Highly Reseolved Imaging of Hyperpolarized Helium-3 Ventilation Dynamics using fast 3-d UTE and k-t PCA

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Purpose: Ventilation is a dynamic process involving the constant exchange of gas in the air spaces throughout the respiratory cycle. Obstructive airways diseases, such as asthma, can detrimentally influence lung physiology in ways that can affect the regional rates of gas wash-in and wash-out. Magnetic resonance imaging (MRI) of hyperpolarized helium-3 (HP-He3) gas has been used previously[1] to capture these dynamic processes in 4 dimensions (3D + time), and has been particularly useful for the study of asthma in younger children who are not always able to maintain or perform a breath hold [2]. Here, we improve on previous dynamic methods with a 3D radial ultra-short echo time (UTE) k-space acquisition scheme[3] coupled with compressed sensing reconstruction in hybrid k-t space[4]. The results demonstrate ventilation dynamics with increased spatial and temporal resolution and robustness against flow and motion artifacts.

Methods: Pulse Sequence: A center-out radial spoiled gradient echo acquisition with ramp sampling was used, similar to, [4]. Notable acquisition parameters were: TE = 330 us, TR = 1.8 ms, flip angle 0.88 degrees, 2x radial oversampling, 36 cm field-of-view, 128x128x128 matrix size yielding 2.81 mm^3 isotropic spatial resolution. Radial view ordering was psuedo-randomized such that the sphere was uniquely sampled with approximate angular uniformity every 250 ms. In total, 19980 angles were acquired, with ~125 acquired every 250 ms. Reconstructed images were generated using principal components (PC) in k-t space (k-t -PCA)[3]. Training data for estimating the PC set were reconstructed at low spatial resolution (32x32x32 matrix) and 250 ms temporal resolution. The PCs were computed from this training data and those with singular values greater than 4% of the maximum (5 total components) were used to constrain the reconstruction of the full resolution data. **Experimental:** A quadrature transmit/receive vest coil tuned to the helium resonant frequency at 1.5 T (48.6 MHz) was placed around the torso. HP-He3 gas used for imaging was polarized to ~35% polarization using spin exchange optical pumping in a commercial polarizer (Polarean, Research Triangle Park, NC). A 60 pound swine was administered anesthetic (Inhaled 1-5% Isoflurane via endotracheal tube), and placed in a 1.5 T MRI scanner (GE Healthcare HDx, Milwaukee, WI) and provided mechanical ventilation with 100% oxygen. The dose administered included 150 ml HP-He3 gas mixed with 350ml UHP N_2 gas for a total volume of 500ml, prepared in a Tedlar bag (Jensen Inert, Coral Gables FL). A swine model of lung disease was used for data acquisition. For HP-He3 imaging, mechanical ventilation was temporarily suspended and the 500 ml volume of gas was administered by compressing the bag of gas, expelling the contents into the lungs (see Fig1A,t=0-5). Mechanical ventilation was resumed ~15 sec post inhalation (i.e. 15 sec breath-hold).

Results: Reconstructed image data in Figure 1 demonstrates the image quality and the ability to recover a variety of temporal processes. The inhalation, breath hold, and exhale maneuver and associated timing are shown in A (middle right). Figure 1B (left) shows coronal and axial reformats from 5 time frames during inhalation. The same 5 frames are shown as coronal plane maximum intensity projections in C. The inhalation time points clearly show diaphragm and other motion. Background shows residual streak artifacts that are not desirable but are lower in signal intensity. Images of the gas wash-out in Fig1D are limited MIPs, using only a 2cm thick slab covering most of the trachea.

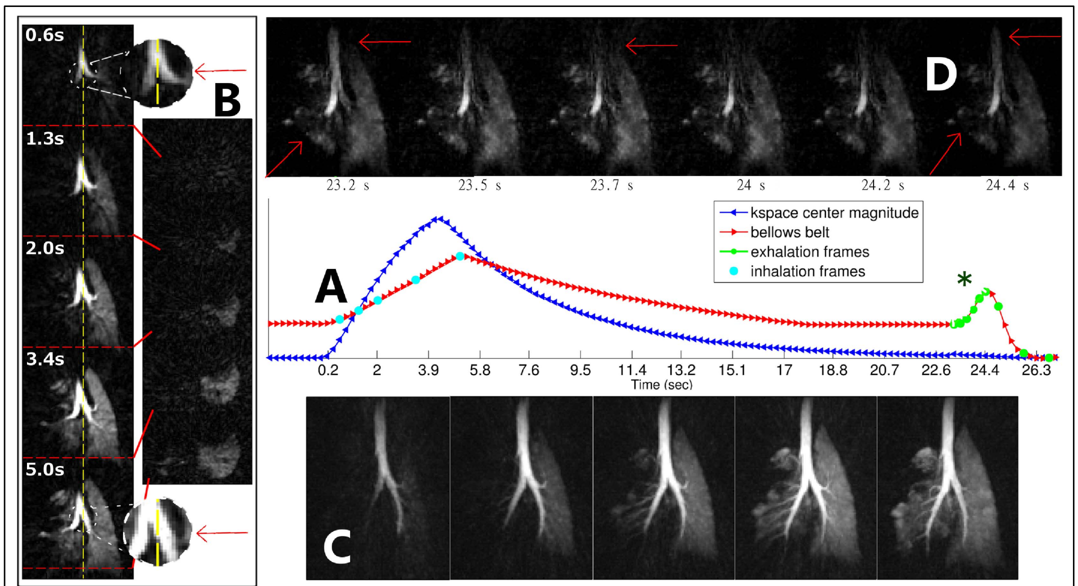

Figure 1. A) Time course of bellows and k-space center **B)** coronal and axial reformats (single slices) during inspiration. **C)** coronal MIPs during wash-in and **D)** limited MIPs during gas washout; Note the very fast gas washout in the left main bronchus relative to the injured right side and refilling of the trachea after resumption of mechanical

Discussion/Conclusion: This data shows the feasibility of the method for improved dynamic HP-He3 MRI, demonstrating the ability to obtain high quality images with increased spatiotemporal resolution compared to previous approaches. The acquisition scheme coupled **with a short readout and repetition time presents a** more flexible and robust approach for minimizing motion and flow artifacts than previous approaches using multi-echo radial approaches,[5]. Further work and testing is necessary to validate under more diverse and challenging conditions of free-breathing and bulk motion. Quantification of regional gas kinetics remains a challenge for dynamic HP-He3 MRI and also requires further study.

References: 1) Holmes et al., Magn Reson Med. 2009 Dec;62(6):1543-56. **2)** Cadman et al., Journal of Allergy and Clinical Immunology. 2013 Feb;131(2):369-376. **3)** Johnson et al, Magn Reson Med. 2013 Nov;70(5):1241-50. **4)** Pedersen et al, Magn Reson Med. 2009 Sep;62(3):706-16. **5)** Holmes et al, Magn Reson Med. 2008 May;59(5):1062-71.