spacing leads to an increased distortion in EPI. However, distortion may not be an insurmountable problem with a number of potential solutions having been proposed earlier for correction[3,4].

Methods

A diffusion-weighted SIR sequence was developed on a 3T scanner (Siemens Tim Trio, Erlangen, Germany). In a multislice diffusion-weighted SIR sequence (Fig.1), two neighboring slices are excited for every set of refocusing pulses and diffusion gradients. The time difference between the two 90 deg. pulses is 4.6 ms. A readout dephasing gradient applied between the excitation pulses separates the echoes from the different slices in the EPI readout. After the double refocusing RF pulses, two echoes are formed during each EPI ADC readout. Since each slice experiences a different readout dephasing gradient moment, the echoes are refocused at different times in the readout, one early and the other late.

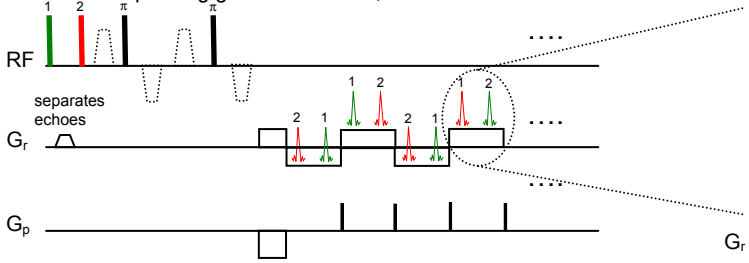

Figure 1. Schematic of the SIR sequence. Two neighboring slices are excited by the two 90 deg. pulses (1&2). The readout dephasing gradient applied between the excitation pulses separates the echoes during the signal readout. Readout shows two different echoes during each period, each echo representing one slice. Dotted gradients between the RF pulses denote diffusion gradient pulses.

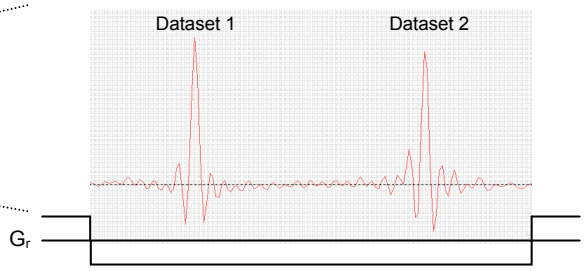

Figure 2. Data acquired in a volunteer during a single readout gradient (one ADC readout) with no phase encoding. Two echoes are seen in the ADC, and the data is cut into two sections to sample the two slices.

Three healthy volunteers and one patient were scanned on a 3T scanner, under IRB guidelines. A 3-scan trace protocol was used and protocols were optimized for the SIR and non-SIR sequences separately. The imaging parameters are different to account for the fact that the readout bandwidth is limited in SIR due to the requirement of a larger readout matrix. Imaging parameters were as follows (Non-SIR/SIR): TR = 8300/5500 ms, TE = 81/96 ms, EPI echo spacing = 0.81/1.14 ms, b-value = 1000 s/mm^2, FOV = 210 x 210 mm^2, matrix = 96x 96, in-plane resolution = 2.2 x 2.2 mm^2, slices = 72, slice thickness = 2 mm, GRAPPA = 2, averages = 4. The actual readout matrix size for the SIR sequence is 192, which is then cut into two sets of 96 points each. Data were analyzed by measuring SNR in the images. In 2 subjects, multidirectional diffusion data were acquired with conventional and SIR EPI to compare the ADC, FA, and Trace weighted images.

Results

The data acquired during one readout gradient is shown in Fig. 2. There are two distinct echoes that are formed at t=(duration of Gr)/4 and 3x (duration of Gr)/4, which are symmetric about the center. A comparison of the non-SIR and SIR trace, ADC, and fractional anisotropy (FA) maps are shown in Fig. 3 and Fig. 4. The image quality is equivalent with SIR and non-SIR. Although increased spatial distortions are expected in the SIR data, they were not apparent. The total imaging times for the non-SIR and SIR sequences were 2:38 min. and 1:45 min. respectively, which represents a total time savings by a factor of 1.5. The SNR comparison shows that there is an approximate 10% reduction in SNR with SIR as compared to conventional EPI (15.13±1.06 vs. 16.58±0.93), which is expected, due to a longer TE. Considering the overall time savings and resulting higher SNR efficiency (SNR per unit time) with SIR, this may be an acceptable compromise.

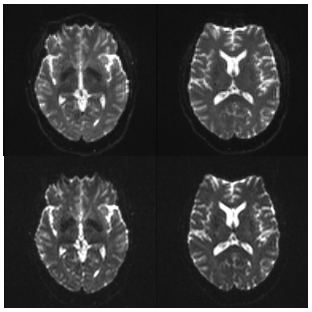

Figure 3. Multiple slices acquired using a non-SIR (top row) and SIR acquisition (bottom row). Image quality is comparable between non-SIR and SIR techniques despite a 1.5x savings in imaging time with SIR. Note that the spatial distortions are quite similar, even in inhomogeneous areas of the brain

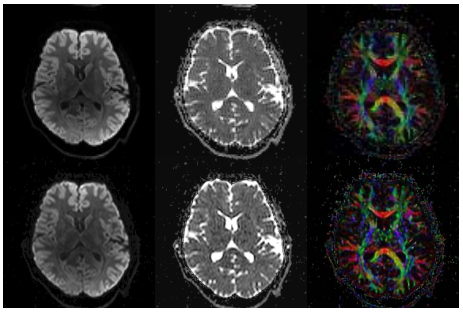

Figure 4. Comparison of Trace weighted images, ADC, and FA maps using a non-SIR (top row) and SIR (bottom row) acquisition. The image quality is comparable between the non-SIR and SIR techniques.

Discussion

Results showed that the image quality using the SIR sequence was comparable to the conventional EPI, non-SIR sequence. SIR provided a 1.5 times acceleration as compared to the conventional EPI sequence. The gradient and RF efficiency are also increased with SIR since we now sample twice the number of slices for every set of diffusion gradients and inversion pulses. One of the potential limitations of SIR may be in very high spatial resolution DWI, where doubling of the readout matrix that is necessary to maintain resolution may make the echo spacing prohibitively long but can be shortened by parallel imaging. Recent advances such as readout segmentation[5] may be combined with SIR EPI to reduce the echo spacing and keep it low even for high-resolution applications.

Conclusion

We have reduced the scan time in diffusion weighted imaging by a factor of 1.5 with a compromise in spatial distortions and a small penalty in SNR. The increase in efficiency could be used for shortening scan times, for additional slices and increased spatial coverage, or higher angular diffusion resolution.

References:

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4. Zaitsev M, et al. MRM 52(5) 1156-66, 2004. 5. Porter DA, Heidemann RM. MRM 62(2) 468-75, 2009.