Gradient-modulated SWIFT for SAR reduction and controlled short-T2* sensitivity

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]*School of Physics and Astronomy, University of Minnesota, minneapolis, Minnesota, United States*

Introduction Specific absorption rate (SAR) becomes a serious concern with increasing field strength, especially during imaging of fast relaxing spins, which usually require a high excitation bandwidth. This creates even more problems for experiments using large volumes and potentially power-inefficient RF coils. In this work, a modified SWIFT [1] sequence using gradient modulation during the pulse (GM-SWIFT) is analyzed in comparison with standard SWIFT. GM-SWIFT reduces SAR and acquisition time while maintaining image quality. Additionally, the choice of gradient modulation influences the lower limit of the short T_2* sensitivity. The latter can be exploited to suppress unwanted image haze due to ultra-short T_2* signals from rigid materials such as the plastic coil housing.

Methods The RF pulse and gradient in GM-SWIFT were modified according to the GOIA approach [2]. Two phantoms and a human tooth were imaged. The first phantom was a custom machined resolution phantom ($MnCl_2$ solution with T_1~ 280 ms in a plastic container) and second was a T_2 phantom, composed by 7 tubes of $MnCl_2$ solution of different concentrations. The T_2* values of the T_2 phantom were determined by spectroscopy. The specific correlation procedure described in [3] was used to process the GM-SWIFT data and obtain images. Experiments were performed with 31cm 9.4 T (tooth) and 90 cm 4T (two phantoms) magnets interfaced to Agilent DirectDrive consoles. BW was 125 kHz for the tooth experiment and 62.5 kHz for the phantom experiments. Flip angles were 2º, 4º, and 6º for tooth, resolution phantom, and T_2 phantom experiments, respectively.

Results As shown in Fig.1c, RF amplitude, SAR, and acquisition time T_{acq} all decrease as g_m increases while other sequence parameters are held constant. Due to higher RF power efficiency GM-SWIFT allows smaller T_p for fixed RF amplitude, leading to reduced acquisition time for a given resolution over standard SWIFT. When g_m is 0.9, GM-SWIFT reduces RF amplitude, SAR, or T_{acq} by 70%, 90% and 45%, respectively, as compared to SWIFT. Images of the resolution phantom at f_{RF} (defined as the ratio T_p/T_{acq}) = 0.25 is shown in Fig.2. Negligible differences in the intensity profiles of GM-SWIFT and SWIFT images can be seen in the selected area (yellow line). This experiment shows that the image quality of GM-SWIFT is comparable to SWIFT. On the other hand, SWIFT detects essentially all protons in the objects, including the plastic material commonly used in coil building. Due to the limited bandwidth, these highly broadened signals cannot be resolved. However, GM-SWIFT shows controllable sensitivity to spins with different T_2*. With large gradient modulation, GM-SWIFT is less sensitive to spins with extremely short T_2*, and as result, generates images with cleaner background. As shown in Fig.3, the SNR (= signal to background noise ratio) of different T_2* phantom tubes drops as T_2* decreases or as g_m increases. Take g_m = 0.8 for example (blue line), as compared to SWIFT (g_m = 0); GM-SWIFT has higher SNR for T_2*>400 µs, and lower SNR for T_2*<400 µs. The SNR is nearly zero for T_2*<100 µs. One reason for the higher SNR for GM-SWIFT in this specific phantom is less background noise from unresolved signal of tubes with extremely short T_2*. Without those tubes, the SNR of GM-SWIFT for T_2* > 400 µs should be at the similar level as SWIFT. Although GM-SWIFT lacks sensitivity to spins with T_2* < 100 µs (marked as red region), it still preserves signal with T_2*~200 µs (marked as blue region). This point is exemplified by the tooth images (Fig.3, blue region), in which the T_2* of dentine is about 200~300 µs. GM-SWIFT with g_m= 0.8 can still preserve the signal from dentine well and delineate the shape of dentine to a comparable degree as SWIFT, but with slightly more blurring (yellow arrows). To demonstrate the invisibility of extremely short T_2* spins, in Fig. 3 red region, a piece of rubber with T_2*~ 50 µs was placed on top of the phantom. It is visible and poorly resolved in the SWIFT image, but is invisible in the GM-SWIFT image (red arrows). The background is also much cleaner in GM-SWIFT than SWIFT, due to the invisibility of the plastic container of the phantom in GM-SWIFT case.

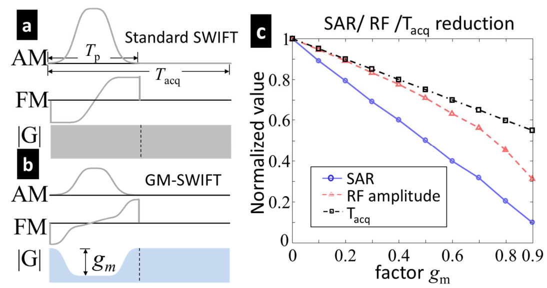

Fig.1 The diagrams of SWIFT (**a**), GM-SWIFT (**b**) sequences and simulated SAR, RF amplitude, and T_{acq} as a function of modulation factor g_m (**c**).

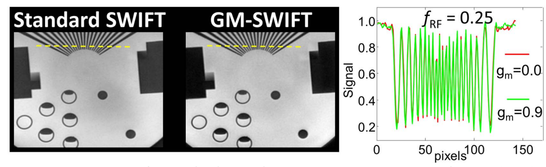

Fig.2 Images of resolution phantom at g_m = 0 and 0.9 (**left**); Intensity profiles plot over the yellow dashed line (**right**).

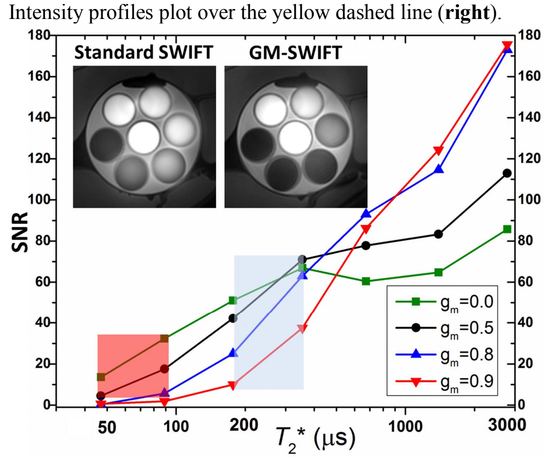

Fig.3 SNR (actually it is signal to background ratio) of T_2* phantoms with different T_2* values and g_m factors.

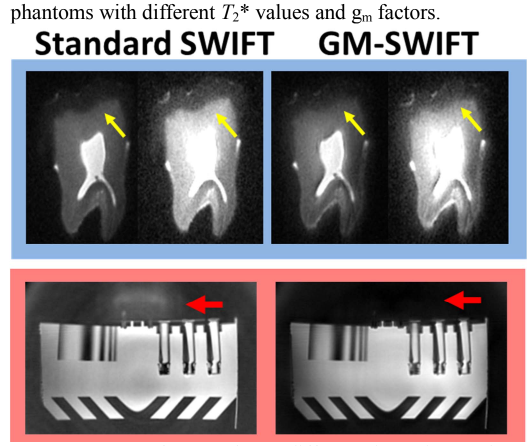

Fig.4 Images of a tooth at different intensity scale and resolution phantom and a piece of rubber (red arrows) obtained by SWIFT and g_m=0.8 for GM-SWIFT.

Conclusion In summary, GM-SWIFT can achieve reduction of SAR, RF amplitude or acquisition time, and provides control over the T_2 sensitive range for producing a clean background in images. The tradeoff is some reduction in the sharpness of short T_2* spins, depending on the level of gradient modulation. By manipulating the gradient, GM-SWIFT can maximize the efficiency of RF power and provide a way to find the optimal settings that balance RF amplitude, SAR, scan time, and image quality considerations.

Reference [1] D. Idiyatullin et al. J Magn Reson 181, 342, 2006 [2] A. Tannus et al. NMR Biomed. 10, 423,1997 [3] Jinjin Zhang et al. ISMRM, No. 2382, 2013

Acknowledgement This research is funded by grants P41 EB015894, KL2TR000113, S10 RR023730, S10 RR027290 and WM KECK foundation.