A modular MRI probe design for large rodent neuroimaging at 21.1 T (900 MHz)

P. L. Gor'kov[1], C. Qian[1], B. L. Beck[2], M. Clark[1], I. S. Masad[1,3], V. D. Schepkin[1], S. C. Grant[1,3], and W. W. Brey[1]

[1]National High Magnetic Field Laboratory, Tallahassee, FL, United States, [2]McKnight Brain Institute, University of Florida, Gainesville, FL, United States, [3]Chemical and Biomedical Engineering, Florida State University, Tallahassee, FL, United States

Introduction

The emergence of 21.1-Tesla, 105-mm bore vertical magnet (1) has opened new opportunities for high-resolution ^{1}H MRI, as well as for MRI of low-γ nuclei (^{23}Na, ^{13}C) where sensitivity gains are very crucial. However, many practical challenges must be addressed to utilize this unique instrument. Because of the wavelength effects at high ^{1}H frequency (900 MHz), animal loading has a large influence on tuning and B_1 homogeneity of the probe. The RF probe must be able to tune between different size animals without significant distortion of B_1 fields. Saline phantoms are widely used to evaluate B_1 homogeneity in volume coils at lower magnetic fields, but they loose relevance at 21.1 T because of dielectric resonance effects. New phantoms are required for successful RF coil development at higher fields. Another challenge is posed by the lack of probe space in the 57-mm clear bore of the gradient stack. The body of adult rat fills most of that space; a clever mechanical design is needed to accommodate additional animal equipment, such as an anesthesia supply, respiratory monitor, restraints and other life support features, together with RF cables and remote tuning access for at least 2 RF channels. In this work, we report the design of 21.1-Tesla MRI user probe developed for head imaging in adult rats up to 350 g.

Methods

The 900 MHz rat head MRI probe is comprised of a few easily detachable modules (Fig. 1). The probe frame is connecting to the animal cradle, which is in turn interfaced to the RF coil probehead. The RF probehead supports bite bar restraint, anesthesia, vacuum supply and other accessories. Tuning and matching of the coil is done from the bottom of probe body, which is 2 meters long. Because of space constraints, the cables, tuning rods and restraints were routed under the relatively flat belly of the rat. RF coil patterns are electrodeposited onto rigid PEEK formers. The RF shield is copper-plated on the inside of a G-10 cover tube. Special attention was paid to the rigidity of probehead assembly, because any flexibility in RF elements or leads at 900 MHz may result in resonance shifts. Our implementation of coil shielding significantly improved tuning stability and eliminated the need for commonly used ground current traps. The probehead design is completely self-contained and can be worked on independently, facilitating collaboration between the NHMFL and other RF groups around the country. The transmit/receive volume coils are based on the low-pass birdcage geometry with a 55-mm length and animal clearance diameters up to 35.5 mm. The coils are tuned to proton or low-γ nuclei, e.g. ^{23}Na. Double-tuned ^{1}H/^{23}Na and ^{1}H/^{13}C coils are in development along the lines of Isaac et al. (2). We will present a novel single-tuned ^{1}H coil designed for high fields, which can tune over a wide range of sample loads with minimal distortion of B_1 field homogeneity.

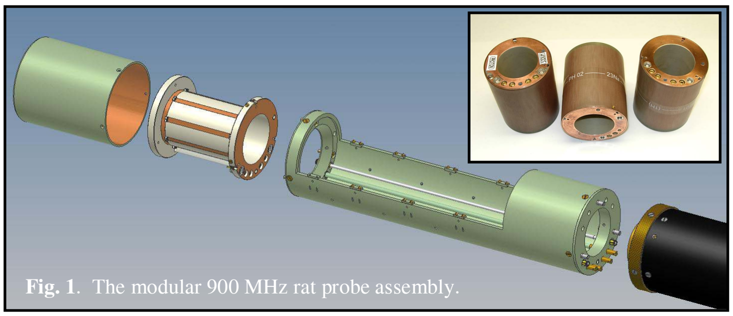

Fig. 1. The modular 900 MHz rat probe assembly.

MRI experiments below were performed on live rats and on fixed rat heads using a Bruker Avance console with Paravision 3.0.2. Images were acquired for both ^{1}H (900 MHz) and ^{23}Na (237 MHz) signals. All experiments with animals were conducted according to the protocols approved by The Florida State University Animal Care and Use Committee.

Results

The proton images of rat brain were acquired *in vivo* using a multi-slice RARE sequence (Fig. 2) and FLASH gradient echo sequence (Fig. 3). Parameters for RARE image: effective TE=1 ms, TR=3.5 s, NEX= 4, RARE factor = 4; for gradient echo image: TR=500 ms, TE=4 ms, NEX=4. The in-plane resolution was 117 x 117 µm for RARE and 234 x 469 µm for gradient echo image, with the same slice thickness of 500 µm. The images were acquired within 15 and 8.5 min, respectively. A high resolution 3D gradient echo image of rat brain (*ex vivo*) is shown in Fig. 4 with isotropic resolution of 80 µm. The acquisition time was 12.5 hours, TE = 7.5 ms, TR = 150 ms, NEX = 2. Fig. 5 shows sodium gradient echo image of a fixed rat head with TE = 2.5 ms, TR = 50 ms, NEX = 10. The unique resolution of sodium imaging of up to 0.5 x 0.5 x 0.5 mm was achieved in 34 min. As seen in this image, sodium intensity is high throughout the brain. Some increase in sodium is noticeable at the edges of the brain. This high-resolution sodium imaging is an important tool for studies of tumor response to therapy.

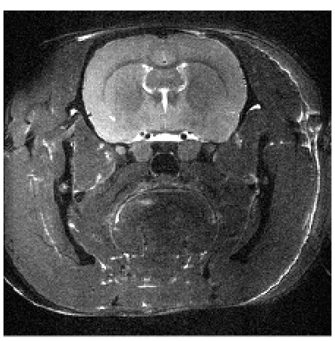

Fig. 2. *In vivo* ^{1}H RARE, axial, adult 350-g rat, 117 x 117 x 500 µm, 15 min acquisition time.

Fig. 3. *In vivo* ^{1}H FLASH GRE, coronal, adult 350-g rat, 234 x 469 x 500 µm, acquisition time 8.5 min.

Fig. 4. *Ex vivo* ^{1}H 3D GRE, coronal high-res, 80 x 80 x 80 µm, 12.5 hrs acquisition time.

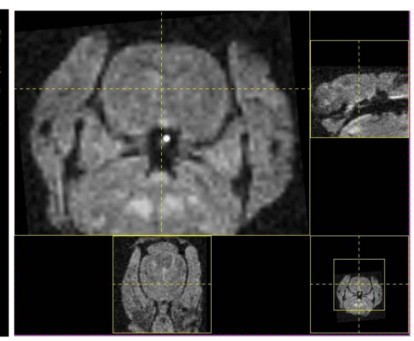

Fig. 5. *Ex vivo* ^{23}Na 3D GRE, isotropic resolution 0.5 x 0.5 x 0.5 mm, 34 min acquisition time.

Conclusions

Development of RF probe technology for high magnetic fields enabled high resolution MRI of rat heads in a 21.1-Tesla (900 MHz) magnet system. These novel *in vivo* MRI capabilities create new opportunities for users conducting biomedical research on large rodent models, especially in low-γ MRI, where the gain in sensitivity is crucial. Our 900 MHz facility is funded by the NSF and is free for users in the imaging community. Interested researchers are encouraged to apply for instrument time.

Acknowledgement

Special thanks to R. Desilets, J. Kitchen, K. Shetty, and A. Blue who have made valuable contributions to this project. We thank Dr. P. Thanos of Brookhaven National Laboratory for providing *ex vivo* samples and Dr. Jeong-Su Kim (FSU) for providing live rats. The study was supported by NHMFL through NSF Cooperative Agreement (DMR-0084173) and the State of Florida.

References

(1) Fu R., et al., J. Magn. Reson. 177 (2005) 1–8; (2) Isaac G., et al., J. Magn. Reson. 89 (1990) 41–50; (3) Schepkin V.D., et al., ISMRM 2008.