Body Imaging at 3T: Lower SAR yields Improved Coverage with VERSE and Modulated Angle Refocusing Trains

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To meet the challenge of providing adequate coverage at high field strength, a combination of two complementary methods is proposed: reshaped waveforms with the VERSE technique and a modulated angle refocusing train. It was hypothesized that pulses can be reshaped and flip angles can be modulated such that power is cut in half and thus coverage doubled. Volunteer experiments at 3T using an SSFSE sequence in the abdomen demonstrate a power reduction of 50% with unchanged contrast and SNR and improved resolution.

Introduction

While imaging at 3T can theoretically provide a two-fold improvement in SNR compared to 1.5T, it is also burdened by a four-fold increase in peak and integrated RF power. Fast spin echo sequences(1) designed to operate at or near regulatory power limits at 1.5T face severe restrictions at 3T. If nothing is changed, coverage must be limited significantly and the advantages of high-field imaging are lost.

Common approaches to reducing RF power include using reduced flip angle(2) and linearly stretching the pulses. Both of these strategies can degrade image quality. Stretching RF pulses results in longer echo spacing and thus exacerbates the effects of relaxation through the echo train. Reducing refocusing flip angle produces signal from stimulated echo pathways which have mixed T1 and T2 contrast as well as lower overall signal levels. To meet the challenge of providing adequate coverage at high field strengths, more advanced means of reducing power without adversely affecting signal, contrast and resolution are needed.

We propose two complementary methods to reduce power without degrading image quality: First, we reshape the individual RF waveforms with the Variable-Rate Selective Excitation(3) (VERSE) technique. Second, we modulate the flip angle of the refocusing pulses through the pulse train(4,5,6). We hypothesize that pulses may be reshaped and flip angles may be modulated such that power may be reduced by 50% without adversely affecting contrast, resolution, signal or artifact level.

Methods

Experiments were conducted on a GE *Signa VH/i* 3T scanner with CRM gradients (40 mT/m, 150 mT/m/ms). VERSE waveform reshaping and flip angle modulation were implemented as modifications to the product single-shot fast spin echo (SSFSE) pulse sequence.

The baseline sequence utilized a constant train of 130°, 1840µs refocusing pulses. For the modified sequence, refocusing RF pulses were redesigned with identical bandwidth but a 1.5× increase in time•bandwidth for improved slice profile, and reshaped with VERSE such that the pulse width was identical to the baseline case, the peak power was 75% less, and the integrated power was 22% less. The excitation pulse was also redesigned and reshaped, decreasing the pulsewidth with negligable impact on peak or total power. Figures 1 and 2 compare the baseline refocusing RF pulse and slice-select gradient to the modified RF pulse and slice-select gradient.

A novel flip angle modulation strategy was employed wereby relatively high flip angles (130°) were employed prior to the effective echo time (TE_{eff}) in order to preserve T2 contrast, then the flip angle was varied in a controlled fashion to take advantage of stimulated echo pathways which prolong relaxation. Total power was 36% less with the modulated angle pulse train as compared to the constant angle pulse train. The predictable signal decrease which occurred during the ramp down phase was demodulated during image reconstruction. The modulated refocusing flip angle schedule is shown in Figure 3.

A volunteer was imaged during free breathing using a body coil to transmit and a four-element phased array coil to receive RF signals.

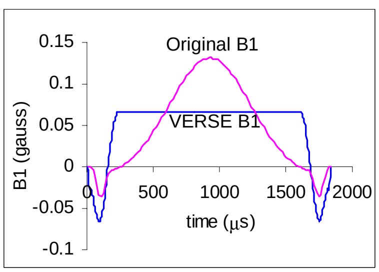

Figure 1

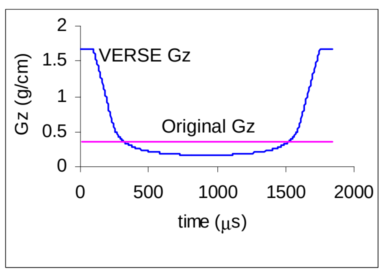

Figure 2

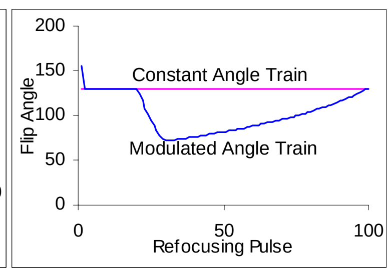

Figure 3

Results

The combined use of VERSE waveforms and flip angle modulation provided a power reduction of 50% This translates to a two-fold increase in coverage in a given amount of time. Figure 4 shows *in vivo* image quality – contrast and SNR are unchanged while resolution is improved.

Discussion

Whereas previous modulated flip angle techniques significantly affected contrast(4,5,6), employing relatively high flip angles prior to TE_{eff} preserved T2 contrast. The use of VERSE pulses enabled higher time•bandwidth pulses (thus a flatter slice profile) to be used for slice-selective refocusing while preserving pulsewidth and reducing power. Resolution is improved because flip angle modulation prolonged relaxation and because VERSE reshaping of the excitation pulse reduced echo spacing. The combination of VERSE waveform reshaping and modulation of flip angle through the pulse train has proven to be a beneficial combination for limiting power at high field.

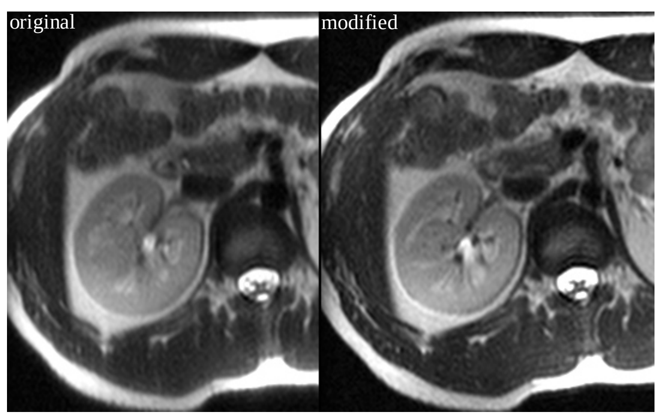

Figure 4

References

(1) J Hennig, A Nauerth, H Freidburg. *RARE Imaging: A Fast Imaging Method for Clinical MR*. Magn Reson Med 1986; 3:823-833
(2) J Hennig, *Multiecho Imaging Sequences with Low Refocusing Flip Angles*. J Magn Reson 1988; 78:397-407
(3) S Conolly, D Nishimura, A Macovski, G Glover. *Variable-Rate Selective Excitation*. J Magn Reson 1988; 78:440-458
(4) D Alsop. *The Sensitivity of Low Flip Angle RARE Imaging*. Magn Reson Med 1997; 37:176-184
(5) J Mugler, B Kiefer, J Brookeman. *Three-Dimensional T2-Weighted Imaging of the Brain Using Very Long Spin-Echo Trains*. Proc. ISMRM 2000 p 687
(6) R Busse, S Riederer. Reducing SAR in Real-Time SSFSE Imaging with Variable-Flip Hard Refocusing RF Pulses. Proc. ISMRM 2001 p 1790