Diffusion-weighted Line-scan Echo-planar Spectroscopic Imaging for Improved Accuracy in Metabolite Diffusion Imaging

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Introduction

Metabolite diffusion is expected to provide useful information on cellular and tissue microstructures and functions such as permeability and transport [1, 2]. Although several studies have been done using diffusion-weighted spectroscopy, only a few studies have been done using diffusion-weighted spectroscopic imaging [3-5]. One reason is that an efficient measurement technique has not yet been developed to obtain accurate metabolite diffusion images. The most challenging issue in developing the technique is to suppress motion artifacts caused by cardiac pulsation or respiration [4, 5]. Such motions during the diffusion time cause phase errors due to an imbalance of the diffusion gradients. The phase errors hinder accurate phase-encoding and produce ghosting artifacts in imaging. They also hinder accurate amplitude summation and cause significant signal loss in signal averaging. These phase errors are known to be dependent on spatial location and to vary with time, so correcting such phase errors using conventional phase-encoding is significantly difficult.

In this paper, we present diffusion-weighted line-scan echo-planar spectroscopic imaging (DW-LSEPSI) to obtain accurate metabolite diffusion images. This technique uses line-scan and echo-planar techniques instead of phase-encoding to reduce motion artifacts. Because there is no phase-encoding, ghosting artifact is eliminated. The combination of line-scan and echo-planar techniques enables correction of phase errors at each spatial pixel in signal averaging, because the combination can identify the location of all pixels on the line per shot. Acquisition of diffusion-weighted spectroscopic images (DWSI) and apparent diffusion coefficient (ADC) maps of metabolites is demonstrated by applying DW-LSEPSI to a phantom and to a rat brain *in vivo*.

Methods

The developed DW-LSEPSI method uses line-scan and echo-planar techniques to acquire spatial and spectral information, and diffusion gradients to add diffusion information (Fig. 1). The region excited by the line-scan having a diamond-shaped transection is shifted diagonally, i.e., along the x-direction, shot-by-shot in a short time period, which maximizes the signal-to-noise ratio (SNR) per measurement time to up to half the SNR using normal slice selection [6]. The oscillating readout gradient is used to acquire both the spatial information in the y-direction and chemical shift information simultaneously. Thus, the spatial locations of acquired pixels are identified for each shot. Signal averaging is performed along with phase correction at each pixel; the phase correction is calculated so as to equalize the phase of the residual water signal.

We compared DW-LSEPSI with DW-EPSI [3], which uses phase-encoding instead of line-scanning in the x-direction, on 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 100-mM N-acetylaspartate (NAA) solution at 24°C and was oscillated at 110 cycles/minute at an amplitude of 0.3 mm along the z-direction driven by the respirator. The measurement parameters were a TR of 4000 ms, TE of 136 ms, spectral bandwidth of 7.24 ppm (128 points), FOV in y of 40 mm (16 pixels), and slice thickness of 2.5 mm. FOV in x was 40 mm (16 encodes) for DW-EPSI and 30 mm (12 lines) for DW-LSEPSI, which equalized their spatial resolutions at 2.5 mm. To equalize their measurement times, we used 8 acquisitions for DW-EPSI and 128 for DW-LSEPSI. Diffusion gradients were added in the z-direction, of which δ/Δ = 6/62 ms and b = 0, 550, 1090, and 1700 x 10^6 s/m^2. A male 280-g-weight Wistar rat anesthetized with isoflurane was used. The parameters were the same as above except for the b-values: b = 0, 550, 1700, and 3030 x 10^6 s/m^2. Remarkably, this experiment was done under free breathing conditions without cardiac gating.

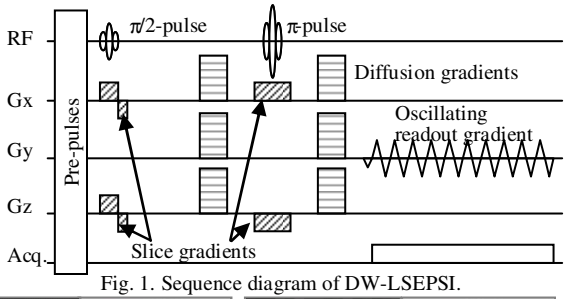

Fig. 1. Sequence diagram of DW-LSEPSI.

Results and Discussion

As shown in Fig. 2, good spectroscopic images were obtained by DW-EPSI and DW-LSEPSI at b = 0. Although ghosting artifact and signal loss are evident in DW-EPSI at b = 550, no clear artifact can be seen in DW-LSEPSI. The calculated ADCs of water and NAA by DW-LSEPSI were 2.35±0.15 and 0.72±0.04 x10^{-9} m^2/s, respectively, which show good agreement with previously reported values. Similarly, motion artifacts can be reduced by DW-LSEPSI *in vivo* (Fig. 3). The calculated ADC of NAA using DW-LSEPSI was 0.34±0.04 x10^{-9} m^2/s, which seems to indicate spatial variance while its average is in a range of reported values. Further improvement of this technique is needed to measure ADC precisely, however, the results suggest this technique will be a powerful tool to investigate spatial information about metabolite diffusion *in vivo*.

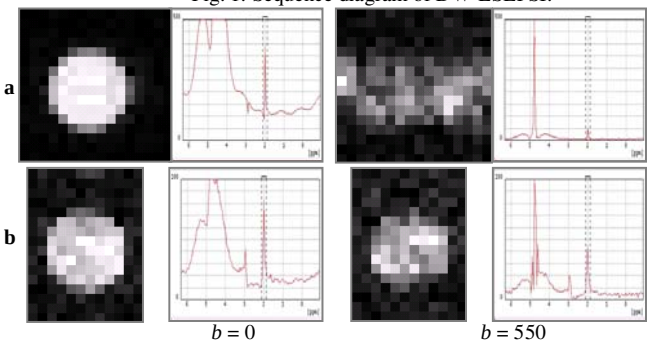

Fig. 2. DWSI of oscillating phantom using (a) DW-EPSI and (b) DW-LSEPSI. The left images show NAA maps.

Conclusion

We developed DW-LSEPSI to obtain accurate diffusion-weighted images and ADC maps of metabolites by reducing motion artifacts. The technique will lead to studies on metabolite diffusion images both in basic science and in clinical use.

References

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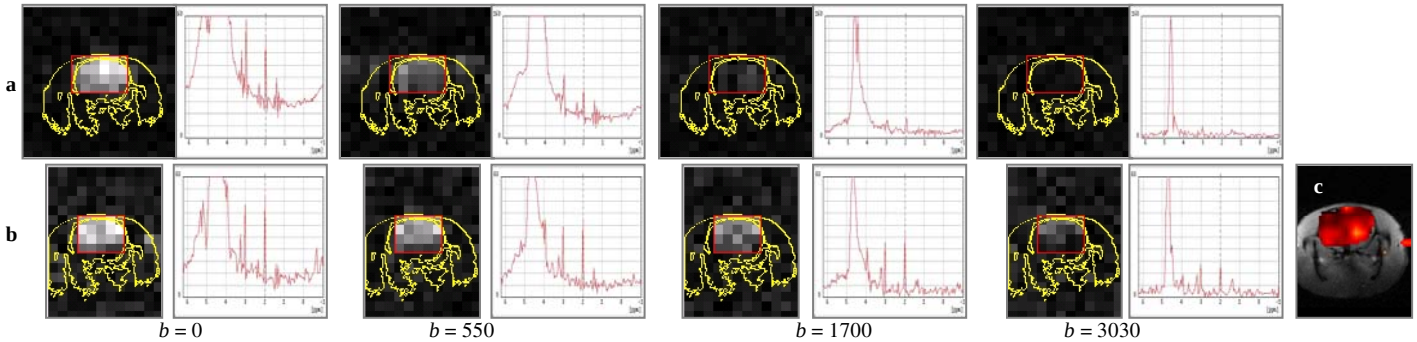

Fig. 3. DWSI of rat brain using (a) DW-EPSI and (b) DW-LSEPSI. The left images show NAA maps and the right graphs show average spectra in the red rectangles in the left images. Yellow lines in the left images show edges of a rat head. (c) ADC map of NAA using DW-LSEPSI. Color represents ADC value.