Short-time-scale and Long-time-scale ^{3}He Diffusion MRI in Emphysema: Which is More Sensitive?

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Introduction: Emphysema is defined as an abnormal enlargement of the lung airspaces distal to the terminal bronchioles. Recent studies have shown that hyperpolarized (HP) ^{3}He diffusion MRI, including measurements at short (~1 ms) and long (~1 s) time scales, is sensitive to emphysematous changes [1-4]. Short-time-scale apparent diffusion coefficient (ADC) values have been shown to correlate well with histology [4]. However, long-time-scale ADC measurements are thought to be more sensitive [2,3]. The goal of this work was to perform a preliminary comparison of the relative sensitivities of short and long time scale ADC measurements for emphysematous changes in the lung.

Methods: The short-time-scale ADC is commonly measured by using an interleaved gradient-echo (GRE) pulse sequence that samples only a small fraction of the magnetization for each *k*-space line. Thus, this sequence can be appended before a stimulated-echo (STEAM) based long-time-scale ADC measurement [3] to yield a combined pulse sequence that can measure co-registered ADC maps at both short and long time scales in one breath hold. For the short-time-scale ADC, *b* values of 0 and 1.6 s/cm^2 were used, and for the long-time-scale ADC measurement a *b* value of 60 s/cm^2 with a tag wavelength of 10mm and a diffusion time of 1.5 s were used.

The combined pulse sequence was applied in 15 healthy subjects (5 males and 10 females, age range: 52-79 yrs) and 3 age-matched subjects with mild emphysema (2 males and 1 female, age range: 52-61 yrs) following inhalation of 400-700 ml ^{3}He mixed with N_2 to yield a total volume of approximately 1 liter. Imaging was performed on a 1.5T commercial scanner (Sonata, Siemens) modified by the addition of the multi-nuclear imaging package and a flexible RF coil (CMRS, Brookfield, WI). ^{3}He was polarized to ~30% by the collisional spin-exchange technique using a commercial system (Model 9600, MITI). MR data was acquired during a breath-hold period lasting no more than 15 seconds. Axial multi-slice ADC maps for both short and long time scales were collected. The means of the ADC values were calculated. The percentage of pixels whose long-time-scale ADC was greater than 0.03 cm^2/s (%ADC$_{Long}$ > 0.03) was also calculated and compared to the mean values.

Results and Discussion: Co-registered ADC maps at both short and long time scales were collected in all healthy and emphysema subjects. The ADC maps were homogenous for most healthy subjects with mean ADC values of 0.245 ± 0.042 (SD) cm^2/s for the short time scale and 0.0195 ± 0.0037 (SD) cm^2/s for the long time scale, which agree well with literature values [2,3]. The value of %ADC$_{Long}$ > 0.03 was 10.34% ± 10.64% (SD) for the healthy group. Figure 1 presents co-registered ADC maps from a subject with mild emphysema (Gold Stage 0). For both time scales, regional elevations of the ADC values are clearly observed. However, the regional changes in the long-time-scale ADC are more apparent and more extensive than those in the short-time-scale ADC. The short-time-scale mean ADC for the emphysema group was 0.357 ± 0.032 (SD) cm^2/s, 46% greater than that for the healthy group (Fig. 2(a)). The long-time-scale mean ADC for the emphysema group was 0.0381 ± 0.0068 (SD) cm^2/s, 95% greater than that for the healthy group (Fig. 2(b)), suggesting that the long-time-scale ADC is more sensitive to early emphysematous changes. The value of %ADC$_{Long}$ > 0.03 for the emphysema group was 65.49% ± 17.84% (SD), 549% greater than that for the healthy group (Fig. 2(c)). The increase in this parameter for the emphysema group compared to the healthy group is much large than the corresponding increases in the long-time-scale mean ADC (95%) and the short-time-scale mean ADC (46%), indicating that %ADC$_{Long}$ > 0.03 may be a more sensitive parameter for detecting early emphysematous changes.

Conclusion: This preliminary comparison of short-time-scale and long-time-scale ADC measurements in a small group of healthy and emphysema subjects strongly suggests that the long-time-scale ADC may be more sensitive to early emphysematous changes than the short-time-scale ADC. A study in a larger group of subjects with varying degrees of disease severity is warranted.

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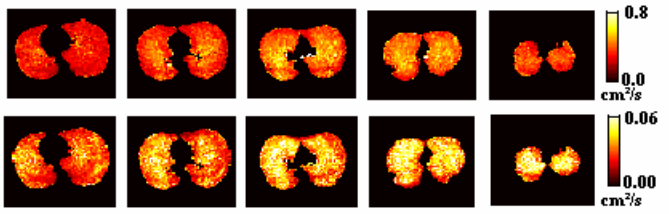

Fig. 1. Co-registered ADC maps from a subject with mild emphysema (Gold Stage 0) acquired at two different diffusion times in one breath hold.

Top row: Short-time-scale ADC, diffusion time = 1 ms;
Bottom row: Long-time-scale ADC, diffusion time = 1.5 s.

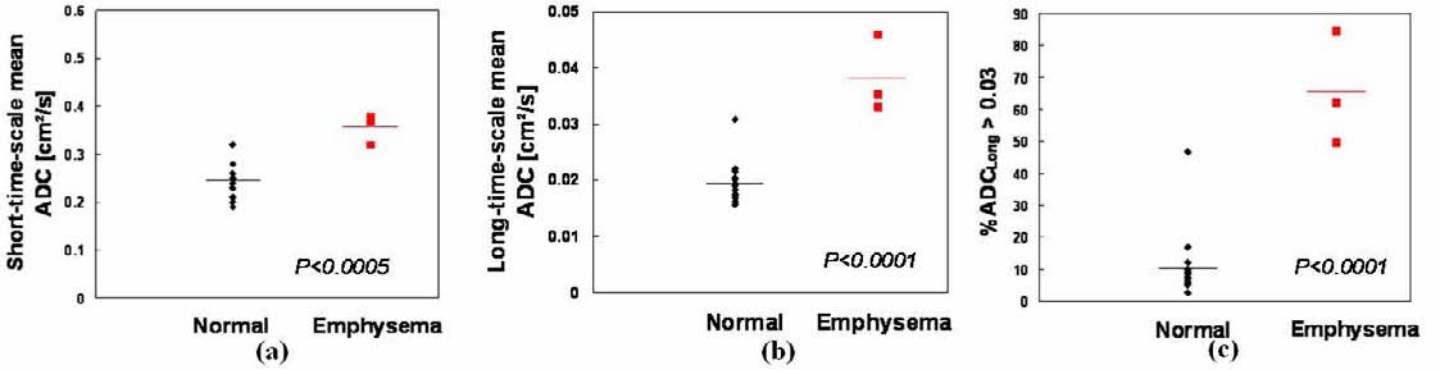

Fig. 2. (a) Short-time-scale mean ADC values, (b) long-time-scale mean ADC values, and (c) the percentage of pixels with a long-time-scale ADC greater than 0.03 cm^2/s (%ADC$_{Long}$ > 0.03) for all subjects.