

Experimental investigation of non-gaussian diffusion in hyperpolarized ^3He MRI of lungs

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Introduction

The diffusion of ^3He gas in confined inter-connected spaces of complex geometry has been shown to deviate from Gaussian behavior when measured with pulsed gradient spin echo methods (PGSE). These deviations can arise from a variety of geometrical and time dependent factors, including the airway geometry and inter-connectivity [1], the airway orientation with respect to the diffusion weighting gradients and the gradient timing and strength [2]. Diffusion kurtosis [3, 4] has been proposed as a means of quantifying this deviation of the signal decay as a function of diffusion b-value from an exponential. In this work we analyze the ^3He diffusion behavior with PGSE sequences using many b-values in well defined geometrical cylindrical models. Data was fitted to both Gaussian and kurtosis models.

Methods

The phantoms were built from polypropylene tubing and Y-connectors commercially available from Harvard Apparatus (Kent, UK). The 1st phantom consisted of three bundles of straight parallel tubes of different respective inner diameters (inner diameters: 0.5, 0.67 and 1mm). Hyperpolarized gas can be delivered to each bundle independently or all three simultaneously to simulate the contribution from airways of different diameters to the MR signal. In the 2nd phantom, to simulate the effect of airway anisotropy, several turns of tubing were wound on the surface of a plastic cylinder of diameter 6 cm. By directing the diffusion-sensitization gradient perpendicular to the axis of the cylinder (i.e. parallel to the plane of the circular turns), the presence of airways oriented in all possible (in-plane) angular directions with respect to the gradient is simulated with this phantom ("anisotropy phantom"). A 3rd phantom (lung tree phantom) that combines the presence of airways of different dimensions and anisotropy was built from Y-connectors following a branching-tree pattern with five generations with inner diameters ranging from 4–1.5 mm, which reproduce approximately generations 4 till 9 of Weibel's lung model [5]. A 60 ml syringe was used to experimentally determine the near free diffusion coefficient of the gas mixture used in this work (~ 700 ml N_2 and 150 ml ^3He). Hyperpolarized helium of polarization about 25% was obtained using a Helispin polarizer (GE, USA). Diffusion experiments were performed on a 3T Philips Intera system. Global ADC data was obtained from FID acquisition after bi-polar diffusion gradients. The diffusion gradient timing parameters were similar to those used in [1] and the gradient strength was varied in 60 equal steps from 0 to 30 mT/m. A custom-built birdcage coil (15 cm diameter) was used for high SNR.

Results and Discussion

Fig. 1a shows the data for the bundle phantom, the diffusion signal deviates from a single exponential (straight line in log plot) for b-values higher than 6 s/cm^2 . For the anisotropy phantom this deviation is much more evident (Fig 1c), with a significant deviation from monoexponential behavior visible above 4 s/cm^2 . These exponential deviations can be more clearly observed in Fig. 1b and 1d which show the residuals from both the monoexponential and the kurtosis model fits as a function of the number of b-values used to compute the fit. These results suggest that for the experimental models used in this work and the experimental conditions, the anisotropy is the most important

contributor to non-monoexponential diffusion behavior. This maybe due to the fact that the tubes used in the bundle phantom have diameters within a relative narrow range and there is no connectivity between the tubes.

Fig. 1e shows the results obtained with the lung-tree phantom. Deviation from monoexponential behavior is observable but is less evident than in the anisotropy phantom. This is due to the fact that a large fraction of the gas in this phantom resides in the "major airways" where the regime is one of near free diffusion since the inner diameter of the three first generations is larger than the ^3He diffusion length corresponding to the diffusion time used in these experiments. In Table 1, the results of the fits to the models for the experiments with the three phantoms are summarized. It can be appreciated that in fact the measured diffusion parameters in the tree phantom are close to the values measured in the syringe.

Phantom	ADC_k	ADK	ADC
Syringe	0.88	0.44	0.79
Three bundles simultaneously	0.15	0.78	0.14
Anisotropy phantom (0.76 mm tube)	0.36	0.62	0.31
Lung tree	0.76	0.41	0.72

Table 1. Summary of the fitted parameters of the curves shown in Fig. 1. ADC_k and ADK are the two parameters obtained from the kurtosis model fit and ADC is the value obtained from the single parameter monoexponential fit.

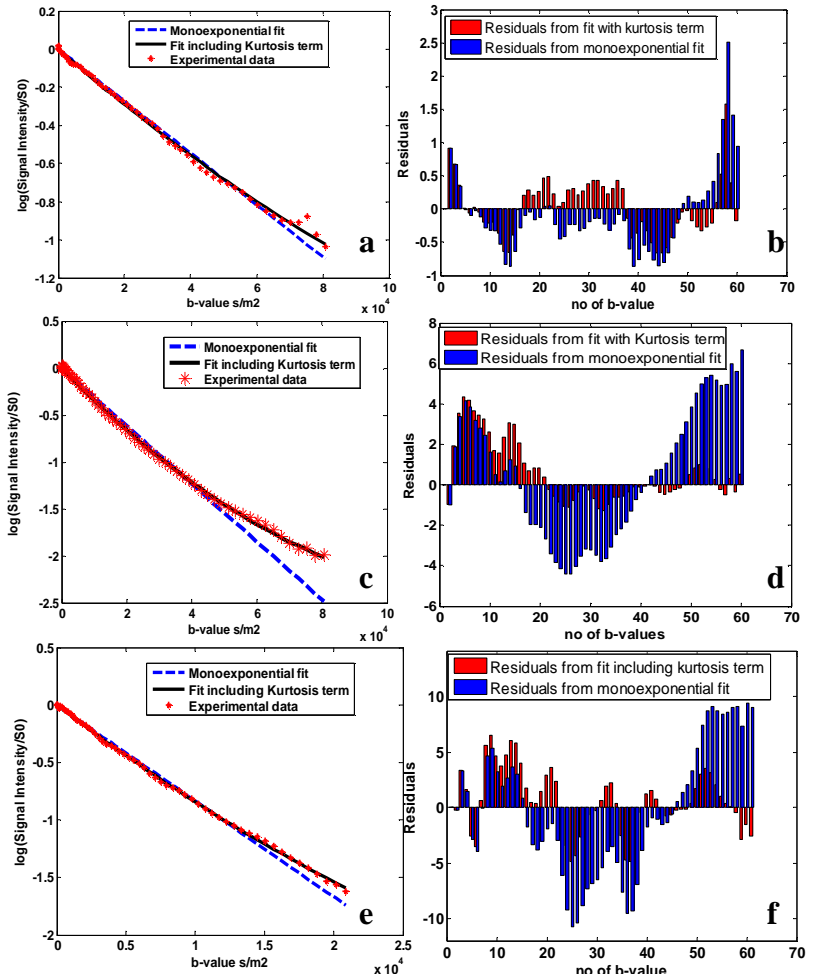


Figure 1. Fitted curves and residuals for the monoexponential and kurtosis models in the bundle phantom (a, b), the anisotropy phantom (c, d) and the lung tree phantom (e, f)

Conclusion The results obtained in this work demonstrate that the phantoms used here are valid physical models to study the sources of non-Gaussian diffusion behavior in the lung and can be used to validate the predictions of theoretical and numerical simulations.

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