Restoration of EPI Susceptibility Distortion at 3 Tesla: Comparison of Fluid Registration with Phase-Encoding Gradient Reversion

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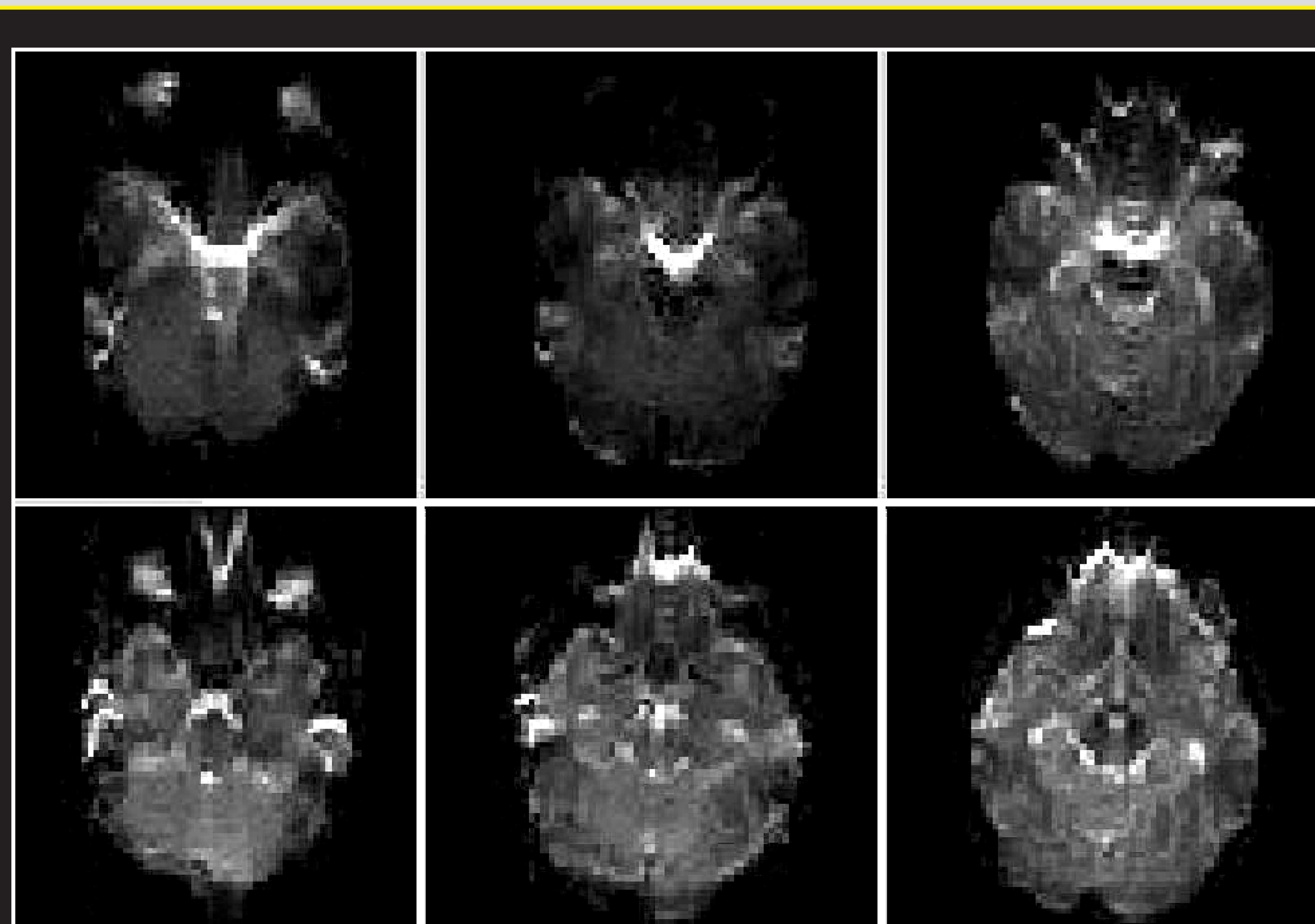
Introduction

We propose a cross evaluation of restoration methods for echo planar images acquired at 3 T, where the effect of susceptibility distortions is rather conspicuous. Two methodological strategies were tested to un-distort the images: (i) image registration of the distorted image with an undistorted (reference) image that has a similar contrast [1, 2], and (ii) co-registration of two distorted images – acquired with phase-encoding gradients of opposite sign [3, 4, 5]. To assess the restoration success, tests included phantom experiments as well as in vivo imaging of the normal human brain. Results of the methods are compared using undistorted reference images, or, in case of the phantom, compared with the known structure.

Methods

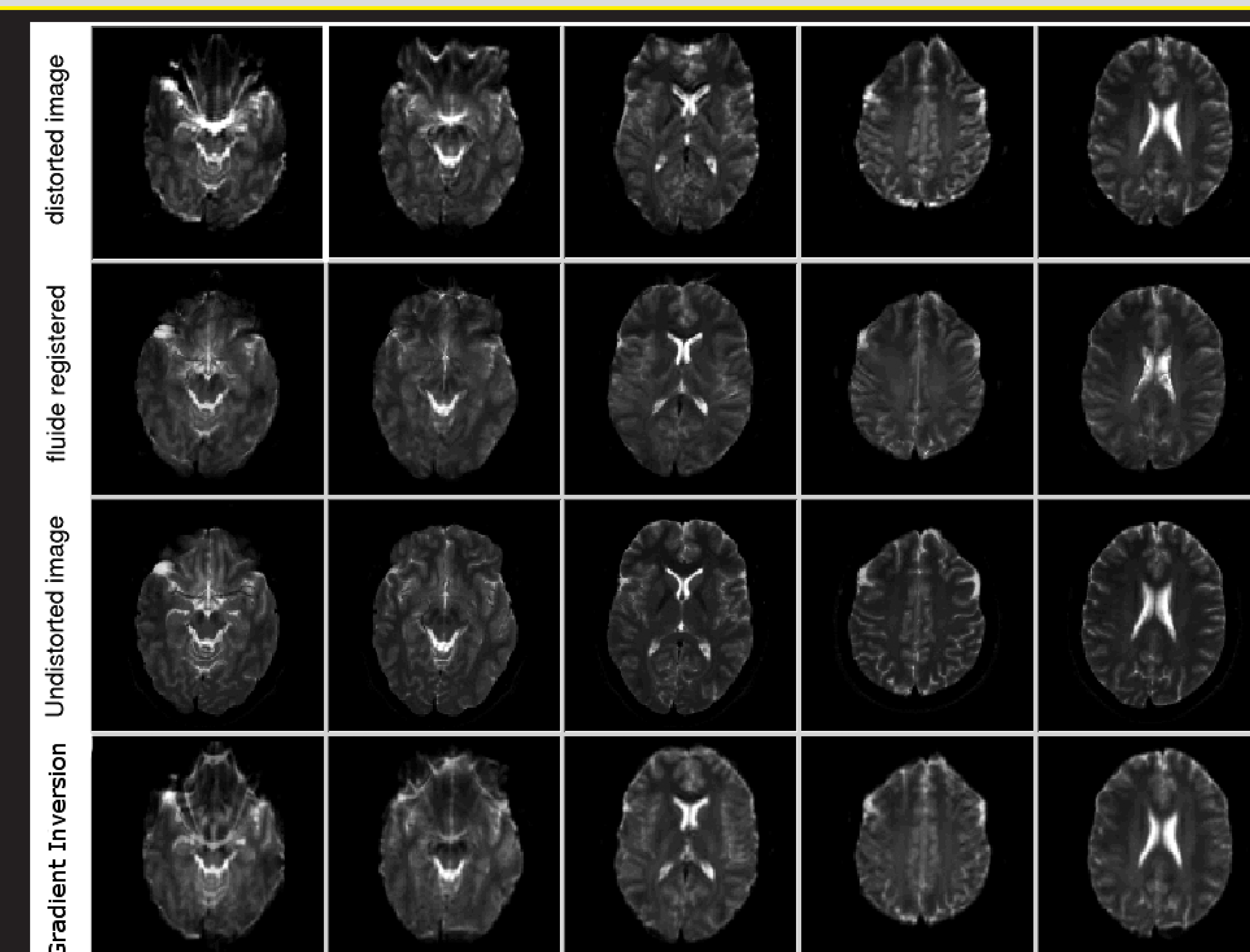
All experiments were performed at 3T (MAGNETOM Trio, Siemens, Erlangen, Germany) using a standard birdcage headcoil. The amount of distortions was investigated with a blipped spin-echo EPI sequence (TR 4 s, TE 86.2 ms, bandwidth 1000 Hz/pixel, 128 x 128 or 64 x 64 acquisition matrix, half-Fourier reconstruction, 10 averages) with frequency-selective fat saturation. Two series of images were recorded with reversed phase-encoding directions (right to left and left to right or anterior to posterior and posterior to anterior in the phantom and in vivo experiments, respectively). A typical level of Nyquist ghosts was 1.6% of the object's image intensity.
A structured water phantom consisting of a cylindrical 1-L borosilicate glass beaker (DURAN, Schott, Mainz, Germany) with additional vertically oriented polyethylene tubes (1.2-mm wall thickness, 15-mm external diameter) of similar length as the beaker was used for the in vitro studies. The phantom was filled with aqueous NaCl solution (1.712 mol/L) and centered in the imaging coil in an upright position. The 2D images were oriented perpendicularly to the beaker's long axis in the phantom study (i.e., along the y-direction) with a field of view (FOV) of 128 mm. With this orientation, potential distortions along the slice-selection direction had no visible effect on the images due to the symmetry of the phantom.
In vivo brain images were recorded in healthy young human volunteers after informed written consent had been obtained. The 2D images were oriented along the bicommisural plane (AC-PC), and the FOV was 192 mm (slice thickness 4 mm, gap 1 mm). In all experiments, automated shimming was performed to minimize large-scale magnetic field inhomogeneities. Subsequently, spin-warp reference images were recorded with phase-encoding from right to left using proton-density and T2-weighted RARE sequences (TR 4 s, TE 12 or 103 ms, refocusing pulses 150 °, RARE factors of 7 or 9, bandwidth 100 Hz/pixel, matrix 256 x 256, 2 averages).

1



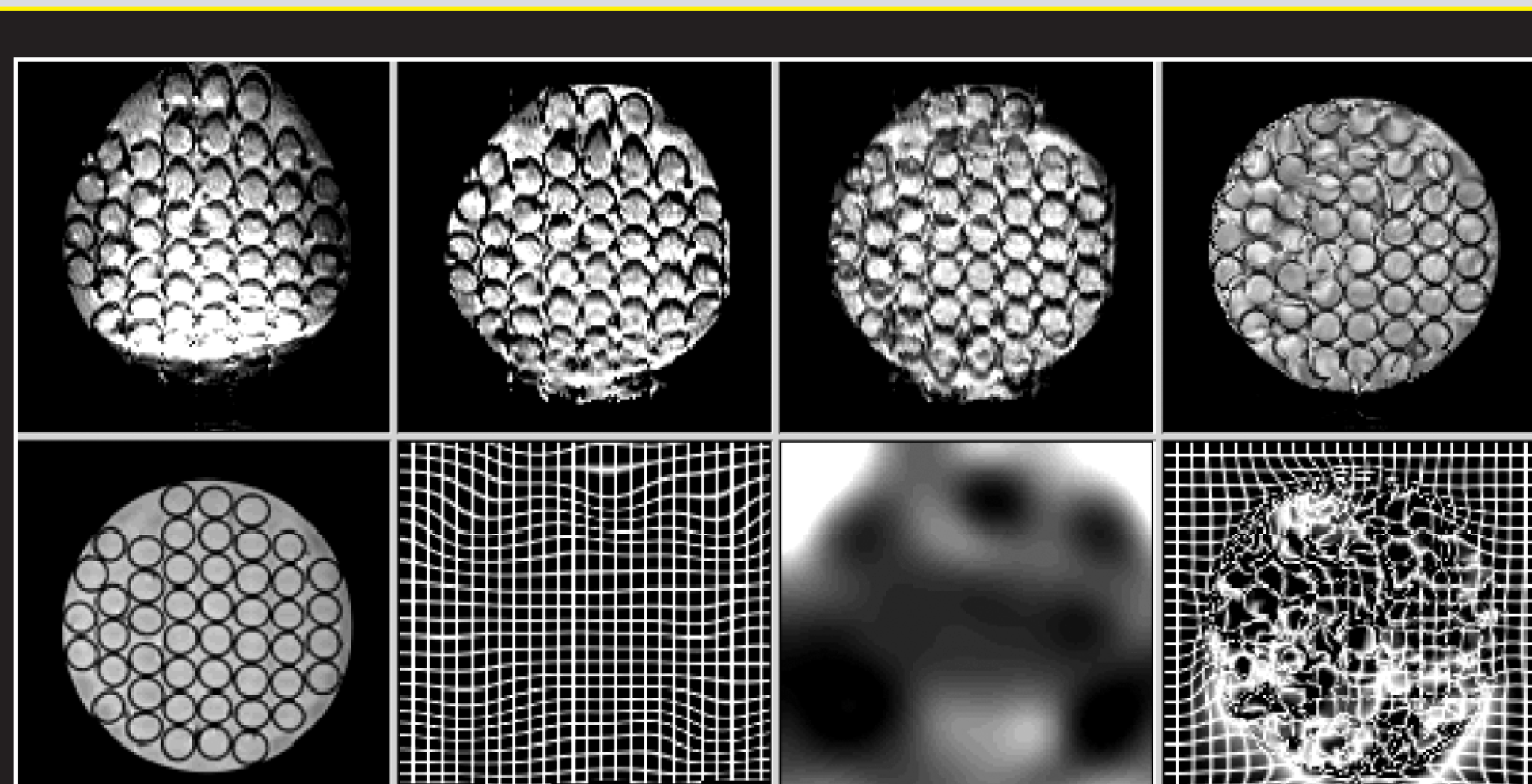
The first three slices above the nasal sine of the opposite blipped images does not represent the same locations in the imaged subject because of distortions in both phase encoding and slice select direction.

2



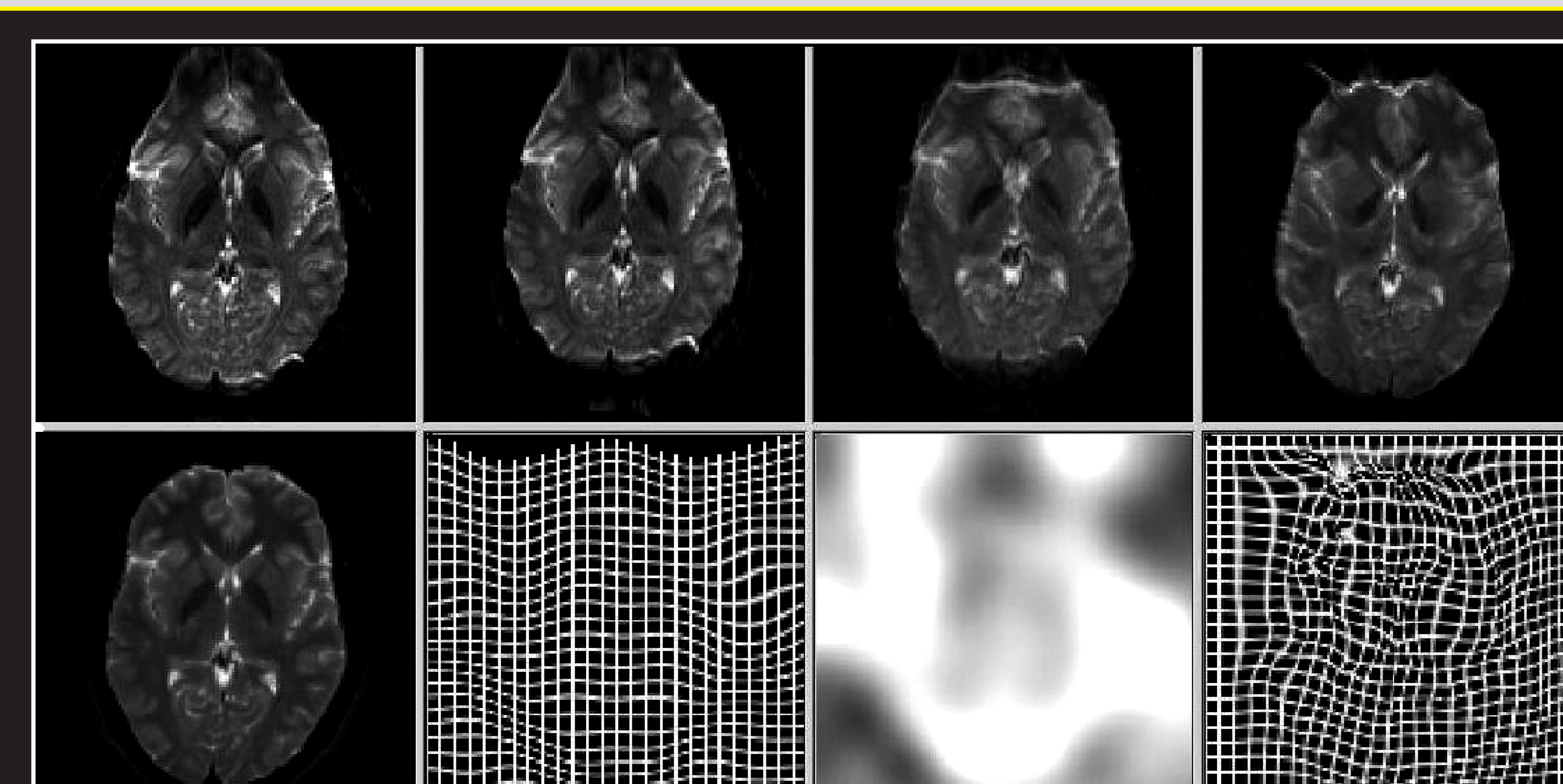
Comparison of distorted EPI images (top row) with results after fluid-dynamic registration (2nd row), undistorted RARE images (3rd row), and results from reversed-gradient correction (bottom row).

3



Restoration of a phantom image: SS-SE-EPI image, gradient inversion restored image using only the positive blipped image, gradient inversion restored image using both blipped images, fluid registration restored image (first row in the order). In the second row RARE T2 weighted undistorted image, distortion map computed by the gradient inversion algorithm, distortion field in grey-scale, distortion field computed by the fluid registration.

4



Restoration of an in-vivo image: SS-SE-EPI image, gradient inversion restored image using only the positive blipped image, gradient inversion restored image using both blipped images, fluid registration restored image (first row in the order). In the second row a spin-warp reference image, distortion map computed by the gradient inversion algorithm, distortion field in grey-scale, distortion field computed by the fluid registration.

Results & Discussion

From mere visual inspection (Fig. 2) results obtained by fluid-dynamic image registration schemes appear to be better than those obtained using reversed-gradient methods, because they account for large displacements and are able to correct for distortions in slice select gradient direction, too. A closer inspection of the (computed) distortion field revealed implausible reconstruction, primarily in read-out direction. This effect is not in accordance with susceptibility distortion on SE-EPI images, and requires to be taken under control. Since susceptibility distortions increase with field strength, we suppose that fluid-dynamic registration may be the better solution to estimate the distortion field at 3 T or above, especially for high-resolution imaging.
It may be interesting to modify fluid-dynamic image registration to implement a fluid-dynamic regularization for reversed-gradient methods to unify the advantages of a reconstruction based on the information from both images and the feature of the fluid registration to account for large displacements.

References

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