3D Hyperpolarized ^{3}He MR Imaging of the Lung using an Interleaved-Cylindrical k-Space Trajectory

Kai RUPPERT[1], John P. MUGLER III[1]
[1]University of Virginia, School of Medicine, Department of Radiology, Charlottesville, VA USA;

Introduction

Lung ventilation imaging using hyperpolarized ^{3}He is performed predominantly with two-dimensional (2D) gradient-echo (GRE) pulse sequences [1]. However, for a full evaluation of the number, size and distribution of ventilation defects in certain lung diseases, such as asthma [2], a full three-dimensional (3D) image set is highly desirable. Since data collection usually spans only a single breath-hold, and since the hyperpolarized magnetization is in a non-equilibrium state, standard 3D-GRE sequences, such as 3D FLASH, are too slow and suffer from a relatively low signal-to-noise ratio (SNR) secondary to the large number of radio-frequency (RF) pulses. Echo-planar-type pulse sequences, on the other hand, are hampered by the large magnetic field inhomogeneities in the lung and offer only modest spatial resolution due to diffusion-induced signal attenuation from the imaging gradients [3].

In this work we explore the feasibility of using a single-slab 3D GRE-based pulse sequence with an interleaved-cylindrical k-space trajectory [4,5] for hyperpolarized ^{3}He imaging of the lung. This technique is characterized by a low number of RF excitation pulses, a high sampling efficiency and excellent off-resonance behavior.

Methods

The current pulse-sequence implementation collects k-space data along 16 helical interleaves per cylinder, each of which performs 4 revolutions during a 7.68 ms sampling period. To take maximum advantage of the available slew rates, oscillating trapezoidal gradient waveforms are used for spatial encoding in the plane perpendicular to the axis of the cylinder, while a constant gradient along the cylinder axis simultaneously traverses k-space in the third dimension. The full trajectory consists of 48 concentric cylinders. The sampled data is regridded to yield a 96 x 96 x 64 rectilinear matrix, zero-filled to 128 x 128 x 64 before FFT.

Imaging was performed in 3 healthy volunteers using a 1.5-T commercial whole-body imager (Vision, Siemens Medical Systems, Iselin NJ), with maximum gradient strengths and slew rates of 25 mT/m and 41 T/m/s, respectively. The hardware was modified by the addition of a broadband amplifier, permitting operation at the ^{3}He resonant frequency of 48.5 MHz. The RF coil was a quadrature flexible transmit-receive design (Medical Advances, Milwaukee, WI). Pulse-sequence parameters included: TR/TE 12.2/5.8 ms, flip angle 2°, coronal orientation, acquisition time 9.4 seconds. The cylindrical field of view had a diameter of 360 mm and a length of 240 mm, which yielded (before zero filling) an isotropic image resolution of 3.75 mm. The ^{3}He gas was polarized to approximately 35% via spin exchange with an optically pumped rubidium vapor (Model 9600 Xenon Polarizer, Nycomed-Amersham Imaging, Durham, NC).

Informed consent was obtained prior to imaging from all subjects. Immediately before the start of the pulse sequence, each subject inhaled a 1 liter mixture of gas (350 ml of hyperpolarized ^{3}He, 650 ml of ^{4}He or N_2).

Results

Three perpendicular slices, reformatted from the 3D-image set for one of the volunteers, are shown in Fig. 1. The images appeared slightly blurred in the coronal plane, presumably due to the depletion of the non-equilibrium magnetization by RF pulses and T1 decay during the acquisition. Since the cylinders of the trajectory were sampled from the center outwards, these effects result in a low-pass k-space filter in the plane perpendicular to the axis of the cylinder. Variable-flip-angle RF pulses could be used to mitigate these effects and thereby eliminate this blurring. The signal voids corresponding to the major pulmonary blood vessels appeared somewhat larger than those in comparable 2D FLASH images [1], likely due to the relatively long echo time of 5.8 ms.

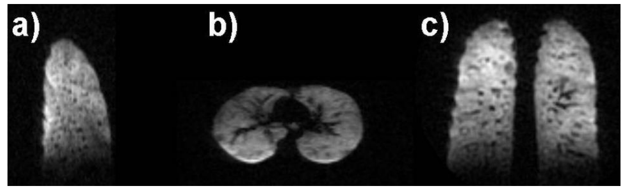

Fig 1. (a) Sagittal, (b) axial and (c) coronal images of the lungs reformatted from the 3D data set of one of the volunteers.

Discussion

This first implementation of a 3D-GRE pulse sequence with an interleaved-cylindrical k-space trajectory generated high-quality images without any major image artifacts. The only point of concern is the relatively long echo time that results in signal loss near major blood vessels due to the large magnetic field inhomogeneities in these regions. We are currently addressing this issue by investigating the potential of a partial k-space acquisition, which would shorten the echo time to less than 3 ms. It is also worth noting that restrictions in the current measurement control software prevented us from employing variable flip angles, as discussed above, and from reducing the degree of oversampling near the k-space origin, which would decrease the acquisition time. An anticipated upgrade of the MR software will permit these improvements in the near future. In an optimized form, we expect that the 3D interleaved-cylindrical pulse sequence can provide the same spatial resolution as demonstrated in this study in an acquisition time of less than 5 seconds, and therefore may be a valuable tool for characterizing lung ventilation, even in patients with compromised respiratory function.

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 2000; in press.
3. Saam B, Yablonskiy DA, Gierada DS, Conradi MS. MRM 1999; 42:507-514.
4. Wong EC. 2nd SMR 1994; 25.
5. Ruppert K, Mugler III JP. 7th ISMRM 1999; 1630.

This work was supported in part by Siemens Medical Systems, Nycomed Amersham, the University of Virginia Pratt Fund, and NIH grants HL 59022 and NS 35142.