Selective saturation of Xe dissolved into tissue and Xe bound with hemoglobin in human lungs in hyperpolarized ^{129}Xe MR

Y. Chang[1], T. A. Altes[1], I. M. Dregely[2], S. Ketel[3], I. C. Ruset[2,3], J. F. Mata[1], F. Hersman[2,3], J. P. Mugler III[1], and K. Ruppert[1]

[1]Radiology, University of Virginia, Charlottesville, VA, United States, [2]Physics, University of New Hampshire, Durham, NH, United States, [3]Xemed LLC, Durham, NH, United States

Introduction: In recent years hyperpolarized xenon-129 (HXe-129) MRI and MRS have been used extensively in studies of lung functions [1-6]. These studies exploit the circumstance that the resonance frequency of xenon dissolved in the lung parenchyma and bound to hemoglobin is shifted by about 200 ppm relative to the gas-phase frequency. It is thus possible to saturate the dissolved-phase xenon without disturbing the gas-phase xenon and obverse the subsequent decrease of the gas-phase signal (exchange) or the re-growth of the dissolved-phase signal (uptake) due to the rapid gas-exchange processes between the dissolved-phase compartments and the alveolar airspaces of the lung. At field strengths of 1.5 T or higher two dissolved-phase peaks can be readily distinguished: xenon bound to hemoglobin at 200-225 ppm (depending on the species and oxygenation level) and xenon dissolved in lung tissue and blood plasma at approximately 197 ppm.

closer look at the dissolved-phase signal reveals two separate peaks, one from Xe dissolved into lung tissue and blood plasma (TP Xe) at 197 ppm and the other from Xe bound with hemoglobin (BL Xe), which has a species-dependent resonance frequency. Selective saturation of an individual peak, instead of the entire dissolved-phase region, would allow studies of exchange dynamics of gas-phase Xe with a specific type of dissolved-phase Xe (TP Xe or BL Xe), which would provide further insights of the gas exchange processes in the lung. Such a technique is not feasible for some species if these two peaks are too close together (e.g., 5.5 ppm in rabbits). For humans, fortunately, the peak of BL Xe is at 217 ppm, 20 ppm apart from that of the TP Xe. In this work we demonstrate that it is possible to selectively saturate either single dissolved-phase peak for human subjects by applying a narrow-bandwidth RF pulse.

Methods: Experiments were performed on both 1.5-T (Avanto) and 3-T (Trio, both from Siemens Medical Solutions) imager with custom-made rap coils (MR solutions). One normal subject was used for each field. Enriched ^{129}Xe was polarized to 15% with a Xemed (New Hampshire) polarizer. The subject breathed in 500 cc of Xe in a bag and 700 cc of air in another at the same time followed by a breath hold of 8 s while data were being collected. The oxygen level is no less than 21% in the total inhaled gas. The MR sequence consists of 16 RF pulses and data acquisitions (bandwidth 32.6 Hz, 1024 data points). The center frequency of each of the Gaussian-shaped RF pulse sweeps from 230 ppm to 188 ppm at a step of 6 ppm. Two RF durations were used inerleavingly in each sequence. Repetition time (TR) is 500 ms to allow signal recovery in the dissolved phase.

Results: Fig. 1 shows all the phased, real-channel spectra acquired for the 7-ms RF pulses at 1.5 T. The center frequency of the corresponding RF, from top to bottom, steps from 230 ppm evenly down to 188 ppm. We see that the 3rd spectrum, whose RF is at 218 ppm, is a clean excitation of only the BL Xe without TP Xe contamination at 197 ppm; whereas the last three spectra with the RF below or equal to 200 ppm show the opposite: excitations of only TP Xe at 197 ppm. Fig. 2 shows the results of a similar experiment performed in the 3-T field. Due to further frequency separation of the two dissolved-phase peaks in a higher field, the RF bandwidth can be increased and thus its duration was reduced to 5 ms. Again, the 218-ppm RF excites only the BL Xe, which was clearly not affected by RF pulses between 200 and 188 ppm. Fig. 3 compares the signal strength for different RF durations at a fixed frequency at 1.5 T. SNR increases as the pulse duration becomes shorter and the frequency bandwidth becomes wider. However, for the 5 ms RF pulse a slight excitation of the TP Xe at 197 ppm is visible.

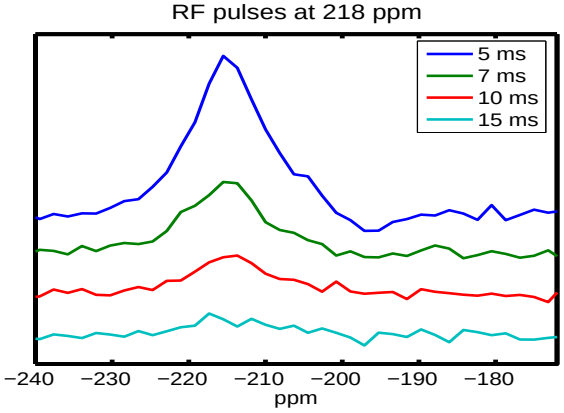
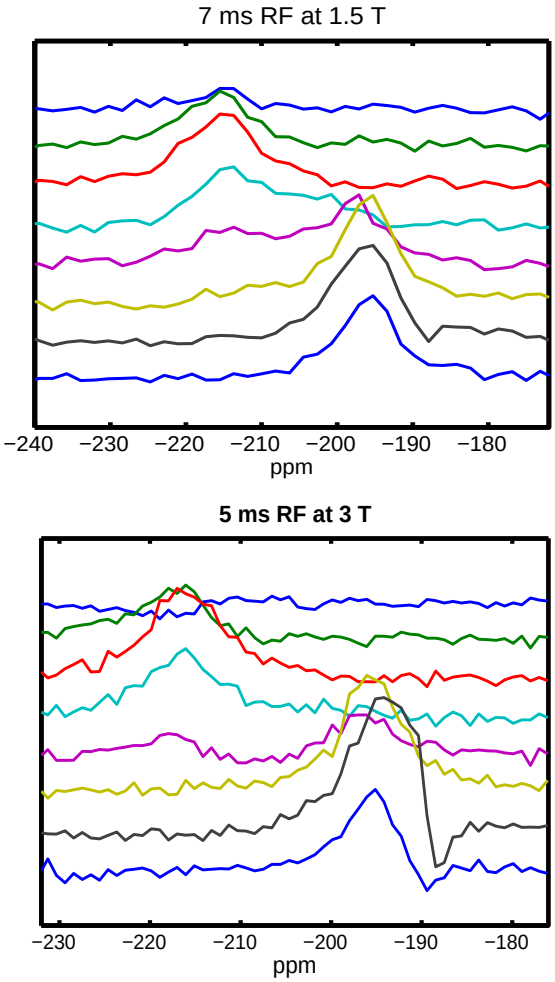


Figure 3. Spectra taken with different 218-ppm RF pulse durations at 1.5 T. The SNR decreases as the corresponding pulse duration becomes longer and the frequency bandwidth becomes narrower. For the 5-ms RF, there is a slight excitation of the TP Xe at 197 ppm, which is not desirable for our purposes.



Figures 1, 2: Spectra taken at 1.5 T and 3 T using 5 ms and 7 ms RF pulses, respectively. The center frequency of each spectrum, from top to bottom, is 230, 224, 218, 212, 206, 200, 194 and 188 ppm, for both plots.

Conclusion: For humans, the 20-ppm separation between the TP Xe and the BL Xe frequencies in the lung allows us to saturate an individual dissolved-phase peak without exciting the other by carefully choosing a RF duration. We showed that 7-ms and 5-ms Gaussian RF at 1.5 T and 3 T, respectively, result in clean excitation of a single peak with reasonable SNR.

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