

## Multi-Coil Shimming of the Mouse Brain at 9.4 Tesla

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**INTRODUCTION:** The homogenization of magnetic field distributions in the mouse brain is a difficult task. Air-tissue interfaces, such as the one between the auditory cavities and the brain, create strong, localized and complex magnetic field distortions. Conventional, low order spherical harmonics shimming is able to compensate for large-scale, shallow field variations, but is not able to deal with the complexity of the multiple, localized distortions in the mouse brain.

After the introduction of the multi-coil approach for shimming the human brain [1-3], here we present the first experimental realization of the multi-coil concept in a miniaturized setup to allow improved shimming of the mouse brain at 9.4 Tesla.

**METHODS:** The multi-coil setup consisted of 24 coils (15 turns, diameter 13 mm) that were distributed in 4 rings of 6 coils each. The coils were made of copper wire and mounted on the inside of an acrylic former with an inner diameter of 32 mm. The center two rings of coils, i.e. 12 coils, were driven in the  $\pm 1$  A range; the outer two rings were driven with a maximum of  $\pm 1.9$  A. A custom-built Bolinger RF antenna was placed inside the multi-coil setup to surround the mouse head and was used for RF transmission and signal reception. Experiments were carried out on a 9.4 Tesla animal system. Field maps were calculated from seven single-echo GE images (field-of-view  $16.0 \times 16.0 \times 20.1$  mm<sup>3</sup>, matrix  $80 \times 80 \times 67$ , echo time delays 0 / 0.1 / 0.2 / 0.5 / 1.0 / 2.0 / 3.0 ms). The multi-coil shimming was applied to the whole brain or to single slices thereof (Fig. 1), and compared to the performance of zero- to third-order spherical harmonic shimming. The homogeneity of the magnetic field after shimming of 4 mice was assessed by the standard deviation and the full width at half maximum of the frequency distribution, as well as the span that included 80%, 85%, 90%, 95%, 98% and 99% of the frequency values. All field measurements, data analysis and hardware handling were done with custom-made software and methods.

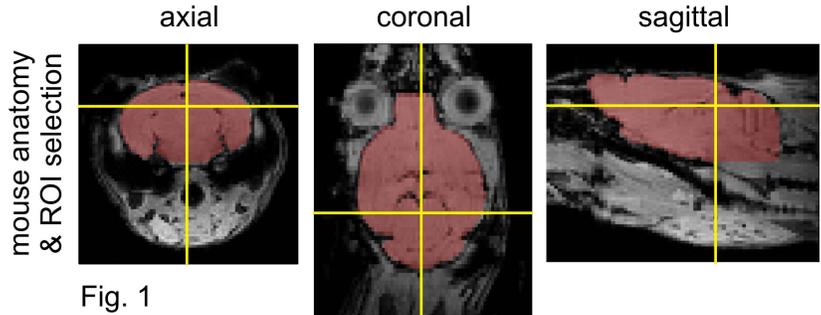


Fig. 1

**RESULTS:** The quality measures with the multi-coil approach were improved by 25-50% for whole brain shimming of the mouse brain compared to conventional zero- to third-order spherical harmonics shimming. The performances of both methods were similar for slice-specific shimming, if the spatial pattern of the magnetic field inhomogeneity was simple and spherical harmonics shimming was sufficient. In slices with strong, localized and complex distortions, however, spherical harmonics shimming performed poorly, and major improvements were achieved with the multi-coil shimming. Figure 2 shows the field distribution of the axial and coronal slices from the ROI of figure 1 after the slice-specific removal of the zero- to third-order spherical harmonic terms (left column) and after multi-coil shimming (right column). In the axial slice, the span to cover 95% of the frequency distribution was narrowed from 482 Hz to 173 Hz and the full width at half maximum of the frequency distribution was reduced from 78 Hz to 23 Hz. These improvements of 64% and 70%, respectively, not only reflect the improved suppression of high amplitude magnetic field distortions, but also demonstrate the major overall homogenization of the bulk voxels with the multi-coil shim approach.

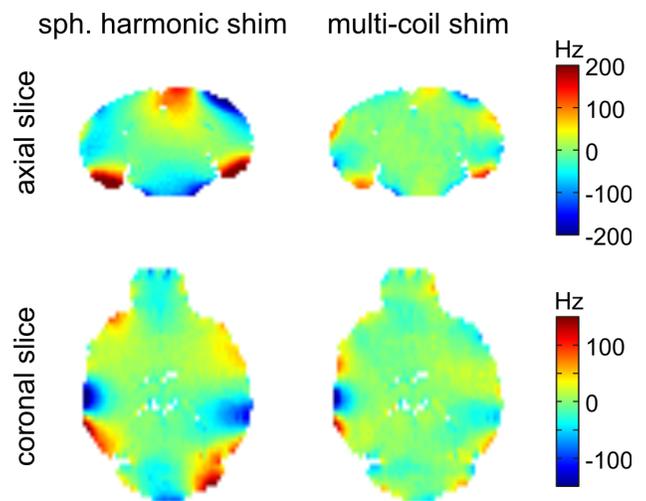


Fig. 2

**DISCUSSION:** Shim fields were generated with a set of circular coils for volume- and slice-shimming of the mouse brain at 9.4 Tesla. The array of localized coils allowed the synthesis of complex and high amplitude magnetic fields that closely resembled the magnetic field distortions in all 4 mouse brains and allowed largely improved field homogenization compared to low-order spherical harmonics shimming. A thorough calibration of the multi-coil system is considered key for the determination of all 24 coil currents from a single reference field map, i.e. multiple iterations were not necessary. Increased modeling capabilities and further shim improvements are expected from a further expansion of the coil matrix.

This research was supported by a Brown-Coxe Fellowship and NIH grants R21/R33-CA118503, R01-EB000473 and P30-NS052519  
[1] Proc. ISMRM (2009), 3079; [2] Proc. ISMRM (2009), 3081; [3] Magnetic Field Homogenization of the Human Prefrontal Cortex with a Set of Localized Electrical Coils. Magn Reson Med (2009), *in press*.