Magnetization Preparation during the Steady State: Fat Saturated 3D TrueFISP

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Introduction
Acquisition of fat suppressed images is usually based on a selective saturation of fat resonances followed by an imaging block to read out the remaining water signal (1). A segmented approach is found in fat saturated 3D gradient echo sequences which are frequently used for contrast enhanced MR angiography. Here, the echo train is interrupted for every 100 to 300 ms to insert the fat preparation block. Gradient echo sequences such as FLASH, FAST, or CE-FAST (PSIF), however, detect an echo signal that is composed of a superposition of several steady-state configurations. A perturbation of the established steady-state magnetization will interrupt the balanced flow of transverse and longitudinal steady states, and may thus result in fluctuations of echo amplitudes and in a modified image contrast. This is not a severe problem in T1-weighted, RF spoiled FLASH sequences since the loss of coherent steady states may even improve the T1-weighted contrast. The more T2-weighted gradient echo sequences like CE-FAST (PSIF) and TrueFISP (2), however, are very sensitive to any modifications of their steady-state magnetization.

The major interest of the present work is focused on finding a way to insert a magnetization preparation block into a 3D gradient echo sequence without modifying its intrinsic imaging contrast. TrueFISP offers the possibility to interrupt its continuous echo formation without a significant disturbance of the established steady-state. The fat saturation technique presented here allows to acquire the known, high signal-to-noise TrueFISP images without the usually very intense fat signals.

Methods
The basic timing scheme of TrueFISP described by Oppelt et al. (2) consists of alternating $\alpha \pi/2$ excitation pulses and an echo refocusing at TE = TR/2. The dephasing of spins between consecutive RF pulses due to switched gradients is zero. The steady-state magnetization before and after an RF pulse (and at the echo time TE) is thus a single magnetization vector, and not a superposition of several dephased states of transverse and longitudinal magnetization as found in FLASH-type sequences.

The TrueFISP scheme thus offers the possibility to interrupt the $\alpha \pi/2$ pulse train with only a minor disturbance of the established steady-state. If an $\alpha \pi/2$ pulse is applied after the last $-\alpha$ pulse the resulting magnetization vector will be aligned exactly along z direction, and a second $\alpha \pi/2$ pulse will tip the magnetization back into the steady-state position. The initial $\alpha \pi/2$ pulse after the preparation block shown in Fig. 1 corresponds to the known $\alpha \pi/2$ preparation of TrueFISP (3). The final $\alpha \pi/2$ pulse before the preparation block is the counterpart of the initial $\alpha \pi/2$ pulse and acts as a flip back pulse to store the steady-state magnetization in the z direction. Since, in the ideal case, the complete steady-state magnetization is stored as pure z magnetization between the two $\alpha \pi/2$ pulses, spoiler gradients and spectral excitation pulses can be applied during this period without disturbing the steady-state signal of TrueFISP.

Discussion
The most unique feature of this technique is that even tissues with a very long T1 relaxation rate are not saturated by the periodically inserted preparation block. A comparable approach seems not to be applicable for non-balanced gradient echo sequences, since, in this case, a simple flip back pulse ($-\alpha$ pulse after the train of $\alpha$ pulses) is not able to convert all transverse configurations into longitudinal magnetization, which is insensitive to the fat preparation block. The T2-like contrast of fat saturated TrueFISP might compete with fat saturated, T2-weighted spin echo based sequences. T2-weighted spin echo or multi spin echo sequences, however, require a long TR of several seconds, and 3D acquisitions are thus very time-consuming and not feasible during a single breathhold. Fat saturated TrueFISP may thus offer an additional modality for rapid and highly resolved 3D imaging, including its high signal-to-noise ratio and T2 over T1 contrast. The potential use of this technique in clinical applications is obvious, since the unique combination of a very short TR and fat saturation enables to measure heavily T2 weighted 3D images within a single breathhold. Further applications may also include ECG gated imaging of coronary arteries, where fat saturation is essential to separate vessels from background tissue. The presented $\alpha \pi/2 - \alpha \pi/2$ scheme can be used as a template to incorporate other preparation techniques within a TrueFISP sequence.

Results

Figure 2 shows two identical slices measured without and with fat saturation. The signal intensities of the kidneys, the liver, and the spinal canal are similar, whereas nearly no fat signals are visible.

Figure 3 shows maximum intensity projections (MIP) of sub volumes of different 3D data sets acquired during breathhold. The small bowel and some of its vasculature is clearly separated from other background signals and small vessels and spinal roots are nicely resolved. The MIP images demonstrate the strong T2 contrast of fat saturated 3D TrueFISP. The renal calices, the ureter, and the gall bladder show a stronger signal compared to the abdominal aorta or the inferior vena cava.

References