Ventilation/Perfusion MR imaging of the lung using T1-weighted ultra-short echo time (UTE) imaging: animal experiment in a 3 T clinical MRI system

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Introduction: Ultra-short TE (UTE) imaging in conjunction with projection acquisition of free induction decay (FID) can reduce TE to less than 100 μs thus minimizing signal decay caused by short transverse relaxation time (T2/T2*). This allows detection of endogenous MR signal of the lung parenchyma compared to a conventional short echo image sequence (1). Using an UTE sequence, we have demonstrated in a transgenic murine model that the emphysematous lung parenchyma had reduced signal intensity (SI) and T2* that closely related to the parenchymal tissue density (2). We hypothesize that the capability of the method to acquire inherent MR signal of the lung parenchyma should allow us to assess changes in SI due to inhalation of molecular oxygen or intravenous injection of gadolinium (Gd). In the present study, we tested the feasibility of a T1-weighted UTE sequence for assessment of regional pulmonary ventilation/perfusion which is essential for the evaluation of a variety of lung diseases.

Materials and Methods: MRI studies were conducted in a 3 Tesla (T) whole-body human scanner (Achieva™, Philips Medical Systems, Best, Netherlands) with a small solenoid coil (I.D. 63 mm). We first imaged a series of phantoms including 0-5 mM Gd aqueous solutions using a 3 dimensional (3D) radial FID sampling UTE sequence with various combinations of TRs/flip angles for optimization of T1-weighing. With the optimized imaging parameters, five 8-week old normal rats were subjected to the following MRI session. Under anesthesia with 1.5-2% isoflurane mixed in either medical grade air or 100% oxygen through a home-made mask, each entire lung in the selected volume of interest (VOI) was imaged in supine position with the UTE sequence at two different TEs of 100 μs and 2.3 ms. The other imaging parameters were: TR = 10 ms, flip angle = 30º, FOV=50^3 mm^3, matrix size=84^3 (affording reconstructed 260 μm isotropic resolution), NEX=1. The total scan time was approximately 2.5 min. A set of four UTE images was acquired for each rat first with air inhalation (baseline) and then with 100% oxygen inhalation, respectively. In addition, UTE imaging was performed with different flip angles (5º, 10º, 20º) to measure T1 of the lung parenchyma under both conditions. Subsequently, under air inhalation, four pre-contrast (baseline) and 12 post-contrast UTE images were obtained before and after intravenous injection of Gd at a dose of 0.2 mmol Gd/kg. On both the oxygen- and Gd-enhanced images, the SI of the lung parenchyma was 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 a reconstructed axial image. On the oxygen-enhanced images, %change in noise-corrected SI [$(SI_{post} - SI_{pre})/SI_{pre} \times 100$] relative to baseline or T1 measured with the air-inhalation and the 100% oxygen-inhalation were compared. On the Gd-enhanced images, %change in noise-corrected SI relative to baseline were measured in the same ROIs as investigated on the oxygen-enhanced images and plotted against time after the injection.

Results: Figure 1a demonstrates a representative map of %change in SI after inhalation of 100% oxygen on a UTE image. SI in the lung parenchyma was increased (15.1 ± 3.9 %, $P = 0.001$, Fig 1b) by inhalation of 100% oxygen in which the enhancement was higher than that in the surrounding tissues, e.g. skeletal and cardiac muscles. At the same time, the T1 of the lung parenchyma was reduced by ~24% (air: 1370 ± 159 ms v.s. 100% oxygen: 1049 ± 93 ms, $P < 0.01$). Figure 2a is a representative map of %change in SI right after injection of Gd, demonstrating strong enhancement over the lung parenchyma. Time course of %change in SI of the lung parenchyma before and after (up to 30 min) is shown in Figure 2b. SI increased 580 ± 172 % right after Gd-injection, and then gradually decreased over time, still retaining 329 ± 132 % ($P < 0.001$) up to 30 min after the injection. In the animal that had regional pulmonary embolism, several regions showed perfusion deficit (red allow, Fig. 3b) in which the increase of SI was lower up to 15 min after Gd injection than that in the normal parenchyma. By contrast, the abnormal regions showed almost identical changes in SI with the surrounding normal parenchyma in response to oxygen inhalation.

Discussion: We demonstrated that a T1-weighted UTE sequence detected change in SI after administration of 100% oxygen gas or 0.2 mmol Gd/kg Gd in the lung parenchyma in rats. Reduced T1 resulting from oxygen inhalation were also observed. It is important to note that all obtained images were not degraded by obvious motion artifact although neither cardiac nor respiratory gating was implemented. This was because of the trajectory through k-space in which the FID is sampled from the center of the k-space, the so called kooshball trajectory (3), and thus the center of k-space is heavily oversampled. This was a great advantage in generation of the calculated images (e.g. ventilation/perfusion maps) and assessment of regional parenchymal function since the currently presented ventilation/perfusion MR imaging methods (4) are particularly sensitive to motion artifact/position mismatch. Although the temporal resolution was not as high as the currently presented ventilation/perfusion MR imaging methods, the T1-weighted UTE sequence was feasible and showed the potential for ventilation/perfusion imaging as a new MRI method. Further evaluations are needed to establish the diagnostic value of the method in various pulmonary diseases.

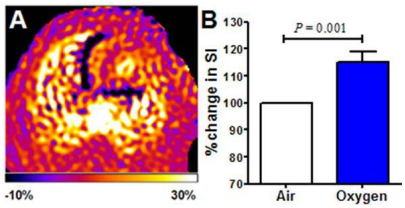

Fig 1. Typical map of %change in SI on the T1-weighted UTE imaging (**A**) and %change in SI (**B**) by inhalation of 100% oxygen in a normal rat lung.

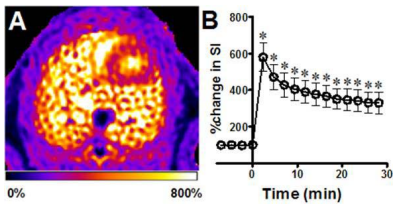

Fig 2. Typical map of %change in SI on the T1-weighted UTE imaging (**A**) and %change in SI (**B**) by i.v. injection of Gd in a normal rat lung. * $P < 0.001$ by Dunnett's multiple comparison test.

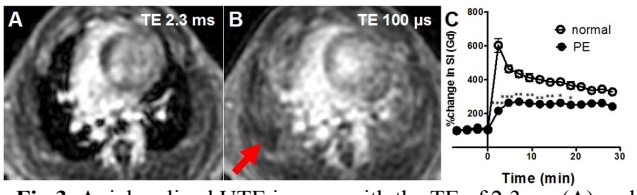

Fig 3. Axial resliced UTE images with the TE of 2.3 ms (**A**) and 100μs (**B**) immediately after 0.2 mmol/kg Gd injection. Note that a perfusion defect (red allow) is only detected with the short TE and the region shows less enhancement compared to surrounding normal parenchyma (**C**). * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ by Student's t-test.

Acknowledgements: This work was supported in parts by Philips Electronics Japan, Ltd. Cooperative Research grant.

References: 1. Gewalt et al. Magn Reson Med 29:99 (1993), 2. Takahashi et al. In Proceedings of the 17th Annual Meeting of ISMRM: pp11 (2009), 3. Rahmer et al. Magn Reson Med 55:1075 (2006), 4. Chen et al. Radiology 213:871 (1999)