A Combined Solenoid-Surface RF Coil for High-Resolution Whole-Brain Rat Imaging on a 3.0 Tesla Clinical MR Scanner

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Introduction: Models derived from the rat brain have been used to study human neurological disorders from a spectrum of disciplines including oncology, trauma, psychiatry, and neurology. Magnetic resonance imaging (MRI) has extended research opportunities within these fields by affording the serial evaluation of the in vivo rat brain to monitor disease progression and/or response to therapy. To broaden availability beyond high field-strength (4.7 – 17 T), small bore magnets, existing clinical scanners have been adapted for rat brain imaging via implementation of custom-built and commercially available coils. Custom-built coils have utilized a variety of designs including double-saddle[1], loop-gap resonator-based[2], and inductively coupled solenoid[3] coils. The particular advantage of using solenoid coils with small animals in clinical scanners is the ability to align the coil and sample orthogonally with B_0, which results in an increased signal-to-noise ratio (SNR) due to a more efficient coil design. Within the domain of commercially available products, wrist[4], orbit[5], and surface coils[6] have been exploited for rat brain imaging with varying results. Most recently, small diameter surface coils[7] have emerged as the dominant approach. Surface coils have a strong coupling to superficial tissues. The superficial location of the rat brain lends itself to imaging with surface coils.

Purpose: In this study, we sought to develop an RF receive only coil dedicated for rat whole-brain imaging at 3.0 T. The advantages provided by solenoid and surface coils were combined to yield a multi-channel coil with high SNR specific to the entire rat brain volume. Performance was compared to 1) a commercially available, two-channel, phased-array carotid surface coil (Pathway MRI, Seattle, WA, USA); 2) a commercially available multi-turn solenoid mouse body coil with internal diameter (ID) of 40 mm (Philips, Best Netherlands); 3) a single-loop, surface coil with internal diameter of 30 mm; and 4) a two-turn, single channel (i.e. modified Helmholtz) coil.

Methods: The coil was constructed over PVC tubing with an ID of 31 mm and outer diameter (OD) of 33 mm. Two single-turns of 6 mm wide copper foil were placed 21 mm apart with respect to their center lines. These coils were denoted Channel (Ch.) 1 and Ch. 2 (Figure 1). The relative placement of Chs. 1 and 2 was selected to provide sufficient coverage of the entire length of rat brain, while maintaining spacing to minimize noise correlations from tissue. Double-sided circuit board was used to mount all circuit elements for Ch. 1 and Ch. 2 (Figure 1). A surface coil construct (Ch. 3) was appended to the 2-channel solenoid coil by A) exploiting the portion of the circuit board connecting Ch. 1 and Ch. 2 necessary for their decoupling, B) attaching an additional single-sided circuit board 120° away from A for circuit element placement, and C) utilizing the segments of 6 mm copper foil between A and B (Figure 1). The coil depicted in Figure 1 is subsequently referred to as the rat brain coil.

The single-loop, surface coil with ID of 30 mm was constructed from 3/16” copper tubing since a commercially available small surface coil is not presently available for imaging at 3.0 T. The modified Helmholtz coil was constructed over identical PVC tubing as the rat brain coil. Spacing between the two-turns of copper foil (width, 6 mm; distance between center lines, 22 mm) was placed to provide similar FOV as the rat brain coil with regards to 3 dB loss of maximum SNR.

A $CuSO_4$ phantom doped with NaCl to simulate loading of the coil with a rat was used for comparing SNR between coils. All images were acquired on a 3.0 T, whole-body scanner (Philips Achieva, Best, Netherlands). An adult, 305 g male Wistar rat was used for in vivo imaging of the rat brain. A 3D T2-weighted spin echo sequence with TR/TE = 2000/90 ms, echo-train-length = 12, and α = 90° was used to acquire isotropic images of the entire rat brain volume. Scan parameters were: number of excitations (NEX) = 2, FOV = 28×28×14 mm, matrix = 112×112×56 for an acquisition resolution of 0.25×0.25×0.25 mm^3, subsequently zero-filled interpolated to 0.125×0.125×0.125 mm^3. Scan time was 60.6 minutes.

Results: At a depth of 6 mm from the surface of the phantom (Figure 2) and along a 30 mm segment aligned at the center of the long axis of the coil, the mean ± standard deviation (range) percent increase in SNR by the rat brain coil compared to corresponding regions in the mouse body coil, the 3 cm surface coil, the modified Helmholtz coil, and the carotid surface coil was 71.5±10.5% (52.2% – 91.9%), 60.8±9.2% (40.6% – 77.9%), 78.4±10.3% (60.2% – 95.6%), and 242.4±19.8% (207.3% – 286.5%). Representative images of the in vivo rat brain are shown in Figure 3. A spectrum of both gray and white matter structures were identified.

Conclusion: In this study, we present a simple, multi-channel RF receive-only coil specific to whole-brain rat imaging at 3.0 T in a clinical MR scanner. The coil utilized the strengths of both solenoid and surface coils to provide improved SNR across the entire rat brain volume when experimentally compared to a variety of other coils. The increase in SNR was utilized to acquire isotropic, high-spatial resolution images of the entire rat brain volume in a reasonable scan time to demonstrate the full range of coverage afforded by the coil design. Alternatively, the improved SNR can be used to further improve resolution, reduce scan times, or improve temporal resolution during dynamic studies. As clinical scanners progress towards increasing field-strengths, RF coil designs that improve SNR may provide greater access to small animal imaging and expand experimental opportunities.

References: 1. *Radiology* 1988;166(3):835-838 **2.** *Physics in Med and Bio* 2007;52(22):N513-522 **3.** *Medical Physics* 2003;30(6):1241-1245
4. *J NeuroOnc* 1999;43(1):11-17 **5.** *Inv Rad* 1995;30(4):214-220 **6.** *Radiology* 1995;197(2):533-538 **7.** *J Neuroscience Methods* 2008;172(2):168-172
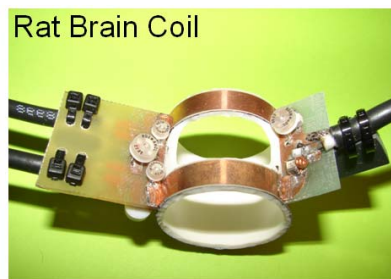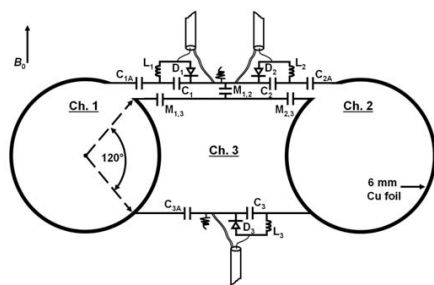
Figure 1. Schematic and photograph of the rat brain coil. C_1, C_2, and C_3 refer to the input capacitors for each channel. $M_{a,b}$ refers to the decoupling capacitor between Chs. A and B.
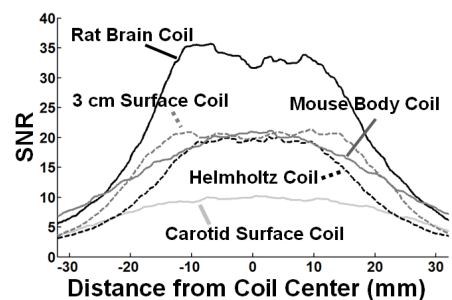

Figure 2. Comparison of SNR between coils at a depth consistent with the center of the rat brain.
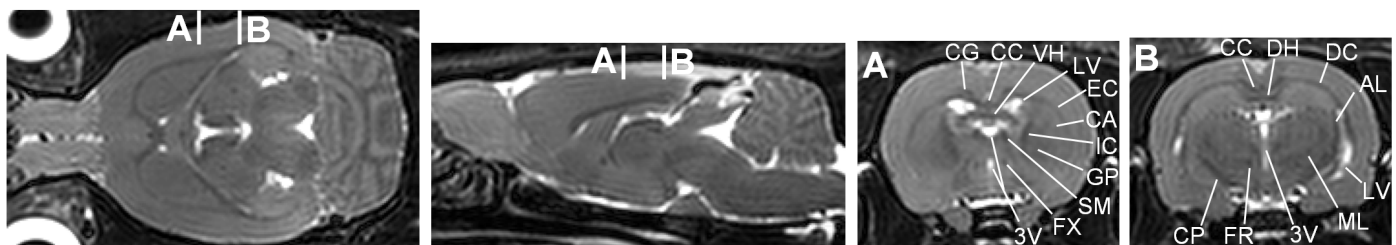

Figure 3. In vivo rat brain images. AL= alveus of the hippocampus; CA= caudate putamen (striatum); CC= corpus callosum; CG= cingulum; CP= cerebral peduncle; DC= deep cerebral white matter; DH= dorsal hippocampal commissure; EC= external capsule; FR= fasciculus retroflexus; FX= fornix; GP= external globus pallidus; IC= internal capsule; LV= lateral ventricle; ML= medial lemniscus; SM= stria medullaris; VH= ventral hippocampal commissure; 3V= third ventricle