Spectral-Spatial Long-T_2 Suppression Pulses for Multislice UTE Imaging

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Introduction

Tissues with sub-millisecond T_2 values can be directly observed with ultra-short echo time (UTE) imaging [1]. Long- T_2 suppression enhances the contrast of the short-T_2 species that are often obscured or outnumbered. We have recently introduced improved long-T_2 suppression pulses [2,3]. However, the performance of these pulses is suboptimal in interleaved multislice imaging because they are only spectrally selective and applied once per TR, causing T_1 recovery to compromise the suppression in later slices. In this work, we have developed spectral-spatial versions of these long-T_2 suppression pulses for interleaved multislice 2D UTE imaging.

Methods

First, a long-T_2 suppression pulse is designed with a limited number of samples. A single-band pulse, only suppressing water long-T_2 species, or a dual-band pulse, with an additional fat suppression band, can be used. The pulse samples are used to scale the amplitudes of spatial subpulses, designed with the SLR algorithm. An alternating slice-select gradient accompanies the subpulses, resulting in spatial selectivity [4,5].

The suppression pulses are applied before a UTE half-pulse excitation and a radial readout. One slice is acquired after each spectral-spatial suppression pulse, spatially shifted appropriately, and the acquisitions are spaced evenly within the TR. In contrast, when a spectral suppression pulse is used, all slices are acquired immediately after excitation to minimize T_1 recoverysince it is applied once per TR to minimize short-T_2 signal loss. 7 interleaved slices were acquired with TR = 500 ms, TE = 80 µs, 1 mm resolution, 5 mm slice thickness and a 60° flip angle on a GE 1.5T scanner.

Results

The RF and gradient waveforms of a 20 ms single-band spectral-spatial suppression pulse with 1 ms subpulses, as well as simulated spectral-spatial and T_2 profiles, are shown in figure 1. Figure 2 shows a 25 ms dual-band spectral-spatial suppression pulse, using 0.5 ms subpulses, and its profiles. Both pulses were designed for a 1 cm slice thickness, shown in the spectral-spatial profiles, and their T_2 profiles are nearly identical. The effect on out-of-slice short-T_2 species is negligible. RF amplitude constraints are not an issue because the suppression pulse envelopes are very low amplitude.

The phantom images in figure 3 confirm that the spectral-spatial suppression pulses have the same T_2 response as the spectral pulses. The last slice acquired using a spectral suppression pulse (Fig. 3c) shows T1 recovery in the longer T_2 phantoms. The brain images in figure 4 from the fifth interleaved slice also show poor suppression with the spectral pulse due to T_1 recovery in the gray and white matter, whereas the spectral-spatial pulse creates better contrast for the short- T_2 components such as the falx cerebri (arrow). The bright spots in the brain tissue are due to flow.

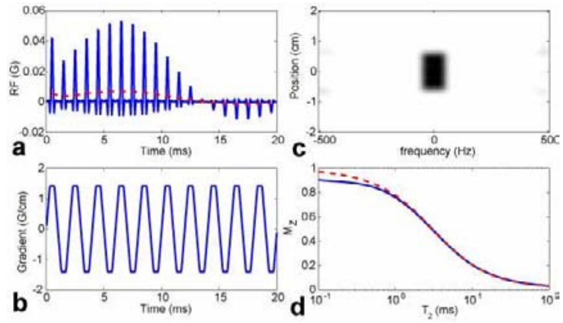

Figure 1: *Single-band spectral-spatial long-T_2 suppression pulse. (a) RF and (b) gradient waveforms. (c) Spectral-spatial and (d) T_2 profiles. The red dashed lines in (a) and (d) are for the equivalent spectral suppression pulse.*

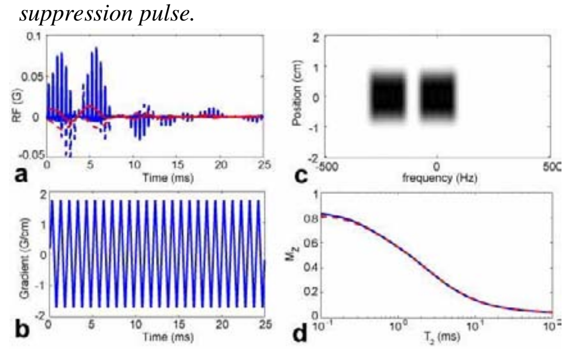

Figure 2: *Dual-band spectral-spatial long-T_2 suppression pulse. (a) RF and (b) gradient waveforms. (c)Spectral-spatial and (d) T_2 profiles. The red lines, low amplitude in (a) and dashed in (d), are for the spectral pulse.*

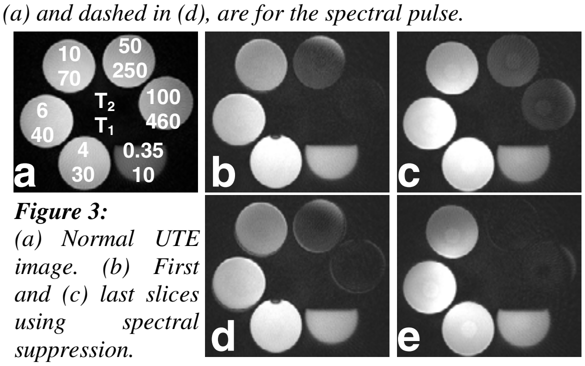

Figure 3: *(a) Normal UTE image. (b) First and (c) last slices using spectral suppression. (d,e) Same slices using spectral-spatial suppression. The longest T_2/T_1 phantom shows increased signal in the last slices with the spectral suppression (c).*

Discussion

For optimal performance, each set of slices associated with a given spectral-spatial suppression pulse should be separately shimmed, reducing the chance of off-resonance artifacts. Multiple slices can also be acquired after each spectral-spatial suppression pulses when the T_1 values are sufficiently long.

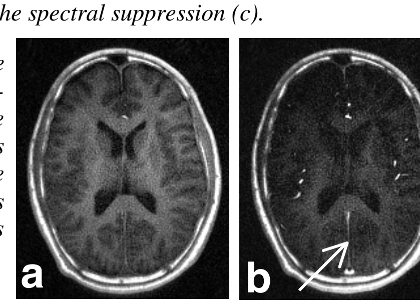

Figure 4: *Fifth acquired UTE slice with (a) spectral and (b) spectral-spatial suppression pulses. The spectral suppression shows significant T_1 recovery, while the spectral-spatial suppression is as expected. The falx cerebri has excellent contrast (arrow).*

References:
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[4] Meyer CH, et al. MRM 15: 287-304, 1990. [5] Zur Y, MRM 43: 410-20, 2000.