Contrast-Enhanced Angiography using T1-weighted TrueFISP

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ABSTRACT
A new contrast-enhanced MR angiography technique is presented based on a T1-weighted TrueFISP (FIESTA, balanced FFE) sequence. T1 weighting is accomplished by periodically inserted inversion pulses during the TrueFISP echo train. Since blood mixed with a gadolinium-based contrast agent has similar T1 and T2 values (~50-100ms) the ratio T2/T1 is close to one which results in a strong TrueFISP signal while the background is saturated by the inversion pulses. Theoretical calculations and experiments demonstrate a gain of up to two in contrast-to-noise ratio compared to the established techniques based on RF-spoiled gradient-echo sequences.

INTRODUCTION
Contrast-enhanced magnetic resonance angiography (CE-MRA) is based on an artificial shortening of the T1 of blood by injection of a contrast agent. The high contrast between tissue and blood is generated with a strongly T1-weighted RF-spoiled gradient echo sequence which suppresses the signal of the surrounding tissue. The signal amplitude of these sequences depend on the flip angle, TR and T1 of the tissue and is given by the Ernst formula. Using an optimized flip angle the signal of blood with contrast agent is about 15-25% of M0, and about 1-5% of M0 for tissues without contrast agent. The signal intensity for SSFP sequences (TrueFISP, FIESTA, balanced FFE) is approximately given by 0.5M0T2/T1. Gadolinium-based contrast agents have nearly equivalent relaxivities R1 and R2 (about 5500/Ms and 4500/Ms, respectively) which results in a T2/T1 ratio of about one and therefore an SSFP signal of 40-50% of M0 for blood with contrast agent.

THEORY AND METHOD
Assuming a T1 of 50ms for blood during the first-pass of the contrast agent and a T1 of 500ms for the surrounding tissue, a RF-spoiled gradient echo sequence can provide an optimized contrast S_{blood}-S_{tissue} of 15-20% of M0 (1). For TrueFISP the signal of blood with a T1 of 50ms and a T2 of 60ms is about 45% of M0 (2). The signal of the surrounding tissue depends on the particular T1 and T2 values and can also reach up to 50% of M0 (CSF, Water). In order to suppress these background signals an inversion pulse is inserted periodically within the TrueFISP echo train. Depending on the repetition period of the inversion pulse background signals will be significantly reduced due to saturation and inversion recovery effects. The signal of blood with contrast agent will recover immediately after the inversion pulse an will give the full SSFP signal. The resulting contrast between blood and surrounding tissue will thus mainly depend and the repetition interval of the inversion pulse and on T1 of the surrounding tissue. Fig. 1 shows the measured signal evolution between two inversion pulses of water with two different concentrations of contrast agent (T1=50 and 500ms).

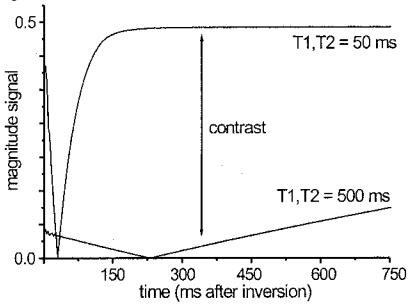

Fig. 1: Signal time course between inversion pulses for water with two different T1s.Signals were measured with TrueFISP with 70° flip angle.

RESULTS
All experiments were performed on a Siemens Sonata 1.5T scanner. Fig. 2 shows a comparison between T1-TrueFISP and T1-weighted FLASH (same TR, band width and resolution) for bottles of water with different concentrations of contrast agent. The flip angle for FLASH (α=23°, TR=3.2ms) was optimized for a maximal contrast between the T1=50ms and T1=500ms water bottle. For T1-TrueFISP the flip angle was 70° and the inversion pulses was applied every 819 ms. T1-TrueFISP shows an increase in signal and contrast by a factor of about two compared to FLASH. The image noise was the same in both experiments.

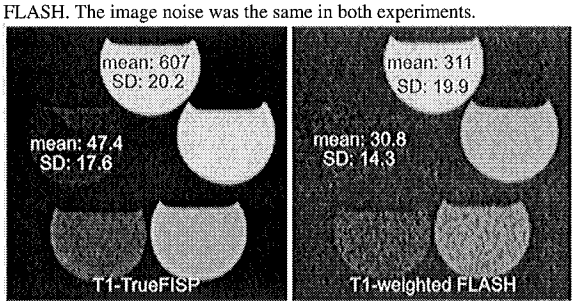

Fig.2:Left T1-TrueFISP and right T1-weighted FLASH for phantoms with different T1 values.

In vivo images were acquired for the femoral arteries and the descending aorta. Fig. 3 left shows a subtraction of two T1-TrueFISP data sets acquired before and during the first pass of contrast agent. On the right is a MIP of a single data set without subtraction.

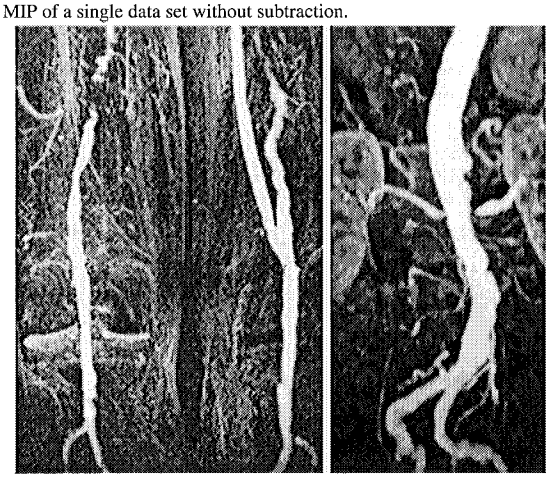

Fig.3: Coronal MIPs of CE-MRA acquired with T1- TrueFISP(FL=70°, TR/TE=3.2/1.6 ms).

DISCUSSION AND CONCLUSIONS
T1-TrueFISP offers an excellent contrast between gadolinium containing blood and surrounding tissue. Depending on the imaging parameters the achievable contrast with T1-TrueFISP is up to two times higher than the contrast of conventional T1-weighed FLASH sequences. Imaging speed of T1-TrueFISP and FLASH is comparable except for a short delay between inversion pulse and data acquisition which increases the scan time by about 10% compared to FLASH. A possible drawback of T1-TrueFISP is the strong signal of fat even for short repetition intervals of the inversion pulse. In some cases (Fig. 3 left), this requires the subtraction of two data sets before and during contrast agent application. However, using the proposed steady-state fat saturation for TrueFISP (3) a selective suppression of fat signals should be possible.

REFERENCES
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