Lung ventilation mapping with bolus inhalation of He-3 and dynamic projection He-3 MRI using I-HYPR reconstruction.

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Introduction: Fast acquisition He-3 MRI has been shown to measure lung ventilation in humans [1]. High temporal resolution methods utilizing EPI [2], spiral imaging [3], or projection imaging [4, 5] have demonstrated the potential for quantitative, dynamic hyperpolarized (HP) He-3 MR imaging of lung ventilation. The iterative highly-constrained back-projection (I-HYPR) reconstruction method has previously been shown to maintain quantitative temporal image data while diminishing under-sampling artifacts, allowing for dynamic projection MRI at high spatial and temporal resolution [6]. We extend these previous works to a 2D projection acquisition combined with I-HYPR reconstruction and a compact bolus inhalation to allow quantitative parametric mapping of ventilation without breath-hold. Such techniques may prove invaluable in assessment and treatment planning for chronic obstructive lung disease such as cystic fibrosis [7] and asthma [1].

Methods:

Imaging: He-3 was polarized to approximately 30% using an optically pumped rubidium vapor spin exchange polarizer (IGI.9600.He; GE Healthcare, Milwaukee, WI, USA). A 100 ml bolus of He-3 gas was introduced to a 3.3 m length of 6.4 mm inner diameter plastic tube. MRI of a healthy volunteer was scanned using a clinical 1.5T MRI system (GE Healthcare, Milwaukee, WI, USA) with a chest coil (IGC Medical Advances, Milwaukee, WI, USA) tuned to the resonance frequency of He-3 (~ 48 MHz). A 2D SPGR projection imaging acquisition was implemented (TR/TE = 6/2.6 ms, flip angle = 1.8°, BW = ±62.5 kHz, Matrix = 128x128, FOV = 40 cm, 20 cm slice thickness). The healthy volunteer was asked to take a deep breath through the He-3 filled tube until at full inspiration to total lung capacity (TLC) and then to breathe normally for the remainder of the exam. Just before inhalation, the ends of the tube were opened to room air.

Reconstruction and analysis: The I-HYPR reconstruction algorithm was implemented with a 180 projection moving window composite with reconstructed time-frames consisting of 9 angles for a frame-rate of 18.5 frames-per-second (54 ms temporal resolution). Each reconstructed image was corrected for RF and T_1-related signal loss by fitting the DC term in k-space during the brief pause at TLC and applying a global correction factor. Upslope and arrival time mapping were performed. Upslope mapping represents the rate of regional ventilation while the arrival time mapping represents the delay of ventilation relative to the peak of the bolus in the trachea (tracheal input function, TIF). The TIF was defined in the trachea just superior to the first airway bifurcation point (carina). Both upslope and arrival time were calculated on a single-pixel basis. Upslope was calculated as the rate of signal change per second from the first enhancing time-point to the first maximum ventilation time-point; defined at 10% and 90% of maximum pixel value respectively. Arrival time maps were calculated as the time difference from the peak of the TIF and the time-point when each pixel value reached 50% of the maximum ventilation value.

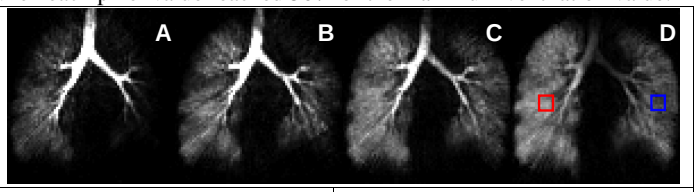

Figure 1: A, B, C and D are every third spin density image from 1.188 to 1.674 seconds in the HP He-3 time course. The images were selected to demonstrate the delay in ventilation between the lower right lobe, the lower left lobe and the left apical region; this is quantified in the arrival time parametric map (Fig. 2B). Notice the bolus of He-3 has nearly left the trachea by 1.674 seconds (D).

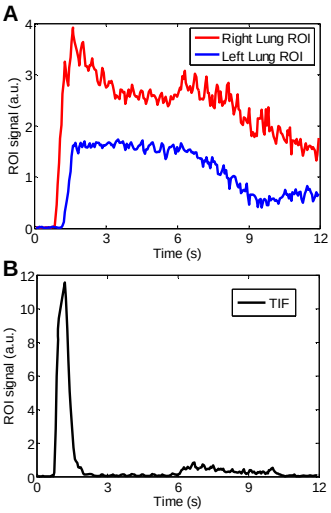

Figure 2: ROIs placed in the right (red) and left (blue) lung demonstrate typical signal time curves of the HP He-3 time data structure (A, notice the ROI placement in figure 1.D). Compact bolus nature of the tracheal input function (B) with full width at half maximum < 0.6 s.

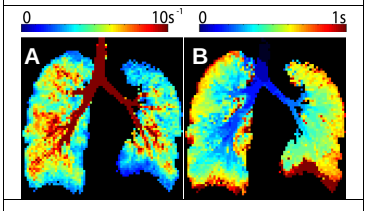

Figure 3: Upslope parametric map (A) demonstrates the relative speed of He-3 arrival. Units are signal change per second. Arrival time parametric map (B) shows the ventilation delay between the peak of the tracheal input function (Fig. 2A) and 50% pixel enhancement. Units are in seconds

Results: The spin density images demonstrate early ventilation of the right lung (Fig. 1A) followed by ventilation in the mid to lower (Fig. 1B) and the apical regions of the left lung (Fig. 1C). Within the left lung, differential ventilation times between the lower and apical regions are apparent (Fig. 1B,C). Figure 1D shows that the bolus of He-3 has nearly left the trachea by 1.67s into the exam. ROIs drawn in the parenchyma demonstrate the spatially and temporally resolved dynamic ventilation differences from the inspiration phase to the brief pause at TLC, to the later signal increase during initial expiration (Fig. 2A). Notice that signal in the left lung is delayed and exhibits a lower rate of change (Fig. 2A). The delivery system for the HP He-3 gas provided a temporally compact bolus in the trachea (Fig. 2B). The He-3 bolus full width at half maximum was < 0.6 seconds. The temporal resolution allowed for greater than 20 samples of the TIF distribution.

The upslope (Fig. 3A) and arrival time (Fig. 3B) maps quantify and spatially resolve the observed ventilation differences between the lower right, lower left and left apical regions (Fig. 3), succinctly condensing this ventilation information. The upslope and arrival time maps successfully illustrate and quantify subtle regional differences in slowed and delayed ventilation (Fig. 3).

Conclusions: This novel application of I-HYPR to spatially under-sampled PR imaging with bolus inhalation of HP He-3 lung ventilation MRI allows for regional parametric mapping and improved accuracy in dynamic functional imaging of lung ventilation with MR. The administration of a bolus inhalation frees this method from the constraints of a mandatory breath-hold. In the lung diseased patient population, the potential clinical utility of a free-breathing, quantitative, dynamic functional lung MRI method is substantial. Future works will aim to apply quantitative compartmental modeling and to compare inhalation and expiration dynamics in healthy and diseased populations.

References: 1. Holmes *et al.* JMRI, 26:630-636 (2007). 2. Pai *et al.* Proc. ISMRM, 14:866 (2006). 3. Salerno *et al.* MRM, 46:667-677 (2001). 4. Wild *et al.* MRM, 49:991-997 (2003). 5. Lehmann *et al.* RoFo 176(10):1399-408 (2004). 6. O'Halloran *et al.* MRM, (in press). 7. Kournellis *et al.* JMRI 22:420-426 (2005).