Variable Field Strength MR System for Hyperpolarized Noble Gas Imaging of Rodent Lungs

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Introduction

Hyperpolarized ^{129}Xe (xenon) has become a promising contrast agent for clinical lung MR imaging. With hyperpolarization, the available magnetization is independent of magnetic field strength. Furthermore, above a cut-off Larmor frequency when the sample (i.e. body) noise dominates the RF coil noise [1], the signal-to-noise ratio (SNR) is expected to decrease with field for band-matched imaging due to a reduction in the transverse relaxation time, T_2* [2]. The optimum clinical field strength for lung imaging has been predicted to correspond to low field strengths (0.05-0.2 T) [3]. Low field MR systems can be less expensive compared to conventional high field systems and may permit new applications (e.g. interventions). As well, open magnet concepts can be helpful for posture dependence and for improving compliance of claustrophobic patients and children. The optimum field strength for hyperpolarized gas lung imaging will depend on the sample/coil size and geometry and field-dependence of the lung properties (i.e. relaxation times, susceptibility effects).

The objective of this work was to build a variable-field MR imaging system to experimentally validate the hyperpolarized gas image SNR and spatial resolution dependence on field strength. A broadband, variable field (0.01 – 0.15 T) MR system for rodent imaging has been developed and preliminary ^{1}H and ^{129}Xe results are reported. A feature of this system is that signals from different nuclei (^{1}H, ^{3}He, ^{129}Xe) can be obtained with the same RF coils and electronics which can be helpful for comparison purposes and has the additional potential to image different nuclei with the same experimental setup.

Methods

Figure 1 shows a block diagram of the low-field imaging system. The magnet sub-system comprised a six-coil electromagnet powered by DC power supplies (Xantrex XKW 80-37) providing field strengths up to 0.15 T. Magnet cooling was facilitated by a set of aluminum plates sandwiching the resistive coils and connected to a dedicated chilled water supply (20 kW). The construction of the magnet, including: winding procedures, fabrication of the cooling plates and structural supports have been described previously [4]. The field produced by the magnet was 14.95 Gauss/A, the resistance of the magnet was 1.45 Ohm, and the design homogeneity over 10 cm was 10.33 ppm.

The RF sub-system incorporated a broadband (0.1 - 100 MHz) RF power amplifier (1kW, TOMCO Technologies, Australia) interfaced to custom-built RF coils, preamplifiers and transmit/receive switches for different frequencies (eg. 900 kHz for xenon and 3.4 MHz for water, at 80 mT). The gradient/shim sub-system consisted of three-axis gradient amplification (Techron MAG77803S1) interfaced to a self-shielded gradient coil (MAGNEX, SGRAD MK III 305/178/S, 18 cm bore) with 16 independent channels of active shimming controlled by a dedicated shim power supply (Resonance Research Inc.). The entire system was controlled by a computer console (0.1-100 MHz, Apollo, TECMAG, USA).

As a preliminary demonstration and in order to facilitate mechanical shimming, signals from water (doped with gadolinium 293.3g/L), and hyperpolarized ^{129}Xe at 900 kHz were obtained with 20 kHz bandwidth and TR = 260 ms. The hyperpolarized natural abundance xenon gas (26.4% ^{129}Xe) was produced by spin exchange optical pumping using a home-built, continuous-flow polarization system [5]. The polarizer use a 60W diode array laser (λ=794.8 nm, Coherent, Santa Clara, USA). Signals from small (1 cc) hyperpolarized xenon samples with the un-shimmed magnet were acquired. We estimated the xenon polarization by comparing the xenon signal to the water signal (ie. thermal equilibrium magnetization).

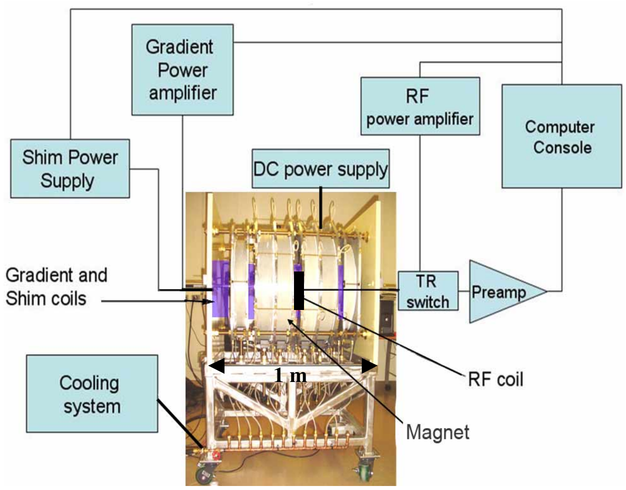

Figure 1: Block diagram of the MR imaging system

Results

Figure 2 shows spectra obtained from the low-field system following initial mechanical shimming (no resistive shimming). In this figure, the spectra from ^{1}H and ^{129}Xe obtained at 900 kHz with the same coil are shown together. The polarization estimated for xenon was 3.4 % which was the approximate value expected for the polarizer set-up.

Discussion

A low-field MR system capable of operating at magnetic field strengths up to 0.15 T is presented. The variable field permits signals from different nuclei and at different field strengths to be obtained. The improved homogeneity anticipated following optimal mechanical and resistive shimming (~ 5 ppm) combined with the low field is expected to yield long T_2* values (~ 200 ms) which will improve the SNR through narrow bandwidth imaging and may permit improved diffusion and relaxation time measurements compared to higher fields. Measured ^{129}Xe polarization was in good agreement with the expected value. The system will be useful for measuring the field dependence of SNR, spatial resolution and relaxation times in rodents to determine the optimum field strength for hyperpolarized noble gas MR imaging of the lungs. A future goal will be to use this system to obtain images of ^{1}H and hyperpolarized ^{129}Xe and ^{3}He gas in the same study.

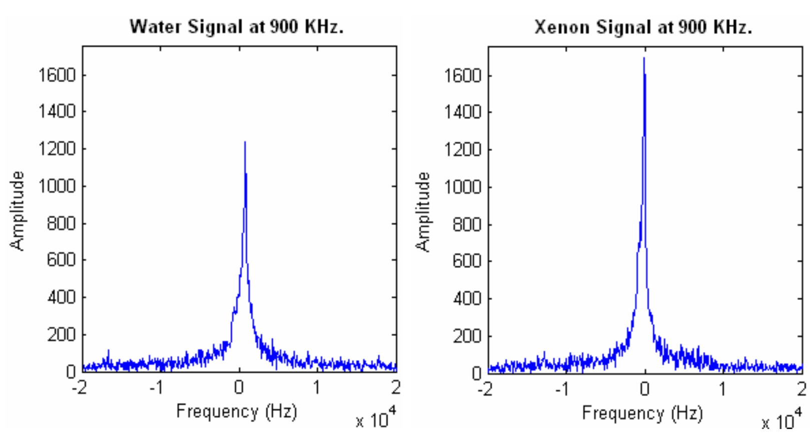

Figure 2: Water and Xenon spectra acquired with the un-shimmed magnet.

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