Optimization of SNR via cryogenically cooled radiofrequency coils in hyperpolarized noble gas MR imaging of the lungs.

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Introduction

In MR imaging, the static magnetic field strength is generally made as large as possible to achieve the most signal (ie. magnetization). However, with the use of hyperpolarized noble gases (HNG), ^{3}He and ^{129}Xe, available magnetization is independent of the static magnetic field strength. In fact, the optimal signal to noise ratio (SNR) for clinical lung imaging is expected is to occur between 0.1 T and 0.3 T [1] where the noise from the radiofrequency coil (RF coil) dominates over the sample noise [2]. The low field MR imaging provided by HNG allows for less expensive MR systems and may permit the use of an open bore MR imaging system [3]. Further gains in SNR at low magnetic field strength can be realized by minimizing the coil noise in the conductor by decreasing the resistance at low temperature. Figure 1 shows that only by operating at a low field strength are significant increases in SNR made available by decreasing the temperature of the RF receiver coil. The objective of this work was to measure the improvement in SNR provided by cooling RF coils with liquid nitrogen, using ^{129}Xe gas as a source of signal. Expected SNR improvements were calculated and actual SNR improvements were measured using ^{129}Xe gas phantom as well as in in vivo ventilated rats.

Methods

A "half saddle" receiver coil (diameter 8.5 cm, length 21cm, 10 turns of wire) was constructed using insulated copper wire. This was loaded into a transmitter coil and sealed with expanding foam, to create a pocket for liquid nitrogen to flow into (see Figure 2). The imaging volume was insulated from the cold operating temperature (measured to be 118 K). Hyperpolarized natural abundance xenon gas (26.4% ^{129}Xe) was produced using a continuous flow polarization system employing a 60W diode array laser (λ = 794.8 nm, Coherent, Santa Clara, USA). 64 x 64 images were acquired using a gradient echo sequence with a flip angle of 8^0 and a TR time of 15 ms. In vivo SNR values were obtained using ^{129}Xe gas in a Sprauge Dawley rat that was ventilated with a custom system using a University approved animal care protocol [5].

Results and Discussion

Table 1 shows the calculated and measured SNR gain in accordance with the parameters described above. Expected gain in SNR values were calculated from the Q values of the coil which were measured using a Bravo MRI II analyzer Measured SNR increases were significant (~50%) at low temperature. Although this improvement is less than the factor of about three predicted by theory (Fig. 1), this is not unexpected since the theory presumes a full bird-cage operating at 77K rather than the half saddle coil operating at 118 K used in this study. The sample was unavoidably cooled somewhat but this likely has a small effect on measured SNR gain values. The next step in this work is to find a better insulating medium (such as sapphire which conducts heat in only one direction) that allows the coil to work at lower temperatures without damaging the sample and use different coil geometries (such as full saddle and birdcage) to find the optimal SNR.

Conclusion

This study confirms that significant SNR gains from both the phantom and a live small animal can be achieved if the temperature of the RF receiver coil is cooled to very low temperatures. Measured SNR gains were found to correspond to the expected trend predicted by theory. These gains are only possible because of the low noise from the sample attainable at low magnetic field strength and the high signal provided by the hyperpolarized ^{129}Xe gas .

Acknowledgements

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References

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Sample	Expected SNR Gain	Measured SNR Gain
Phantom (syringe trapped ^{129}Xe gas)	1.57	1.55 ± 0.08
Live Rat	1.46	1.41 ± 0.10

Table 1 – Expected and measured SNR gains due to cryogenic cooling of RF coil for a phantom sample and a deceased rat sample. Results are normalized to the coil operating at room temperature.

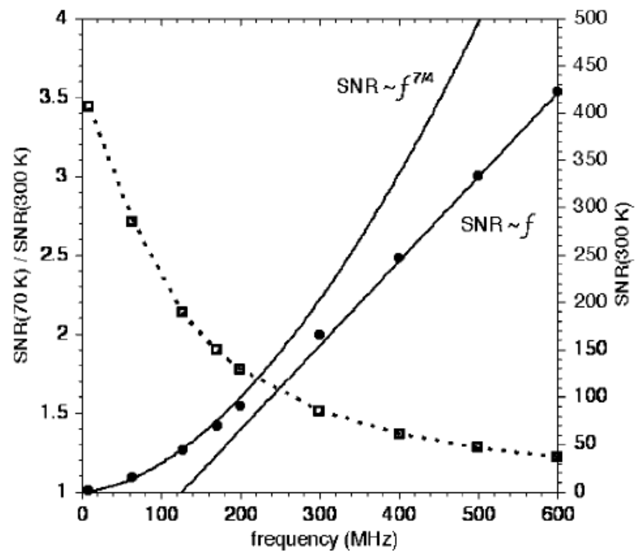

Figure 1 – Expected SNR gains (squares) at 77 K as a function of frequency of precession. Simulated SNR for a coil operating at room temperature coil (circles) is also shown for both coil dominated and sample dominated noise regimes [4].

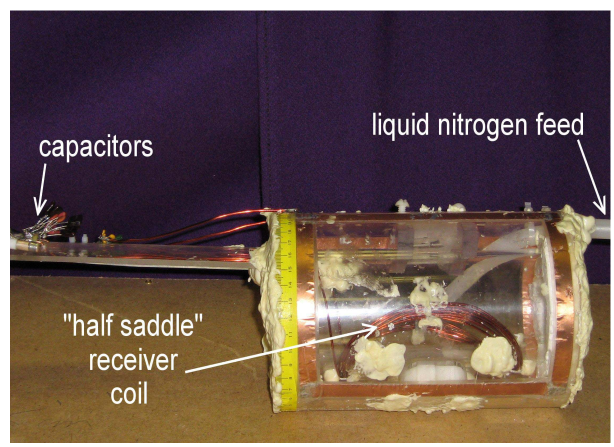

Figure 2 – Half saddle coil placed in transmission unit. A plastic tube (right) fills the contained with liquid nitrogen; capacitors are removed (left) to protect them from extreme temperature change.