Cardiovascular MRI in Mice In Vivo at 9.4T with a 1500 mT/m (150 Gauss/cm) Actively Shielded Gradient Coil

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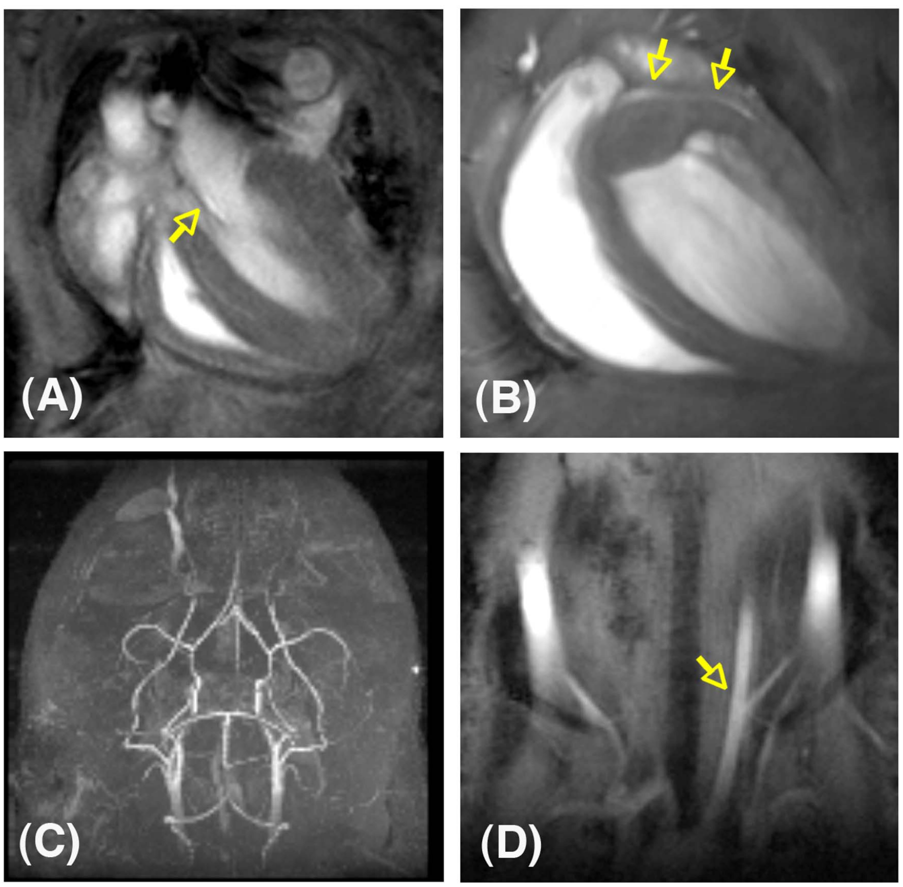
Background and Aims: The small size of the mouse heart requires cardiac MRI in mice to be performed at high field strengths, usually greater than 7 Tesla. While these high field strengths provide the opportunity for improved signal to noise, they also present several technical challenges that can severely affect image quality. These include increasing field inhomogeneity, shorter transverse relaxation times, increased susceptibility artifacts and increased spin dephasing due to motion or flow. These technical challenges often preclude the visualization of fine cardiovascular structures in mice such as valves and small vessels.

Since all of the artifacts listed above become progressively more problematic at longer echo times (TE) we aimed in this study to develop a high performing 1500 mT/m (150 Gauss/cm) gradient insert for cardiovascular MRI in mice at 9.4 T. We hypothesized that high-resolution images could be obtained with this gradient system with echo times of 1 ms or less, and that this in turn would facilitate the visualization of fine cardiac and vascular structures in mice.

Methods: The constructed gradient coil has an external diameter of 113mm and an internal diameter of 60mm, and consists of a primary coil, a shim coil and a shield coil. The primary Z-coil is a multi-turn single layer wire structure distributed anti-symmetrically about the center of the assembly and connected in series to the similar but opposite Z-coil shield. The primary X and Y coils are made up of four, four-layer quarter-coil patterns each connected in series to four double-layer quarter-coil patterns of the shield. A total of 48 individual coils were used to construct the X and Y gradients. The 7-channel shim system consists of Z0, Z2, Z3 C2, S2, ZX, and ZY and is capable of supporting 5A per channel and 1000 (C2/S2) to 2100 (Z0) Hz/cm/A. Other specifications include: Strength 1500 mT/m with rise time 100 us (300 V, 150 A), Field linearity 5% +/-, shielding > 99%, duty cycle at 1500 mT/m of 5.5 % (X), 7% (Y), 10.5% (Z).

MRI was performed with this gradient coil at 9.4 T (Bruker, Biospec) on healthy wildtype C57Bl/6 mice ranging in age from 6-12 weeks. Mice exposed to surgical ligation of the left coronary and right carotid artery were also imaged. Gradient echo images were acquired as 2D FLASH cines and as 3D angiograms, without the use of any exogenous contrast agents. ECG and respiratory gating were used in the cine images but not in the 3D angiograms.



Results: High quality images were obtained in all mice imaged. 2D cines (A, B, D) were obtained with FOV 25mm, slice 1mm, MTX 200x200 (125 um in-plane), flip angle 30, TE 1ms, Nex 4. Angiograms (Panel C) were obtained with a resolution of 150 x 120 x 120 um in a 20 minute 3D acquisition.

The short TE (1ms) of the cine images reduced motion and flow related artifacts substantially. The bright blood effect was maintained throughout the cardiac cycle and flow related spin dephasing, which is extremely prominent in mice, was not seen in either systole or during rapid ventricular filling in diastole. This allowed the anterior (arrow in panel A) and posterior mitral valve leaflets to be clearly seen throughout the cardiac cycle.

The short TE reduced motion and flow artifacts to the extent that the left coronary artery could be clearly visualized with 2D cine imaging in a 6-week old mouse (Panel B), weighing significantly < 20 g.

The 3D angiogram of the circle of Willis, shown in panel C, reveals that even medium and small sized peripheral arteries can be imaged with this gradient without the need for exogenous contrast agents. Cine MRI of the carotid artery could also be performed with excellent quality. As shown in Panel D, the left common carotid artery could be imaged with a 2D FLASH cine without the presence of motion or flow artifacts. (The right common carotid has been surgically ligated).

Conclusion: A novel 1500 mT/m actively shielded gradient coil has been constructed and used to perform cardiovascular MR imaging in mice in vivo at 9.4 Tesla. The properties of this gradient have allowed fine vascular and cardiac structures to be imaged with a new level of clarity and resolution. While gradients in the range of 400- 600 mT/m are currently thought to be adequate for cardiac MRI in mice, our experience with this gradient suggests that a gradient strength of 1000-1500 mT/m is significantly more optimal.