Time-Dependent Hyperpolarized ^{3}He Diffusion MR Imaging: Initial Experience in Healthy and Emphysematous Lungs

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Introduction

Several studies have reported apparent diffusion coefficient (ADC) values of ^{3}He gas in the lung, however few have explored the dependence of these ADC values on the effective diffusion time of the pulse sequence [1,2]. As the motion of ^{3}He is restricted in the lung, the measured ADC should change as a function of the diffusion time, provided that the long time limit has not been reached. The time dependence of the ADC might provide further insight into the restricting environment of the lung, thus providing a new tool for probing changes in the lung microstructure with disease. In this investigation, we measured ADC values in the human lung at various effective diffusion times to investigate the time dependence of the ADC in healthy volunteers and in a patient with severe emphysema.

Methods

Hyperpolarized ^{3}He MR imaging was performed in 3 healthy volunteers and in a patient with severe emphysema using a 1.5-T whole-body imager (Magnetom Vision, Siemens Medical Systems, Iselin, NJ). Data for 2-3 slice positions (acquisition time, 9-14 seconds) were collected after the subject inhaled 350 ml of 20-30% polarized ^{3}He (Model 9600 Helium Polarizer, Nycomed-Amersham Imaging, Durham, NC) diluted to 1.0 L with nitrogen. A gradient-echo (FLASH) pulse sequence (TR/TE 14.6/10.4 ms, FA 6°, FOV 52.5 x 60 cm, slice thickness 3 cm, matrix 80 x 128) was used and diffusion-sensitization gradients were added in the slice-select direction to achieve a b-value of 1.6 s/cm^2. For each slice position, three coronal images with different spacings between the diffusion gradient waveforms (0.5, 2.5, and 4.5 ms), and one coronal image without the diffusion-sensitization gradients, were collected in an interleaved fashion. ADC images were calculated for each of the diffusion times by linear least squares fitting of the natural log of the signal versus the b-value.

Results

The ADC values for the healthy volunteers and the emphysema patient are shown in Table 1. For all lung regions in all subjects, the mean ADC decreased as the effective diffusion time increased, consistent with diffusion in a restricted environment. Figure 1 shows representative ADC histograms, which include the trachea and parenchyma, from a healthy volunteer for each of the diffusion times. In the healthy volunteers there were statistically significant differences between the mean ADC values in the parenchyma measured at each of the three diffusion times ($p<0.01$). The decrease in mean ADC as a function of diffusion time was different in the parenchyma as compared to the trachea, which is evidenced by the difference in the separation of the peaks on the ADC histogram (Fig 1). The percent change in ADC was greater in the parenchyma than in the trachea, and was greater in healthy subjects than in the emphysema patient. The greatest difference in mean ADC values between the healthy volunteers and the emphysema patient occurred at the shortest diffusion time.

Table 1: Mean ADC at various diffusion times

		1.8 msec	3.8 msec	5.8 msec
Emphysema	Trachea	1.60	1.31	1.24
	Parenchyma	0.67	0.54	0.50
Healthy	Trachea	1.33	1.10	1.03
	Parenchyma	0.22	0.17	0.15

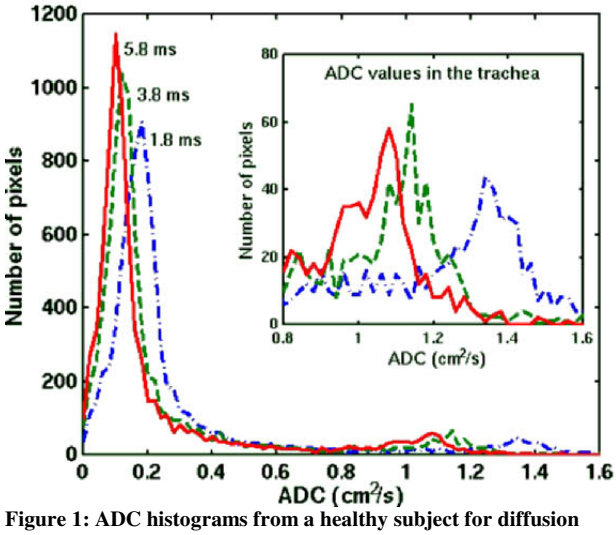

Figure 1: ADC histograms from a healthy subject for diffusion times of 1.8, 3.8 and 5.8 ms. The inset shows the ADC values in the trachea for these three diffusion times.

Discussion

As expected, the ADC values decreased with increasing effective diffusion time, a trend that is characteristic of restricted diffusion. For the shortest diffusion time, the measured ADC exhibits nearly a 10-fold reduction from the free diffusion coefficient of ^{3}He gas. This indicates that it is unlikely that the short diffusion time behavior, which provides a measure of the surface-to-volume ratio, can be probed in the normal lung because sufficient diffusion weighting cannot be achieved in less than 1.5 ms with our current gradient system (25 mT/m, 42 T/m/s). The trend of decreasing ADC values also indicates that the long-time diffusion limit has not been reached for the diffusion times used in this experiment. In the long-time limit, the ADC would provide a measure of the tortuosity of the airways in the lung. When using a gradient-echo-based pulse sequence at high field, T2* limits the diffusion times that can be probed. Thus, in the range of diffusion times which are practically achievable with a gradient-echo pulse sequence, the ADC values are likely to be dependent on the diffusion-encoding scheme.

Conclusions

The time dependence of the ADC may aid in determining the optimal diffusion time for a specific application, or may provide additional information about the lung microstructure. From this preliminary analysis, it appears that using a short diffusion time might result in the largest differences in ADC values between normal and emphysematous parenchyma.

References

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