Multi-Slice High Resolution Cerebellum Diffusion Tensor Imaging Using Pre-IR Inner Volume Excitation

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Introduction

Diffusion tensor imaging (DTI) is known to exhibit promising potential probing the cerebral white matter integrities [1]. Due to strong sensitivity of DTI to bulk motion, single-shot EPI is commonly used as the readout module for DTI. However, the long echo train in EPI acquisition leads to geometrical distortions in the presence of magnetic susceptibility effects, limiting the achievable spatial resolution.

Reduced field of view (rFOV) imaging accompanied with inner volume excitation or outer volume suppression has been proposed to effectively minimize the geometric distortions in EPI [2-5]. In this work, we propose an alternative inner volume excitation scheme which could achieve multiple slice acquisition with relatively less compromise in SNR loss. High resolution diffusion tensor imaging in the cerebellum was performed to demonstrate the unique advantages of the proposed technique.

Material and Methods

The pulse sequence diagram as shown in Fig.1 was performed for multi-slice rFOV imaging. A non-selective inversion hard pulse was utilized followed by the excitation. A 7-lobe selective refocusing pulse with optimized slice selection profile was applied along the phase encoding direction. EPI acquisition was adopted for sampling the image data. In addition, two crusher gradients clipping the selective refocusing pulse were added to minimize contaminations from imperfect refocusing and from outside of the FOV. Consequently, the contribution to the echo signal would solely come out from the cross section intersected by the excitation and refocusing pulses. For the multiple-slice scheme, each excitation sequence is equally separated in time within one repetition duration (TR).

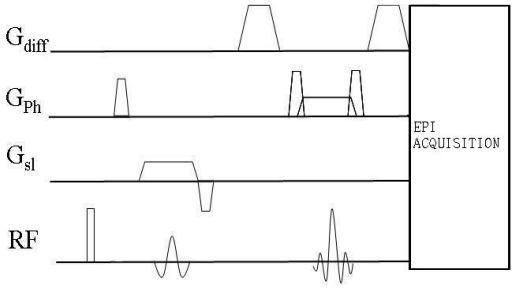


Fig 1. Pulse sequence diagram of pre-IR rFOV excitation scheme. The refocus pulse was slice-selective along the phase encoding direction

Volunteer experiments were performed on a 3.0 T Philips Achieva system. A six-direction DTI sequence was adopted with fourteen continuous slices selected along the sagittal orientation covering the cerebellum. The acquisition matrix was 256x84 with slice thickness 3 mm, leading to a resolution of 0.84x0.84x3 mm^3. TE was 74 ms with TR set to 7500ms. The b value for DTI was 700 s/mm^2. Partial Fourier reconstruction of the factor 0.6 was also applied to shorten the acquisition length. Sixteen averages were acquired to increase SNR.

Since the magnetization inside the volume of interest is irradiated by all the inversion and echo pulses throughout the entire sequence, the effects of all RF pulses on signal evolution have to be evaluated to achieve uniform signal intensity among all slices without prominent signal loss. Assessment of the evolution of magnetization in different slices was investigated using computer simulation with identical parameters as used in the experiment design. The T1 value was set to 1100ms as reported in the literature for white matter.

Results

The longitudinal magnetizations of different slices before being excited, which determines the signal intensity, are plotted in Fig.2(a) versus the number of excitations. Results from Fig.2(a) suggest that SNR becomes similar throughout all slices immediately following the second excitation, suggesting good signal uniformity. Fig.2(b) shows the signal recovery results after experiencing the excitation and refocusing pulses, where is seen that nearly 84% of the magnetization can be restored for TR greater than about 4500ms, thus maintaining sufficiently high SNR even under the effects of the sequential inversion pulses.

The color FA maps of the sagittal slices of the cerebellum are presented in Fig.3(a). The RGB color scheme indicates the three directions of right-left (anatomical anterior-posterior), top-down (anatomical superior-inferior), and through-plane (anatomical medial-lateral), respectively. The whisker plot (color stick along the principal direction with FA > 0.25) overlaid on the FA map of the cerebellum is also demonstrated in Fig.3(b) for the ninth slice.

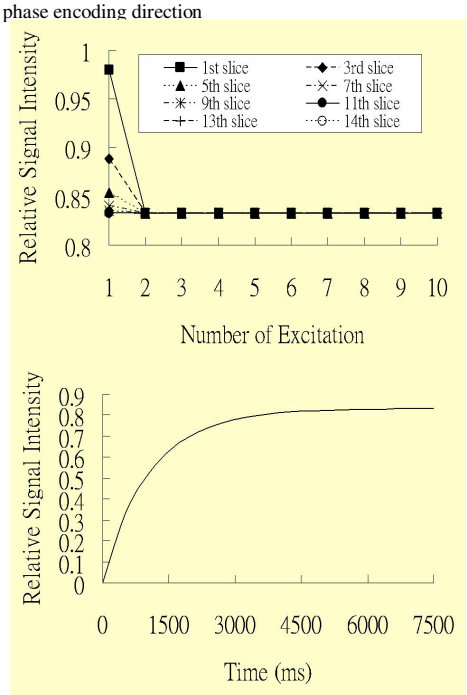
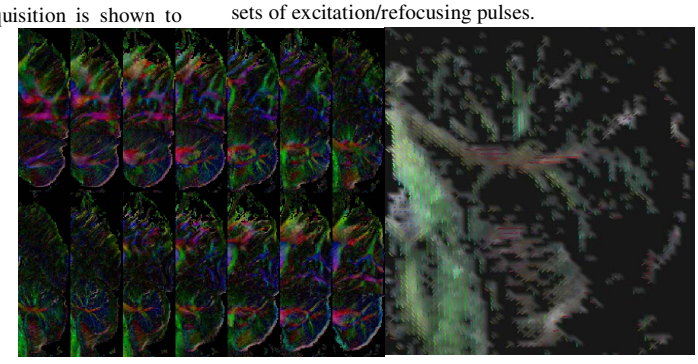


Fig 2. (a) The magnetization evolution of each slice at each excitation. (b) The recovery of longitudinal magnetization is plotted versus TR containing 14 sets of excitation/refocusing pulses.

Discussion

The sequential inversion pulses accompanied with T1 relaxation affects the signal in the volume of interest as expected. Nevertheless, the simulation results show that the SNR throughout all slices becomes consistent after the second excitation. In addition, the longitudinal magnetization after image data acquisition is shown to recover to 84% of the thermal equilibrium level available for the next excitation. Therefore, this excitation scheme could achieve rFOV imaging with relative less compromise in SNR loss.

The geometric distortion in EPI sequences is known to be a severe limiting factor in the presence of magnetic field inhomogeneity. Our work suggests that inner volume excitation for DTI could effectively shorten the acquisition duration for regional imaging without using parallel acceleration, thus alleviating possible parallel imaging-related unfolding artifacts [6]. Alternatively, our rFOV scheme is compatible with parallel imaging in nature, hence providing ample room for further reduction in EPI geometric distortions. Compared with full FOV imaging, the rFOV method is advantageous in that the reduced shimming volume for this technique facilitates easier regional shimming for better field homogeneity than its full-FOV counterpart, where whole-brain volume shimming has to be performed.



(a) (b)

Fig 3. (a) Color-coded FA maps obtained for the cerebellum. (b) The color coded whisker plot magnified to represent the detail orientation of fiber bundles in cerebellum for the ninth slice.

References

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