Human Imaging of Ventilation-Perfusion Ratios Using Hyperpolarized Helium-3 MRI: Preliminary Results

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Introduction: Inhaled hyperpolarized helium-3 (HP ^{3}He) gas acts as a dynamic contrast agent that provides MR images of gas distribution in the lung. However, HP ^{3}He signal quickly decays in the presence of molecular oxygen. Region-of-interest (ROI) analysis of images obtained during static breath-hold sequences reveals that areas of the lung with higher regional alveolar oxygen concentrations demonstrate signal decay more quickly than lung regions with lower alveolar oxygen tensions. While the interaction with oxygen was initially thought to be a profound drawback for lung imaging, it turns out that this property enables researchers to determine regional alveolar oxygen tensions (P_AO_2) through analysis of the rate of signal decay [1,2]. Since local P_AO_2 is also influenced by regional perfusion, HP ^{3}He imaging indirectly provides information about lung perfusion status, and therefore, regional ventilation to perfusion ratios (V_A/Q). While the determination of regional V_A/Q ratios would be of great importance to clinicians and researchers interested in normal and abnormal lung physiology, no technique is available that can provide this information on a regional basis without the use of radioactive materials. To obtain V_A/Q by HP ^{3}He MRI, the partial pressure of oxygen (P_AO_2) is first measured [1] and then conventional gas-exchange equations are utilized to derive the regional V_A/Q ratio [3].

Methods: Work was performed under an approved FDA IND and IRB protocol. Hyperpolarized ^{3}He gas was prepared through spin exchange collisions with optically pumped rubidium atoms using a commercial prototype noble gas hyperpolarization system (Amersham Health, Durham, NC). The ^{3}He gas was polarized for approximately 14 hours to achieve an average polarization of 38%. A human subject then inhaled 500 ml of a mixture of 80% HP ^{3}He gas (diluted with N_2 to 6 mmol/l) and 20% O_2. Measurements of regional alveolar oxygen pressure were performed using a novel single-acquisition sequence**.** The key idea of this sequence is to initially acquire two images at a relatively short time interval in order to obtain the regional flip angle. The angle obtained in this manner is then used to extract the oxygen-induced decay rate from the rest of the series. The method also takes into account oxygen-induced depolarization during the initial flip angle determination using an iterative procedure. The MR images were analyzed by first calculating P_AO_2 and then deriving the V_A/Q ratio for 32 regions of interest (ROIs) over the entire lung volume.

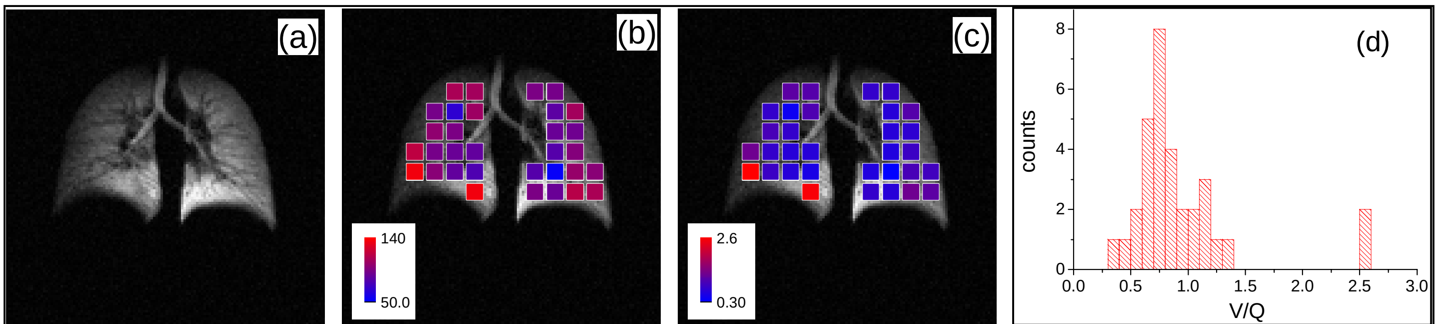

Fig 1(a): MR image of the human lung.

Fig 1(b): Color plot of the P_AO_2 values in torr.

Fig 1(c): Color plot of the V/Q values.

Fig 1(d): Histogram of the V/Q values from part (c).

Results and Discussion: Helium gas distribution was homogeneous throughout the lung. The pixels were binned (binning size was 8 x 8 pixels) to reduce noise. The bins were then masked for SNR and homogeneity. In 32 ROIs regional P_AO_2 averaged 96 torr (range 54 to 134 torr). The average V_A/Q ratio for the entire lung was 0.93. Regional V_A/Q ratios ranged from 0.32 to 2.6. Hyperpolarized gas had no effect on serum blood counts or chemistries. It appears to be well tolerated in humans.

Conclusion: This is the first demonstration of the use of HP ^{3}He MRI techniques to obtain both regional P_AO_2 and regional V_A/Q in humans. Adding O_2 to the HP ^{3}He gas mixture just prior to inhalation in order to simulate room air O_2 concentrations will add safety for imaging human subjects with advanced lung diseases. Further development and refinement of these techniques may provide an important tool to clinicians and researchers interested in pulmonary physiology.

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