Fractional and Relative Anisotropies Are Depended on Selecting the EPI Readout Gradient Modulation Frequency at 4 Tesla MRI.

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Introduction

Diffusion tensor magnetic resonance imaging (DT-MRI) (1) is generally performed using an echo planar imaging (EPI) acquisition to map directional water diffusion (2). However, the oscillating magnetic field gradients of the EPI acquisition can result in considerable mechanical vibrations which lead in turn to magnetic field fluctuations causing Nyquist ghosting in the EPI data (3, 4). The bandwidth (BW) and frequency of oscillations (i.e. echo spacing, ES) of EPI acquisitions should be chosen carefully to avoid triggering resonant mechanical vibrations and to reduce acoustic noise (5). Hence, the range of bandwidth and echo spacing variations at high magnetic fields can be too limited to effectively eliminate N2 ghosting with detrimental effects on quantitative MRI, such as DT-MRI. However, the impact of N2 ghosting on diffusion tensor measures, especially on fractional anisotropy (FA) and Trace of the diffusion tensor has not thoroughly been evaluated. The objective of this study, therefore, was to investigate effects of EPI readout gradient modulation frequency, which is directly associated with the EPI readout bandwidth, on the accuracy of DT-MRI measurements at a high magnetic field system.

Methods and Materials

All data were acquired using a 4 Tesla MRI system (Bruker/Siemens MedSpec, Germany) for both phantom and human studies.

Phantom Studies: A spherical water phantom was used to study the relationship between the EPI bandwidth and the Nyquist ghost for a spin echo (SE) EPI acquisition with a matrix size of 128x128, complemented by diffusion sensitization gradients of up to b = 800 sec/cm^2 along six directions for DT-MRI. We acquired SE EPI data with a matrix size of 128x128 and five 5mm thick transversal slices and 10mm gaps between slices. The EPI readout bandwidth was varied from 0.798 kHz/pixel (ES= 1.32 ms) to 2.170 kHz/pixel (ES= 0.71 ms). To analyze the phantom data, we manually drew a region of interest (ROI) in the three middle slices in the background area where the N2 ghosts were most prominent to obtain the mean and standard deviation. The resulting data were analyzed to determine the relationship between the magnitude of the N2 ghost and the readout bandwidths and to select three ideal or non-ideal bandwidths.

Human Brain Studies: Nine volunteers (4 males, 5 females) were studied using the SE EPI sequence at three different bandwidths. For the DT-MRI study on the human brain, forty imaging slices, each 3mm thick and with a 1mm gap between slices, were acquired. Other imaging parameters for DT-MRI were the same as phantom studies. DT-MRI was repeated with three different EPI readout encoding bandwidth settings that were 1.260 (ES=0.86ms), 1.446 (ES=0.76ms), and 2.170 (ES=0.71ms) kHz/pixel, based on the results from phantom studies. Maps of FA, RA, and Trace were calculated from DT-MRI data [14]. Two ROIs were defined the outside and inside brain areas to obtain mean and standard deviation of all maps and images. We tested two issues: 1) whether N2 ghosting was a function of both directionality of diffusion encoding and bandwidth variations, as well as their interactions. 2) The extent to which composite indices of diffusion, such as FA, RA, and Trace were impacted by variations of bandwidth.

Results

Phantom Studies: The phantom studies demonstrated a systematic relationship between bandwidths and the intensities of Nyquist ghosts. ANOVA showed significant effects by both bandwidths (F=168.7, p=0) and slices (F=24.4, p<0.00001). With the post-hoc test for the three slices (slice 2-4), there were significant differences between slice 4 and 2 or 3, but there was no significant difference between slice 2 and 3. Starting at low bandwidth BW=1.45 kHz/pixel (ES=0.77 ms), the magnitude of the N2 ghost increased steadily with increasing EPI readout bandwidths until the intensity of the artifact stabilized at BW= 2.170 kHz/pixel, corresponding to an EPI echo spacing of 0.71 ms. In the DT-MRI of the phantom study, the ANOVA test shows no significant effects on slice positions for b=800 data (F=3.952, p=0.02) and for b=0 data (F=3.20, p=0.05). However, there were significant effects on the bandwidths for the b=800 data (F=2035, p<0.000001) and for the b=0 data (F=207.4, p<0.000001). The magnitudes of the N2 ghost between the six diffusion encoding directions were no significantly different (F=0.753, p=0.58) for b=800 data. The magnitude of the N2 ghost between b=0 and b=800 was significantly different (F=223.4, p<0.000001).

Human Studies: EPI bandwidth variations substantially corrupted diffusion anisotropy indexes (i.e. FA and RA) (F=10.5, p=0.0001). In contrast to FA and RA, Trace did not significantly vary as a function of bandwidth (F=1.48, p=0.25). On the b0 images with the ROI of the inside brain, there was no significant difference (F=0.34, p=0.71). On the b=800 images with the inside brain ROI, the ANOVA test showed a significant effect by bandwidths (F=8.57, p=0.0003), independent of diffusion encoding directions (F=0.14, p=0.98). It was possible to minimize bandwidth dependence (F=1.48, p=0.25) by tuning the modulation frequency of the EPI readout gradient.

Discussions and Conclusions

We expect that the N2 ghost effect could be less on both 1.5T and 3.0T MRI systems than that on 4.0T MRI if the gradient system is identical. Diffusion anisotropic indexes of DT-MRI data are sensitive to the readout bandwidth of EPI due to associated Nyquist ghosting. Therefore, the selection of the EPI readout encoding bandwidth is critical to mapping the diffusion anisotropy. However, the effect can be minimized by tuning the modulation frequency of the EPI readout gradient. The results further showed that N2 ghosting induced by bandwidth variations was unrelated to the diffusion encoding directions. This should substantially simply potential retrospective corrections of diffusion measurements in presence of N2 ghosting.

Conclusion: N2 ghosting in EPI can markedly interfere with measurements of diffusion, especially for FA and RA. To the extent to which N2 ghosting is related to characteristic mechanical vibrations of the gradients during EPI, the effects can effectively be minimized by tuning the modulation frequency of the EPI readout gradient.

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References

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