Single breath-hold 3D Q-Space imaging of lung structures using He-3 MRI

R. L. O'Halloran[1], J. H. Holmes[1,2], Y-C. Wu[3,4], A. L. Alexander[1], and S. B. Fain[1,4]

[1]Medical Physics, University of Wisconsin, Madison, WI, United States, [2]Applied Science Laboratory, GE Healthcare, Waukesha, WI, United States, [3]Waisman Laboratory for Brain Imaging and Behavior, University of Wisconsin, Madison, WI, United States, [4]Radiology, University of Wisconsin, Madison, WI, United States

Introduction: Diffusion-weighted (DW) MRI can provide structural information about the anatomy on a smaller scale than the nominal voxel size by sensitizing the acquisition to microscopic restriction of the random diffusion of the imaged nuclei. In hyperpolarized He-3 MRI, DW methods have proven useful in evaluating the progression of degenerative lung diseases such as emphysema [1, 2] and also in detecting early emphysematous changes in asymptomatic smokers [3]. Q-space imaging (QSI), an extension of DW MRI in which multiple diffusion weightings are measured provides quantitative measures of the length on a sub-voxel level and can account for multiple spatial scales of diffusion. QSI has also been applied to HP He-3 NMR spectra acquired over the whole human lung [4], however, the constraints of imaging time and limited magnetization have prevented this technique from being applied to spatially-resolved hyperpolarized He-3 imaging of the lung *in vivo*. To meet these challenges a radially under-sampled stack-of-stars acquisition combined with an iterative constrained reconstruction is proposed. In the present work, the iterative HYPR (I-HYPR) reconstruction [5], an extension of the HYPR reconstruction [6] shown to be more robust to decreased sparsity, is used to reconstruct more quantitatively accurate 3D images from the under-sampled data. This methodology is validated in a porous phantom. Feasibility is demonstrated in a healthy human volunteer for 3D QSI in a 13-15 s breath-hold that includes simultaneous correction for signal loss due to RF and T_1 over the duration of the breath-hold.

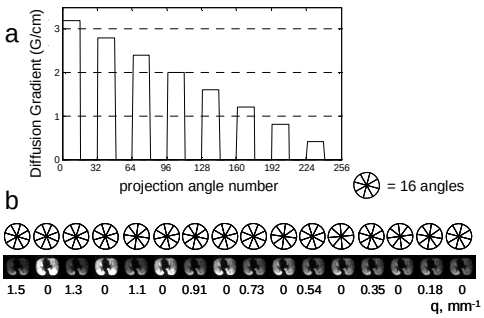

Figure 1: (a) The diffusion gradient is switched every 16 angles. Every other image is acquired without diffusion weighting to correct for RF and T_1. (b) Each wheel represents an image reconstructed from 16 projections. All 16 images for a central slice are shown.

Methods: *MRI:* A novel 3D stack-of-stars diffusion-weighted hyperpolarized He-3 MR acquisition was performed in 14 adult volunteers (3 severe asthmatics, 7 non-severe, 4 normals; mean Age 32 ± 13) and 3 children (mean Age 9 ± 1) following inhalation of 14 % TLC of He-3 gas mixture. The same sequence was performed on one healthy normal volunteer in the supine position following separate inhalations of 3 different volumes of He-3 gas mixture. Imaging was performed on a 1.5 T MR scanner (Signa Hdx, GE Healthcare) with a transmit/receive chest coil tuned to the He-3 resonant frequency with 42 cm FOV, ±62.5 MHz bandwidth, 128 readout points, 256 projections (16 projections per image for a total of 16 images), TR/TE = 2.2/0.7 ms, and 8 slices. The total scan time was 13-15 s.

Data Analysis: Iterative HYPR was performed on each set of 16 diffusion-weighted radial projections to form an image at each q-value using a constraining image composed of all 256 projections to improve signal to noise (Figure 1). All images were corrected for T_1 decay by fitting the 8 unweighted images to an exponential decay model to determine T_1. Corrected diffusion data were fit to a Gaussian model to determine the root mean squared (RMS) displacement, X_{RMS}. Mean X_{RMS} values were computed for each subject.

	Age		n	X_{RMS}
Adults	32(13)	All	14	333(22)
		Severe Asthma	3	345(45)
		Non-severe Asthma	7	324(11)
		Normal	4	339(19)
Children	9(0)	All	3	312(9)

Table 1: Comparison of the whole lung average X_{RMS} values in the adult and pediatric subjects showing the expected increase in alveolar size with age.

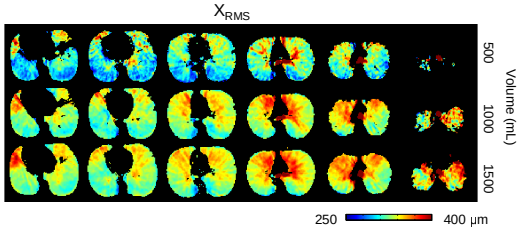

Figure 2 Results from study on dependence of X_{RMS} with inhaled volume. X_{RMS} maps from the three inhaled volumes are compared showing expansion of the structure size with increase in inhaled volume. Note the dependence of X_{RMS} on the apical to basal location and on the anterior to posterior location.

Results and Discussion: Measured whole lung q-space values for all subjects are compared in Table 1. The adult subjects have significantly higher X_{RMS} values than children. This agrees with the known increase in alveolar size with age as observed previously for the ADC measure [7]. Figure 2 summarizes the results of the experiment in which the inhaled volume was increased from 500 to 1500 mL. Measured X_{RMS} values decreased from anterior to posterior, and decreased from apex to base as expected. Similarly, X_{RMS} increased by a mean of 20 µm over the entire lung as the inhaled volume increased from 500 mL to 1500 mL above FRC. This suggests that a small level of microstructural may be occurring during inhalation.

Conclusion: This work demonstrates that hyperpolarized He-3 QSI in the human lung is possible with undersampled radial acquisition and constrained reconstruction techniques. This also represents the first non-invasive *in vivo* study of the dependence of structure size on inhaled volume in human lungs. The observed differences between the adult and pediatric subjects suggest this technique may be useful in longitudinal quantitative assessment of lung structure. The 14 adults and 3 children studied are part of ongoing studies of severe and childhood asthma and future work will focus on using the technique to study the changes in airway structure size in response to clinical outcomes and risk factors in these subjects.

References: [1] deLange et al. Radiology 1999. [2] Saam et al. MRM 2000. [3] Fain et al. Radiology 2006. [4] Shanbhag et al. JMRI 2006. [5] O'Halloran et al. MRM 2008. [6] Mistretta et al. MRM 2006. [7] Altes et al. JMRI 2006.