Minimizing Diffusion Encoding of Slice Selection in Stimulated Echo Imaging

Paul Kinchesh[1], Michiel Kleinnijenhuis[2], Karla L Miller[2], and Sean Smart[1]

[1]*Department of Oncology, University of Oxford, Oxford, United Kingdom,* [2]*FMRIB Centre, Nuffield Department of Clinical Neurosciences, University of Oxford, United Kingdom*

Target Audience: MRI community performing diffusion weighted imaging with high *b*-values and long diffusion times.

Purpose: Diffusion weighted imaging (DWI) using very high *b*-values and long diffusion times (Δ) typically uses the stimulated echo (STE) in order that large diffusion encodings can be produced without incurring excessive T_2-related signal loss. For long Δ a significant bias can be introduced through the diffusion encoding effect of the slice selection gradients that are typically used in multi-slice implementations of the STE scheme. Compensation of this effect has recently been achieved by adjustment of the prescribed diffusion encoding gradients [1], but the nature of the adjustment is specific to the exact choice of experimental parameters. In this report we show that the effect can simply be minimized through reduction of the diffusion encoding effect of the slice selection gradients themselves, as often implemented in STEAM MRS, thus providing a more straightforward method for maintaining suitable control over the applied diffusion encoding scheme.

Methods: MRI was performed at 9.4 T (Varian VNMRS) using a 25 mm ID quadrature birdcage coil (Rapid Biomedical). A conventional DW-STE imaging sequence was modified to replace the pre and post crushing gradient pulses before and after the 2nd and 3rd RF pulses, respectively with integrals as per conventional refocussing of the slice selective gradient used for excitation pulses (Fig. 1). The effect is to ensure that there is minimal phase accumulation in the slice direction that results in additional, unwanted diffusion weighting. The scheme results in a refocused FID signal derived from the 3rd RF pulse. This FID is eliminated in the diffusion weighted scans due to the crushing effect of the 2nd diffusion encoding gradient pulse. Low *b*-value (nominal b = 0) scans are performed with a very low diffusion weighting (b ~ 100 s/mm^2 for Δ = 400 ms) such that there is sufficient diffusion gradient moment to crush the FID signal. This was confirmed by the absence of signal when running the STE sequence with the first RF pulse (RF_1) turned off. The performance of the modified scheme was verified with an agar gel phantom and post mortem human brain tissue.

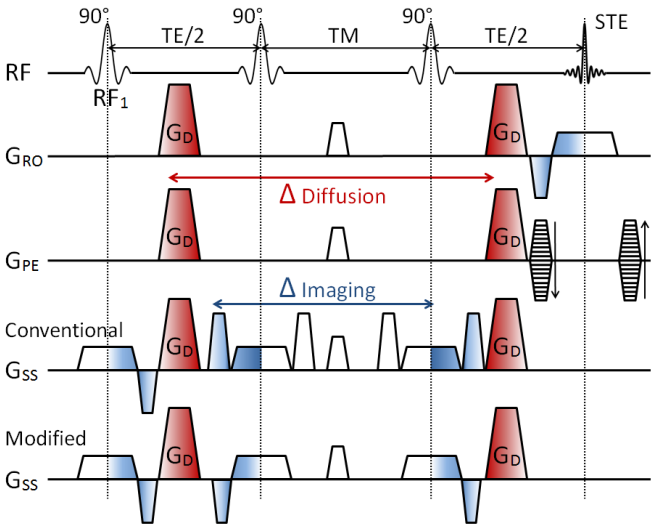

Fig. 1. Conventional and modified DW-STE imaging sequence.

Results: Fig. 2 shows DW-STE profiles of an agar gel phantom with G_D aligned parallel and antiparallel to G_{SS} for the conventional and modified DW-STE imaging sequence. Fig. 3 shows low *b*-value DW-STE images of post mortem human brain tissue using the modified scheme.

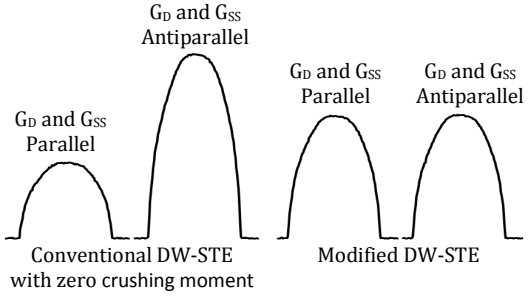

Fig. 2. Uniformly scaled DW-STE profiles of agar gel phantom. δ = 2.22 ms, Δ = 50 ms and G_D = 169 mT/m applied parallel and antiparallel to G_{SS}. Nominal b = 500 s/mm^2, slice thickness 1 mm, RF pulse durations 1 ms.

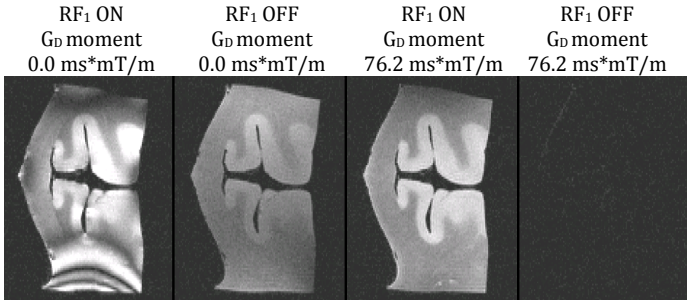

Fig. 3. Uniformly scaled DW-STE images of post mortem human brain tissue. Slice thickness 400 µm In-plane resolution 400 µm × 400 µm.

Discussion: Fig. 2 clearly demonstrates the reduced diffusion encoding of the G_{SS} imaging gradient prescription in the modified DW-STE scheme with respect to the conventional scheme. Fig. 3 demonstrates that a low *b*-value scan (b = 66 s/mm^2 in the slice selection direction and b = 56 s/mm^2 in the readout and phase encode directions for Δ = 400 ms) in the modified scheme has sufficient gradient moment (76.2 ms*mT/m) to crush the FID signal. For high *b*-value long Δ DTI, δ = 2.22 ms, Δ = 400 ms and G_D = 231 mT/m represent typical values, giving a nominal *b*-value = 7515 s/mm^2. When applied parallel and antiparallel to G_{SS} the *b*-values in the slice selection direction of the conventional sequence with zero crushing gradient moment were 13376 s/mm^2 and 3359 s/mm^2 respectively. For the modified sequence the corresponding *b*-values were 7556 s/mm^2 and 7483 s/mm^2. The vastly increased disparity exhibited by the conventional sequence is entirely due to the diffusion encoding of the slice selection gradients themselves, and is very simply minimized in the modified scheme.

Conclusion: A simple modification to the standard DW-STE scheme enables near-complete elimination of the diffusion weighting derived from the G_{SS} imaging gradients, thereby maintaining the fidelity of the magnitude and direction of any applied diffusion encoding scheme. As such, the modification obviates the need for complicated compensation of the applied diffusion encoding scheme and simplifies calculation of the full *B*-matrix when it is required for robust derivations of diffusion metrics.

Reference: 1. Lundell H, Alexander DC, Dyrby TB. High angular resolution diffusion imaging with stimulated echoes: compensation and correction in experiment design and analysis. NMR Biomed. 2014; 27: 918–925.