Effect of Molecular Oxygen on Relaxation Times at Clinical Field Strengths

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Target audience: This work is of interest to both basic researchers working on the effects of molecular oxygen on MRI as well as clinical scientists working in the field of oxygen enhanced MRI.

Purpose: Molecular oxygen is paramagnetic and is well known to influence the relaxation properties of different tissues in magnetic resonance imaging [1]. Currently, the only way to increase oxygen tension in human tissue above physiological levels is to inhale pure oxygen [2]. Little is known regarding the dependence of oxygen partial pressure on relaxation times (T_1 and T_2) in bodily fluids. Therefore, the aim of the presented work was to investigate the influence of molecular oxygen on relaxometry measurements at clinical field strengths.

Methods: We performed basic relaxometry experiments in a phantom with varying oxygen partial pressure ranging from 0-760mmHg (0mmHg, room air, 380mmHg, 494mmHg, 760mmHg). All experiments were performed at both 1.5T and 3.0T. Inversion recovery imaging with 20 inversion times (range TI=100ms-15s) was performed to measure T_1, and spin-echo imaging with increasing echo time was performed with 9 echo times (range TE=10ms-2s) to estimate T_2. Using measured values of T_1 and T_2 at different oxygen tensions permitted calculation of the relaxivities (r_1 and r_2) of oxygen.

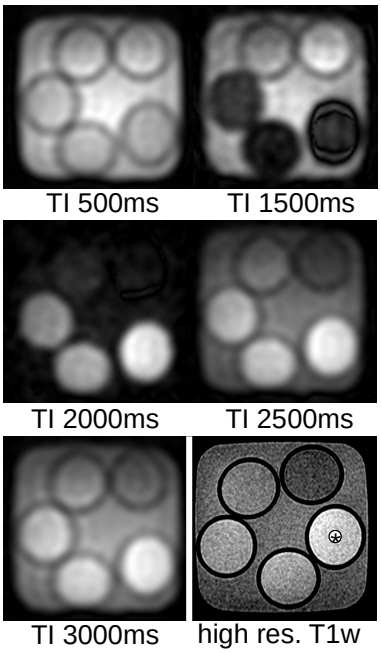
Results: Differences in oxygen tension can be visualized qualitatively and also quantified with MRI. The effects can be observed at both 1.5T and 3.0T. The T_1 of saline ranged from 3.05s to 1.88s at 1.5T and 3.03s to 2.04s at 3.0T, respectively, when increasing oxygen partial pressure from 0 to 760mmHg.

The T_2 of saline ranged from 2.66s to 1.77s at 1.5T and 1.97s to 1.36s at 3.0T, respectively, increasing oxygen tension from 0 to 760mmHg. The calculated relaxivities of oxygen were $r_1=2.82 \times 10^{-4}$ $s^{-1}mmHg^{-1}$ and $r_2=2.73 \times 10^{-4}$ $s^{-1}mmHg^{-1}$ at 1.5T, and $r_1=2.21 \times 10^{-4}$ $s^{-1}mmHg^{-1}$ and $r_2=3.28 \times 10^{-4}$ $s^{-1}mmHg^{-1}$ at 3.0T.

Discussion: In this work, we have measured the effect of oxygen on T_1 and T_2 in saline at clinical field strengths. Dissolved oxygen shortens the T_1 of saline by up to 40% and the T_2 by approximately 30%. Both, the T_1 and the T_2 shortening effects are more pronounced at 1.5T.

Conclusion: Characterization of the paramagnetic effects of molecular oxygen will facilitate feasibility calculations and optimization strategies for clinical and research utility of this contrast mechanism. Based on our results, optimization of T_1 weighting may improve the SNR of oxygen-enhanced imaging. The results suggest that the injection of oxygen-saturated or desaturated saline could be used as a contrast agent when imaged with appropriately T_1 weighted acquisitions.

References: [1] O'Connor JP, Jackson A, Buonaccorsi GA, et al. Organ-specific effects of oxygen and carbogen gas inhalation on tissue longitudinal relaxation times. Magn Reson Med. 2007;58:490-6. [2] Jones RA, Ries M, Moonen CT, et al. Imaging the changes in renal T1 induced by the inhalation of pure oxygen: a feasibility study. Magn Reson Med. 2002;47:728-3.



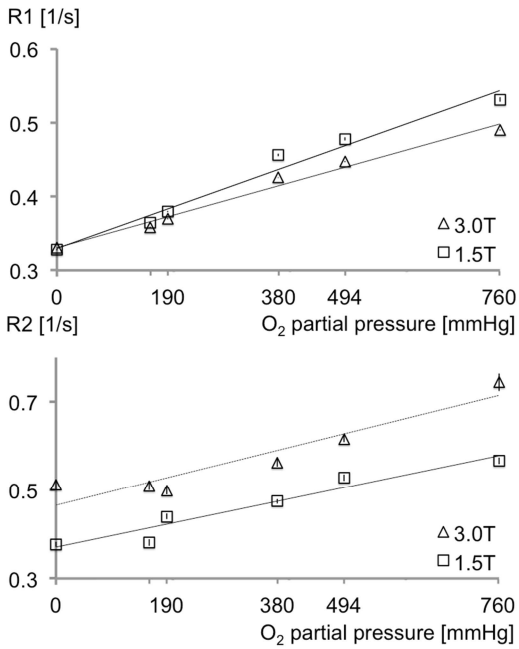


Figure 1: Example inversion-recovery images at selected TI times (left) demonstrate qualitative differences in T1. Note the signal differences of the saline / oxygen solutions near the zero crossing (2000ms). One representative axial slice of a high spatial resolution T_1 weighted acquisition of the oxygen phantom at 3.0T (bottom left). 5 flasks filled with saline at different stages of oxygen saturation are imaged. The brightest signal is achieved with the 100% oxygen saturated saline solution (asterisk). Flasks with ~65%, ~50%, ~25% and 0% oxygen saturation are positioned clockwise.

Plots of relaxation rates R1 and R2 versus oxygen partial pressure in saline at both 1.5T and 3.0T (right). Standard error for R1 and R2 was evaluated and found to be so small that bars are not visualized outside the markers.