Correction of Eddy Currents for Time-domain-interleaved Blipped-phase-encoding Echo-planar Spectroscopic Imaging

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Introduction

Speed is one of the technical challenges for spectroscopic imaging (SI). To speed up filling the time- and k-space, several techniques for simultaneously adding a phase-encoding gradient with an oscillating readout gradient used in echo-planar spectroscopic imaging (EPSI) have been presented [1-3], and one of which leads to single shot imaging [3]. One of the technical issues is that EPSI requires a high-performance gradient system to quickly switch the oscillating gradient and to reduce eddy current distortion caused by the strong oscillating gradient. A time-domain-interleaving technique is proposed to reduce the switching speed [4], and an eddy current correction (ECC) technique using a water signal [5] is known to be effective in reducing this distortion [6,7]. The ECC technique is also effective in EPSI with a phase-encoding readout gradient [3]; however, ECC should be carefully applied for the phase-encoding direction because the spatial shift caused by a chemical shift appears along this direction.

We propose an ECC technique for time-domain-interleaved blipped-phase-encoding EPSI (TDI-BPE-EPSI). This technique is used to correct the spatial shift by roughly estimating the chemical shift before applying the ECC. Acquisition of spectroscopic images with less eddy current distortion is demonstrated by applying TDI-BPE-EPSI to a phantom and a rat brain *in vivo*. The presented ECC technique will be also useful in diffusion-weighted spectroscopic imaging.
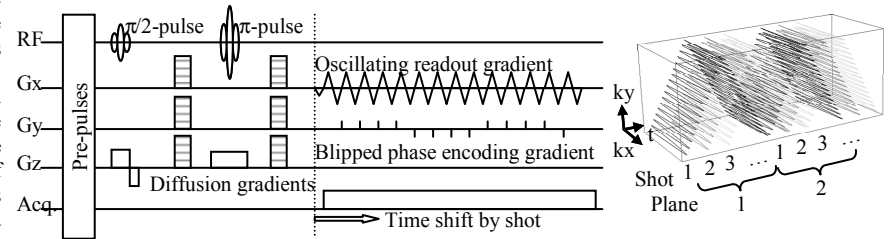

Fig. 1. Sequence diagram of TDI-BPE-EPSI and its trajectory in k-space.

Methods

The TDI-BPE-EPSI technique uses an oscillating readout gradient and a blipped phase-encoding gradient while data acquisition, which are shifted over time shot by shot (Fig. 1). A water reference for ECC is obtained with non-water suppression in the pre-pulses. The blipped gradients are inserted at each cycle of the oscillating readout gradient, which leads to slower oscillation of the trajectory in the ky direction than in the kx direction. Thus, the spatial shift due to the chemical shift tends to appear in the ky direction, and prevents the application of ECC at the correct location of the water signal. To reduce such miscorrection, an algorithm of ECC with spatial correction is proposed (Fig. 2). The shot and plane constitutes the time direction in an interleaved manner. Steps 3-6 in this figure enable a rough estimate of the spatial shift due to the chemical shift before applying ECC, which corrects the data phase using the water reference.

We performed a phantom experiment and a rat brain experiment *in vivo* using a 7-T MRI for a small-animal study with transmit volume and receive surface coils. The phantom consisted of a bottle filled with 12.5 mM of *N*-acetyl aspartate (NAA), 10.0 mM of creatine (Cr), and 3.0 mM of phosphorylcholine (PCh). The TDI-BPE-EPSI uses blips at each cycle, and 16 consecutive positive blips and 16 consecutive negative blips were added four times at each acquisition. Time-domain interleaving was applied 32 times by shifting the time for 1 cycle of the oscillating readout gradient. Other measurement parameters of TDI-BPE-EPSI were a TR/TE of 3000/136 ms, spectral bandwidth of 7.24 ppm (128 points), FOV in the x and y directions of 40 mm (16 pixels), slice thickness of 2.5 mm, and number of accumulation = 4. The proposed algorithm of ECC was compared with two other algorithms to estimate the effect of spatial correction: ECC with a spatially averaged water signal, and ECC without spatial correction. A 265-g male Wistar rat anesthetized with isoflurane was used. To confirm the stability of the proposed algorithm, a diffusion gradient was added to enlarge the eddy currents. The b-values used were 0, and 2009×10^6 s/m^2 for the x, y and z directions.

Results and Discussion

As shown in Fig. 3, An ECC with spatial correction shows a sharp spectrum and a relatively clear NAA image reflecting the sensitivity of the receive surface coil. The ECC with a spatially averaged water signal shows broadened and reduced peaks of major metabolites. The ECC without spatial correction shows severe distortion at NAA because the spatial shift of NAA was almost half of the y direction, and thus it corrected with almost no water signal. As shown in Fig. 4, the large eddy currents caused by the diffusion gradient can be corrected effectively using the proposed ECC technique. However, The NAA image and spectrum at b = 2009 (z) shows slight distortion, especially at the center of the image, which is thought caused by the respiratory motion of the rat, because the motion along the z direction is more severe than along the other directions.

Conclusion

We developed an ECC technique for TDI-BPE-EPSI to reduce distortion caused by eddy currents. This technique uses correction of the spatial shift due to a chemical shift in the phase-encoding direction to align metabolites and water location, which leads to effective phase correction in ECC. This technique may be used for diffusion-weighed SI, which causes more eddy currents.

References

[1] Mansfield. J Physics 1977;C10:L55. [2] Ebel et al. MRM 2007;58:1061. [3] Posse et al. MRM 2009;61:541. [4] Matsui et al. J Magn Reson 1986;67:476. [5] Klose. MRM 1990:14;26. [6] Posse et al. MRM 2007;58:236. [7] Shirai et al. ISMRM 2009:2380.

(1) Array data on k-space: $S(shot,plane,kx,ky)$

(2) FT on x, y: $S(shot,plane,x,y)$

(3) FT on shot along time: $S(\sigma_s,plane,x,y)$

(4) Spatial shift along y depending on σ_s: $S(\sigma_s,plane,x,y')$

(5) FT^{-1} on shot along time: $S(shot,plane,x,y')$

(6) Phase correction using water reference: $S(shot,plane,x,y')$
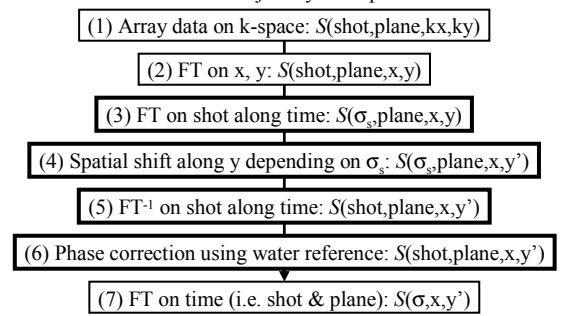
(7) FT on time (i.e. shot & plane): $S(\sigma,x,y')$

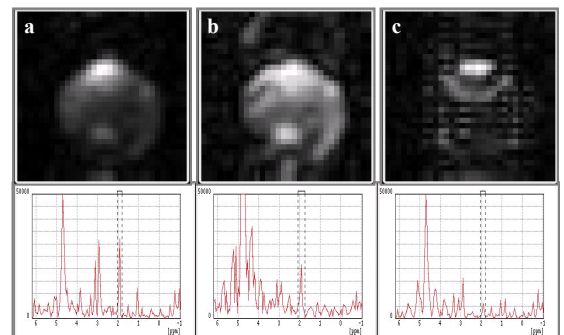Fig. 2. Algorithm of ECC with spatial correction. FT: Fourier transform.

Fig. 3. TDI-BPE-EPSI of phantom using (a) ECC with spatial correction, (b) ECC with spatially averaged water signal, and (c) ECC without spatial correction. Upper images show NAA concentration and lower graph show spectra from whole region.
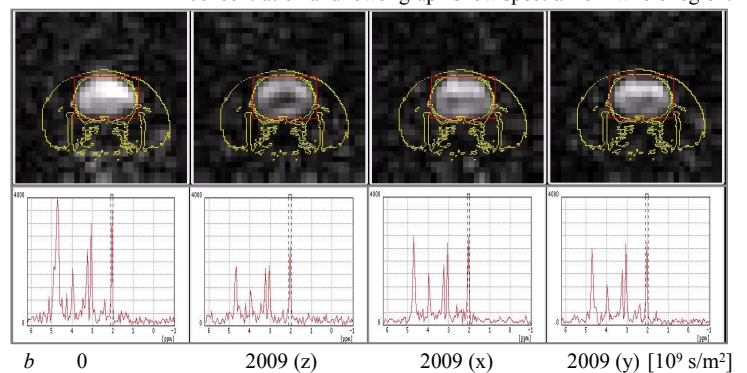

Fig. 4. DWSI of rat brain using TDI-BPE-EPSI with ECC.