Dynamic 3D He-3 MRI for longitudinal evaluation of childhood asthma

J. H. Holmes[1,2], R. L. O'Halloran[2], T. A. Bley[3], C. J. Francois[3], M. L. Schiebler[3], R. F. Lemanske[4], R. L. Sorkness[4,5], and S. B. Fain[2,3]

[1]Applied Science Laboratory, GE Healthcare, Madison, WI, United States, [2]Department of Medical Physics, University of Wisconsin-Madison, Madison, WI, United States, [3]Department of Radiology, University of Wisconsin-Madison, Madison, WI, United States, [4]Department of Pediatric Medicine, University of Wisconsin-Madison, Madison, WI, United States, [5]Department of Pharmacy, University of Wisconsin-Madison, Madison, WI, United States

Introduction: Assessment of lung function in pediatrics provides significant challenges including subject motion and risks associated with ionizing radiation. Hyperpolarized He-3 (HPHe3) MRI has been used in asthmatics for depiction of lung ventilation [1] as well as gas trapping on forced exhalation [2,3]. Further, the use of projection acquisition and the I-HYPR reconstruction [4] have been employed for improving the depiction of moving objects [5]. The multi-echo VIPR (ME-VIPR) acquisition using HP He-3 has been shown to enable retrospective imaging of variable individual volunteer breath-hold times [6]. The work presented here combines the ME-VIPR acquisition with retrospective conventional re-gridding during the breath-hold and an I-HYPR reconstruction for depicting respiratory dynamics. These methods can provide significant advantages in pediatric imaging where volunteer cooperation may be challenging.

Methods: Five 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 14% of the subject's total lung capacity. To minimize total exam time, volunteer's were imaged using a limited protocol lasting ~45 min including: 1) localizer, 2) 3D SPGR, 3) HPHe3 3D dynamic scan, 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. An 8 half-echo ME-VIPR acquisition was modified to acquire 3 unique full projections to accommodate the assumed geometry of the I-HYPR reconstruction. Imaging parameters included a 60 s total acquisition, cubic 42 cm FOV, effective acquired matrix of 128^3. Unique angle sets were acquired every 0.1s to cover the full sphere of k-space and enable cine reconstructions. Trajectory corrections were applied to compensate for deviations in the k-space trajectory due to gradient imperfections [7]. Reconstruction of the breath-hold was performed using re-gridding of only the data acquired during the breath-hold as determined based on the center sample of k-space (DC-term). A radially varying density compensating filter was applied to mitigate under-sampling in the projection data. Time-resolved 3D data-sets were reconstructed using an I-HYPR reconstruction with 1s of time-frame data and a 10s sliding-window composite image data; six iterations were performed using the I-HYPR algorithm.

Results: An example of data reconstructed to include only the breath-hold shows good depiction of ventilation in subject 1 (Fig 1). Evaluation of the DC term in k-space acquired during each TR showed this subject performed a breath-hold of 12s total and images were then reconstructed to use all of the breath-hold data. Lung fissures are seen in reformats of the 3D data sets (Fig 1, arrows). Note that signal drop-off is evident near the apex of the lungs due to coil sensitivity. Two subjects were found to display ventilation defects that were small and diffuse in nature (Subjects 1 and 4), other subjects were found to display homogeneous ventilation signal. Time-resolved 3D image volumes depict movement of the chest wall and diaphragm during the forced exhalation in subject 2. To date, expiration dynamics have shown relatively homogeneous gas kinetics in all 5 subjects.

Figure 1. Re-formats of breath-hold 3D image volume for pediatric subject 1, a) coronal, b) sagittal, c) axial. Lung fissures are evident (arrows). Reduced coil sensitivity is visible in apex of images a & b.

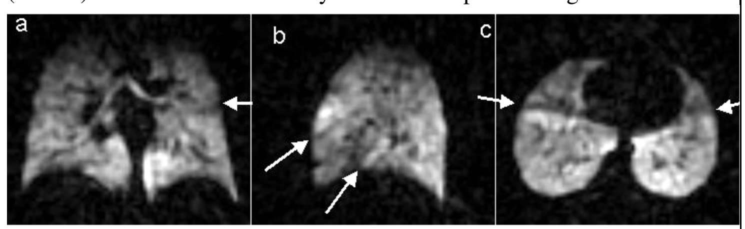
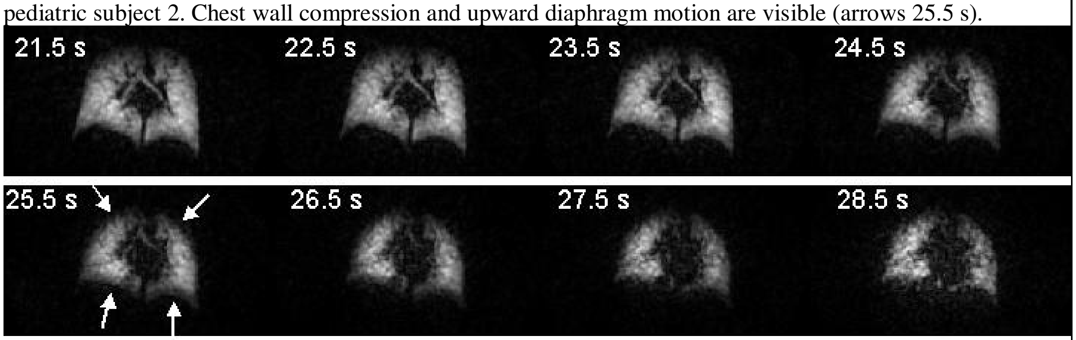


Figure 2. Single 3.3 mm slices from sub-set of time-resolved 3D image volumes during forced expiration in pediatric subject 2. Chest wall compression and upward diaphragm motion are visible (arrows 25.5 s).



Conclusions:
The current dynamic imaging technique is well suited for depicting regional differences in ventilation kinetics in the pediatric population. Preliminary results have shown heterogeneous distributions of ventilation defects and gas trapping that correlated well with regions of air trapping on MDCT in asthmatic adult subjects. This work is part of an ongoing study of the origins of childhood asthma with longitudinal imaging at childhood (9 yrs) and adolescence in 50 subjects stratified by asthma risk factors and severity of symptoms. The overall aim of the study will be to determine if heterogeneous ventilation abnormalities are present in childhood asthma, and if not, to examine how these abnormalities develop and resolve under asthma therapies. Future work will incorporate a new linear rigid body rf-coil (Rapid Biomedical, Columbus, OH) with greater coverage and stability with the technique to provide homogenous coil sensitivity over the entire lung volume during dynamic maneuvers and patient motion.

References: [1] Altes et al. JMRI 2001;13:378-384. [2] Salerno et al. MRM 2001;46:667-677. [3] Holmes et al. JMRI 2007;26:630-636. [4] O'Halloran et al. MRM 2008;59:132-139. [5] O'Halloran et al. ISMRM 2007, A3363, [6] Holmes et al. MRM 2008;59:1062-107. [7] Duyn et al. JMR 1998;132:150-153.

Acknowledgements: Hartwell Foundation, GE Healthcare, NIH 2T32-CA09206-26, NIH R01-HL069116, Sandler Program for Asthma Research