Design and Fabrication of a Magnetic Resonance Stage Microscope

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Introduction Traditional high-resolution MR microscopy has depended heavily on volume coils, both gradient and RF, to maintain sensitivity[1]. However, the restricted volume available for living organisms within the imaging hardware is both a potential confound and a practical inconvenience for the experiment. A functional MR stage microscope could be applied to any small, hydrated, opaque system, including embryos, insects, marine animals, biofilms, bioreactors, cell cultures, porous media and plants. The stage microscope format provides unhindered access to the sample from above, encouraging the future integration of optical imaging equipment with MR microscopy. We describe here the development of the necessary hardware for magnetic resonance microscope design analogous to an inverted stage microscope which addresses these limitations. The development of this microscope parallels revived interest in the use of uniplanar gradient sets to improve gradient efficiency for localized cardiac imaging[2]. The stage microscope format is also applicable to larger organisms where MRM of superficial structures is of interest.

Methods The stage microscope design described here consists of three main components: (1) A planar RF surface coil mounted within the sample stage, (2) A uniplanar three-axis, water-cooled gradient set and (3) A support frame for mounting within a conventional horizontal bore high-field magnet. Gradient current densities for each axis were derived using an adapted stream function target field method. Current density was modeled within a finite area using a constrained 2D spline approach. A weighted cost function was used during stream function optimization which allowed the competing influences of gradient uniformity and current efficiency to be balanced (via the parameters α and β):

$$F(\varphi) = \alpha \int_{\Omega} d\Omega \left[B_z(\varphi, x, y, z) - B_z^{\text{targ}}(\varphi, x, y, z) \right]^2 + \beta \int_{S} ds \left[\left(\frac{\partial \varphi(x,z)}{\partial x} \right)^2 + \left(\frac{\partial \varphi(x,z)}{\partial z} \right)^2 \right]_{y=0} \qquad [1]$$

Here, Ω is the surface of the ellipsoidal target volume and S is the current plane at y=0. Penalization of the stream function gradient forces current density to be placed closer to the volume of uniformity, resulting in higher efficiency gradient generation at the expense of gradient uniformity. Heat generation is a particular problem for small gradient sets, and we employ a compact water-cooled heat exchange coupled to the gradient conductor module with a high thermal-conductivity ceramic. A narrow, actively cooled air-flow gap between the gradient module and sample stage coil provides additional thermal insulation of the sample from gradient heating.

Results and Discussion: Gradient efficiency for 40mm square double layer conductors was measured at 2.2, 1.5 and 1.0G/cm/A for X, Y and Z axes respectively. Combined active water and air cooling reduced the temperature increase at the RF coil plane to less than 0.5°C for temporal mean currents up to 1A (20°C stage) or 3A (37°C stage) without additional thermostatic control. This prototype is estimated to be capable of sustaining 50A peak current. The incorporation of thermostatic control of the sample medium is planned for the next phase of development with the aim of achieving high-resolution MR microscopy of multiple living organisms, such as developing embryos and cultured tissue explants, under experimentally appropriate environmental conditions.

References: (1) Tyszka, J. M.; Fraser, S. E.; Jacobs, R. E. *Curr Opin Biotechnol* **2005**, *16*, 93. (2) Aksel, B.; Marinelli, L.; Collick, B. D.; Von Morze, C.; Bottomley, P. A.; Hardy, C. J. *Magn Reson Med* **2007**, *58*, 134.

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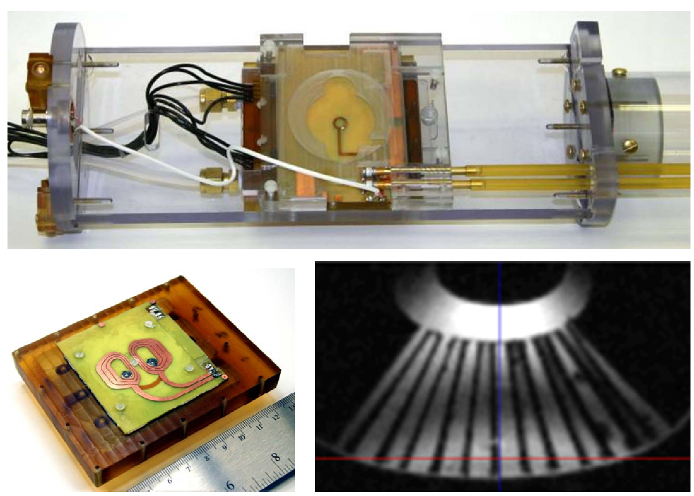

Figure 1: (a) Completed stage microscope prototype showing the sample stage, 5mm RF surface coil, and gradient wiring. (b) Gradient module with the uniplanar Y-axis conductor plane visible, mounted on the water cooled heat exchanger. (c) Uncorrected uniformity phantom image demonstrating typical convergent distortion in the XY plane.