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Inherent eddy current compensation for high-resolution DTI using bipolar diffusion gradients

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Introduction:

Clinical diffusion-weighted imaging (DWI) often employs a single-shot echo-planar imaging (EPI) readout to increase acquisition speed. This comes at a cost, however, since conventional DWI sequences employ a spin echo (SE) sequence with either unipolar or bipolar diffusion-sensitizing gradients on both sides of the 180º refocusing pulse. This configuration shortens the separation between strong diffusion gradient pulses and the EPI readout and forces partial k-space acquisition. The close proximity of strong diffusion gradients and the EPI readout increases direction dependent eddy current artifacts . while the reduction in k-space coverage decreases SNR. Here we propose a novel single-sided bipolar (SSBP) SE DWI sequence that reduces this eddy current artifact and improves SNR by separating diffusion-sensitizing gradients from the EPI readout and acquiring full k-space EPI data with reduced TE as compared to a conventional twice-refocused spin echo (TRSE) diffusion preparation DWI technique [1].

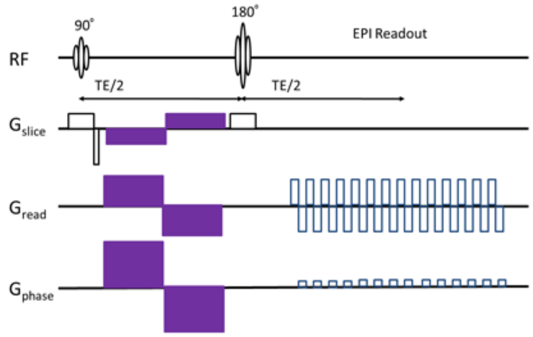

Fig. 1: Pulse sequence diagram for high-resolution DTI using an single-sided bipolar (SSBP) diffusion preparationwith full k-space EPI readout.

Materials and Methods:

Healthy volunteers were scanned on a commercial GE 3T MR750 scanner using the newly developed SSBP-DWI and the TRSE-DWI sequences with the same scan parameters: 20 slices with 5mm slice thickness, a 220x220 mm^2 FOV with 192x192 imaging matrix, TE=92ms, TR=10s, parallel imaging (2x acceleration), b=800 mm^2/s, 20 directions and echo spacing of 944s. The echo train length was 96 for SSBP-DWI and 64 for TRSE-DWI.

Results:

Our preliminary results indicate that, using SSBP diffusion preparation, it is possible to obtain high-resolution images with superior SNR and significantly reduced eddy current distortions compared to the TRSE-DWI. In the SSBP-DWI baseline (non-diffusion weighted) images, the SNR was 8.7% higher than in the corresponding TRSE-DWI image, due to the use of full k-space acquisition in SSBP-DWI. More importantly, SSBP-DWIs showed virtually no eddy current distortion while the TRSE-DWIs exhibited prominent residual eddy current distortion at the periphery of the brain (Fig. 2), most likely due to the imperfect eddy current compensation, which assumes a mono-exponential decay. In addition to reducing eddy current distortion due to the bipolar nature of the diffusion-sensitizing gradients[2], SSBP-DWI separates strong diffusion gradients and the EPI readout without increasing TE. It is important to note that for large b-values, SSBP-DWI requires longer TEs as compared to TRSE-DWI, potentially resulting in lower SNR. However, this issue can be resolved with availability of stronger gradients.

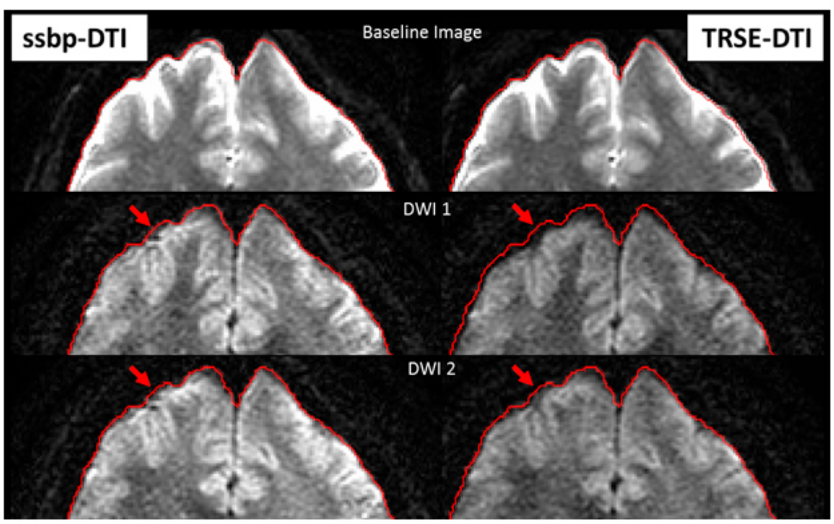

Fig. 2: High-resolution images acquired with SSBP-DTI (left column) have higher SNR and reduced eddy current artifacts compared to the conventional TRSE-DTI technique (right column).

Discussion:

To minimize off-resonance distortions from static B_0 field inhomogeneities, the full k-space EPI readout duration (and implicitly TE) can be further reduced e.g., by using parallel imaging. Unlike the conventional EPI-DWI sequences with partial k-space acquisition, the proposed method does not suffer from signal loss artifacts associated with direction dependent eddy current, which generally lead to underestimation of FA and overestimation of mean diffusivity. SSBP DWI should become more feasible in the clinic, particularly as gradient hardware improves, i.e., gradient strength and slew-rate increase.

Conclusion:

The single-sided bipolar DWI spin echo sequence[3] with a single-shot EPI readout promises improved accuracy of estimation of diffusion properties, both in terms of eddy current compensation and increased SNR, particularly in high-field MRI systems with high-performance gradients.

Bibliography:

[1] Reese et al., MRM 2003;49:177-182; [2] Alexander et al., MRM 1997;38(6):1016–1021;[3] Freidlin et al., JMR 2012;221:24-31;