Motion and distortion correction in diffusion-weighted MRI of the breast at 3T

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INTRODUCTION

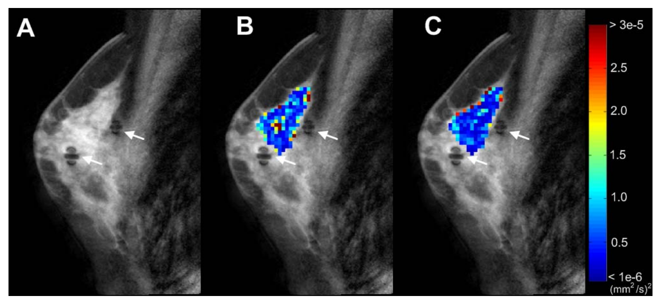
Diffusion-weighted imaging (DWI) is prone to artifacts from both bulk motion of the subject and distortion caused by eddy currents. In addition, DWIs acquired with echo planar imaging (EPI) are susceptible to nonlinear distortion in the phase-encoding direction due to B_0 field inhomogeneities, particularly at field strengths ≥3T. While a body of literature exists on these topics for brain DWI, little attention to these issues has been focused on breast DWI. In this study, the value of image registration and B_0 field map distortion correction are explored in DWI of the breast.

METHODS

Image Acquisition. Data were acquired from four healthy females with no history of breast disease and an age range of 28 to 53 years and one patient with invasive ductal carcinoma (age = 47 years). The breast cancer patient was scanned on two consecutive days, resulting in a total of six data sets for this study. Images were acquired with a 3T Philips Achieva MR scanner (Best, The Netherlands), using a double-breast 4-channel sensitivity encoding (SENSE) receive coil (Invivo Inc., Gainesville, FL). Three sets of slice-matched sagittal images were acquired for each subject: a B_0 field map, a high-resolution T_1-weighted anatomical volume, and a DWI data set. The B_0 field map was generated from double gradient echo images with $TR \backslash TE_1 \backslash TE_2 \backslash \alpha \backslash$NSA = 660ms\2.3ms\4.6ms\40°\1 and a voxel size of 2×2×5 mm^3. The 3D T_1-weighted anatomic volume was acquired with a turbo field echo (TFE) sequence, spectrally-selective adiabatic inversion recovery (SPAIR) fat saturation, and a voxel size of 0.5×0.5×5 mm^3. DWIs were acquired with a single-shot spin echo (SE) EPI sequence with a SENSE parallel imaging acceleration factor of 2, three orthogonal diffusion encoding directions, two b-values (0 and 600 s/mm^2), an 80×80 matrix, 12 slices, voxel size of 2×2×5 mm^3, and $TR \backslash TE \backslash$NSA = 2254ms\48ms\10.

Image Analysis. Bulk motion and eddy current distortion were corrected using a slice-based affine registration of the DWIs from each diffusion direction (DWI_x, DWI_y, DWI_z) to their corresponding images in the non-diffusion-weighted image volume (b=0 s/mm^2). [1-2] Regions of interest (ROIs) were manually drawn using the T_1-weighted anatomical volume to segment the glandular tissue on a central slice for healthy subjects and on the central slice of the tumor in the two data sets from the patient. A two-sample t-test was used to compare the mean value of the ADC variances within the ROI between the uncorrected and the corrected data sets.

The effect of employing B_0 field maps for eliminating nonlinear distortion caused by B_0 field inhomogeneities was also studied. First, the map of pixel shifts caused by the field inhomogeneities was calculated from the double gradient echo data and applied to the b=0 s/mm^2 images [3]. Then, both the uncorrected and B_0-corrected b=0 s/mm^2 image volumes were registered to the subject's T_1-weighted image volume using a nonlinear registration method. [1-2,4] The mean pixel shifts in the phase-encoding direction within the ROIs were then compared.



Example of motion correction results. A) Sagittal T_1-weighted post-contrast image through the center of the tumor in the patient (Day 2). Note the biopsy markers, indicated by white arrows. Panels B) and C) depict the overlay of the variance in individual ADC values within the tumor prior to and after motion correction, respectively. Note that motion correction results (C) in reduced variance between ADC measurements, compared to the pre-correction version (B).

RESULTS

Alignment of the individual diffusion-weighted images resulted in a significant decrease ($p<0.005$) in the mean variance in the individual ADC values for all six data sets. An example is shown in the figure to the right. B_0 field map correction resulted in a significant ($p < 0.001$) reduction of the pixel shifts in the phase-encoding direction required to match the images to the corresponding anatomical in only two of the six cases. However, qualitative evaluation of the registration results showed that the B_0-corrected images were better-matched to the anatomical images than the uncorrected images. The mean pixel shift values within the glandular tissue ROIs for the B_0-corrected and uncorrected image sets are listed in the table to the right.

B_0 field map correction results

	Mean pixel shift in the phase-encode direction (mm)	
	Uncorrected	**Corrected**
Subject 1	0.71	0.65
Subject 2	0.90	0.27*
Subject 3	0.29	0.32
Subject 4	0.44	0.45
Patient – Day 1	2.06	1.03*
Patient – Day 2	1.10	1.00

* $p < 0.001$

DISCUSSION

Subject motion and eddy current distortions may lead to misregistration between individual DWIs within a study, which increases variability in the mean ADC value derived from those images. We have presented preliminary evidence that a slice-based affine registration of the DWIs to the corresponding non-diffusion-weighted images (b=0 s/mm^2) reduces the effects of these artifacts. Nonlinear registration will be explored in the future because bulk subject motion may cause nonlinear deformation of the breast tissue.

Image distortion caused by B_0 field inhomogeneities impedes direct comparison of the DWI data with anatomical images and other parametric maps, such as dynamic contrast enhanced MRI. While the results of the quantitative comparison of the B_0 field map corrected and uncorrected data presented here suggest that there is relatively little distortion in the uncorrected images and that B_0 correction may not significantly improve alignment with anatomical images, the poor registration of the uncorrected images may have resulted in artificially low pixel shift values compared to the corrected images. A combination of B_0 correction and nonlinear registration may provide the best alignment with anatomical images and will be studied further.

REFERENCES

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