Mixed-CPMG Radial-FSE for Diffusion Imaging at 3T

J. E. Sarlls[1], T. P. Trouard[2], and C. Pierpaoli[1]
[1]NICHD, National Institutes of Health, Bethesda, MD, United States, [2]Biomedical Engineering, University of Arizona, Tucson, AZ, United States

Introduction

Radial fast spin-echo (radial-FSE) data acquisition in combination with magnitude filtered-backprojection (FBP) can produce high-resolution diffusion-weighted images that are insensitive to both motion and magnetic field inhomogeneities [1]. The latter feature is particularly desirable at higher field strengths where susceptibility artifacts are particularly problematic. However, in diffusion weighted imaging, decreases in echo magnitude within FSE echo trains due to violation of the CPMG condition are challenging, especially at higher field strengths where there is increased B1 inhomogeneity and where less than 180° refocusing pulses often used. Under these conditions, the CPMG method [2], which uses constant phase refocusing pulses within the echo train, can result in significant loss in echo magnitude within the echo train. A simple mixed-CPMG FSE phase cycling, that alternates the phase of the refocusing pulses between $180_x°$ and $180_y°$ has been reported to yield a stable echo magnitude for 16-32 echoes [3]. This work evaluates the use of this phase cycling in a diffusion-weighted radial-FSE sequence.

Methods

A diffusion-weighted radial-FSE sequence was adapted to include an alternating phase of excitation throughout the train of refocusing pulses (mixed-CPMG), including the 180° RF used in the Stejskal-Tanner diffusion-weighted preparation period. To emphasize the effects on echo magnitude, the refocusing pulses in the echo train were set to 160°. One consequence of the mixed-CPMG method is that the phase of every other odd and even echo is the opposite of the other odd and even echoes, which requires manipulation of the data before reconstruction. This manipulation is not necessary for radial data reconstructed with magnitude FBP as only the magnitude of the data is used. Data were collected on a 3T GE Excite scanner, with gradients capable of 40 mT/m using a standard quadrature head coil. A 3 mm axial slice from a simple bottle of saline was scanned with the conventional CPMG echo train and mixed-CPMG echo train with the following parameters: TR/TE_{eff} = 2000/102 ms, ETL=8, FOV=24 cm, 256 readout points, 256 radial lines, δ = 9.5 ms, and Δ = 37ms.

Results

The magnitude of the center point of echoes for a single TR period at different b-values and diffusion weighting directions is plotted in Fig.1. For the b = 0 data collected with a CPMG echo train (Fig.1a) the echo magnitude essentially follows a T_2 decay curve, whereas the mixed-CPMG data (Fig.1b) has an increase in peak magnitude in the middle of the echo train. When diffusion weighting is added to the sequence, the echo magnitude rapidly decays along the conventional CPMG echo train with discrepancies between direction of diffusion. The echo magnitude in the mixed-CPMG echo train is more stable, though oscillations in intensity are observed. Although there is less directional discrepancy, some bias still exists, e.g. the minimum echo magnitude for weighting in the Y-direction is lower. Images reconstructed from CPMG and mixed-CPMG acquisitions are shown in Fig.2. The intensity of the phantom collected with diffusion weighting and a CPMG echo train has non-uniform areas of shading and has an overall intensity that is considerably lower than data collected with the mixed-CPMG echo train. The b = 0 images are more similar in intensity, although there is some shading in the CMPG image compared to the mixed CPMG image.

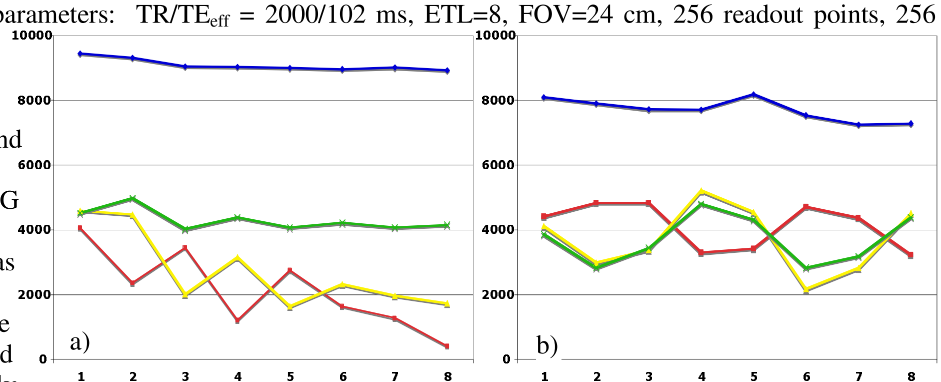

Fig. 1. Plots of the magnitude of the echo center point for data collected in a single TR with CPMG (a) or a mixed-CPMG (b) echo train. **Blue** lines correspond to a b-value=0 s/mm^2. B-value=730 s/mm^2 on the X-axis (**red**), Y-axis (yellow), or Z-axis (**green**).

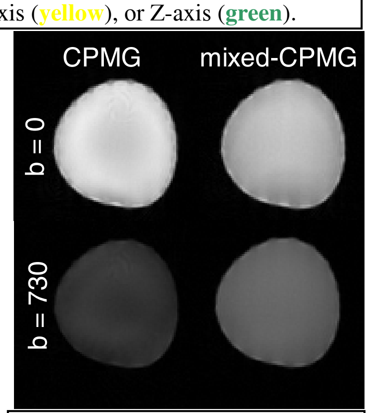

Fig. 2. Images from the datasets with b = 0 and 730 s/mm^2 diffusion weighting on the X-axis.

Discussion

The violation of the CPMG condition for diffusion-weighted FSE sequences at 3T is substantial. A simple phase cycling within the echo train is effective in reducing signal decay within the echo train. However, oscillations in echo intensity remain and appear to be dependent on the direction of the applied diffusion gradients. It is possible that the eddy currents generated from the diffusion gradients are partly responsible for the violation of the CPMG condition, the specific form of which, is dependent on the specific eddy current generated. Artifacts from signal variation in radial-FSE can be minimized with appropriate view collection order so that oscillation within the echo train may not be problematic. Adopting the mixed-CPMG phase cycling method for diffusion-weighted radial-FSE is a step towards using this type of sequence for performing quantitative high-resolution diffusion imaging, i.e. DTI, at 3T.

References: [1] Trouard *et. al.,* MRM, 42:11, 1999. [2] Meiboom *et. al.*, Rev. Sci. In., 29:688 1958. [3] Pipe *et. al.,* MRM, 47:42, 2002.