Sweep Imaging with Fourier Transform (SWIFT)

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INTRODUCTION

In NMR there are basically three types of the RF excitation: sequential, simultaneous and random. Accordingly, three different NMR techniques were developed, which respectively are: continuous wave (CW), pulsed, and stochastic. Nowadays pulsed FT spectroscopy dominates the field of high resolution NMR. MRI has additional technical requirements over high resolution NMR. Because the objects of interest are much larger than a test tube, inevitably the static and RF fields used in MRI are more inhomogeneous than those used in high resolution NMR. In a search for solutions, researchers have reconsidered old, almost forgotten NMR techniques. This article presents a new MRI method which might be considered as a combination of all three basic types of the NMR techniques. As in CW, the new method uses RF sweep excitation. However, in the presented method, the sweep rate exceeds the sweep rate of the CW method by more than a few orders of magnitude. Unlike the CW method in which the signal is acquired in the frequency domain, here the signal is considered as a time function, as in the pulsed FT method. Finally, the method uses the correlation method, identical to the one used in stochastic NMR, to extract proper spectral information from the spin system response. Hereafter the acronym SWIFT for this new SWeep Imaging with Fourier Transform method will be used.

The rapid-scan FT technique (*1, 2*) and SWIFT technique have many common properties, but are different in point of view to system response on excitation. They consider the system response in frequency domain and time domain, respectively. Due to this difference the SWIFT technique has a few advantages, one of them is that the spectra obtained by SWIFT technique are insensitive to the linearity of the sweep rate. This gives the opportunity to use a broad class of frequency modulated pulses (*3*) having more uniform excitation profiles than the chirp excitation required in rapid-scan FT.

The main advantage of SWIFT is the virtually simultaneous excitation and acquisition of signal. Accordingly, the proposed method has a "zero echo time", and so has significant benefits for studying objects having very fast spin-spin relaxation (or very short T_2). In particular, the method is expected to find extensive applications for MRI of quadrupolar nuclei, such as sodium-23, potassium-39, and boron-11. Here, a qualitative description of the new technique is provided, and proof-of-principle is shown by simulated and experimental data.

METHOD

The simplest realization of the method is presented in Fig.1a. The scheme employs a sequence of frequency-modulated pulses with short repetition time T_R that exceeds the pulse length T_P by at least the amount of time needed for setting a new value (or orientation) of a magnetic field gradient used to encode spatial information. The images are processed using 3D back-projection reconstruction. In the present implementation, frequency-modulated pulses from the hyperbolic secant family (*HSn* pulses) (*3*) were tested. In Fig.1b one shaped pulse is represented which consists of *N* different sub-pulse elements with time-dependent amplitudes and phases. During the FM pulse, an isochromat follows the effective RF field vector until the instant resonance is attained. At resonance, the isochromat is released from the RF pulse's "hug" and thereafter almost freely precesses with a small decaying modulation, yielding spectral contamination. Thus, to extract proper spectral information from such a spin system response, processing must be done using a cross-correlation method which is identical to the method of recovering phase information in stochastic NMR (*4, 5*).

The theoretically achievable signal-to-noise ratio (SNR) per unit time for the SWIFT technique for $T_R << T_1$ is the same as that for pulsed FT. During SWIFT acquisition the applied imaging gradients usually exceed all intrinsic gradients due to susceptibility or inhomogeneity. For this condition the images obtained are fully independent of transverse relaxation and signal intensity depends only on T_1 and spin density. The maximum T_1 contrast depends on effective flip angle and the best compromise between sensitivity and contrast will have flip angles exceeding two times the Ernst angle. If flip angles are very small, T_1 contrast is negligible, and contrast comes entirely from spin density. Other kinds of contrast can be reached by an appropriate preparation sequence prior to or interleaved with the image acquisition.

CONCLUSIONS

In conclusion, the SWIFT technique has many novel and beneficial properties for MRI: (a) *fast*: The method avoids not only delays associated with refocusing pulses or gradient inversion, but also time for an excitation pulse, which is integrated with the acquisition period. Of course, like all fast imaging sequences, SWIFT is limited by existing imaging system hardware and chosen compromise between acquisition speed, spatial resolution and SNR. (b) *sensitive to short* T_2: The method is sensitive to all excited spins having $T_2 > 1 / SW$ (*SW* = spectral width). Of course, to be specifically resolved, $T_2 > N / SW$ must be satisfied, which is theoretically feasible even for solid objects by increasing *SW*. (c) *reduced motion artifacts*: Because the SWIFT method has no "echo time" it is less sensitive to motion artifacts. It loses less signal due to either diffusion in the presence of a gradient or uncompensated motion than other fast sequences. (d) *reduced dynamic range requirement*: Because the different frequencies are excited sequentially the resulting signal is distributed in time with decreased amplitude of the acquired signal. This allows more effective utilization the dynamic range of the digitizer. (e) *quiet*: Last, but not the least, because the SWIFT method uses a small step when changing gradients between projections, fast gradient switching that creates loud noise can be avoided. This property is very important for people having ligyrophobia.

SWIFT may also be operated in rapid updated mode to reach high temporal resolution in dynamic studies (*6*). This pseudo-temporal resolution is possible because projection reconstruction, unlike Fourier imaging, samples the center of k-space with every acquisition.

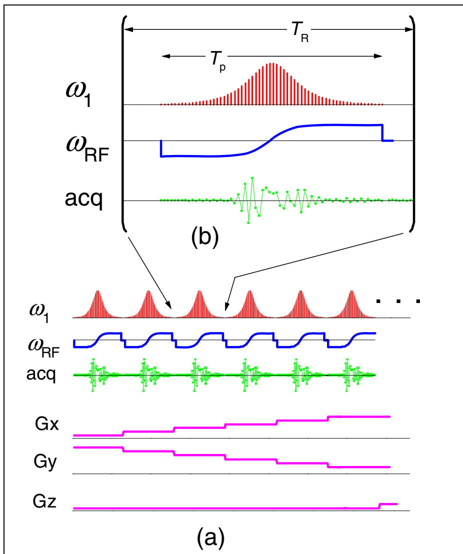

Fig.1. (a) The SWIFT pulse sequence scheme and (b) detailed presentation of the repeated part of the sequence.

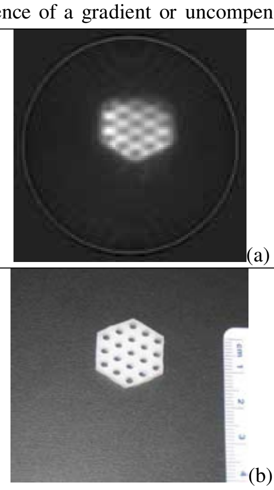

Fig.2. (a) A selected slice in 3D imaging of the semisolid object having T_2 ~ 0.3 ms that was used as a sample test of the sensitivity of the SWIFT to the short T_2 and (b) its photo.

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