Improved PSF Mapping Acceleration Technique for EPI Geometric Distortion Correction at 7 Tesla

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INTRODUCTION

The point spread function (PSF) mapping method can detect geometric distortions in EPI reliably [1-4] and the measured PSF can be used as a convolution kernel for distortion correction. However, especially for high resolution EPI the PSF data acquisition is time consuming due to its multi-shot nature. A reduced field of view (rFOV) technique in PSF dimension has been proposed previously to allow fast acquisition [3]. However the maximum FOV reduction is usually restricted by the local distortion due to the fold-over effects in the shift map. Thus, acceleration is limited to a factor 4 at ultra high field such as 7T [5]. In this work, we proposed an improved acceleration technique which allows further FOV reduction by solving the fold-over artifacts.

MATERIALS AND METHODS

We propose further acceleration by acquisition of the PSF data with a new sampling pattern in PSF dimension. A full resolution acquisition with very high rFOV factor (16) in the PSF dimension is combined with only 5 samples around the k-space center with lower rFOV factor (2). The PSF data with high rFOV factor, show strong fold-over effects due to the acceleration and need unwrapping. The low resolution acquisition is used to resolve the fold-over effects. The reconstruction for the proposed method is illustrated as flowchart in Fig. 1. Two shift maps with and without wrapping effects are calculated from the 1st and 2nd parts of acquisition of the PSF data, respectively. The wrapped shift map is unwrapped by the shift map without fold-over effects and the final shift map is obtained after smoothing and weighted linear extrapolation of the shift map to the areas outside of mask [6]. After that, the unwrapping procedure of the wrapped 3D PSF data from 1st part of acquisition is followed by using the final shift map and only 5 magnitude PSF samples, which are most close to the PSF's peak, are collected along the undistorted dimension as a kernel. PSFs in a no-signal area are estimated by using 2D b-spline interpolation with the final shift map [6]. Finally, the collected and estimated kernel is normalized in the distorted dimension. By using the convolution kernel, the distortion correction is performed by one-dimensional resampling (along the phase encoding axis) of each column.

Conventional gradient-echo EPI and corresponding PSF data with a fully sampled PSF data set of a healthy volunteer were acquired at 7 Tesla (Siemens Healthcare, Erlangen, Germany). Measurement parameters were TR/TE = 1000/26 ms, resolution = 160×160, FOV = 224×224 mm, grappa factor 2, partial Fourier 6/8. The proposed reconstruction was based only on the samples described above. Reconstruction employing all samples [6] was also performed.
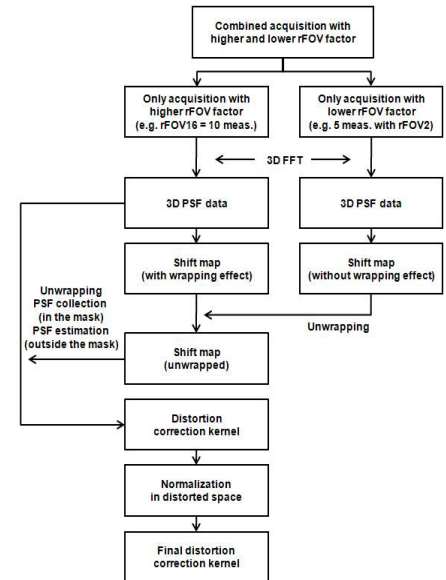

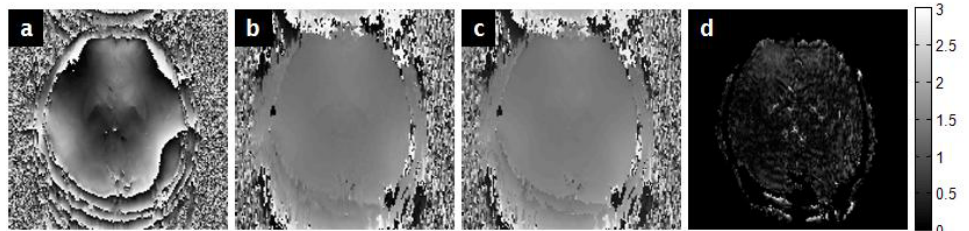Fig. 1 The proposed reconstruction in order to obtain a distortion correction kernel.

Fig. 2 The shift map with (a) and without (b) wrapping effect calculated from each 3D PSF data. (c) an unwrapped shift map by using the shift map of (b), and (d) shows the difference between (b) and (c)
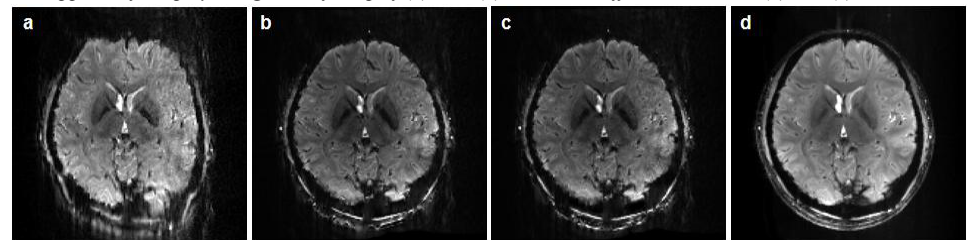

Fig. 3 The distortion correction results in an in-vivo human brain. (a) distorted EPI image, (b) correction result by using full PSF acquisition, (c) correction result by the proposed method, and (d) shows an artifact free gradient echo reference image.

RESULTS AND DISCUSSION

Figure 2 shows that the full acquisition shift map (Fig. 2b) and the reduced acquisition (Fig. 2c) are very similar. At most 3 pixel differences occur in regions at the mask boundary outside of the brain. The distortion corrected images (Figure 3) from a human brain show virtually now difference in the accelerated PSF determination. Improved delineation of the brain outline, i.e. in the occipital region, is evident and the geometry agrees very well with the reference image (Fig 3d). The correction quality in the proposed method is similar to the original correction result (Fig. 3b) despite very high acceleration (full acquisitions (160) / suggested acquisitions (14) ≈ factor 11 reference scan time reduction). As an added benefit, the reconstruction time for the PSF reference method is reduced by a factor (≈ 6) due to smaller data size and fewer FFT and interpolation steps.

CONCLUSION

This study demonstrates that the suggested method allows for much faster acquisition and reconstruction of EPI data with distortion correction, while the high correction fidelity is maintained.

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