Rapid Hyperpolarized He-3 Ventilation Scanning with an Optimized 3D Acquisition Scheme

K. Ruppert[1,2], G. W. Miller[2], T. A. Altes[2], J. F. Mata[2], E. E. de Lange[2], J. R. Brookeman[2], J. P. Mugler III[2]

[1]Advanced MRI Technologies, Sebastopol, California, United States, [2]University of Virginia, Charlottesville, Virginia, United States

Introduction: Hyperpolarized He-3 ventilation scans are typically obtained by employing rapid multi-slice gradient-echo (GRE) acquisition schemes such as 2D FLASH (1). However, for an accurate quantification of ventilation defects (2), in particular when using automated computer algorithms, a 3D data set with isotropic resolution would be highly desirable. Since the available scan time is limited by the breath-hold capabilities of the subject (20-30s in healthy volunteers, < 10s in children and patients with severe lung disease) and, to a lesser degree, the T1 of the hyperpolarized gas in the lung, conventional 3D MRI pulse sequences tend to be too slow to achieve the desired image resolution or quality.

In this work we propose the use of a 3D-GRE pulse sequence with an optimized interleaved-cylindrical *k*-space trajectory (3,4) to address these problems. We compare the image quality and acquisition speed obtainable with a commonly-used 2D FLASH sequence to that of the cylindrical 3D sequence. The latter also features a variable-flip-angle algorithm, which compensates for the decay of the gas signal due to T1 and the applied RF pulses, by monotonically increasing the flip angle of the radio-frequency (RF) excitation pulses throughout the acquisition.

Methods: All experiments were performed on a 1.5T commercial whole-body imager (Sonata, Siemens Medical Solutions, Malvern, PA) equipped with a broadband imaging package and modified by the addition of a vest-shaped transmit/receive RF coil (IGC Medical Advances, Milwaukee, WI) tuned to the He-3 resonant frequency of 48 MHz. He-3 was polarized to about 35% by collisional spin exchange with an optically pumped rubidium vapor using a commercial system (Model 9600 Helium polarizer, Magnetic Imaging Technologies, Inc.). All experiments were performed under Physician's IND #57866 for imaging with hyperpolarized He-3, following a protocol approved by our institutional review board.

The 2D FLASH images were collected with the following parameters: TR/TE 6.7/2.85, BW 200Hz, matrix 80×128, FOV 241×386 mm^2, TH 10mm, flip angle 10°, 31 axial slices. The speed-optimized 3D cylindrical trajectory consisted of 64 concentric cylinders where each cylinder was formed by a radius-dependent number of interleaved helices along which 1536 data points per interleave were sampled with 50% asymmetry. Prior to ventilation imaging, the relationship between the RF-pulse amplitude and resulting flip angle was carefully calibrated in a separate He-3 breath-hold scan. To generate approximately constant transverse magnetization for the acquisition of each *k*-space cylinder, the flip angle of each excitation RF pulse was progressively increased according to the formula:

$$\theta_{n+1} = \arcsin\left(e^{T_R/T_1}\tan\theta_n\right),$$

where a value of 25 seconds was assumed for T_1. Un-encoded acquisitions were inserted periodically throughout the pulse sequence and subsequently analyzed to verify the flatness of the signal evolution. The collected data were gridded onto a subsampled 128×128×128 matrix and Fourier transformed. Other imaging parameters were: TR/TE 11/4.2ms, FOV 386×386×386mm^3 (isotropic resolution). After obtaining informed written consent, we imaged the lung of a 20-year-old female who had a large left lung pneumatocele but was otherwise healthy. The volunteer was ventilated with 480 ml He-3 diluted with N_2 to a total volume of 1 liter.

Results: Figure 1 compares a representative axial slice acquired with the 2D FLASH sequence (a) to axial (b), sagittal (c) and coronal (d) slices through the 3D data set obtained with the 3D interleaved-cylindrical sequence. The 2D image quality is somewhat superior with respect to SNR and signal loss due to susceptibility differences around blood vessels. However, the current 3D sequence prototype yielded a more than threefold increase in through-slice resolution with half the acquisition time. The isotropic 3D data also permitted high-resolution surface renderings (Fig. 1e-g) that, besides the pneumatocele, clearly show the presence of additional small, peripheral ventilation defects scattered throughout the lung.

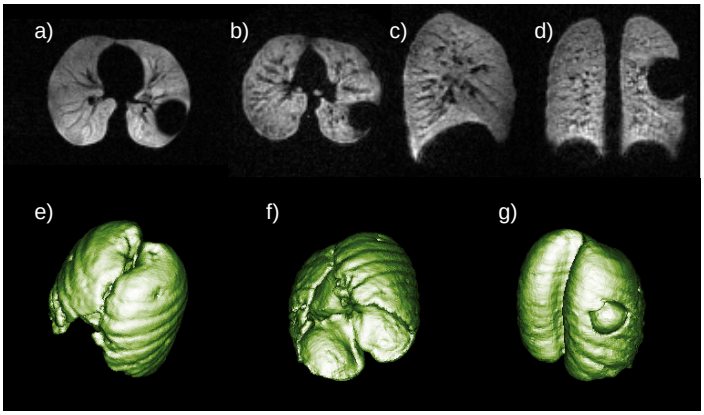

Figure 1: Image quality comparison between (a) a 2D multi-slice FLASH acquisition (3×3×10mm^3) and (b-d) a 3D interleaved-cylindrical acquisition (3×3×3mm^3). (e-g) The surface rendering of the 3D data set emphasizes the improved detectability and quantifiability of ventilation defects due to the isotropic and continuous coverage of the entire lung.

Discussion: One of the unsolved issues for hyperpolarized He-3 lung ventilation scans is the development of methods to accurately quantify the ventilation defects present. While conventional 3D acquisition methods are readily available, they tend to be of limited use for hyperpolarized-gas MRI due to their long acquisition time and their large number of RF excitation pulses, which gives rise to low SNR images due to the non-equilibrium nature of the gas magnetization.

A 3D interleaved-cylindrical GRE sequence could offer a way around these restrictions. Despite the modestly inferior image quality when compared to that of a 2D FLASH acquisition, the sequence prototype overall yielded very good images of high clinical significance. We are currently implementing various sequence improvements that will reduce the impact of the field inhomogeneities, boost the SNR and simultaneously decrease the acquisition time to approximately 4s or less without affecting the image resolution.

In summary, we demonstrated the feasibility of reducing the total acquisition time for a hyperpolarized He-3 lung ventilation scan by 50-75% through the use of an appropriately designed and optimized 3D pulse sequence while maintaining the in-plane resolution and increasing the through-slice resolution threefold when compared to a conventional 2D multi-slice FLASH scan. This will allow us to obtain isotropic high-resolution 3D data sets even in children or patients with compromised respiratory functionality without reducing the anatomical coverage.

References

[1] de Lange EE, Mugler III JP, Brookeman JR, et al. Radiology 1999; 210:851-857. [2] Altes TA, Powers PL, Knight-Scott J, et al. JMRI 2001; 13:378-384. [3] Wong EC. 2nd SMR; 1994, 25. [4] Ruppert K, Mugler JP. 9th ISMRM; 2001, 945.

Acknowledgements

This work was supported by NIH grant R44RR16397, CTRF grant IN2002-01 and Siemens Medical Solutions.