Correcting Breast DWI distortion with Reversed phase encoding direction

Zhan Xu[1], Leah Henze Bancroft[1], Andrew L Alexander[2,3], and Frederick Kelcz[4]

[1]Department of BioMedical Engineering, University of Wisconsin Madison, Madison, WI, United States, [2]Department of Medical Physics and Psychiatry, University of Wisconsin Madison, Madison, WI, United States, [3]Waisman Laboratory for Brain Imaging, University of Wisconsin Madison, Madison, WI, United States, [4]Department of Radiology, University of Wisconsin Madison, Madison, WI, United States

INTRODUCTION: The apparent diffusion coefficients (ADC) of breast tissues may improve the characterization and detection of malignant breast tumors without contrast agents. However, Diffusion Weighted Imaging (DWI) uses echo-planar imaging (EPI) methods that are highly sensitive to imperfect fat suppression, and geometrical distortion due to magnetic field inhomogeneities, which limits its application in the clinic. A common way to fix B0 inhomogeneity distortion is applying B0 fieldmap correction. Field map correction methods [1] are very difficult to apply in the breast due to the high level of fatty tissue. Here we implement a B0 inhomogeneity correction scheme based on two identical DWI scans with reversed phase encoding directions (PeDir), and comparing the corrected DWI data with T2W images to assess the correction.

METHODS: Distortions in EPI are mainly in the PeDir. This distortion is caused by the differences in the phase accumulation during phase-encoding. In our work, we implement correction by averaging the displacement of two DWI with reversed PeDir. The distortion shifts for one PeDir will be in the opposite direction but the same amount for reversed phase encoding. The undistorted pixel location is the center of two shifted locations. Since the distortions are primarily in PeDir, the sum of pixel intensities along PeDir within the same columns in EPI images with reverse phase encoding should be the same. By integrating the signal intensities in both images, the corresponding displacements can be estimated [2]. The integrals provide the matching points in two images, so we can restore the locations and intensities of the undistorted image in a manner of backward unwrapping. The restored location $\hat{x}$ is the mathematical average of two matching point location, the restored intensity $i(\hat{x})$ can be achieved in this manner $\frac{2i_1(x1)i_2(x2)}{i_1(x1)+i_2(x2)}$[2].

This technique was applied to breast imaging studies of 4 patients with IRB approval. All scans utilized a GE signa HDxt 1.5T scanner, a GE HD 8-channel breast coil. Two consecutive DWI with reversed PeDir are scanned with 3000ms TR, 81.8ms TE, 90° flip angle, b=0 and b=1000 s/mm2. Only 3 slices are acquired at the location of tumor. Other parameters include 256*256 image matrix over a 24cm FOV with voxel size 0.94*0.94*7mm^3 was acquired in 30 seconds. Patients are requested to hold their breath during the DWI scan. The second DWI utilizes the same parameters, but the polarity of Phase Encoding was reversed. A baseline T2W without fat suppression was acquired to get undistorted geometry of tumor with 5600ms TR, 125.7ms TE, 90° flip angle, 256*256*28 image matrix over 18cm FOV and voxel size is 0.7*0.7*4 mm^3.

RESULT AND DISCUSSION: Using our method, we are able to restore the correct location and shape of entire breast as well as tumor shown in fig 1. Fig 1a, taken from a clinical DWI sequence showing distortion along the inferior breast is superiorly displaced. 1b shows similar distortion along reversed PeDir inferiorly. By comparing the reconstructed DWI b_0 image (1c) with inverted gray scale T2W image (1d), the shape and location of lesion in DWI appears corrected. The signal intensity in the corrected b=1000 DWI (1e), non lesion regions are better identified, such as glandular tissue (arrow in 1d & 1e) which might look like lesion in T2W.

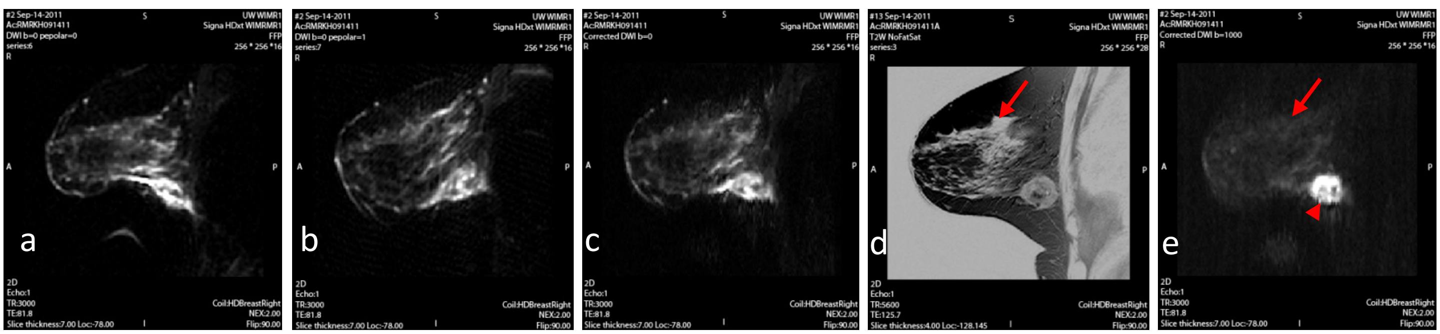

Figure1: (a)b_0 DWI with PeDir pointing up,(b) b_0 DWI with PeDir point down,(c) b_0 of corrected DWI,(d)T2W No fat Suppression, shown with inverted gray scale, to be more compatible with other images in this set, (e)b=1000 of corrected DWI. Arrow pointing at glandular tissue, arrow head pointing at tumor

Correction with fieldmap requires a DWI and a fieldmap sequence, our method requires 2 EPI sequences which are much faster than a filed map. Our method also includes averaging, so the SNR of corrected images will be increased by roughly a$\sqrt{2}$ factor. Our method also helps to reduce eddy current distortions which are also reversed in the acquisition. In 1b there is a clear motion ghosting (stripe pattern), but it's almost invisible in the corrected image (1c & 1e). Our method also decreases influence of noise at estimating matching points significantly by integration. Assuming noise influence in the 1st pixel is 1, then when integrating to 256th pixel in the same column, noise influence in the sum of 256 pixels has been reduced $\sqrt{256}$ times. The 1st pixel in one DWI will be the 256th in the reversed PeDir DWI in integration. Assuming the noise level varies little across two DWI scans, for matrix size of 256*256, average noise influence in estimation matching points for pixels in the same column will be reduced by $\frac{sum(\sqrt{1},\sqrt{2}...\sqrt{256})}{256} \div 2 = 5.4$ times.

The corrected DWI images also result in improved calculation of ADC value. Fig 2a shows a malignant lesion displaying high signal intensity on DWI (arrow head in 1e) and low ADC value compare to surrounding pixels(arrow in 2a). The benign lesion in Fig (2b) displays a high ADC value (arrow in 2b).

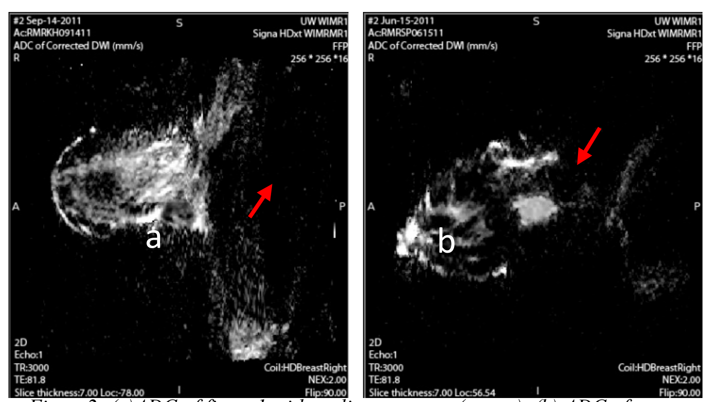

Figure2: (a)ADC of figure1 with malignant tumor(arrow), (b) ADC of a benign tumor (arrow) on a different patient

CONCLUSION: Magnetic distortion correction with reversed PeDir will significantly improve the anatomic fidelity of DWI images in the breast, and this is useful because diagnosis of location, shape, and pathological manner of tumor based on DWI will be more reliable. Reconstruction from 2 DWI also increases SNR and decreases artifact significantly. Future work will investigate the quantitative diffusion measurements as they relate to tumor type and grade.

REFERENCE: [1] Jezzard P, et.al. Magn Reson Med 1995. [2]H. Chang et.al, IEEE Trans. Med. Imaging, 11(1992)[3] N. H. G. M. Peters, et.al. Journal of Magnetic Resonance Imaging 2010, vol. 31, no. 5