Regional Lung Perfusion Mapping Using Hyperpolarized 3He MRI and Validation to Microsphere

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Introduction

Alveolar oxygen consumption during a breath hold is governed by the capillary perfusion rates and the end and pre-capillary oxygen concentration gradients, (i.e., Fick's principle). Rearranging terms gives the following expression of alveolar perfusion rates,

$$Q = \frac{dP_A O_2(t)}{dt} \frac{V}{RT} \frac{1}{[O_2]_A - [O_2]_V} \quad (1)$$

where Q, P_AO_2, V, R, T, $[O_2]_A$, and $[O_2]_V$ represent, the local blood flow, alveolar partial pressure of oxygen, local lung volume, Ideal gas constant, temperature, arterial oxygen concentration, and venous oxygen concentration, respectively. Observe that all terms on the right-hand side of equation (1) can be measured experimentally using ^{3}He MRI and venous blood gases. The perfusion limit is assumed to hold so that Adair's equation can be used to determine arterial oxygen concentration from P_AO_2. Local lung volumes are obtained by comparing a known lung volume, (e.g., trachea, to a region of interest after successively re-breathing the subject to the equilibrium condition).

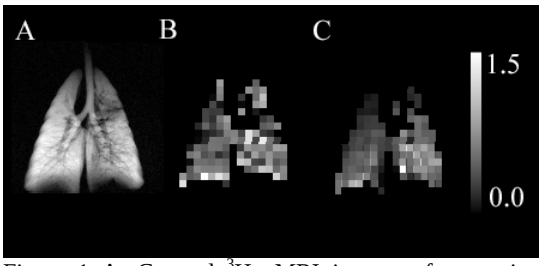

Figure 1 A: Coronal ^{3}He MRI images of a porcine lung. B and C represent perfusion maps obtained after and before microsphere injections, respectively. Units in ml of blood per min per unit lung volume.

Method

Experiments were conducted under an IACAC approved protocol. 20 kg, Yorkshire pigs were induced, intubated, paralyzed, and maintained on isoflurane anesthesia. Vital signs were monitored during the procedure. IVC and right ventricle catheters were placed under fluoroscopic guidance. The pigs were then placed in a double tuned birdcage coil, for proton and ^{3}He, and positioned in a 1.5-T whole-body imager (Sonata, Siemens). The lungs were localized in space using a series of proton images. 500 ml of ^{3}He/N_2 gas, net activity of 6.2%, was used to ventilate the pig for 5 cycles. The hyperpolarized ^{3}He was generated via the spin-exchange optical pumping method using a commercial polarizer (Amersham Health, Durham, NC). MRI imaging began immediately after the fifth inflation using a 2D fast gradient-echo pulse sequence with the following imaging parameters: flip angle, 2.5^0; TR/TE, 7/1.6 ms; FOV, 24x24 cm; matrix size, 128x128; slice thickness, 2 cm. Interscan time was minimized for the first two images in the series, thereafter interscan times were set at 6 seconds. The first two images were used to calculate regional flip angle. The remaining images were used to obtain the oxygen degradation rates. Immediately after helium imaging concluded blood was withdrawn from the right ventricle at a rate of 12 cc/min. 30 seconds later five million microspheres were injected into the IVC at a rate of 5 million microspheres per minute. At the conclusion of the injection the pigs were sacrificed and their lungs were fixed with Waymouth and agarose solution. The lungs were cooled, harvested, and sectioned. The sectioned lung segments were then sent for processing (IMT, Irving, CA).

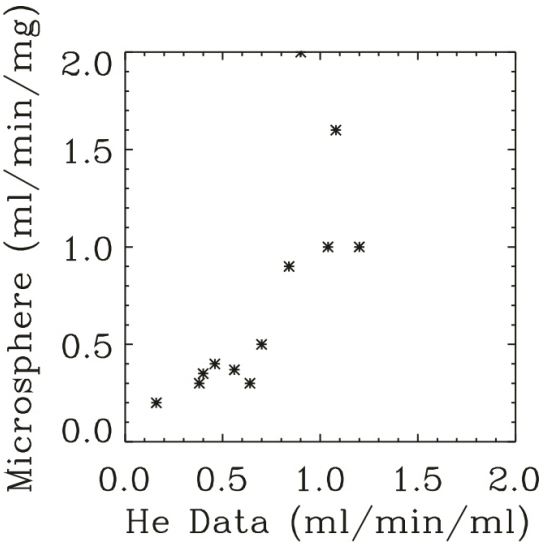

Figure 2. Helium perfusion measurements vs. microsphere data-from figure C above. Note the relatively good agreement between microsphere and ^{3}He data.

Results and Discussion

Figure 1 depicts coronal ^{3}He images of porcine lungs used to calculate regional oxygen tensions, and perfusion maps obtained immediately before and after the injection of microspheres. The first experiment was performed in the absence of oxygen in the inspired ^{3}He gas mixture. During the second experiment 20% oxygen was included in the inspired mixture. In figure 2 we compare sample microsphere data with the results obtained using HP ^{3}He MRI. Note the relatively good correlation between the microsphere data and ^{3}He data.

Conclusion

Local measures of the rate of change of oxygen tensions in a lung can be used to calculate regional lung perfusion. Preliminary results suggest that HP ^{3}He measurements agree with those obtained using the microsphere methods. This technique may lead to a noninvasive method for studying the pathophysiology of diseases affecting pulmonary circulation.

Acknowledgments

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