Halving Imaging Time of Whole Brain Diffusion Spectrum Imaging (DSI) Using Simultaneous Echo Refocusing (SER) EPI

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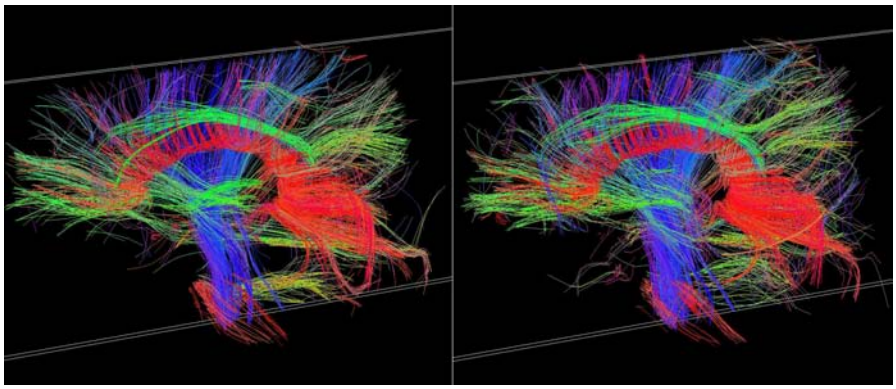
DSI of the brain promises the visualization of neural connectivity previously unattainable by noninvasive means [1]. Previously, DSI has been limited to use with cooperative and motivated volunteers due to the long study times required, typically 20 to 30 minutes. These long scan times are both due to the need for hundreds of diffusion encoding axes at high b-values in DSI and the need for full brain coverage. Here we present a method for reducing the total scan time by nearly one half to a clinically reasonable 11 minutes, while still satisfying the anatomic and encoding requirements of DSI.

Methods and Results: The present study uses the SER method [2] to double the number of images acquired in a single echo planar (EPI) echo train. SER time-multiplexes and simultaneously refocuses the signal from two adjacent slice planes in a single EPI echo train. When the data is reconstructed, each half of the acquired k-space data is transformed into a complete image of the corresponding slice. Since each diffusion encoding generates two slices, this provides a data acquisition rate of nearly twice that of a conventional single-shot diffusion encoded EP acquisition.

Two identical studies were completed, comparing conventional single-slice EPI DSI and SER-EPI DSI. A normal volunteer was scanned with informed consent, using an eddy current insensitive diffusion gradient pulse scheme [3] in a spin echo EPI pulse sequence with and without modifications for SER DSI, and a standard protocol. The data was collected using a Siemens Allegra scanner (Siemens Medical Systems, Erlangen, Germany) with maximum gradients of 40 mT/m, 2.5 us/(mT/m) slew rate, and a standard quadrature RF head coil. The imaged volume covered the whole brain at isotropic 3.2 mm resolution, with a 64x64 image matrix. 30 conventional EPI slices were acquired in 20 minutes and 15 SER-EPI double slices in 11 minutes, both using 258 diffusion encoding values with a maximum b = 8500 sec/cm^2. The TE/TR of conventional DSI was 126/4600 ms, and SER DSI was 139/2600 ms. In both cases, the readout time was minimized according to the sampling and gradient capabilities of the scanner. Magnitude images resulting from the two methods were remarkably similar, only being distinguishable by slightly different contrasts and intensity. At b = 0, SNR of the conventional DSI was 35:1, and the SER DSI was 30:1. Diffusion tractographs (see figure) were produced offline from the two sets of data using the methods

Discussion: Comparison of the source images and tractographs from the two methods showed matching quality and detection of white matter tracts, differing only in the time required for acquisition. Observable differences can be attributed to differing relaxivity contrast between the scans (due to differences in TE and TR).

SER retains EPI's single-shot phase coherence, vital at high b-values, while doubling the amount of information per acquisition. The SER technique significantly impacts MRI techniques like DSI which require a long encoding time compared to the total signal sampling time. In general, as the ratio of sampling time to encoding time of a specific technique increases, its efficiency increases. With the time of the EPI readout train small compared to the diffusion encoding time, expanding the readout to accommodate an addition echo is practically free as a percent of total scan time; in the present example SER increases the TE from 126 ms by only 13 ms. This longer TE and additional readout time of SER does increase susceptibility artifact; slightly increased distortion around the frontal lobe could be detected in these SER DSI source images, but the resulting tractographs were unaffected. Parallel imaging techniques could be used to reduce susceptibility artifacts by shortening the echo period, however, they may not have nearly the impact as SER-EPI in reducing DSI scan time as they cannot change the one-to-one relationship between long diffusion encoding periods per slice, while in SER this ratio is effectively halved. Increased "SER factor" with 3 or more slices per diffusion encoding could also be considered and optimized, and may be appropriate for accelerated multicoil acquisitions.



Tractographs; (right) conventional multislice DSI, 20 min. scan (left) SER DSI, 11 min. scan. Fibers are greater than 6 mm in length, incident on a 6 mm sagittal slab.

While the total acquisition time has been nearly halved, the difference in clinical acceptance between a 20 minute scan and an 11 minute scan is much more significant. At 11 minutes, the DSI scan could be reasonably included in a routine clinical scan without great hardship to the patient or an unacceptable increase in total exam time. The SER method can be similarly advantageous to any high-b diffusion MRI. Additional speedup is forthcoming; using a new body-centered cubic table [4] in which the number of encoding steps can be reduced by 25%, reducing the present SER DSI scan time to 8 minutes. SER DSI can be combined with new encoding techniques and multicoil hardware to further shorten total scan time, extend coverage, or improve resolution according to specific diagnostic needs.

Conclusion: SER-EPI has produced 3D DSI images of the whole brain in 11 minutes, a 45% time reduction from prior techniques. This step to reduce the scan time of DSI enables the incorporation of DSI imaging into routine use and clinical protocols.

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