Three dimensional imaging of ventilation dynamics in asthmatics using HYPR ME-VIPR

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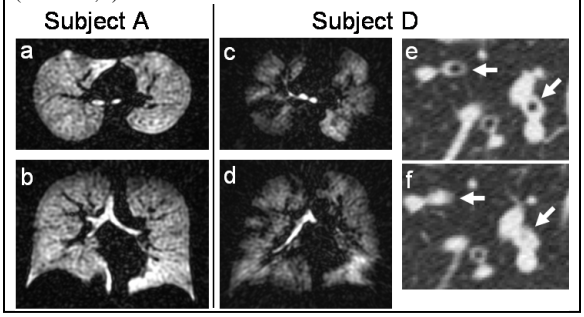
Introduction Dynamic hyperpolarized He-3 gas imaging of the lungs has been used in the study of obstructive lung diseases using accelerated non-Cartesian 2D acquisitions to detect abnormalities in physiology including gas uptake and gas trapping [1,2,3]. The use of a multi-echo vastly undersampled isotropic projection acquisition (ME-VIPR) for accelerating data acquisition in hyperpolarized (HP) He-3 lung imaging has been demonstrated for retrospectively accommodating lost patient breath-holds as well as for dynamic imaging [4]. Further, the use of the HYPR reconstruction technique [5] has been shown for exploiting spatial-temporal correlations to improve SNR for dynamic imaging in ventilation studies [6]. The work presented here extends these techniques to the study of asthma in patients.

Table 1. Spirometry and imaging results

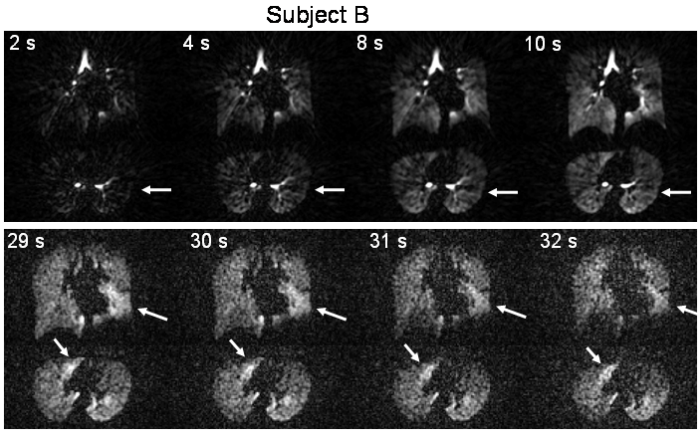
Subject	FEV_1 %pred	% ventilated volume
A	96.5	94.2
B	89.0	93.2
C	96.0	94
D	75.6	73.2

Figure 1. Breath-hold He-3 data for subjects A and B showing relatively homogeneous signal in subject A (a, b) and defects in subject D (c, d). Axial MDCT images of the lower right lobe show mucus plugging comparing 2 slices separated by 1.3 mm (arrows e, f).



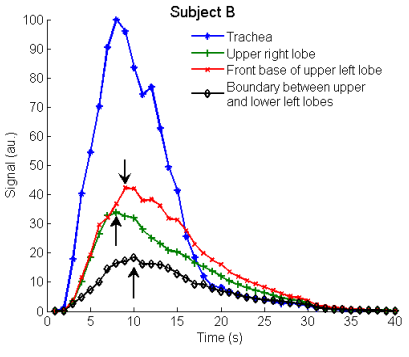
Methods Four patients with asthma were imaged, 2 subjects (C and D) were imaged during a common cold viral infection. Imaging studies were performed on a 1.5 T clinical scanner (GE HealthCare, Milwaukee, WI) using an excite/receive coil tuned to 48 MHz (Medical Advances). Imaging was performed during dynamic patient respiration including inspiration (~2-6 s), breath-hold (~15 s), forced expiration, and followed by tidal breathing for a total time of 60 s. Acquisition parameters included a cubic 42 cm FOV, ± 125 kHz BW, ~1 deg. flip angle,TR/TE_1 of 4.4 ms / 0.22 ms, and ramp sampling was performed with maximum radial distance from the center in k-space corresponded to 64 evenly spaced points on a Cartesian grid. A bent trajectory was used to improve angular sampling and the projections were acquired such that the angles were sequentially incremented within a single TR. During the 60 s acquisition, 600 unique interleaved angle sets were acquired, each set covering the full sphere of k-space. This angle scheme allows cine-type reconstruction to readily accommodate variable patient breath-hold times. Dynamic HYPR images were reconstructed using a composite image constructed with a radially varying temporal filter (tornado filtering) [7] with data from 10 s making up the outer regions of k-space and the center made up of 5 s. HYPR time-frame data was composed of 1 s and each set of 8 half-echo angles sampled per TR were interpolated onto the respective central angle in order to form a full projection. Dynamic images were analyzed using custom software written in MATLAB (Mathworks, Natick, MA) with ROI's manually placed in regions of the lungs and trachea to track patient motion during respiration. The percent ventilated volume was determined based on segmentation of a breath-held 2D multi-slice FSE proton acquisition and He-3 data using the method outlined by Woodhouse et al [9].

Figure 2. Subset of dynamic time-frames during inspiration (top) and expiration (bottom). A boundary is visible between lobes in the left lung showing delayed filling in Fig. 3 during inspiration (arrows top). Clearance of gas from the trachea and diaphragm motion are visible as well as hyper-intense regions that persist during exhalation (arrows bottom). Note images are individually scaled.



Results Data from the breath-hold period of the exam were reconstructed for each subject to provide a high resolution image of the ventilation (~15 s of data). HP He-3 ventilation is shown in subjects A and D demonstrating relatively normal (Fig. 1 a,b) and abnormal ventilation (Fig. 1 c,d). As further validation, mucus plugging was detected in Subject D using MDCT in regions corresponding to ventilation defects (Fig 1 e,f). Percent ventilated volumes for each subject during the breath-holds are compared with FEV_1 %predicted (Table 1). Figure 2 shows individual time-point image reformats of coronal and axial views for both the inspiration and expiration phases in subject B. A region of delayed filling is depicted during inspiration (arrows). Diaphragm motion and clearance of gas from the trachea are depicted during expiration (30 s) as well as regions of hyper-intense signal that persist on expiration (arrows). Analysis of the signal dynamics within the lungs during inspiration showed two regions of delayed filling in subject B relative to the surrounding regions of the lungs (Fig. 3 arrows). Subjects A and B were not found to demonstrate significant regions of delayed filling. The ventilation defects in subject D were found to persist throughout inhalation as well as the breath-hold phases.

Figure 3. Time-course of signal in ROI's placed at various regions in dynamic images with different filling times including delayed filling in regions of the left lower and upper lobes (arrows).



Conclusions and Discussion Whole lung 3D imaging of respiration dynamics is demonstrated using the rapid ME-VIPR acquisition and HYPR reconstruction allowing improved depiction of lung function. This 3D technique provides the ability to detect regional differences in signal kinetics at high spatial and temporal resolution. Further, the acquisition provides flexibility to use all data acquired during the subject's breath-hold to improve image quality. The technique is shown in 4 asthmatics and validated with spirometry and MDCT. This work provides significant advantages in accommodating variable patient breath-holds and will be part of an on-going study in childhood origins of asthma. Future work will include optimization of the HYPR reconstruction and application to pO_2 mapping [10] and quantification of regional gas uptake [11].

References [1] Salerno et al. MRM 2001;46:667-677 [2] Koumellis et al. JMRI 2005;22:420-426 [3] Holmes et al. JMRI 2007;26:630-636 [4] Holmes et al. MRM in press. [5] Mistretta et al. MRM 2006;55:30-40 [6] Holmes et al. ISMRM (2007)461 [7] Barger et al. MRM 2002;48:297-305 [8] Woodhouse et al. JMRI 2005;21:365-369 [9] Denninger et al. MRM 2002;47:105-114 [10] Dupuich 2003;50:777-783