Motion Artifact Reduction Using Bipolar Diffusion Gradients in Diffusion-weighted Echo-planar Spectroscopic Imaging

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Introduction

Diffusion-weighted spectroscopic imaging (DWSI) is expected to provide useful information on cellular and tissue microstructures and functions such as permeability and transport [1-4]. However, an accurate measurement technique has not yet been developed to overcome long measurement time, low signal-to-noise ratio, and large motion artifacts. The most challenging issue in developing this technique is to suppress motion artifacts caused by cardiac pulsation or respiration [2-4]. Such motions during a diffusion time cause a phase error due to an imbalance of the diffusion gradients. The phase error hinders accurate phase-encoding and produces ghosting artifacts in the imaging, it also hinders accurate signal intensity summation and causes significant signal loss in signal averaging.

We propose a diffusion-weighted echo-planar spectroscopic imaging (DW-EPSI) technique [1], using bipolar diffusion gradients, to reduce motion artifacts. Bipolar diffusion gradients are known to be effective in reducing ghosting artifacts in diffusion-weighted imaging [5]; however, their effect on signal loss in accumulation has not been extensively studied, which is important to obtain accurate metabolite signals in DWSI because ghosting artifacts are blurred and signal loss sometimes becomes a major artifact when the accumulation times is large. Numerical analysis is performed to estimate the signal loss by motion using bipolar diffusion gradients and the Stejskal-Tanner diffusion gradient. Reduction in motion artifacts is demonstrated by applying DW-EPSI using bipolar diffusion gradients to a phantom and a rat brain *in vivo*.

Methods

The developed DW-EPSI uses an oscillating readout gradient to restrict ghosting artifacts only in the y-direction and uses bipolar diffusion gradients to reduce motion artifacts caused by the first order moment of moving objects (Fig. 1). Numerical analysis is performed to estimate signal loss by motion in a simple oscillation case using the Stejskal-Tanner diffusion gradient (ST) and bipolar diffusion gradients (BP) by the following equations:

$$S_{ST}(a,f,\delta,f,G,D)=\int_0^{1/f}\cos\left(\gamma G\delta a\left(-\cos\left(2\pi f\left(t+\Delta\right)\right)+\cos\left(2\pi ft\right)\right)/2\right)dt\cdot\exp\left(-D\gamma^2\delta^2\left(\Delta-\delta/3\right)\right),$$

$$S_{BP}(a,f,\delta,f,\Psi,G,D)=\int_0^{1/f}\cos\left(\gamma G\delta^2 af\pi\left(\sin\left(2\pi f\left(t+\Psi\right)\right)+\sin\left(2\pi ft\right)\right)/2\right)dt\cdot\exp\left(-2D\gamma^2\delta^2\left(\Delta-\delta/3\right)\right),$$

where a and f are the amplitude and frequency of the oscillating object, G, δ, and Δ are the amplitude, duration and interval of diffusion gradients, Ψ is an interval of the pair of bipolar gradients and D is a diffusion coefficient. The key points of these equations are integrals, which mean that the effect of motion is averaged by the many accumulations used in spectroscopic imaging. Typical cases in which a = 0.1 mm, δ/Δ = 6/62 ms for ST and δ/Δ = 12/12 ms and Ψ = 30 ms for BP are calculated for various b-values and cycles per minute (CPM) (Fig. 2). This shows that BP is less sensitive to motion than ST.

We compared DW-EPSI using ST and BP using a 7-T MRI for a small-animal study using a phantom and a rat brain *in vivo*. The phantom was a bottle filled with 0.1% Gd-DTPA solution at 25°C and was oscillated at 110 CPM at an amplitude of 0.3 mm along the z-direction driven by a respirator. The measurement parameters were a TR/TE of 3000/136 ms, spectral bandwidth of 7.24 ppm (128 points), field of view (FOV) in the x and y directions of 40 mm (16 pixels), slice thickness of 2.5 mm, and 8 acquisitions. Diffusion gradients were added in the z-direction at b = 0, 200, 500, 1000, and 1500 x 10^6 s/m^2. 265-g male Wistar rat anesthetized with isoflurane was used. The parameters were the same as above except that the b-values were b = 0, 2009 x 10^6 s/m^2 for x, y, and z directions.

Results and Discussion

As shown in Fig. 3, the signal intensity using ST with motion was much attenuated compared to that using BP. The experimental attenuation was almost similar to that calculated using numerical analysis, although the calculated attenuation using ST showed oscillation along b. The difference is assumed to be caused by fluctuation of the phantom motion and relatively low number of accumulations. Note that BP is not perfect in reducing signal loss compared to the ideal non-motion case, which is caused by higher order moments of moving objects. The results show how much accuracy we can expect by using ST and BP, and how less we can control the motion of objects to achieve certain accuracy. As shown in Fig. 4, DW-EPSI using bipolar diffusion gradients provides good diffusion-weighted spectroscopic images of a rat brain *in vivo*. The average trace apparent diffusion coefficient (ADC) of *N*-acetyl aspartate (NAA) was 0.16 x 10^{-9} m^2/s. These results show the effectiveness of DW-EPSI using bipolar diffusion gradients in reducing motion artifacts, as well as its limitation of accuracy in measured signal intensity. The numerical analysis of signal loss by motion will be helpful in investigating accuracy of metabolite diffusion.

Conclusion

We proposed a DW-EPSI technique using bipolar diffusion gradients to reduce motion artifacts. This technique is proven to be less sensitive to motion. Numerical analysis showed the expectation and limitation of the reduction of signal loss by motion, which will be useful in analyzing obtained diffusion-weighted images or ADC maps of metabolites.

References

[1] Bito et al. MRM 1995;33:69. [2] Ronen et al. ISMRM 2008:3356. [3] Bito et al. ISMRM 2009:334. [4] Posse et al. ISMRM 2009:3521. [5] Prasad et al. MRM 1991;18:116.

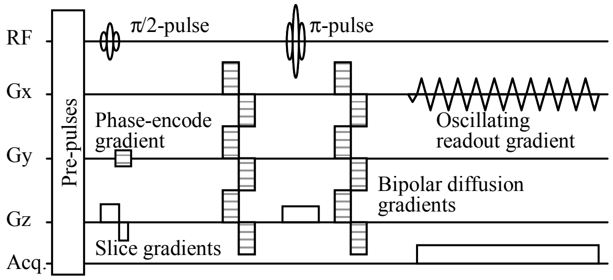


Fig. 1. Sequence diagram of DW-EPSI with bipolar diffusion gradients

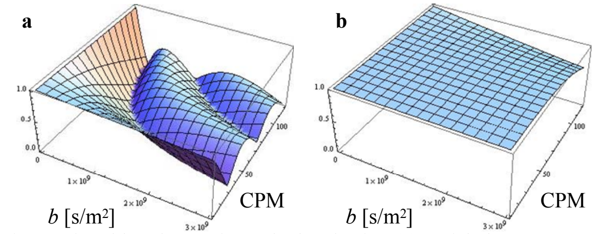


Fig. 2. Signal loss by motion calculated using (a) Stejskal-Tanner diffusion gradient and (b) bipolar diffusion gradients

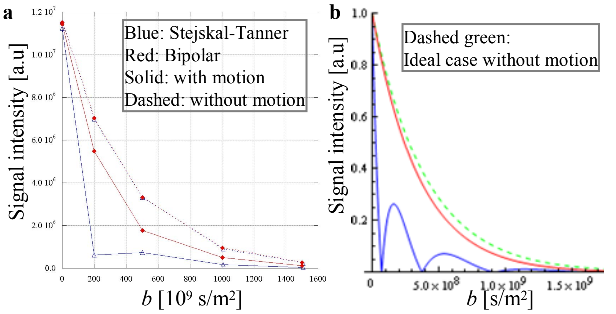
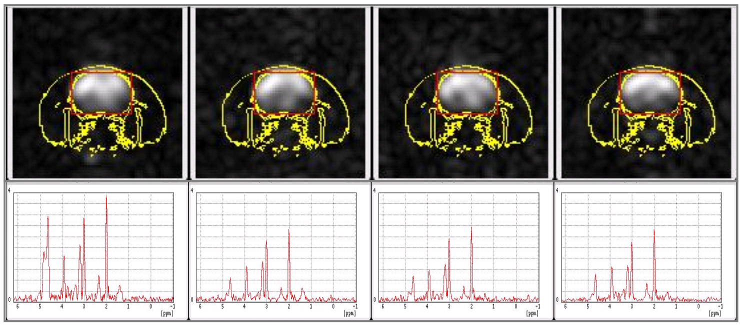


Fig. 3. Signal intensity vs. b value obtained by (a) phantom experiment and (b) numerical analysis



b: 0 2009 (z) 2009 (x) 2009 (y) [10^9 s/m^2]

Fig. 4. DWSI of rat brain using DW-EPSI with bipolar diffusion gradients. Upper images show DWI of NAA and lower graph show DW spectra from brain.