A delivery system for hyperpolarized 129Xe MRI of small animal lungs

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Introduction

Although MRI has exhibited its powerful capability of diagnosing soft tissue disease since 1970s [1], the inherently limited signal sensitivity, compared with other biomedical imaging techniques such as CT, positron-emission tomography, or single-photon emission computed tomography, demands further investigations. The development of hyperpolarized (HP) noble gas isotopes ^{129}Xe has drawn much attention for a variety of NMR applications in the past decade owing to its highly enhanced polarization by several orders of magnitude. Recently, it has been further demonstrated that HP ^{129}Xe gas, once inhaled, is capable of providing intense MR signals and images in the pulmonary airspaces that are inaccessible by conventional methods using proton (^{1}H) MRI [2].

HP ^{129}Xe is commonly produced by an indirect polarization method mostly involving spin exchange between optically pumped Rb vapor and Xe noble gas. During these processes, nitrogen and helium are typically added as buffer gases in order to achieve a higher polarization for HP ^{129}Xe, which represents only a small fraction of the original gas mixture [3]. As such, proper freezing and thawing schemes become inevitable for mass production and subsequent usage of HP ^{129}Xe gas. Furthermore, its delivery to target medium of interest without significant loss in spin polarization is also an important issue, especially in MRI-related applications. In this preliminary study, we report a special design for HP ^{129}Xe storage and delivery, which consists of a storage chamber made up of a spiral freeze trap and a glass chamber, as shown in Figure 1(a) and 1(b), respectively. The glass chamber, which is divided into two isolated compartments by a Teflon piston, is capable of delivering HP ^{129}Xe gas continuously through an external pressurization source (air). Furthermore, the amount of ^{129}HP Xe gas delivered at the outlet is controlled by a non-magnetic pneumatic valve, which can be synchronized to the ventilation of animal as well as the acquisition sequences of the MRI Scanner.

Materials & Experimental Methods

Continuous optical pumping of natural abundant Xe was carried out in a Rb-containing pumping cell placed under a magnetic field of ca. 0.02 T using a gas mixture of 2%Xe, 1%N_2, and 97%He. The operating temperature and pressure are at ca. 403 K and 4 atm, respectively. As a result, HP ^{129}Xe gas with polarization of ca. 2% can be fabricated at a production rate of ca. 2-3 sccm. To accumulate a desirable amount of HP ^{129}Xe gas, the feed was continuously frozen at 77 K in the spiral storage chamber placed under a static magnet field of ca. 0.05 T while also evacuating the excess buffer gases by a rotary pump. Subsequent delivery of the HP ^{129}Xe can be made by thawing the novel gas into the pre-evacuated delivery chamber kept under a warm water bath to minimize relaxation. Spin-lattice relaxation time (T_1) measurements and image acquisitions of HP ^{129}Xe gas in the storage/delivery chamber were carried out on a MRI scanner (Bruker 3T MEDSPEC/BIOSPEC) using a home-built surface coil operating at a Larmor frequency of 34.66 MHz. A 2D FLASH and single pulse sequences with ca. 4^{o} hard pulses were used during the aforementioned experiments.

Results and Discussion

Figures 2 display the T_1 signal decays of HP ^{129}Xe gas in the storage and delivery chambers. The inner surfaces of these glass apparatus were coated with SurfaSil siliconizing fluid to minimize relaxation. The T_1 for HP ^{129}Xe gas in the storage and delivery chambers were determined as 155.0 and 71.4 minutes, respectively. Figures 3(a) and 3(b) show the HP ^{129}Xe images of the storage and delivery chambers, respectively; both were acquired at a gas pressure of ca. 0.5 atm. Thus, it may be concluded that the prolonged relaxation times and successful MR images of these tests readily render the undertaking HP ^{129}Xe MRI of small animal lungs and related disease diagnosis studies.

References
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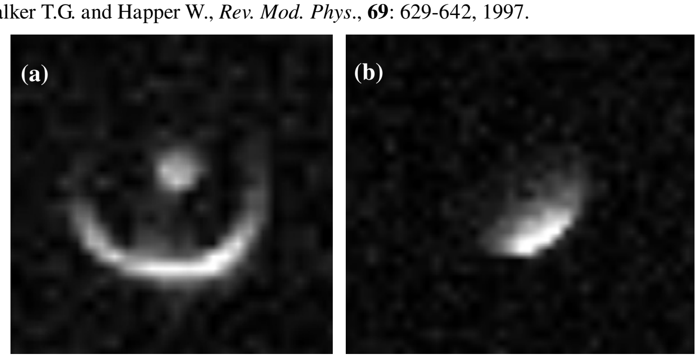

Figure 3. HP ^{129}Xe images of the (a) storage and (b) delivery chambers. Experimental parameters: 64X64, FOV 12.0/12.0 cm, Flip angle: 4^{o}, TR = 25 ms, TE = 3.4 ms, and numbers of repetition: 40.

Figure 1. Pictures of the home-designed storage/delivery system, (a) spiral storage chamber, and (b) delivery chamber, consists of inlet valve (1, 4), outlet valve (2), Teflon piston (3), pneumatic valve (5), and external pressurization air inlet (6).

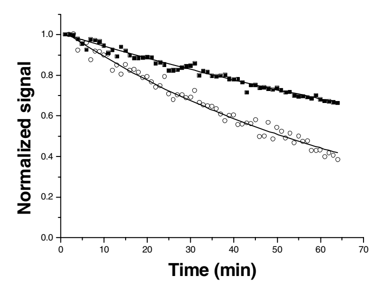

Figure 2. T_1 signal decays of HP ^{129}Xe gas in the storage (■) and delivery (O) chambers. Measurements were carried out with 64 accumulated scans of a ca. 4^{o} hard pulse with a repetition time of 60 sec.