Optimum Ventilation Mixture Ratio for Maximizing Hyperpolarized ^{129}Xe MR Brain Signal

X. Zhou[1], Y-S. Tzeng[1,2], J. K. Mansour[1], M. L. Mazzanti[1], Y. Sun[1], and M. S. Albert[1]

[1]Radiology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, United States, [2]Biomedical Engineering, Boston University, Boston, MA, United States

Introduction

Weak ^{129}Xe signal strength is currently a main obstacle towards the advancement of Hyperpolarized (HP) ^{129}Xe MRI of the brain. On a few occasions, we have noticed that changing the oxygen content of the gas used to ventilate rats lead to significant changes in brain ^{129}Xe MR signal. On the one hand, a higher oxygen-level ventilation results in a faster relaxation of HP ^{129}Xe in the gas phase [1]; on the other hand, oxygenation increases the longitudinal relaxation time of ^{129}Xe in the blood [2-3]. Thus, an optimum oxygen-nitrogen mixture ratio may exist for maximizing HP ^{129}Xe MR signal in the brain, which is helpful for the application of HP ^{129}Xe in vivo studies.

Approach

First, an analytical model for ^{129}Xe polarization, as it travels from the ventilator to the rat brain, was developed. Despite the many assumptions made in the formulation, the model predicts an optimum of approximately 25% oxygen-75% nitrogen for maximum brain ^{129}Xe MR signal.

HP ^{129}Xe MR spectroscopy was then conducted on two male Sprague-Dawley rats (175-200 g). The rats were ventilated alternately with 2 oxygen-nitrogen breaths, and 2 ^{129}Xe breaths. Five different oxygen-nitrogen mixtures were used to ventilate each rat: 40% O_2-60% N_2, 35% O_2-65% N_2, 30% O_2-70% N_2, 22% O_2-78% N_2, and 15% O_2-85% N_2. The MR spectra were acquired after nine repetitions of the gas alternation. All MR measurements from rat brain were carried out on a Bruker Biospec 4.7 T MRI system using a dual-tuned surface coil tuned to the ^{1}H and ^{129}Xe resonance frequencies (200 and 55.4 MHz, respectively). The ^{129}Xe was polarized in a gas flow through system (IGI.XE.2000, GE Healthcare) to a level of 10%. Between mixtures, the tube between the tank and the delivery system was purged with the next oxygen-nitrogen mixture. The brain peaks were normalized according to the gaseous phase ^{129}Xe T_1 decay. A pulse oximeter was attached to a hind paw of the rat at all times to monitor its blood oxygenation and pulse.

Results and Discussion

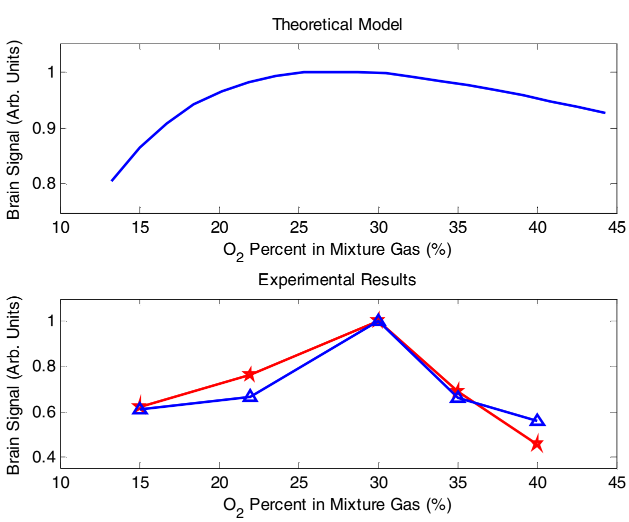

Fig. 1. Theoretically simulated and experimental HP ^{129}Xe signals from the brain with different O_2 percentage in the mixture gas.

Mixtures with oxygen content equal to or higher than 22% all resulted in blood oxygenations of 100%, but a 15% oxygen mixture resulted in blood oxygenation levels from 90-95%. Fig. 1 shows the relative strengths of the ^{129}Xe brain peaks as a function of oxygen percentage in the mixture gas as predicted by the model, and as measured from the rats experimentally. It can be seen that while the optimum mixing ratios for maximizing brain signal are different between the model and that obtained experimentally by 5%, even more striking is the difference in shape between the ratio-signal curves. While the model predicts a smooth curve to describe this phenomenon, the experiment shows a maximum between two abrupt signal drop-offs. The disparity between the predicted and experimental ratio-signal curves is likely explained by inadequate assumptions in the model: among other things, the relationship between blood oxygen level and pulse is not accounted for. However, confirming the existence of an optimum ventilation mixture ratio is extremely valuable for future animal and human brain experiments.

Conclusion

An optimum ratio of oxygen-nitrogen mixture was predicted with a model, and experimentation confirmed the existence of such a value (30% O_2-70% N_2). This should help future MR scientists design experiments to utilize as much of the limited ^{129}Xe polarization as possible.

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References

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