Posture Dependent Effects on Human Pulmonary Oxygen Partial Pressure

R. N. Scheidegger[1,2], D. Chonde[1,2], L. L. Tsai[2,3], M. S. Rosen[1,4], S. Patz[3,5], R. W. Mair[1], and R. L. Walsworth[1,4]

[1]Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, United States, [2]Harvard-MIT Division of Health Sciences and Technology, Cambridge, MA, United States, [3]Harvard Medical School, Boston, MA, United States, [4]Dept of Physics, Harvard University, Cambridge, MA, United States, [5]Radiology Dept, Brigham and Women's Hospital, Boston, MA, United States

Introduction: The alveolar partial pressure of oxygen, p_AO_2, is a key measure of the effectiveness of pulmonary ventilation and pulmonary perfusion. Gravity induces vertical gradients in transpulmonary pressure and pulmonary vascular pressures leading to regional heterogeneity of pulmonary ventilation and perfusion, which in turn induces a vertical p_AO_2 gradient [1,2]. Some animal studies have suggested that similar p_AO_2 heterogeneity still remains in the upright lung during weightlessness such that gravity does not solely account for the observed pattern [3,4]. Non-invasively observing the effect of gravity on lung physiology has been a challenge because clinical scanners restrict the subject to a horizontal position. We have designed and built an open-access human MRI system to permit study of pulmonary function with subjects in a variety of postures [5,6]. We present a study of human p_AO_2 mapping in subjects in both vertical and supine positions.

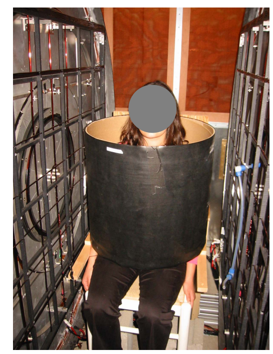

Figure 1: Subject sitting vertically in the open-access MRI system.

Methods: Upright and horizontal human lung images were acquired with a custom open-access MRI system (Figure 1) operating at B_0 = 6.5 mT (65 G) applied field, allowing ^{3}He MRI at 210 kHz. Volunteers at FRC inhaled ~ 500 cm^3 of polarized ^{3}He gas from a Tedlar bag, which was filled directly from a home-built spin-exchange polarizer. Eight 2D GRE images (FOV = 50 cm, matrix size = 128 x 32, TR/TE = 64/10 ms, NEX = 1, FA = 3°) were acquired with 5-second inter-image delays during a single breath-hold for p_AO_2 calculation from the ^{3}He MRI signal decay. Image acquisition was repeated in a second breath hold for reliability estimation. Excitation flip-angles were calibrated precisely beforehand using phantoms as the subject loading of the RF coil at 210 kHz was minimal and reproducible [6]. Image analysis and p_AO_2 calculation was performed using Prospa software (Magritek, New Zealand). All protocols were approved by the Partners Human Research Committee at Brigham & Women's Hospital, under an inter-institutional IRB agreement with Harvard University.

Results: Phantom flip angles were uniform and normally distributed (mean=3.60°, stdev=0.05°). Figure 2 shows sample p_AO_2 maps from the human lung, acquired while a subject was lying supine (axial, coronal) and sitting vertically (coronal).

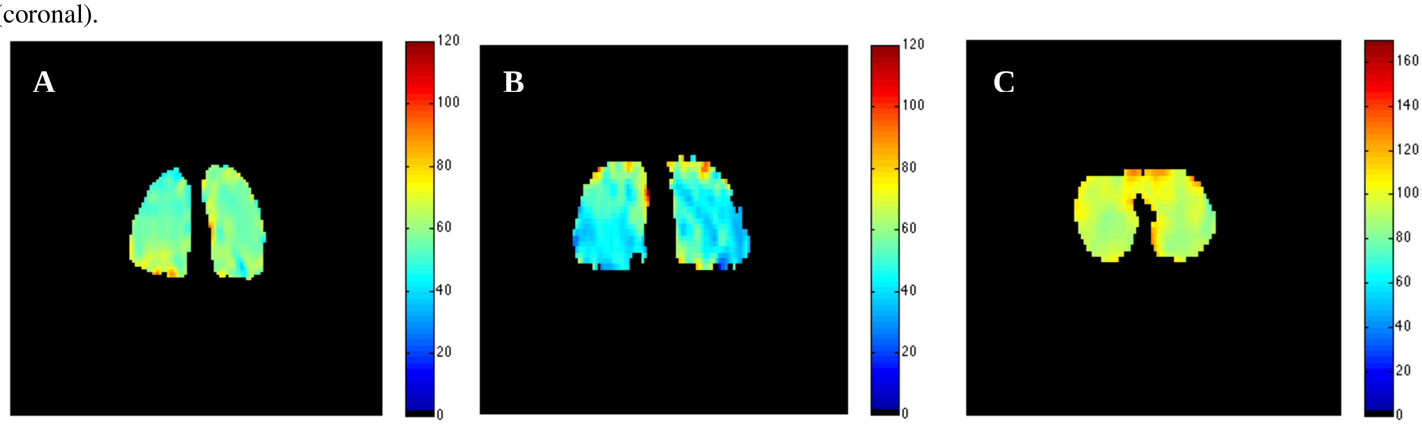

Figure 2: A) Calculated p_AO_2 map obtained from MR signal decay in 5 successive coronal images in supine volunteer. B) Calculated p_AO_2 map obtained from MR signal decay in 3 successive coronal images in vertical subject. C) Calculated p_AO_2 map obtained from MR signal decay in 8 successive axial images in supine volunteer. The color bar indicates the value of p_AO_2 in units of torr.

Discussion: Our imager permits, for the first time, a non-invasive, direct comparison of p_AO_2 distribution with the subject in vertical and horizontal orientations. Histograms of p_AO_2 values in the upright and horizontal lung were significantly different ($p<0.01$). In the vertical lung the standard deviation of p_AO_2 values was higher than that of the horizontal lung (11.6 torr vs. 6.4 torr, respectively) indicating higher p_AO_2 heterogeneity in the vertical position. This is seen as a p_AO_2 gradient in the top third of the lung in the vertical orientation, which is consistent with the "zones of the lung" description by West [2]. It results from a higher degree of perfusion in the lower region of the lung when vertical. The p_AO_2 map obtained when the subject is supine is very uniform. Horizontal coronal and axial p_AO_2 histograms were also significantly different ($p<0.01$) due to a slight gradient from top to bottom in the supine axial image.

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