The Use of Binomial Pulses for Suppression of Long T2 Signals

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Introduction: Ultrashort TE (UTE) imaging has the promise of visualizing tissues not previously visible with MRI. Contrast in UTE is typically fairly flat because little T2* decay has occurred before data acquisition starts. Contrast has been improved by subtracting late echoes from early echoes leaving those tissues with short decay times. Unfortunately, the subtraction results in an increase in noise despite the increase in contrast. Josan et al. [1] have proposed an inverted double half pulse slice selection method for long T2 suppression in two-dimensional imaging to obviate the need for subtraction. Similarly for non-selective excitations, a 1, -1 type first order binomial pulse could be used to suppress signals from long T2* tissues. However, the duration of these pulses needs to be longer then the T2* of the tissues from which we are trying to suppress signal resulting in poor off resonance behavior. The TELEX method [2] was proposed to address the off-resonance issues by employing 180 degree pulses, between long duration hard pulses to refocus spins similar to the way fast spin echo refocuses spins. SAR limits, especially at higher field strengths, place a lower limit on the duration of the refocusing pulses resulting in a fairly narrow excitation bandwidth. Here, the use of binomial pulses [3] of higher order (+1-2+1, +1-3+3-1, +1-4+6-4+1, etc.) have been proposed as a way to improve the off-resonance behavior while staying within SAR limits. The pulses described here use the maximum allowable B1 for the shortest pulse duration and widest bandwidth. For tissues with T2 much longer than the duration of the RF pulse, the positive and negative areas of the binomial excitation pulses results in no residual magnetization being excited. For tissues with short T2, the effects of the earlier parts of the binomial pulse will be reduced by the decay occurring during the RF pulse resulting in a signal inversely proportional to T2*. For small tip angles, we can think of the binomial pulse as being apodized by a time-reversed T2* curve.

Methods: An investigational ultra short TE (UTE) pulse sequence was modified by replacing the excitation pulse with a binomial pulse. Phantom data are acquired on a 3T GE scanner (Signa HD, GE Healthcare, Waukesha, WI). The imaging phantom contains channels of water doped with varying amounts of MnCl resulting in T2 relaxation times of approximately 100µs, 1ms, 10ms, 100ms and 1000msec. The imaging parameters for radial acquisition include: 30×30cm FOV, TR 100ms, BW±125kHz, 0.59mm in-plane resolution, 1609 rays, 512×512 matrix, are acquired with total scan time 2 minutes and 38 seconds. Effective echo time depends on the T2 of the tissue so we specify the time between the end of the RF pulse and the beginning of data acquisition to be 8µs. Regions of interest are chosen in the phantom and data are acquired for varying center frequencies. Images are demodulated to bring the center frequency of the image back to resonance and signal magnitudes are compared. *In vivo* imaging is performed on the hand of a health volunteer.

Results: The flip angle described below refers to the flip angle of the first and last lobe of the 121 pulse. For example, for a flip angle of 30 degrees, the three sub-lobes will have flip angles of 30, -60, 30 degrees with durations of 80, 160, and 80 microseconds, respectively. Doubling the flip angle will double the pulse durations. Signal from various regions of interest in our T2 phantom are used to observe the relationship between T2* and the flip angle and duration of a second order binomial pulse as shown in Fig. 1. Fig. 1a) shows the response of the phantom with a 100µs T2*. On-resonance, signal is excited because short T2 species do not see the full area of the early lobes of the 1-2+1 binomial pulse. The signal excited increases with increasing flip angle. Varying frequency has little effect because of the broad spectrum of short T2 material. For T2 approximately equal to the RF pulse durations, signal increases with pulse duration however off-resonance excitation has a greater effect. For the phantom with T2 greater than the RF pulse duration, there is little signal excited even with fairly long RF pulse durations as seen in Fig. 1c). Unfortunately, varying frequency yields more excited signal. Figure 1d) helps optimize the flip angle/pulse duration to yield maximum contrast-to-noise given the T2s of the material.

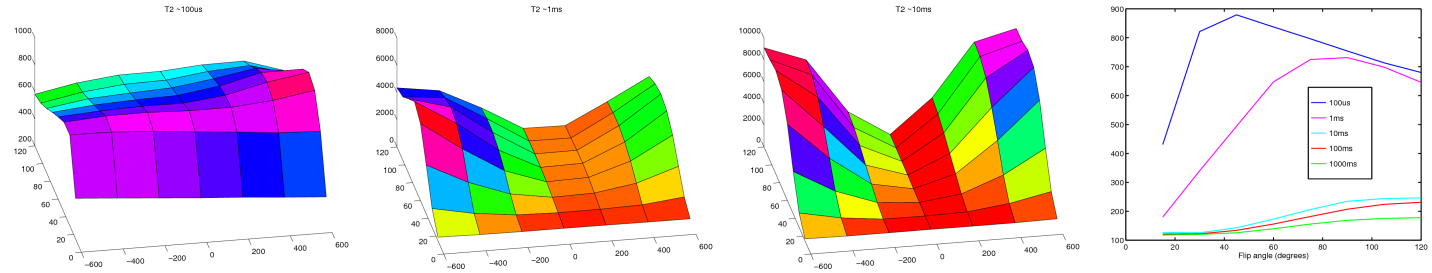

Figure 1: Signal response to 121 pulse of 100us, 1ms and 10ms T2 phantoms.

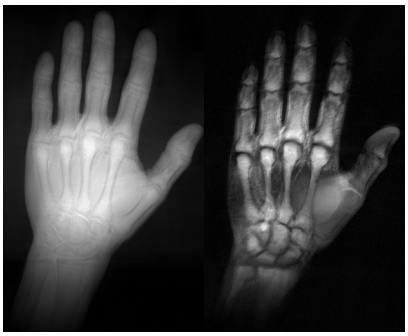

Figure 2. In vivo images: hard vs 1331pulse.

Figure 2 shows *in vivo* images acquired with a hard excitation pulse and with a third order (1-3+3-1) binomial pulse to suppress signals from tissues with long T2s. The image is a projection through the hand.

Discussion and Conclusion: Off-resonance is a problem in this method. With careful selection of the timing between pulses, signal nulls can be placed on the water and fat peaks however B0 field inhomogeneity does tend to spread out the frequencies over which the techniques should suppress signals. Increasing the order of the binomial pulses helps broaden the stop bands but in practice SAR grows very quickly. Second and third order binomial pulses seem to be most useful *in vivo*.

Reference: 1. Josan et al, ISMRM 2007; p1711 2. Sussman et al. MRM 40:890-899 (1998); 3. Bernstein MA, King KF and Zhou XJ; Handbook of MRI Pulse Sequences 2004