Quantitative Ultra-short Echo Time Imaging for Massive Iron Overload Assessment: A Way to Make It Happen

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INTRODUCTION

Clinical management of patients with iron overload (IO) requires accurate assessment of body iron which can be achieved non-invasively by measuring the hepatic iron content (HIC) via R2* MRI[1,2]. In this context, R2* MRI techniques typically employ single breath hold multi-echo gradient echo (mGRE) imaging and are widely used to predict HIC. However, previous R2*-HIC biopsy studies have shown that their precision is limited for high IO (HIC > 20 mg Fe/g) and might even fail for massive IO (HIC > 25 mg Fe/g) because conventional mGRE imaging is intrinsically limited to detect high HIC values as the associated T2*-weighted MR signal decays too rapidly. This problem could be overcome by using ultra-short echo time (UTE) imaging that allows for very short delays between RF excitation and data acquisition (< 0.1 ms) and enables the detection of tissues with very short T2* times[3]. Slice-selective 2D UTE imaging is accomplished via half pulse excitation[3,4] and center-out radial sampling. However, 2D UTE imaging is sensitive to various system imperfections[5], e.g. gradient delays, which may hamper quantitative R2*-based HIC assessment. Here, we describe the implementation of a 2D UTE sequence that allows for precise R2* measurements in hepatic iron overload. The sequence was evaluated in phantom experiments and *in vivo*.

MATERIALS & METHODS

The 2D UTE sequence (Fig. 1) was implemented on clinical 1.5 T and 3 T systems (Avanto and TRIO, Siemens Healthcare, Erlangen, Germany). Axial slice selection was achieved via two half sinc-pulse excitations (pulse duration: 1 ms) with respectively inverted slice selection gradients and complex combination of the acquired data via center-out radial and ramp sampling. Parallel spatial saturation (SAT) bands were applied to suppress unwanted out-of-slice signal contributions[6]. Conventional truncated sinc-shaped SAT pulses were employed in contrast to previously proposed relatively long quadratic phase pulses[6] to achieve shorter repetition times (TR). Standard Gaussian CHESS pulses were applied for fat saturation to reduce streaking artifacts arising from high signal intensities originating from percutaneous fat.

The sequence uses a multi-echo readout for R2* quantification. However, to realize dense sampling of the rapid signal decay for very short T2* times, additional UTE echoes with small TE increments (ΔTE) compared to the first (UTE) echo (TE_1) need to be acquired. The radial sampling process of the UTE sequence is intrinsically insensitive to motion artifacts and does therefore not necessarily require breath holding as opposed to Cartesian acquisition schemes[1,2]. Hence, 5 multi-echo, interleaved readouts (12 echoes per readout, spacing between echoes: 1.8 ms) with small ΔTE-shifts were acquired in free breathing with TE_1 = 0.1 ms and ΔTE = 0.25 ms. The concept of the free breathing interleaved multi-echo UTE (FBI-mUTE) sequence is shown in Fig. 1. Other imaging parameters were: TR = 52.5 ms, number of radial lines: 192, flip angle: 20°, slice thickness: 10 mm, gap between slice and SAT bands: 10 mm. Reconstruction of the 60 individual images was done via standard Kaiser-Bessel regridding.

The sequence was evaluated for R2* quantification[7] in phantoms (2% agarose gel, volume: 500 ml) using a mGRE sequence[2] as reference. Phantoms contained iron nano-particles at different concentrations to cover the clinically relevant R2* range from low to massive HIC. The sequence was further applied in patients with transfusional IO enrolled in an on-going IRB approved study for HIC assessment.

RESULTS & DISCUSSION

Application of the spatial SAT pulses minimized unwanted out-of-slice signal contributions arising from a phantom positioned behind the phantom at iso-center (Fig. 2). These signal contributions distort the observed signal decay if no SAT pulses are applied and thus affect R2* quantification. Streaking artifacts due to high signal intensities seen in percutaneous fat tissue were reduced by using CHESS FS pulses (Fig. 3). Correct R2* estimation using the proposed interleaved 2D UTE concept with CHESS FS and spatial SATs was verified in the phantom experiments (approximate range of R2* values: 25-2600 1/s). Linear regression analysis between mGRE and FBI-mUTE R2* data showed results of y = 1.00x - 5 at 1.5 T and y = 1.00x – 2 at 3 T. The successful application of the FBI-mUTE imaging concept was also demonstrated *in vivo*. Figure 4 compares breath hold and free breathing UTE images; motion artifacts from breathing are barely visible. The FBI-mUTE approach was successfully applied in more than 90 patients without technical failures and allows for precise R2* quantification at 1.5 T and 3 T in patients with high and massive IO. Especially at 3 T, the mGRE-based R2* evaluation can become unreliable as indicated by large standard deviations (SD) (Fig. 4c/d). In sub-groups of patients with R2* > 1000 1/s, the mGRE sequence yielded average R2*-SDs of 320 1/s (1.5 T: 10 cases) and 373 1/s (3 T: 16 cases) versus 109 1/s (1.5 T) and 96 1/s (3 T) on the basis of the FBI-mUTE images. We conclude that the proposed UTE sequence could provide a means to precisely measure R2* in massively iron overloaded patients by minimizing out-of-slice signal contribution and streaking artifacts. As the sequence employs a different excitation scheme (half pulses in contrast to conventional sinc pulses) and furthermore applies CHESS FS and spatial SATs, R2*-HIC calibrations on the basis of the presented FBI-mUTE sequence should be established in a larger patient population.

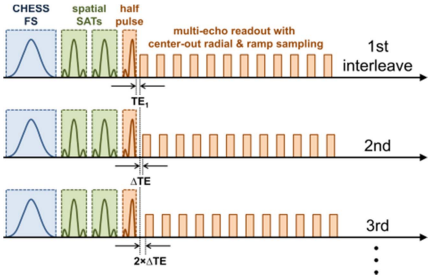

Fig. 1: Schematic of 2D FBI-mUTE sequence with CHESS FS and spatial SAT preparation.

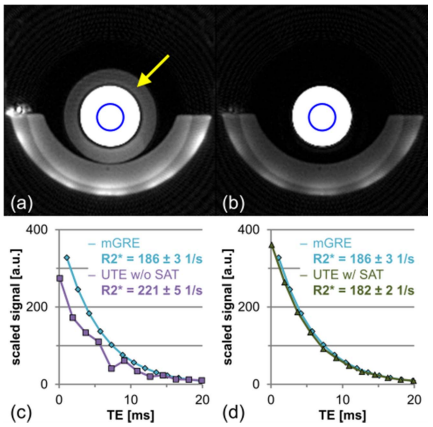

Fig. 2: UTE images without (a) and with (b) SAT bands. Substantial out-of-slice signal contributions can be seen (yellow arrow). (c,d) The out-of-slice contributions also distort the R2 signal decay inside the phantom (regions of interest (ROI) indicated as blue circles).*

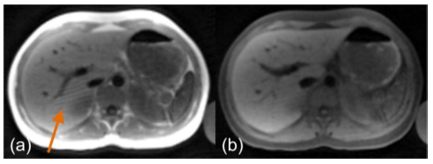

Fig. 3: Reduction of streaking artifacts (orange arrow) in UTE images without (a) and with (b) CHESS FS.

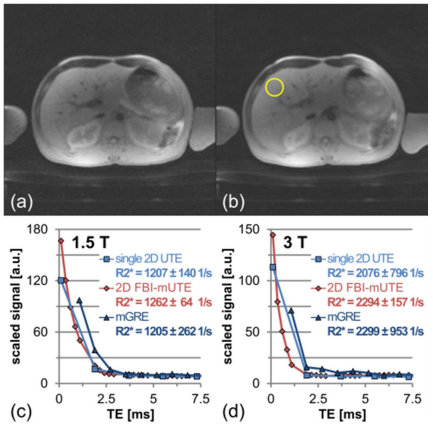

Fig. 4: Breath hold (a) vs. free breathing (b) 2D UTE. In vivo application for R2-MRI (c,d). ROI indicated as yellow circle in (b).*

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