Progress in Rapid and Short Acquisition Delay Imaging with SWIFT

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Background

SWIFT (*1*) (SWeep Imaging with Fourier Transform) is a novel imaging sequence utilizing frequency-swept pulse excitation with nearly simultaneous signal acquisition in the time between pulse elements. SWIFT utilizes the correlation method(*2*) which removes phase differences due to the time of excitation and produces FID data as if the spins were simultaneously excited by a short duration pulse.

Here, we review progress in the fundamentals and applications of SWIFT. Of interest are signal-to-noise properties, limitations of standard hardware, and use of separate digital receivers.

Methods

We implemented SWIFT on a 4 T, 90 cm bore magnet system with Varian INOVA console and Siemens Sonata gradient subsystem. The extremely short excitation to acquisition delay, τ_a, required that coils used with SWIFT must be stripped of polymers and other sources of short T_2 background signal, especially near the coil elements or electronic components. We prepared several dual-loop quadrature surface coils of sizes from 3 to 15 cm. The quadrature hybrid protected the receive preamp without the need for additional T/R switching.

Results

We discovered several hardware limitations: fidelity with regards to harmonic content and blanking of the RF transmit system; phase stability and rapid gating of the RF receive subsystem; and timing variations introduced in sequence compilation for real-time. Some of these were correctable in post-processing. However, compared to constraints imposed by turnkey clinical systems, especially minimum transmit to receive delay, our system performed admirably.

We report examples of SWIFT imaging in various settings with phantoms showing limits of short T_2 signal capture and resolution, ex-vivo tissues, and human imaging. (see figure 1a-c). We also briefly report SWIFT results in zoom imaging, fat separation, inversion and T_2 selective preparation.

Discussion

SWIFT seems to occupy a fundamentally new space in MRI, having rapid acquisition rate of views, and short acquisition time delay τ_a, yet not stressing the gradient hardware. Instead the stress is shifted to the RF transmit and receive systems. SWIFT has several intriguing properties.

First, it has an intrinsically short excitation to acquisition time delay τ_a, at present hardware-limited to ~5-10μs. This provides sensitivity to very fast relaxing spins, similar to that achieved by UTE (Ultra-short TE) sequences(*3*).

Second, the use of frequency-swept pulses, particularly those of the HSn family of pulses(*4*), allows lower peak-power excitation. Peak power is especially low when compared to the peak power needed by single hard pulse excitation, making it easier to achieve larger effective flip angles and T1 contrast, without resorting to inversion preparation.

Third, the excitation profile and phase behavior of HSn pulses are well behaved at near 90° flip angles, removing some of the disadvantages of previous correlation or stochastic based methods(*5*).

In its current implementation, SWIFT utilizes a radial sampling scheme with isotropic spiral(*6*) (single or interleaved) view ordering. This gives rise to the fourth property: the gradient updating, which is continuous, does not require a short rise time. Very little stress is placed on the gradient subsystem and the sequence is quiet, even at short TR and rapid acquisition speeds. Currently speeds of 360 views per second can be obtained at 125 kHz bandwidth, without parallel acceleration.

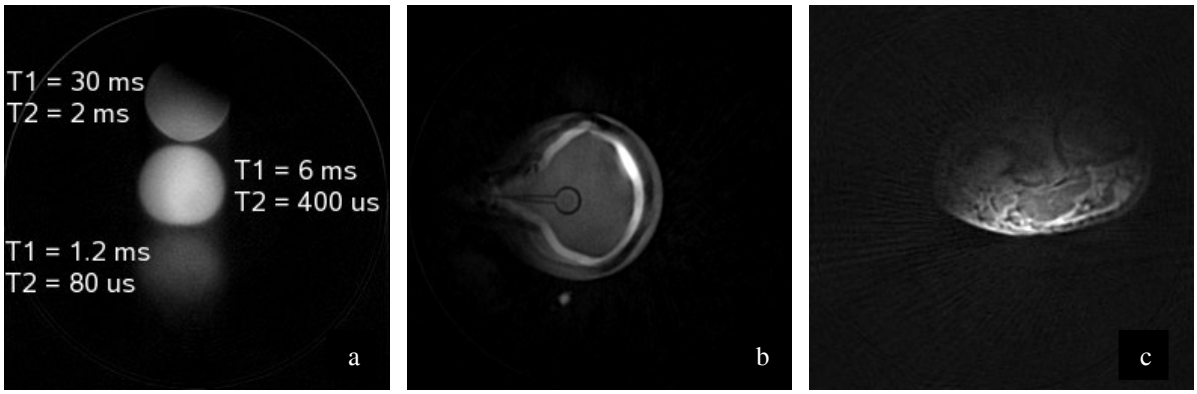

Figure 1 a) 78 kHz SWIFT image of short T_2 phantoms consisting of water doped with 4 mM, 20 mM, and 100 mM of $MnCl_2$
b) 30 cm FOV 62 kHz rapid (50 s total acquisition time for 4000 views) and quiet 3d image of breast phantom
c) 13 cm FOV 62 kHz Human wrist image, axial slice of 3d, at radius/ulna tip taken with quad surface coil

Conclusion

We demonstrated the emerging capabilities, progress, and limitations in implementation of the SWIFT sequence. SWIFT continues to develop into a useful new rapid and very short T_2 sensitive method for MRI. We gratefully acknowledge support by NIH Grants 5R01CA092004 and 5P41RR008079, and the Keck Foundation.

References

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