View Angle Tilting for Distortion Compensated EPI: Effects of RF Pulse Width on Image Blurring and Slice Profile

Cheng Li¹, Felix Wehrli¹, and Hee Kwon Song¹
¹Radiology, University of Pennsylvania, Philadelphia, PA, United States

Introduction: Echo planar imaging (EPI) is often the preferred imaging sequence when rapid data acquisition is essential. The primary drawback of the EPI sequence is that the technique is sensitive to off-resonance effects, such as B₀ and susceptibility-induced field inhomogeneities and chemical shift. These effects cause local image distortions or displacements, primarily along the phase-encoding direction. Various strategies have been proposed to reduce these distortions. In multi-shot EPI, the long echo train of a single-shot EPI is split among two or more separate shots, effectively reducing the distortions by factor equal to the number of shots. With this approach, however, the total imaging time is proportionally increased and the method becomes more sensitive to motion. Various post-processing strategies have also been proposed [1-2], but these methods typically require additional data. Recently, the method of view-angle tilting (VAT) for distortion-correction in the frequency-encoding direction [3] was extended to EPI for the phase-encoding axis [4-5].

Methods: Figure 1 shows the VAT-EPI sequence implemented in this work. It is a standard EPI sequence with two differences: First, a VAT gradient is applied along the slice-encoding axis, as is done in original VAT technique [3]. However, whereas the VAT gradient is relatively short when used with conventional spin- or gradient-echo imaging (since the readout period is short), a much longer pulse is played out during the entire EPI readout period. One difference of the current implementation compared to that of previous reports is the use of a constant VAT gradient in lieu of a series of blips. A constant gradient is simpler to implement (the amplitude should equal that of the slice-encoding gradient), and has the advantage that any distortions along the readout axis is also corrected, albeit they are expected to be small. Relevant imaging parameters include: 64x64 matrix, 660us echo spacing, 2.5us dwell time, 42 ms echo train length. For this work, the RF pulse width (sinc with one sidelobe on each side) was varied to investigate its effects on image sharpness.

In order to evaluate the slice profile of the VAT-EPI sequence for different pulse widths, identical excitation pulses were incorporated into a gradient echo sequence and the frequency and phase encoding axes rotated in order to image the slice profile. Phantom experiments were carried out on a Siemens 1.5T system.

Results and Discussion: Figure 2 shows phantom images acquired with a standard gradient echo and EPI sequences, showing high levels of image distortions in EPI due to susceptibility-induced field inhomogeneities. Figure 3 compares VAT-EPI images and the corresponding slice profiles for different RF pulse widths. The effectiveness of the VAT technique is clear in removing the in-plane image distortions. However, image blurring becomes problematic unless longer RF pulses (with lower bandwidths) are utilized. However, the lower RF bandwidths cause the slice profiles to become increasingly distorted. One common misconception is that the blurring in VAT is due to partial voluming effects caused by the tilt angle. However, as was reported previously, the blurring is in fact caused by through-plane spin dephasing and subsequent k-space modulation during the readout period [6]. This is confirmed by the fact that for the shortest RF pulse width, the image is completely blurred out and spans the entire FOV, something that cannot be explained by partial voluming effects. Some residual N/2 ghosting, unrelated to the VAT phenomenon, is also visible.

Conclusion: This work describes the implementation of the VAT methodology for EPI sequences as a means to eliminate in-plane distortions. As the results demonstrate, an RF pulse length on the order of the duration of the total EPI readout period is required to minimize image blurring due to through-plane spin dephasing during the echo-train readout. However, there is a cost associated with the strategy: the trade-off between in-plane blurring and slice profile distortion.

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