Functional Lung Imaging of Childhood Asthma Using Radial MRI with Hyperpolarized Noble Gas

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INTRODUCTION: Assessment of lung function in pediatrics poses significant challenges due to variable ability to cooperate with respiratory maneuvers. Imaging of lung function is an attractive option but conventional approaches share increased concerns associated with ionizing radiation exposure. Radial dynamic 3D imaging using multi-echo VIPR (ME-VIPR) acquisition with HP He-3 and I-HYPR reconstruction [1] can capture images of ventilation over the whole lung with good isotropic resolution, and sufficient temporal resolution to adapt to the subject's ability to perform respiratory maneuvers. Diffusion-weighted MRI with HP He-3 MRI also provides a means to assess microstructure of the lung parenchyma without ionizing radiation. In this work, a routine protocol for assessment of lung ventilation and parenchymal microstructure in children at-risk for asthma aged 9 years is presented.

MATERIALS AND METHODS: A total of 40 subjects were imaged from 8/14/2008 to 10/30/2009 using a protocol incorporating dynamic 3D imaging of hyperpolarized He-3 (HPHe3) MRI [2] in conjunction with a diffusion q-space acquisition [3] for short breath-hold times ranging from 7-13 seconds, but with adaptability to shorter breath-hold times as necessary. Both acquisitions are designed to maximize data acquisition efficiency using radial imaging with constrained reconstruction [1]. Forty pediatric subjects, 9 years of age, were imaged on a 1.5T clinical MR system with broadband capabilities (Signa HDx, GE Healthcare, Waukesha, WI). HPHe3 was prepared to ~27% polarization using a commercial polarizer system (GE Healthcare, Waukesha, WI) and mixed with nitrogen to produce an inhaled dose of ~5 mM at a volume of fuctional residual capacity plus 14% of the subject's total lung capacity. The first 5 Studies were performed using a transmit receive coil provided by Medical Advances (Milwaukee, WI). The remaining studies were performed using a linear elliptical coil providing a more uniform B1 field (Rapid Biomedical, Cleveland, Ohio). To minimize total exam time, volunteers were imaged using a limited protocol lasting ~45 min including: 1) localizer, 2) 3D SPGR, 3) HPHe3 3D dynamic scan, and 4) HPHe3 diffusion weighted scan. During the dynamic acquisition, subjects were asked to inhale the HPHe3, perform a short breath-hold, and force the gas out upon exhalation. Breath-hold times were verbally coached, however, the subjects were free to exhale at their individual comfort level. Imaging parameters included a 60 s total acquisition, cubic 42 cm FOV, effective acquired matrix of 128^3. Time-resolved 3D data-sets were reconstructed using an I-HYPR reconstruction with 1 s of time-frame data and a 10 s sliding-window composite image data; six iterations were performed using the I-HYPR algorithm. Reconstruction of the breath-hold was performed with 3D gridding of only the data acquired during the breath-hold as determined based on the center sample of k-space (DC-term).

Diffusion weighted scans were performed over a 3D volume consisting of 8 axial slices at a 3 cm thickness, FOV = 42 cm, ±62.5 kHz BW, nominal flip angle of 2° and in-plane resolution of 3.3 mm2 using a fast-GRE 3D stack-of-stars sequence with radial acquisition in the axial plane and conventional phase encoding in the superior-inferior (z-axis) direction [**Error! Bookmark not defined.**]. A total of 256 unique projection angles were acquired per phase encode with 16 projections acquired per each of the 8 non-zero q-values and 16 projections without diffusion weighting acquired between each set of diffusion-weighted projections. The order of weightings was interleaved to mitigate sensitivity to motion due to loss of breath-hold. Non-weighted projections were acquired at intervals evenly interspersed throughout the breath-hold to correct the diffusion weighted data for signal loss due to flip angle and T1-decay and to identify loss of breath-hold if necessary. The root mean square diffusion length (Xrms) was calculated as a preliminary metric of small airway and alveolar structure in the lung parenchyma.

Figure 1: Dynamic frames

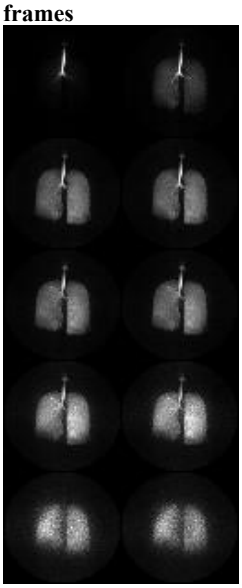
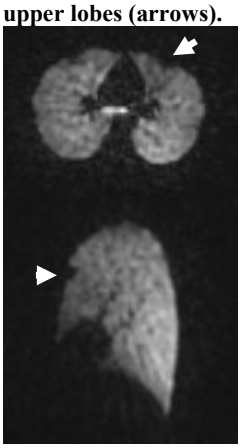
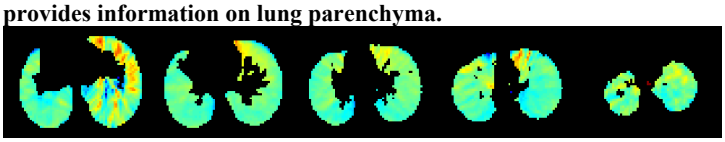


Figure 2: Breath-held ventilation from one 3d volume representing 1 second of data capturing ventilation defects in the anterior right and left upper lobes (arrows).



RESULTS: There were two technical failures, one due to coil malfunction and another due to a corrupt raw data file. On a scoring scale of 1 to 4 with 1 non-diagnostic and 4 excellent 85% of cases scored 3 or higher for performance including: Large airway visualization (>85%), parenchymal visualization (>87%), robustness to motion (>90%) and suppression of streak artifact (90%). An example of typical image quality is shown for dynamic (**Fig. 1**) and images of ventilation (**Fig. 2**) for one subject. A ventilation defect in the anterior left upper lobe is shown in both the axial and sagittal planes for reference. The Xrms differences depicted in a parametric map for the same subject reflects heterogeneity in parenchymal structures varying from anterior to posterior and from apex to (**Fig. 3**). Other subjects demonstrate more homogeneous ventilation signal.

Figure 3: Parametric modeling of the root mean square diffusion distance acquired with the 3D q-space method in the same subject provides information on lung parenchyma.



DISCUSSION AND CONCLUSIONS: The imaging protocol presented is well suited for depicting regional differences in ventilation kinetics and parenchymal microstructures in the pediatric population. Preliminary results have shown heterogeneous distributions of ventilation defects and gas trapping. This work is part of an ongoing study of the origins of childhood asthma with longitudinal imaging at childhood (9 yrs) and adolescence with results available after the investigators are unblended to the study populations.

REFERENCES: [1] O'Halloran et al. MRM 2008;59:132-139. [2] Holmes, J.H. et al., Magn Reson Med, 2008. 59(5). [3] O'Halloran et al. Proc. Intl. Soc. Mag. Reson. Med. 17 (2009) p, 5.