Performance of a 200 MHz cryogenic RF probe designed for small animal MRI/MRS

D. Ratering[1,2], C. Baltes[1,2], J. A. Massner[1], D. Marek[3], and M. Rudin[1,2]

[1]Institute for Biomedical Engineering, University & ETH Zurich, Zurich, Switzerland, [2]Institute of Pharmacology & Toxicology, University Zurich, Zurich, Switzerland, [3]Bruker BioSpin AG, Fällanden, Switzerland

INTRODUCTION Magnetic resonance imaging (MRI) and spectroscopy (MRS) in small rodents demand for high sensitivity. Sensitivity per unit time is the crucial parameter determining data quality and acquisition speed.

One option to increase the signal-to-noise ratio (SNR) per unit time is to decrease the noise of the MR experiment. The dominant noise sources are the biological sample itself and the thermal noise of the receiver electronics. For small animal MRI/MRS sample noise and thermal noise are of comparable magnitude. Thus, reducing receiver noise allows for a significant increase in sensitivity. This noise reduction can be achieved by cooling down the receiver chain.

This study aims to evaluate the performance of an ultra-cooled radiofrequency (RF) probe in comparison to a home-made RF surface coil of equal dimensions and a commercially available volume resonator probe, both operating at room temperature.

METHODS The expected gain in SNR from a cryogenic RF coil compared to a room temperature (RT) coil with equal dimensions was estimated according to Darrasse and Ginefri [1] (Fig.1).

Experiments were carried out using a Pharmascan 47/16 imager (Bruker BioSpin GmbH, Karlsruhe, Germany) operating at 200MHz. RF probes used for both transmission and reception were: a) a circular cryogenic RF coil (CP-SC, temperature: <30K, diameter: 20mm) connected to a cooled preamplifier (77K), b) a home-made RF surface coil (RT-SC, temperature: 293K, diameter: 20mm) and c) birdcage-type volume resonator (RT-VR, temperature: 293K, inner diameter: 22mm). The cryogenic RF probe and the corresponding closed-cycle Cryo-Platform working with cold helium gas like the one used in high-resolution NMR were provided by Bruker (Bruker BioSpin GmbH, Karlsruhe, Germany, and Bruker BioSpin AG, Fällanden, Switzerland).

In vitro experiments were performed using a cylindrical PMMA phantom (inner diameter: 16mm) filled with 0.9% physiological NaCl solution using conventional gradient echo (GE) and spin echo (SE) sequences (parameters: FOV: 20x20x0.5mm^3, Matrix Size: 256x96, SE: pulse angle: 90°, TE/TR: 12/1000ms, GE: pulse angle: 30°, TE/TR: 6/100ms). *In vivo* measurements were carried out on C57/Bl6 mice using SE sequences (Parameters: FOV: 20x20x0.5mm^3, Matrix Size: 200x200, FA: 90°, TE/TR: 12/3500ms). In all MRI experiments noise calculations were performed from additional measurements without excitation RF pulse (pulse angle: 0°) to avoid signal contamination.

Single voxel MR spectra were acquired in a phantom containing 33 mM N-acetyl aspartate (NAA) solved in physiological saline and in C57/Bl6 mice using PRESS sequences (Parameters: volume: 4x4x4mm^3, Averages: 50, TE/TR: 20/2500ms). Water suppression was achieved using the VAPOR [2] technique. In MRS noise values were estimated from the spectra between -2 to -3 ppm.

In all experiments receiver gain and pulse angles were carefully adjusted for the ROI closest to the surface using B1 field maps to ensure a reliable comparison between the involved RF probes. Each *in vitro* experiment was repeated five times for reproducibility calculations. All animal experiments were performed in accordance to the Swiss law for Animal Protection.

RESULTS *In vitro* MRI measurements yielded an average gain in SNR by a factor ≥2 for GE and SE sequences (Tab.1). ROIs (Fig. 2a, 2b, circles) were analyzed at various depths. Comparing surface coils for the *in vitro* measurements, SNR of the cryogenic probe was superior by a factor of 2.1-2.7, while when comparing with the RT-VR the SNR gain depended as expected on the depth of the ROI, ranging from 4.9 at surface to 1.4 at a depth of 6mm (Fig. 2c). *In vivo* the SNR gain of the cryogenic coil compared to the RT surface coil varied only slightly from 1.9 to 2.1 (Fig. 2c). In MR spectroscopy, comparable gains in SNR were found for both *in vitro* and *in vivo* experiments (Tab.2 and 3).

in vitro	SNR(CP-SC)/SNR(RT-SC)	SNR(CP-SC)/SNR(RT-VR)
SE	2.13±0.01	4.82±0.02
GE	2.05±0.01	4.94±0.02

Tab.1: SNR gain (mean±STD) for SE and GE sequences measured in the ROI closest to the coil (Fig. 2b).

in vitro	mean SNR±STD	FWTM(NAA) [Hz]
CP-SC	659.19±33.80	5.79±0.07
RT-SC	279.36±6.38	8.18±0.05
SNR gain	2.36±0.09	

Tab.2: Mean SNR±STD and gain in SNR (mean±STD) for *in vitro* MR spectroscopy measurements. Quality of the shimming can be seen from the full width at 10% of the maximum (FWTM) NAA singlet.

in vivo	mean SNR±STD	FWHM of NAA singlet [HZ]
CP-SC	44.29±2.58	12.15±0.36
RT-SC	22.59±1.40	16.51±1.29
SNR gain	1.96±0.12	

Tab.3: Mean SNR±STD and gain in SNR (mean±STD) for *in vivo* MR spectroscopy measurements. Quality of the shimming can be seen from the full width at half maximum (FWHM) NAA singlet.

DISCUSSION The use of ultra-cooled probes in small animal MRI/MRS leads to an increase in SNR by factors ≥2 in comparison to a RT surface coil. The experimental values are in good agreement with theoretically expected gains in sensitivity for a probe cooled down to 30K in view of the approximations made in the theoretical calculation such as neglecting the noise figure of the preamplifier [1]. The gain in sensitivity allows enhancing image quality by increasing the SNR or at a given SNR either reducing scan time or increasing spatial resolution. Furthermore, ultra-cooled probes represent an economically attractive alternative to enhance the performance of a given system in routine operation.

REFERENCES [1] Darrasse L, Ginefri JC, Biochimie; 85:915-937, 2003; **[2]** Tkac I, et al., MRM; 41:649-656, 1999

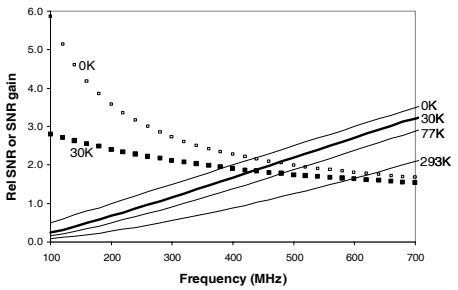

Fig.1: Theoretical estimation of the effect of coil cooling on the SNR (lines, relative to the SNR at 200MHz and 0K) and SNR gain as compared to the performance at room temperature (symbols) as a function of resonance frequency. All other parameters were kept constant.

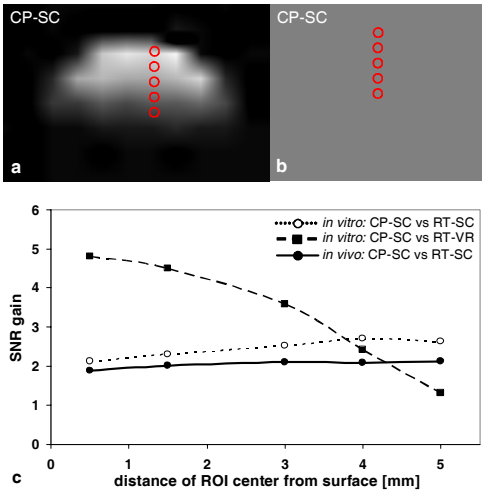

Fig.2: Axial images of the mouse brain (a) and the PMMA phantom (b) acquired with a SE sequence. (c) SNR gain of cryogenic RF probe compared to RT surface coil and RT volume resonator at various depths (circles in a, b).

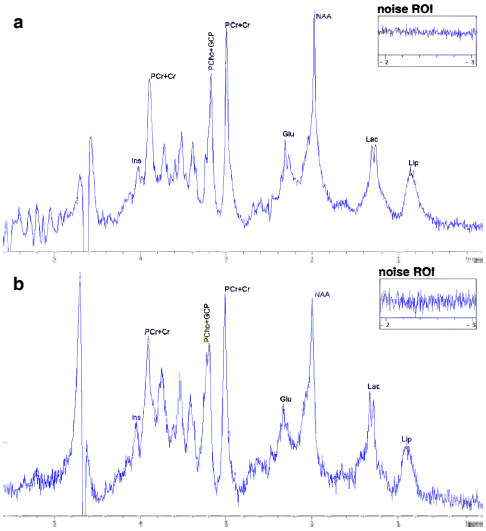

Fig.3: *In vivo* MR spectra acquired with a PRESS sequence using a cryogenic RF probe (a) and a RT surface coil (b). Inset: Regions used for noise calculations (equally scaled).