Out-of-slice Saturation with Steady State Preservation for Improved Slice Selectivity in 2D UTE Imaging

Axel J. Krafft[1], Ruitian Song[1], Ralf B. Loeffler[1], Matthew D. Robson[2], and Claudia M. Hillenbrand[1]
[1]*Radiological Sciences, St. Jude Children's Research Hospital, Memphis, TN, United States,* [2]*MRS Unit, Oxford University Centre for Clinical Magnetic Resonance Research, Oxford, United Kingdom*

Introduction

Ultra-short echo time (UTE) imaging allows for very short delays between excitation and data acquisition of ≤ 100 µs and enables the detection of very short T_2^* tissue samples, e.g. cortical bone, tendons or menisci [1-3]. Slice-selective 2D UTE imaging is achieved via half pulse RF excitation [4] and center-out radial sampling. 2D UTE multi-echo readout imaging can be performed within a single breath-hold and used for quantification of very fast T_2^* species even in abdominal organs such as the liver. Unfortunately, the half pulse slice profile is sensitive to gradient imperfections and the steady state (SS) of the magnetization, as two half pulse excitations with opposite slice selection gradients are added to form the desired slice profile. Recently, a method using out-of-slice saturation (SAT) was presented [5] to improve the half pulse slice profile. To maintain short image acquisition times (TA), such SAT intervals are typically inserted into a segmented imaging chain. However, in segmented imaging the SS of the magnetization is disturbed which might lead to image artifacts especially for radial acquisitions and hence to errors in 2D UTE based T_2^* quantification. In this work, a 2D UTE pulse sequence with out-of-slice SAT is introduced that preserves the imaging SS similar to [6] for improved T_2^* mapping.

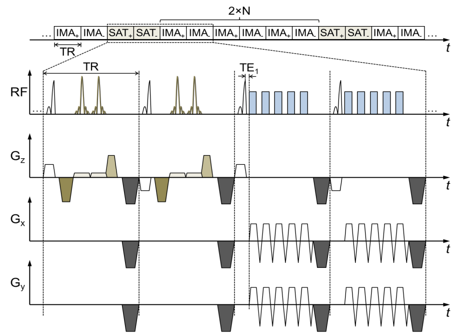

Fig. 1: Diagram of steady state preserving 2D UTE-SAT pulse sequence.

Materials and Methods

The 2D UTE out-of-slice SAT sequence was implemented on a 1.5 T clinical MR system (MAGNETOM Avanto, Siemens, Erlangen, Germany). As illustrated in Fig. 1, the sequence uses a segmented application of imaging (IMA) blocks with half-sinc RF pulses, opposite slice selection gradients and multi-echo radial readouts (indicated as IMA_+ & IMA_-). After the acquisition of N segments (total number of IMA blocks $= 2\times N$) two SAT blocks (indicated as SAT_+ & SAT_-) are inserted. Each SAT block applies two 90°-sinc SAT pulses (duration: 2560 ms) to suppress unwanted signal contributions from both sides of the imaging slice. For SS preservation, the half pulse excitation scheme is maintained throughout the SAT intervals. Furthermore, all gradients are adjusted to have the same overall 0th-momentum in SAT and IMA sections: Within each SAT section, a preceding gradient pulse (dark yellow) balances the two slice selection gradients of the SAT pulses and the subsequent spoiler gradient (light yellow). The readout gradients within the IMA sections are completely rephased, and at the end of each SAT and IMA section identical spoiler gradients are used. Initially 2 SAT and 2×5 IMA dummy intervals are applied to establish the imaging SS.

The slice selectivity of the 2D UTE-SAT sequence was examined in an agarose phantom. To directly evaluate the slice profile the readout plane was oriented parallel to the slice selection direction. 2D UTE-SAT images (TR/TE = 20/0.1 ms, FOV: 220×220 mm², radial views: 192, slice thickness: 10 mm, $\alpha_{half} = 15°$, BW: 870 Hz/px, gap SAT-IMA: 5 mm, SAT thickness: 70 mm; Fig. 2a) with and without SS preservation were acquired for different N. The out-of-slice background signal to noise ratio (BNR) was calculated (ROI indicated in Fig. 2b). Then, the 2D UTE-SAT sequence was applied for T_2^* measurements of 7 phantoms (cf. insert in Fig. 3). Multi-echo UTE images ($TR/TE_1 = 50/0.1$ ms, $\Delta TE = 1.7$ ms, 10 readouts, FOV: 240×240 mm², radial views: 128, $\alpha_{half} = 10°$, slice thickness: 10 mm BW: 870 Hz/px,) with and without SS preservation were acquired. For comparison, T_2^* times were also quantified from conventional multi-echo 3D gradient echo (GRE) acquisitions. To precisely measure the very short T_2^* time of phantom #1 ($T_2^* < 0.5$ ms), additional single echo 2D UTE and 3D GRE images were acquired with otherwise same parameters. T_2^* times were retrieved by fitting a mono-exponential decay.

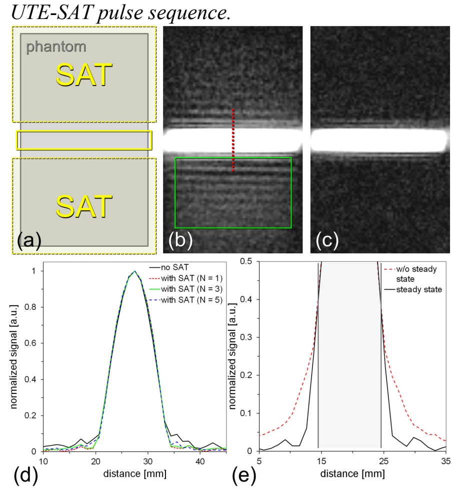

Fig. 2: (a) SAT locations. (b)/(c) UTE slice profile images w/o & w/ SAT. (d) UTE slice profiles (red dotted line in (b)) w/ SS preservation. (e) Slice profiles w/o & w/ SS preservation for N = 1.

Results and Discussion

Figures 2b and 2c show 2D UTE slice profile images with SS preservation without and with ($N = 5$) SAT pulses respectively. Without SAT pulses out-of-slice excitation is clearly observable. In Fig. 2d, slice profiles of the SS-preserving UTE sequence are presented. Without SAT pulses out-of-slice excitation (background signals in the range of 5-10 %) can be seen even at distances ≥ 15 mm from the slice center. BNR values of 3.7/1.1/1.3/1.3 (no SAT/N=1/N=3/N=5) were found for the SS-preserving UTE-SAT sequence vs. 5.3/4.1/2.1/1.8 without SS preservation. For the UTE-SAT sequence without SS preservation, stronger background suppression was achieved for a higher number of segments which could be explained by less disturbance of the SS. In Fig. 2e, UTE-SAT slice profiles for $N = 1$ are compared. The ideal slice profile is indicated as grey shaded area. Without SS preservation the boundaries of the slice appear widened whereas a well-defined slice profile is achieved with the SS-preserving technique. With a linear regression coefficient of 1.0057 (Fig. 3), the T_2^* values obtained with the SS-preserving UTE-SAT sequence are in excellent agreement to the corresponding values of the 3D GRE measurement. Without SS preservation deviations in T_2^* quantification of up to 10 % were seen especially for T_2^* values ≥ 5 ms.

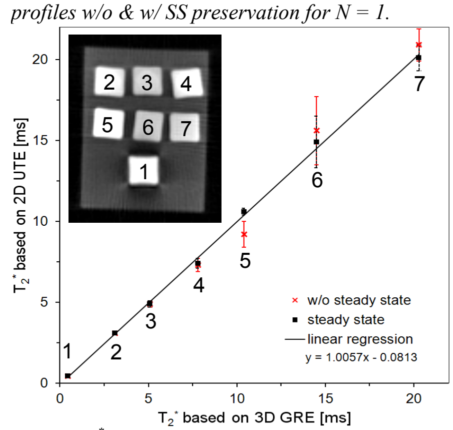

Fig. 3: T_2^* quantification based on 3D GRE and 2D UTE-SAT w/o & w/ SS preservation.

In summary, the presented UTE-SAT sequence is a simple and robust technique to suppress unwanted out-of-slice signal contributions while maintaining the magnetization SS for accurate T_2^* quantification over a wide range. As out-of-slice SAT pulses are employed, interleaved multi-slice imaging on the basis of the SS-preserving UTE-SAT is prohibited. However, with TAs in the range of 10-20 s multi-echo images can be easily acquired within a single breath-hold so that multiple breath-holds could be performed to achieve a sufficient spatial coverage also for mapping of very short T_2^* times in abdominal organs [7]. To improve the spatial selectivity of the SAT pulses, the sinc-shaped SAT pulses could be replaced by advanced SAT pulses as presented in [5]. With the segmented application of the SAT sections, the overall RF power deposition is only slightly elevated which might be an important advantage for implementations of the sequence at higher field strengths.

References [1] Bergin CJ et al. Radiology 91;179:777-81. [2] Robson MD et al. J Comput Assist Tomogr 03;27:825-46.[3] Holmes JE et al. Radiography 05;11:163-74. [4] Pauly J et al. Proc Soc Mag Reson Med 90;9:28. [5] Josan S et al. Magn Reson Med 09;61:1090-95. [6] Rauschenberg J et al. Magn Reson Med 11;66:123-34. [7] Chappell KE et al. J Magn Reson Imaging 03;18:709-13.