Anisotrophic Diffusion in Human Lungs using ^{3}He MR spectroscopy

D. D. Shanbhag[1], T. A. Altes[2], J. F. Mata[2], G. W. Miller[2], J. Knight-Scott[1]

[1]Biomedical Engineering, University of Virginia, Charlottesville, Virginia, United States, [2]Department of Radiology, University of Virginia, Charlottesville, Virginia, United States

Introduction:

Measurement of ^{3}He apparent diffusion coefficient (ADC) in the human lungs presents an opportunity for probing the morphology of the lung microstructure. Currently ^{3}He diffusion weighted imaging is used to determine the ADC along a single axis by sampling the diffusion curve using only a few b-values (frequently two). As the ^{3}He gas motion is less restricted along the axis of the airways as compared to the directions orthogonal to it, the diffusion in lungs is anisotropic [1]. However, given the time constraints for the imaging technique, an anisotropic measurement of diffusion is difficult and highly susceptible to noise due to sparse sampling of diffusion curve. In this study, we demonstrate the application of ^{3}He magnetic resonance spectroscopy (^{3}He-MRS) to determine global anisotropic diffusion *in vivo*. The method is robust because it densely samples the diffusion curve over a large range of b- values within a single, short breathold (< 7s).

Methods and Materials :

^{3}He spectroscopy data was collected from five healthy volunteers. All the experiments were performed on a 1.5T whole body Siemens Sonata MRI system using a helium chest coil. For each subject, 158 lung spectra were collected during a 6.25 s breathold using a non-selective 5°, 1 ms rectangular RF pulse and TE/TR = 9 ms/ 39.6 ms. Bipolar sinusoidal gradients were used for diffusion sensitization along the *right-left* (**R-L**), *anterior-posterior* (**A-P**) and *head-foot* (**H-F**) anatomical directions with the volunteer in *feet first supine position*. Fifty b-values (from 54.0 s/cm^2 to 0.0 s/cm^2) were sampled along each of the directions mentioned above. The first eight FIDs were collected without the diffusion sensitization gradients to obtain a measure of flip angle and T_1 attenuation effects. The FIDs were phase corrected and the peak areas obtained using AMARES algorithm provided in jMRUI (version 2.1). The data were corrected for flip angle dependent attenuation and T_1 relaxation using the method described in [2] and fitted to a multi exponential model $S = \sum_{n=1}^{m} S_n e^{-bD_n}$, $m \geq 1$ where D_n is a measure of global ADCs in human lungs. The curve fitting was done with a Marquardt-Levenberg fitting algorithm.

Results and Discussion:

Table 1.

Bi-Exponential Model	Uncorrected			Corrected		
	H - F	R - L	A - P	H - F	R - L	A - P
D_1 (cm^2/ s)	0.1441	0.1394	0.1220	0.1770	0.1686	0.1524
D_2 (cm^2/ s)	0.0342	0.0300	0.0223	0.0406	0.0354	0.0291
Mono-Exponential Model	Uncorrected			Corrected		
D (cm^2/ s)	0.0785	0.0755	0.0688	0.0952	0.0922	0.0847

Figure 1 readily shows that the diffusion curve *in vivo* does not follow a mono-exponential model. A bi-exponential model fits well to the experimental data. Models with m > 2 had very high coefficients of variation, did not improve the fit, and were consequently rejected. Figure 2 was obtained by turning off the alternative diffusion sensitizing gradients. As is evident from figure 2, there is substantial flip angle and T_1 related signal loss (~60%) during the entire experiment. This signal loss should be accounted for when measuring the ADC as the diffusion curve also incorporates this attenuation. In spectroscopic examination signal loss is measured using the first eight and last three data points which are collected without the diffusion sensitizing gradients [2].Table 1 illustrates the effect of the signal correction on ADC values in a healthy volunteer. The ADC values obtained using a mono-exponential model are also shown in the table.

This study demonstrates the anisotropic nature of diffusion in human lungs. H-F direction demonstrated the largest ADC value which suggests that this direction offers least restraint to diffusion of ^{3}He. The A-P direction had the lowest ADC value which indicates maximum restraint to diffusion along this direction. As is evident from figure 3, four of the five healthy volunteers showed the trend (H-F > R-F > A-P). Only one healthy volunteer did not show the trend. Possible sources of this artifact include bulk motion, breathing by the patient , or a true lung morphology.

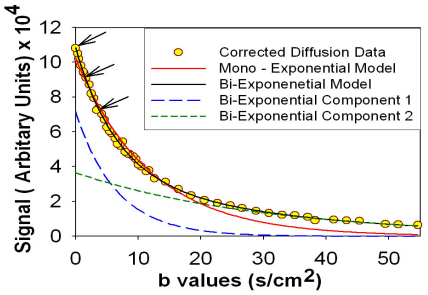

Figure 1. ^{3}He diffusion curve along H-F direction using spectroscopy. Arrows indicate the b-values (0.0 s/cm^2, 1.6 s/cm^2 & 4.0 s/cm^2) used in a conventional imaging experiment.

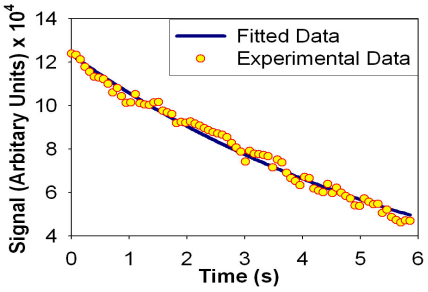

Figure 2. Effect of flip angle attenuation and T_1 relaxation during a single breathold (6 ms) in a healthy volunteer.

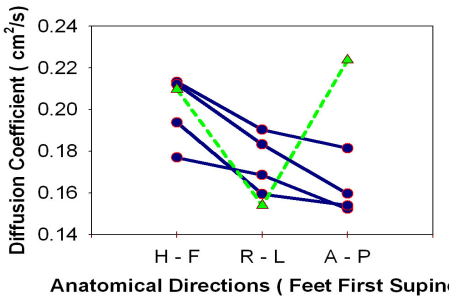

Figure 3. ADC obtained from bi-exponential model for five volunteers along the three anatomical directions.
(Note : *Only D_1 component shown in figure*)

Conclusion:

The mono-exponential model was found to follow the diffusion curve only for b-values < 15 s/cm^2. For the range of b-values (0 to 54 s/cm^2) used in the experiment, the failure of mono exponential model was conspicuous. A bi-exponential model fit the experimental data well. The anisotropic diffusion in lungs was distinctly manifested. Thus ^{3}He-MRS provides a useful probing tool of lung morphology by allowing dense sampling of diffusion curve over a large range of b-values, along three directions within a single short breathold.

References:

[1] Yablonskiy D.A., Sukstanskii A.L., Leawoods J.C., et. al, Proc Natl Acad Sci U.S.A, 99(5):3111-3116, 2002.

[2] Knight-Scott J., Smith A. L. and Mugler J.P., *Proc .ISMRM* , pg. 1898, Sydney, April 1998.