Initial Orientational Lung Imaging in an Open-Access Human-Scale Low-Field MRI System

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Introduction

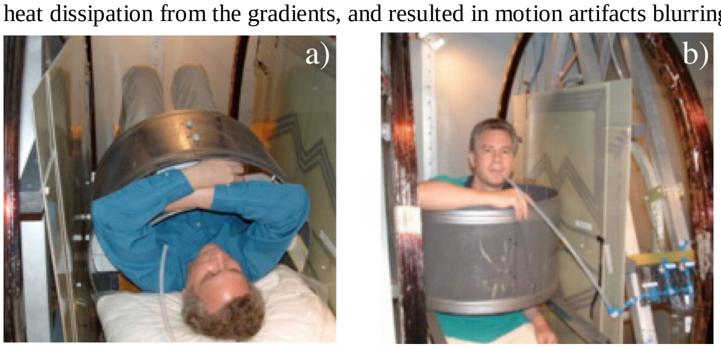
A current subject of much debate in the lung physiology community concerns the role of gravitational effects on lung inhalation and function, such as the role of gravity in fundamental cardiopulmonary physiology, e.g., the origin of perfusion heterogeneity in the lung [1]. The recent advances in spin-exchange optical pumping [2] have made laser-polarized ^{3}He MRI a powerful method for studying lung structure and function. However, in conventional MRI systems, patients are restricted to lying in a horizontal position. As the high spin polarization of laser polarized ^{3}He does not require a large applied magnetic field, we can therefore benefit from novel magnet design that does not restrict the patient, while still permitting high-quality laser-polarized gas MRI. We have previously demonstrated the benefits of very low field (~20 gauss) imaging of small samples of laser-polarized ^{3}He gas [3,4]. More recently, we reported the design and testing of an open-access human-scale imaging system that operated at similarly low magnetic fields [5]. Here, we present initial human lung images from that prototype imager, in which it was possible to vary the orientation of the subject in a two-dimensional plane, and outline design constraints for an optimized open MRI system.

Methods

The basic design of the prototype open-access human scale MRI system was reported previously [5]. The B_0 field of 20 - 70 Gauss was created by two pairs of Helmholtz coils, with custom-designed planar gradients allowing complete orientation of subjects in a plane ~ 75 cm wide. Low-RF frequency control was provided by a SMIS console, its output mixed down to produce kHz frequencies. Because of the large difference in output impedance of the B_1 transmit amplifier and input impedance of the receiver pre-amplifier, separate human-sized transmit and receive coils were used. Both coils had Q ~ 100, resulting in narrow frequency bandwidths at a Larmor frequency of 127 kHz, which required image post-processing to remove the frequency response of the coil, which was convolved on the image dataset [6]. The subject inhaled ~ 500 cm^3 of ^{3}He gas laser-polarized to a polarization ~ 35%. ^{3}He inhalation images were obtained with the subject lying horizontally, and sitting vertically. A second-generation system has been designed with dramatically improved B_0 homogeneity of 50 ppm across a 40 cm DSV, improved gradient switching times, a single transmit/receive coil to reduce cross-coupling noise, and a commercial console designed to work in the kHz frequency range.

Results

Figure 1 shows the subject in two different orientations in the first-generation open-access MRI scanner. A patient table support held the subject and B_1 coils in place for horizontal imaging. For vertical imaging, the subject sat on a stool, while the coils were held by removable supports. Figure 2 shows images acquired in each orientation. When horizontal, the image clearly shows the shape of the diaphragm against the bottom of the lungs, and the heart cavity. The vertical image clearly shows the distension of the lungs typical of the vertical position. The images were acquired without slice selection, and the coils were not sensitive to the top of the lungs and gas in the main airways. The imaging time of 7 seconds was limited by heat dissipation from the gradients, and resulted in motion artifacts blurring the vertical image.



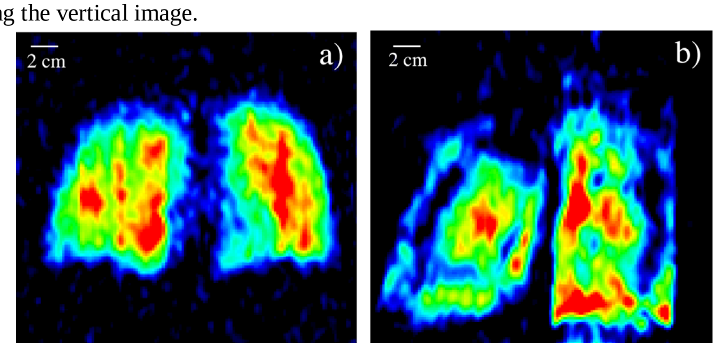


Figure 1. (left) Photographs of a subject in the prototype open-access, human-scale low-field imager. The subject is shown horizontally on the patient support table (a), and sitting vertically on a stool (b). **Figure 2.** (right) Laser-polarized ^{3}He gas inhalation MR images acquired at B_0 = 3.8 mT (38 Gauss, 127 kHz). A standard FLASH gradient echo sequence was used, with TE/TR = 10/100ms, flip angle α = 8º, NS = 1, data size = 128× 64. Total image acquisition time was 7 seconds. Images were acquired when the subject was lying horizontally (a), and while sitting vertically (b).

Discussion

As we have shown previously [3-5], laser-polarized ^{3}He can be imaged at very low fields and produce images of comparable quality, in terms of SNR and resolution, to those obtained at high fields. We have now shown this feature can be exploited to image a human subject in radically different orientations, and that clear differences in the lung shape are observed as a function of orientation. A high flip angle was employed and slice selection was not used in order to optimize SNR. Limitations of the first-generation system, generally resulting from the adaptation of pre-existing equipment, included low T_2* in the only moderately homogeneous B_0 field, and direct coupling noise between the two B_1 coils. The second-generation open-access human imager has a B_0 homogeneity of ~ 50 ppm over a 40 cm DSV, which will extend in-vivo T_2*'s into the 100's of ms. Faster gradient heat dissipation will result in sub-second imaging times, and a single B_1 coil for transmit and receive will dramatically reduce system noise.

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