Fast Fat Saturation for Balanced SSFP Imaging at Low Flip Angles using Alternating TR

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INTRODUCTION

Many applications of balanced SSFP (TrueFISP, FIESTA, b-FFE) imaging require suppression of fat signal, as fat appears very bright in the image due to its high T2/T1 ratio, thereby concealing signal from regions of diagnostic interest, e.g. coronary arteries. Several methods to suppress fat signal have been proposed and are in use [1-5], but they show different trade-offs as doubled imaging time, reduced S/N ratio, transient image artefacts, or the need of additional post-processing. In our work a novel technique is proposed which shows excellent fat-suppression in b-SSFP 2D and 3D imaging while maintaining S/N ratio and SAR, total imaging time increases only about 30%.

METHOD

The modified b-SSFP sequence (Fig.1) shows a repetition time altered between TR1 and TR2. HF-Pulse traverse a four phase cycle (0°-90°-180°-270°), while the switching of spin-warp gradients and SSFP signal acquisition takes place only during TR1. Transversal magnetization is fully refocused at each RF-pulse centre time. Slice selection gradient amplitude shows an alternating polarity to avoid the need of additional gradients in slice direction during TR2 which speeds up the sequence as TR2 is preferably short. With TR1=3.44 ms and TR2=1.15 ms the frequency response function (FRF) for the sequence in Fig.1 has the shape depicted in Fig. 2. θ denotes the total precession angle experienced for the different isochromats during TR1. Spins in fatty tissue (off resonance frequency 217 Hz) experience a dephasing of $\theta = 270°$ and their signal is suppressed by the sufficiently broad stopband around 270° in Fig 2. As longitudinal and transversal components are mixed in a different manner than in a standard b-SSFP sequence the contrast behaviour is modified. In Fig. 3 steady state signal for on-resonance spins is simulated for arterial blood (T1/T2=1.2s/0.2s) and muscle (T1/T2=0.3s/0.06s) at different flip angles. Compared to standard b-SSFP signal is enhanced at low flip angle values, for blood showing a value near the one yielded with standard b-SSFP at optimal flip angle. This is an essential feature as SAR can be kept in uncritical regions despite the doubled number of applied RF pulses.

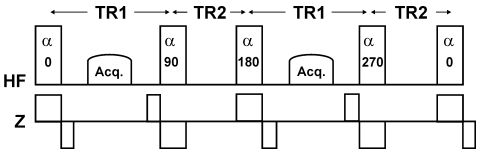

Fig.1: Modified b-SSFP sequence. Common spin warp gradients are not depicted but are applied in readout and phase encoding direction during TR1.

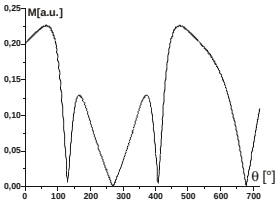

Fig.2: FRF for dephasing angle accumulated during TR1 for TR1=3.44 ms, TR2=4.58 ms

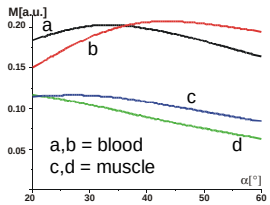

Fig.3: Signal amplitude for standard b-SSFP (b,c) and sequence from Fig.1 (a,d)

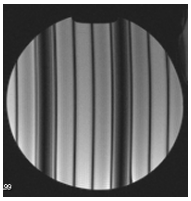

Fig.4: Phantom with shim gradient in readout direction. Broad stopband is obvious.

RESULTS

All experiments were performed on a Siemens Sonata 1.5T System. The simulated FRF was qualitatively reproduced by applying a shim gradient in readout direction (Fig.4). Pulse phase cycle was applied according to Fig. 1, with TR1 = 3.4 ms and TR2= 1.2 ms, with $\alpha = 40°$. To drive the magnetization into steady state 500 preparation sequence cycles were applied. The simulated sequence characteristics regarding fat suppression and contrast behaviour are evident in the 3D phantom experiments in Fig. 5B. Centre partition of eight 3 mm slices ist shown. To acquire the image in Fig 5A all RF pulses with 90° and 270° phase were switched off, which converts the sequence into standard b-SSFP. The in-vivo experiments (Fig. 7) show fatty tissue suppressed, depicted are MIPs of a 3D slab with eight 2 mm partitions, with in-plane resolution of 1.5 x 1.5 mm and readout bandwidth of 810 Hz/Px.

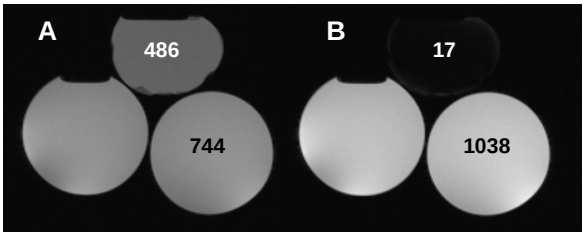

Fig. 6: Phantom experiments with two bottles of doped water and a bottle of fat an top. Slice Thickness 3 mm. A) Standard b-SSFP, B) modified SSFP Sequence from Fig. 1. Windowing of A and B is identical. Numbers denote signal amplitude in arbitrary units. Efficient fat sat and increased on-resonance signal is visible.

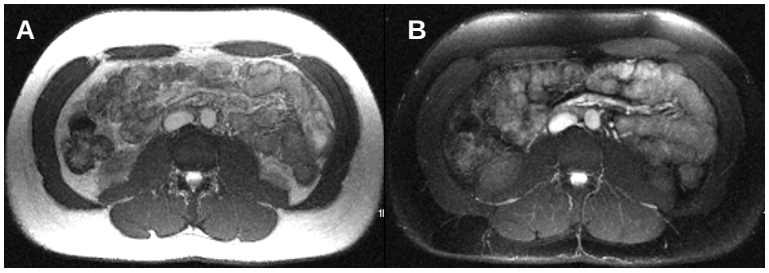

Fig. 7: In-vivo experiments. A) Standard b-SSFP, B) modified SSFP sequence from Fig. 1. Image are MIPs from a 3D data set of 8 slices with 2mm thickness. Homogenous fat sat and enhancement of on-resonant signal is evident. Windowing in A and B is identical.

DISCUSSION

The modified b-SSFP sequence from Fig.1 shows good results in achieving fat suppression in vivo. It offers a promising tool e.g. for imaging blood vessels. Simulation and phantom experiments show high signal at low flip angles, while both S/N and SAR are not significantly affected if compared with standard b-SSFP at higher flip angles Imaging time is increased only about 30%. Further examinations are underway to quantify contrast behaviour for different tissues. First moment of gradient pulses in slice selection direction is not nulled at RF-pulse centre time, which should affect flow sensitivity. To null first moment a common 3-lobe gradient shape as in standard b-SSFP can be implemented, however this will raise the shortest possible TR2 value. Frequency selectivity can easily be modified by changing the RF- pulse phase cycle. A 0°-0°-180°-180° cycle with TR1/TR2=3 gives a fat image with suppressed on-resonance signal. Also by adaptation of RF pulse phases it is possible to vary the timing pattern while keeping the stopband at a certain value. Thereby TR2 can be shortened until it matches slice selection gradient time.

REFERENCES

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