Reduction of Blurring in View Angle Tilting MRI

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Abstract View Angle Tilting registers off-resonance shifts with a gradient on the slice selection axis during readout. Unfortunately, VAT is known to suffer from blurring, and it has been thought that this was due to the view angle. Here, we demonstrate that the major source of blurring with VAT is not the view angle, but amplitude modulation by the transform of the slice profile. We provide one solution with an optimized RF pulse.

Introduction View Angle Tilting[1] has been used for reducing distortions around prostheses[2] and interventional devices[3]. With VAT, off-resonance shifts occurring during readout are compensated by slice shifts. This is done by applying a gradient on the slice selection axis during the readout and of equal amplitude to the slice select gradient. Blurring with VAT is in part due to the view angle $\Theta=\mathrm{atan}(G_z/G_x)$ which can be reduced by increasing the readout bandwidth or reducing the excitation bandwidth.

An additional and larger source of blurring with VAT which has not been previously recognized is the modulation of the receive signal by the transform of the slice profile as k_z is traversed with the VAT gradient. For a conventional sinc RF pulse of duration 3.2 ms and a readout duration of 8 ms, this modulation is a severe low pass filter. The purpose of this work was to demonstrate this source of blurring and provide one method to reduce it with an optimized RF pulse.

Methods The ideal RF pulse has a duration equal to the readout duration, has a positive amplitude throughout, and is without a reduction in bandwidth. We designed an equiripple pulse and optimized it with zero flipping to maximize the minimum signal during the echo. This is similar to optimization by minimizing the maximum received signal described by Pauly[4]. The optimized VAT pulse has a time-bandwidth product of 6 and a duration of 8 ms, for a bandwidth of 750 Hz. There is an approximately quadratic phase across the slice[5]. The pulse was incorporated into a VAT spin echo pulse sequence as the excitation pulse. The excitation bandwidth was comparable to the 886 Hz bandwidth of the default minimum phase pulse.

Gel and gadolinium-doped water phantoms were placed in the head coil of a 0.5T Signa SP scanner. Two needles were placed in the water perpendicular to B_0. Images were acquired perpendicular to the needles with the following parameters: TE/TR = 20/500, FOV 24, slice 5 mm, BW = ±16kHz, with and without VAT and the optimized RF pulse. Images were also acquired without readout and phase encode gradients to demonstrate the signal modulation in each case. For the case of the optimized RF pulse, the data was demodulated by the phase of the spin echo, as measured from the data without readout and phase encode gradients.

Results Three images are shown in Figure 1: (a) a spin echo image demonstrating needle artifacts, (b) a VAT image with the default 3.2 ms minimum phase RF pulse demonstrating considerable blurring, and (c) the VAT image with the optimized RF pulse. Although the 44° view angle in (c) is similar to the 48° view angle in (b), there is little loss of resolution compared to (a).

The amplitude modulations of each of these three cases is shown in Figure 2. The modulation of the optimized RF pulse is considerably broader than the modulation of the 3.2 ms minimum phase RF pulse.

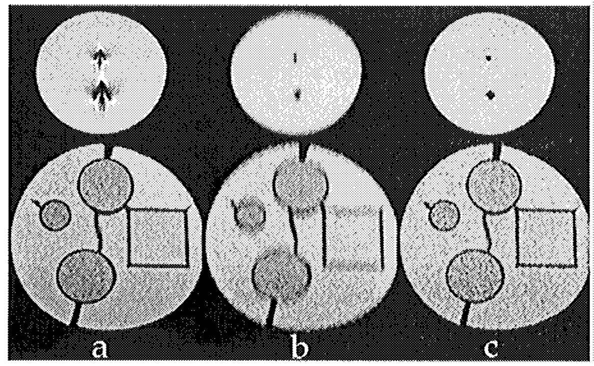

Fig. 1. (a) Spin echo, (b) VAT with default 3.2 ms minimum phase RF pulse, and (c) VAT with 8 ms optimized RF pulse.

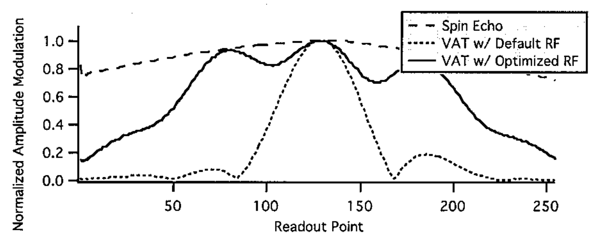

Fig. 2. Amplitude modulations for the images in Fig. 1.

Discussion This work demonstrates that amplitude modulation by the transform of the slice profile is the major source of blurring with VAT. In addition, we show that the excitation pulse should be matched to the readout duration for best results and illustrate one method for doing this without sacrificing excitation bandwidth. Alternatively, the readout duration could be reduced to match the excitation pulse by making sure that data is acquired only during the central lobe of the amplitude modulation. This is the case with a ± 64 kHz receive bandwidth and a 3.2 ms sinc RF pulse.

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