Detection of pulmonary embolism with hyperpolarized 3He MRI: a comparison of pO2-based and susceptibility-based techniques

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Introduction: Pulmonary embolism (PE) is a common, elusive, and deadly condition, with an annual incidence of over 600,000 cases, with 200,000 deaths, in the United States alone. In recent years, hyperpolarized ^{3}He MRI has been applied with the aim of PE diagnosis. To date, two techniques have been proposed. The first technique measures the pulmonary partial pressure of oxygen by utilizing the fact that the alveolar partial pressure of oxygen is elevated in the region where blood flow is blocked by PE (1). The second technique uses gadolinium (Gd) to modify the magnetic susceptibility difference between the lung airway and tissue, and this modification is recorded through the phase of the HP ^{3}He MRI signal (2). In this work, we present a comparison of the two techniques by performing an in-vivo experiment on a pig model with simulated pulmonary embolus.

Methods: The *in-vivo* animal experiment was conducted under a protocol approved by the Animal Use Committee at the University of Pennsylvania. In the PE experiment, a normal Yorkshire pig (~20kg) was transported to an interventional radiology lab where a balloon catheter was placed in the mid-portion of the right lower lobar pulmonary artery via passage through the femoral vein and the right atrium of the heart. The size of the balloon (Boston Scientific Corp., Natick, MA) was 9 mm x 2 cm. Arteriography was performed through the balloon catheter guide wire lumen to confirm the position of the balloon. The pig was then transported to a 1.5T Siemens Sonata MRI scanner for imaging. In the experiment, three measurements were performed in which the pO2 and susceptibility difference were simultaneously measured. First, the balloon was deflated and the animal was in a normal state. A baseline measurement was performed. After the baseline measurement, PE was simulated by inflating the balloon with saline solution until the affected artery was completely occluded. A volume of 15mL Gd was injected through an ear vein by a power injector at the rate of 2.0mL/s; this injection was followed by a saline flush. The second measurement was initiated 10 minutes after the Gd injection. The third measurement was performed after another 15mL Gd was injected to further enhance the susceptibility difference between the airway and lung tissue. In each of the three measurements, 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 prototype ventilator. A small flip angle gradient echo sequence, in which eight gradient echoes were generated by inverting the readout gradient in each TR, was used in the three 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=15ms, TE_1/echo separation=2.08ms/1.42ms, bandwidth: 800Hz/Px, matrix size=64×64, and flip angle ≈ 4.5 degrees. In each measurement, a series of six images was acquired for each echo with delays of 0, 2.880, 10.163, 16.743, 21.323 and 24.203 seconds with respect to the first image to measure oxygen partial pressure (pO_2) and oxygen depletion rate (R).

Fig.1 A series of six images was acquired for pO2 measurement. Upper row: baseline measurement; bottom row: the measurement where the simulated PE was activated. Note that signal decays more quickly in the PE region, than in the rest of the lung.

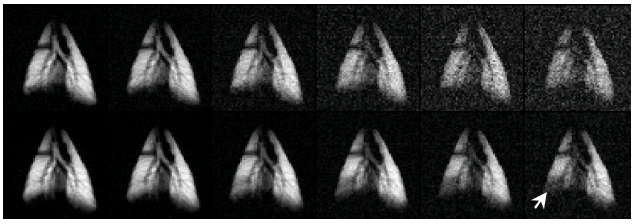


Fig.2 Fitted pO2 maps of the three measurements. In the second and third measurements, pO2 values were elevated in the region where blood flow was blocked by PE.

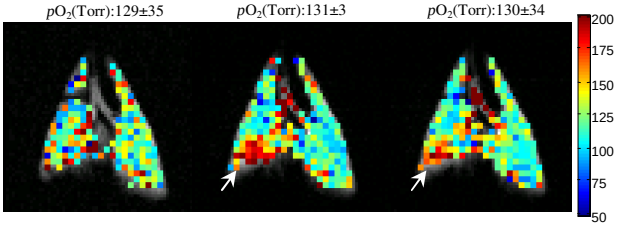


Fig.3 Multiple echoes acquired for susceptibility measurement (for simplicity, only the odd number of the eight echoes are shown). Top row: baseline measurement; bottom row: the second measurement with simulated PE activated and Gd injected.

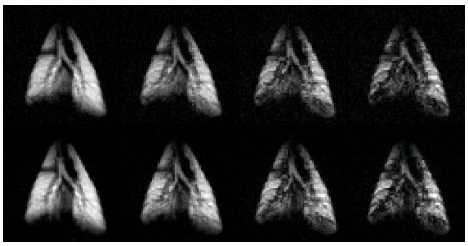
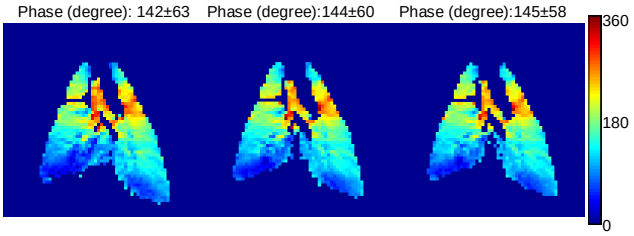


Fig.4 Phase maps of the three measurements. It should be noted that no significant phase changes were observed after the simulated PE was activated.



Result and Discussion: Figure 1 shows the six raw images of the first echo of the middle slice acquired in the baseline and the second measurements. In the right lower region, where the lobar pulmonary artery was blocked by the balloon, the ^{3}He MRI signal decayed more quickly. In the same region, elevated pO2 values were observed in the fitting parametric maps. Figure 3 shows the eight echoes acquired for the middle slice (for simplicity, only the odd number of echoes are shown). It should be noted that in the PE region, no obvious differences were observed between the baseline and second measurements. This observation is confirmed in Figure 4, where no significant differences can be seen in the phase maps of the three measurements.

Conclusion: In this work, we present a comparison of pO2-based and susceptibility-based hyperpolarized ^{3}He MRI techniques for the detection of pulmonary emboli in a pig model. The experiment results show that the pO2-based technique is more sensitive than the susceptibility-based technique. The results also suggest that a superparamagnetic intravascular contrast agent may be needed to introduce the measurable magnetic susceptibility difference if the susceptibility-based technique is applied for the detection of PE.

References: 1) Aman Jalali *et al.*, *Mag Res Med*, 51:291–298 (2004) 2) Ivan E. Dimitrov *et al.*, *J. Mag Res Imag*, 21:149–155 (2005)