Ventilation and Perfusion Ratio obtained by Polarized Carbon-13 and Polarized Gas MRI

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Introduction: The lung's primary purpose is to supply enough oxygen to the body to meets its metabolic needs and to remove carbon dioxide formed as a byproduct of metabolism. The body does this most efficiently when it matches ventilation, the delivery of air to the lungs, with perfusion, the delivery of blood to the lungs. The ventilation perfusion ratio (V/Q) is the most common measure of this matching. A ratio of one is considered ideal. Diseases that affect ventilation and or perfusion perturb the V/Q from one. The V/Q is therefore an important measure of lung function. MRI measures of V/Q typical based on hyperpolarized gas MRI's ability to determine regional oxygen levels. The regional oxygen levels are then converted to regional V/Q ratios using a series of mass balance equations. This approach performs poorly in regions of the lung with low ventilation due to signal to noise constraints, and for V/Q far from oxygen's blood air partition coefficient. In these circumstances an alternate methodology is desirable. We explore the possibility of elucidating regional ventilation and perfusion through the use of a hyperpolarized gas MRI wash in technique to determine regional ventilation, and HP ^{13}C MRI to illustrate regional perfusion.

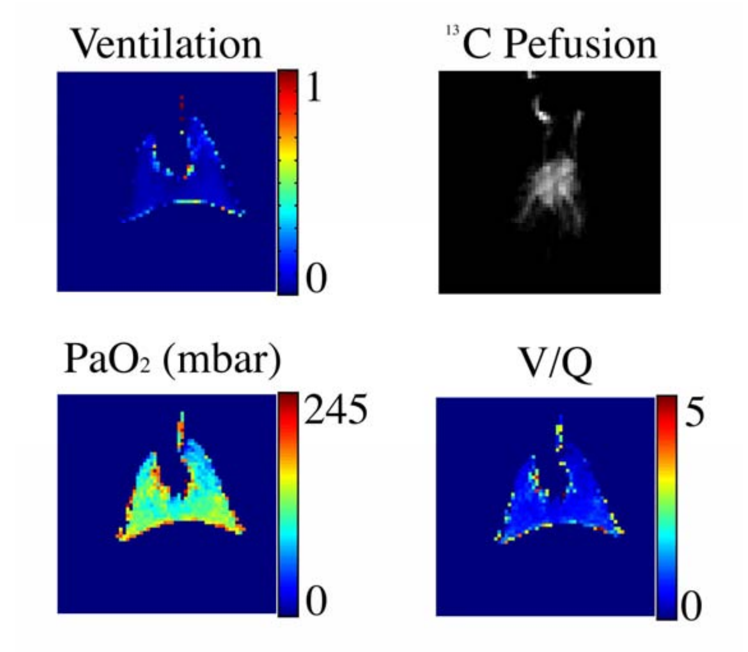

Figure 1. Fractional ventilation, ^{13}C perfusion imaging, PaO_2, and V/Q as a function of position. Note how the HP ^{13}C angiogram and fractional ventilation are relatively homogeneous. This is expected in a healthy supine animal and corresponds to a near uniform V/Q centered at 1.0.

Method: Two 4 kg New Zealand rabbits were induced, intubated, and maintained using ketamine anesthesia. Central venous and arterial catheters were placed. The rabbits were attached to a computer controlled MRI compatible ventilator and placed in a supine position inside of a solenoidal coil. The tidal volume was fixed at 25 ml. The I to E ratio was set at 1: 4, and the inspired oxygen at 20%. The respiratory rate was set at 50 breaths per minute. The ventilator parameters, except for tidal volumes were then adjusted to maintain the rabbit's end tidal PCO_2 at 40 mm Hg and oxygen saturation greater than 98%. A warming blanket was used to maintain the rabbit's core temperatures in the physiologic range. Regional ventilation was determined by measuring the build up of magnetization in a region of the lung after seven sequential HP ^3He-O_2 breaths (20%-80% mixture). Helium polarization ranged from 30% to 40 %. One image was taken after each ^3He-O_2 breath using a multislice 2D GE pulse sequence with the following imaging parameters: FOV 140 mm; slice thickness 15 mm; T_R/T_E 7.3 ms/3.6 ms; resolution 64×64. Perfusion images were obtained after injecting 2 ml of 300 mM solution of HP hyrdoxyethylpropionate into the right atrium, using a tFISP pulse sequence with the following imaging parameters: TR/TE, 4.6/2.3 msec; FOV, 140 mm, matrix size, 64 x 64; flip angle 180°; slice thickness of 15 mm. A total of 15 images were obtained at 1 second intervals. At the conclusion of the imaging session alveolar oxygen concentrations were measured using a single acquisition HP MRI oxygen sensing experiment using the same imaging parameters as for the ventilation experiment. Interscan times were set at 0, 6.4, 5.7, 3.7, and 1.7 s. Oxygen values were reconstructed using a multiple regression approach. Cardiopulmonary monitoring was performed to ensure that the rabbit's cardiopulmonary status remained stable during the entire imaging experiment.

Results and Discussion: Figure 1 depicts fractional ventilation, PaO_2, and V/Q maps as a function of position for a coronal slice through the main stem bronchi. A corresponding HP ^{13}C angiogram taken just anterior to the ventilation imaging is shown as well. Note how the fraction ventilation and perfusion images are nearly homogenous suggesting that the rabbit rabbit's ventilation perfusion ratio will be nearly homogenous. No ventilation or perfusion defects are seen. This is expected since this is a healthy rabbit in the supine position. V/Q maps generated from PaO_2 measurements are shown for comparison and confirm these observations.

Conclusion: HP ^3He MRI wash-in techniques can be combined with HP ^{13}C MRI perfusion images to obtain critical insight into regional ventilation perfusion ratios. The results agree will with the standard HP oxygen to V/Q mapping methods and can be used to augment this approach in diseased states where ventilation is low or for V/Q ratios corresponding to oxygen values far from the oxygen blood air partition coefficient.

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