Use of Gradient Crushers on Multiple Axes for Diffusion Imaging of Thin Slices with Reduced TE

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Introduction:

Diffusion weighted imaging (DWI) is commonly used in clinical settings for diagnosis and characterization of cerebral ischemia, as well as for visualizing the structure of the white matter tracts. Dual spin echo (DSE) is often employed with DWI to reduce eddy-current induced image distortions. In order to maintain image quality of DWI at the thinner slices, it is important to apply gradient crusher pulses of adequate area around the 180 degree pulses to crush any free induction decay (FID) or stimulated echoes with DSE. Because the slice select direction (Z axis) typically has the largest voxel dimension, crushers applied along this dimension are the most efficient for most clinically relevant protocols. However, for thin slice protocols, slice select crushers with large areas are required. The increased gradient crusher area produces an increase in TE. This abstract describes a method of maintaining adequate crushing strength with a smaller impact on TE by applying the crusher pulses on all axes simultaneously.

Methods:

Figure 1A shows a typical DSE diffusion weighted EPI sequence with a slice thickness of 5 mm. For simplicity, this work will focus on DSE diffusion weighted EPI sequences, but the same effect can be seen with single spin echo techniques. Note the presence of crushers around both 180 degree RF pulses on the Z gradient axis. Note also that the left hand crusher lobe is bridged with the slice select refocusing gradient. We can calculate the phase dispersion, ϕ caused by the crusher gradient. Calling the area under the crusher, A, we have $\phi = A\gamma\Delta x$, where Δx is the slice thickness and γ is the gyromagnetic ratio. So for a 5 mm slice with A = 2500us*G/cm, we have ϕ = 2500us*G/cm*2*π*4257Hz/G*0.5cm = 33.4 radians. According to Hennig [1], in order to generate adequate crushing of unwanted magnetization, the minimum phase dispersion within a voxel should be ~4π radians. As the slice thickness decreases, the amplitude of the left hand crusher lobe decreases in order to maintain the necessary slice select refocusing (Figure 1B: Δx = 1 mm). For the same crusher gradient amplitude, a thinner slice produces proportionally less phase dispersion. For example, a 1 mm thick slice with the same gradient area would produce just 6.7 radians of phase dispersion. To generate adequate phase dispersion for a 1 mm slice thickness, the gradient area would have to be more than doubled. Assuming constant gradient amplitude, the TE must increase.

Fortunately, for thin slices the voxel becomes more isotropic. Because of this, application of crushers along the X and Y axes becomes as effective as the Z axis crushers. To demonstrate this, let us assume a 256 mm FOV scan with a 128X128 imaging matrix. The phase dispersion from a 2500us*G/cm area crusher on the X or Y axis is 2500us*G/cm*2*π*4257Hz/G*0.2cm = 13.4 radians. This phase dispersion is double the dispersion introduced by the Z crusher for 1 mm thick slice.

A modification was made to the sequence to apply crushers of identical gradient area along the X, Y, and Z axes simultaneously (Figure 1B with the inclusion of the black trapezoids on the X and Y axes. For an isotropic voxel, a factor of 3 increase in the phase dispersion can be achieved with this technique with no increase in TE.

Data were acquired on a 1.5 T and 3.0 T TwinSpeed systems (GE Healthcare Technologies, Waukesha, WI) with a standard transmit/receive head coil. Initial studies were performed with NiCl doped spherical phantoms to demonstrate the effect of inadequate crushing, and the benefit of implementing the crusher gradient on all three axes. Following informed consent, volunteers were scanned to confirm these results.

Results:

Figure 2A shows the coronal reformat of 1.6 mm thick axial slices acquired with the pulse sequences in Figure 1B (without black trapezoids). The insufficient crushing of the 1.6 mm acquisition is shown by the banding artifact in the reformatted images. With the addition of identical crushers on the X, Y, and Z axes (Figure 1B with black trapezoids), the banding artifact is removed, as seen in Figure 2B. The acquisitions used to obtain Figures 2A and 2B had an identical TE of 78.7 ms. Similar results were seen *in vivo*. Figure 3A was obtained with 2.6 mm slices with a Z axis crusher alone, while Figure 3B was obtained with crushers applied to all axes, resulting in the elimination of the banding artifact.

Discussion and Conclusion:

The use of DWI with thinner slices has risen with the higher SNR afforded by higher magnetic field strength MR systems. With thin slice diffusion imaging, this work demonstrates the benefit of applying the gradient crushers on all three axes to produce a reduction of TE. By implementing this technique, adequate crushing is generated with reduced TE relative to single axis crusher.

References:

[1] Hennig, JMR 78:397-407, 1988.

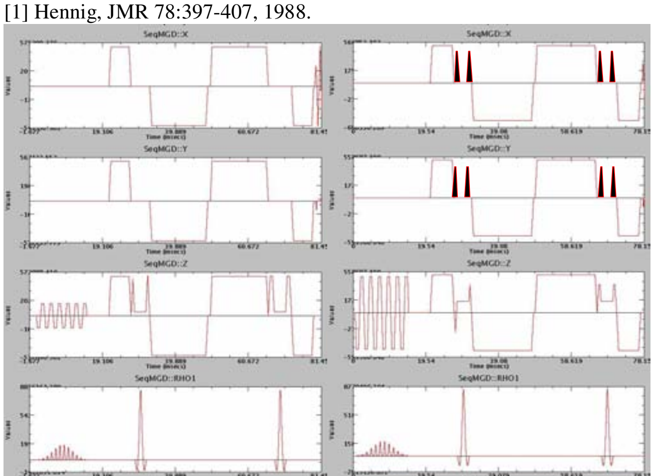

Figure 1A Figure 1B

Figure 1: Pulse sequence diagrams for dual spin echo diffusion weighted EPI sequences with slice thicknesses of (A) 5 mm and (B) 1 mm. The black trapezoids represent additional crushers introduced on the X and Y axes. Readout gradients are not shown.

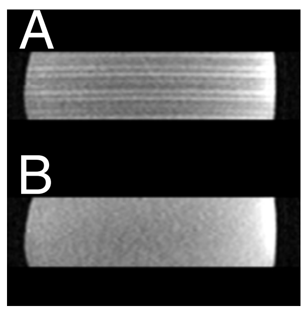

Figure 2: Coronal reformats of axially acquired diffusion weighted images with slice thickness of 1.6mm with crushers on Z axis only (A) and on all axes (B). Both were acquired with TE of 78.7 ms.

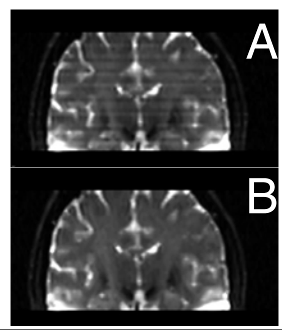

Figure 3: Coronal reformats of *in vivo* axially acquired images with slice thickness of 2.6 mm are shown with crusher on the Z axis alone (A) and with crushers applied to all 3 axes (B). The additional crushers eliminate the banding artifact.