High Resolution Rodent Cochlea Imaging on a 3T Clinical Magnet

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INTRODUCTION: The mammalian cochlea contains small fluid-filled chambers that are indicators of the health of the inner ear,[(1,2)] and cochlear imaging requires very high spatial resolution to accurately assess this small structure. While some inner ear magnetic resonance microscopy has been performed at lower field strengths, these typically have involved very long scan times[(3)] or thick slices[(4,5)]. The highest reported resolution for live animal cochlea is 78µm isotropic at 4.7T in 34 minutes[(6)]. The objective of this study was to improve guinea pig (**GP**) cochlear imaging to isotropic resolutions of 100µm on a 3.0T clinical magnet by using specialized gradient and RF coils (**Fig. 1**).

This work developed a small animal system for *in vivo* rodent imaging on a clinical MR system. Insert gradients (**IG**) allowed for higher spatial resolution than the body gradients alone could achieve. Specialized RF coils were developed to fully utilize the resolution achievable by the IG. Animal safety and monitoring equipment was integrated into the system to obtain easy and robust access to the animal for optimal coil and wire placement and to ensure animal comfort and safety.

METHODS: Composite Gradients: This work used the system's body gradients simultaneously with a small IG for composite gradient mode imaging (**Fig. 2A**). Composite mode imaging enabled an increase in the maximum gradient strength and slew rate, thereby reducing the echo time, echo spacing, and repetition time, while maintaining high resolution[(7)].

Tx/Rx Coils: The phased array used for this study consisted of four 27mm diameter loops mounted onto a cylindrical, plastic syringe (**Fig. 2B**). One end of the syringe was cut to a semicircle so that the bottom half was removed, so that it could be placed over different rodent head sizes. A custom transmit RF coil (**Fig. 2C**) was implemented to avoid the increased RF power requirements necessary for the body RF coil to penetrate the IG. The transmit-only RF coil was a 102mm diameter, 98mm long, low-pass RF birdcage. Removable RF shielding was implemented to reduce RF coil sensitivity to the IG and water cooling system. The RF shielding allowed the system to operate without the IG in place.

Animal Positioning, Safety, and Monitoring: An acrylic support structure was built so that the animal, coils, and monitoring equipment could be positioned outside the gradient system. Isoflurane (Fluriso, Vet One, USA) was administered using a vaporizer (Matrx VIP 3000 Iso, Veterinary Anesthesia Systems, Inc., UT, USA) for animal comfort and to reduce animal movement. A MR-compatible monitoring and gating system (ERT Module 1030, SA Instruments, Inc., NY, USA) monitored the animal's breath, pulse rates and temperature.

Live Animal Experiments: Animal studies occurred with IACUC approval. To observe the separation between the scalar chambers, 3D FLASH MR images with the composite gradient were obtained at 100µm isotropic resolution with the following parameters: TR/TE = 20/3.1 ms, flip angle = 50°, averages = 5, total scan time = 32min52sec. Gadolinium (Multihance, Bracco Diagnostics, Inc., Monroe Township, NJ, USA) was injected into the right middle ear cavity, diluted with saline by a factor of four.

RESULTS: 3D FLASH images using composite mode are shown (**Fig. 3**). The membranes separating the inner ear chambers are visible in these images. Magnified images of the cochlea show the increase in SNR and contrast with (**Fig. 3B-D**) and without enhancement (**Fig. 3E-G**).

DISCUSSION: Specialized Tx/Rx coils, positioning equipment, and monitoring hardware was developed for a small animal IG. This hardware was essential in obtaining 100µm isotropic resolution images of a live GP cochlea in a 3T human scanner. The smallest commercial coil available for this clinical system was a much larger wrist coil that was unable to fit inside the IG. Initial experiments involved small, custom Tx/Rx birdcages, which were insensitive and inhomogeneous as a tight Tx/Rx volume coil could not be formed due to the proximity of the GP ears to its large shoulders. Additionally, the revised setup allowed for easy, yet robust and repeatable, positioning of the RF coils, animal monitoring cables, and other equipment for optimal SNR and animal safety.

CONCLUSION: A small animal system was developed that achieved good *in vivo* 100µm isotropic resolution images of the GP cochlea in a scan time of 33 minutes for FLASH imaging. The separate chambers within the cochlea can be distinguished, along with many of the features of the cochlea.

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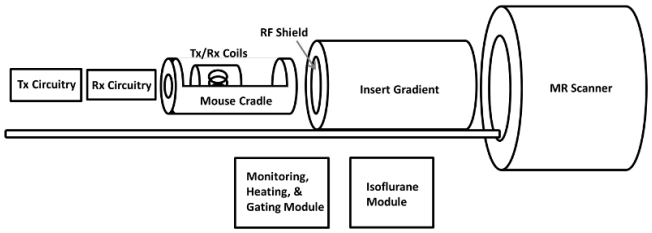

Figure 1: Schematic showing the scanner, insert gradient, RF coils, and monitoring equipment, prior to insertion into the scanner.

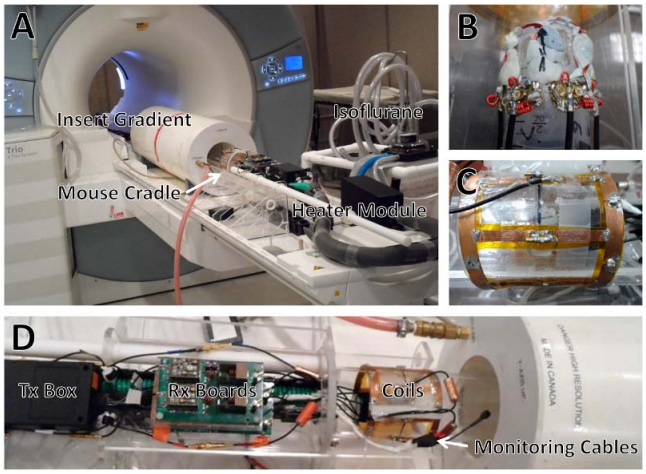

Figure 2: A: Picture of the entire setup. The insert gradient provides additional gradients simultaneous with the standard body gradients. The mouse cradle provides structural support so that the entire system can slide into the gradients, maintaining coil and monitoring wire placement on the GP. The heater module provides heat that passes through an insulated plastic hose before reaching the GP. Vaporized isoflurane ensures that the rodent remains asleep and immobile throughout the experiment. **B:** Four channel receive RF coils. **C:** Low-pass birdcage coil used for transmit-only. **D:** Top-view picture of the insert gradient and RF system. The Tx box, Rx boards, and coils all easily slide into the insert gradient. The head of the GP is placed within the receive coils, that are centered in the transmit coil. The Tx box ensures that the transmit coil is properly DC biased to be tuned only during transmit. The Rx boards contain preamplifiers and provide DC biasing to the receive coils to detune them during transmit. The animal monitoring cables are shielded so that they have minimal effect on the coils.

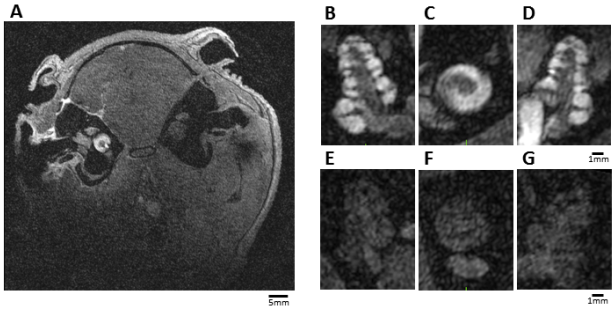

Figure 3: A: Axial plane image of the entire GP head following diluted gadolinium injection into only the right middle ear cavity. **B-D:** Three orthogonal reconstructed magnified views of the right cochlea demonstrate contrast enhancement of the cochlear chambers. **E-G:** The left middle ear cavity remains unenhanced at poor SNR.