Local Ferroshims Using Office Copier Toner

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INTRODUCTION

fMRI studies performed using GR-EPI sequences are sensitive to local magnetic field variations caused by air-tissue-bone interfaces, resulting in image distortion in the phase encoding direction and signal dropout from intravoxel dephasing. Variations that are on a distance scale too small to be corrected using conventional whole body current shims were the subject of detailed analysis in Ref. 1. It was concluded that at least nine additional higher order shim polynomials are required to shim a human head. As an alternative to current shims, a passive ferroshim insert was made by gluing 720 nickel elements to the surface of a Mylar foil that was later placed inside a local head gradient coil. The improvement in magnetic field uniformity was apparent, but the construction itself was laborious and required about a week. In this study, we present a new method to construct a high order ferroshim matrix in an overall time of an hour or less.

METHODS

All studies were carried out on a 3 T BIOSPEC 30/60 Bruker scanner equipped with a homemade balanced torque three-axis local head gradient coil (2) and an end capped bandpass birdcage rf head coil. Data acquisition was done on an SGI Challenge 10000 workstation equipped with Pentek 16 bit A/D converters. In the first step, an automatic 3D shimming was performed using the method described in Ref. 3. Raw data from this procedure was saved and fed to a program that produced a set of Postscript files used to print a ferroshim matrix on paper using an office copier. We found that the toner of copy/print cartridges 113R273 used in our office printer Xerox Document Centre 230ST is magnetic and well suited for production of ferroshim inserts. A two-sided rectangular 38x31 mm block over-printed 10 times weighs about 160 mg and is equivalent to 140 mg of Ni. The shimming program itself, in the first step, decomposes the magnetic field inside the head into a set of dipole fields placed on the surface of a cylinder 290 mm in diameter and 372 mm long. Weighted least squares singular value decomposition is used to fit the field, which is the most time-consuming step. The solution gives positive and negative values for dipoles (S_i). Negative values are unacceptable for ferroshims. This problem can be solved by adding a uniform field produced by all positive dipoles, which cancels the negative values to zero. This is equivalent to a resonance frequency shift. It is not the most effective method, since it adds more mass to the edges of the cylinder. Instead, all scanner shimming polynomials, including a constant field, were decomposed to a set of dipole fields D_{ij}, where i counts dipoles and j counts polynomials, and used to solve the problem: $P_i = S_i + \sum D_{ij} \cdot X_j \geq 0$ where the $\sum P_i$ is the minimum. The simplex method of linear programming was used to calculate the L1 solution for positive values of ferro elements P_i. The magnetic field produced by such a shim insert is not uniform, but can be easily corrected by standard 3D automatic shimming as in the first step.

RESULTS

Several shimming inserts were tried for both a phantom and a human head. Initially we used 24 dipoles circumferencially and 12 dipoles along Z. The magnetic field map contained 29x29x29 points over a 20cm cube. For the phantom, the map was smoothed and every second point was used, yielding 700 usable pixels on average. Ten seconds on a 1 GHz computer running Linux were required to produce the set of Postscript files used to print four quadrants of the shimming mask on four 11x17 inch pages. Ten overprints were used to produce the final shim matrix. When all usable pixels were used, the computation time increased to 6 minutes. Fig. 1b shows an EPI image of the head with a tagging grid for these conditions. The procedure was still fast, but improvement along Z was inadequate. Use of 21 elements along Z gave better results, but computation time increased to 26 minutes. Three pages were used for a single quadrant with 10 overprints each. Fig. 2 shows a phantom for this shim matrix.

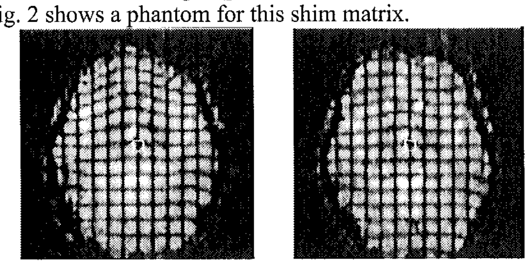

Fig. 1. a) standard shim b) ferroshim

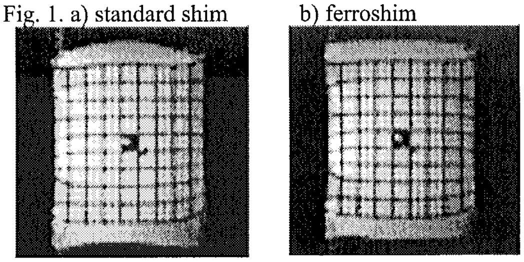

Fig. 2. a) standard shim b) ferroshim

DISCUSSION

The process of creating ferroshim inserts is robust, but very dependent on the cartridge toner contents. For a specific cartridge, the deposition was within 5% of the amount desired and did not change over a few days. Our only experience with another cartridge gave a 40% difference in mass deposition and 20% in magnetic media contents. For that reason the ferroshim program contains a normalization factor determined experimentally.

REFERENCES

1. Jesmanowicz, A., Starewicz, P., Hyde, J.S. *Proc. 8th ISMRM,* 1378, 2000.
2. Wong, E.C., Bandettini, P.A., Hyde, J.S. *Proc. 11th SMRM,* 105, 1992.
3. Jesmanowicz, A., Hyde, J.S. *Proc. 5th ISMRM*, 1983, 1997.