Ultra-short echo time (UTE) MR imaging of the lung: assessment of tissue density in the lung parenchyma

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Introduction: Computed tomography (CT) is the standard method for imaging of the lung parenchyma but carries potential radiation risk. One of the fundamental difficulties in MR imaging of the lung is the existence of severe magnetic field susceptibility effects arising from the massive interface between the interstitial tissue and alveolar airspace (1). Consequently, the lung parenchyma has very short T2, and therefore usually is not visible on conventional proton MR images. The utility of ultra-short TE (UTE) imaging in conjunction with projection acquisition of the free inducting decay (FID) allows us to reduce TE to less than 100 μsec to minimize signal decay caused by short T2 relaxation time, and brings inherent MR signal of the lung parenchyma compared to a conventional short echo image sequence (2). In the present study, we tested our hypothesis that the variability of the MR signal of the lung parenchyma obtained using the UTE sequence represents the fractional volume of lung tissue (tissue density), including static water and flowing blood, similar to that observed on CT images. For this purpose, we measured signal intensity (SI) and T2* of the normal murine lung at different positive end-expiratory pressures (PEEPs). Adjustment of PEEP levels enables the generation of a pseudo-pathological condition in which changes in intrinsic interstitial tissue density can be introduced in a controlled fashion.

Materials and Methods: Under anesthesia, eight 8-week old normal mice were tracheaostomized using a non-metallic cannula and connected to a PC-control small animal ventilator (flexiVent™, SCIREQ, Quebec, Canada). Each animal was mechanically ventilated at a rate of 24 breaths/min in which the durations of inhalation/exhalation, and end-expiration were set as 0.2/0.3 s, and 2 s, respectively. Four different PEEP levels (0, 5, 10, and 15 cmH_2O) were applied to produce different tissue density in the lungs. MRI was performed in a 3 Tesla (T) whole-body human unit (Achieva™, Philips Medical Systems, Best, Netherlands) with a small solenoid coil (I.D. 63 mm). Each entire lung in the selected volume of interest (VOI) was imaged with a respiratory-gated 3D radial FID sampling UTE sequence with different TEs of 100 μs and 800 μs at end-expiratory phase, which was repeated at four different PEEP levels. The other imaging parameters were: TR=10 ms, flip angle=10º, FOV=40^3 mm^3, matrix size=68^3 (affording reconstructed 120 μm isotropic resolution), and 2 NEX. For all 3D images, volume rendering (VR) image of the entire lung was generated to measure the lung volumes. SIs were measured in four different regions of interest (ROIs, two for each right and left lung) which were selected, taking care to avoid main pulmonary vessels, on the constructed axial image. All measured SIs were normalized to the SI of the 50 mmol/L Gd phantom. Signal-to-noise ratio (SNR) and %change of the noise corrected SIs (3) between the two different TEs were also calculated to investigate the correlation with the lung volumes.

Results: Figure 1 demonstrates representative re-sliced axial UTE images (TE=100μs) and VR images of the lung in a mouse at four different PEEP levels. As the PEEP became higher, the SI of the parenchyma on the UTE images became lower while the %change in SI between the two TEs increased. The T2* of the normal lung parenchyma at atmospheric pressure (0 cmH_2O) was 0.91 ± 0.10 ms and it decreased as the PEEP became higher. The lung volume at 15 cmH_2O (1016.1 ± 136.1 mm^3, $P < 0.001$) was almost twice as large as that at 0 cmH_2O (470.0 ± 44.9 mm^3). Figure 2 demonstrates the correlation between the MR-derived parameters and lung volume. The lung volume shows high correlation with the SI at TE of 100 μs ($P < 0.0001$, $R^2 = 0.82$, Fig. 2a) and of 800 μs ($P < 0.0001$, $R^2 = 0.79$, Fig. 2a), %change ($P < 0.0001$, $R^2 = 0.69$), and T2* ($P < 0.0001$, $R^2 = 0.71$, Fig. 2b). Moreover, the SNR correlated the reciprocal of lung volume at both TE of 100 μs ($P < 0.0001$, $R^2 = 0.73$) and 800 μs ($P < 0.0001$, $R^2 = 0.86$), but the slope at TE of 100 μs was significantly larger than that at TE of 800 μs ($P < 0.0001$).

Discussion: When the lung inflates, the tissue density in the lung is reduced, as observed in e.g. emphysema due to enlargement of alveolar airspace, in proportion to reciprocal of increase of lung volume under assumption that the interstitial tissues homogenously distribute and equally expand. Both SI and T2* measured by the UTE sequence reduced responding to inflation of the lung. Further, the high correlations between the SI and T2* and the lung volume suggest that these MRI parameters are sensitive to the tissue density in the lung parenchyma. It was evident that the sensitivity increases with shorter TEs since the slope of the correlation between the SNR and the reciprocal of the lung volume was greater at TE of 100 μs than that at TE of 800 μs. Blood oxygenation level may also influence SI although it is trivial under controlled respiration as in the present study.

Using UTE imaging, the direct observation of the MR signal and quantitation of the short T2* in the lung parenchyma would have the potential to assess interstitial tissues density/volume for the detection and characterization of non-uniform disruption of lung architecture as the low attenuation areas on CT images but without incurring the risks of radiation exposure.

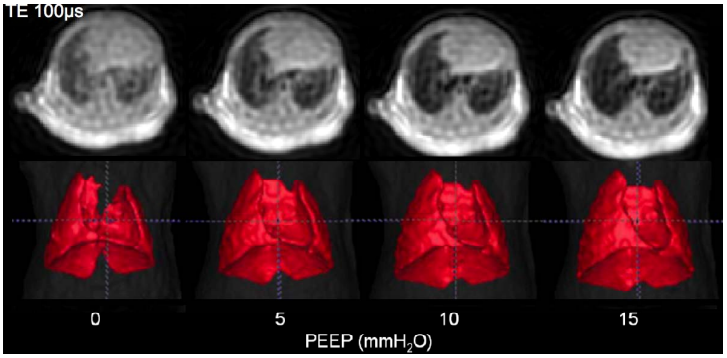

Fig. 1. Typical reconstructed axial UTE images and volume rendering images of the lung in a mouse at four different PEEP levels.

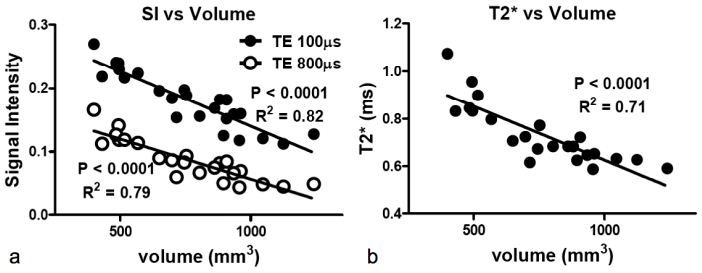

Fig. 2. Correlation beteen tsignal intensity (SI, a) and T2* (b) measured by UTE sequence and the lung volume.

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References: 1. Takahashi et al. Eur J Radiolo 64:367 (2007), 2. Gewalt et al. Magn Reson Med 29:99 (1993), 3. Miller et al. Magn Reson Imaging 11:1051 (1993)