A branching-tree lung phantom for hyperpolarized noble gas MRI

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Introduction

Hyperpolarized noble gas MRI is able to provide useful information related to structural and physiological properties of lungs and lung diseases. To relate the measured parameters (e.g. relaxation times, diffusion coefficients, flow rate) to lung properties (e.g. airway diameter, surface area, connectivity) several mathematical and computer models have been proposed [1-3]. Validation of these models has generally been done indirectly by comparison to known lung properties or histological sections. Direct comparison of computer simulations and measurements on a phantom built following the Kitaoka acinus model has been reported [3]. However, the geometry of this model significantly differs from the lung geometry (e.g. rectangular airway cross-section, square-angle branching). Similarly, different experimental methods and/or pulse sequences are used by different groups and their results are difficult to compare since they are performed in different subjects under different experimental conditions. In this work, we describe the construction of a simple branching-tree lung phantom made of commonly available parts that can be easily reproduced in any laboratory. Preliminary experimental results obtained with this phantom are reported, including dynamic ventilation imaging and diffusion measurements.

Methods

The phantom was built from polypropylene Y-connectors commercially available from Harvard Apparatus (Kent, UK). Figure 1 shows part of the phantom consisting of five generations with inner diameters ranging from 4–1.5 mm, which reproduce approximately generations 4 till 9 of Weibel's lung model [4]. Other generations can also be modeled since a large range of Y-connectors with other diameters are readily available. Hyperpolarized helium of polarization about 25% was obtained using a Helispin polarizer (GE, USA). 2D (coronal projection image, TR/TE: 4.8/2.1 ms, 128x128, FOV: 20cm, flip angle: 7°), 3D (TR/TE: 5.3/1.4 ms, 100x100X100, FOV: 20cm, flip angle: 1°) and dynamic ventilation (series of 2D coronal projections with frame rate ~87 ms) images were obtained on a 1.5T GE HDx system using a spoiled gradient-echo sequence. Diffusion experiments were performed on a 3T Philips Intera system. Global ADC data was obtained from FID acquisition after bi-polar diffusion gradients. 1D diffusion profiles were obtained by adding a read-out gradient. For both sequences, the diffusion gradient timing parameters were similar to those used in [1], and the gradient strength was varied from 0 to 15 mT/m in 60 equal steps. Custom-built transmit-receive birdcage coils (15 cm diameter) were used.

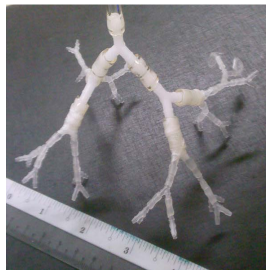

Figure 1. Photograph of the phantom with five "airway" generations.

Figure 2. 3D ^{3}He image obtained from the phantom. All five airway generations are clearly visible.

Results and Discussion

Fig. 2 shows a reconstruction of a 3D ^{3}He image obtained from the phantom. All five generations of the phantom can be clearly observed which proves the phantom can be used to assess the spatial resolution of the MR system and ^{3}He imaging method down to 1 mm. Fig. 3 shows a series of images acquired during the injection of ^{3}He in the phantom using a syringe to simulate the results of dynamic ventilation imaging during inhalation. The image series exhibits excellent temporal and spatial resolution. It can be observed how the gas reaches all five "airway" generations of the phantom. The global diffusion experiments resulted in an ADC value of 0.79 cm^2/s with the diffusion gradient in the Z direction (up-down direction in Fig. 3) and 0.70 cm^2/s with the gradient in Y direction (perpendicular to Fig. 3 plane), where more restriction is present.

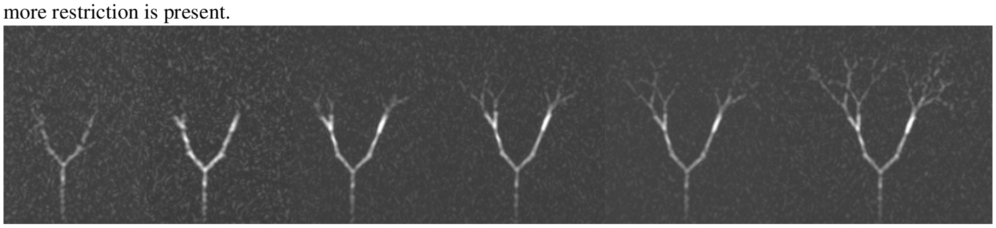

Figure 3. Dynamic ventilation imaging of the phantom during simulated gas inhalation. ^{3}He was slowly injected into the phantom from a syringe while images were acquired.

Fig. 4 shows the 1D diffusion-weighted profile of the phantom corresponding to the b=0 s/cm^2. The calculated ADC values for each of the peaks (locations) marked in the spectrum are presented in Table 1, which indicates the presence of different levels of diffusion restriction at these locations due to the presence of different airway dimensions and orientations. The volume-weighted average of these ADC values (0.73 cm^2/s) is in good agreement with the corresponding global ADC value reported above (0.70 cm^2/s). The phantom may also be useful in other diffusion measurements such as long range ADC, anisotropy and tortuosity.

T2* effects can easily be simulated by submerging the phantom in water, since polypropylene fibers have been proven to be a good model for lung susceptibility effects [5]. The accurate knowledge of the dimensions and geometry of the phantom components and their spatial arrangement allows simulations to be easily constructed that exactly reproduce the phantom geometry and can be compared directly to experimental data.

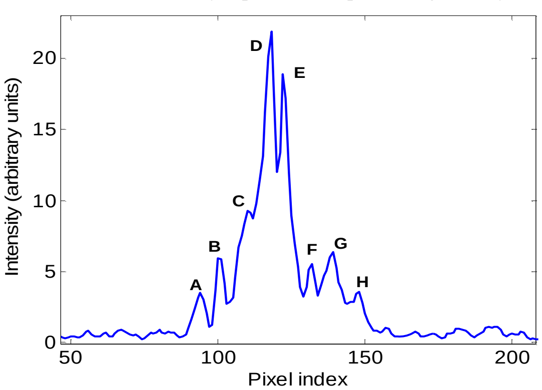

Figure 4. Profile (1D projection) of the phantom corresponding for the b=0 step of the diffusion experiment with a read-out gradient during acquisition.

Conclusion

The results obtained in this work demonstrate that this phantom is a valid physical model of the lung that can be used to validate the predictions of theoretical and numerical simulations in HNG MR imaging. The phantom may be very useful in the investigation between geometrical properties of the lung and measured MR parameters.

	A	B	C	D	E	F	G	H
ADC (cm^2/s)	0.66	0.68	0.64	0.76	0.90	0.65	0.50	0.65

Table 1. ADC values obtained from the data shown in Fig. 4, for the locations marked A-H.

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