Diffusion imaging of human vertebrae in vivo with a non-CPMG single shot fast spin echo technique

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Introduction

Diffusion weighted (DW) magnetic resonance imaging measures the mobility of tissue water on a microscopic level and has been successfully used in the management of patients with acute stroke and brain tumor. Recently, DW images and corresponding images of apparent diffusion coefficients (ADC) were also found useful to help differentiate benign from malignant vertebral compression fractures [1-2]. DW imaging of spine, however, is technically challenging because the standard echo-planar based technique is highly sensitive to magnetic field inhomogeneity (in single shot mode) and to motion (in multishot mode). As a result, several other techniques, such as steady-state free-precession, line scan, PROPELLER, and displaced single-shot fast spin echo (ssFSE), have been investigated for their potential as an alternative.

In this research, we demonstrate the feasibility of using a newly-developed non-CPMG ssFSE [3-4] to acquire DW images of human vertebrae in vivo. The new technique employs a quadratic RF phase modulation to emulate the action of perfect 180^o refocusing pulses and therefore does not suffer from the 50% signal loss as incurred by the displaced ssFSE technique. Our preliminary results show that the new technique can be used for acquiring artifact-free DW images of the spine and for subsequent generation of ADC maps.

Methods and experiments

The Carr Purcell Meiboom Gill (CPMG) condition required in conventional fast spin echo (FSE) is usually violated when DW gradients are added to FSE. To preserve the CPMG condition, Norris et. al and Alsop [5-6] proposed to eliminate one of the two transverse signal components after DW weighting. An obvious drawback of their approaches is the 50% signal loss compared to the conventional FSE. The technique used here was based on the works of Murdoch [7] and Le Roux [3]. Instead of attempting to satisfy the CPMG condition, quadratic phase modulation of the refocusing RF pulse train is used to relax the CPMG condition because it emulate the action of perfect 180^o refocusing pulses.

The original implementation of the technique is described elsewhere by Le Roux et. al. [4]. Aside from the diffusion gradients, the gradient waveform used here was identical to that in conventional FSE. The transmitter phase for the refocusing pulse train, however, was modulated quadratically so that the sequence does not rely on the stringent CPMG condition. As a penalty, the quadratically phase-modulated non-CPMG technique requires theoretically double sampling of at least half of the k-space. Additionally, certain "overscan" phase encoding steps, which could lead to significant increase in minimum echo time and thus a reduction in signal-to-noise ratio, are needed to model the phase of receiver coils. For this work, only two "overscan" lines were used and found to be sufficient because the receiver phase information was derived largely as a part of prescan calibration.

The modified non-CPMG ssFSE pulse sequence was evaluated on a normal volunteer and a patient using two 1.5 Tesla clinical scanners (GE Medical Systems, Milwaukee, WI). The pulse sequence ran in single shot mode, with the following imaging parameters: field-of-view (FOV) = 32x16 cm, acquisition matrix = 128x64, slice thickness = 4mm, slice gap = 1mm, receiver bandwidth = 125 kHz, b = 350 s/mm^2, eight signal averages. Typically, five slices were acquired in 3:30 – 4:30 minutes. For both volunteer and patient studies, a CTL spine phased array coil (USA Instruments, Ohio) was used. At the end of data acquisition, the reconstruction algorithm automatically generated five images per slice, corresponding to T2-weighted, three diffusion-weighted (along each of the three physical axes), and a diffusion trace weighted images. The T2 and diffusion trace weighted images were then used to calculate an ADC map for each slice location.

Results

Fig. 1a, b, c) show respectively the T2-weighted, diffusion trace-weighted, and ADC images for the patient, who has basal cell carcinoma of anterior mid-chest with metastasis to thoracic spine at the location of T4 and T11. The images were acquired with minimum echo time of 91ms at a scanner with 2.2 Gauss/cm and SR 120 gradients. For the volunteer study (not shown) at another scanner with 4.0 Gauss/cm and SR 150 gradient, a minimum echo time of 72ms was achieved for the same imaging parameters. The two lesions (arrows) were slightly hyperintense on T2-weighted image, nearly isointense on DW image and clearly hyperintense on the ADC map. The mean ADC values for two ROIs placed at T4 and T11 were measured to be 0.0015 mm^2/s and 0.0013 mm^2/s, respectively. These values were consistent with neoplastic lesions according to Ref. [2].

Conclusions

The non-CPMG ssFSE sequence with diffusion weighting is capable of generating artifact-free DW and ADC images of human vertebrae in vivo and thus believed to be potentially useful to help characterizing vertebral compression fractures. Because it is single-shot and based on FSE, the technique could also be useful for study of tumors that are located at other body parts where echo planar based technique is not readily applicable.

References

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