Lung inflation state dominates over intrapulmonary pO_2 regarding T_2^* of ^{3}He in human lungs

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Introduction: Molecular oxygen (O_2) is paramagnetic (χ_{vol}=1.8 ppm), and when present increases the magnetic susceptibility of lung gas. This effect has been demonstrated for investigation of pulmonary ventilation via the effective transverse relaxation time T_2^* of lung parenchyma [1]. In that method, T_2^* of the protons in lung tissue was mapped at baseline and after a few minutes of inhalation of pure O_2. The elevated intrapulmonary partial oxygen pressure (pO_2) results in an increased susceptibility gradient across the alveolar membranes, resulting in a shortening of the ^{1}H T_2^* by about 10% [1]. Thus, by mapping the change in T_2^*, an estimate of ventilation is obtained. A more direct approach for quantification of pulmonary ventilation is presented by the imaging of hyperpolarized ^{3}He. Measurements of T_2^* of intrapulmonary ^{3}He have attracted some interest in the past, as they are sensitive to lung microstructure [2]; however, other factors, such as the lung inflation state [3], diffusional motional narrowing and B_0 field strength [4, 5] have an influence on T_2^* as well, and present potentially confounding factors. The aim of this work was to investigate the influence of intrapulmonary pO_2 on T_2^* of ^{3}He in human lungs.

Materials and Methods: T_2^* maps of ^{3}He were obtained from the lungs of a healthy volunteer with ethics and regulatory approval. A double-interleaved 2D gradient-echo sequence, written in-house, was used on a GE 1.5T HDx scanner (GE, USA). Sequence parameters were: 64×64 matrix, FOV 38 cm, slice thickness 10 mm, 7 axial slices, TE_1 = 3.8 ms, TE_2 = 13.8 ms, TR = 20 ms, receiver bandwidth ±15.63 kHz, flip angle 7°. ^{3}He was polarized to ~20% using a Helispin polarizer (GE, USA). During each scan, the volunteer inhaled a mixture of 200 ml ^{3}He and 300 ml N_2. In order to reproduce lung inflation state well, two scans were performed both at baseline and after the volunteer had been breathing pure O_2 for about 4 minutes. For the first scan, the volunteer was asked to inhale the bag containing ^{3}He from a state of full expiration. In the second scan, the volunteer was asked to top up her lungs to full inspiration, with room air or O_2 respectively, after inhalation from the bag.

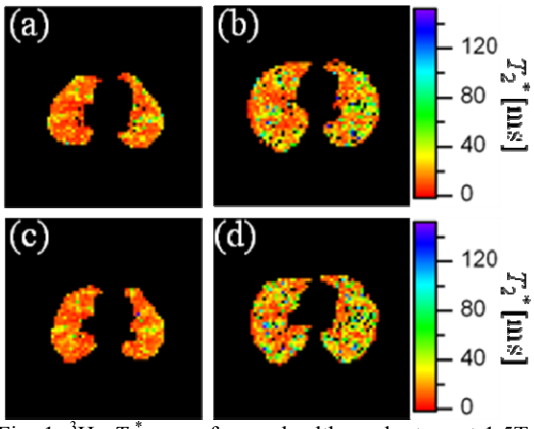

Fig. 1: ^{3}He T_2^* maps from a healthy volunteer at 1.5T, at expiration (a, c) and inspiration (b, d), at baseline (a, b) and after 4 min O_2 (b, d).

Results and Discussion: Figure 1 shows typical T_2^* maps obtained at full expiration and inspiration, at baseline and after O_2 prewash. While maps at inspiration have regions of visibly longer T_2^*, no difference is apparent between maps acquired at air breathing baseline and after O_2. Figure 2 shows the mean values of T_2^* for each acquisition as a function of slice number. Averaged over all slices, mean values at expiration of 16.3 ± 1.1 ms and 16.8 ± 1.0 ms are observed at baseline and after O_2 respectively. At inspiration, the values are 27.5 ± 1.4 ms and 27.4 ± 1.2 ms respectively. It follows that while changes in the inhalation state can account for a change of ~60% in T_2^*, the influence of O_2 appears to be negligible. If a small influence is present, it is likely to be masked by the effect of lung inflation, particularly as the reproduction of lung volumes in spontaneously breathing human volunteers and patients is not trivial. This behaviour differs from intrapulmonary ^{1}H, where a reduction of T_2^* by ~10% was observed after O_2 prewash [1]. A possible explanation is the fact that ^{1}H signal is detected from the alveolar walls, while ^{3}He is present in the alveolar gas spaces. O_2 in the gas spaces increases the susceptibility difference between gas and tissue but the resulting field inhomogeneities appear mainly close to the tissue-gas interfaces. Virtually all intrapulmonary ^{1}H spins are located in the immediate vicinity of these interfaces. Whereas the ^{3}He samples the whole alveolar space, and thus experiences less field inhomogeneity on average, with diffusional motional narrowing playing an additional role, making its T_2^* less sensitive to intrapulmonary pO_2. While this work demonstrates that lung inflation state dominates over a potential pO_2 effect, such an effect is still expected to be present via the known shortening of T_{2CPMG} via dipole-dipole interaction [6]; however, at 1.5T $T_2^* << T_{2CPMG}$, thus any effect on T_2^* appears to be too small to be convincingly detected and separated from the influence of the natural variation in lung inflation state. The findings of inflation state dependence are consistent with those measured previously at 1.5T [3], albeit at different echo times and voxel size. For the gradient echo sequences typically used for imaging of hyperpolarized noble gases, a long T_2^* is desirable. The finding presented here shows that inhalation of O_2 has no negative effect on T_2^*, which might influence decisions in handling of patients who benefit from ventilation with O_2. Nevertheless, the well-known shortening of T_1 of ^{3}He by increased pO_2 [7] should still be taken into account when making those decisions.

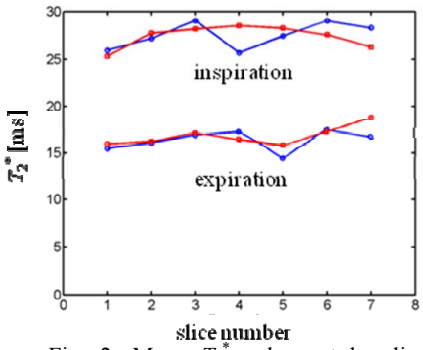

Fig. 2: Mean T_2^* values at baseline (blue) and after O_2 prewash (red). Upper curves: inspiration, lower curves: expiration.

References: [1] Pracht et al., MRM 53, 1193-1196 (2005) [2] Chen et al., MRM 42, 729-737 (1999) [3] de Rochefort et al., Proc. ISMRM 12, 2724 (2004) [4] Salerno et al., MRM 53, 212-216 (2005) [5] Deppe et al., JMRI 30, 418-423 (2009) [6] Vignaud et al., Proc. ISMRM 11, 1384 (2003) [7] Deninger et al., JMR 141, 207-216 (1999) **Acknowledgements:** EPSRC DTA #EP/P503809/1 and grants #GR/S81834/01(P) #EP/D070252/1; EU Framework VI (Phelinet); GE for polarizer support