Diffusional Kurtosis Imaging in the Lung Using Hyperpolarized ^3He

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Introduction

Magnetic resonance imaging (MRI) using inhaled hyperpolarized gas has been shown to be capable of demonstrating lung airway structure (1, 2). As ^3He diffusion is impeded by airway and alveolar walls, measurements of the apparent diffusion coefficient reflect lung structure at the alveolar level and can provide a quantitative characterization of lung micromorphology (3-6). However, the short T_2* of ^3He in human lungs restricts diffusion measurements to short time, and hence length, scales. Consequently diffusion imaging is sensitive to changes within alveoli and acinar airways, and is relatively insensitive to changes in the bronchioles. Diffusional kurtosis imaging (DKI) quantifies the degree to which diffusion in biological tissue is non-Gaussian and is particularly sensitive to diffusion over larger distance scales (7). DKI uses the same type of pulse sequence used for conventional diffusion-weighted imaging. However, a series of at least three different *b* values are necessary and a somewhat larger maximum *b* value is desirable. In addition to the apparent diffusional kurtosis (ADK), DKI gives an estimate of the conventional apparent diffusion coefficient (ADC) from the same experiment.

Method

Three symptomatic male firefighters who were involved in the rescue efforts after the collapse of the World Trade Center were studied. The firefighters suffered from a variety of symptoms including cough, wheezing, shortness of breath, chest pain, dyspnea on exertion and asthma-like symptoms. Five healthy control subjects were also studied. All experiments were performed on a 1.5T whole-body MR scanner (MAGNETOM Avanto; Siemens). A gradient-echo fast low-angle shot (FLASH) sequence with a flip-angle of 4° was used to obtain 3 coronal or axial slices (image matrix 80 x 128, slice thickness 15mm, FoV 332.5 x 380mm, bandwidth 270Hz, echo time 10.5ms, repetition time 14ms). The number of slices was limited by the need to acquire images with 6 different *b* values during a single 20s breath hold. Non-overlapping bipolar gradient pulses were applied consecutively on all three axes to achieve isotropic diffusion weighting. *b* values were 0, 3, 6, 9, 12 and 15s/cm^2. Parametric maps of ADK and ADC were created by fitting the image signal intensities on a voxel-by-voxel basis to formula [16] given in Ref. 7.

Results

Figure 1 shows a coronal ventilation image with no diffusion weighting of one of the healthy controls. It can be seen that with the described experimental setup sufficient SNR can be achieved. In Fig. 2 parametric maps of the ADK and of the ADC of a coronal image of the same subject are shown. The mean values for the ADK and the ADC for controls and firefighters are listed in Table 1. Although there was no statistically significant difference in the ADC (p=0.95), the firefighters had a substantially reduced ADK with a p value approaching significance (p=0.098).

	ADK	ADC
Firefighters	0.263±0.049	0.213±0.022
Controls	0.337±0.038	0.212±0.024

Tab. 1: Mean ADK and ADC for firefighters and healthy controls. The ADC is in units of cm^2/s.

Discussion and Conclusion

The presented work demonstrates the successful application of diffusional kurtosis imaging to human lungs. Three firefighters involved in the 9/11 rescue efforts and five healthy controls were investigated. The decreased ADK in combination with a normal ADC in the firefighters suggests bronchiolar constriction causing airway obstruction. The presence of air trapping demonstrated by CT supports this interpretation. Furthermore, despite the normal ADC the firefighters had highly abnormal pulmonary function tests, indicating severe airflow obstruction, air trapping, and airway hyperreactivity. DKI is easily performed on modern MR scanners, with trivial modifications for slightly higher *b* values than conventional diffusion measurements and may provide information that is complementary to that provided by conventional diffusion imaging.

References

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Fig. 1: Coronal image with no diffusion weighting of a healthy control showing homogeneous distribution of signal throughout the pulmonary gas space.

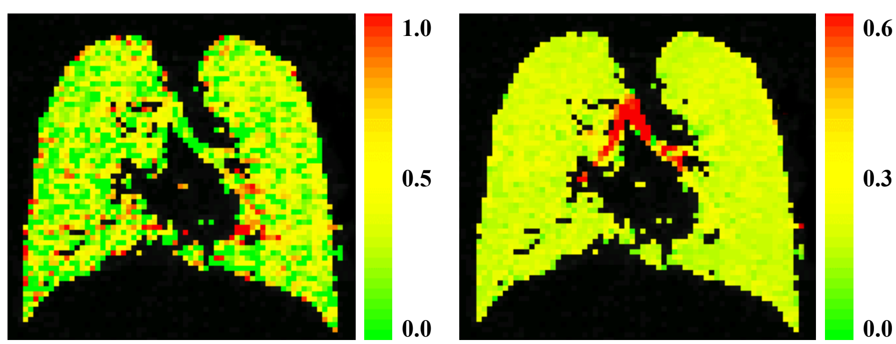

Fig. 2: Parametric maps of coronal images of the apparent diffusional kurtosis (left) and the apparent diffusion coefficient (right) of a healthy control. The scale bar for the diffusion coefficient is in units of cm^2/s.