Efficient EPI distortion correction using non-phase encoded reference data

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Introduction

Diffusion weighted (DW) EPI may improve tumor characterization in oncology body MRI beyond T2W-TSE sequences. However, B0 inhomogeneities cause phase accumulation during EPI acquisition and result in image distortions. This is especially true at high fields and large field-of-views. Image distortions may hamper comparison of DW images with T2W-TSE. Several correction methods exist like B0 field mapping [3], point spread function (PSF) mapping [4], and reversed gradient polarity method [2] optionally extended with registration or model function fitting. In practice, additional scan time, misalignment due to differences in breath-hold states and/or significant computational time, complicate implementation of a number of those approaches, especially for abdomen MRI. Here we implement and evaluate a correction method based on the non-phase encoded reference acquisition as described in [1]. It reuses the EPI reference data measured for Nyquist ghost removal, so does not require additional calibration scans. We show that this method provides good global correction in the presence of smoothly varying B0 field offsets.

Methods

The phase correction is achieved by subtracting the phase of the non-phase encoded reference echoes (navigators) from the phase of the normal data.
EPI reference data is measured at the start of the scan using the same sequence as the scan itself but omitting the phase encode gradient, thus measuring the K_y=0 profile several times. The reference data is then Fourier-transformed along the K_x direction. Elimination of the fat fraction in the reference data is crucial and is done by spectral fat suppression. In a first step, the reference data is used for the standard Nyquist ghost correction (aligment of even and odd echoes). In a second step, a modulus weighted fit along time provides the phase evolution per X-location. This phase evolution is calculated using combined data from all channels to prevent removal of the coil phase required for SENSE unfolding. A smoothing operation further assures that the phase is slowly varying along the X-direction to avoid discontinuities in the reconstructed images. In addition, the phase deviation is limited to a maximum value (typically 1ppm) to prevent global over-correction due to strong local field phase variations.
All experiments were performed using a 16-channel Torso coil on a Philips 3.0T TX clinical scanner with modified reconstruction software implementing the per-echo phase correction. Parameters of the DW-EPI sequence, for both the phantom images and the volunteer images: 25 axial slices covering 200 mm, FOV: 375 mm (RL) x 300 mm (AP), voxel size 3mm x 3mm, TE/TR = 28/1933 ms, 3 measurements, SENSE factor 2, 70% partial fourier, 37 EPI readouts, BW k_x/k_y 3657/44 Hz /pixel, SPIR fat suppression, diffusion b = 20 s/mm^2, scan time 19s (single breath-hold).
Anatomical reference images were acquired using a T2W-TSE sequence: 25 axial slices covering 200 mm, FOV: 375 mm (RL) x 300 mm (AP), voxel size 1.3mm x 1.6mm, TE/TR = 80/1250 ms, SENSE factor 2, 60% partial fourier, 58 TSE readouts, BW k_x = 192 Hz /pixel, scan time 50s (3 breath-holds).


a b c

Figure 1: DW-SE-EPI images of the manufacturer's head phantom (25cm diameter), (a) without correction and (b) with echo-phase correction using the non phase-encoded navigator echoes. (c) Reference image (SE).

Results

Figure 1 shows results of the proposed phase navigator distortion correction method on a phantom. The overall distortion is improved in Fig. 1b compared to Fig. 1a. Application of the phase correction better aligns the DW-EPI image to the non-EPI reference image Fig. 1c.
Figure 2 shows the results of the phase navigator correction method for DW-EPI in abdomen. Here we see that the overall tilt of the non-corrected image (Fig. 2a) is improved on the phase corrected image (Fig. 2b). The effectiveness of the correction can be appreciated even better from the zoomed images. A line is added, as guide, on the T2W-TSE image (Fig. 2f) indicating the fat/muscle interface. It is copied to the DW-EPI images to show the mismatch between the non-corrected image (Fig. 2d) and the reference, and to show the better correspondence of the phase corrected image (Fig. 2e) with the reference.

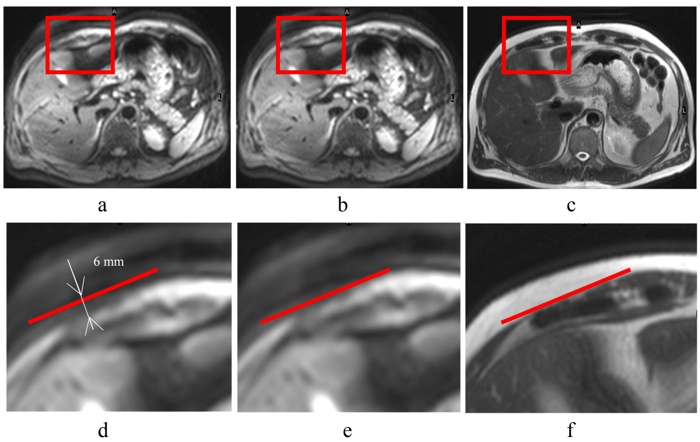

Figure 2: 3T DW-EPI abdominal images demonstrating the effect of the phase navigator distortion correction method: (a) standard reconstruction and zoomed view (d); (b) phase corrected reconstruction and zoomed view (e); (c) and (f) show the (zoomed) T2W-TSE reference image at the same location. A line in the zoomed T2W-TSE image indicates the fat/muscle interface and is propagated to the other zoomed images. It demonstrates a better alignment of the phase corrected image with the T2W-TSE.

Discussion

Phase correction using the non phase-encoded reference data is able to improve the geometric accuracy of EPI images as demonstrated in the previous images. Application of the phase correction re-aligns the image in Fig. 2a to the T2W-TSE image, Fig. 2c. Geometry correction is thus possible using the fat-suppressed reference echoes: the phase of the main water component dominates the measured average phase, and correction shifts the water part of the image back to its original location. However, at locations where the average phase is dominated by a small intense structure with an excessive frequency offset, the method may be subject to over-correction. The correction may shift small features with frequency offsets of opposite sign relative to the average frequency further away from their true location. The correction method presented here achieves good global distortion correction and provides a good starting point for other techniques that are dedicated to distortion correction due to such local frequency variations.

References

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