SAR Reduction at 3T for Fast Spin Echo Sequence Using an Optimized VERSE Algorithm

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Introduction

SAR deposition becomes an increasing concern at high fields since deposited RF power scales roughly as the square of the B_0 field. Constant amplitude RF pulses are the most power efficient waveforms in terms of achieving a given nutation in a given amount of time, however when applied with a constant slice-select gradient, they produce very poor slice profiles. Typically, sinc-like pulses are used to achieve slice-selective refocusing, but at the cost of increased SAR deposition. A more power efficient means of slice-selective excitation has been developed, termed VERSE [1], in which the slice select gradient waveform and transmit frequency are modulated while keeping the RF amplitude as constant as possible, given the limitations of the gradient subsystem.

To implement this technique, standard RF waveforms and constant slice-select gradients are "re-shaped" while maintaining equivalent nutation across the slice profile. One approach [2] is to perform this operation off-line and enable the scanner to load these pre-computed waveforms. This however, lacks flexibility and is either limited to "worst case" scenarios (thinnest possible slice, heaviest possible patient, worst performing gradient subsystem, etc.), or requires a whole array of different pre-computed waveforms to fit any given scenario. A more flexible approach is to perform waveform reshaping in real-time on the scanner host allowing optimal waveforms to be computed for any given slice thickness or patient weight while allowing the operator the option to trade, for instance, robustness to off-resonance against power savings. This approach has been demonstrated in the abdomen for a single shot spin-echo (SSFSE) sequence [4], but it was unclear whether it could be applied to a more general fast spin-echo (FSE) sequence and maintain robust image quality over a wide range of contrast types and clinical applications. The purpose of this work was to implement real-time VERSE waveform reshaping in an FSE sequence and determine how well it would perform under a wide range of clinical scenarios.

Methods

A standard fast spin-echo (FSE) sequence was modified so as to reshape the tailored RF pulses (typically used on 3T scanners) in a real-time manner. The goal was to maintain the echo-spacing (so as to maintain contrast and resolution in comparison with the standard sequence) while reducing average RF power per pulse. With reduced RF power, shorter scan times or increased coverage in a given scan time can be achieved while operating within regulatory limits. The implementation was tailored such that the VERSE modified sequence provided comparable SNR, CNR and off-resonance behavior to the standard sequence over all applications to which the fast spin-echo sequence is routinely clinically applied.

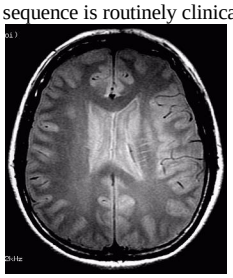
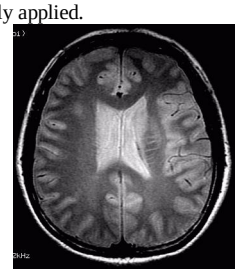


Figure 1: (a) Standard



1(b) VERSE

Several volunteers were scanned with several different coils and protocols on a GE 3T *Excite* scanner equipped with a *TwinSpeed* gradient module (max. amplitude and slew rate of 4G/cm and 150T/m/s). A wide range of protocols and coils were examined. Three in particular are shown here. In the head, a standard head coil was used to obtain a ρ-weighted image (TR=2500ms, TE=27ms, ETL=8, 24 slices). T1-weighted images (TR=800ms, TE=12ms, ETL=3, 17 slices) were also acquired using a 8 channel brain coil. In the abdomen, a 8-channel phased array coil was used with a T2-weighted protocol (TR=2000ms, TE=85ms, ETL=29) in which 20 slices were acquired.

Results

In the head (Figures 1 and 2), the reduction in SAR with VERSE was 23% and 33%,respectively, for equal scan time. For the ρ-weighted scan, the number of slices in one acquisition was sufficient to cover the entire anatomy of interest for both the standard and modified sequence. In such a case, the benefit is a reduction in SAR deposition which would enable scanning for prolonged times before exceeding FDA limits. For the T1-weighted study, the minimum repetition time (TR) was not SAR limited. As a result, the standard and VERSE provided equal coverage. In the abdomen (Figure 3), VERSE reduced scan time from 49s (for standard sequence) to 32s given equal SAR and coverage, allowing the scan to be performed in a single breath-hold. (In conjunction with ASSET there was a further reduction in scan time to 24s.) If on the other hand, the coverage and total scan time for the VERSE modified sequence and the standard sequence are matched, a 44% reduction in average SAR deposition is obtained. Average SAR reduction of about 20-50% was typical over a wide range of applications without operator intervention while maintaining image quality.

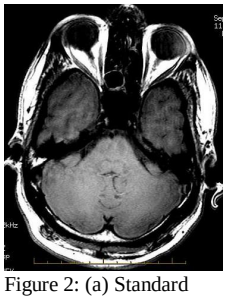
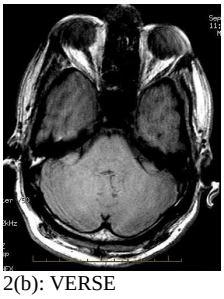
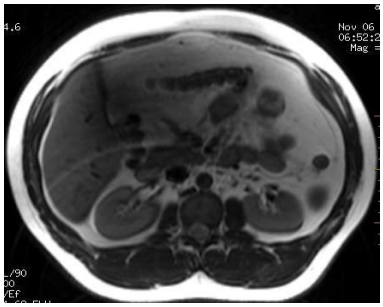


Figure 2: (a) Standard



2(b): VERSE



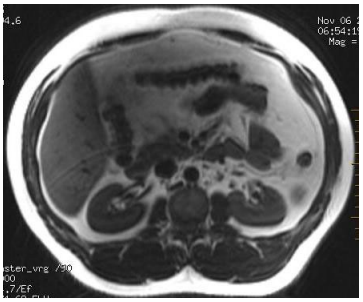


Figure 3: Standard (left) VERSE (right)

Discussion

Clinical viability of an FSE sequence employing VERSE requires several important factors to be considered. Reduction in RF power may come at the expense of a deterioration of off-resonance behavior which in turn may result in a reduction in SNR. Inflexibility in pulse rescaling can lead to sub-optimal pulses which can exhibit artifacts ranging from ringing, ghosting and shading to poor image contrast. Clinically useful sequences also require transparency in the choice of various scaling parameters for VERSE re-shaping while maintaining consistent behavior over a range of prescriptions. The work undertaken here along with sample results demonstrates viability of the technique in a clinical environment at 3T. Further work in VERSE reshaping of selective inversion pulses will provide added RF power reduction and make possible longer fast spin-echo scans without exceeding regulatory SAR limits.

References

[1] S. Conolly, D. Nishimura, A. Macovski, G. Glover. *J Magn Reson* 1988; 78:440-458

[2] Y. Zur, J. Hug, A. Montag, D. Outmezguine, R. Busse. *Proc. ISMRM*, 2003, p. 958

[3] G. Matson. *Magn. Res. Med.* 1994;12:1205-1225.

[4] R. Busse, Y. Zur and X. Li. *Proc. ISMRM, 2003*, p. 206.