An Investigation of Fundamental Pitfall in SSGR

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Introduction: Sufficient fat suppression is often used in post contrast T1w-images and is crucial for all techniques using EPI-readout e.g. fMRI, DWI and perfusion. Common fat suppression techniques rely on short inversion recovery pulses (STIR) or spectrally selective pre-pulses, both increasing acquisition time and SAR. Gomori et al. (1) and Ivanov et al. (2) reported in 1988 and 2010 respectively, two techniques that, in Spin-Echo based sequences at higher field strengths, can achieve sufficient fat suppression, without the use of per-pulses. Both techniques take advantage of the fat-water chemical shift (~3.35 ppm) and uses different transmit bandwidths (tBW_{90}, tBW_{180}), (2) and/or different gradient polarity (1) (**SSGR**) to shift position of fat during excitation and refocusing. The SSGR method has undoubtedly shown good fat suppression ability when applied to DWI and T1w-imaging.

However, this work shows that one need to consider the slice-selection direction compared to the choice of fat displacement direction, to prevent acquisition of distorted images. For the SSGR method, depending on gradient polarity, the excited and/or refocused fat position is pushed either against or along the slice-selection direction. For multi-slice acquisition, this may be crucial due to the fact that spatially displaced excitation and refocusing of fat can interact and form an echo in latter slices. To the best of our knowledge, neither of the inventors nor any users of the two methods have reported this problem. This work investigates the birth of the misplaced echo and shows how it can be eliminated by pairwise changing the crusher-amplitudes between slices. The motivation to this work came from implementing the SSGR method and acquiring the two images shown in Fig. 1, having the slice-selection direction as only difference.

Material and Methods: When applying a gradient, the frequency shift (~3.35 ppm) between fat and water yields a spatial displacement between protons in fat and water precessing with the same frequency. The extent of displacement d is $d = \delta j B_0/G = \delta B_0/(tBW * \Delta z)$ [mm], where δ the chemical shift in ppm, j = +-1 depending on gradient polarity, B_0 is the main magnetic field, G is the gradient amplitude, tBW the transmit bandwidth of the RF pulse and Δz is the slice thickness.

To be able to visualize and investigate misplaced fat signal arising from previous slice positions, a fat-water phantom, angled ~60 degrees relative to the scanners z-axis was used. On a GE 750 3T system, three scans a), b) and c), all using the SSGR method was acquired. For easier understanding and schematic visualization of fat displacement in multi-slice acquisition only five slices were acquired. G, tBW and j were chosen to yield Δz=5 mm, d_{90}=5 mm and d_{180}=-5 mm for all scans (Fig. 2). Scan a) (Fig. 3a) used the opposite slice selection direction compared to scan b) and c) (Fig. 3b-c). Scan c) was acquired with varying crusher-amplitudes between slices. Standard interleaved slice order was used.

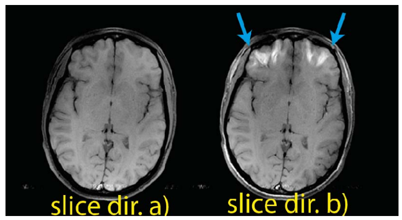

Fig. 1 SSGR image showing misplaced fat signal from orbit

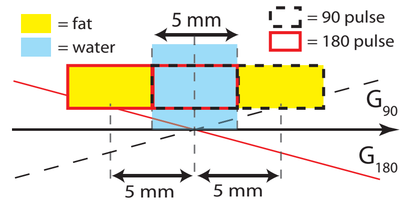

Fig. 2 Schematic figure showing displacement of fat relative water, when using SSGR

Results: Fig. 3 shows the images acquired in scan a) and b) with their corresponding theoretical time-RF scheme. Black numbers give relative temporal information of when, within one TR, an RF pulse occurred and the numbers position reveals whether it was an excitation or refocusing pulse and at which spatial position it excited/refocused water and fat. Misplaced fat signal is only seen in images from b) at spatial position -10, -5 and 10. The false signal is marked with blue arrows showing its spatial source. Fig. 3c shares the same time-RF scheme as b), but no misplaced fat signal can be seen.

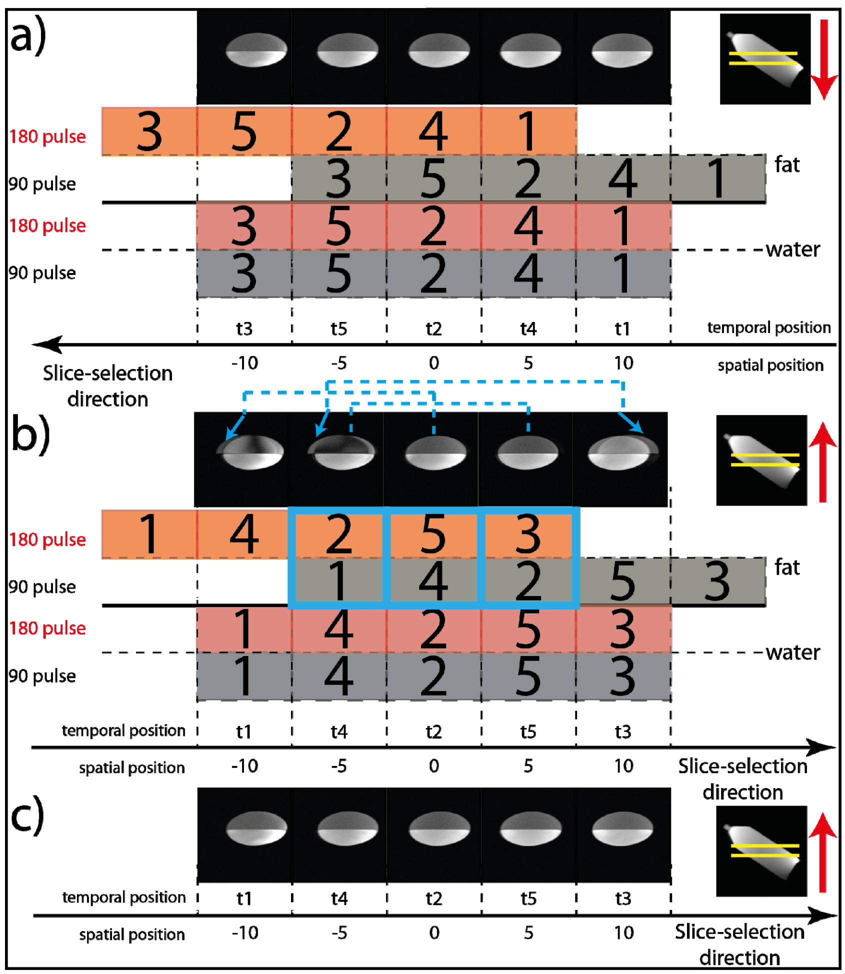

Fig. 3 Showing images obtain with scan parameters a), b) and c) and corresponding theoretical time-RF scheme

Discussion & Conclusion: Misplaced fat signals are created from overlaps between displaced excitation and refocusing pulses. Comparing time-RF scheme from a) and b), it can be concluded that an echo is only formed if the excitation, refocusing and acquisition of affected slices are subsequent w.r.t temporal position. Critical positions are framed blue in Fig. 3b. For example in Fig. 3b, the slice acquired at spatial position 10, temporal position t3, gets contaminated with fat signal arising from spatial position -5. At spatial position -5, fat was excited at t1 and refocused at t2, thus forming an echo at t3. The fact that the misplaced signal is eliminated if the crusher-amplitudes are varied, reveal that the total gradient momentum during t2 and t3 conspire to refocus the misplaced echo in t3. Comparing with Fig. 3a, displaced excitation and refocusing pulses does not affects any slice in crucial temporal order, thus no misplaced echo is formed.

We have highlighted a severe artifact that can occur when using SSGR or similar fat displacing methods. By deriving the birth of the artifact we understand how to avoid it by the choice of slice-selection direction and have proposed a method using varying crusher-amplitudes which eliminate the artifact independent of slice-selection direction. There may be other ways to eliminate the artifact, e.g. introducing variable killer areas etc.

Reference:
[1] Gomori et al. Fat Suppression by Section-Select Gradient Reversal on Spin-Echo MR Imaging. Radiology1988;168:493-495.
[2] Ivanov D, et al. A Simple Low-SAR Technique for Chemical-Shift Selection with High-Field Spin-Echo Imaging. Magn Reson Med 2010;64: 319–326.