Shaped Fat Saturation with 2D Spatially Selective Multi-Frequency RF Pulse Design in Parallel Transmission

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Target Audience: RF engineers and MR physicists. **Purpose:** To avoid interference of unwanted signals with the region of interest, a localized suppression is often necessary. Typical examples in spectroscopy are the fat signal suppression in the vicinity of the prostate (1) or the suppression of the scalp cap (2). To date the localized signal suppression is realized by the manual arrangement of multiple saturation slabs, which can be time consuming and anatomically inaccurate. The application of multidimensional spectral-spatially-selective radiofrequency pulses (SSSRF) would overcome this issue enabling the saturation of arbitrarily shaped patterns. However, due to their long pulse durations, sensitivity to off-resonance effects and other practical limitations, they have not been realized, yet.

In this work we introduce multi-frequency shaped saturation pulses with parallel transmission (pTX) on a commercially available 3T scanner. The SSSRF pulses based on a variable-density 2D spiral trajectory were evaluated in phantom and human in-vivo experiments, saturating the fat signal in the scalp cap. The performance of the SSSRF pulses was further compared to a non-selective Gaussian fat saturation pulse.

Methods: To overcome the practical limitations of SSSRF saturation pulses, the combination of several approaches is necessary: First, with the usage of multiple transmit channels (pTX) SSSRF pulses can be undersampled/accelerated without aliasing artifacts. Furthermore, by incorporating the prevailing B1 and B0 maps into the pulse design, pTX allows for mitigation of off-resonance effects and flip angle non-uniformity. Second, the design of SSSRF pulses with higher flip-angle levels as required for saturation still remained challenging within given RF hardware and SAR limits. To tackle this problem, we recently proposed a variable density trajectory design, which inherently offers an RF-power-efficient pulse design (3-4). The proposed approach takes advantage of the a-priori knowledge of the desired target pattern and available B1 magnitude to adjust the sampling density in k-space and has been shown to be superior to common variable or equal-density sampling strategies (3-4). Finally, to control the frequency response of SSSRF pulses, the RF pulse optimization has to be extended by the frequency dimension. Particularly, the SSSRF pulse has to be designed to saturate the fat signal only and not the water signal.

To evaluate the performance of the proposed SSSRF fat saturation pulse optimization, phantom and human in-vivo experiments were pursued. In the phantom study, a fat-water phantom setup (FOV 240x240 mm^2) was used to analyze the frequency response of the localized suppression. SSSRF pulses were designed to saturate a rectangular shaped pattern for *a)* solely the fat signal and *b)* both fat-and-water containing areas. In the human experiments (FOV 220x220 mm^2), a rim-shaped pattern was chosen to saturate the fat signal in the scalp cap as often required in spectroscopy. In both scenarios, the fat saturation performance was further compared with a Gaussian FATSAT pulse, which globally saturates the fat signal over the whole FOV. Images were acquired on a 3T MAGNETOM Skyra (Siemens, Erlangen, Germany) equipped with two transmit channels, using a prototype gradient echo sequence with matrix = 256x256 and TR/TE = 50/10 ms. SSSRF pulses were optimized according to the multi-frequency small-tip-angle optimization approach proposed in (5), using the target-driven variable-density 2D spiral trajectory of (4). In all experiments, the frequency response was defined only for two discrete design frequencies, i.e. for 0 Hz (water) and -420 Hz (fat). SSSRF pulse durations were 10 ms. No additional high-flip optimization strategy was applied. RF pulses were further regulated to stay within RF hardware and SAR constraints.

Results/Discussion: Phantom und human results are shown in **Fig. 1**. The phantom study (**Fig. 1a**) reveals that the SSSRF pulses can achieve similar fat saturation performance as the commonly used FATSAT and does not show any visible artifacts in the water band. Next to the localized saturation, the proposed SSSRF pulse also includes the saturation of multiple frequency bands at once with satisfying performance (**Fig. 1a,** top right). Further improvement can be expected, when more design frequencies are defined. The results were further confirmed in human in-vivo experiments. The fat signal was completely saturated in the neck by both the FATSAT and SSSRF fat saturation pulse. However, in the SSSRF experiment residual fat signal could be observed towards the forehead due to insufficient B1 and B0 data. This is likely due to low SNR in those areas. On the other hand, the difference images reveal that the SSSRF pulses generally affect the water band signal less than the FATSAT.

Conclusion: The proposed SSSRF pulse design enables the saturation of multiple frequency bands at the same time. The proposed approach was successfully evaluated with the shaped saturation of the fat signal in phantom and human in-vivo experiments. The designed pulses offer comparable saturation performance as the commonly used global FATSAT pulse and showed less interference with the water band.

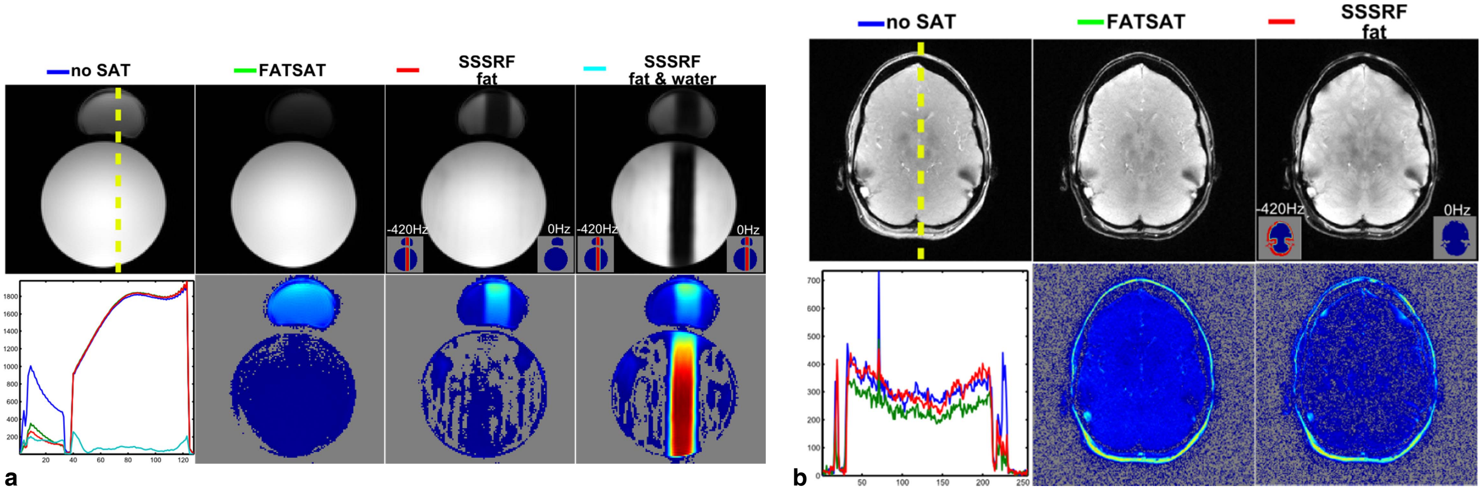

***Figure 1: a** Phantom experiments. **b** Human in-vivo experiments. Top row shows MR images with different fat saturation techniques. Bottom row shows respective 1D profiles (dashed yellow line from top to bottom) and the difference to the non-saturated image. Defined target pattern for the used design frequencies are attached at the lower corners of the MR images.*

References: [1] Scheenen et al. (2007). Rad 245:507-516. [2] Ramon et al. (2010). MRM 63:592-600. [3] Schneider et al. (2013). Proc. ISMRM 21:4261 [4] Schneider et al., abstract this meeting. [5] Setsompop et al. (2009). MRM 61:493-500.