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

P. L. Gor'kov1, C. Qian1, B. L. Beck2, M. Clark1, I. S. Masad1,2, V. D. Schepkin1, S. C. Grant1,3, and W. W. Brey4

1National High Magnetic Field Laboratory, Tallahassee, FL, United States, 2McKnight Brain Institute, University of Florida, Gainesville, FL, United States, 3Chemical 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 1H MRI, as well as for MRI of low-γ nuclei (23Na, 13C) 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 1H frequency (900 MHz), animal loading has a large influence on tuning and B1 homogeneity of the probe. The RF probe must be able to tune between different size animals without significant distortion of B1 fields. The RF probe head 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 a 21.1-Tesla MRI user probe developed for head imaging in adult rats up to 350 g.

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

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. 23Na. Double-tuned 1H/23Na and 1H/13C coils are in development along the lines of Isaac et al. (2). We will present a novel single-tuned 1H coil designed for high fields, which can tune over a wide range of samples loads with minimal distortion of B1 field homogeneity.

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 1H (900 MHz) and 23Na (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.

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