Design and 3D-Printing of MRI-Compatible Cradle for Imaging Mouse Tumors

Deborah Donohoe, BA1; Bonnie Freudinger, ME2; Alexander Sherman, BS2; Katherine Dennert, MS1; Rajeev Kumar, PhD2
1 Advocate Aurora Research Institute; 2 Medical College of Wisconsin

Background
Magnetic resonance imaging (MRI) in animal research provides a wealth of information regarding an animal’s condition without the need for dissection and is a relatively safe technique. MRI allows repeated measures at progressive time points on the same animal, thereby decreasing the number of animals needed for an experimental protocol, and does not require potentially unsafe radiation exposure to produce images.

The Advocate Aurora Research Institute neuro-oncology team uses a low-field MRI instrument designed specifically for mice with external receiver module to accept various imaging coils (ST Scout, Synaptive Medical, Toronto, Canada) (Figure 1a) to study glioblastoma multiforme tumors and treatment options in a mouse model. The instrument features a small-bore (3-cm inner diameter) imaging tunnel (Figure 1b) and plug-in, interchangeable imaging coils (Figure 1c) allowing greater flexibility and multiple scan options as compared to traditional, fixed imaging coils incorporated in the MRI imaging tunnel. Use of a non-traditional hand-made animal immobilization system, cradle, using tape to position the animal (Figure 1d) often results in undesired scan variability and inconsistencies in animal position from scan to scan. Commercially available cradles offering image & position consistency are incompatible with this imaging system and custom fabrication is cost-prohibitive.

Objective
The objective was to design and develop a cost-effective, custom, 3D-printed cradle capable of delivering consistent, repeatable images. 3D-printing has been widely used to create a variety of medical devices including custom components for MRI.

Design and Testing

Design strategy
The desired MRI-compatible cradle must meet the following requirements:

- Non-ferromagnetic material
- Secure, consistent animal positioning
- Flexibility for variations in mouse size
- Ease of use and cleaning
- Achieve consistent repeatable images
- Accommodate inhalation anesthesia
- Accommodate physiologic monitoring
- Cost effective
- Fit into 3-cm inner bore

In collaboration with the Medical College of Wisconsin Engineering Core, we determined that an open, cradle-style device (Figure 2a) incorporating stereotaxic positioning features (bite bar and ear bars) and anesthesia cone would provide the optimal animal position consistency while providing flexibility to accommodate interchangeable imaging coils without repositioning the mouse. Computer-aided design drawings (Figure 2b) were generated in Solidworks design software. The cradle was printed with 3D systems Project 3500 and Multijet printing using M3-X off-white acrylonitrile butadiene styrene-like material. Prototype was tested, design modified, new cradle printed and tested again until a suitable cradle was identified.

Testing methods
Cradle material selection and fit were evaluated prior to image testing. Quality of images with respect to clear definition and absence of electrical interference were then tested using phantom materials such as a liquid filled glass ampule and a viscous material to simulate brain tissue. (Figure 3a,b). Phantom material testing was also used to assess stability and ease of oil placement. Finally, the cradle was tested using mice to assess consistency and stabilization of body position, inhalation anesthesia delivery and ability to monitor physiologic conditions of the mouse (Figure 4a). Images produced using the hand-made cradle system were compared to images produced using the new cradle and evaluated with respect to image quality (Figure 4b,c).

Results and Discussion
Two versions of the cradle were needed: an initial prototype and a final, acceptable cradle.

Testing with the prototype confirmed the plastic resin material was non-ferromagnetic and compatible with our MRI. Although the material is not autoclavable, the material can be easily and effectively disinfected with standard cleaners such as quaternary ammonia and ethanol. The fit within the 3-cm inner bore was appropriate and allowed placement of imaging coil for the phantom phase of testing without evidence of electrical interference. When we moved to mouse-phase testing, however, we experienced difficulty in maintaining consistent anesthesia delivery. We determined a modification was needed in the anesthesia cone component. Testing was suspended until the design was modified and a new cradle was printed.

Phantom testing was repeated with the new cradle to confirm previous results and mouse testing resumed. The second cradle provided adequate anesthesia delivery, supported placement of physiologic monitoring equipment and was found to accommodate mice of a variety of sizes. Improved consistency in mouse positioning was achieved through the use ear bars and bite bar incorporated in the new cradle. Additionally, we observed improved image quality and more consistent images using the new cradle when compared images generated using the hand-made cradle (Figure 4b,c). We accredited improved image quality to the stable head positioning and improved body alignment provided by the stereotaxic features, believing these features decrease position changes that may result from spontaneous animal movement while under anesthesia. Consistent, higher resolution images will enable more reliable assessment of tumor position and size in our research application. In addition, employing the stereotaxic cradle reduced set-up time, ultimately decreasing the amount of time animals were under anesthesia.

We achieved our objective of designing and developing a cost-effective, custom, 3D-printed cradle capable of delivering consistent, repeatable images within the strict tolerances of our mouse-specific low-field MRI unit while retaining ease and flexibility of the unique interchangeable imaging coils.

As an added benefit, this project promoted cooperation between institutions and strengthened collaboration to achieve a common goal. Despite optimization required when upgrading devices, 3D printing offers multiple avenues for improving science while at the same time decreasing economic impact and serves as a valuable tool for small laboratories with limited equipment budgets.

Figure 1. Features of existing MRI unit
a. Synaptive ST MRI with external receiver module and interchangeable imaging coil (encircled in yellow). b. Imaging tunnel with 3-cm inner diameter. c. Plug-in imaging coil. d. Hand-made mouse cradle with anesthesia cone and tape (yellow arrow).

Figure 2. Prototype design images
a. Stereotaxic cradle with bite bar (orange arrows), ear bars (blue arrows), and anesthesia delivery cone (yellow arrows). b. CAD drawing of stereotaxic cradle.

Figure 3. Phantom-phase testing
Images showing clear definition and absence of electrical interference generated using phantom materials: a. liquid filled ampule b. simulated brain tissue.

Figure 4. Mouse-phase testing
a. Mouse positioned in 3D-printed cradle showing head coil placement. b. Axial MRI image of mouse head using hand made cradle and tape showing low resolution, blurry edges. c. Axial MRI image of mouse head using 3D-printed cradle showing improved resolution, defined edges.