Time efficient fat suppression for T1-w SE imaging at 3T: in your face

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Introduction: Fat suppression is used in post contrast T1w Spin-Echo images for accurate delineation of the regional contrast uptake. Fat suppression can be achieved by for example using spectrally selective pre-pulses, inversion-recovery pulses (STIR) or a combination of both (SPIR). Common for these methods are that they require additional RF pulses, which increases SAR and lengthens the acquisition time. On our system we have observed that for conventional Spin-Echo, adding a fat saturation pre-pulse can lead to nearly three times longer scan time for a fixed set of slices. In 1988, Gomori et al. introduced the Section-Select Gradient Reversal (**SSGR**) technique that inverts the polarity of the gradient applied during refocusing to create a spatial shift between excited and refocused fat slice (2). Recently, Ivanov et al. proposed a similar technique that applies different transmit bandwidths for the excitation and refocusing pulses, creating a similar effect (1). Ivanov indicated that his method should be less sensitive to inhomogeneities, with less off-resonance water suppression for both techniques. Both techniques have been applied for EPI-based diffusion imaging in 3T and 7T, reporting good results. An implementation of SSGR for T1w Turbo SE on 1.5T, 3T and 7T was shown in 2009 by Takahara et al. (3).

With the goal to achieve sufficient fat suppression in 3T for T1w SE images, without the associated increase in SAR and acquisition time, this work reviews both methods, (1) and (2), w.r.t. fat suppression, undesired on-resonance water saturation, acquisition time and T1-w contrast. Both methods are benchmarked against the manufacturer's two fat saturation techniques, both using spectrally selective pre-pulses with different spectral selectivity.

Theory: 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 $d = \delta\ B_0/G = \delta\ B_0/(tBW * \Delta z)$ [mm], where δ the chemical shift in ppm, 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. The fat suppression efficiency is proportional to the displacement between the excited and refocused fat slice. Fig. 1 demonstrates how the magnitude of fat displacement, for a given slice thickness, is governed by the transmit bandwidths (tBW_{90}, tBW_{180}) of respective RF pulse (Fig.1a) and the displacement direction by the gradient polarity (Fig. 1b).

SINC pulses with a time-bandwidth product of 4 were used for both the excitation and refocusing. To counteract the slice narrowing effect from accompanying crusher gradients, the refocusing slices was increased by ~30%, corresponding to a reduced gradient amplitude of ~30%. For that reason, the displacement effect increases when tBW_{180} is lower than tBW_{90} (Fig. 1a). For a fixed slice profile (time-bandwidth product), the tBW_{90} and tBW_{180} are proportional to the inverse of their respective pulse widths (PW_{90} and PW_{180}), which in turn also affects the echo time, TE.

Method 1: Method by Ivanov et al., using different *tBWs* (Fig. 1a), without gradient reversal. Maximum fat suppression is achieved by maximizing the difference between tBW_{90} and tBW_{180}. The maximum achievable B_1 in the system restricts the maximum BW_{90} and maximum allowed TE restricts minimum tBW_{180}. Maximum tBW_{90} was 2500 Hz and disallowing TE above 16 ms yields a minimum tBW_{180} of 350 Hz. A healthy volunteer was imaged on a GE 750 3T system using TE/TR = minimum/650 ms, Δz = 3 mm and tBW_{180} = 350-650 Hz (in steps of 50 Hz).

Method 2 (SSGR): The SSGR technique (Fig. 2b) inverses the gradient polarity for the refocusing gradient to displace the fat slice in opposite directions. This displacement can be further increased by reducing the *tBWs*. For simplicity, tBW_{90} was set to 900 Hz and disallowing TE above 16 ms, the minimum tBW_{180} became 550 Hz. During same exam as for method 1, method 2 (SSGR) was scanned with same TE, TR and slice thickness but with tBW_{180} = 550-1150 Hz (steps of 100 Hz).

For reference, a standard T1-w SE was also acquired with standard RF pulses and with the same scanning parameters, without and with two types of fat selective saturation pulses. Same transmit and receive gains were kept in all scans for quantitative comparisons.

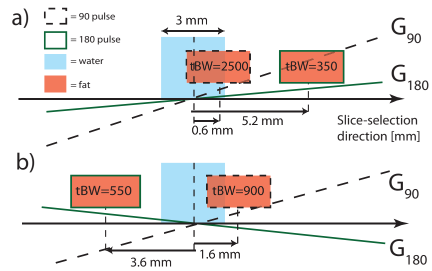

Fig. 1 a) Displacement of fat using different *tBWs* and same gradient polarity (method 1), b) Displacement of fat using different *tBW* and opposite gradient polarity (method 2) (SSGR).

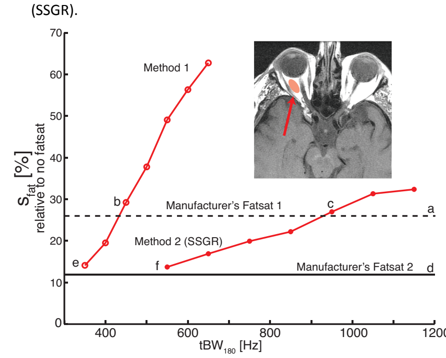

Fig. 2 Fat suppression ability for method 1 and 2(SSGR) as a function of tBW_{180}, compared to the manufacturer's two fat saturation techniques

Results: The mean intensity value from a ROI placed in the fat intense region intraconal of the orbit (Fig 2) was measured for all fat suppressing techniques. Compared to the mean intensity value from the ROI in the image using no fat saturation, a measure of fat suppression efficiency was given for each method. Fig. 2 shows the percentage fat suppression, as a function of tBW_{180}, for methods 1 and 2. The fat suppression achieved using the manufacturer's two different pre-pulses are also shown. From Fig. 2, two tBW_{180} configurations from each method, best corresponding to the magnitude of fat suppression using the manufacturer's Fatsat 1 and Fatsat 2, were selected. In Fig 3, images corresponding to a-f in Fig. 2 are compared w.r.t. percentage fat suppression (red), percentage on-resonance water suppression (blue), minimum TE (yellow) and maximum number of slices possible in one acquisition (green).

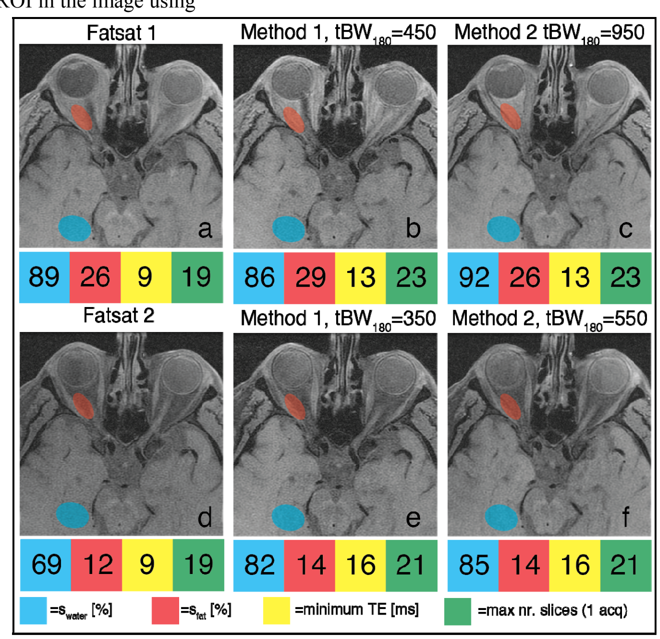

Fig. 3 Comparison of fat suppression methods, a-f chosen from Fig. 2. All images are windowed equally.

Discussion & Conclusion: We have shown that both investigated techniques can achieve sufficient fat suppression without the use of a pre-pulse, which is beneficial both in terms of acquisition time and SAR. Moreover, using one of the vendor's pre-pulse (Fatsat 2) at 3T in particular, the WM signal is significantly reduced, making the WM/GM nearly indistinguishable (Fig. 3d). Compared to the vendor's fat saturation techniques, the fat/water ratios of method 1 and 2 are comparable or better (Fig. 3), while allowing for more slices per *TR*. It should be noted that the number of slices/TR using certain settings drops down to ~11 slices with the same *TR* when using pre-pulses, which is about a third of the slices compared to no fat saturation. However, both proposed methods are sensitive to susceptibility gradients near tissue-air interfaces, especially in the basal part of the brain. Despite previous claims (1), method 1 was not found advantageous over method 2 (SSGR), when it comes to preserving water signal in off-resonance regions, fat saturation efficiency, or lower TE. Rather, method 2 (SSGR) was found superior in all these aspects. Depending on the application, one may trade between the level of fat suppression, off-resonance water signal and slice coverage by altering the *tBWs*.

References:

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