Experimental investigation of the non-Gaussian diffusion of ^{129}Xe in human lungs

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Introduction:
Measurements of the apparent diffusion coefficient (ADC) of hyperpolarized ^{3}He gas have been shown to be sensitive to lung emphysema [1]. Short-range diffusion of ^{3}He in the lungs is non-Gaussian and the b-dependence of the ADC has been used to extract morphometric information about the sub-pixel geometry of lung airways [2,3]. The ADC of ^{129}Xe has also been shown to be sensitive to human lung disease [4]. Due to the lower diffusivity of ^{129}Xe, it has been predicted theoretically [5] that it may be more sensitive than ^{3}He to changes in alveolar structure caused by emphysema. However, the measurement of ADC at multiple b values is challenging for ^{129}Xe due to the lower SNR achievable and also due to the longer diffusion times required to obtain large b values (due to the low gyromagnetic ratio), which result in large TE and acquisition time. In this work we present preliminary results of the measurement of the b-dependent ADC of ^{129}Xe in healthy human volunteers at 1.5 T.

Methods:
In vivo experiments were conducted on 2 healthy volunteers with local ethics approval. All volunteers were scanned using a 1.5T (GE HDx) whole body MRI system with a transmit-receive vest coil (Clinical MR Solutions, USA). A 2D spoiled gradient echo(4 slices, slice thickness 30mm, 32x32 matrix, TR: 36 ms, TE:12.1 ms, FOV: 35 cm, flip angle 7°) with bipolar diffusion gradients (G = 33 mT/m) and a diffusion time of 5 ms (rise and fall times 0.3 ms, pulse duration 3ms, delay between gradient lobes: 1.4 ms) was used and the slices were acquired consecutively.

^{129}Xe was polarised to ~14% with a home-built regulatory-approved spin exchange polariser [6]. The inhaled gas mixture consisted of 350 ml hyperpolarized xenon (isotopically enriched ^{129}Xe) and 650 ml N_2. For all scans, the subject exhaled to functional residual capacity (FRC) and then inhaled the hyperpolarized gas mixture from a 1L Tedlar bag.

Results and Discussion:
Diffusion weighted images of two subjects were obtained with SNR values high enough (~20) that allowed the calculation of the ADC for all the b values. Figure 1 shows the b dependence of normalized diffusion signal (S/So) decay (averaged over the whole lung) and average diffusivity (ADC= -ln(S/So)/b) obtained for the two subjects. The ADC values obtained for each b value are shown in Table 1, these values are in good agreement with previously published results from single b-value experiments [4,7]. The signal behaviour shows the non-monoexponential behaviour characteristic of non-Gaussian diffusion. The ADC decreases with increasing b value similar to the behaviour found in ^{3}He lung diffusion experiments.

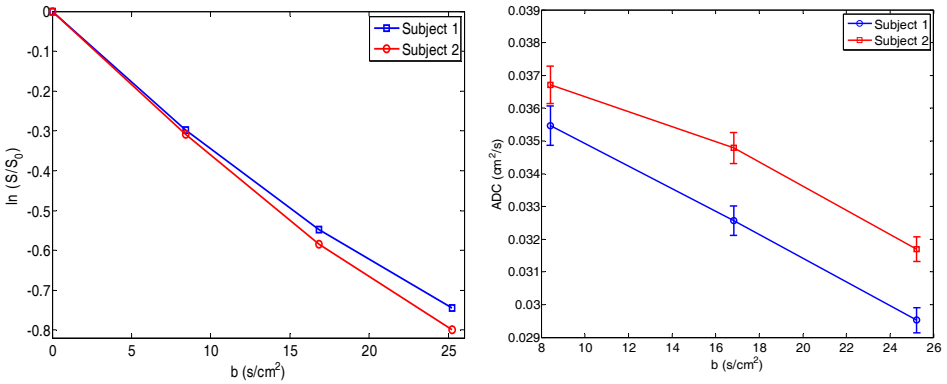

Figure 1. Average lung ^{129}Xe diffusion signal (left) and ADC (right) values as a function of b obtained from two healthy volunteers.

b (s/cm^2)	ADC (cm^2/s)	
	Subject 1	Subject 2
8.4	0.036	0.037
16.8	0.033	0.035
25.2	0.030	0.032

Table 1. Average lung ^{129}Xe ADC values measured in two healthy volunteers at three b values.

	Subject 1	Subject 2
DDC	0.028	0.031
α	0.83	0.86

Table 2. Estimated parameters of the stretched exponential model fitted to the ^{129}Xe diffusion data.

The data was fitted to a stretched exponential [8] to assess the degree of non-Gaussian behaviour. The results demonstrated that while at a diffusion time of 5 ms, the ^{129}Xe diffusivity parameter (DDC) is ~5 times smaller than for ^{3}He (at 1.8 ms) [8], the heterogeneity index α was similar. We plan to explore the behaviour of DDC and α at different diffusion time scales with both ^{3}He and ^{129}Xe to establish the relationship between these parameters and lung microstructure. In future work, we also plan to perform b-dependent ADC measurements in patient with lung diseases (e.g. emphysema).

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