B0 map reconstruction via exploiting active shimming information and its application on distortion correction for EPI

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TARGET AUDIENCE: Researchers with an interest in B0 mapping and distortion correction for EPI.

PURPOSE:

On many modern MRI scanners, active shimming is provided for subject-by-subject corrections to the static field inhomogeneity. During the active shimming procedure, a 3D double-echo gradient echo sequence acquires volumetric data corresponding to the region of interest, which is used to estimate the unwanted harmonics. Then the current for each shim coil is calculated and applied to remove the unwanted harmonics [1]. However, field inhomogeneity cannot be fully compensated due to the limited shimming orders. The field map after active shimming is still required for some applications with a high demand of B0 homogeneity, e.g. EPI distortion correction [2]. The field mapping is normally achieved via evaluating the phase evolution of multi-echo gradient echo measurements, which is acquired separately from routine scans with additional time. In this study, we propose a B0 mapping method which reconstructs the field map via exploiting the information provided by active shimming. We demonstrate the application of the proposed B0 mapping method on the EPI distortion correction.

METHODS:

When active shimming is applied, the static magnetic field ΔB is a superposition of the original inhomogeneous field $\Delta B_{\text{original}}$ and the compensating field $B_{\text{compensating}}$ generated by shimming currents, given by $\Delta B = \Delta B_{\text{original}} + B_{\text{compensating}}$. ΔB can be reconstructed by calculating $\Delta B_{\text{original}}$ and $B_{\text{compensating}}$ separately, which can be described as follows.

During the active shimming procedure, the volumetric data used to estimate the shim current are generally acquired by 3D low resolution double-echo gradient echo sequence. The original field map can be estimated using: $\Delta B_{\text{original}} = \Delta\phi / (\gamma \Delta TE)$, where ΔTE is the TE difference of these two echoes and $\Delta\phi$ is the phase difference of corresponding images. Note that in this step a region growing based phase unwrapping method [3] is used to remove phase wraps in the phase difference image $\Delta\phi$. The compensating field $B_{\text{compensating}}$ is generated by the currents in shimming coils which are designed to produce different orders of spherical harmonics. $B_{\text{compensating}}$ can be calculated in the spherical coordinated system:

$$B_{compensating}(r,\theta,\phi) = \sum_{n=0}^{\infty}\sum_{m=0}^{n}\left(\frac{r}{R_0}\right)^n \left(A_n^m I_n^m \cos(m\phi) + B_n^m I_n^m \sin(m\phi)\right) P_n^m(\cos\theta) \; ,$$

where A_n^m and B_n^m are coefficients related to sensitivities of the (m ,n) order shimming coil and I_n^m is the corresponding shimming current. The reconstructed ΔB then can be used for the EPI distortion correction. For each slice acquired by EPI sequence, a 2D field map with the same orientation, resolution and position is interpolated from the 3D field map. For each pixel the shift in phase-encoding direction is given by: $\Delta n_{\text{PE}} = \gamma \Delta B \cdot T_{\text{esp}} \cdot N_{\text{PE}}$, where T_{esp} is the echo spacing of EPI sequence and N_{PE} is the matrix size in the phase-encoding direction, which can be used for the distortion correction consequently. The described field map reconstruction and distortion correction method were implemented using Siemens IDEA.

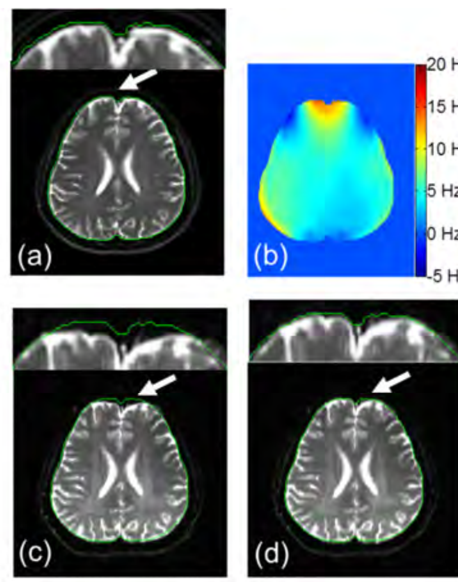

FIG. 1. *(a)TSE image without distortion; (b) field map; (c) EPI image before distortion correction; (d)EPI image after distortion correction.*

EXPERIMENTS AND RESULTS:

The study was performed on a commercial 3T scanner (MAGNETOM Spectra, Siemens Healthcare). Experimental data were obtained on a healthy volunteer using diffusion-weighted (DW) EPI sequence with active shimming. The imaging parameters were as follows: TE/TR = 111/7000 ms, readout bandwidth = 900 Hz/Pixel, FOV = 22 x 22 cm^2, Matrix = 192 x 192, b = 0, 1000 s/mm^2, diffusion mode = 3-Scan Trace, diffusion scheme = bipolar, average = 2. Generalized auto-calibrating partially parallel acquisition (GRAPPA) was used for parallel imaging with acceleration factor of 2. After data collection, the proposed B0 map reconstruction and distortion correction was performed online.

Fig. 1 shows images of one slice containing the frontal lobe region. Fig. 1a shows a T2-weighted TSE image. Fig. 1b shows the corresponding field map of the same slice, which was reconstructed using the proposed method. Fig. 1c and d show the DW-EPI images with b = 0 with and without the distortion correction. The contours generated from TSE images with same slice position are overlaid on Fig. 1c and d. It notes that there are obvious distortions in the frontal lobe, which has been substantially improved in the image using the proposed method (Fig. 1d).

DISCUSSION AND CONCLUSION:

At present B0 mapping normally relies on additional acquisition, which is executed in addition to the routine MRI applications and increase the scan time. We have demonstrated that the proposed B0 reconstruction method can be successfully applied to the EPI distortion correction, whilst maintaining the same acquisition time.

REFERENCES:

[1] Gretter R. Magn Reson Med. 1993 29 :804-811
[2] Jezzard P et al. et al. Magn Reson Med 52:1156-1166
[3] Zhou K et al. Magn Reson Med 62:1085-1090