$T_{1\rho}$-Weighted MRI Senses Partial Pressure of Oxygen

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INTRODUCTION

Partial pressure of oxygen (P_{O2}) is an important physiologic parameter, which has obvious implications in determining the cerebral metabolic rate of oxygen ($CMRO_2$) and the efficacy of radiotherapy, amongst several other functionally and clinically relevant examples. Particularly for determination of $CMRO_2$ via the hyperoxia approach suggested recently (1), a global brain arterial P_{O2} is inferred from the end-tidal O_2 partial pressure since there is currently no method available for mapping P_{O2} in the brain. In this study, we explore the sensitivity of $T_{1\rho}$-weighted imaging for changes in P_{O2} in a controlled in vitro setting and compare it to the known effect of dissolved oxygen on T_1 and T_2 relaxation times. We also explore $T_{1\rho}$-weighted MRI detection of P_{O2} changes in the brain by administration of increased FiO_2 to rats and human subjects.

METHODS

Five phantoms were prepared by adding 15 mL of physiologic saline to 20 mL syringes and balancing gas via a 5 mL syringe filled with appropriate mixture of oxygen and air to yield P_{O2} of 279, 399, 520, 640, and 760 Torr with an accuracy of ±1 Torr. These phantoms were positioned at an angle of 45° within a clinical extremity coil to allow for a slice through just the liquid portion of the mixtures and then imaged on a 1.5 T clinical MRI scanner. The T_2, T_1, and $T_{1\rho}$ relaxation times were determined for the phantoms by using a spin echo sequence and varying the echo time, by a saturation recovery approach, and by varying the time of spin-locking length (at a spin-locking frequency of 250 Hz) via a prepared fast spin echo sequence, as previously described in detail (2), respectively.

Ten female Sprague-Dawley rats (200-300g) and 2 human subjects were studied on the 1.5 T clinical scanner in accordance with institutionally approved protocols and using the same $T_{1\rho}$ sequence used for the phantoms, with TR = 1s, TE = 17 ms, TSL = 120 ms, ETL = 16, and spin-locking frequency of 250 Hz. The rats were anesthetized with Nembutol® (50 mg/kg) and studied with a head coil specially designed for the application. For gas delivery to the rats, an inhalation mask and a calibrated custom-made ventilation system were utilized to vary FiO_2 from 20% to 100% with 20% increments, making up the remainder of the volume with nitrogen. The human subjects were studied with a clinical head coil. 40% FiO_2 was administered to the human subjects in the magnet via a clinical face mask and a patient tube extended to a wall-mounted hospital oxygen dispenser providing medical grade O_2.

RESULTS AND DISCUSSION

Figure 1 provides the measured T_2, $T_{1\rho}$, and T_1 relaxation times of each phantom with the given P_{O2}. All exponential curvefits for determining these relaxation times resulted in correlation coefficients of 0.943 to 0.999. All three of these relaxation times demonstrate a linear relationship to P_{O2}, with correlation coefficients equal to 0.997, 0.952, and 0.994, for T_2, $T_{1\rho}$, and T_1, respectively. The relaxation time difference between the highest and lowest P_{O2} is 1.3 fold for T_2, 4.3 fold for $T_{1\rho}$, and 2.8 fold for T_1, suggesting that $T_{1\rho}$-weighting is most sensitive to P_{O2} changes.

Figure 2 provides representative change in the normalized $T_{1\rho}$-weighted MRI signal, measured in a region of interest corresponding to the bilateral frontoparietal cortex of the rat, as a result of stepwise increase in FiO_2. As expected from the phantom data, a highly linear relationship (correlation coefficient of 0.998) is seen between the $T_{1\rho}$-weighted signal and FiO_2, which is expected to be linearly proportional to P_{O2}. A representative $T_{1\rho}$-weighted signal change is also seen in a region of interest consisting of the bi-frontal human cerebral cortex due to increase in FiO_2 to 40% from room air.

Collectively, these data suggest that $T_{1\rho}$-weighted MRI is linearly sensitive to P_{O2}, to an extent greater than that seen with both T_1 and T_2 relaxation. While it remains a focus of our present endeavors to tease out the optimal spin-locking frequency for P_{O2} detection in the brain and other organs and to pursue a localized P_{O2} map, the potential utility of $T_{1\rho}$-weighted imaging for monitoring inspired oxygen induced changes, specifically as they relate to the effect of dissolved oxygen, is readily apparent.

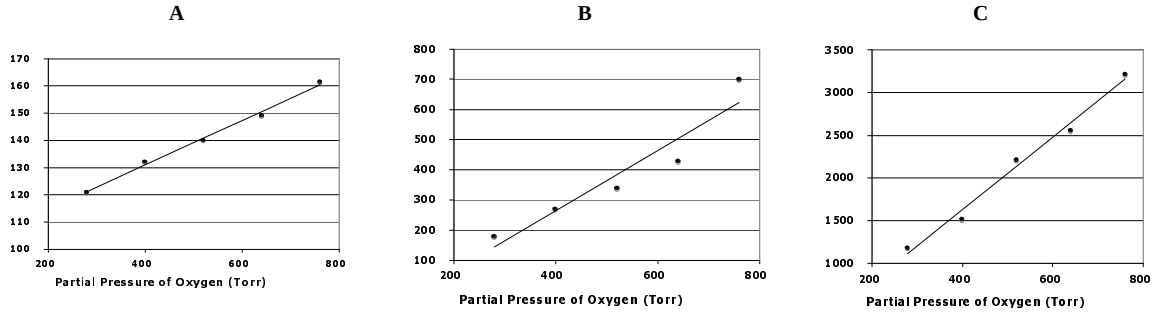

Figure 1: The effect of dissolved oxygen on A) T_2, B) $T_{1\rho}$, and C) T_1 relaxation times of physiologic saline phantoms.

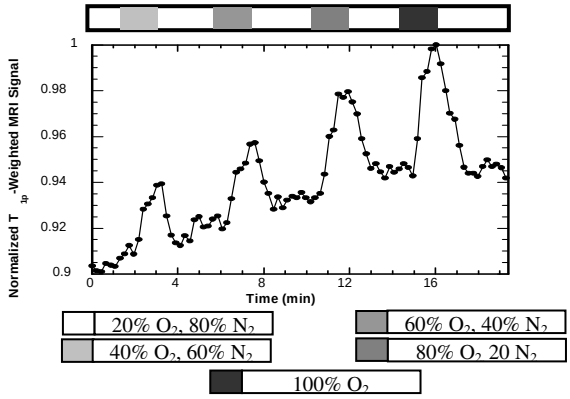

Figure 2: Representative $T_{1\rho}$-weighted brain MRI signal enhancement observed during sequentially incremented % respired O_2 (FiO_2) in rats.

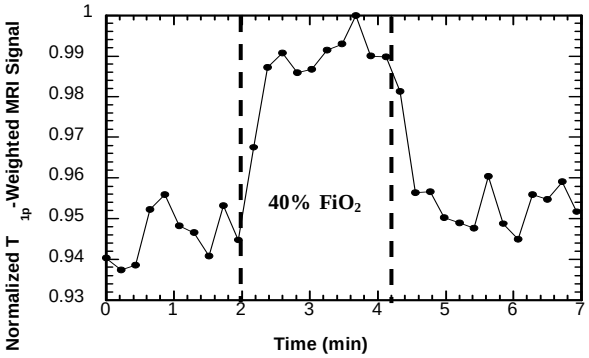

Figure 3: Representative human brain cortical signal enhancement observed with $T_{1\rho}$-weighted MRI during inhalation of 40% Oxygen. The vertical dashed lines mark the transition to and from room air to increased FiO_2.

REFERENCES: 1. Chiarelli et al. (2007) NeuroImage; 37: 808-20. 2. Tailor et al. (2003) Magn Reson Med; 49: 479-87.