Reduced opposed phase effects in balanced SSFP-imaging using TIDE

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Introduction

Balanced steady state free precession sequences (b-SSFP; such as TrueFISP, balanced FFE, FIESTA…) are finding widespread applications in cardiac and abdominal MR imaging and benefit from high SNR and short repetition times. However, a major drawback of b-SSFP imaging is its sensitivity to off-resonance effects.
This sensitivity leads to signal oscillations during the transient phase at the beginning of an MRI experiment which appear as artifacts in the resulting image. Different approaches already exist to suppress these oscillations [1-4].
In the SSFP steady state the sensitivity to off-resonance leads to another problem, know as opposed phase effect. This effect occurs in voxels (areas) with a mixture of water and fat. Due to the different precession frequency (Δf = 220Hz at 1.5T) the signal of these two pixel compartments can have a phase difference of pi at echo time and therefore cancel each other, appearing as black borders around organs. The effect directly depends on the repetition time (TR) and can be reduced with short TR. However, due to hardware limitations the opposed phase effect is always a problem with typical clinical parameter settings for TrueFISP imaging (TR = 3…4ms).
In this work the influence of variable flip angles in TIDE [4] sequences concerning the opposed phase effect was analyzed and compared to a standard TrueFISP sequence with α/2-preparation [1]. It is demonstrated that the opposed phase effect is reduced using TIDE.

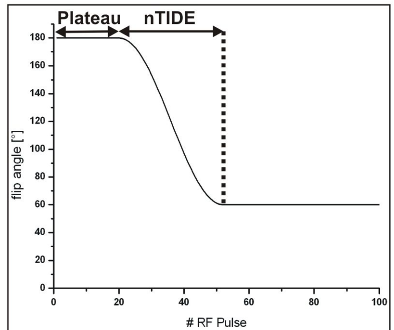

Fig. 1) Flip angle scheme for TIDE sequence. After *#plateau* = 20 pulses, the flip angle is ramped down from α_{max} = 180° to α_{min} = 60° in *#nTIDE* = 32 steps using a sinusoidal function.

Method

The flip angle scheme of a TIDE sequence is shown in figure 1 [4]. Starting with 20 pulses *(#plateau)* with a high flip angle (α_{max}=180°) the flip angle is ramped down over *nTIDE* = 32 pulses to a lower value (α_{min}=60°). A sinusoidal ramp function is used. A α/2-TR/2-pulse-preparation was used before imaging [1]. Constant repetition time (TR) and echo time (TE) was used for all rf-pulses, the RF phase was altered by 180° fur successive excitations.
Simulations with different parameter sets for flip angle scheme and repetition times TR based on the Bloch equations were performed in Matlab (TheMathworks, Natick, USA) to estimate the signal behavior. All experiments (water-fat phantom and healthy volunteers) were performed on a 1.5T system (Siemens Sonata, Siemens Medical Solutions, Erlangen, Germany). Resulting images were compared to a standard TrueFISP imaging sequence.

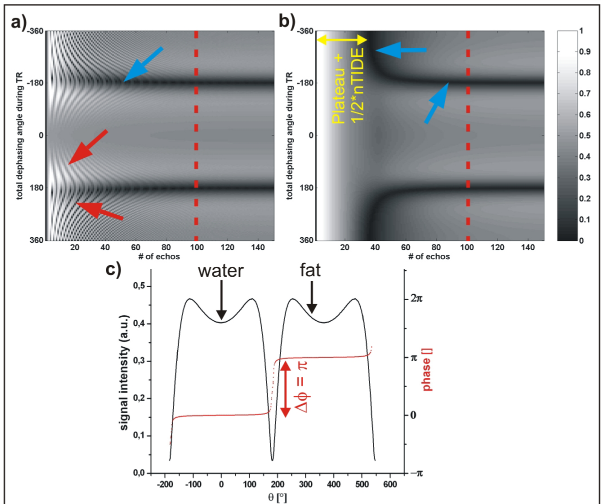

Fig. 2) The figures show the signal intensity along the time axis (pulse number) as a function of the off-resonance frequency for TrueFISP (**a**) and TIDE (**b**) imaging. Grayscale values represent the absolute signal intensity ranging from 0 (black) to 1 (M0). The vertical scale represents the off-resonance-dependent dephasing angle between successive pulses. The stopbands, dividing areas with phase increment of π, are indicated by blue arrows.
Parameters for the simulations were T1/T2/TR/TE = 100ms/100ms/4ms/2ms. For TrueFISP a flip angle of 60° was used, while the flip angle scheme from figure 1 was used for TIDE simulation. Strong signal oscillations appear in the beginning of the TrueFISP simulation (fig. 2a, red arrows) but not in TIDE simulation. For TIDE the apperance of the stopbands (fig. 2b, blue arrows) is controlled by the length of the plateau and half of the ramp (fig. 2b, yellow arrow).

Fig. 2c) Amplitude and phase response profile after 100 RF pulses for TrueFISP imaging (identical to TIDE). Plots were calculated at TE=TR/2 = 2ms as a function of the off-resonance-dependent dephasing angle θ during TR. The phase difference $\Delta\phi$ of π and the stopbands between fat and water are seen.

Results

Figure 2 shows the simulated signal intensity along the time axis as a function of the off-resonance frequency. The vertical scale represents the off-resonance-dependent dephasing angle between successive pulses for (a) TrueFISP and (b) TIDE. The stopbands (marked with blue arrows), known from the frequency response function, can be seen as black stripes. In the SSFP steady state these stopbands divide areas with a phase increment of pi.
For the TIDE simulations the stopbands are absent in the beginning of the RF excitation and appear at later times when the flip angle is decreased. The appearance of the stopbands can be controlled by the length of plateau and ramp down *(#plateau* and *#nTIDE*, see also figure 2b).
In comparison to standard SSFP imaging the signal intensities during the transient phase are independent of the resonance-offset and thus demonstrate a homogeneous signal decay over the entire off-resonance spectrum. As a result, spins with different resonance frequencies do not demonstrate a phase difference at the echo time TE (no pi phase jump). Therefore, during the transient phase the TIDE sequence behaves like a TSE sequence with ideal 180° refocusing pulses and is insensitive against off-resonance effects [1].
In order to avoid the opposed phase effect, the central k space line has to be sampled within this homogenous range.
Figure 3 shows abdominal axial images of a healthy volunteer with TrueFISP (3a) and TIDE (3b) imaging. In addition, a Half Fourier sampling (5/8) was used in TIDE such that the k-space center is traversed during the homogeneous transient signal decay. It is clearly visible that the opposed phase effect is reduced by the TIDE sequence. Note, that the TIDE image provides a different contrast in comparison to standard SSFP imaging.

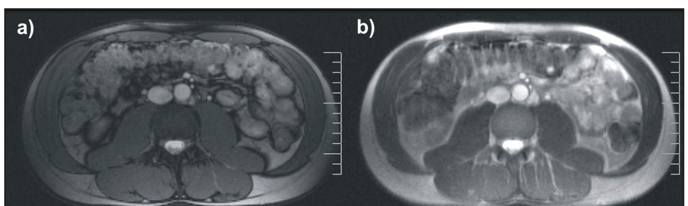

Fig. 3) Experimental measurement on a healthy volunteer. **a)** TrueFISP (TR/TE/FA = 3.7ms/1.85ms/60°), **b)** TIDE (TR/TE = 3.7ms/1.85ms, Half Fourier Factor 5/8, central k-Space line after 30 pulses)

Discussion

It was demonstrated that opposed phase effects can be eliminated using TIDE resulting in improved image quality. However, image contrast is also affected and changed by the TIDE sequence if the central k space line is recorded early. Potential application of contrast modified TIDE imaging are promising and merit further exploration in the future.
Nevertheless TIDE can be used for fast localizing in coronal or abdominal imaging, where the contrast itself is not as important. Another application is magnetization prepared b-SSFP imaging, like IR-SSFP, for which contrast is determined mainly by the inversion, or fat-saturated SSFP imaging [5], where the central k-space line has to be sample early after saturation due to the short T1 of fat.

References

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