SNR Analysis of Variable Refocusing Flip Angle FSE

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Introduction

For fast spin echo sequences, power can be greatly reduced while suffering only modest reduction in signal by using low flip angle refocusing pulses, provided the flip angles of the first few pulses are modulated so as to maintain pseudo-steady-state (pss) conditions in the spin system (1).

Recent studies have demonstrated that the flip angle can be modulated not just in preparation for imaging in the pseudo-steady-state, but also during data acquisition (2-5). If low order phase encodes are acquired using high flip angles, while high order phase encodes are acquired with low flip angles, the resulting signal modulation causes low-pass filtering. This filtering may be accepted to take advantage of the higher SNR (4), or it may be corrected to eliminate the resolution loss due to flip modulation (3,5).

The purpose of this study was to determine the SNR benefit of variable refocusing flip angle FSE when controlling for low-pass filtering effects.

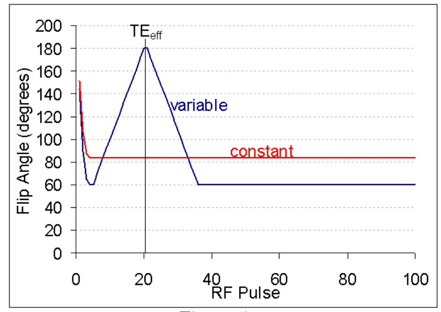

Figure 1

Methods

Two refocusing flip angle schedules were designed (Figure 1), each with average RF power of 25% compared constant 180° refocusing pulses. The first was a variable refocusing flip (VRF) schedule. The second was a constant flip refocusing (CRF) schedule.

Signal amplitude modulation due to flip angle variation throughout the echo train was calculated analytically (1,5) and then used to filter the raw data. The expected signal modulation was applied directly to the CRF data to emulate the low-pass filtering of flip angle variation, and its inverse was applied to the VRF data to cancel the same effect. In all, four cases were studied: VRF, VRF with signal modulation correction, CRF, and CRF with signal modulation emulation.

A GE Signa 3T scanner was used to collect data in phantoms and volunteers using a modified half-Fourier single-shot fast spin echo (SSFSE) pulse sequence. The phantom experiments were performed in order to verify that the calculated filters were adequately emulating and correcting for signal modulation due to flip angle variation and to measure SNR. Volunteer experiments were performed to visualize the effect of low pass filtering due to VFR and filtering, and to assess overall image quality.

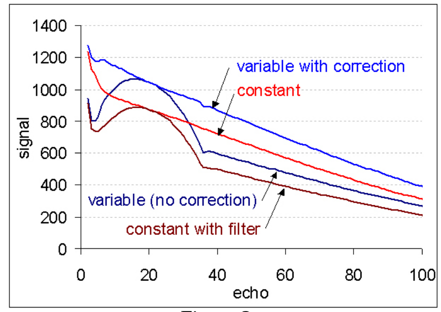

Figure 2

Results

Figure 2 shows the results of an experiment in which data were collected while the phase encode gradients were disabled. With correction, the effect of flip angle variation was eliminated from the signal amplitude leaving only relaxation effects. Signal from the filtered CRF data emulates the (uncorrected) VRF data, with only a scaling factor due to the pss-signal difference between 180° and 84° refocusing.

Table 1 shows the relative theoretical and measured SNR for the four cases studied. Values were normalized to the VRF case. For the blurred cases, filtered CRF showed a 15% SNR advantage over VRF and for the un-blurred cases, CRF showed a 16% SNR advantage over corrected VRF.

technique	pss-signal	filter noise factor	theoretical rel. SNR	measured rel. SNR
VRF	1.00	1	1.00	1.00
VRF, corrected	1.00	1.38	0.72	0.70
CRF	0.81	1	0.81	0.82
CRF, filtered	0.81	0.75	1.08	1.15

Table 1

Figure 3 shows the results of a volunteer study. The VRF image exhibits high SNR, but some blurring. The filtered CRF data appears to have similar high SNR and blurring as the VRF data. Blurring was eliminated in the corrected VRF data set and was never a problem in the CFR data. SNR is reduced, but still quite acceptable.

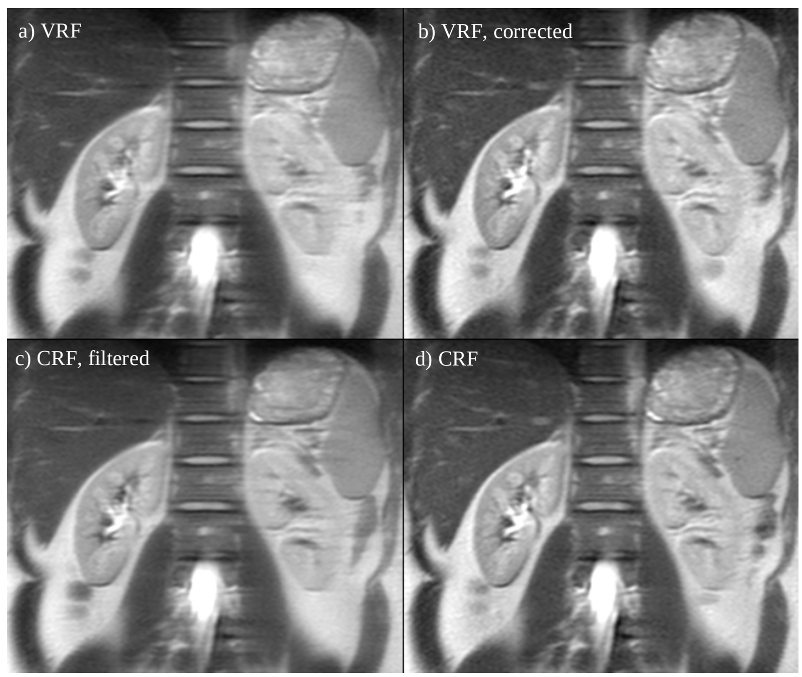

Figure 3

Discussion

Reducing refocusing flip angle is an important means of reducing RF power, but signal is reduced as well. While varying the flip angle to acquire the center of k-space with high signal echoes may restore SNR, signal modulation leads to blurring. Correcting for this blurring leads to lower SNR than a constant refocusing flip angle schedule with equal average power. For applications in which some blurring is deemed an acceptable price for increased SNR, low-pass filtering of data from a constant refocusing schedule provides a bigger SNR advantage than variable flip refocusing. In these cases, filters specifically designed for SNR advantage, rather than occurring as a bi-product of uncorrected flip-angle modulation, may yield greater advantage than the filter used here.

While flip angle modulation for the purpose of boosting SNR is not as effective as equivalent low-pass filtering, there are other useful applications for the technique. It may be used to preserve contrast at a given TE (3,5), to retard relaxation during a very long readout train (2), and to improve the efficacy of a fast-recovery "tip-up" pulse (6). Overall, high field imaging with reduced flip angles can yield higher SNR than imaging at lower field strength with flip angles approaching 180°, even when controlling for power.

References

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