Using Absorption-Mode Images to Improve In Vivo DTI Quality

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Introduction

Diffusion MRI using a conventional Stejskal-Tanner spin-echo (DW-SE) sequence remains one of the best approaches in the rodent central nervous system (CNS) due to its unrivaled image quality and ease of use. Since SE sequences are hindered by lengthy scan times, a diffusion weighted multiple spin-echo (DW-MSE) variation has been introduced[1,2]. In this design, images from multiple echoes are combined in order to improve the signal to noise ratio (SNR) without increasing the imaging duration (Fig. 1). However, images combined using complex data can suffer from artifacts caused by phase variations resulting from the imperfect 180-pulse, diffusion weighting and physiological motion, whereas images combined using magnitude values suffer from non-gaussian noise distributions that can alter the diffusion measurements[3]. This is especially the case seen in the in vivo spinal cord images due to the profound respiratory motion induced phase variation (Fig. 2). Herein, we demonstrate the advantages of combining DW-MSE images using appropriately phased absorption-mode image[4] that eliminates phase artifacts and noise correlations of traditional DW-MSE.
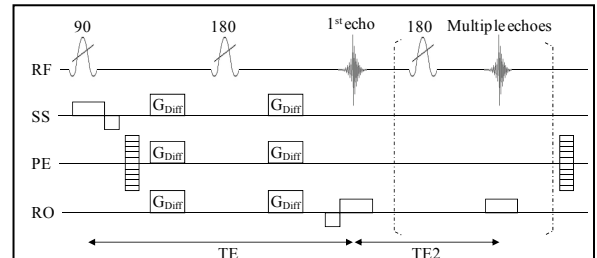

Fig. 1 DW-MSE pulse sequence. Note that the phase encode step and the diffusion gradient pair are outside the MSE acquisition loop ensuring each of the multi-slice MSE images undergoing the same diffusion weighting.

Material and Methods

The DW-MSE sequence is shown in Fig 1. Crusher gradients of alternating polarity were added in the slice-selection direction to eliminate the secondary echoes. The b factors for such a sequence can be considered additive for successive echoes. Bayesian probability theory was used to estimate a constant zero-order phase and two first-order phases[4]. Images for each echo were independently phased and the coherent signal was moved onto the real channel to eliminate the effect of phase variation. The phased diffusion weighted images were then added from multiple echoes for the calculation of diffusion tensor.

The MSE acquisition for diffusion tensor imaging (MSE-DTI) was first compared with SE-DTI on a water phantom (17°C), and then on the *in vivo* mouse spinal cords (T13, n = 3). The acquisition parameters were: TR ~1200ms, TE 28 ms, TE2 15ms; Δ 21 ms; δ 7 ms; b-value 0 and 1000 s/mm^2; FOV 1 × 1 cm^2, data matrix 128 × 128 zero-filled to 256 × 256; nt 1; 3 echoes for MSE-DTI, 1 echo for SE-DTI; diffusion encoding directions 6 for deriving the diffusion tensor. SNR = 0.66 × (Signal of white matter / SD of Noise) of the image. *In vivo* acquisition time was 20 min.

Results

The measured ADCs of a water phantom (images not shown) were not different between SE-DTI (1.88 ± 0.05) and MSE-DTI (1.87 ± 0.04, magnitude, and 1.87 ± 0.04, absorption). In vivo spinal cord experiments demonstrated the superiority of absorption-mode echo combination (Fig 2.). Compared to conventional DT-SE (ne = 1), the SNR increased by 18.2% using the magnitude-mode MSE-DTI (ne = 3) and increased by 49.8% using absorption-mode MSE-DTI (ne = 3). RA maps derived from the absorption-mode images provided the best gray/white matter contrast (Fig. 3) and had the least noise. Using a region of interest analysis of spinal cord white matter, RA values were not significantly different between SE-DTI (0.99 ± 0.03), magnitude-mode MSE-DTI (1.01 ± 0.01), or absorption-mode MSE-DTI (1.01 ± 0.03).

Discussions and Conclusions

Our results suggest that absorption-mode combination of MSE-DTI images yields a SNR increase of nearly 50% compared to SE-DTI images. Importantly, this increase in SNR comes without an increase in imaging duration and also reduces correlated noise and phase cancellation artifacts. Thus, the proposed method should benefit animal diffusion weighted imaging by substantially improving throughput or increasing spatial resolution.

References

1. Gulani et al., MRM, 1997, 38: 868-873; **2.** Mori et al., MRM, 1997, 37: 336-340; **3.** Kristofferson, JMR 2007, 187: 293-305. **4.** Bretthorst, Larry, JMR 2008, 191: 184-201.
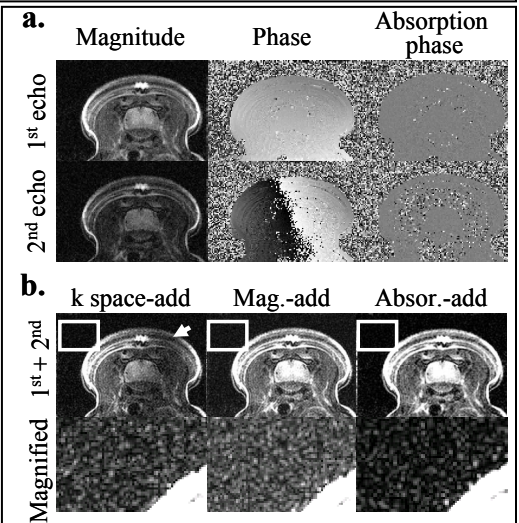
Fig. 2 (a) *In vivo* mouse spinal cord images of MSE-DTI images show severe phase variations between the first and second echoes. After phasing to generate the absorption-mode images, there is no phase difference between echoes. (b) When using the k-space data to combine MSE-DTI images, a dark stripe artifact appears (white arrow), that is caused by the incoherent phases between echoes. This problem can be solved by using magnitude images for combination. However, the resulting Rician noise distribution could bias the diffusion measurements. The absorption-mode image provides excellent tissue contrast without being affected by the Rician noise. The noise level of each image is shown by the magnified regions marked in white.
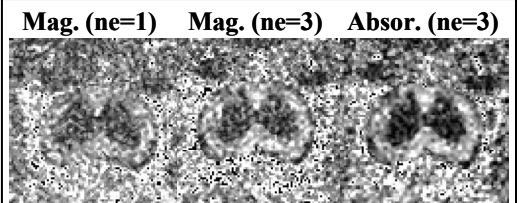

Fig. 3 The RA maps of mouse spinal cord are calculated by magnitude and absorption-mode images. The absorption-mode image shows the best image quality among the three groups, allowing the regions of interest being clearly identified.