Intrinsic fat saturation of TIDE with variable flip angles due to modified stop bands

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Introduction

Balanced steady state free precession sequences (b-SSFP; also known as TrueFISP, FIESTA, balanced FFE …) are widely used in cardiac and abdominal imaging. They typically result in image contrast determined by T2/T1 [1]. In order to suppress signal oscillations from on- and off-resonant spins at the beginning of an experiment, the TIDE method was introduced [2]. TIDE provides higher image quality and reduced artifacts from off-resonant spins [2]. Additionally, the variable flip angle scheme of TIDE modifies the frequency response, leading to varied behavior of stop bands as compared to standard SSFP imaging [3]. We investigated and exploited the modified behavior of the frequency response in order to achieve intrinsic fat suppression in SSFP-type imaging.

Method

Simulations were performed in Matlab (TheMathworks, Natick, USA) using Bloch equations to investigate the signal behavior of on- and off-resonant spins. Figure 1 shows the flip angle profile of a TIDE sequence (a) and the corresponding frequency response (b). The TSE-like behavior of TIDE in the beginning of the experiment is clearly visible as insensitivity to off-resonance effects [3, 4]. During the transition from TSE behavior to TrueFISP steady state, the well-known stop bands run in from the sides (vertical red line in 1b). At the entrance of the stop bands, the spectrum of suppressed frequencies is broad. This effect is clearly visible in the frequency response profiles (1c) after 60 pulses (cf. the plot after 130 pulses: signal in the steady state). The signal evolution for off-resonant spins (1d, blue curve) shows a clear minimum while passing through the stop band. On-resonant spins, however, show a smooth transition into steady state.

In order to achieve fat suppression the central k space part must be sampled during the appearance of the stop band. This is realized in TIDE using Partial Fourier (PF) acquisition. The position of the stop band can be controlled by sequence parameters such as repetition time (TR), preparation pulses (#m), and ramp down steps (#nTIDE).

Experimental measurements on phantoms and healthy volunteers were performed on a 1.5T Magnetom Espree system (Siemens Medical Solutions, Erlangen, Germany) using a body array coil. We compared the TIDE sequence with intrinsic fat suppression (FS-TIDE) with standard TrueFISP and TrueFISP with fat saturation pulse and centric reordering (FS-TrueFISP).

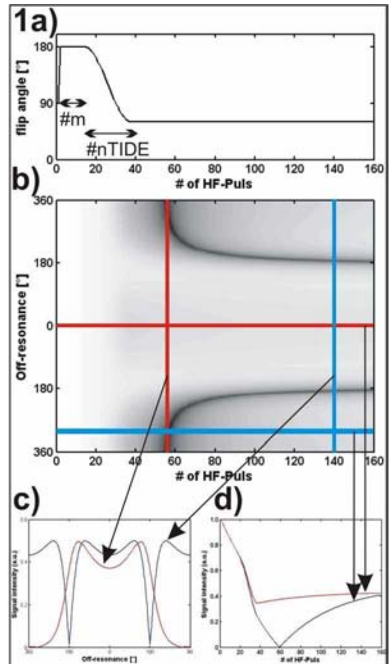

Fig.1: a) flip angle shape of TIDE sequence with #m=16 preperation pulses, #nTIDE=24 ramp down steps, and 60° flip angle.
b) frequency response over the first 160 pulses. TR/TE=4/2ms; T1=T2=200ms; signal intensity: wh=1, bl=0
c) frequency response profile after HF pulse #60 (red) and #140 (blue).
d) signal evolution for on- (red) and off-resonant spins (blue).

Results

Figure 2 shows results from experiments using different fat (1&2) and water (3&4) phantoms and figure 3 abdominal images from a healthy volunteer. Fat suppression is achieved excellently using FS-TIDE (2c, 3c) in comparison to FS-TrueFISP (2b, 3b) (Note: Imaging parameters are listed in the figure caption). Eddy current artifacts due to centric reordering can only be seen in phantom 4 by using FS-TrueFISP, since FS-TIDE uses linear reordering. Furthermore, a comparison of figures 3a and 3c shows that image contrast of non-fat tissues is similar in FS-TIDE and TrueFISP. Imaging time and specific absorption rate values (SAR) are not affected by fat suppression as compared to normal TIDE imaging.

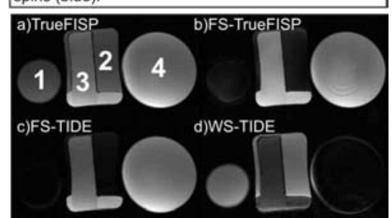

Fig.2: water (*3&4*) and fat (*1&2*) phantoms:
a) normal TrueFISP
b) TrueFISP with fat saturation pulse and centric reordering (FS-TrueFISP)
c) FS-TIDE: TIDE with fat suppression (#m=12, #nTIDE=24, 5/8 PF)
d) WS-TIDE: TIDE with water suppression (#m=2, #nTIDE=24, 5/8 PF, different resonance frequency)
Imaging Parameters: TR/TE = 4.48/2.24ms, 60°

Discussion

As our studies indicate, TIDE inherently provides homogenous fat suppression due to the modified frequency response profile. The stop band, controlled by TIDE-parameters, is broad enough to suppress a wide spectrum of off-resonant frequencies.

By adapting the resonance frequency of the scanner or the phase cycling of RF pulses, the water phantoms can also be suppressed (see 2d). However, due to the dependency of the stop band on T2, only one water phantom is suppressed perfectly. The T2-dependency should be taken into account in further studies.

In the transition through the stop band off-resonant spins undergo a phase jump. Artifacts from this effect were not recognized in any of our measurements. Nevertheless, this effect should also be investigated in future work. By using repTIDE [2], an adaption to 3D imaging can be realized.

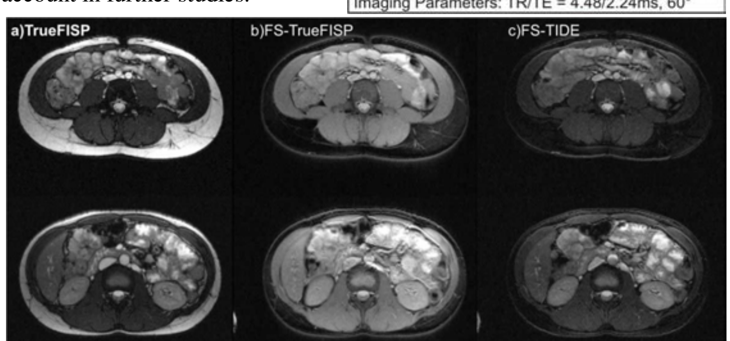

Fig.3: experimental results on heathy volunteer with: a) TrueFISP, b) FS-TrueFISP c) FS-TIDE (#m=1, #nTIDE=16, 5/8 PF). Imaging Parameter: TR/TE = 4.48/2.24ms, 60°, 256 Matrix

References

[1] Zur Y, et al., MRM 6: 175-193 (1988)
[2] Hennig J, et al., MRM 48: 801-809 (2002)
[3] Paul D, et al. ISMRM (2005), #1390
[4] Paul D, et al. ISMRM (2005), #1011