Crusher Gradient Reversal to Eliminate Stimulated Echo Artifacts in Dual Spin Echo Diffusion MRI

G. Wu[1], S. Lee[1], X. Zhao[1], and Z. Li[1]
[1]GE Healthcare, Waukesha, WI, United States

Introduction

The dual spin echo (DSE) technique is to reduce eddy-current-induced distortion in diffusion MRI by applying two refocusing RF pulses after the excitation RF pulse adjusting the timing of diffusion gradients(1). DSE is a train of three RF pulses, and a stimulated echo could be formed after the second refocusing RF pulse, which is unwanted signal in diffusion imaging. Increasing the crusher gradients before and after the refocusing pulses is a usual way to kill the stimulated echo signal. However, this method is not always effective for diffusion MRI, especially when diffusion gradients are applied to the three gradient axes simultaneously, such as using the tetrahedral gradient configurations(2). Besides the crushers before and after the refocusing pulses, diffusion gradients play a role of crusher too. These two kinds of crushers could cancel out each other on all three axes, and cause not enough crusher gradient amount to kill the stimulated echo signal. This effect becomes harder to avoid by adjusting the area of the pre-180° and post-180° crushers when multiple b-values are used within a single scan. In this work, a crusher gradient reversal method is proposed to overcome the stimulated echo artifacts in DSE diffusion MRI. By reversing the crusher gradients according to the polarity of the diffusion gradients, we were able to make the crusher gradients and diffusion gradients always add up together, instead of cancelling out, so that there are enough crushers to kill the stimulated echo signal.

Methods

Fig. 1 shows the slice direction gradients (Z) in a DSE diffusion MRI. S1, S2 and S3 are the slice selection gradients for the excitation, 1^{st} refocusing, and 2^{nd} refocusing RF pulses, respectively. C1-4 are the crusher gradients before and after the two refocusing pulses and D1-4 the diffusion gradients. There could be C1-4 and D1-4 on the readout (X) and phase-encoding (Y) directions too. Table 1 shows the total crusher amount that a stimulated echo experiences (S1-3 ignored here) on X, Y, and Z directions for each tetrahedral gradient configuration. The tetrahedral configurations are represented with the polarity of diffusion gradient D1. The crusher amount on X, Y, and Z could be all very small. For example, if the crusher gradients on Z are set as C3=C4=2*C2≈2*C1, on X and Y as C3=C4=0, and if |D1|+|D4| is very close to |C1| with a given b-value, the total crusher amount for the tetrahedral configuration (-, -, +) could be very small on all X, Y, and Z directions, so that there are not enough crushers to kill the stimulated echo signal.

To avoid canceling out between the crusher gradients and the diffusion gradients, the proposed method is to reverse the polarity of the crusher gradients (C1-4) with the following logic: if polarity of C1is opposed to that of D1, reverse C1 and C2, otherwise, reverse C3 and C4. With this logic, the crusher amount on X, Y and Z directions for all the four tetrahedral gradient configurations will become |D1|+|C1|+|C4|+|D4|, and the goal to kill the stimulated echo signal could be achieved no matter how b-values are prescribed.

Experiments were conducted on a GE MR750 3T scanner (Milwaukee, WI). A single-shot, DSE diffusion EPI sequence with tetrahedral gradient configurations was used to acquire data. Imaging parameters were as follows: scan plane = Axial, FOV = 24cm, slice thickness = 5mm, slice spacing = 0, readout direction: right-left, matrix = 128x128, TR = 6s, TE = min (82.3ms), ramp sampling: ON, 4 b-values (10, 20, 30, 1000 s/mm^2). Volunteers were recruited and scanned with informed consent.

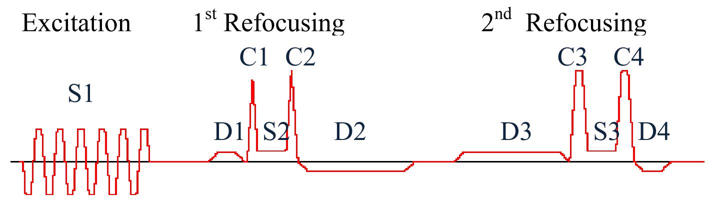

Fig. 1 Slice direction gradients (Z) in a DSE diffusion MRI

Table 1 Total crusher amount that a stimulated echo experiences on X, Y, and Z directions for each tetrahedral gradient configuration

<table>
<tr><th>Tetrahedral configuration (X, Y, Z)</th><th>Crusher amount on X</th><th>Crusher amount on Y</th><th>Crusher amount on Z</th></tr>
<tr><td>(+, +, +)</td><td>||D1|+|C1|-|C4|+|D4||</td><td>||D1|+|C1|-|C4|+|D4||</td><td>||D1|+|C1|-|C4|+|D4||</td></tr>
<tr><td>(+, -, -)</td><td>||D1|+|C1|-|C4|+|D4||</td><td>|-|D1|+|C1|-|C4|-|D4||</td><td>|-|D1|+|C1|-|C4|-|D4||</td></tr>
<tr><td>(-, -, +)</td><td>|-|D1|+|C1|-|C4|-|D4||</td><td>|-|D1|+|C1|-|C4|-|D4||</td><td>||D1|+|C1|-|C4|+|D4||</td></tr>
<tr><td>(-, +, -)</td><td>|-|D1|+|C1|-|C4|-|D4||</td><td>||D1|+|C1|-|C4|+|D4||</td><td>||D1|+|C1|-|C4|-|D4||</td></tr>
</table>

Results and Discussion

Fig. 2 shows images from the (-, -, +) tetrahedral configuration. Top-row images were acquired with the regular DSE diffusion EPI and bottom-row images with the proposed crusher gradient reversal diffusion EPI. The b-value of left-column images was 10 s/mm^2 and right-column 20 s/mm^2. With the regular DSE, periodic line artifacts are seen. Either changing C1 and C2 or C3 and C4 could remove these artifacts. This indicates these artifacts are due to stimulated echo. No stimulated echo artifacts were seen on images for b-value = 30 s/mm^2 and 1000 s/mm^2. In a multi-b-value scan, the amplitude of diffusion gradients is determined as approximately proportional to the square root of b-value. With some certain b-values, it is possible the total crusher amount that are combination of the diffusion gradients and the crusher gradients becomes not enough to kill the stimulate echo signal, as described in the previous section.

As shown at the bottom row in Fig 2, the stimulated echo artifacts could be eliminated by the proposed crusher gradient reversal method. The crusher gradient reversal method allows the diffusion gradients and the crusher gradients to be added up, and kills the stimulated echo signal universally and not specific to some certain b-values. Since the crusher gradient reversal method does not need to change the area of crusher gradients, the sequence performance, such as minimum allowed TE, is not impacted.

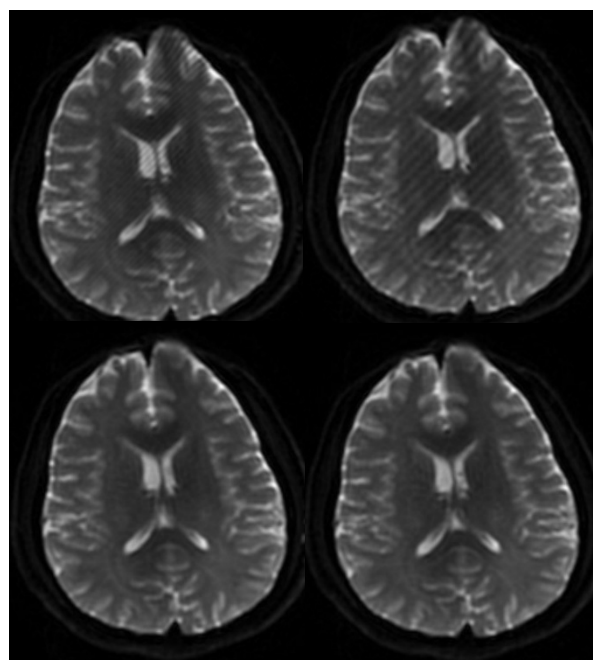

Fig 2 Stimulated echo artifacts (top row) and removal using crusher gradient reversal (bottom row). Left column is for b-value=10 s/mm^2, and right for b-value=20 s/mm^2.

Conclusion

Reversing the polarity of crusher gradients per that of diffusion gradients could effectively overcome the stimulated echo artifacts in dual spin echo diffusion MRI. The artifact removal is not specific to certain b-values and does not impact the sequence performance.

References 1. Reese TG *et al*, MRM 49:177-182 (2003). 2. Contouro TE *et al*, MRM 35:399-412 (1996).