Quantitative T1 Imaging with Inversion Recovery TrueFISP

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Introduction
Most T1 quantification techniques are based on measuring the longitudinal magnetization at different time intervals T1 after an inversion or saturation pulse (1). Conventionally, one data set with a given T1 is acquired after each inversion pulse and the experiment is repeated after a sufficient long recovery period (>5T1) with different T1s (single-point method(1)). As an alternative to this time consuming technique, inversion recovery Snapshot FLASH can be used (2). Here, the magnitude of the longitudinal magnetization is acquired continuously during its recovery using a FLASH sequence with low excitation flip angles of 5° to 10°. An intrinsic drawback of this method is the influence of the excitation pulses on the recovery of longitudinal magnetization even for small flip angles. Inversion recovery prepared TrueFISP was first proposed by Deimling and Heid (3) to modify the mainly T2 weighted image contrast of TrueFISP. In this work, we examined the possibility to replace the intrinsically T1 weighted FLASH readout module by a TrueFISP readout module to continuously acquire the recovery of longitudinal magnetization after inversion. Quantitative T1 measurements on phantoms and on humans based on FLASH and TrueFISP were compared to the gold standard of separately acquired T1 measurements.

Methods
The FISP sequence as proposed by Oppelt (4) consists of consecutive α excitation pulses with alternating polarity. The gradient areas between these α pulses are zero for all three gradient axes. Except for T2 effects, no transverse magnetization is lost between α pulses, and, except for T1 effects, the longitudinal magnetization before and after one TR remains the same. A completely different mechanism is found in FLASH or GRASS sequences where transverse magnetization is not refocused during TR due to an unbalanced readout and slice selection gradient. The resulting loss of transverse magnetization (which is partially RF-refocused in GRASS but completely spoiled in RF spoiled FLASH) generates a strong T1 contrast since echo amplitudes are mainly controlled by the amount of recovery of longitudinal magnetization between RF pulses. A segmented inversion and saturation recovery TrueFISP sequence was implemented on a Siemens Sonata system. TR was 3.375 ms, and TE was TR/2. Acquisition of the recovery of longitudinal magnetization was started immediately after inversion or saturation using a segmented TrueFISP readout. Depending on the required time resolution the number of echoes acquired for each segment was 4-32. Total acquisition time during recovery was 3.8 seconds. As described in (3) each TrueFISP train was prepared by a α/2 excitation pulse to bring magnetization close to the steady-state, and to minimize the oscillation of echo amplitudes after start of excitation. In addition, a segmented RF spoiled FLASH sequence with same parameters as for the TrueFISP sequence was implemented to compare both sequence types in terms of T1 accuracy and SNR.

Results
Fig. 1 shows the signal evolution of TrueFISP and FLASH measured on a NiSO4 phantom for different flip angles α. The echo amplitudes [real part, divided by sin(α) (FLASH) and sin(α/2) (TrueFISP)] were acquired after the inversion pulse in increments of TR = 3 ms (phase encoding gradient was set to zero). As a reference, the squares indicate the separately measured echo amplitudes after a single 20° excitation pulse for different times T1 after inversion (TR = 10 sec). TrueFISP clearly shows minor deviations of echo amplitudes from the reference curve even for flip angles up to 5°. The FLASH echo amplitudes show a significant T1 saturation effect during recovery and some oscillations after start of acquisition for flip angles higher than 10°. Even for a flip angle of 5° FLASH shows a stronger deviation from the ideal recovery curve than the 50° TrueFISP. Further T1 measurements were performed on a human brain as depicted in Fig. 2. The T1 values in the scattered plot were taken from region 1 of the T1 map shown right. T1 of white matter is confined to a small region of about 550 to 600 ms and is in good agreement to the reference T1 values for the 50° TrueFISP but is lower for the 10° FLASH. Region 2 positioned within gray matter and CSP reveals an increased variability in T1 values. However, T1 estimations based on the 50° TrueFISP are closer to the dashed line than those of the 10° FLASH. The variability of T1 values in region 2 might be due to head movements between the TrueFISP/FLASH measurements and the reference scan (single excitation at TR=90, 190, 290, 490, 890, and 1690 ms).

Discussion
The detection of the longitudinal magnetization during its recovery after inversion or saturation by a TrueFISP sequence seems superior to the conventional Snapshot FLASH technique. The continuously refocused transverse magnetization results in a strongly reduced influence on the free M0 recovery as compared to the spoiled FLASH technique. Experiments on phantoms and humans support the significant improvement of T1 quantification based on TrueFISP versus FLASH. The spoiling of transverse magnetization in FLASH generally leads to an underestimation of T1 since longitudinal magnetization is permanently used up during signal detection. As demonstrated, TrueFISP provides excellent results if T2 is greater than several TRs. For very small T2, however, the steady-state signal of TrueFISP comes close to the FLASH signal and thus shows an increased T1 sensitivity. A further advantage of TrueFISP is its resistance to flow and motion as demonstrated in recent applications on cardiac imaging. In addition, the short TR of TrueFISP reduces its sensitivity to off resonance effects, and phase cycling schemes like CISS are not mandatory at a field strength of 1.5 T.

References