T_2^* Measurements of Dissolved-Phase ^{129}Xe in the Human Lungs at 1.5 T and 3 T

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Target Audience: Hyperpolarised gas and lung MRI community.

Purpose: ^{129}Xe gas is soluble in blood and tissue, this produces a large observable chemical shift in its NMR resonance frequency found about 220 ppm away from the gas frequency. This could serve as a potential method to image and quantify gas exchange in the lungs [1-3]. Knowledge of the *in vivo* relaxation constants is important in determining optimal sequence parameters for dissolved phase ^{129}Xe imaging. The measurement of the T_2^* of dissolved phase ^{129}Xe in human lungs at 1.5 T and 3 T are presented here.

Methods: Experiments were performed on two whole-body clinical MR systems; a 1.5 T Signa HDx (GE, Milwaukee, WI, USA) and a 3 T Philips Achieva (Best, Netherlands). Flexible twin Helmholtz quadrature transmit-receive coils (CMRS, USA) of the same geometry [4] were used at both field strengths. ^{129}Xe was polarised by Rubidium spin exchange [5] using a homebuilt regulatory-approved polariser. After 50 minutes of cryogenic accumulation of flowing gas (3% mix of 86% 129-enriched xenon), the frozen xenon was rapidly sublimated and collected in 500 mℓ doses in a 1 ℓ Tedlar bag which was filled up with medical grade N_2 gas. The typical polarisation of the gas after thawing was 14% [6]. Three healthy (never smoked) volunteers participated in this study at both 1.5 T and 3 T, (female, 26 years old, 50 kg; female, 31 years old, 60 kg; male, 26 years old, 80 kg). Written consent was acquired from all volunteers and approval was obtained from the local ethics committee. T_2^* measurements were made from whole lung coronal slices with a 2D interleaved gradient echo imaging sequence with 2 distinct TEs. The TEs were chosen with consideration of the phase evolution of the signal due to the chemical shift difference between ^{129}Xe dissolved in red blood cells (RBCs) and dissolved in plasma/tissue **(Fig. 1)** 24.5 ppm apart. Sequence parameters were: 1 coronal whole lung projection interleaved with two TEs at a TR of 200 ms, FOV of 40 cm2, resolution of 32 × 32 matrix, bandwidth 8 kHz, flip angle 33°. The TE_1/TE_2 used at 1.5 T were 2.9 ms / 5.2 ms, and the TE_1/TE_2 used at 3 T were 1.7 ms / 2.9 ms.

Results: The results were reproducible (repeated with volunteer 1 with average T_2^* of 1.65 ± 0.06 ms /1.61 ± 0.12 ms and 1.62 ± 0.12 ms /1.58 ± 0.12 ms in the left and right lung regions of interest at 1.5 T), however, due to hardware limitations and the longer time period required to rephase the red blood cells (RBC) and plasma signals at 1.5 T, the second interleave images (TE = 5.2 ms) were at noise level in larger volunteers, and thus are not shown in the table. T_2^* of dissolved ^{129}Xe as measured from the imaging experiments were 1.6 ms and 1.0 ms at 1.5 T and 3 T respectively, summarized in **Table 1**. Examples of the images obtained at 3 T at both TEs are shown in **Fig. 2**.

Conclusions: In this study, the transverse relaxation times, T_2^*, of dissolved ^{129}Xe gas in the human lungs at both 1.5 T and 3 T were measured is 1.6 ms and 1.0 ms respectively in three healthy volunteers. This is in rough agreement with whole lung spectroscopy results reported at 1.5 T of 1.5 – 2.4 ms. T_2^* of dissolved xenon was also measured to be 2 ms at 2 T and 0.67 ± 0.30 ms at 9.4 T in rat lungs and 0.7 ± 0.1 ms at 9.4 T in mouse lungs. These results also suggest a non-linear dependence of $1/T_2^*$ with magnetic field strength B_0, similar to observation made in this study in the human lungs, suggesting a contribution of chemical exchange as well as static dephasing effect. These short T_2^* values demonstrate that one of the most important parameters needed to achieve better dissolved-phase ^{129}Xe images is the minimization of echo time (TE).

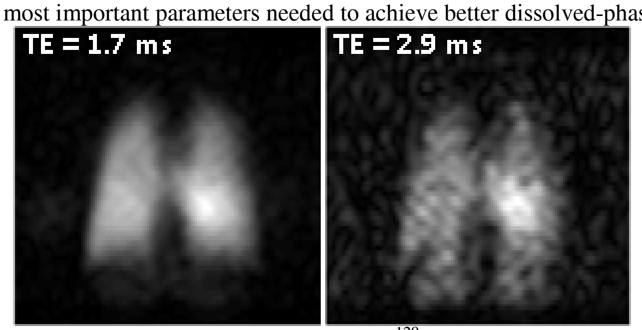

Figure 2. An example of dissolve phase ^{129}Xe images at 2 TEs collected in an interleaved fashion from lungs of a healthy volunteer at 3 T.

Gender, age,[weight]	Region of Interest	T_2^* at 1.5 T [ms]	T_2^* at 3 T [ms]
F , 26 , [50 kg]			
Repeat 1	Left lung	1.65 ± 0.06	0.9 ± 0.03
	Right lung	1.61 ± 0.12	1.0 ± 0.05
Repeat 2	Left lung	1.62 ± 0.12	--
	Right lung	1.58 ± 0.12	--
F, 31, [60 kg]			
	Left lung	--	1.0 ± 0.03
	Right lung	--	1.0 ± 0.03
M, 26, [80 kg]			
	Left Lung	--	1.1 ± 0.05
	Right lung	--	1.0 ± 0.03

Table 1. Mean T_2^* values measured from left / right lung regions of interest.

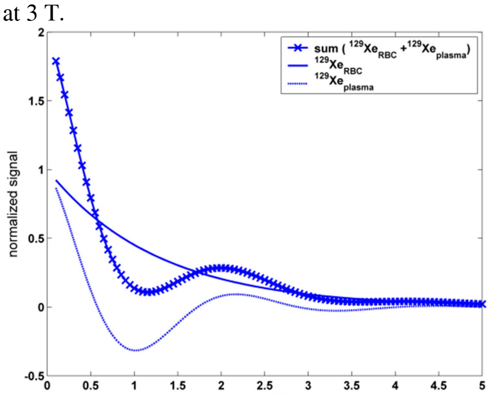

Figure 1.
Simulations done in Matlab of the beating signal decay caused by difference in phases of ^{129}Xe dissolved in RBC vs. tissue as they resonate at slight different frequencies 24.5 ppm apart at 1.5 T with T_2^* of 1.26 ms and 0.94 ms (from spectroscopy data) for $^{129}Xe_{RBC}$ and $^{129}Xe_{plasma}$ respectively.

References: **1.** Driehuys B, Cofer GP, Pollaro J, Mackel JB, Hedlund LW, Johnson GA. Imaging alveolar-capillary gas transfer using hyperpolarized 129Xe MRI. *Proc Natl Acad Sci U S A.* Nov 28 2006;103(48):18278-18283. **2.** Patz S, Hersman FW, Muradian I, et al. Hyperpolarized (129)Xe MRI: a viable functional lung imaging modality? *Eur J Radiol.* Dec 2007;64(3):335-344. **3.** Ruppert K, Mata JF, Brookeman JR, Hagspiel KD, Mugler JP, 3rd. Exploring lung function with hyperpolarized (129)Xe nuclear magnetic resonance. *Magn Reson Med.* Apr 2004;51(4):676-687. **4.** Xu X, Norquay G, Parnell SR, et al. Hyperpolarized (129) Xe gas lung MRI-SNR and T(2) (*) comparisons at 1.5 T and 3 T. Magn Reson Med. Jan 31 2012. **5.** Walker TG, Happer W. Spin-exchange optical pumping of noble-gas nuclei. Rev Mod Phys. Apr 1997;69(2):629-642. **6.** Norquay G, Parnell SR, Xu X, Parra-Robles J, Wild JM. Optimized Production of Hyperpolarized ^{129}Xe at 2 Bar for In Vivo Lung MRI. Journal of Applied Physics. 2012.