

# A diffusion coefficient distribution model to describe the b-value dependence of ADC in diffusion-weighted hyperpolarized gas MRI

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**Introduction:** The apparent diffusion coefficient (ADC) in diffusion weighted HP gas imaging of the lung has proven to be a useful measurement in the diagnosis of obstructive lung disorders (1, 2). Changes to the geometry of the lung's airways and alveolar structures impair respiration in these diseases, and the diagnostic utility of ADC stems from its ability to detect these microstructural changes in the lung parenchyma (3). However, reproducibility is limited, as the measured ADC value has been shown to depend on the b-value, presumably because of the inhomogeneous restriction of diffusion (3). We hypothesize that a diffusion distribution function, P(D), may be measured that describes the distribution of spaces with different diffusion length scales within the voxel. The P(D), unlike the ADC, should be independent of b-value and may therefore be a more useful metric than ADC to evaluate lung microstructure.

## Methods:

Assuming a distribution of diffusion coefficients within a given voxel, P(D), the signal attenuation at a given b value, s(b), may be described as:

$$s(b) = e^{-b \cdot \text{ADC}(b)} = \int_0^{\infty} e^{-b \cdot D} \cdot P(D) \cdot dD \quad (1)$$

Given a number of measurements at different b values, the distribution P(D) may be determined by the Laplace transform. If an upper boundary is imposed based on physical limitations (e.g.  $D_0 = 2 \text{ cm}^2/\text{s}$ , the free diffusion coefficient of pure He at STP), and assuming a non-negative, real valued Laplace transform over the region of support  $\{0, D_0\}$ , iterative numerical inversion makes the ill-posed inversion more tractable and less sensitive to noise.

Diffusion measurements were performed on several phantoms filled with 1 atm of pure He-3 and in the lungs of a Brown Norway rat during a breath-hold of 2.8 mL of He-3. The phantoms were constructed from 5 cm inner diameter PVC pipe sealed at both ends with end-caps. One contained a piece of synthetic sponge cut in the shape of a half-cylinder to occupy half of the space in the phantom for a net volume of 160cc. The other phantom contained porous foam and was similarly constructed for a net volume of 160cc. The photograph in Figure 2 shows samples of the foam and sponge. Free diffusion data were obtained from the sponge phantom in a region that contained no sponge.

A 2D diffusion weighted scan with b-values ranging from 0.1 to 3  $\text{s}/\text{cm}^2$  and  $\delta = \Delta = 1.46 \text{ msec}$  was acquired on a 1.5 T MR scanner (Signa Excite, GE Healthcare, Milwaukee, WI). A chest coil tuned to the He-3 resonant frequency was used to transmit and receive. Imaging was carried out using a fast-GRE sequence, with a +/-31.25 kHz readout bandwidth,  $64 \times 64$  image matrix, 1 slice at a ~4 cm thickness (phantom), TR/TE of 7msec/3.6 msec and flip angle of  $\approx 7^\circ$ . Identical parameters were used for the rat study except that a 5mm slice thickness was used.

**Results and Discussion:** The measured data points are plotted in dark blue in Figure 1a for all experiments. Reasonable fits were obtained over the range of measured b-values. The plots on the right (Fig. 1b) show the resulting P(D), transform pairs are color-coded. As a point of reference, note that the free diffusion distribution presented in Figure 1b (pink) approaches a delta function as expected. This can be contrasted with the distribution for the rat lung, which has a large peak near zero, corresponding to the restricted regime (cyan). The diffusion distribution for the sponge (red) and foam (green) phantoms lies somewhere in the middle of these two extremes and are represented by a range of intermediate diffusion terms in agreement with the expected heterogeneity of these structures (Fig. 2).

**Conclusion:** We have presented a model for the behavior of ADC as a function of b-value. The observed results in phantom experiments agree qualitatively with the model and appear useful in assessing the degree of restriction and inhomogeneity within the media tested. Future work will seek to further validate the technique by establishing reproducibility in phantoms and in small animal models of asthma and COPD.

## References:

(1). Salerno et al Proc. ISMRM 11 2003. (2). Morbach et al JMRI 2005. (3). Yablonskiy et al PNAS 2002.

Figure 1

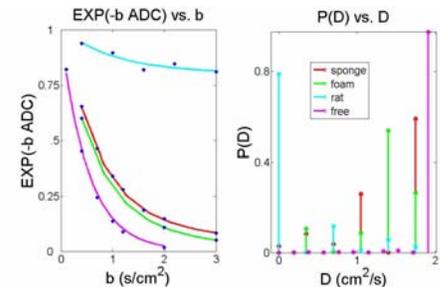


Figure 2

