Ultrashort Echo Time (UTE) 3D MRI of lungs in healthy subjects at 3 Tesla: assessment of lung tissue density

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Introduction: Numerous studies in animals or in humans have demonstrated the possibility of imaging lung tissue using pulse sequences with echo time shorter than 1 ms in order to overcome the fast decay of the NMR signal. In animals, these UTE (Ultrashort Echo Time) techniques have been applied to probe the loss of parenchyma tissue in animal models of emphysema [1,2]. The question whether UTE MRI can reliably assess lung tissue density in a clinical setup remains to be addressed. This point is crucial to make lung MRI amenable to routine use in respiratory diseases such as interstitial lung diseases, emphysema or air trapping. The aim of this study is to implement and validate a robust MRI protocol in a clinical scanner in order to assess the sensitivity of UTE sequences for quantifying, in healthy volunteers, the variations of lung tissue density induced by gravity dependence and lung inflation. The hypothesis is that variations in UTE signal will reflect variations in lung tissue density, with lower signal corresponding to lower lung tissue density.

Material and methods:

MRI acquisitions: 12 healthy volunteers (five women, seven men), age 22.6 ± 1.9 years, weight 64.6 ± 8.1 kg, were examined in supine position. MR acquisitions were performed on a 3 Tesla MR system. The integrated body coil was used for excitation and a flexible surface torso coil with 16 elements was used for detection and parallel imaging acceleration. A first dataset was acquired using a 3D UTE sequence with subjects freely breathing at tidal volume. Volume selection was equal to 375 mm^3 with outer volume saturation and fat suppression. The repetition time was set to 3 ms, echo time to 0.19 ms, pixel bandwidth to 1447 Hz and the flip angle to 8°. No signal averaging was used. Image matrix size was set to 288x288x100 corresponding to a pixel size in axial plane of 1.3 mm and a slice thickness of 3.75 mm. Image acquisition was gated during expiration phase, i.e. at functional residual capacity, using an echo navigator. The total scanning time was ranging between 7 and 9 minutes, depending on the breathing rate of the volunteer. A second and a third dataset were acquired without respiratory gating at end-inspiratory (i.e. total lung capacity) and end-expiratory (i.e. residual volume) breath hold. The acquisition of each of these dataset was obtained using three separate breath hold of 20 seconds duration each.

Image analysis and quantification: For free breathing acquisitions, three native axial slices were selected at apical, mid-, and basal level (for breath hold acquisitions, two slices at apical and basal levels were selected). For each selected slice, four ROIs (region of interest) were manually delineated in anterior and posterior regions of both right and left lungs. ROIs were drawn in the peripheral lung parenchyma in order to avoid main blood vessels. For each ROI within the lung parenchyma, a corresponding muscle ROI in the vicinity was delineated Typical defined ROIs are shown in Figure 1. The lung-to-muscle signal ratio was then computed for anterior and posterior, and right and left parts of the lung at each level. Additionally, a ROI located outside the subject was drawn for background noise measurements and computation of ROIs SNR.

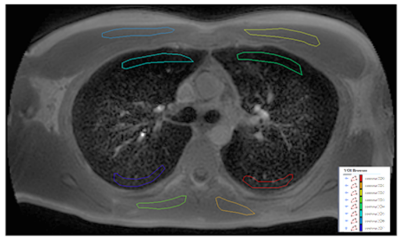

Fig 1. UTE axial apical slice selected from an end-expiratory breath hold 3D acquisition with defined ROIs in peripheral lung and skeletal muscle.

Results: Average SNR of lung parenchyma resulted in 34.6 ± 16 for free-breathing acquisitions, 7.4 ± 3.3 for end-inspiratory breath-hold acquisitions, and 11.8 ± 3.2 for end-expiratory breath-hold acquisitions.

On free-breathing datasets, average lung-to-muscle signal ratios varied from 0.34 (anterior ROIs) to 0.58 (posterior ROIs) (see Fig. 2). By contrast, no difference was found between lung sides or levels. On breath-hold datasets, lung-to-muscle signal ratios ranged from 0.14 to 0.49. These ratios were significantly greater in end-expiratory acquisitions than in end-inspiratory acquisitions (>70% increase), and significantly greater in posterior than in anterior areas (> 40% increase) ; p<0.001 for all comparisons (see Table 1).

Discussion: The free breathing UTE protocol used in this study allows a large recovery of the longitudinal magnetization from the lung tissue. For a typical breathing period of 4 s, the longitudinal magnetization between each gated acquisition is almost completely recovered and represents 95 % of the full magnetization. Neglecting the transverse relaxation at TE < 0.2 ms, the free breathing 3D UTE acquisition can be considered essentially as a proton-density (i.e. water-density) weighted imaging sequence. The vertical gradient observed in tissue density (52% increase of lung/muscle signal ratio between anterior and posterior regions) is related to the compression of elastic lung tissue and to the increase of blood volume in dependent lung due to gravity effect [3, 4]. The ability of UTE sequences to assess the lung water density and its variations are further exemplified in the breath hold acquisitions performed at total lung capacity and at residual volume. Due to the very short repetition time, breath hold 3D acquisitions are both proton-density and T_1-weighted. T_1 values in skeletal muscle and lung at 3 Tesla have been measured very similar in the order of 1400 ms [5]. Consequently, the lung/muscle signal ratio provides a relevant estimation of lung density with respect to muscle density. The increase in signal intensity ratio observed between expiration and inspiration are comparable to the changes in tissue density reported in CT study [6], in order of 66% and 62% in respectively non-dependent and dependent regions of the lungs.

	Anterior	Posterior	*p-value*
Lung breath-hold			
inspiration	0.136 +/- 0.054	0.234 +/- 0.066	<0.001
expiration	0.316 +/- 0.095	0.490 +/- 0.132	<0.001
p-value	<0.001	<0.001	/

Table 1. Lung/muscle signal ratio in breath hold acquisitions

Conclusions: The combined use of radial k-space scanning, of very short echo time, of respiratory gating or breath hold maneuvers proved to be very efficient to yield large SNR (> 30) in the lung parenchyma with millimetric in plane spatial resolution. The SNR in lung parenchyma was large enough to assess regional signal intensity variations, corresponding to water density changes due to gravity or lung inflation, in healthy subjects.

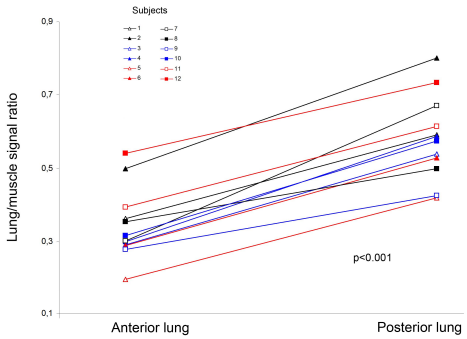

Fig 2. Lung/muscle signal ratio for all subjects in free breathing protocols. Significant increase (p<0.001) was observed between anterior and posterior lung regions.

The use of free breathing protocol with respiratory gating applied in this study has key advantages for imaging the lung tissue density. First of all, this protocol avoids breath hold which might be problematic for patients with pulmonary diseases. Its duration, shorter than 10 minutes, appeared to be easily tolerated by the volunteers. It requires no active participation from the subject and is thus likely to be compatible with most of the patients. This type of UTE imaging protocol with 3D coverage of the lungs will certainly be in the future of great interest for assessing, without ionizing radiation, the changes in lung tissue or in lung water density occurring in pulmonary diseases.

References: [1] M. Takahashi, *JMRI*, 2010 [2] M. Zurek, *Magn. Res. Med*., 2012 [3] H. Hatabu, *Eur. J. Rad* ,1999 [4] R.J. Theilmann, *JMRI*, 2009 [5] G.E. Gold, *AJR*, 2004 [6] J. A. Verschakelen, *AJR*, 1993