Evaluation of Signal-to-Noise Ratio, T2, and T2* for Hyperpolarized Helium-3 MRI of the Human Lung at Three Magnetic Field Strengths

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Target audience: Imaging scientists and physicians interested in the basic characteristics of hyperpolarized-gas MRI of the human lung.

Rationale & Purpose: Because the magnetization of hyperpolarized gases is independent of the static magnetic field strength of the MR scanner, there has been significant interest in the possibility of imaging at magnetic field strengths lower than those most commonly used for clinical MRI. In addition to lower cost, lower magnetic field strengths may provide an opportunity for improving the performance of certain techniques, or even using techniques that perform poorly at high magnetic field strengths, since susceptibility-related effects diminish with decreasing field strength. Although several studies have investigated the properties of hyperpolarized-gas MRI at relatively low field strengths [e.g., 1-3], to our knowledge there has not been a systematic investigation to directly compare the lung-imaging characteristics obtained at 1.5T to those for field strengths below 1.5T. The goal of the present study was to evaluate the field-strength dependence of hyperpolarized helium-3 (HHe3) signal-to-noise ratio (SNR), and T2 and T2* values, for MRI of the human lung at field strengths between 0.4T and 1.5T.

Methods: All imaging was performed using the same commercial 1.5T whole-body MRI scanner (Avanto, Siemens), which was ramped to two lower field strengths and shimmed (Resonance Research Inc., Billerica, MA) at each field strength. Flexible chest, transmit/receive He3 RF coils of identical size and geometric configuration (Clinical MR Solutions, Brookfield, WI) were used at all three field strengths; only the 1.5T RF coil included proton-blocking circuits. Image data for determining SNR (ventilation [spin-density] images), whole-lung T2 values, and T2* maps were obtained at 0.43T, 0.79T and 1.5T in 16 healthy volunteers of whom 9 were imaged at all three field strengths. Helium-3 gas was polarized by collisional spin exchange with optically-pumped rubidium/potassium vapor using a custom-built system, yielding polarizations between 50 and 60%. For each MR acquisition, the subject inhaled a gas mixture containing HHe3 and medical grade nitrogen for a total volume equal to approximately one-third of the subject's forced vital capacity. Helium-3 "dose" (total magnetization) was determined for each inhalation using a commercial polarization-measurement system (Model IGS.9900.Xp; Amersham Health). All experiments were performed under a Physician's IND for imaging with HHe3 using a protocol approved by our institutional review board. Informed consent was obtained in all cases.

For determination of SNR, a gradient-echo pulse sequence was used with TR/TE 6/2.3 ms, flip angle 9°, voxel size 3.3 x 3.3 x 10 mm. Mean whole-lung SNR values were normalized by the subject's ventilated lung volume and the administered HHe3 dose. Corresponding values for each subject were compared using repeated measures one-way ANOVA. Whole-lung T2 relaxation times were calculated from a Carr-Purcell-Meiboom-Gill spin-echo-train pulse sequence (echo spacing, 30 ms) without spatial encoding. Least-squares fitting was performed with mono- and bi-exponential functions over echo train durations of 2.9s for 0.43T and 0.79T, and 0.8 s at 1.5T. For the T2* measurements an interleaved-acquisition gradient-echo pulse sequence was used with TE values of 2.1/22.1, 2.1/17.1, 2.1/12.1 ms at 0.43T, 0.79T and 1.5T, respectively. After thresholding the images to suppress background noise, T2* maps were calculated as the difference between the natural logarithms of the signal intensities, divided by the difference in TEs.

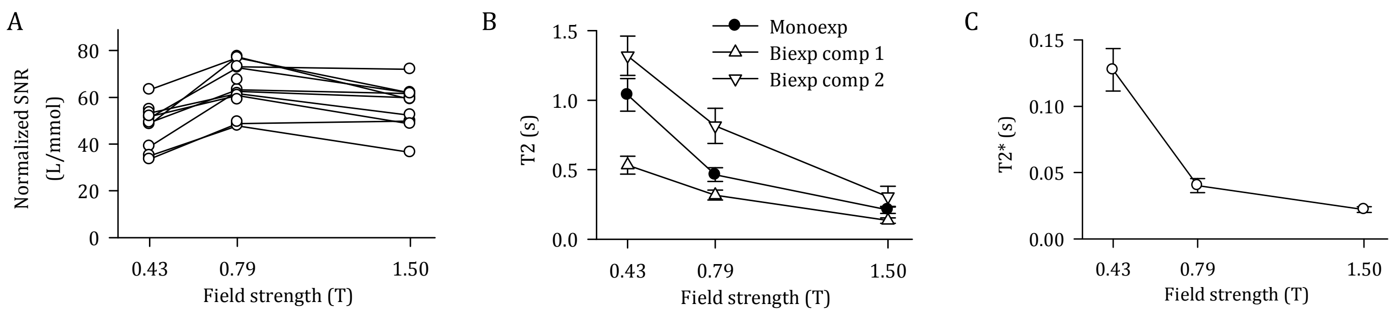

Figure 1. (A) Graph demonstrating the effect of field strength on normalized SNR. Data from individual subjects are connected with lines. **(B)** Graph showing mean (± standard deviation) over all subjects of whole-lung T2 values as a function of field strength based on mono-exponential or bi-exponential least-squares fits. The triangles show the long T2 ("comp 1") and short T2 ("comp 2") components of the bi-exponential fit. **(C)** Graph depicting the effect of field strength on mean (± standard deviation) of T2* over all subjects.

Results: Without normalization, combined SNR values at all three field strengths were 71±22. As shown in Figure 1A, there was a mild dependence of normalized SNR on field strength; the values were statistically different among field strengths ($p < 0.05$), with the highest values at 0.79T. The difference between 1.5T and 0.79T may be associated with minor performance degradation of the RF coil at 1.5T from the proton-blocking circuits. The general trend of decreased SNR at 0.43T may reflect the expected relative increase in the coil component of noise at lower frequency. As expected, both T2 and T2* values demonstrated an inverse relationship with field strength (Figures 1B, 1C). For the mono-exponential fit, the T2 values at the 3 field strengths were statistically different as assessed with ANOVA on ranks ($p<0.05$). Two exponential components provided a much better fit of the T2 signal decay than one component, particularly at 0.43T and 0.79T (Figure 2). However, we do not know whether the two T2 components from the bi-exponential fit can be associated with some aspect of the lung microstructure. T2* values were also statistically different among field strengths as assessed with ANOVA on ranks ($p<0.05$).

Conclusion: Hyperpolarized He3 MRI of the human lung provides similar SNR at field strengths between 0.4T and 1.5T. T2 and T2* values demonstrate an inverse relationship to field strength between 0.4T to 1.5T, as expected. The decrease in susceptibility effects at lower field, as reflected in longer T2 and T2* values, may have significant advantages for designing pulse sequences that are inherently sensitive to such effects, such as SSFP methods. The 3-fold increase in T2* at lower field would allow lower receiver bandwidths to be used, which provides a concomitant decrease in thermal noise and thus relative increase in SNR.

References: **1.** Tseng CH et al. Phys Rev Ltr 1998; 81:3785. **2.** Durand E et al. Magn Reson Med 2002; 47:75. **3.** Bidinosti CP et al. J Magn Reson 2003; 162:122.

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