High-resolution Diffusion Tensor Imaging at 3T with Radial-FSE

J. E. Sarlls[1], and C. Pierpaoli[1]

[1]NICHD/LIMB/STBB, National Institutes of Health, Bethesda, MD, United States

Introduction

For high-resolution diffusion tensor imaging (DTI), collecting diffusion-weighted images (DWIs) images at 3T or higher fields could compensate for smaller voxels with an inherent gain in signal-to-noise ratio (SNR). However, at high field there is an increase in susceptibility effects, which degrade the quality of single-shot echo planar images (EPIs) near air/tissue interfaces. The goal of this work is to produce very high-resolution DWIs (voxel size < 1mm^3), suitable for clinical DTI mapping at 3T, free from artifacts in areas of elevated susceptibility. To accomplish this goal we use a radial fast spin-echo (FSE) acquisition, which has been shown to produce high-resolution DWIs that are insensitive to both susceptibility and bulk motion at lower field [1]. At 3T, however, there are additional obstacles to overcome. For example, there is a decrease in B_1-homogeneity, which is problematic for diffusion prepared FSE sequences as they often violate the CPMG condition, resulting in exaggerated echo decays. We show that a successful strategy involves implementing an approach that combines a mixed-CPMG phase cycling scheme [2], to mitigate the violation of the CPMG condition for FSE sequences with a diffusion preparation, and a wider refocusing than excitation slice [3], to mitigate the lack of B_1-homogeneity.

Methods

The diffusion-weighted radial-FSE sequence consists of a Stejskal-Tanner diffusion preparation period followed by a train of 180° RF refocusing pulses with a mixed-CPMG phase cycling scheme that alternates the RF phase between the x' and y' axes. By introducing a user-controlled variable for the refocusing slice gradient, a refocusing slice that is wider than the excitation slice was incorporated and was found to greatly reduced oscillations in the echo decay curve when the refocusing slice width was ≥300% of the excitation slice. Data was collected on a 3T GE Excite scanner, with gradients capable of 40 mT/m. A 1% agarose gel phantom doped with 0.025% by volume of ProHance gadoteridol, was scanned to test the accuracy of diffusion measures. Diffusion-weighed EPI data were collected for comparison. Scan parameters were 1 mm^2 in-plane, 3mm slice thickness, b-value=500 s/mm^2 with TE/TR = 62/2000ms and ETL = 8 for radial-FSE, and TE/TR = 100/3000ms and NEX = 4 for EPI. For *in vivo* brain imaging scan parameters were 1 mm^2 in-plane, 1.5mm slice thickness, b-value=1000 s/mm^2 with TE/TR = 82/3000ms, NEX = 4, and 10 reps for EPI; the radial-FSE data were collected using peripheral gating to minimize effects of cardiac pulsation with TE= 62, ETL=4 and the subjects heart rate was ~50 BPM, yielding a TR~1200ms for a total scan time equal to that of the EPI data. The image resolution of the radial sequence can be higher but for this work we limited the resolution to the highest achievable by the manufacturer's EPI sequence used for comparison.

Results

FIG. 1 shows the average echo magnitude at each echo point for data collected using the radial-FSE sequence with mixed-CPMG phase cycling and the default 150% wider refocusing than excitation slice (red) and 300% wider refocusing slice (blue), in addition to radial-FSE using a conventional CPMG phase cycling (green). As expected, the CPMG curves with b=500 have a more severe decay yielding ADC=1/3 trace(D)=2.66x10^{-3} mm^2/s, a value significantly higher than that expected for water at room temperature. The mixed-CPMG phase cycling with the default slice width reduces the echo decay yielding ADC=2.12x10^{-3} mm^2/s, but the remaining variance in echo attenuation for different directions is still problematic for anisotropy calculations. When a 300% wider refocusing slice is used the decay along the echo train is smooth, without oscillation, regardless of diffusion weighting or direction; in addition, the SNR increases by a factor of 1.7. A six diffusion direction DTI data set collected with a 300% wider slice had an ADC=2.03x10^{-3} mm^2/s and FA=0.05, comparable to that calculated form the EPI DTI data of ADC=2.07x10^{-3} mm^2/s and FA=0.07. FIG. 2 shows Trace and DEC anisotropy maps calculated from EPI (FIG. 2a,top row) and radial-FSE (FIG. 2b, bottom row) six diffusion direction DTI data sets. The Trace images computed from the EPI data show marked susceptibility artifacts and geometric distortions both in the Pons (yellow arrow) and in the temporal lobes. The corresponding DEC maps appear blurred in these regions. Geometric distortion and susceptibility artifacts are virtually absent in the radial-FSE images. DEC maps of the Pons at 4x magnification, shown on the right side of each panel, highlight the anatomical information lost in the EPI images. For example, in data acquired with the radial-FSE sequence (FIG. 2b) bundles of descending motor fibers (blue), and a group of transverse pontine fibers positioned anteriorly to them (red) in the ventral portion of the Pons are all visible. In the corresponding data acquired with the EPI sequence (FIG. 2a) the red ventral transverse fibers are completely absent and there is a significant loss of the adjacent descending motor fibers.

Conclusion

A modified diffusion-weighted radial-FSE sequence has been presented for imaging at 3T that employs both mixed-CPMG phase cycling and use of a refocusing slice that is 300% wider than the excitation slice. With these modifications, high resolution DTI of less than 1mm^3 voxels may be obtained of structures near air/tissue interfaces that are currently impossible to image accurately with EPI. To our knowledge this is the first work that demonstrates successful DTI mapping with a radial-FSE acquisition at 3T.

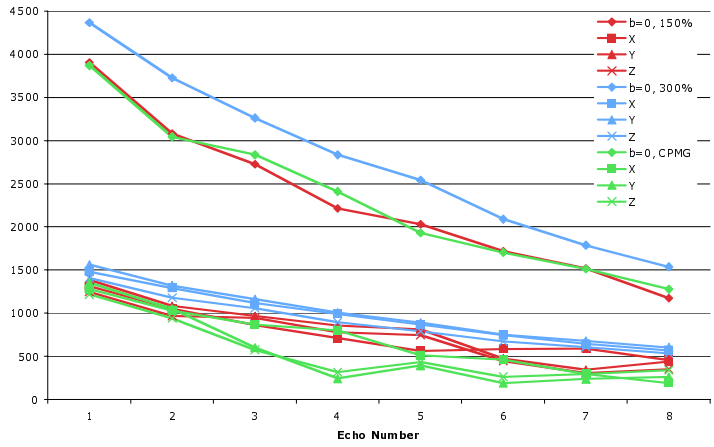

FIG 1. Plots of the average echo magnitude of radial-FSE data sets collected using the mixed-CPMG with 150% (red) and 300% (blue) wider refocusing slice, and conventional CPMG phase cycling (green).

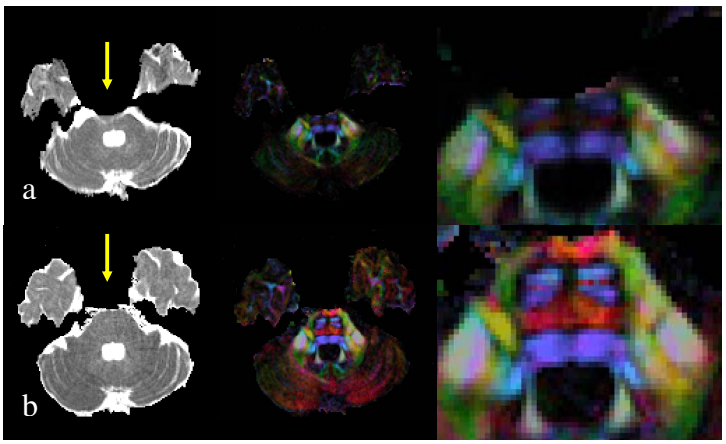

FIG 2. DTI data sets of a normal volunteer collected with single-shot EPI, **a**, and the modified radial-FSE sequence, **b**. Trace, DEC, and 4x magnified images of the brainstem region are shown.

References: [1] Trouard *et. al.,* MRM, 42: 11-18, 1999. [2] Pipe *et. al.,* MRM, 47: 42-52, 2002. [3] Pell *et. al.*, JMRI, 23:248-252, 2006.