# Using PLACE for EPI distortion correction of diffusion weighted images (DWIs)

**S. Chavez[1], E. Ramsay[1], D. Plewes[1,2], G. Stanisz[1,2], and Q-S. Xiang[3]**
[1]Imaging Research, Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada, [2]Medical Biophysics, University of Toronto, Toronto, Ontario, Canada,
[3]Department of Radiology, University of British Columbia, Vancouver, B.C., Canada

## Introduction

An EPI sequence can acquire the k-space signal of an entire slice in a single shot (after a single rf). While this allows for very fast signal acquisition, it comes at the expense of two well-known and important image artifacts: N/2 ghosts and distortion along the phase encode (PE) direction introduced by the inherent sensitivity to $B_0$ inhomogeneity [1]. While there are phase correction methods available on most scanners to reduce the ghosts, the distortion remains uncorrected for standard single-shot EPI sequences. Diffusion weighted imaging (DWI) involves the acquisition of diffusion sensitized SE signal along the three orthogonal planes to extract the apparent diffusion coefficient (ADC) of water in tissue. It has been found that changes in ADC are indicative of disease in many applications [2]. Due to the diffusion sensitization gradients, DWIs are highly sensitive to motion and thus require fast imaging acquisitions. Most commonly, DWI is performed using an EPI readout hence suffering distortions along the PE direction and making co-registration of ADC maps to other anatomical scans problematic.

Recently, a simple method has been proposed to correct for EPI distortions by introducing an extra phase "blip" to encode the PE coordinate. This method, called PLACE (Phase labeling for additional coordinate encoding) [3] has been successfully applied to fMRI [4] and it comes with no cost to scan time due to the many acquisitions per slice already required for fMRI analysis. In this feasibility study, the application of PLACE to DWI is demonstrated. Overcoming the challenges of ramp sampling, partial Fourier k-space coverage and loss of SNR due to diffusion sensitization, PLACE is shown to be an effective tool for EPI distortion correction for DWIs.

## Theory

PLACE exploits the phase relation between two EPI acquisitions that differ by a single "blip" in the phase encode direction. For no distortion, the phase relation between the two resulting images would be a phase ramp across the image where the phase is indicative of the coordinate in the PE direction. However, for EPI acquisitions with distortion, the phase relation, although still indicative of PE coordinate, will be distorted. Restoration of the expected phase ramp can be used to correct the distortion and restore the image signal to its correct location along the PE direction.

## Method

Data were acquired using a slightly modified, standard DWI sequence on a 1.5T scanner (Signa, GE Healthcare). The modification consists of the option to insert a single extra phase encode "blip". Data were acquired with and without the extra "blip" and reconstructed identically. The standard DWI sequence consists of a ramp sampled, partial Fourier k-space data sampling scheme. Reconstruction consisted of the scanner manufacturer's phase correction for N/2 ghost reduction and regridding (to account for ramp sampling). Data were acquired with no diffusion sensitizing gradients (b=0) to yield the $I_0$ image, followed by diffusion sensitizing gradients along each of the three orthogonal directions to yield: DWIx, DWIy, DWIz (DWIs sensitized for diffusion along the x-,y- and z-coordinates of the scanner). Each DWI, with and without extra "blip", were then combined with PLACE for EPI distortion correction. The corrected DWIs were then used to determine the ADC map according to a pixel-wise calculation: $\langle DWI \rangle = I_0 \exp(-b \cdot ADC)$ where $\langle DWI \rangle = (DWI_x + DWI_y + DWI_z)/3$. A banana was used as the phantom for this study because it has internal structure that is sensitive to diffusion weighting and it was expected to produce simple yet noticeable distortions due to its irregular shape. For this feasibility test b=600 was used to maintain high SNR. The banana was placed horizontally in a quadrature headcoil and axial slices were acquired with PE along the transverse AP direction. A SE image was also acquired as an undistorted reference.

## Results

The banana EPI images show that there is a stretching along the PE direction due to $B_0$ inhomogeneities introduced by the particular shape of the fruit. The result is that the banana looks wider than it is. In the centre, this distortion is a factor of approximately 20% which can be appreciated by the overlaying red arrows, of equal length, indicating the central width for the distorted images. PLACE was successfully applied on this data set to give corrected images that agree much more closely with the reference SE image (see blue outline of SE image overlayed on DWIx with and without PLACE). The extent of the bright edges of the ADC maps are the result of thresholding for signal extraction required to perform the ADC calculations.

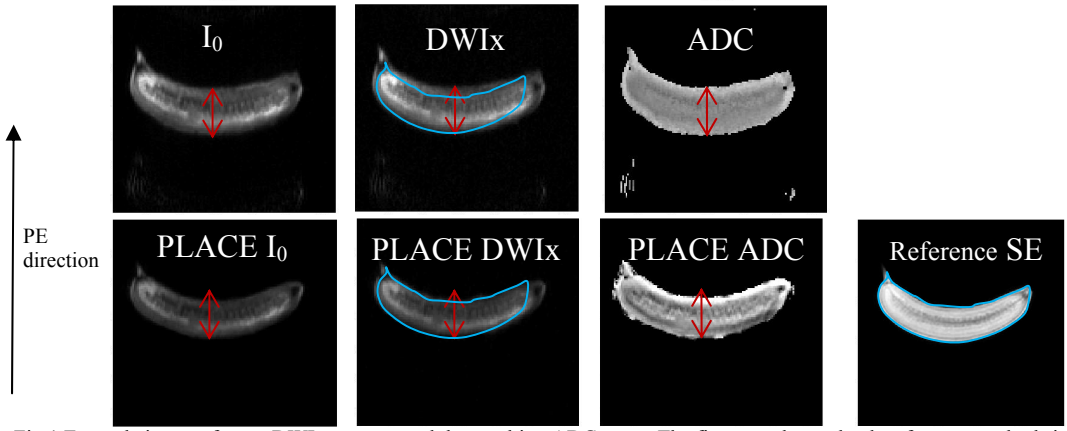


Fig.1 Example images from a DWI sequence and the resulting ADC maps. The first row shows the data from a standard single-shot EPI-based DWI sequence. Two such image sets, with and without extra "blip" were collected. The distortion causes the banana to appear wider than it is. The second row shows the images obtained using PLACE for distortion correction as well as a reference SE image used to assess the amount of distortion and correction.

## Conclusion

This work shows that using PLACE to correct the distortion of DWIs is feasible despite the challenges of partial k-space sampling and ramp samping. The simplicity and efficiency of the PLACE technique makes it an attractive option for DWI and it could also easily be extended to DTI. For purposes of this study, a single extra "blip"was used but it is expected that a greater number of extra "blips" can be used to accentuate the phase difference between the two required input image sets, making PLACE more sensitive to small distortions. The ideal number of "blips" can be optimized for each application. Although PLACE is expected to be particularly sensitive to motion when applied DWIs *in vivo*, use of the PLACE correction information from the $I_0$ could be used to correct the diffusion sensitized images. Investigation into the *in vivo* application of PLACE-DWI, particularly for brain and prostate, is currently underway.

**References**: [1] Jezzard et al., *MRM* 34, 1995 [2] Chinnaiyan et al., *PNAS* 97, 2000 [3] Xiang et al., *MRM* 57, 2007 [4] Arnold et al.,*ISMRM* 4633, 2009