A single-axis composite shim coil insert for spectroscopy in the medial temporal lobe of the human brain

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Introduction: High field magnetic resonance imaging (MRI) and spectroscopy (MRS) suffer from large B_0 inhomogeneities due to the magnetic susceptibility differences between tissues, bone, and air, causing artifacts in MRI images and line broadening in MR spectra. These field inhomogeneities can be divided into two types: relatively large inhomogeneities with minimal variation between subjects, and smaller, subject specific inhomogeneities. In this abstract we propose that very efficient, short, single-axis composite shim coils be designed to compensate for the largest, most significant inhomogeneities that are approximately consistent between subjects, while system shims be used to fine-tune the field on a sample specific basis. Optimal performance would be achieved by designing a separate composite coil for each specific imaging region. For example, separate coils could be designed for the frontal, temporal, parietal or occipital lobes of the human brain, and these insert shim coils would be switched into and out-of the scanner on a study-specific basis. Each coil would require less power and occupy less space than a set of general purpose, high order shims. We demonstrate the efficacy of our shimming method with a composite shim coil designed using a boundary element method (BEM) [1], for correcting the field inhomogeneity over the medial temporal lobe of the human brain, where the presence of air causes significant field inhomogeneities. Reduction of the field inhomogeneity in this region of the brain will allow for higher resolution MR spectroscopy of the hippocampi, possibly facilitating diagnosis of Alzheimer's disease and other neuro-degenerative diseases via quantitative measurement of specific metabolite concentrations.

Methods: The BEM relies on discretization of the surface current density into a weighted set of basis functions over the elements of a mesh. The magnetic field, power, and torque of the coil are derived in terms of the unknown current density, and used to create a functional. The functional is used to find the current density, with optimal power and torque properties, that yields the desired magnetic field.

Field maps of 10 normal human brains were derived using the RASTAMAP algorithm [2] from image data acquired with a 4T Varian MRI system. In order to obtain unshimmed field maps, the effect of the system shims was removed by subtracting the shim fields from the field maps. Linear (gradient) shim fields were not subtracted. The field maps were averaged, and an offset, 6 cm diameter spherical volume (DSV) region of interest (ROI) encompassing the medial temporal lobes was identified (Fig. 2). A cylindrical surface mesh was created with 8300 elements, a diameter of 40 cm, and a length of 30 cm. The resulting composite shim coil would be used in an insert mode (Fig. 1), similar to the implementation of an insert gradient system. Our implementation of the BEM was accomplished in Matlab and C++, and using this tool we found the current density of the composite coil capable of correcting the averaged field inhomogeneity in the DSV.

The discrete wire pattern of the composite coil was obtained using a 3D algorithm [1]. A Bio-Savart elemental equation was used to calculate the shim field. The optimal shim current was calculated using linear least squares fitting to the profile of the averaged field map. The final field profile achievable with the composite shim was determined for each subject and compared against the best profile attainable using the existing whole-body shims. Histograms of the field inhomogeneities for each subject were calculated and lorentzian line-shapes were fit to the histograms in order to determine the line width (full-width at half-maximum). Simulated shimming was repeated with misalignments of the subject within the coil to test the accuracy with which subjects must be positioned.

Results and Discussion: The wire pattern of the final coil is shown in Fig. 3, while three slices through the field profiles created by the coil are shown in Fig. 4. For each slice, the composite shim alone was found to reduce the field inhomogeneity by a factor of 2 as compared to that obtained using the system shims. The line-width for the entire 6 cm DSV was decreased from 6.31±0.14 Hz to 3.61±0.15 Hz. This coil, constructed with 1 mm diameter wire and 60 windings, would have an inductance of 950 µT, a resistance of 1.65 Ω, and would require a current of 0.25 A to produce the results shown. The power dissipated would be 100 mW and therefore water cooling would not be required. A key question is how sensitive this customized shim coil would be to small differences in subject positioning within the coil. The results in figure 6 show that a single subject can be positioned over a region approximately ± 1 cm away from optimal in the x-direction without any significant reduction in uniformity (similar results were obtained for displacements in the y and z directions).

These results predict that an insertable, composite coil would allow significant improvements in shimming the medial temporal lobe of the brain with dramatically less power than the system shims. Further improvement in homogeneity is expected when system shims are used in combination with the composite shim. Our intention is to develop a series of coil inserts, each customized to a different region of the brain or other anatomical area. These coils would be inserted into the scanner bore as necessary for different studies, acting similar to an insert gradient system, but operating at drastically less power. We hypothesize that this approach will enable a significant step forward for in vivo shimming at the highest magnetic fields.

References, Acknowledgements: [1] Pool and Bowtell, CMR Part B. 31:162-175 (2007). [2] Klassen and Menon, MRM 51:881-887 (2004). (Funding from 1 R01 MH080913 NIH/NIMH)

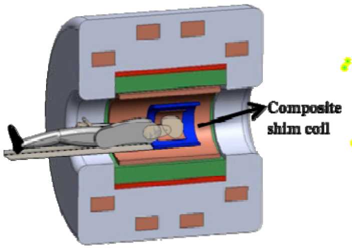

Fig. 1 Cross-sectional schematic view of the composite shim coil (blue) within an MRI system

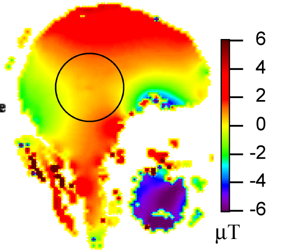

Fig. 2 A saggital slice of the field inhomogeneity of the head with shimming subtracted. The circle shows the location of the DSV and encloses the medial temporal lobes.

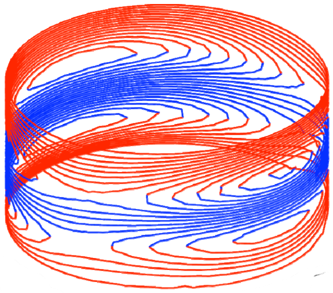

Fig. 3 The composite coil with a diameter of 40 cm and a length of 30 cm. The number of windings was reduced for clarity.

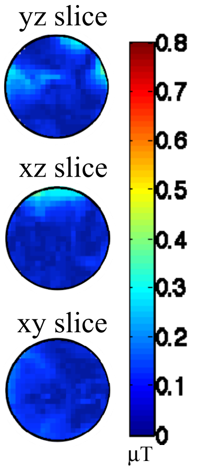

Fig. 4 Planar slices of the field inhomogeneity through the centre of the DSV when our simulated composite was used.

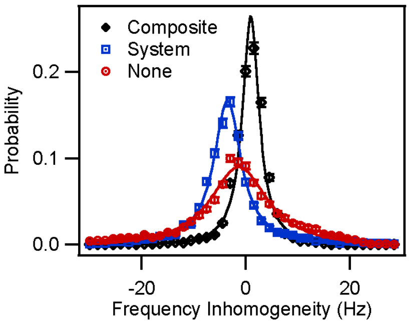

Fig. 5 Histograms with Lorentzian fits of the field inhomogeneity inside the DSV when our composite shims (◇), existing system's whole-body shims (☐) and no shims were used (○).

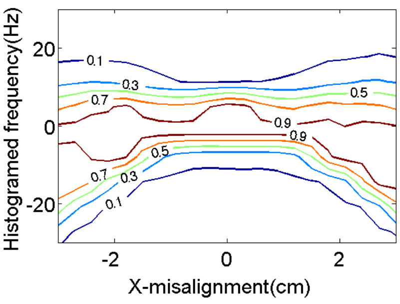

Fig. 6 Histogrammed frequency inhomogeneity within the DSV as a function of misalignment in the *x*-direction.