Designing Long-T_2 and Combination Long-T_2/Fat Suppression Pulses for Ultra-short Echo Time (UTE) Imaging

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Introduction:

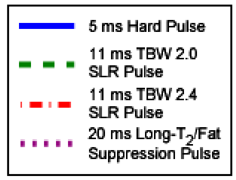
Ultra-short echo time (UTE) imaging has recently become of interest for possible clinical applications [1,2]. Long-T_2 species dominate UTE images if they are not suppressed. We introduce a new set of long-T_2 suppression pulses designed with the Shinnar-Le Roux (SLR) pulse design algorithm [3]. They are low-amplitude, long-duration RF pulses that have improved off-resonance bandwidths over previous hard long-T_2 suppression pulses [4]. We also have designed a long-T_2 suppression pulse that includes fat-saturation.

Theory:

We solved the Bloch equation for M_Z at conclusion of a RF pulse, $\omega_1(t)$. We included T_2 decay but not T_1 decay and assumed T_2 is much shorter than the pulse duration to obtain the following result:

$$M_Z(T_2) \cong 1 - T_2\int_0^T |\omega_1(t)|^2\, dt = 1 - T_2\int_{-\infty}^{\infty} |\Omega_1(f)|^2\, df \qquad (1)$$

This result shows that short-T_2 attenuation is proportional to the integrated squared spectrum of an RF pulse.



Methods:

The SLR pulse design algorithm is useful for designing long-T_2 suppression pulses because it allows us to put most of the pulse energy in the suppression band. Equation (1) tells us that this limits short-T_2 attenuation while maximizing bandwidth. The algorithm also creates the minimum power RF pulse for a given profile [3]. The pulses are maximum phase to assist the suppression and shrink the transition widths. We also used the complex remez algorithm to design pulses with fat-saturation and long-T_2 suppression [5]. The RF pulses used are shown in figure 1 with different time scales. Analysis was done using a full Bloch equation simulation and experiments were done on a GE Excite 1.5T scanner.

Results:

Figure 2 shows the simulated spectral and T_2 profiles of the four long-T_2 suppression pulses from figure 1. The 11 ms time-bandwidth (TBW) 2.0 SLR pulse and the 5 ms hard pulse have identical T2 profiles, but the SLR pulse has a flatter suppression band. The 11 ms TBW 2.4 SLR pulse has a wider bandwidth than both so the short-T_2s are more attenuated. The 20 ms long-T_2/fat suppression pulse includes a spectral band to saturate fat. This additionally attenuates the M_Z of short-T_2s an amount proportional to the width of the extra suppression band.

Figure 3 shows in vivo UTE images of the left ankle with **(b)** and without **(a)** suppression pulses. A 5” surface coil was used with TE = 80 µs, TR = 500 ms, 5 mm slice thickness, and 3:12 per image. The tendons (arrows) not obscured by other tissues when the long-T_2/fat suppression pulse was used.

Conclusion:

We have created long-T_2 suppression pulses with improved spectral profiles, as well as designed a long-T_2 and fat suppression pulse for UTE imaging applications. Since the short-T_2 attenuation is proportional to bandwidth, the application of these pulses is limited. The pulses shown can image T_2s less than a few ms have approximately a ±1 ppm suppression bandwidth. Using RF long-T_2 suppression pulses is advantageous over image subtraction because it has no artifacts from motion or eddy currents.

References:

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[5] Karam LJ, *et al*, *IEEE T Circuits-II*, 42(3):207-216, 1995.

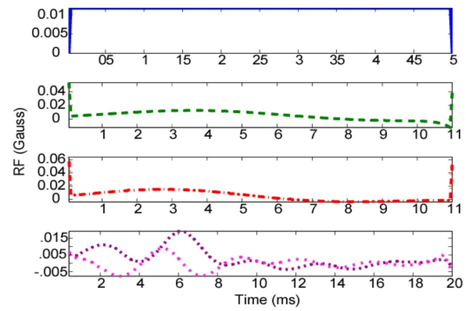

Figure 1: Plots of four long-T_2 suppression pulses. The 20 ms long-T_2/fat suppression pulse is complex.

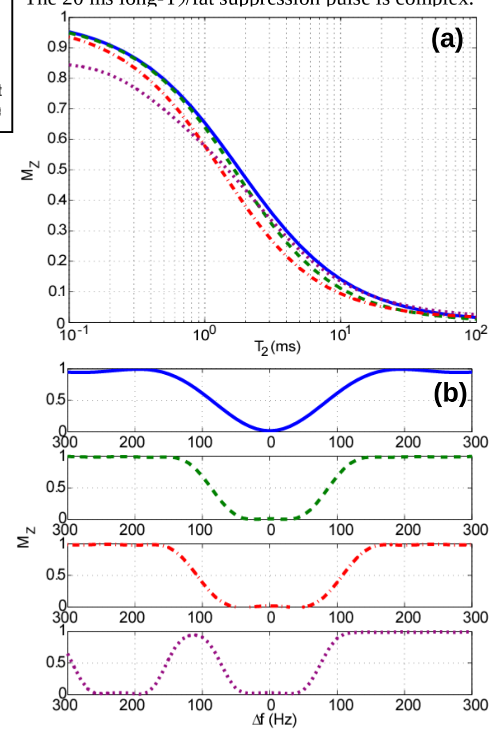

Figure 2: (a) T_2 profiles for the four pulses shown in figure 1. **(b)** Off-resonance profiles at 1.5T with T_2 = 100 ms. As the pulse bandwidth increases, so does short-T_2 attenuation.

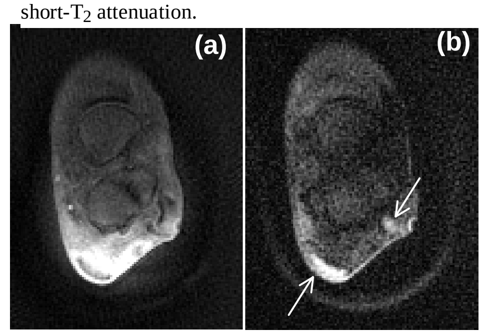

Figure 3: (a) UTE left ankle image with no suppression. **(b)** Using 20 ms long-T_2/fat suppression pulse. With suppression, the tendons (arrows) are easy distinguishable. The plastic boot holding the ankle is also visible.