Subject-Specific, Helmet-Restraint, RF Coils for Awake, Non-Human Primate MR Imaging

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***Abstract*—In non-human primate [NHP] neuroimaging, the head needs to be immobilized. This is currently achieved via surgical implants; however, this method is invasive with risks of medical complications and limits the number of subjects that can enroll in a study due to the long waiting time after surgery for the implant area to heal and high cost. The purpose of this study is to demonstrate a non-invasive, subject-specific, restraint helmet with an integrated MRI RF coil. This system removes the need for invasive head post implantation and can be designed and implemented quickly at a low cost. Low dose computed tomography (CT) images were processed to create a subject-specific restraint helmet and structure of an RF coil. The helmet coil was 3D-printed from polylactic acid (PLA) plastic. The measured S_{11} of the fabricated coil is -32 dB indicating a good match at 127.8 MHz (the frequency corresponding to 3T MRI). Imaging was performed on a MR spherical phantom, and a high signal-to-noise ratio of 924 in the region of interest was measured.**

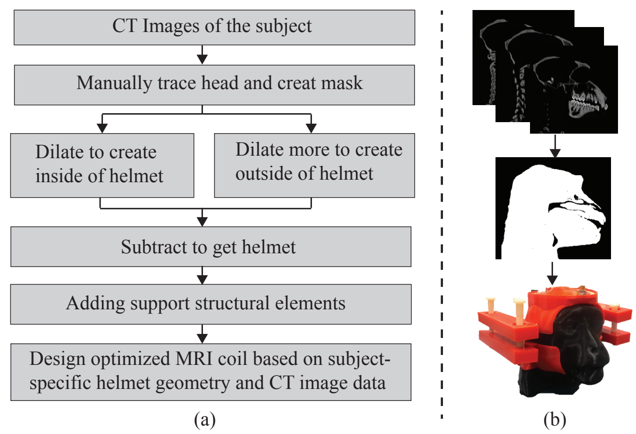

Fig. 1. (a) The required steps to convert CT images into a 3D subject-specific helmet. (b) CT images of the subject, headmask and the printed prototype.

I. Introduction

Animal models are a valuable tool for studying brain structure and function in the field of neuroscience. The Rhesus Macaque is a commonly-used non-human primate (NHP) model because it is a highly functioning species with similar brain structure and chemistry to humans and is capable of performing cognitive tasks. Anesthesia is often used to minimize animal movement in imaging studies, but cognitive tests require an awake subject. For awake conditions, the head needs to be immobilized. Typically, this is done by implanting biocompatible cranial screws and a head post, but this invasive approach has several limitations: first, the surrounding areas of the head post can become infected which threatens the health of the animal and the potential success of the experiment. Second, this procedure limits the number of subjects that can be enrolled for cognitive neuroimaging studies due to an 8-week period required for implant healing and the high cost of surgery. Non-invasive restraint devices have been developed by other groups [1], [2] for NHP imaging. Herein we demonstrate the design and construction of a low-cost, subject-specific restraint helmet with an integrated MRI coil, removing the need for invasive head post implantation. Such a system cannot currently be obtained from any commercial vendor but can be designed and implemented rapidly utilizing additive manufacturing (3D printing).

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II. Design Procedure and Experimental Results

Fig. 1(a) shows the required steps to convert CT images (acquired under anesthesia) into a subject-specific helmet coil for MR imaging. First, CT images were processed manually to restrict the image to only the head and neck, removing all other objects present in the field of view. Next, automated segmentation was performed (in MATLAB) to mask images based on intensity to obtain an outline of the head, fill the head mask, and to remove zero-labeled voxels due to air. Then a series of dilation steps we used to create the inner surface of the helmet (using fewer dilation cycles) and the outer surface of the helmet (using more dilation cycles). Subtraction of the two dilated masks yielded the shape of the helmet. Manual trimming and adjustment of the helmet design opened the face and ears. The helmet model was then imported into 3D design software (Solidworks) to attach a supporting frame and add structure for RF coil design. The helmet was manufactured using an FDM 3D printer (Ultimaker Extended 3+) and PLA plastic. Dielectric properties (dielectric constant and loss tangent) of PLA was

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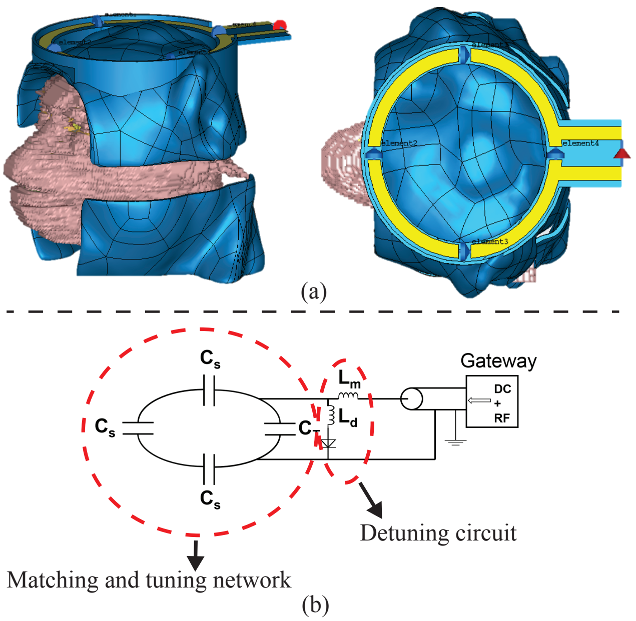

Fig. 2. (a) Full wave electromagnetic simulation model in CST. (b) circuit diagram of the tuning, matching, and detuning network.

measured using a resonator circuit technique developed by the authors at MRI-relevant frequency ranges and was used in electromagnetic (EM) simulations to design the RF coil. Note that 3D-printed polymers are unstandardized materials and the dielectric properties are likely to vary between manufacturers, thus it is important to measure them before applying EM simulations. Fig. 1(b) shows the CT images and the head mask of the subject used in this project as well as the final printed helmet coil.

The CAD file of the designed helmet coil was imported to EM simulation software (CST Microwave Studio) to design a single channel receive-only RF coil. Conductive elements of the loop are implemented with 6-mm wide copper tape. Coil inductance was estimated using full-wave EM simulation. Component values for matching and tuning networks were optimized within CST. Fig. 2(a) shows the full-wave electromagnetic simulation and the animal model from the simulation software. The coil was matched to 50 Ω and tuned to 127.8 MHz. A detuning circuit was designed to minimize interactions between the loop coil and integrated body transmit coil. When the PIN diode (UMX5101, Microsemi, Aliso Viejo, CA) used in the detuning circuit is forward biased with sufficient DC current, it creates a short circuit making the inductor L_d resonate in parallel with the capacitor C_t presenting a very high impedance at the desired frequency and open circuit the loop [3]. The components used for the tuning/matching network consist of fixed non-magnetic capacitors (Johnson Manufacturing), one variable capacitor (Johnson Manufacturing, JMC80H85), and fixed non-magnetic inductors (Coilcraft 132 series). Fig. 2(b) shows the circuit diagram of the tuning, matching, and detuning network. MR imaging was performed on a spherical

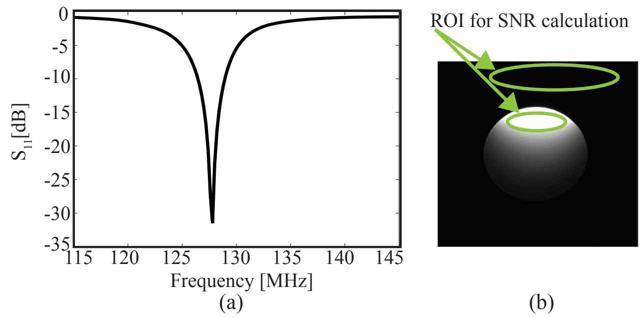

Fig. 3. (a) Measured reflection coefficients of the constructed coil. (b) MR image of the phantom

phantom. A custom-built gateway (Clinical MR Solutions, Brookfield, WI) provides integration to the 3T MRI scanner (Signa PET/MR, GE Healthcare, Waukesha, WI) and includes a BNC connection, a low-noise preamplifier, and active decoupling circuitry. MR sequence parameters included: pulse sequence= 3D SPGR, TE= 1.1 ms, TR= 3.7 ms, spatial resolution= 1x1x2 mm.

Fig. 3(a) shows the measured reflection coefficients of the coils. The measured S_{11} of the fabricated coil achieves a value of less than -30 dB at 127.8 indicating an excellent match. Fig. 3(b) shows the MR images of the phantom scanned using the 3D printed helmet coils. The region of interest for calculating the SNR, calculated using mean of the signal over standard deviation of noise method, is shown in Fig. 3(b). A high signal-to-noise ratio of 924 was present within the region of interest.

III. Discussion and Conclusion

The goal of this project was to develop a subject-specific restraint helmet integrated with an MRI coil. Using CT imaging, a non-invasive model of the head was created to inform semi-automated design of the helmet created using additive manufacturing and provide input to simulations that provide design parameters for a receive-only single-channel MRI coil. This method removes the need for invasive head post implantation and develops a subject-optimized MRI coil for the highest SNR in rapid and low-cost manner. Design and construction of the restraint helmet with an integrated multi-channel RF coil is currently underway and results of *in vivo* imaging will be presented and discussed at the symposium.

References

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