Magnet Design Considerations for Parallel Mouse Imaging

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Introduction. Mouse imaging is a growing sector of MRI, driven by a number of large-scale phenotyping projects to track mutagenesis in mice [1,2]. One option for imaging mice is to use insertable RF coil arrays in large-bore magnets; such a technique may image up to 16 mice in parallel [3,4]. Insertable RF mouse coil arrays generally contain only a single layer of RF coils in a close-packed hex configuration, but a dedicated mouse scanner has flexibility for different geometries. Here we show that a mouse scanner with a long, narrow homogeneous volume that can accommodate 16 mice end-to-end uses less conductor mass than a comparable design with a 20-cm DSV that fits a 16 mouse RF coil array, as well as allowing possible improvements in cryostat construction, gradient strength, and RF shielding.

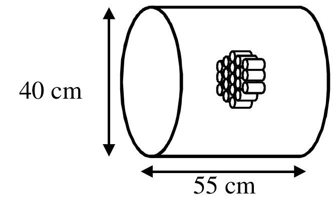

Figure 1.

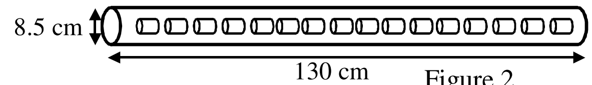

Figure 2.

Methods. We simulated two magnet designs with the given specifications using an ℓ_1-norm optimization algorithm that produces minimum-conductor-mass designs [5]. Both magnet designs satisfied a 1 ppm homogeneity constraint at 7 T. The first design is for a 40-cm-bore magnet with a 20-cm spherical ROI (Figs. 1 & 3). Such a magnet could accommodate an array of 19 mouse RF coils such as the "Millipede" array [5]. The second design is for a 8.5-cm-bore magnet with a cylindrical ROI that is 3 cm in diameter and 128 cm long (Figs. 2 & 4). This magnet could accommodate 16 mouse RF coils placed end-to-end, assuming each RF coil is 6 cm in length and allowing 2 cm of space between coils.

Results. The large-bore design is about 55 cm long and uses 8 coils. The magnet requires 4.94×10^6 Amp-turns of current; assuming the conductor is wound directly on the 40-cm diameter bore using 3 mm^2 wire with current density 1000 A/mm^2, the amount of conducting wire required is 6.2 km.

The narrow-bore design is essentially a solenoid because of the long homogeneous volume. The total length of the narrow-bore design is about 130 cm. The magnet requires 7.63×10^6 Amp-turns of current, which means a total wire length (using the same wire as above, wrapped on the 8.5-cm bore) of 2.0 km. Thus, the total amount of conductor needed to construct this magnet is over 3 times smaller than for the magnet with a spherical ROI.

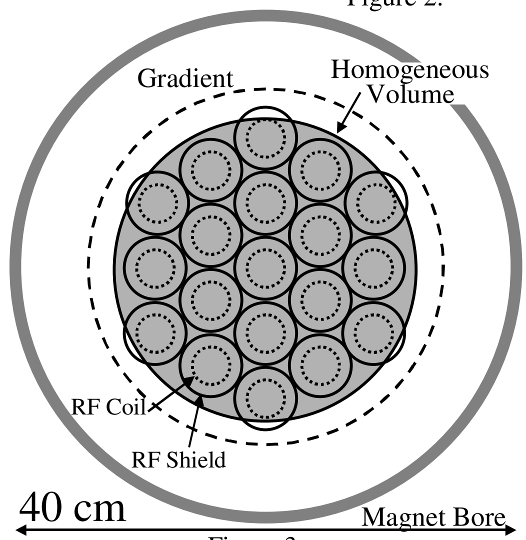

Figure 3.

Discussion. The bore of the long, narrow magnet would contain 16 short gradient coils (6 cm diameter, 8 cm length) with shielding (8.4 cm diameter) to compensate for gradient falloff. Because the gradient coil power scales as r^5, these 16 coils would use substantially less power than a single 28 cm diameter gradient coil for a larger bore magnet. The total power consumption of the 16 smaller gradient coils would be almost 140 times smaller than the power required for the larger coil, based on the radius scaling factor. The lower power requirements could enable much stronger gradients, useful for the speed and resolution desirable for mouse scanning. In addition, the gradient for each mouse could be independently controlled, making independent cardiac gating for each mouse feasible.

Insertable RF coils (4 cm diameter) would be loaded with mice and slid into the bore. The end-to-end configuration of the RF coils will require a complete cylindrical shield (5.75 cm diameter) surrounding each RF coil. The endcaps of each cylindrical shield could be attached after the mouse is inserted, leaving a small gap for connections required for the life support apparatus. The end-to-end RF coils should provide better isolation than RF coils in a hex configuration, reducing the need for postprocessing to compensate for interaction between RF channels. The gap between the RF coil and the shield will accommodate the tubing required to bring anesthesia to the mice in the bore, as well as to provide controlled air flow for temperature stability.

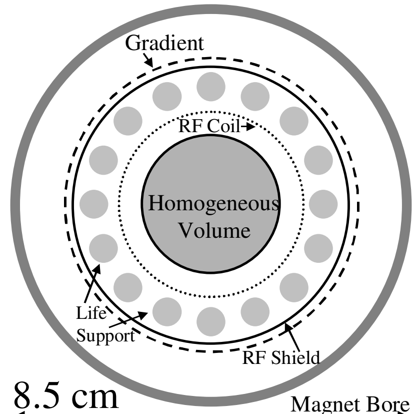

Figure 4.

In addition to reducing the construction cost of the magnet, the smaller bore magnet will allow higher field strengths to be reached much more easily. Cryostat design can be much simpler because stresses due to high field, which scale with the bore radius, will be greatly reduced. Cryogen boil-off rates will also be slower due to the smaller surface area of the cryostat.

In conclusion, we have found that a magnet with a long, narrow homogeneous region may be a desirable design for parallel imaging of mice in large-scale phenotyping projects. A long, narrow magnet uses over three times less conductor mass to construct than a comparable larger bore magnet that could also be used to image 16 mice in parallel. In addition, this configuration has considerable advantages for cryostat construction and RF shielding, as well as drastically reducing gradient power. Providing life support may be more difficult in the long configuration because the mice are not directly accessible during the scan, but temperature monitoring and anesthesia flow should still be possible.

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