Long-T2 Suppression with Low Flip-Angle b-SSFP Ultra-short TE (LA-bUTE)

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Target Audience MRI scientists and radiologists interested in clinical application of ultra-short TE MRI.

Purpose Ultra-short TE (UTE) imaging has been shown to be clinically feasible to image tissues with very short T2 components (T2 about tens or hundreds of micro-seconds, such as tendon, ligment, menisci).[1] It can also be applicable to characterize human brain gray and white matter.[2] UTE generally employs radial readout starting from center of k-space to achieve shortest TE possible. A major technical difficulty of UTE is long-T2-species (including fat) suppression, because these signals overshadow short-T2-tissues-of-interest usually with low signal and fine structure. Variations of pre-pulse suppression and echo subtraction are the current two approaches used to enhance short-T2 to long-T2 contrast.[3,4] In this study, a **L**ow flip-**A**ngle **b**-SSFP **UTE** (**LA-bUTE**) sequence is introduced to achieve up to 50% of long-T2 signal suppression without time penalty. It is also demonstrated that full suppression of long-T2 can be achieved when LA-bUTE is combined with traditional pre-saturation pulses with only slight increase on scan duration.

Theory When very short TR (<<T2) is employed, transverse spins can add coherently (or destructively) resulting in enhanced (or reduced) MR signal. For species with very short T2 (much shorter than TR), spin coherence resulted from earlier RF excitation is negligible. At very low flip angle regime, b-SSFP signal of long-T2-species can add destructively leading to long-T2 suppression effect, without compromising short T2 tissue signal. A simplified description of low-flip-angle (FA=1~3°) b-SSFP signal behavior has been offered by Lee and Pauly.[5] Using their derivation, in a small-flip-angle b-SSFP sequence with 180º RF phase cycling, on-resonant signal is $\mathbf{M_{b\text{-}SSFP}} = M_0*\sin(\alpha)*(1-\exp(-TR/T2))/(1-\exp(-2TR/T2))$, which is 50% of $\mathbf{M_{SPGR}}$ ($=M_0*\sin(\alpha)$) for species with long T2 >> TR. Overall, LA-bUTE sequence inherently suppresses long-T2 signal up to 50% compared to a non-bSSFP sequence such as SPGR without sacrificing short-T2 tissue signal. Some of the simulation results are shown in Fig.1. Simulation results also suggest that lower flip angle b-SSFP offers better long-T2-suppression, while higher flip angle has higher SNR (not shown).

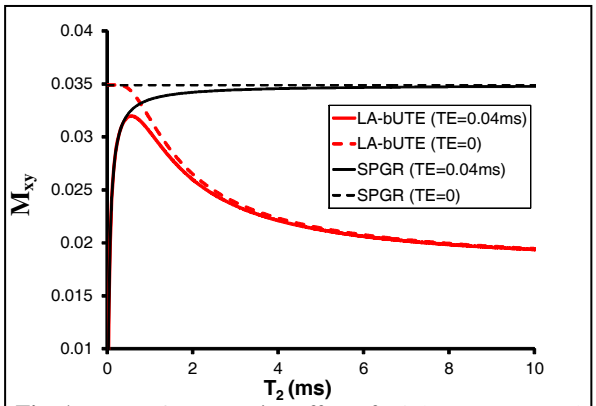

Fig. 1: Long-T2 suppression effect of LA-bUTE compared to SPGR. Simulation parameters: TR/FA=2.3ms/2°.

Methods Phantom experiments were performed on a 3.0 T whole-body MR scanner (Philips Achieva) using a 2-channel surface coil. A 3D UTE sequence was employed to achieve a TE of 100μs [ref]. The imaging phantom comprised a rolled rubber band, a FBIRN agar phantom, and a bottle of oil. Three sequences were tested with FOV=230mm, 80 slices, and 0.6x0.6x5mm spatial resolution. The regular 3D SPGR-UTE sequence had TR/FA=4.2ms/2°, NSA=1, and scan duration 2'08". The LA-bUTE sequence had TR/FA=2.3ms/1°, NSA=4, and scan duration 4'38". Different flip angles were used to compensate for the shortest TR difference. The IR-LA-bUTE sequence had TR/FA=2.3ms/2°, and NSA=2. Each inversion recovery pre-pulse was shared by 80 b-SSFP excitations with linear profile order along slice direction phase encoding, leading to scan duration of 2'52".

Results Typical images from three tested sequences are shown in Fig. 2. Visually, the FBIRN phantom and oil have much stronger signal compared to the rolled rubber band on the SPGR-UTE image (Fig. 2a). On the LA-bUTE image (Fig. 2b), the rubber band has slightly higher signal compared to FBIRN. Quantitatively, S_{rubber}/S_{FBIRN} of SPGR-UTE and LA-bUTE is 0.81 and 1.42, respectively. Bottle oil has non-uniform signal on LA-bUTE due to off-resonances, as expected. It has a wide dark band, showing successful suppression of fat for a large range of frequencies. Fig. 2c shows a typical image obtained with IR-LA-bUTE where almost all FBIRN phantom and on-resonant fat signal are suppressed.

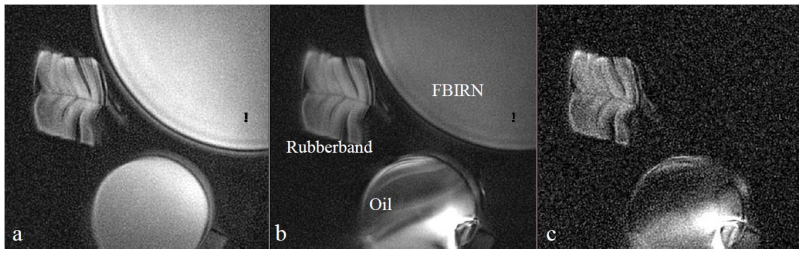

Fig. 2: a) SPGR-UTE (2:08, NSA=1); b) LA-bUTE (4:38, NSA=4); c) IR-LA-bUTE (2:52, NSA=2, and ETL=80). LA-bUTE shows much suppressed long-T2 signal compared to SPGR-UTE. IR-LA-bUTE combines IR with LA-bUTE, leading to almost complete suppression of FBIRN signal.

Discussion A major technical difficulty for UTE imaging is to suppress long-T2 signal so that positive contrast from ultra-short-T2 components can be obtained. Dual echo acquisition of the UTE with subtraction approach can lead to short-T2-only images, but sometimes not desirable due to its inferior image quality, longer scan duration, and SNR loss. Previous technical development has mainly focused on long-T2 and fat pre-saturation pulses before each or several UTE readouts.[3,4] These pre-pulses are generally long and only short echo train length can be used to avoid overwhelming long-T2-signal contamination. Therefore imaging readout duty-cycle is much reduced and scan duration much lengthened. It is particularly difficult to achieve high quality 3D UTE images within reasonable scan duration. In LA-bUTE, long-T2 signal is inherently 50% suppressed while short-T2 signal is maintained. When combined with IR-prepulse, a much longer echo train length can be employed without introducing too much long-T2-signal contamination. It also helps maintain spin steady state to minimize ghosting and blurring due to frequent interruption of the imaging RF train by the pre-pulses. This is critical to obtain high quality UTE images to show low signal and fine structure of the short-T2 components. It is demonstrated that this approach will lead to efficient long-T2 and fat suppressed UTE images within much reduced scan duration. Although not shown here, LA-bUTE can also be combined with other pre-pulse for more sophisticated contrast manipulation.

Conclusion Low flip-Angle b-SSFP UTE (LA-bUTE) is employed to generate out-of-phase coherences for long-T2-species without reducing signal of ultra-short-T2 components. This sequence offers an inherent and constant suppression of long-T2 signal up to 50%. With this technique, 3D UTE images with desired short-T2-to-long-T2 contrast can be obtained within clinically acceptable scan duration.

References 1. M. Robson, et al, NMR in Biomedicine 19:765-780, 2006; **2.** E. Ercan, Proc. Intl. Soc. Mag. Reson. Med. 20 (2012), p4279; **3.** J. Du, et al, MRM 63: 447-455, 2010; **4.** P. Larson, et al, MRM 58:952–961, 2007; **5.** J. Lee, J. M. Pauly, Proc. Intl. Soc. Mag. Reson. Med. 13 (2005), p2346.