A compact compressor for application of metastability-exchange optical pumping of $^3$He to human lung imaging

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Introduction

Hyperpolarized gas magnetic resonance imaging (MRI) has recently emerged as a method to image lungs (1-3), sinuses (4), and the brain (5). The best lung images to date have been produced using hyperpolarized $^3$He, which is produced by either spin-exchange or metastability-exchange optical pumping. For hyperpolarized gas MRI, the metastable method has demonstrated higher polarization levels and higher polarizing rates, but it requires compression of the hyperpolarized gas. Prior to this work, compression of hyperpolarized gas had only been accomplished using a large, complex and expensive apparatus.

In this work we present a compact compressor that is relatively simple and inexpensive, and is capable of producing sufficient $^3$He polarization for imaging human lungs. Our compressor can polarize 1.1 bar-L of 15% hyperpolarized gas in three hours, yielding an average flow rate of $2.6 \times 10^{18} \text{s}^{-1}$.

Materials and Methods

The $^3$He gas is polarized by the metastability-exchange method using an apparatus similar to that described in Ref. 6. Metastable $^3$He atoms are produced by an electrodeless RF discharge at 2-4 mbar of pressure and optically pumped by 3 watts of 1083 nm laser light from an Nd:LMA laser. After being hyperpolarized in a 270 cm$^3$ optical pumping cell, the gas is compressed by a modified two-stage diaphragm vacuum pump into a detachable storage cell. The motorless compressor was modified from its original form by replacing all magnetic parts with non-magnetic equivalents. The compressor and gas recirculation apparatus fits into a cube measuring about 30 cm on a side. For this experiment, the gas was accumulated in a 270 cm$^3$ storage cell made from Corning 7056 glass. The storage cell was immersed in liquid nitrogen during filling to increase the final pressure at room temperature to 4.0 bar from the nominal one bar outlet pressure of the compressor. After the cell was filled, the storage cell valves were closed and the cell was detached from the compression apparatus. The cell was placed in a solenoid to preserve the polarization during the three hour car trip from NIST in Gaithersburg, Maryland to the University of Pennsylvania in Philadelphia, Pennsylvania. Scanning was performed on a 1.5 T whole-body imager using an octagonal, 26-cm diameter, transmit-receive surface coil. Coronal images were obtained using a sequentially encoded 2D, fast gradient-echo pulse sequence with 12 degree nominal constant flip angle, 18 ms/4ms TR/TE, 256 x 128 matrix, and one echo per excitation.

Results and Discussion

Figure 1 shows ventilation images of the lungs of a 25-year old healthy male after inhalation of hyperpolarized $^3$He (images 1A to 1D). The imaging parameters were: FOV, 53 x 53 cm; slice thickness, 9 mm; interslice spacing, 1 mm, number of slices, 8, and total imaging time, 20 s. In the $^3$He images, the trachea and the mainstem bronchi (arrows), and the ventilated pulmonary parenchyma are hyperintense. The images display homogeneous ventilation of the hyperpolarized gas in the lungs of the healthy subject. The average signal-to-noise ratio (SNR) was 71 for the major airways and 38 for the lung parenchyma.

For this compressor, the achievable polarization using pure $^3$He is limited by the relatively high pressure in the optical pumping cell, which ideally would be about one mbar. The contribution to the optical pumping cell pressure due to gas flow could be reduced by using two compressor heads in parallel for the first stage. Using a third compression stage would increase the overall compression ratio. Since almost one-third of the polarization is lost in compression, reducing the polarization loss per stage is critical to the success of a three-stage system.

![Figure 1: Coronal $^3$He lung images of a healthy subject demonstrating uniform parenchymal uptake and strong signal from the major airways (arrows).](image)

We have demonstrated the use of a compact compressor for hyperpolarized $^3$He gas to produce high-quality images of pulmonary ventilation. Goals for the future include improving the polarization level and production rate, and making the apparatus more simple, robust, and compact.

References


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