Gradient-modulated SWIFT

Jinjin Zhang[1,2], Djaudat Idiyatullin[1], Curtis Corum[1], Naoharu Kobayashi[1], and Michael Garwood[1]

[1]*Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, Minnesota, United States,* [2]*Department of Physics, University of Minnesota, Minneapolis, Minnesota, United States*

Introduction Sweep Imaging with Fourier Transformation (SWIFT) is an emerging MRI technique which can capture signals with ultra short T_2 [1]. It applies frequency modulated (FM) pulses for excitation and has nearly simultaneous acquisition in the gaps of a FM RF pulse (fig.1a). In this work, for the first time, the SWIFT sequence was modified to utilize time-varying gradients during excitation (fig. 1b&c). The gradient-modulated offset independent adiabaticity (GOIA) approach was used to modify the pattern of the RF pulse. Linear response theory was used to derive the signal evolution. A specific correlation method to retrieve the spin density for this case was developed. This method highly increases the flexibility of the SWIFT sequence and allows, for example, RF power reduction and increased effective acquisition bandwidth.

Theory Because SWIFT utilizes a single frequency modulated pulse for each repetition, the RF pulse introduces a time-frequency dependent phase for each component of the resulting signal. In conventional (constant readout gradient) SWIFT, the spin density can be retrieved by correlation of the RF pulse and the signal [1]. In GOIA-SWIFT, due to the modulated gradient, the correlation does not apply [3]. To obtain a solution, we assumed that: 1) during the frequency sweep an isochromat with frequency f_0 achieves resonance at time t that is determined by the FM function; 2) the isochromat evolves "freely" (with changing gradient) in the transverse plane after the time t when it was excited. According to linear response theory and the properties of FM pulses and SWIFT, the signal response for GOIA-SWIFT can be derived, as $r(t)$ in the following equation [1,2,4]. Then, the reconstruction requires the following transform of the RF pulse $x(t)$ and signal $r(t)$. The spin density $H(\omega)$ can be separated out finally. Notice that the transform for $X(\omega)$ and $R(\omega)$ are different. This reconstruction method works for any gradient modulation $g(t)>0$.

$$r(t)=\int_0^\infty x(t-\tau)\left\{\int_{-\infty}^{\infty} M_{xy0}(\omega)\exp\left[i\omega\int_{t-\tau}^{t} g(t')dt'\right]d\omega\right\}d\tau;$$

$$\begin{cases} R(\omega)=\int_0^\infty r(t)\exp\left[-i\omega\int_0^t g(t')dt'\right]g(t)dt; \\ X(\omega)=\int_0^\infty x(t)\exp\left[-i\omega\int_0^t g(t')dt'\right]dt; \end{cases}$$

$$\Rightarrow R(\omega)=X(\omega)H(\omega)$$

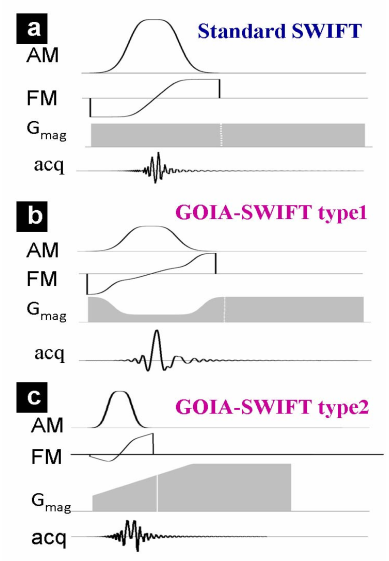

Fig.1 Pulse diagrams of standard SWIFT and GOIA-SWIFT

Materials & Methods *Simulation:* The relationship between RF power and flip angle were simulated by Bloch equations for both standard SWIFT and GOIA-SWIFT. *Experiment:* All images were acquired on 4T Agilent human scanner. We used gradient modulation factor g_m=0.2 (the ratio of minimum gradient value to the original constant one). Phantom with$T_1 \approx 280$ ms was used. In human brain imaging, standard SWIFT was limited to a maximum flip angle of 4°, based on SAR and hardware constraints. With GOIA-SWIFT, a higher maximum flip angle of 8° was attained due to better efficiency of the GOIA pulse. Acquisition time was 6 min, using bandwidth (BW) =62.5 kHz.

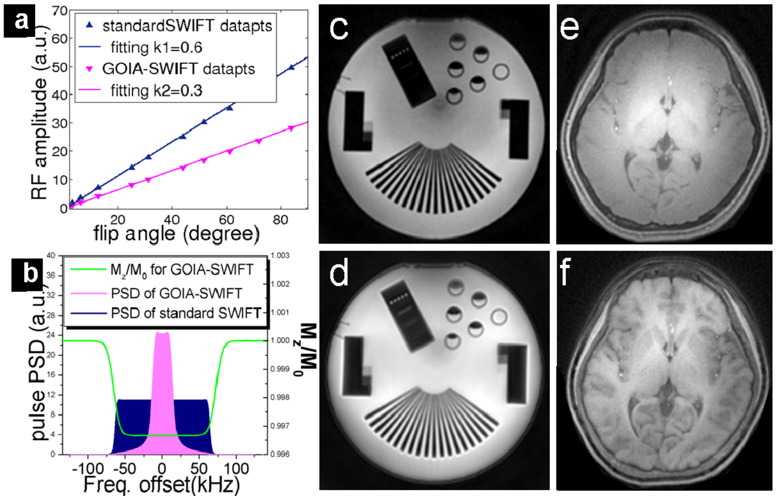

Fig2. a) Simulations about RF amplitude, k is the slope of the fitting; b) power spectral density and excitation profile; c) & d) are SWIFT and GOIA-SWIFT images of a resolution phantom at the same power; e) & f) are SWIFT and GOIA-SWIFT in vivo images of a healthy volunteer at the same power

Results In fig.2a, simulation results are shown for the case of g_m=0.2. The RF amplitude needed for given flip angle in GOIA-SWIFT is only 50% of standard SWIFT. The power spectral density in fig. 2b reveals how more power is concentrated in the frequency range where most spins are excited. As a result, GOIA-SWIFT offers better power efficiency. The phantom images (fig. 2c & 2d) show that the image quality of standard and GOIA-SWIFT is comparable. The brain images in figs. 2e & 2f, demonstrate that GOIA-SWIFT can achieve higher flip angles and give more T_1-contrast than standard SWIFT using the same RF power level. In fig. 2e, the flip angle was not high enough to show T_1 contrast. While in fig. 2f, GOIA-SWIFT achieved twice flip angle and created apparent T_1 contrast between the white and gray matter.

Conclusion For the case shown (type 1 with g_m =0.2), GOIA-SWIFT can reduce at least 50% of the RF amplitude, which means 70% of the SAR in this case, while keep similar image quality. Furthermore, with various kinds of choices of the gradient modulation, GOIA-SWIFT can also achieve higher effective acquisition BW, which will reduce artifacts and increase the resolution for imaging ultra-short T_2 signals.

References [1] Idiyatullin D. et al. J. Magn. Reson. 181,342-349,2006 [2] Tannus A. et al. NMR Biomed. 10, 423–434,1997 [3] Ernst R. et al. Principle of Nuclear Magn. Reson. in 1 and 2-D, Oxford Univ. Press, P91 [4] Blumich B. et al. J. Magn. Reson.60, 37-45,1984. **Acknowledgement**:This research was funded by grants P41 EB015894, S10 RR023730 and S10 RR027290