Three-dimensional PO_2 mapping of human lungs in a short breath hold using hyperpolarized xenon-129

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Purpose: It has long been argued that hyperpolarized-gas measurements of oxygen partial pressure (PO_2) in the lung should be made using a true 3D acquisition with non-selective RF pulses, not only to obtain seamless whole-lung coverage and 3D spatial resolution, but also to avoid quantitative bias due to gas diffusion between neighboring slices during 2D slice-selective acquisitions [1]. Here we demonstrate a 3D pulse sequence for mapping apparent PO_2 with sub-centimeter in-plane resolution using a single short breath hold of hyperpolarized xenon-129, and assess the repeatability of the quantitative results in human subjects.

Methods: Repeated PO_2 scans were performed in 10 human subjects (8 healthy, 1 former smoker, 1 cystic fibrosis). The inhalation procedure was kept as similar as possible for both scans in each subject. In seven of the studies (5 healthy, smoker, CF), the subject inhaled ~700 ml of hyperpolarized xenon-129 starting from the end of a normal tidal expiration, followed by 250 ml of room air to clear xenon-129 from the trachea. In the other three studies (3 healthy), the subject inhaled a mixture of 800 ml xenon-129 and 200 ml oxygen starting from the end of a normal tidal expiration, followed by a small (unmeasured) inhalation of room air to clear the trachea. Xenon-129 gas was polarized to ~50% using a commercial system (Xemed LLC) and MR imaging was performed at 1.5T using a whole-body scanner (Siemens Avanto) and homebuilt elliptical RF chest coil.

Fig. 1: Timing diagram for PO_2 scan. Three complete 3D image sets are acquired (green).

Each PO_2 scan was performed during an 11s breath hold at the end of the inhalation procedure, and consisted of three cardiac-triggered 3D image acquisitions arranged as shown in Fig. 1. Apparent T1 was calculated pixel-by-pixel from the reconstructed magnitude images I_1, I_2, I_3, using the formula: $T1 = (t_{21} - t_{32}) / \log (I_1 I_3 / I_2^2)$, where t_{21} (t_{32}) is the time between triggers for the 1st and 2nd (2nd and 3rd) images. The T1 map was converted to PO_2 using the appropriate conversion factor: $PO_2 = 2040$ mm Hg · s / T1 [2]. Whole-lung mean PO_2 was computed for each scan, and the coefficient of repeatability was calculated using one-way analysis of variance. Imaging pulse sequence: 3D image sets were acquired using a spoiled gradient pulse sequence with non-selective RF excitation pulse and stack-of-spirals *k*-space trajectory (8 slew-rate limited spiral interleaves in the axial imaging plane, and 20 partitions in the head-foot direction). Other parameters included: TR = 6.0 ms, TE = 0.4 ms, flip angle = 3.7°, pixel resolution = 7.5×7.5×20 mm. This pulse sequence acquires a whole-lung 3D image of inhaled xenon-129 in just under one second.

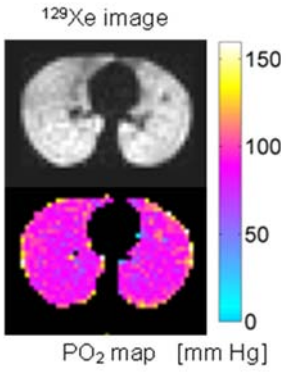


Fig. 2: Axial partition from a PO_2 scan of a healthy subject (female, 25 years old).

Results: Figure 2 shows a representative xenon-129 image and apparent PO_2 map of a central partition from one of the healthy subjects, showing relatively uniform ventilation and PO_2. Heart-motion artifacts were noticeably absent in all scans. Figure 3 shows multiple contiguous partitions from both scans of the CF subject. Ventilation and PO_2 are nonuniform, and remarkably similar variations are evident in both scans. Figure 4 shows the mean apparent PO_2 computed over the whole lung for all scans. The repeatability was excellent and highly significant ($r = 0.97$, $p < 0.01$).

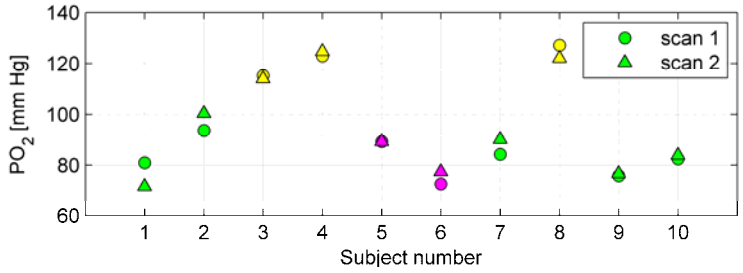
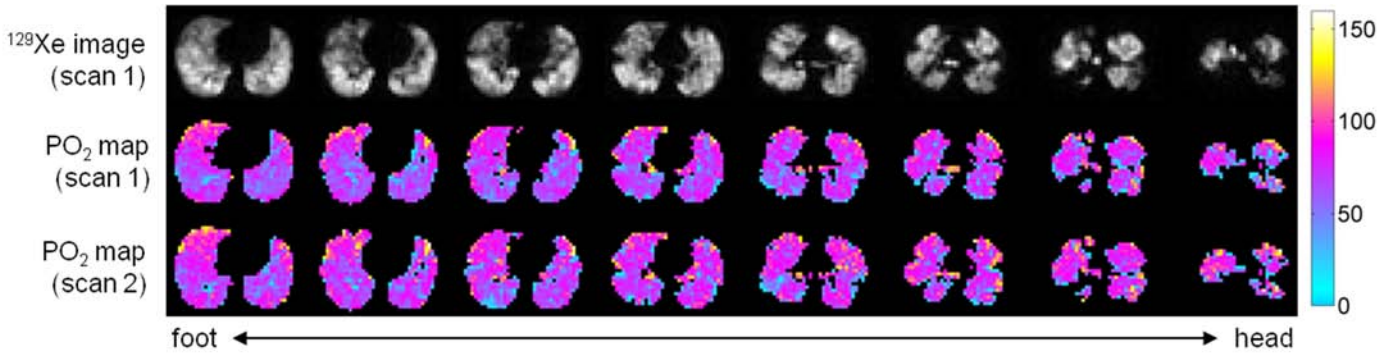


Fig. 4: Repeatability of whole-lung mean PO_2. Yellow markers are healthy subjects that inhaled 20% oxygen mixture; green are other healthy subjects; magenta are non-healthy subjects. The repeatability coefficient r is 0.97.

Discussion: It is clear from this data that the composition of the inhaled mixture influences the measured values, as the highest PO_2 values were measured in the 20% oxygen inhalations. It is also clear that at the inhaled volumes used here (> 1 L), we are not measuring steady state PO_2. It would be highly desirable to make the PO_2 measurement at steady state using an inhaled volume of ~500 mL containing 21% oxygen, but the available SNR did not allow for this in the present study. A more sensitive RF coil would help in this regard.

Fig. 3: Multiple axial partitions from both PO_2 scans of the cystic fibrosis (CF) subject (male, 37 years old).



Conclusions: We have demonstrated the first pulse-sequence method capable of obtaining 3D PO_2 maps with sub-centimeter resolution in a short breath hold. Our results suggest that the breathing procedure and oxygen concentration of the inhaled mixture affects the measured PO_2, but also suggest that such measurements are highly repeatable when the same procedure is used.

References: [1] J.M. Wild et al. *Magn Reson Med* 2005; 53:1055. [2] S. Patz et al. *Eur J Radiology* 2007; 64:335.

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