Slice Shimming Method for Reduction of Susceptibility Artifacts with PatLoc System

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Introduction

A homogeneous magnetic field is critical to ensure high quality magnetic resonance imaging and spectroscopic experiments. Practically this is usually achieved by shim coils, each of which has an independent driving current to generate a complimentary magnetic field to compensate the field inhomogeneity. These usually include three first order orthogonal linear shim coils in the x-, y-, and z-directions and five higher order zy, zx, xy, z^2, and x^2-y^2 shim coils [1]. However, such a setup is optimal for tuning the magnetic field across a large FOV comparable to the bore size of the magnet. Localized field inhomogeneity is difficult to be compensated by such global shim coils. For example, in echo-planar imaging of human brain, strong susceptibility artifacts are usually localized to the tissue-air space around bi-temporal lobe and frontal lobe. These regions brought noticeable image distortion artifacts and strong signal loss in both imaging and spectroscopic measurements.

Recently the Parallel imaging technique using localized gradients (PatLoc) has been proposed to provide generalized spatial encoding [2]. In this work, we attempt to apply the PatLoc system to achieve a better shimming and improved the field homogeneity. Specifically, we used the surface gradient coils in the 8-channel PatLoc system as the shim coils to reduce the distortion of brain echo-planar imaging.

Methods

Localized spatial encoding magnetic field (SEMs) in the PatLoc allows "slice shimming". Instead of improving the field homogeneity across all image voxels globally, we aim at achieving more localized shimming in a single slice by independently manipulating driving currents in each channel of the PatLoc system (Figure 1).

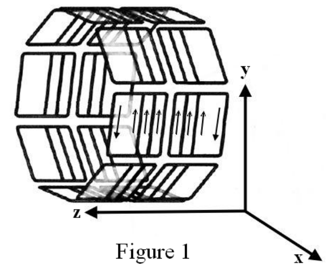

Figure 1

Provided with eight SEMs in the PatLoc system, we used the least-squares method (LSM) to derive the optimal driving currents α_i (i=1…8) in order to reduce the magnetic field distortion. Consider the slice has n-by-n voxels, we write a linear equation $\mathbf{b}=\mathbf{A}\alpha$, where the vector **b** indicates the values of the off-resonance field map and the vector $\mathbf{a}_i$ represents the SEM generated from unit current in PatLoc channel i. Provided with a spatial mask **r**, we can estimate α using the weighted least squares solution: $\alpha=(\mathbf{A}^T\mathbf{R}^2\mathbf{A})^{-1}\mathbf{A}^T\mathbf{R}^2\mathbf{b}$, where **R** is a diagonal matrix with elements from **r**. Field compensation is achieved by driving each channel of the PatLoc system with current intensity $-\alpha_i$.

The simulation used the human brain echo-planar imaging data acquired from a 3T MRI system. Axial slice EPI was acquired with the following parameters (Matrix size=96×96, TR=2 s, TE=42.3 ms, flip angle=90º, bandwidth=100 kHz, slice thickness =4 mm, FOV=240 mm × 240 mm, phase-encoding direction: anterior-posterior). We also collected gradient echo images at the same slice with variable TEs (TE=42.3 ms to 56.588 ms, step in 0.752 ms) to estimate the field map [3]. Given the relative position of the PatLoc system, we calculated the theoretical SEMs in the FOV. A spatial mask covering the brain was used to create the matrix **R** in order to specifically minimize the field inhomogeneity within the brain. All calculations are done using MatLab (Mathworks, Natick, MA, USA).

Results and Discussion

The simulation results at two different slices are illustrated in Figure 2 and Figure 3. Strong field inhomogeneity was found around the temporal lobe and the frontal lobe (maximal 0.81 ppm). After correction, we improved field inhomogeneity: the peak-to-peak off-resonance was reduced from 0.70 ppm to 0.29 ppm in Figure 2, and from 1.13 ppm to 1.12 ppm in Figure 3. Specifically, the inhomogeneity at temporal lobe and frontal lobe was respectively reduced from 0.25 ppm to 0.20 ppm and from 0.60 ppm to 0.11 ppm in Figure 2, and respectively reduced from 0.261 ppm to 0.256 ppm and from 0.81 ppm to 0.58 ppm in Figure 3.

Here we demonstrate the feasibility of slice shimming using the PatLoc system to improve the local magnetic field homogeneity. If the magnetic field fluctuates drastically across voxels, a spatial mask can be tailored to shim a local area of interest. Although EPI image distortion arisen from field inhomogeneity can be effectively achieved by post processing, spectroscopic measurements contaminated by field inhomogeneity must be correct before measurements. Our method can provide good local shimming to reduce susceptibility artifacts in both MR imaging and spectroscopic measurements.

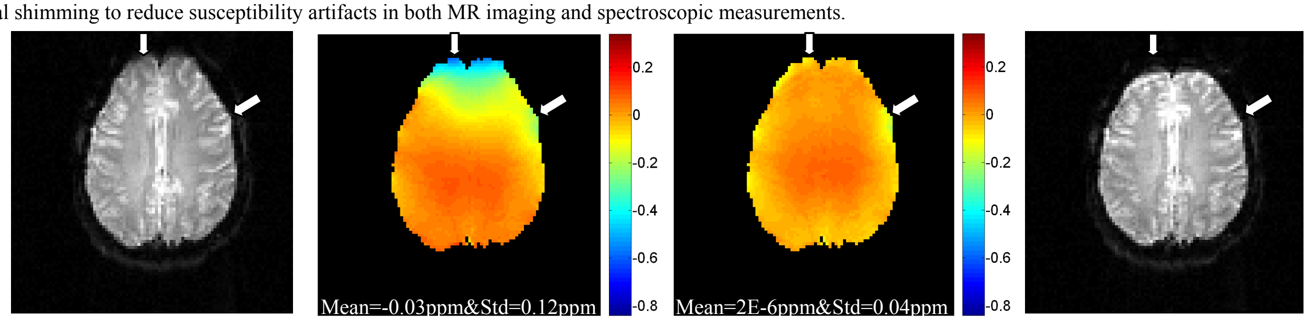

Fig 2 (a) Distorted EPI (b) The original field map (c) The field map after correction (d) corrected EPI

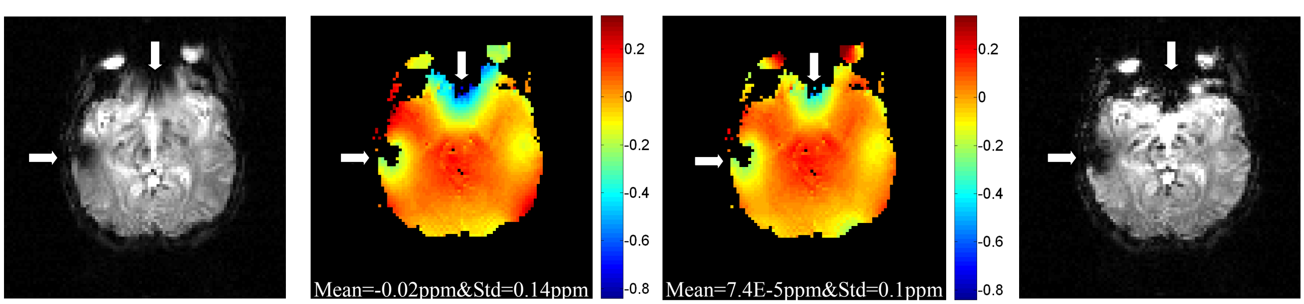

Fig 3 (a) Distorted EPI (b) The original field map (c) The field map after correction (d) corrected EPI

References

[1].Web, P., et al., Magn Reson Med, 1991-20. [2].Henning, J., et al., Magn Reson Mater Phy, 2008-21. [3].Reber, P., et al., Magn Reson Med, 1998-39.