Ultra High-Order Global Shimming of the Mouse Brain using Diamagnetic and Paramagnetic Passive Shims

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Introduction

At ultra-high field, significant residual B_0 inhomogeneity remains in the mouse brain after global optimization of available room-temperature (RT) spherical harmonic shims. Previously, we presented a method for higher-order global homogenization of the mouse brain through linear optimization of distributed diamagnetic and paramagnetic shim elements.[1] It was shown that such passive shims could consistently remove higher (>3rd) order inhomogeneity in the mouse brain. However, it was also computationally demonstrated that even further improvements were possible if the shim grid was moved closer to the mouse brain and the shim composition were optimized on a per-mouse basis. Here, we present the realization of this proposed shim construction with the added consideration of localized shim elements in the animal's auditory cavities. Our results show that use of this passive shim system allows for vast improvements in global homogenization of the mouse brain.

Figure 1: Photograph of constructed passive shim assembly.

Methods

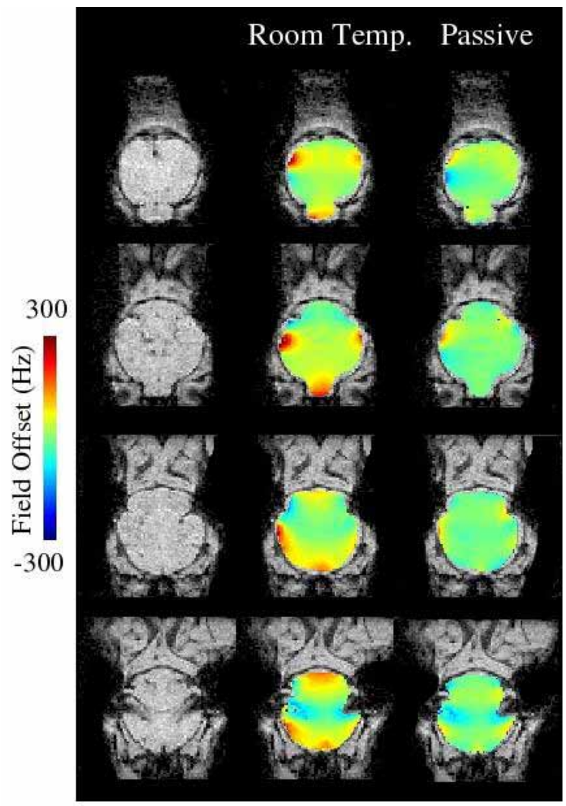
As in [1], optimization of global homogeneity was performed on C-57 BL mouse brains using zirconium (Zr, χ =+92ppm) and bismuth (Bi, χ=-166 ppm) metals. Zr foil (0.25 mm) and raw Bi chunks were acquired from Sigma Aldrich (http://www.sigmaaldrich.com). Experiments were performed on a 9.4 T Bruker small animal magnet using a custom-built volume coil. Basis shim elements 3.2 x 4.6 x 0.25 mm of Zr and 3.2 x 4.6 x 1.0 mm of Bi were again utilized. In [1], shim element locations were constructed on a 3 cm diameter 50 mL polyethylene BD-Falcon centrifuge tube. As also described in [1], the proposed improvement of this geometry included a reduced shim former diameter of 2.5 cm. A shim former was machined out of acrylic stock to these specifications. To allow for populating of the shim on an animal-specific basis, the mouse bed was removable and a 'notched sleeve' principle implemented. In this approach, a sleeve was used to hold all shims in place, but was rotated to allow for populating of individual positions on the shim grid. Figure 1 provides a photograph of this final construction.

Previously [1], shim element induction fields, or 'responses', were empirically measured for each position in the shim grid. Such a method is highly susceptible to the spatial noise of magnetic field map acquisitions. In this implementation, we now utilize rapid magnetostatic solutions of input susceptibility distributions [2][3][4] to computationally and noiselessly characterize the shim assembly. This drastically improves both the stack composition calibration procedure and the linear inversion of the grid compositions.

Localized auditory shims consisted of 2 x 2 x 1 mm Bi shim elements, which behaved roughly as point-dipole induction field sources. These auditory shims acted to directly counter-act the net paramagnetic dipole induced by the auditory cavities. Any imprecision in these local shims was easily compensated by the global passive shim distribution.

Results and Discussion

Diagnostic magnetic field maps were calculated from 5 gradient-echo images acquired with differing echo times of TE = 4 ms + [0.33,1.0,3.0,6.0] ms and TR = 10 ms. Images were collected over 24 0.5 mm coronal slices with a 2.0 cm x 2.0 cm FOV and 80 x 80 data-matrix. Individual phase images were unwrapped through temporal extrapolation. Maps were collected under a) whole-brain least-squares optimized second-order RT shim settings (optimal 3rd order settings were roughly 10x the available amplitudes) and b) combined RT and passive shim settings. Figure 2 presents diagnostic field maps over 4 slices. The improvements in residual homogeneity through use of the passive shim system are clear. Particularly near the periphery of the brain, where significant higher-order inhomogeneity is encountered, do we find drastically increased homogenization capabilities of the passive shim system. Homogeneity improvements were further quantified through absolute mean and 90th percentile frequency offsets over the entire brain. The optimal RT shim setting resulted in mean and 90th percentile absolute offsets of 49.3 and 105.2 Hz, while use of the passive shim decreased these values to 23.7 and 54.0 Hz.



	Room Temp.	Passive
Mean Offset (Hz)	49.3	23.7
90th Percentile (Hz)	105.2	54.0

Figure 2: Measured field map analysis of residual inhomogeneity in the mouse brain after RT shim optimization and combined RT and passive shim optimization. Mean and 90th percentile absolute frequency offsets are also listed for each shim setting

Acknowledgments and References

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