Detection of perfusion-induced susceptibility effect in the lung by hyperpolarized 3He MRI: a co-registration with partial pressure of oxygen

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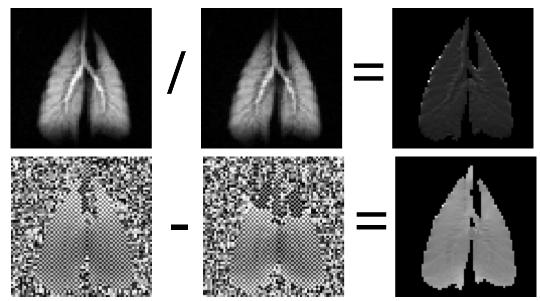
Introduction: Hyperpolarized ^{3}He MRI has been intensively studied for investigating pulmonary diseases. Research has focused primarily on structural and functional aspects of the airspaces, such as apparent diffusion coefficient (ADC), fractional ventilation, and partial pressure of oxygen (P_AO_2). Dimitrov *et al.* presented an indirect method for the detection of lung perfusion, in which gadolinium (Gd) was injected into the subject to modify the magnetic susceptibility difference between the lung airway and capillary bed. The phase change of alveolar ^{3}He gas caused by Gd flowing through the lung tissue was measured [1]. In this work, we present a double-echo acquisition technique for eliminating phase artifacts and for simultaneously measuring the partial pressure of oxygen. This technique allows automatic co-registration of lung perfusion and ventilation images. One direct application of this technique is the detection of pulmonary emboli (PE), local occlusions of blood vessels which cause acute perfusion abnormalities. Another potential application is the diagnosis of lung emphysema, a disease in which tissue destruction changes the local susceptibility.

Method: The *in-vivo* animal experiment was conducted under a protocol approved by the Animal Use Committee at the University of Pennsylvania. A normal Yorkshire pig (~20kg) was scanned with a 1.5T Siemens Sonata MRI system. During the experiment, the pig was sedated with ketamine and placed supine in a commercial birdcage RF coil (RAPID Biomedical, Würzburg, Germany) tuned to the ^{3}He resonance frequency 48.48MHz. A baseline measurement was performed before the Gd injection. A volume of 10mL Gd was injected through an ear vein by a power injector at the rate of 2.0mL/s; this injection was followed by saline flush. A susceptibility measurement was performed 10 minutes after the Gd injection. In each measurement, a tidal volume of 250 mL, consisting of 50 mL O_2 and 200 mL ^{3}He gas, was administered to the animal by a commercial-prototype ventilator. An additional 200 mL ^{3}He was used as a pre-wash to improve the signal-to-noise ratios of the images. A small flip angle gradient echo sequence, in which a second echo was introduced by inverting the readout gradient in each TR, was used in both measurements. Three coronal slices in the supine direction were acquired with the following imaging parameters: FOV=240 mm, slice thickness=25 mm, slice spacing=5 mm, TR=5.8ms; TE_1/TE_2=2.08ms/3.47ms, bandwidth: 800Hz/Px, matrix size=64×64, and flip angle ≈ 4.5 degrees. To measure oxygen partial pressure (pO_2) and oxygen depletion rate (R), six images were acquired for each slice at the following timings: [0.0000, 1.1125, 8.6275, 15.4400, 20.2550, and 23.0700] seconds.

Fig.1: Double echoes for measuring the susceptibility effect in the lung a) magnitude ratio = S_{echo1}/S_{echo2} b) phase difference = $phase_{echo2}$-$phase_{echo1}$. Note: the background noise in the phase difference map is masked according to the magnitude image.



Result and Discussion: The phase difference between the two echoes can be expressed as $\Delta\theta = \gamma*\Delta B*(TE_2-TE_1)$, where γ is the gyromagnetic ratio of ^{3}He, ΔB is magnetic field variation caused by susceptibility difference, TE_1 and TE_2 are the first and second echo time, respectively. As shown in Fig.1, the phase difference map (Fig1.b) was generated by subtracting the phases of the two echoes, which allowed for the removal of the phase artifacts (offsets). The magnitude ratio map (Fig1.a) was calculated from the signal ratios of the first and second echoes and can be used for generating the T2* map. The phase difference maps before and after Gd injection are shown in Fig. 2. The average phase change caused by this susceptibility difference enhancement (Gd injection) was 57 degrees. In Fig. 3, the pO_2 and R parametric maps were generated using a bin-based data processing procedure which applied the multiple regression fitting method to extract the pO_2 and R [2]. It is notable that the global mean values of pO_2 and R were not affected by the Gd injection.

Fig.3: Maps of oxygen partial pressure (pO_2) and oxygen depletion rate (R) before and after the Gd injection. The global mean values of both pO_2 and R were not affected by Gd injection.

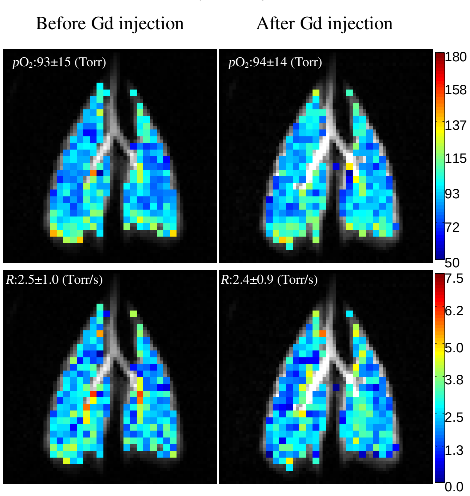
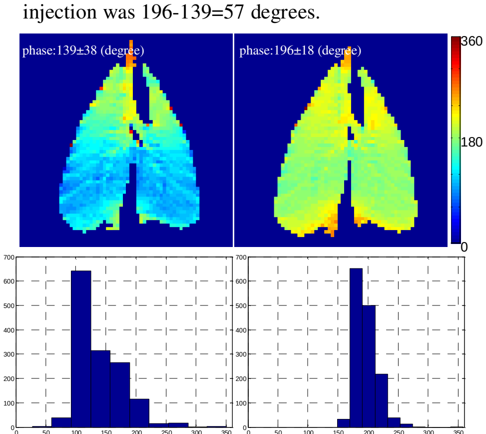


Fig.2: Phase maps and histograms before and after Gd injection. The average phase change caused by Gd injection was 196-139=57 degrees.



Conclusion: In this work, we have presented a double-echo acquisition technique for simultaneously measuring the susceptibility effect and partial pressure of oxygen.

References: 1) Ivan E. Dimitrov *et al.*, *J. Mag Res Imag* 21:149–155 (2005) 2.) J. Yu *et al.*, *Mag Res Med* 2007 (accepted).