UTE Excitation Pulses Followed by Spin Lock to Preserve Magnetization

M. Carl[1], M. Bydder[2], A. Takahashi[1], E. Han[1], and G. Bydder[2]

[1]GE Healthcare, Applied Science Lab, Milwaukee, WI, United States, [2]Radiology, University of California, San Diego, CA, United States

Introduction: UTE imaging has opened up the possibility of imaging tissues with very short intrinsic T_2* values, such as ligaments (~ 4-10ms), tendons (~ 2ms) and cortical bone (~ 0.5ms), which appear dark on traditional MR images [1]. The 2D UTE technique incorporates two VERSE corrected half excitation pulses without a slice select gradient rewinder, followed almost immediately by a radial k-space readout. Two acquisitions, obtained with opposite slice-select gradient polarities are added in order to cancel the imaginary transverse magnetization. To minimize signal decay during the RF pulse itself, UTE excitation are usually operated near maximum RF amplitudes and gradient slew-rates. The rapid gradient slew-rates can cause transient short-term eddy currents and gradient amplifier non-linearities that can last from tens to hundreds of microseconds and may produce image artifacts [2]. Owing to the rapid decay of the signal from the tissues of interest, it may be counterproductive to simply wait until these transients have decayed away before starting the data acquisition. We propose a sequence in which the original UTE excitation pulse is immediately followed by a spin lock pulse, applied 90° out of phase with the excitation pulse. During the spin lock time (TSL) the spins are locked and decay by longer the $T_{1\rho}$ process, and the transients are allowed to decay away. We have investigated this approach by studying the results of Bloch simulations.

Sequence Design: The proposed pulse sequence is shown in Fig.1. The UTE excitation RF pulse along the x-axis tips the magnetization towards the y-axis, and is followed by a spin-lock field along the y-axis. The slice-select gradient is applied as a bipolar gradient to help cancel long-term eddy-currents. Complete cancellation of the imaginary transverse magnetization and generation of a symmetric slice profile requires averaging of all four permutations of slice select-gradient and spin-lock field polarities. The readout gradient and data acquisition starts at a minimum delay time of about 8μs after the spin lock pulse.

Bloch Simulations: T_2* was modeled as a combination of reversible dephasing (T_2') using a Lorentzian distribution of resonance frequencies and irreversible signal decay (T_2) which was modeled as a simple exponential amplitude loss. The MR signal was calculated from:

$$S(t) = \frac{1}{\pi T_2'} \exp\left(-\frac{t}{T_2}\right) \int_{-\infty}^{\infty} \frac{S(t,\omega)}{\omega^2 + (1/T_2')^2} d\omega \qquad \text{with} \qquad \frac{1}{T_2^*} = \frac{1}{T_2} + \frac{1}{T_2'} \qquad (1)$$

where S(t,ω) is the simulated signal for each ω at time t. To confirm the validity of this model, we first simulated a simple spin echo sequence with a refocusing pulse at 1ms and fixed T_2* of 1ms with three distinct values of T_2' of 1.33ms, 2ms, and 4ms (corresponding to the three distinct Lorentzian lineshapes in Fig.2a). As shown in Fig.2b, the simulated signal evolution generates the expected spin echo behavior. The same tissue parameters were used for the simulations of the proposed pulse sequence from Fig.1. A plot of the signal as a function of time using a 0.5ms UTE RF pulse with nominal flip angle of α = 90° for a spin located at iso-center (z = 0) is plotted in Fig.3. The signal during the excitation pulse (black curve) is not maximized at 90° (left dotted vertical line) but at a lower flip angle in agreement with [3]. The oscillating behavior of the signal during the spin lock pulse corresponds to the periodic rephasing of the off-resonance spins at the effective internal spin echo times within the spin lock pulse. The four simulated slice profiles after the completion of the spin lock pulse from the four possible permutations of the slice-select gradient and spin lock field polarities are plotted as a function of z in Fig.4 for the case of T_2' = 4ms, $B_{1\rho}$= 25μT and spin lock time TSL ≈ 600μs (corresponding to the right dotted vertical line in Fig.3). Averaging of all four slice profiles for a given spin lock field yields each one of the final slice profiles shown in Fig.5. Also shown for reference is the slice profile immediately after the completion of the UTE excitation pulse (dotted line). Finally, Fig.6 shows the magnitude of the total summed in-slice signal vs. the total summed out-of-slice signal as a function of the spin lock field. This plot can serve as a metric to evaluate the quality of the slice profile, since the general objective of slice selective excitation is to maximize signal within the nominal slice and minimize signal outside the nominal slice.

Discussion: The amount of signal that can be maintained/recovered using a spin lock depends on both the spin lock field (Fig.5) and the relative proportions of reversible to irreversible signal decay (Fig.3). Hence the proposed pulse sequence would be most useful for tissues with short T_2*s but long T_2s such as bone. Possible limitations of the pulse sequence technique may arise from B_1 inhomogeneities and amplitude limitations (including SAR restrictions), since the ability of a continuous RF pulse to spin lock magnetization and reduce dephasing associated with T_2* decay depends on the available RF power.

Conclusion/Outlook: We have proposed and performed initial investigations on using a UTE excitation pulse immediately followed by a spin lock pulse. Our first simulations have shown promising for retarding the rapid signal decay of very short intrinsic T_2* tissues while allowing the transient short-term eddy currents and gradient amplifier non-linearities from the slice select gradient to decay away.

References: [1] M. D. Robson et. al, J. Comput Assist Tomogr 27, 6 (2003) [2] J. P. Wansapura MRM 46:985-992 (2001) [3] D. J. Tyler et al, JMRI 25:279 (2007)

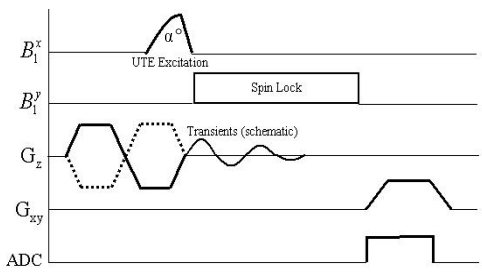

Fig.1: UTE pulse sequence incorporating a spin lock.

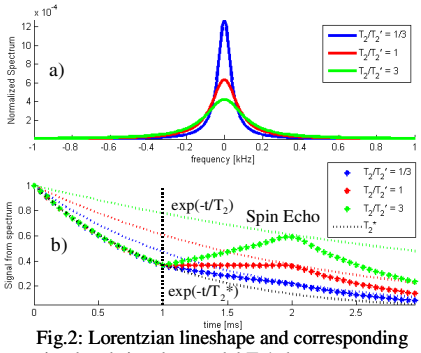

Fig.2: Lorentzian lineshape and corresponding simulated signal to model T_2* decay.

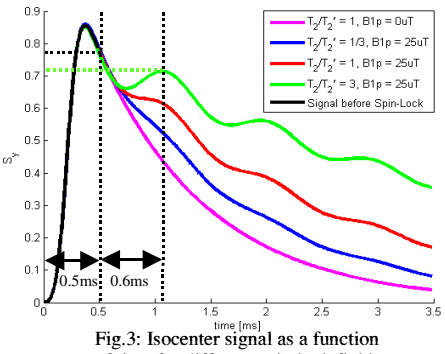

Fig.3: Isocenter signal as a function of time for different spin lock fields.

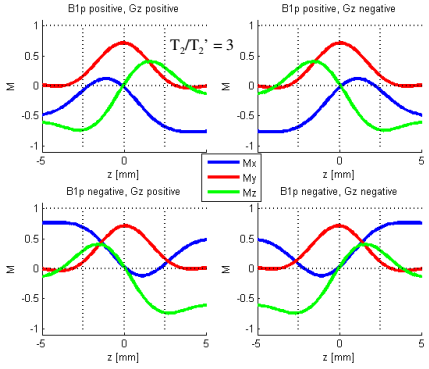

Fig.4: All four required permutations of slice profiles.

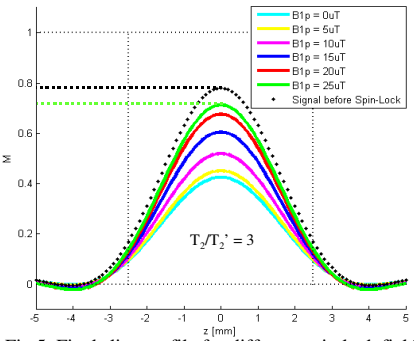

Fig.5: Final slice profile for different spin lock fields.

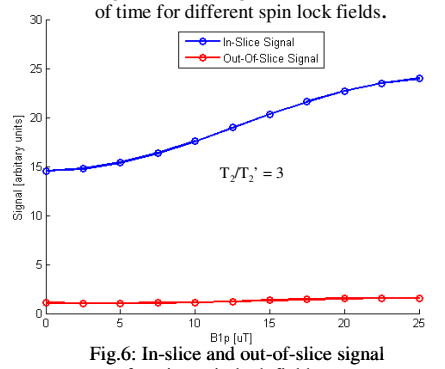

Fig.6: In-slice and out-of-slice signal as a function spin lock fields.