Water Suppression for Diffusion-weighted Line-scan Echo-planar Spectroscopic Imaging

Y. Bito[1], K. Hirata[1], T. Ebisu[2], Y. Kawai[3], Y. Otake[1], S. Hirata[1], T. Shirai[1], Y. Soutome[1], H. Ochi[1], M. Umeda[3], T. Higuchi[4], and C. Tanaka[4]
[1]Central Research Laboratory, Hitachi, Ltd., Kokubunji-shi, Tokyo, Japan, [2]Neurosurgery, Nantan General Hospital, Nantan-shi, Kyoto, Japan, [3]Medical Informatics, Meiji University of Integrative Medicine, Nantan-shi, Kyoto, Japan, [4]Neurosurgery, Meiji University of Integrative Medicine, Nantan-shi, Kyoto, Japan

Introduction

Diffusion-weighted spectroscopic imaging is expected to add insight into cellular microstructures and functions such as permeability and transport [1, 2]. However, there remain challenging technical issues such as long measurement time, low signal-to-noise ratio, and large motion artifacts. To reduce motion artifacts, diffusion-weighted line-scan echo-planar spectroscopic imaging (DW-LSEPSI) has been proposed, however, it requires some technical developments [1]. One of these developments is water suppression (WS). DW-LSEPSI uses short acquisition time for each line and repeats WS in a short period. Thus, the WS technique using a long period, such as chemical shift selective (CHESS) [3] using several pulses or WET [4], cannot be used effectively in DW-LSEPSI, and signal attenuation by WS is quite different in DW-LSEPSI compared to those in other SI using long TR.

In this paper, we present a WS technique for DW-LSEPSI. This technique uses a single CHESS pulse to fit in a short acquisition time and to reduce a water signal using a steady state effect of a short period. Suppression of the water signal is analyzed numerically and demonstrated by applying DW-LSEPSI, with this WS technique, to phantoms and a rat brain *in vivo*.

Methods

DW-LSEPSI uses line-scan and echo-planar techniques to acquire spatial and spectral information, and shifts the excited line shot by shot in a short period [1]. Developed DW-LSEPSI repeatedly adds a single CHESS pulse for WS at each acquisition of a line (Fig. 1). Thus, the signal attenuation ratio of water S_T can be represented by the following equations since it is under the steady state:

$$S_T(T1,TRw,FA,d1) = 1 - \left(1 - \frac{1-\exp(-TRw/T1)}{1-\cos(FA)\exp(-TRw/T1)}\cos(FA)\right)\exp(-d1/T1),$$

where TRw is the repetition time of the WS pulse, FA is the flip angle of the WS pulse and $d1$ is the interval between the WS pulse and π/2-pulse. The signal attenuation ratio S_T is calculated for $T1$ of 0 – 2 s, FA of 0 - 180˚, $d1$ = 25 ms, and $TRw = \infty$ for an isolated WS case and TRw = 250 ms for a typical case (Fig. 2). The results show that the water signal attenuates larger at TRw = 250 ms when FA and $T1$ increase. And, the range of FA to acquire sufficient water attenuation increases at TRw = 250 ms. This suggests that the TRw should be short to stably achieve sufficient WS.

We performed phantom experiments and a rat brain experiment *in vivo* using a 7-T MRI for a small-animal study. The phantoms P1, P1/2, P1/4 and P1/8 were bottles filled with 0.1%, 0.05%, 0.025% and 0.0125% Gd-DTPA solution, respectively, at 25°C. $T1$ of the phantoms and the rat brain were obtained using inversion recovery spin echo sequence. The measurement parameters of DW-LSEPSI were a TE of 136 ms, spectral bandwidth of 7.24 ppm (128 points), field of view (FOV) in the x direction of 40 mm (16 pixels) and y direction of 30 mm (12 lines), slice thickness of 2.5 mm, and the number of accumulations = 1. TRw = 3000 ms (TR = 36000 ms) and TRw = 250 ms (TR = 3000 ms) were used to compare the repetition effect of WS. A single CHESS pulse with a bandwidth = 0.67 ppm was used, changing its flip angle within the range of 0.0 - 2.0 times (0.1 step) of 90˚. A 300-g male Wistar rat anesthetized with isoflurane was used. The parameters were the same as above. Furthermore, to verify sufficient reduction in the water signal, metabolite signals were acquired using the number of acquisitions = 128 and the flip angle of the WS pulse = 117˚, which was found to be the optimum from the above experiment.

Results and Discussion

As shown in Fig. 3, the experimentally obtained signal intensities of residual water show good agreement with the numerically calculated signal intensities shown in Fig. 2. The lines were almost similar to those calculated using $T1$ of P1: 387 ms, P1/2: 686 ms, P1/4: 1116 ms, P1/8: 1602 ms, and that of the rat brain: 1426 ms. However, there were some differences between the experiments and numerical analysis: the minimizing flip angle and signal intensity at a flip angle = 0˚. The flip angle minimizing the residual water signal was different from numerical analysis because the power of the 90˚ pulse was not well adjusted in prescan. The difference between signal intensities with $TRw = \infty$and TRw = 250 ms at a flip angle of 0˚ is assumed due to the effect of excitation pulses added in a TR of 3000 ms when TRw = 250 ms, and the magnetization transfer effect further affects that *in vivo*. As shown in Fig. 4, a water signal can be sufficiently suppressed and a clear spectroscopic image can be obtained *in vivo*. The results will be useful in not only suppressing the water signal but also in leaving a small percentage of the water signal for tracking motion in diffusion weighting because the repetition of WS reduces the water signal less than that of isolated WS, and this reduction may be taken into account for leaving a small enough percentage of the water signal, especially at high b-values.

Conclusion

We calculated and demonstrated effective WS of DW-LSEPSI. The WS in a short period shows particular signal attenuation due to the steady state effect. The numerical analysis of WS will be useful in controlling a water signal to improve accuracy of DW-LSEPSI.

References

[1] Bito et al. ISMRM 2009:334. [2] Posse et al. ISMRM 2009:3521. [3] Haase et al. Phys Med Biol. 1985;30:341. [4] Ogg et al. J Magn Reson B. 1994;104:1.

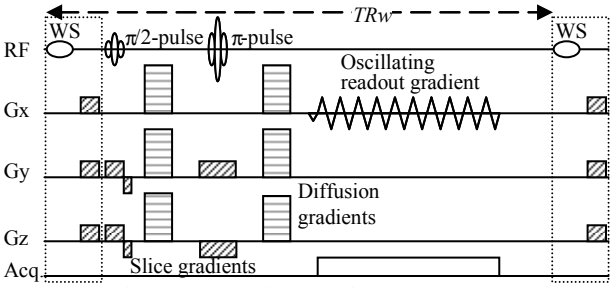

Fig. 1. Sequence diagram of DW-LSEPSI

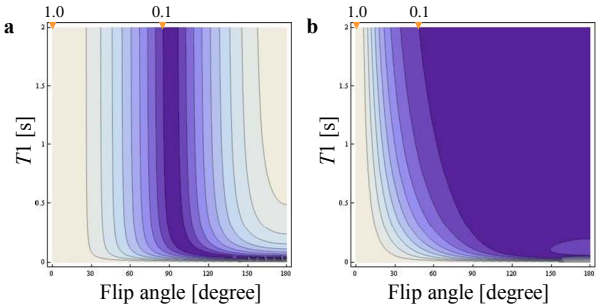

Fig. 2. Signal intensity attenuation ratio of water S_T vs. flip angle of water suppression pulse and $T1$: (a) $TRw = \infty$, (b) TRw = 250 ms

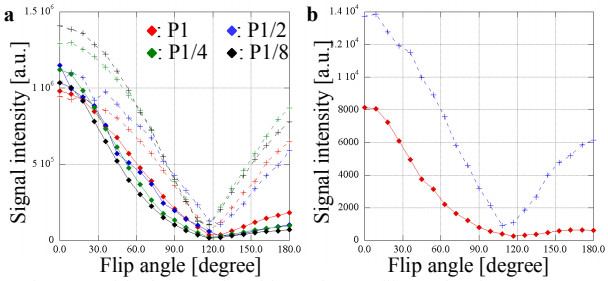

Fig. 3. Residual water signal intensity vs. flip angle of water suppression pulse in (a) phantoms, (b) rat brain. Dashed lines are TRw = 3000 ms and solid lines are TRw = 250 ms.

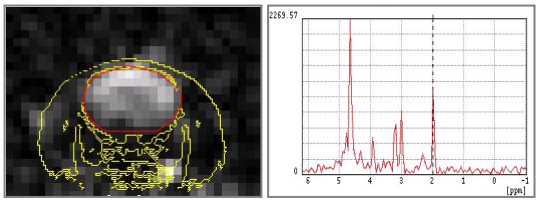

Fig. 4. SI of rat brain using DW-LSEPSI. Left image shows NAA concentration and right graph shows spectrum from brain. Water signal was sufficiently suppressed.