How to avoid artifacts from the FID of the first RF pulse in a twice-refocused spin-echo diffusion-weighted sequence

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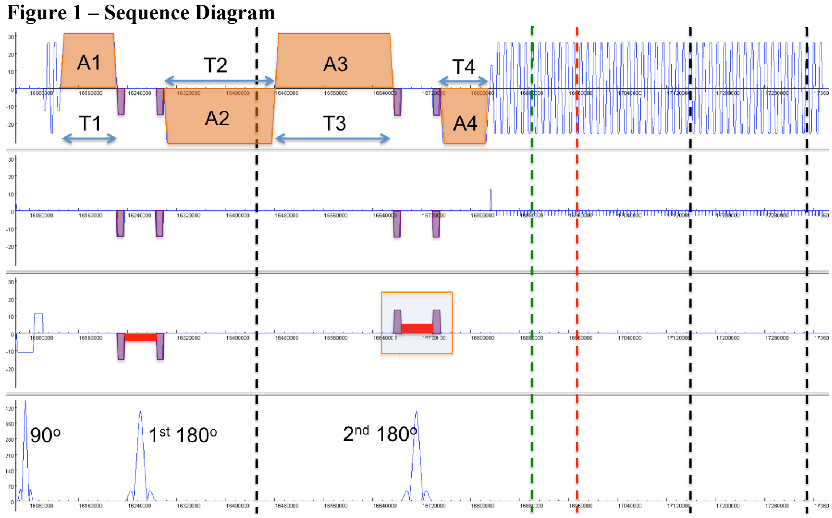
Introduction:

Pulse sequences for MR imaging which contain more than a single RF pulse result in an increasing number of possible signal pathways **(1)**. The twice-refocused spin echo sequence (TRSE) (2), commonly used for diffusion tensor imaging (DTI) (Figure 1), contains 3 RF pulses (1 excitation pulse and 2 refocusing pulses) and can result in 3 FID signals (1 from each RF pulse), 3 Spin echoes (combination of any 2 of the three RF pulses), 1 stimulated echo and 1 twice-refocused spin echo. Detection of the echoes depends both on the RF pulse timing as well as the cumulative gradient moment that a given pathway experiences. As such, pathways can result in unwanted artifacts (3), but can be dealt with by proper timing of the diffusion gradients (4). The adequate size(s) of the crusher gradients (purple trapezoids in Fig 1) can be easily calculated from theory (1) and usually it is enough to implement them on a single gradient axis. The situation becomes more complicated when diffusion-encoding gradients are introduced because they can off-set the effect imparted by the crushers (i.e. diffusion gradients can act simply as large crushers) (5). Note that in Fig. 1 crushers are implemented on all 3 gradient axes. An added complexity of the TRSE sequence is that the gradient moments for the 1st diffusion gradient (A1) does not have to cancel that of the 4th diffusion gradients (A4) and A2 does not have to cancel A3. In other words, while the moments add up to zero for the main twice-refocused spin echo they usually do not for any other coherence pathway. Unless care is taken the crusher gradients might be cancelled out by the non-zero moment of the diffusion gradients resulting in unwanted echoes. This problem is more likely to occur when implementing the slice-select gradient reversal (SSGR) fat suppression in TRSE (5). The aim of this work was to investigate and establish how the spoiler gradients should be implemented TRSE DWI sequence wih SSGR fat suppression.

Figure 1 – Sequence Diagram



*X gradient (top), Y gradient (2nd row), Z gradient (3rd row) and RF (bottom row).The occurrence of the different echoes is indicated by vertical lines: **black** for the 3 spin echoes, **red** for the main twice-refocused spin echo and **green** for the stimulated echo. The lengths of the diffusion encoding gradients are T1, T2, T3 and T4 while their areas are A1, A2, A3 and A4 as indicated in **orange**. Crusher gradients indicated in **purple** and slice select in **red**.*

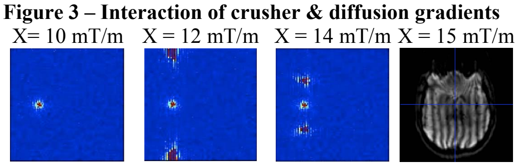
Methods:

Written informed consent was obtained from the subject prior to examination. <u>MRI Data Acquisition</u>: All multi-slice EPI data was collected with bipolar readout gradients on a 3 T scanner (Tim Trio, Siemens) using a 32-channel receive only head coil, TE of 90 ms. In *Experiment 1* we investigated the residual amplitude of the different echo pathways after crushing by selectively turning off 1 or 2 of the RF pulses on a gel phantom. We were primarily interested in only those pathways that could cause the twice-refocused spin echo or FID during the acquisition window. See text in Fig. 2 for more details. In *Experiment 2* we investigated the interaction of the spoiler gradients and the diffusion encoding gradients on both a gel phantom and a human volunteer. Based on the results of the first experiment we chose to have alternate polarity for the X & Y spoilers in two variants: in one the X crusher was set at -15 mT/m and the Y crusher varied 10–20 mT/m and vice versa. See text for Fig. 3 for details.

Results:

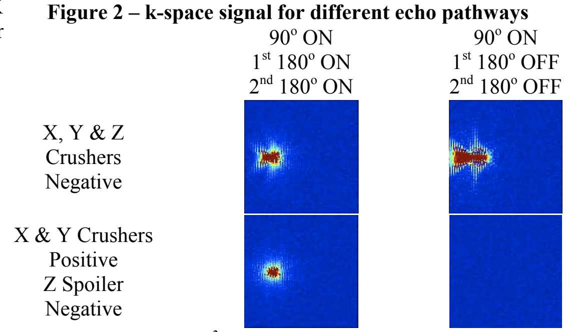
If the crushers are inverted on all three axes both the main spin echo and the FID signal from the 1st RF pulse appear in b0 images (Fig. 2). In DWIs this unwanted FID is crushed out by the non-balanced diffusion gradients of the TRSE scheme. Fig. 3 shows the results of experiments where the X crushers are positive while the Y crushers are negative. Since the TRSE algorithm does not require that the 1st and the 4th diffusion gradient lengths be identical (and in our case A1 > A4), the stimulated echo pathway can be crushed adequately. Only 1 spin echo occurs during the acquisition window. Finally, the FID signals from the 2 refocusing RF pulses do not appear during the acquisition window because they see a non-zero gradient moment from the diffusion encoding (orange trapezoids) and crusher (purple trapezoid) gradients. Leaving only the FID from the 1st RF pulse and the main spin echo.

Figure 3 – Interaction of crusher & diffusion gradients



Crusher gradient amplitude along Z & Y axes = -15 mT/m, while along X it is varied. First 3 sub-figures display invasion of k-space amplitude data by the FID signal from the 1st RF pulse. NOTE, the alternate lines of the k-space data have not been time reversed. For the X gradient amplitude > 17 mT/m the artifactual signal gradually leaves the acquisition window.

Figure 2 – k-space signal for different echo pathways



Imaging b = 0 s/mm² for all acquisitions. The slice select gradient and the spoiler gradients were inverted for the 2nd refocusing RF pulse (see shaded rectangle in Fig. 1) to achieve SSGR fat suppression. Left column = main spin echo, right columns = FID of 1st RF pulse.

Discussion:

In the TRSE sequence, gradient areas A1 and A4 and areas A2 and A3 need not cancel and the FID signal pathway is crushed out in DWIs. However, unless care is taken the crusher gradients, implemented to annihilate exactly that spurious FID signal, might be cancelled out by the non-zero moment of the diffusion gradients. The cancellation between crusher and resultant diffusion gradient moments depends on the b-value, TE, the gradient amplitudes, eddy current decay time and hence cannot be solved easily in general. One possibility would be to always use crushers that are orthogonal to the diffusion encoding direction which is our subject of future work.

References: (1) Hennig (1991) Concepts in Magnetic Resonance Vol. 3:125-143 (2) Reese et al. (2003) MRM Vol. 49:177-182; (3) Wu et al. (2010) Proceedings of ISMRM Abstract #1964; (4) Feiweier et al. (2010) Proceedings of ISMRM Abstracdt #178; (5) Nagy et al. (2008) Magnetic Resonance in Medicine Vol. 60:1256-1260

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