Single-Acquisition Imaging of Hyperpolarized ^{129}Xe in the Gas and Dissolved Phases using an Interleaved 3D-Radial Sequence

S. S. Kaushik[1,2], G. P. Cofer[2], M. S. Freeman[2,3], Z. I. Cleveland[2], and B. Driehuys[2]
[1]Biomedical Engineering, Duke University, Durham, NC, United States, [2]Center for In Vivo Microscopy, Duke University Medical Center, Durham, NC, United States, [3]Medical Physics, Duke University Medical Center, Durham, NC, United States

Introduction: When inhaled, hyperpolarized (HP) ^{129}Xe rapidly dissolves in the pulmonary tissues, where it displays a ~200 ppm chemical shift relative to gaseous ^{129}Xe **[1]**, making it a potentially powerful probe of both ventilation and pulmonary gas exchange. Our group and others have recently demonstrated the ability to directly image ^{129}Xe dissolved in the gas exchange tissues **[2,3]**. These dissolved images display a dramatic gravity-dependent heterogeneity of the gas exchange pattern in the lung. However, because dissolved ^{129}Xe images also depend on the ^{129}Xe ventilation distribution, it would be ideal to acquire images of both phases simultaneously in the same breath. This requirement was elegantly achieved by Mugler et al., **[3]** who used a gradient echo sequence and exploited the chemical shift difference to display the two phases next to one another. However, this approach suffers from T_{2*} losses due to the relatively long TE, and is constrained by the field of view and bandwidth needed to have non-overlapping images while avoiding aliasing. To overcome these problems, we propose imaging using an interleaved radial acquisition scheme, by alternatively pulsing and acquiring on the gas and dissolved phases. In this work, we demonstrate the feasibility of this approach in vitro, by continuously infusing ^{129}Xe into aqueous solutions with hydrophobic gas exchange membranes **[4]**.

Methods: HP ^{129}Xe images and spectra were acquired in a 2T horizontal bore (GE EXCITE 12M4), small animal scanner. Natural abundance (26% ^{129}Xe) xenon (300 ml) was polarized using Rb vapor spin-exchange optical pumping in a prototype commercial polarizer (MITI, Durham, NC). Distilled water and gas flowed at 20 ml/min and 5 ml/min respectively, through a hydrophobic hollow fiber membrane module (MicroModule, Membrana, Charlotte, NC), where ^{129}Xe was infused into the water **[4]**. HP ^{129}Xe infused water passed from the modules through the center of the RF coil, while the ^{129}Xe exhaust from the membrane outlet was also routed into the RF coil and wrapped around the liquid line as illustrated in **Figure 1A**. Imaging employed a 3D radial acquisition which alternatively excited and acquired the two frequencies such that each view of k-space was acquired for both the gas and the dissolved phases. To account for different signal dynamics in the dissolved phase **[4]** a higher flip angle was used. Imaging parameters included: pulse duration (sinc)=1200 µs, views=2500 for each frequency, TE/TR=2/250 ms, BW=8 kHz, FOV=10 cm, resolution=32×32×32, flip angles (gas/dissolved)=20/30°. The k-space data was then split, and the dissolved and gas phase components, were reconstructed separately, using NUFFT reconstruction **[5]**.

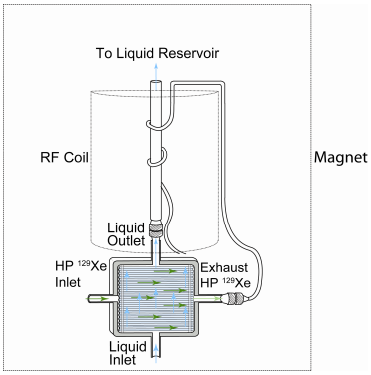

Figure 1: Imaging schematic. The exhaust gas line is wrapped around the water outlet line to enable proper shimming on both phases.

Results and Discussion: The spectrum in **Figure 2A** shows the gas phase xenon signal at 0ppm, and the dissolved xenon signal at 194 ppm. At 2T, this chemical shift corresponded to a 4590 Hz frequency difference between the gas and dissolved phases. Using this frequency difference, 3D images of the gas and dissolved phases were acquired in a single acquisition, as shown in **Figure 2B**. These images have the same resolution and were acquired over a 10 minute time period. The long acquisition was required because of slow dissolved ^{129}Xe magnetization replenishment. However, in human imaging, fully sampled images of the gas and dissolved phase can be acquired almost simultaneously, in a single breath-hold.

Conclusions: These results show that gas and dissolved phase images can be simultaneously acquired using an interleaved radial pulse sequence. This will enable quantitative comparison of ventilation and gas exchange processes, by avoiding the inter-scan variability from polarization, xenon concentration, patient position and tidal volume differences. The radial acquisition will permit shorter TEs, which would overcome the short T_{2*} of xenon in the dissolved phase. Further, by using radial imaging, it should become possible to use the Dixon technique to further separate the dissolved phase **[6]** into its barrier and the red-blood cell contributions.

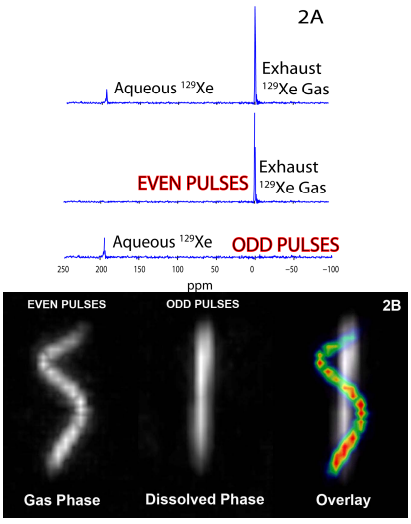

Figure 2: (A) Spectrum acquired using a non-selective pulse on the gas phase shows the chemical shift between the ^{129}Xe gas and dissolved peaks. The dissolved peak is offset from the gas phase by 200ppm (~4400 Hz). The sequence alternatively pulsed on the gas and dissolved peaks with different flip angles as indicated in the figure. **(B)** Maximum intensity projections of the 3D images acquired.

References: **[1]** Mugler et al., Magn. Reson. Med., 1997 **[2]** Cleveland et al., PloS ONE, 2010 **[3]** Mugler et al., Proc ISMRM 18, Stockholm, Sweden, 2010. **[4]** Cleveland et al., J. Phys. Chem. B 2009 **[5]** Song et al., IEEE Trans. Biomed. Eng., 2009. **[6]** Driehuys et al., Proc. Natl. Acad. Sci., USA, 2006.

Acknowledgements: Center for In Vivo Microscopy, NIH/NCRR P41 RR005959, NCI U24 CA092656