3D He-3 Ventilation Imaging Using Multi-echo VIPR

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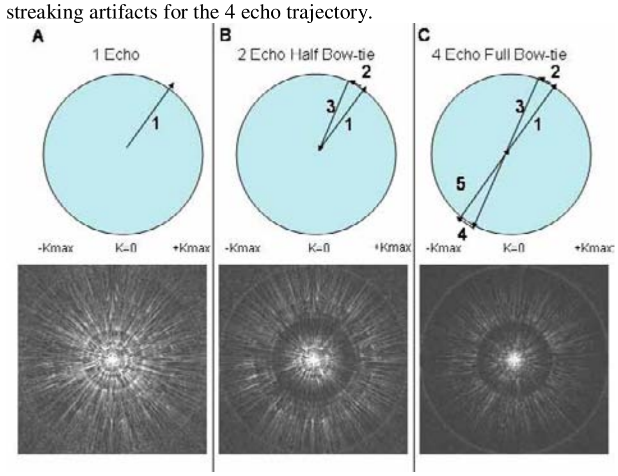
Introduction

Obstructive lung disease is highly heterogeneous [1], requiring 3D coverage at sufficient resolution to detect loci of disease. Hyperpolarized (HP) gas MRI with 3D isotropic resolution will likely improve depiction and analysis of lung structures by reducing partial voluming and providing true cubic voxels for segmentation and measurement. However, achieving this goal within a limited breath-hold remains challenging. Although HP gas imaging provides high contrast to noise ratio (CNR), the polarization is non-recoverable. Therefore, it is desirable to maximize the SNR efficiency (SNR / √scan time) and k-space coverage while minimizing signal loss due to RF decay. Under-sampled PR has advantages in high CNR settings with respect to SNR efficiency [2] but signal attenuation due to RF-decay remains a problem due to PR's non-uniform sampling density in k-space. The hypothesis of this work is that multi-echo 3D under-sampled PR [3] can provide the desired isotropic resolution in HP gas MRI of the lungs with sufficient SNR efficiency and k-space coverage relative to conventional acquisition techniques. Moreover, the use of multiple echoes per TR will mitigate loss due to RF-decay and reduce under-sampling artifact to improve the attainable resolution within a breath-hold.

Methods

Modified 'Bow-tie' k-space trajectories [3], including 1 half-echo (Fig 1a), 2 half-echo (Fig 1b) and 4 half-echo (Fig 1c) implementations were compared to single echo acquisitions by simulating the point spread function (PSF) under conditions of RF-saturation (1.3^o flip angle) and T2* decay (~10ms T2*) (Fig.1, bottom row). Phantom and volunteer studies were performed to validate the simulation results. Imaging was performed on a 1.5T clinical scanner equipped with broadband capability (GE Health Care, Milwaukee, WI). An excite/receive vest coil tuned to ~48MHz, the resonance frequency of He-3, was used (Medical Advances). Parameters included 48cm FOV, BW = +/- 125 KHz, TE / TR of 204 µs / 2050 µs for the half bow-tie and 204 µs / 2840 µs for the full bow-tie. To further improve sampling efficiency and minimize the echo time, ramp sampling was performed. To preserve magnetization, a 1.6^o flip angle was used and 20 unique dithered angle sets were acquired to distribute the modulation due to RF saturation. Two volunteers were imaged; volunteer 1 received a 5.8 mM dose while volunteer 2 received a 5.3 mM dose of He-3 mixed with N_2 gas. Volunteer 1 was imaged using a half bow-tie 2 echo acquisition over a 40 s breath-hold during which ~40,000 projections were acquired. Volunteer 2 was imaged using a full bow-tie 4 echo acquisition during a 20 s breath-hold with ~14000 projections. Images were reconstructed to a 256 cubed matrix for an isotropic 1.88 mm^3 voxel size. For comparison, 17 Cartesian 1.5 mm thick images were acquired with 128 x 80 resolution over a 36 cm FOV using TR/TE = 7.7/4.1 ms, BW = +/-15.63 kHz, and a 9^o flip angle.

Figure 1. k-space trajectories and corresponding PSFs for 3D PR assuming T2* = 10msec and flip angle = 1.3^o showing decreased streaking artifacts for the 4 echo trajectory.



Results

The PSF's show decreased streaking artifacts for the 4 echo trajectory compared to the single echo and 2 echo methods despite the short T2* and RF-saturation (Fig 1, bottom row). Phantom studies corroborated the PSF simulations showing improved SNR from single to 2 and 4 half echo implementations. Volunteer studies (Figs. 3 and 4) also showed improved SNR from the 2 to 4 half-echo case (17.8 vs. 26.7 measured in the trachea) despite being acquired in half the scan time (40 vs. 20 sec) and with a lower dose of HP gas (5.8 mM vs. 5.3 mM). This resulted in a factor of 1.5 increase in SNR efficiency. A single slice from the reformatted 3D data is shown for the 4 echo acquisition demonstrating improved visualization of defects at the periphery of the lung (Figure 3a,b arrows) compared to a reformatted image from the 2D multi-slice acquisition (Fig. 3c, d arrows).

Figure 2. MIP images of the 4 echo (a-d) and 2 echo data (d-f) showing improved SNR for half the scan time using the 4 echo trajectory.

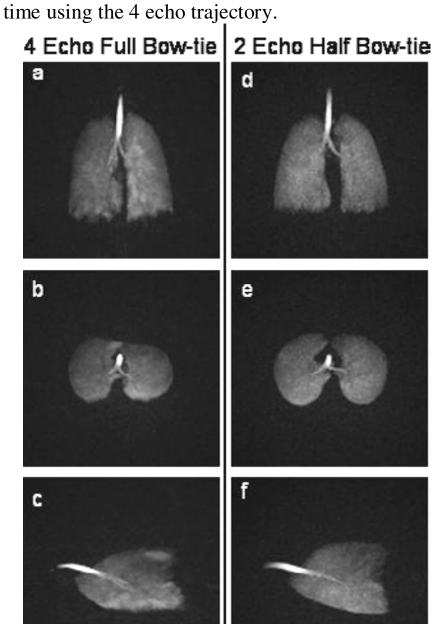
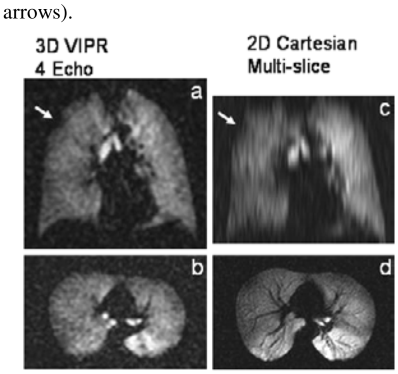


Figure 3. Individual slices of image volumes for 3D VIPR (a,b) and 2D Cartesian (c,d) with small ventilation defect shown (a, c arrows).



Conclusion

We have demonstrated 3D ventilation imaging using multi-echo 3D under-sampled radial imaging. Further optimization of the number of excitations, k-space trajectory, and RF flip angle, will improve image quality and facilitate extension of other applications, such as 3D diffusion-weighted HP gas MRI and oxygen-mapping. Although 3D spiral trajectories [4] may also allow improved SNR efficiency for HP gas lung imaging, multi-echo PR allows less off-resonance due to short readouts and greater flexibility for time resolved applications and T2* mapping within a single breath-hold.

References

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