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

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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 B_o 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]. The primary pitfall of VAT-EPI, however, is the image blurring that can occur if the excitation pulse is not sufficiently long. This issue has previously not been addressed. In this work, the effect of excitation pulse width of a VAT-EPI sequence on image blurring is evaluated, as well as its implication on the slice profile.

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.

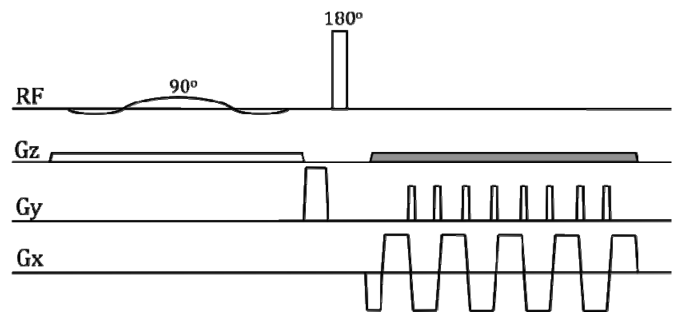

Fig. 1 VAT-EPI sequence. Compared to standard EPI, there is an additional slice-axis gradient (shaded) applied during the entire readout period and the RF excitation pulse is elongated to reduce k-space modulation during the EPI readout.

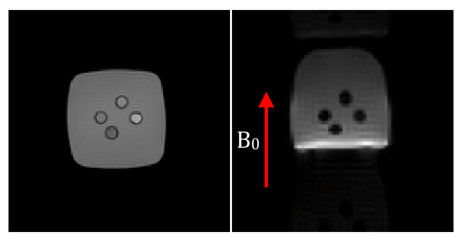

Fig. 2 Coronal gradient echo (left) and conventional EPI (right) images. Signal in the four vials are reduced in EPI due to their short T_2s.

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.

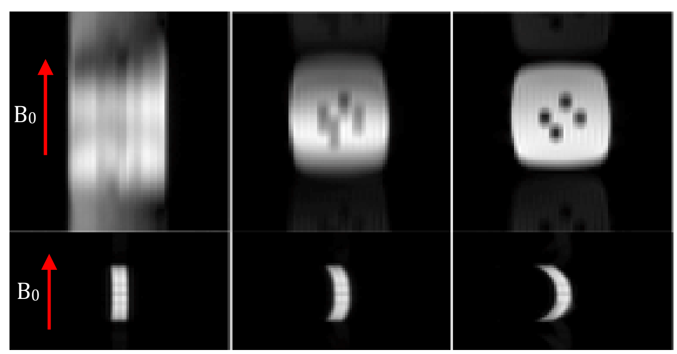

Fig. 3 Coronal VAT-EPI images (top row) and corresponding slice profiles (bottom row) for excitation RF pulse widths, from left to right, 4.3, 18.7, 43.6 ms. For the slice profiles, a coronal slice-selective excitation was followed by a sagittal projection acquisition.

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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References: (1) P Jezzard et al, Magn Reson Med 34:65-73, 1995. (2) JY Chiou et al, IEEE Trans Med Imag 22:200-2005, 2003. (3) ZH Cho et al, Med Phys 15:7-11, 1988. (4) L Yan et al, ISMRM 2009; 2782. (5) S Ahn et al, ISMRM 2011; 2699. (6) K Butts et al, Magn Reson Med 53:418-424, 2005.