Hiding your Fat: Comparison of Fat Saturation Techniques for Single-Shot Fast Spin Echo Sequences for 7T Body Imaging

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Introduction:

Due to inherent B_0 and B_1 inhomogeneities, fat suppression (FS) at 7T is not easily achieved with standard methods (i.e. fat-selective 90° RF pulse followed by spoiler gradients on each axis), especially when performing body imaging with single-shot fast spin echo (SSFSE) sequences (Fig. 1). Here, a novel method using the recently proposed Time Interleaved Acquisition of Modes (TIAMO) [1] and two methods based on slice-selective gradient reversal (SSGR) [2-4] and slice-selective smaller bandwidth refocusing pulses (SSB) [5] are compared in volunteer measurements. The latter techniques profit from higher field strength, as the chemical shift between fat and water (3.5 ppm) gets larger and FS can be accomplished without an increase in scan time or SAR. Another advantage of these techniques is that they can be combined with FS techniques that rely on additional preparation pulses like TIAMO FS.

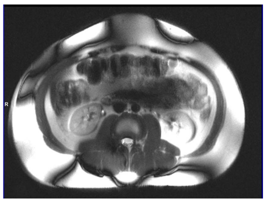

Fig. 1: Example of abdominal image with standard FS (90° fat-selective) showing severe inhomogeneities.

Material and Methods:

All measurements were performed on a 7T whole-body system (Magnetom 7T, Siemens) equipped with a custom-built 8-channel body coil and with a custom 8-channel RF shimming and SAR supervision system capable of fast switching between different sets of amplitudes and phases.

<u>FS techniques:</u> <u>TIAMO FS:</u> multiple fat-selective 90° (nominal) RF pulses (each 3 ms) applied with different RF shims (modes) followed by spoiler gradients on each axis. Here 6 preparation pulses were chosen alternating between the first- and second-order circularly-polarized modes (Cp^+ and Cp^{2+}). <u>SSGR</u>: The slice selection gradients of the 90° excitation pulse and the 180° refocusing pulses are applied with opposite polarity leading to opposite directions of the chemical shift, which means that no spin echo is formed from fat [2-4]. <u>SSB</u>: The refocusing RF pulses possess a smaller bandwidth than the excitation RF pulse due to prolonged duration and same time-bandwidth product. The lower amplitude of the slice-selection gradient shifts the refocusing bandwidth away from the excited fat signal [5]. For excitation a pulse duration of 2 ms was chosen (the same duration as used for the other techniques), and for refocusing a duration of 4 ms.

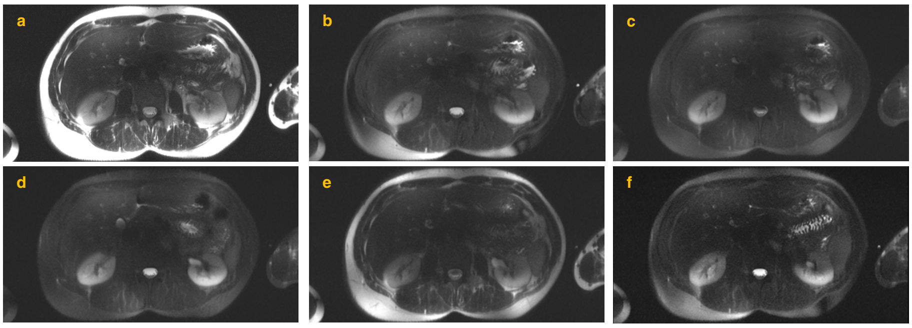

Fig. 2: Abdominal images of a female volunteer without any FS (a), with TIAMO FS (b), SSGR (c), SSGR and TIAMO FS combined (d), SBB (e), SBB and TIAMO FS combined (f).

<u>Imaging parameters</u>: 2D SSFSE with FOV 384 mm x 288 mm, 1 mm x 1mm in-plane resolution, slice thickness 5 mm, 11 transversal slices with 150% distance factor, TR = 1500 ms, TE = 91 ms (97 ms for the SSB technique), phase partial Fourier 5/8, GRAPPA acceleration factor R = 3, bandwidth = 766 Hz/px, and TA = 33 s. For the imaging portions of all sequences, TIAMO with the Cp^+ and Cp^{2+} modes was used. No SAR reduction for the 180° refocusing pulses was applied. Imaging was performed in 3 volunteers (age in years / weight in kg: 21/65; 38/70; 22/65) in 6 different ways: without any FS, with TIAMO FS, with SSGR, SSGR with preceding TIAMO FS, SSB, and SSB with preceding TIAMO FS.

For evaluation of the techniques regarding fat suppression and tissue signal preservation, ROIs were placed identically for all 6 protocols per volunteer in subcutaneous fat (6 ROIs distributed around the body contour), intra-abdominal fat (3 ROIs: one next to each kidney, one next to the spleen), organs (5 ROIs: liver, kidneys, spleen, and pancreas), and muscle (3 ROIs: one in the rectus abdominis muscle and two in the spinal erector).

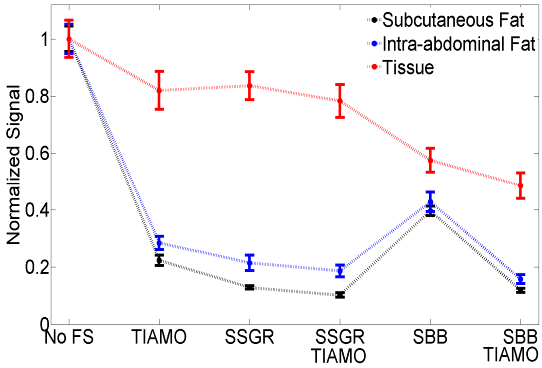

Fig. 3: Signal intensity of subcutaneous / intra-abdominal fat and tissue relative to imaging without FS and averaged over all ROIs. Exemplary data of the same female volunteer as in Fig. 2.

Results:

Figure 2 shows the center slices of the sequence variants using the different FS techniques. SSGR and SSGR combined with TIAMO led to nearly homogeneous FS over the whole FOV in all volunteers. Figure 3 shows measured signal intensities of fat and tissue relative to the sequence run without any FS – averaged over all ROIs. Regarding fat signal, SSGR and both SSGR / SSB combined with TIAMO FS led to sufficient overall FS (Fig. 3; blue and black lines) – in the case of SBB with TIAMO FS not homogeneous over the whole FOV, however. Also, one can clearly see that all FS techniques tend to reduce the signal of other tissues (Fig. 3; red line). The highest signal loss was measured for the combination of TIAMO FS and SBB. Considering overall SAR, the differences between the FS techniques are negligible for 2D SSFSE due to the high number of 180° refocusing RF pulses in the imaging part of the sequence.

Discussion:

SBB shows the largest signal decrease for non-fat tissue. On the one hand this is partially due to the longer TE that has to be chosen to apply prolonged refocusing pulses. On the other hand, FS techniques based on gradients lead to signal loss due to improper slice refocusing. Of the techniques that led to satisfying FS and to acceptable tissue signal decrease, SSGR would be the most favorable technique, as it showed the most homogeneous FS and no additional preparation pulses are necessary.

References: 1. Orzada et al. MRM 64(2):327-33 (2010); 2. Park et al. MRM 4:526-36 (1987); 3. Volk et al. JMR 71:168–74 (1987); 4. Gomori et al. Radiology 168:493-5 (1988); 5. Ivanov et al. MRM 64:319-26 (2010)