Can a generalized passive shimming array improve field homogeneity for human brain imaging at 7 T?

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Introduction

Static magnetic field homogeneities negatively affect image quality, in particular at high magnetic field strength. For human brain imaging, predominant sources of such inhomogeneities are the nasal cavity and ear canals. With the current technology, active shim coils cannot adequately compensate for these spatial field perturbations. Passive shimming has been previously demonstrated in animals [1] and locally in humans [2]. Whole-head passive shimming, as described in [1,3] on a per-subject basis is not practically feasible in human imaging. However, since head shape and its placement in our tight-fitting coil arrays are fairly constant, we investigated the feasibility of generalized passive shimming based on a cylindrical array of ferrous particles, placed in between the transmit and receive coil array, for improved shimming in human brain imaging at 7 T.

Materials and Methods

All measurements were conducted on a GE (Milwaukee, WI) Signa 7 T whole body MRI scanner, with a 32-channel receive-only detector array (Nova Medical, Wilmington, MA) and Nova transmit coil. Post-shimming field maps from existing normal-volunteer studies (n=34), routinely acquired for higher-order shimming (3D EPI: TR=1 s; TE=20/30 ms; FOV=24x18x12 cm³; matrix=64x48x32), were used. The mean field map and standard error over the 34 volunteers (used as weighting factor in fitting) were computed (e.g. Fig. 1). Given the large diameter (28 cm) of the defined grid, solely paramagnetic elements (iron) can be used in practice. Constrained least square fitting was used to determine the iron distribution on a grid of 512 evenly spaced elements (16 rings of 32 elements on a cylinder of 28 cm diameter and 24 cm length along z), including regressors for B_0 and 1st- and 2nd-order shim terms (9 regressors). To investigate the theoretically achievable performance, the fit was repeated allowing for diamagnetic materials as well (bipolar fit). To quantify the spatial field perturbation, multi-echo GRE experiments (FOV=24×18×19.2 cm³; matrix=256×96×24; TR=1 s; TE=7.8/12.9 ms) were performed with and without a small ferrous element (a 25.3 mg, 1 cm^2 section of 25-µm thick steel shim stock (Lyon Industries, South Eglin, IL)) placed at 16.5 cm from magnet isocenter (perpendicular to B_0).

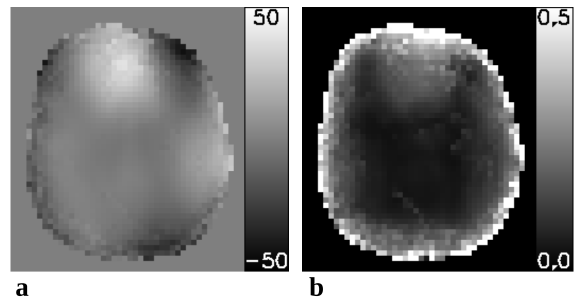

Figure 1: Example slice of the mean field map (a) and standard error (b) over 34 volunteers (in Hz).

Results

Fig. 1 shows an example slice of the mean field map and its standard error over 34 volunteers. Histograms of the field distribution in the mean map (black) and the mean map after subtraction of the calculated field for the paramagnetic-only fit (green) are shown in Fig. 2. The paramagnetic-only fit yielded a very sparse distribution of particles (only 10 non-zero particles) with a maximum particle size corresponding to 212 mg of iron. Fitting reduced the frequency range that comprises 80% of the voxels to 68.1% of that of the uncorrected data. The fit result was subsequently used to correct the original phase data on a volunteer-by-volunteer basis. This reduced frequency range comprising 80% of the voxels to 88.1±7.3% of the uncorrected data. Correction with the bipolar fit result yielded 75.6±10.2%, whereas the ideal correction (using the mean phase map) yielded 73.4±10.8%.

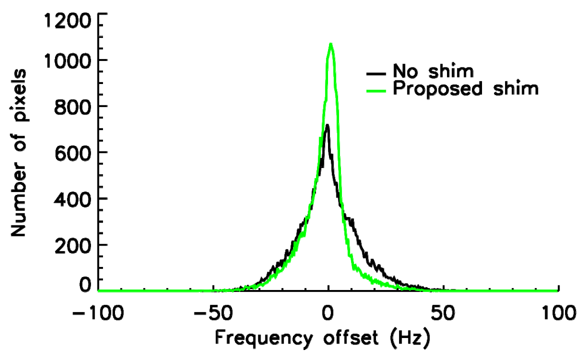

Figure 2: Field distribution histogram without (black) and with (green) the proposed paramagnetic-only passive shimming grid.

Discussion

Preliminary results show that the use of a single shim array for passive shimming of human volunteer is feasible, albeit performance is limited. Only 12% improvement was achieved on average for 34 volunteers without deterioration in any. A tighter-fitting grid, which would allow diamagnetic shims as well, could improve performance to approximately 25%. Quality of the 3D EPI data, normally used for higher-order shimming, was poor. We are currently acquiring GRE data specifically for this project to improve field map quality, but these preliminary data suggest that volunteer-to-volunteer variability limits the potential benefit of a generalized passive shimming solution.

References

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