Introduction

Regional heterogeneity of pulmonary ventilation and pulmonary perfusion is well-known to be influenced by gravity (Fig. 1) [1,2], but is also affected by the lung parenchyma and surrounding organs [3,4]. Of particular interest is the change in gas exchange dynamics when a subject is moved from horizontal to upright. A key measure of the effectiveness of ventilation and pulmonary perfusion is the alveolar partial pressure of oxygen, \( p_{O_2} \). MRI of hyperpolarized \(^3\)He has provided the first regional measure of \( p_{O_2} \) [5-6], from which the traditional ventilation-to-perfusion ratio, V/Q can be inferred [5].

Methods

The open-access human MRI system (Fig. 2) was optimized to operate at \( B_0 = 6.5 \) mT applied field, allowing \(^3\)He MRI at 210 kHz. Subjects inhaled \(-500 \) cm\(^3\) of polarized \(^3\)He gas from a Tedlar bag, which was filled from a home-built spin-exchange polarizer (Fig. 3). Gradient-echo images: no slice select, FOV = 50cm, 128 x 64/32, TR/TE = 64/10ms, NEX = 1, FA = 3\(^\circ\). Multiple 2D images acquired with 5s inter-image delays during a single breath-hold for \( p_{O_2} \) calculation.

Benefits of operation at very-low-field

Determination of \( p_{O_2} \) from \(^3\)He MRI requires precise knowledge of the RF flip-angle. In high-field scanners, the \( B_0 \) magnet design (solenoid) results in RF coils with very inhomogeneous \( B_1 \) being employed. At a Larmor frequency \(-50 \) MHz, these coils load significantly, and so RF flip angle varies with subject. Every \( p_{O_2} \) measurement therefore includes determining the spatially-varying flip-angle (Fig. 4). Our magnet design permits the use of a solenoid as the \( B_1 \) coil, which exhibits a highly homogeneous \( B_1 \) field, and a coil \( Q \) that is not affected by human subject loading (Fig. 5). Hence, our RF flip angle is spatially invariant (Fig. 6), and can be pre-calibrated, simplifying \( p_{O_2} \) measurements at very low field (Fig. 7).

Discussion

Fig. 9B represents the first time \( p_{O_2} \) has been imaged in an upright human subject.

- Our imager permits, for the first time, a non-invasive, direct comparison of \( p_{O_2} \) distribution in the same subject with the subject in vertical and horizontal orientations:
  - When vertical, a significant gradient in \( p_{O_2} \) is seen in the top third of the lung, consistent with the description in Fig. 1 [2,6].
  - The \( p_{O_2} \) map obtained when the subject is supine is very uniform and in agreement with previous MRI results [6].
  - Histograms of \( p_{O_2} \) values in the upright and horizontal lung are significantly different (p<0.01). In the vertical lung the standard deviation of \( p_{O_2} \) values was higher than that of the horizontal lung (11.6 torr vs. 6.4 torr, respectively) indicating higher \( p_{O_2} \) heterogeneity in the vertical position.
  - Measured values of \( p_{O_2} \) are lower than physiologically normal values. This is a result of acquiring this data after a high-resolution 2D image during the same breath-hold.

- Operation at very low field, with an open-access magnet, gives a number of advantages in \( p_{O_2} \) measurement in comparison to high-field clinical scanners:
  - Solenoid \( B_1 \) coil is highly homogeneous, and can be rotated with the subject, so \( B_1 \) is invariant with postural changes.
  - Subject loading is negligible, so \( B_1 \) is constant from subject to subject, and can be calibrated in advance.
  - Time and \(^3\)He magnetization not consumed by mapping a spatially-varying flip-angle during each measurement of \( p_{O_2} \).

References

2. J.B. West et al., J. Appl. Physiol., 19, 713-724 (1964)

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