

Hyperpolarized Xenon-129 Dissolved-phase Signal Dependence on the Echo Time

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Introduction: Upon inhalation approximately 1-2% of hyperpolarized xenon-129 (HXe129) dissolves in the lung parenchyma and gives rise to several resonances that are chemically shifted by approximately 200 ppm relative to the alveolar gas phase (GP). Such a large frequency difference makes it feasible to either exclusively image the dissolved HXe129 with selective excitation pulses [1] or to image both phases simultaneously, appearing side-by-side in the image, by using a suitable imaging bandwidth [2]. Also, although the number of dissolved xenon atoms is small relative to those in the free gas, the two compartments stand in rapid exchange. Thus, the strong but non-equilibrium GP magnetization serves as a reservoir that replenishes the dissolved-phase (DP) magnetization consumed by the imaging pulse sequence. However, the image analysis is complicated by the circumstance that the DP signal does not consist of a single, narrow resonance but, instead, is comprised of a multitude of spectral components that are dominated by the tissue and the red-blood cell peaks. In rabbits, these two peaks are of similar amplitude and separated by about 6 ppm (106 Hz at 1.5T). Thus, an increase of the echo time (TE) will not only decrease the DP signal due to T2* but it will also modulate it by the phase difference of the signal components as well as their relative sizes. In this work we present our preliminary findings in alive and dead rabbits at 1.5T for various TEs.

Methods: Experiments were performed on a 1.5-T commercial whole-body imager (Avanto, Siemens Medical Solutions, Malvern, PA) using a custom-made transmit-receive birdcage RF coil (IGC Medical Advances, Milwaukee, WI). The imaging sequence was a 2D-projection gradient-echo sequence that employed RF excitation pulses with a truncated-sinc waveform of 2.31 ms duration centered 3,660 Hz downfield from the gas-phase resonance. The pulse parameters were chosen such that they provide a high FA at the dissolved-phase resonance (~202 ppm) and a homogeneously low FA at the gas-phase resonance (0 ppm). The following sequence parameters were used: matrix size 36x80; TR 50, 200 or 400 ms, TE 2.8-8.0 ms; flip angle 40° or 80°; FOV 280 mm; receiver bandwidth 110 Hz/pixel. Five New Zealand white rabbits (approximately 5 kg) were imaged. Each animal was anesthetized with a mixture of Xylazine 5 mg/kg and Ketamine 50 mg/kg, intubated, and placed in the xenon RF coil. Immediately before the pulse sequence was started the animal was ventilated with 30 cc of isotopically enriched xenon gas (~87% xenon-129), which was polarized to ~35% using a commercial prototype polarizer (Xemed LLC, Durham, NH). In one animal an IV was placed in a left ear vein. A right groin cut-down was performed, and the right common femoral artery isolated and cannulated with a 3 Fr catheter at which point a set of baseline images were acquired. The animal was then removed from the scanner and 150 cc of blood was withdrawn through the femoral central line while simultaneously replacing the volume with normal saline via the IV. Shortly after the 150 cc was withdrawn, the animal experienced a fatal cardiac arrest. The second set of HXe-129 images was then acquired. The protocol was approved by our Institutional Animal Care and Use Committee.

Results and Discussion: For the chosen pulse sequence parameters, each image depicts the HXe129 GP signal to the left and the HXe129 DP signal to the right, shifted relative to one another by approximately 32 pixels. For both parameter sets displayed in Fig. 1 the signal behaviors are fairly comparable: 1) The GP signal is almost constant over the range of TEs investigated, which comes as no surprise, since the gas-phase T2* is on the order of 50 ms; 2) The DP signal drops rapidly up to a TE of ~4.5 ms. After that it levels off or even increases again. This behavior is further confirmed in Fig. 2 for signal-normalized ROIs in the right lung and the heart. While the signal from the heart decays fairly slowly and with only minor discernible modulations the DP signals almost drop in parallel before bouncing back sharply at 4.5 ms. The inferred modulation period of 9 ms (111 Hz) agrees very well with the 106 Hz frequency separation of the primary DP resonances. However, in the blood-pool weighted signal (low FA, long TR) the initial decrease and subsequent recovery is somewhat more pronounced than in the exchange-site weighted signal (high FA, short TR) most likely due to a shift in the mix of several cancelling signal components. The tremendous impact of these relative component sizes is also demonstrated in Fig. 3 where the collapse of the pulmonary vasculature at high inflationary gas pressure after cardiac arrest heavily reduces signal cancellation at a TE of 5 ms. Additionally, since GP and DP information is available simultaneously, all DP measurements are inherently quantitative because the GP signal serves as a reference, which distinguishes this method from the Dixon technique-based one proposed by Driehuis et al. [3].

Conclusion: The simultaneous imaging of the GP and DP magnetization allows the monitoring and possibly even quantification of HXe129 gas transport processes throughout the pulmonary system. By varying the TE of the image acquisition it appears to be feasible to extract additional information about the regional distribution of the DP sub-compartments, which might be strongly affected by pulmonary interstitial or vascular diseases.

References: [1] Driehuis B et al. 4th IWPF, Boston, 2009. [2] Mugler III JP et al. MRM 1997;37:809-815. [3] Driehuis B et al. PNAS 2006;103:18278-18283.

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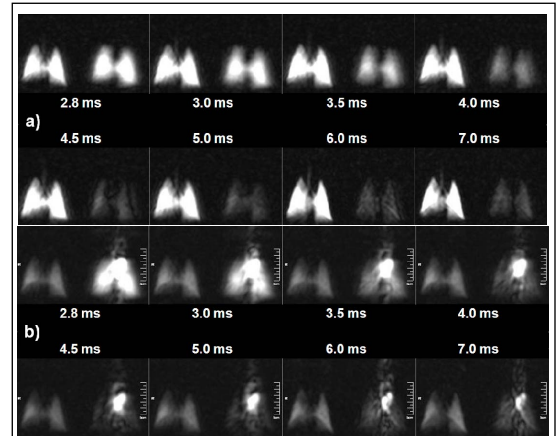


Figure 1. Signal dependence in simultaneously acquired gas and dissolved-phase images on the TE for a) exchange-site weighting (FA 80°, TR 50 ms) and b) blood-pool weighting (FA 40°, TR 400 ms).

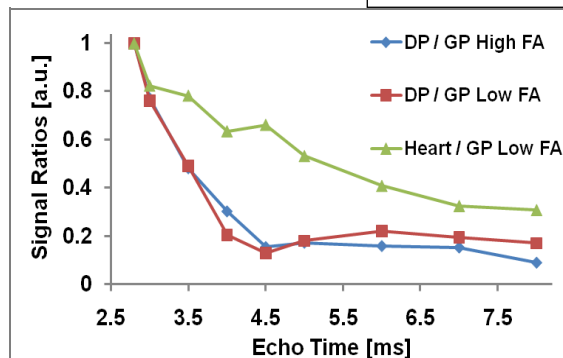


Figure 2. Signal ratios for ROIs in the right lung and the heart in exchange-site weighted and blood-pool weighted DP images as a function of the TE.

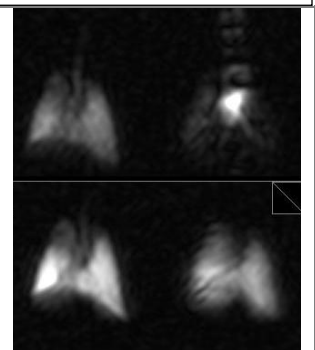


Figure 3. Changes in the HXe129 signal distribution in a rabbit pre and post mortem.