Accurate T1 mapping in rodent lungs using ultrashort echo-time MRI

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Purpose: Regional T1 changes are viewed as a potential diagnostic biomarker in many pulmonary diseases. However, accurate T1 mapping of the lungs, as needed for instance when performing quantitative oxygen enhanced MRI [1], is hampered by low SNRs and cardio-respiratory motion artifacts, especially in small animals. To address these issues, a segmented 2D-IR sequence with ultrashort echo-time (UTE) and radial k-space sampling [2] was implemented. The protocol was validated in phantoms and applied to *in vivo* measurements in rats. Simulations were performed to determine the optimal pulse sequence parameters and to verify the method accuracy.

Methods: The study was approved by the local ethics review board. All experiments were performed on a 4.7 T scanner (Bruker Biospec 47/40, Ettlingen, Germany). Cylindrical vials containing Ni-doped agarose gel were used for protocol validation. The *in vivo* experiments were carried out on freely-breathing Sprague-Dawley rats (n=4, average weight=340 g). A segmented radial 2D-sequence (intra-segment time TS=3.4ms, TE=0.5ms, number of segments=10, steps per segment=40, FOV=60mm, slice=5mm, FA=12°, NA=2, TA=2.1 min), was used to sample the T1 recovery (**Fig1**). In the phantom study, experiments with different FAs (4°, 7°, 12°, 20°) were performed to determine the highest SNR. In the reconstruction, the effect of repeated RF excitations was taking into account, in order to reduce image artifacts. Inversion times (TIs) ranged from 100 - 6000 ms. A three-parameter fitting algorithm was applied to estimate T1 on a pixel level. A standard IR-RARE sequence (TE=3.5ms, slice=5mm, Matrix=196x256, echo train length=6, TA=4.5 min) was used as a reference technique for comparison. The repetition time, TR, of the two sequences was constant and equal to 6500 ms. For imaging protocol validation, the Bloch equations were used to simulate the MR signal intensity as a function of repetition time, flip angle, steps per segment (N), and inversion time for a range of T1s between 500 and 3000 ms.

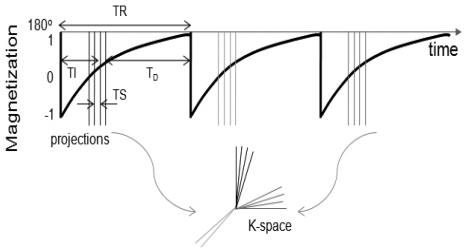

Fig1. The segmented IR-UTE sequence scheme.

Results: The simulations showed that for low FAs (<20°), the proposed method yields accurate T1 estimation; For N=40 and the range of T1s between 500 and 3000 ms, the T1 assessment bias increased with increasing FA, but was less than 0.3% for FAs up to 12°. In the phantom study, the highest SNR was achieved with FA=12° (**Table1**). The comparison between T1 values obtained with segmented IR-UTE and IR-RARE in phantoms demonstrated very good agreement between the two acquisition methods (**Fig2)**. A typical T1 map of the lungs is illustrated in **Fig3**. It can be observed that parenchymal tissue and the pulmonary structures are mapped with high spatial resolution. The assessed lung T1 (mean±SEM out of 4 animals, ROI size of ~1500 pixels in right lung and ~700 pixels in left lung) was 1571±18ms. Correspondingly, the T1 in back muscle was 1640±12ms.

FA	SNR
4°	47.3
7°	71.2
12°	91.5
20°	86.6

Table1. Mean SNR measured in phantoms for tested FAs.

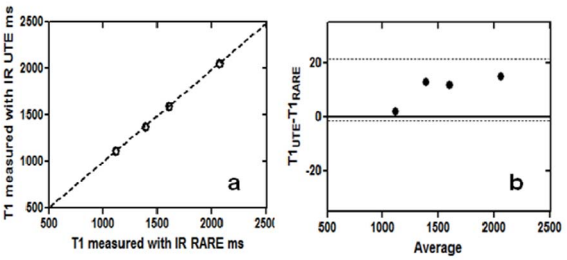

Fig2. Comparison of the T1 values measured with IR-RARE and IR-UTE in the phantom experiments (a). Bland-Altman plot (b). The dotted lines represent mean±2S.D. The T1 difference obtained with two techniques was less than 1% in any phantom.

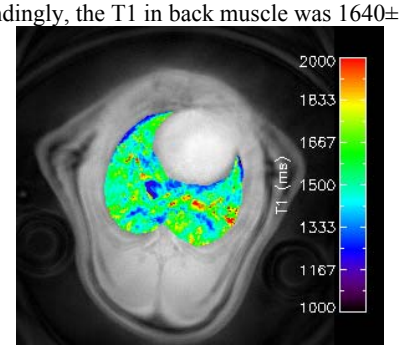

Fig3. A typical T1 map of rat lungs obtained with the segmented IR-UTE sequence.

Discussion: In this study, a robust method for accurate T1 assessment in the lung is presented. A short echo time sequence with optimized FA was applied to achieve a high lung tissue SNR. The temporal efficiency was increased by introducing a train of short RF pulses following the inversion. The accuracy of the technique was demonstrated in phantom experiments, where a good agreement was found when compared to the reference technique. T1 values obtained *in vivo* were in agreement with previously reported results [3]. It can be noted that if N·TS is short compared to T1, the FA that maximizes SNR corresponds to the theoretical prediction by Mugler *et al* [4] for hyperpolarized gas MRI. The optimal FA found via the phantom experiments confirmed this observation. Furthermore, the simulations showed that at the optimum FA, the accuracy of the technique was not hampered by signal depletion during the sampling.

Conclusions: The presented technique enables the T1 of pulmonary structures to be mapped with a high spatial resolution. The protocol has the potential to assess lung properties relevant in various animal models of pulmonary disorders.

References: 1. Jakob P *et al*., MRM 51:1009 (2004);19:542, **2**. Zurek M *et al*., Magn Reson Med 64:401(2010), **3**. Togao O *et al*., J Magn Reson Imaging 34:539 (2011), **4**. Mugler JP, Proc. ISMRM 1998 #1904.

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