Experimental validation of a model for the field dependence of the SNR of hyperpolarized noble gas MR imaging of rodent lungs in vivo

J. Parra-Robles[1], W. Dominguez Viqueira[1], A. Ouriadov[1], W. Lam[1], N. Abdeen[2], G. E. Santyr[1]

[1]Imaging Research Laboratories, Robarts Research Institute, London, Ontario, Canada, [2]Department of Physics, Carleton University, Ottawa, Ontario, Canada

Introduction

In Hyperpolarized Noble Gas (HNG) MR imaging, 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 field strength depends on the sample/coil size and geometry and for human lungs, is predicted to correspond to intermediate field strengths (0.1-0.5 T). However, this SNR maximum does not occur until much higher fields (> 3T) for small coils typically used for small animal imaging. The validity of this SNR model has been previously demonstrated *in vitro* (using desiccated rat lungs), using xenon for field strengths up to 1.89 T (22.17 MHz) [2]. The SNR *in vivo* is expected to be different at higher fields due to the strong shortening of the transverse relaxation time with increasing susceptibility originating from tissue water. In this work the magnetic field strength dependence of the SNR for imaging of small animal lungs *in vivo* is experimentally verified for rat lung images and spectra obtained at 17 mT and 1.89 T using xenon gas and at 3T using helium. In order to estimate the field strength giving optimal SNR, the ratio of noise contributions between the coil and the sample is theoretically predicted and experimentally measured for a range of resonant frequencies and coil and sample sizes.

Methods

The loading factors of six birdcage coils (Morris Instruments, Ottawa, Canada) used for rat and mice imaging were theoretically calculated and experimentally measured. Four rat-sized coils (with radius a= 6 cm, height h= 12 cm and made from copper strips of width w= 12 mm) designed for Larmor frequencies of 22, 35, 80 and 97 MHz and two mouse-sized coils (a=1.75 cm, h= 5.5 cm and w= 6 mm) operating at 97 and 126 MHz were used. Phantoms that simulated the loading of the coils with rats and mice of varying sizes were built from cylindrical plastic tubes. To simulate different animal sizes, two phantoms containing 350 and 500 ml saline solution were used to load the rat coils. With the mouse coil, the phantoms contained 20, 25 and 30 ml saline. The loading factors (lf) were experimentally determined from the quality factors of the empty coil (Q_U) and the coil loaded with a sample (Q_L) as $lf = 1-Q_L/Q_U$. The Q values were measured using an Agilent 4395A (Agilent, Palo Alto, CA) spectrum/network/impedance analyzer [1]. The theoretical loading factors were calculated from theoretical estimates of the coil resistant (R_C) and the equivalent sample resistance (R_S) as $lf = R_S/(R_C+R_S)$. The R_C and R_S values were calculated as [3, 6]:

$$R_C = \frac{\rho_w (8h + 4\pi a)}{w\left[2\rho_w / \mu_0 \omega_0\right]^{1/2}} \qquad R_S = \frac{(1-\eta^{5/2})\, \omega_0^{\,2}\, h^3\, b^4\, \mu_0^{\,2}}{64\pi \rho_s\, a^2\, (a^2 + h^2/4)}$$

where ρ_W and ρ_S are the resistivities of copper and saline, respectively, and b and η are the radius and the gas fraction of the sample, respectively [2].

The 1.89 T experiments were performed within the 30 cm bore of a superconducting magnet (Magnex, Exon, England). The 17 mT imaging was performed in the fringe field of the 1.89T superconducting magnet (passively shimmed) [4]. Both systems were controlled by an MRRS console (Surrey, U.K.). Hyperpolarized natural abundance xenon gas (26.4% ^{129}Xe) was produced using a continuous-flow polarization system that used a 60W diode array laser (λ=794.8 nm, Coherent, Santa Clara, USA) and produced xenon polarizations of up to 22% [5]. The 3T imaging was performed in a GE Signa system (GE Healthcare, USA). Hyperpolarized helium of polarization up to 35% was obtained using a Helispin polarizer (GE Healthcare, USA). The theoretical field dependence of the SNR for rat lungs and estimates for the sample and coil noise contributions were obtained using a model described previously [3].

Results and Discussion

Figures 1 and 2 show, respectively, a xenon spectrum (at 1.89T) and a helium image (3T). The estimated SNR values (Table 1) show reasonable agreement with the theory. Figure 3 and Table 2 show the results of the noise measurements on the RF coils. The field dependence of the loading factors also shows good agreement with the theoretical model.

Conclusion

This study validates the theoretical model *in vivo* for the field dependence of the SNR and indicates that high field strengths (frequencies) may be optimal for HNG lung imaging of small animals such as rats (80-100 MHz) and mice (100-130 MHz).

Acknowledgements

The helium polarizer was made available by Merck.

References

1- Chronik et al. Proc. ISMRM 10, p.58 , 2002
2- Parra-Robles et al. Proc. ISMRM. 13, p. 1825, 2005
3- Parra-Robles et al. Med. Phys. 32: 221-229, 2005.
4- Parra-Robles et al. J. Magn. Reson. 174, 116-124, 2005.
5- Cross et al. J. Magn. Reson. 162, 241-249 (2003).
6- Hurlston et al. Inc. Int J Imaging. Syst Technol, 8, 277–284, 1997.

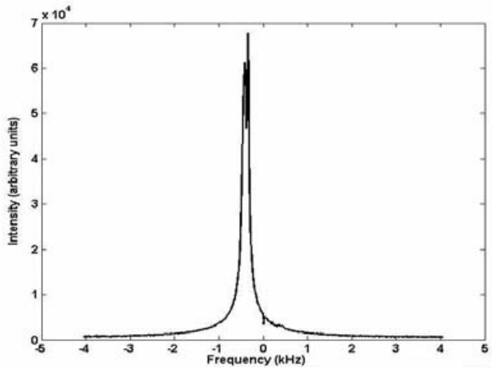

Figure 1. Gradient-echo spectrum of live rat lungs at 1.89 T (xenon).

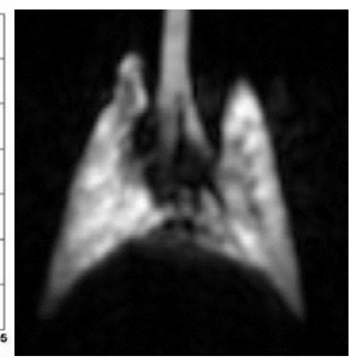

Figure 2. 2D Gradient-echo image of live rat lungs at 3T (helium).

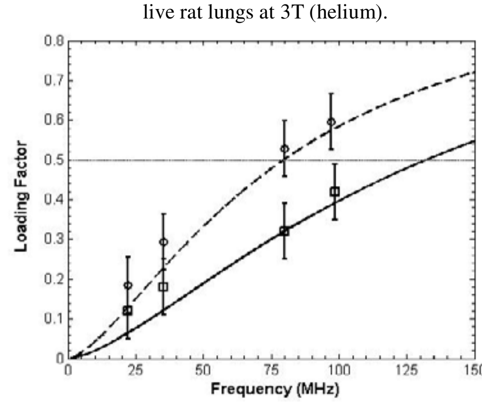

Figure 4. Comparison of theoretical (solid and dashed lines) and measured loading factors for rat coils with 350 ml (squares) and 500 ml (circles) phantoms. Sample noise dominates for $lf > 0.5$.

Larmor frequency	SNR (theory)	SNR (measured)
22 MHz (Xe)	3.92	4.5 +/- 0.5
98 MHz (He)	30.2	33.1 +/- 4.1

Table 1. Theoretical and experimental estimates of the SNR of HNG imaging of rat lungs (relative to the SNR at 17 mT, and normalized to account for pulse sequence and hardware differences).

Sample volume	*lf* at 97 MHz	*lf* at 128 MHz
20 ml	0.19 +/- 0.04	0.42 +/- 0.07
25 ml	0.30 +/- 0.05	0.45 +/- 0.07
30 ml	0.34 +/- 0.05	0.49 +/- 0.07

Table 2. Loading factors of the mouse-sized coil for three different sample volumes