Evaluation of the Apparent Diffusion Coefficient for Hyperpolarized Helium-3 in the Lung at 0.4T and 1.5T

Peter Komlosi[1], Talissa A. Altes[1], Karen E. Mooney[2], G. Wilson Miller[1], Jaime F. Mata[1], Eduard E. de Lange[1], William A. Tobias[2], Gordon D. Cates Jr.[2], and John Mugler III[1]

[1]*Department of Radiology, University of Virginia, Charlottesville, VA, United States,* [2]*Department of Physics, University of Virginia, Charlottesville, VA, United States*

Rationale: The apparent diffusion coefficient (ADC) of inhaled hyperpolarized helium-3 (He3) gas is sensitive to the microstructure of the lung, to the timing and strength of diffusion-sensitizing gradient waveforms, and also to the presence of background field gradients induced by the magnetic-susceptibility difference at the countless air-tissue interfaces in the lung. The latter phenomenon is dependent upon field strength. It has been predicted that susceptibility-related effects might become significant at relatively high field strengths [1]. Even so, a recent study comparing 1.5T and 3T found a systematic difference between ADC values measured at the two field strengths [2]. The goal of the present study was to evaluate the field-strength dependence of He3 ADC values for lower magnetic field strengths.

Methods: Hyperpolarized He3 diffusion-weighted MRI of the human lung was performed at 0.43T and 1.5T in 12 healthy volunteers, each of whom was imaged at both field strengths. All studies were performed on a clinical whole-body scanner (Avanto, Siemens), which, for the lower field studies, was ramped to 0.43T and re-shimmed to achieve field homogeneity 0.9 ppm (RMS) over a 30-cm diameter spherical volume. Flexible chest, transmit/receive He3 RF coils (Clinical MR Solutions, Brookfield, WI), of identical size and configuration, were used at both field strengths. Helium-3 gas was polarized by collisional spin exchange with optically-pumped rubidium/potassium vapor using a custom-built system [3], yielding polarizations between 50 and 60%. Each subject inhaled a gas mixture containing 500 ml of hyperpolarized He3 and medical grade nitrogen for a total volume equal to approximately one-third of the subject's forced vital capacity. After inhaling the He3/nitrogen mixture, the subject then inhaled room air to total lung capacity. All experiments were performed under a Physician's IND for imaging with hyperpolarized He3 using a protocol approved by our institutional review board. Informed consent was obtained in all cases.

A gradient-echo pulse sequence was used with application of a bipolar diffusion-sensitization gradient waveform between the excitation RF pulse and the associated spatial-encoding gradients. During a single breath-hold period, diffusion-weighted data were acquired with diffusion-sensitization along three orthogonal directions (phase-encoding, readout and slice-select) and a b value of 1.6 s/cm^2, yielding ADC maps for three diffusion-sensitization directions per breath-hold. (For a given line of k space, the acquisition order was b = 0, b = 1.6 s/cm^2 [phase], b = 0, b = 1.6 s/cm^2 [readout], b = 0, b = 1.6 s/cm^2 [slice]). Other pulse sequence parameters included: TR/TE 9.8/6.4 ms, flip angle 5°, voxel size 3.3 x 6.6 x 25 mm.

Following application of a threshold to remove background noise, ADC values were calculated from the diffusion-weighted images using the equation ADC = $(\ln S_{b=0} - \ln S_{b=1.6})/\Delta b$; representative images are shown on Figure 1. Corresponding values in each subject were compared using a paired Student's t-test.

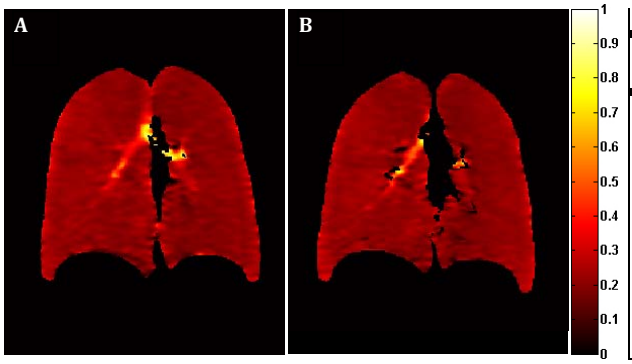

Figure 1. Representative ADC maps obtained at 0.43T (A) and 1.5T (B). Colormap is shown on the right (units, cm^2/s).

Table 1. Subject data and median ADC values.

	0.43T			1.5T			0.43T / 1.5T		
Subject	Phase	Read	Slice	Phase	Read	Slice	Phase	Read	Slice
1	0.211	0.196	0.187	0.212	0.198	0.195	0.998	0.989	0.960
2	0.205	0.207	0.192	0.211	0.206	0.193	0.969	1.005	0.994
3	0.205	0.199	0.193	0.210	0.202	0.199	0.977	0.985	0.968
4	0.213	0.201	0.203	0.217	0.212	0.207	0.983	0.948	0.979
5	0.186	0.179	0.176	0.190	0.187	0.180	0.981	0.957	0.978
6	0.233	0.234	0.221	0.238	0.232	0.225	0.981	1.009	0.979
7	0.200	0.203	0.194	0.206	0.206	0.199	0.971	0.984	0.974
8	0.217	0.199	0.193	0.216	0.196	0.196	1.007	1.017	0.987
9	0.195	0.182	0.188	0.199	0.188	0.193	0.978	0.970	0.973
10	0.182	0.183	0.170	0.196	0.191	0.188	0.931	0.957	0.906
11	0.196	0.186	0.183	0.203	0.189	0.195	0.969	0.982	0.936
12	0.165	0.151	0.150	0.166	0.157	0.157	0.998	0.967	0.952

Results: Median ADC values, averaged over all subjects, were 0.201 ± 0.017 (phase), 0.193 ± 0.019 (readout) and 0.187 ± 0.017 (slice) at a field strength of 0.43T, and 0.205 ± 0.017, 0.197 ± 0.017 and 0.194 ± 0.016 at 1.5T, respectively (for the complete dataset, see Table 1). For each sensitization direction, the median ADC values obtained at 0.43T were typically a few percent lower than those obtained at 1.5T. Considering all subjects, these differences were statistically significant ($p < 0.05$). The trend of higher ADC values with higher field strength is consistent with that previously observed [2], although the magnitude of the effect for 0.43T vs. 1.5T is several times smaller than that for 1.5T vs. 3T. It was also noted that the ADC values were dependent on the direction of the sensitization gradient applied, with the highest to lowest values obtained in the order of phase, readout and slice. These differences may reflect directionality of the lung architecture [4].

Conclusion: For each of three orthogonal diffusion-sensitization directions, ADC values for the healthy human lung based on 2 b-value measurements were, on average, a few percent smaller at 0.43T than at 1.5T. Although the differences were small, they were statistically significant.

References: **1.** Sukstanskii AL et al. J Magn Reson 2010;207: 234. **2.** Parra-Robles J et al. 2011 Int Func Pulm Imaging Workshop, Univ Penn, Philadelphia. **3.** Mooney KE et al. ISMRM 2009; 2166. **4.** Schreiber W et al. Respir Physiol Neurobiol 2005;148:23-42.

Acknowledgements: Supported by NIH grant R01 HL079077 and Siemens Medical Solutions. The authors thank Drs. Piotr Starewicz and William Punchard of Resonance Research Inc. for invaluable assistance with shimming the scanner magnet at 0.43T.