T2-WEIGHTED FAT SUPPRESSED BALANCED SSFP IMAGING (CONTRAST-PREPARED SSFP) FOR INTERVENTIONAL GUIDANCE

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INTRODUCTION: T_2-weighted fat suppressed MR images have demonstrated value in lesion and critical structure characterization in vascular anomalies, oncology, and cardiology, etc.[1-3] However, current techniques used in MR-guided interventions have limited T_2 contrast and fat suppression (balanced steady-state free precession [SSFP]), are slow (turbo spin echo [TSE]), or yield blurry images and inferior speed (half Fourier acquisition single-shot turbo spin echo [HASTE]).[4,5] An imaging technique with sufficient speed for real-time procedure guidance, with additional T_2 contrast and fat suppression is of interest.

PURPOSE: To present and validate a new technique, contrast-prepared SSFP (CP-SSFP).

THEORY: CP-SSFP is an interrupted steady-state technique that incorporates variable flip angle SSFP to establish T_2 contrast (derived from transition into driven equilibrium [T_2-TIDE][6]) and robust fat suppression (modified spectrally selective SSFP [S^5FP][7] with a new inversion recovery[8] scheme) (Fig.1) ***T_2 contrast:*** Designed for thick slices (10mm), T_2 TIDE initiates the SSFP train with a series of 180^o RF pulses that yield T_2 contrast.[6] SSFP excitation RF pulses typically use a broad RF bandwidth (BW) and low time bandwidth product (TBP, RF duration times BW). These pulses, when combined with high flip angles, introduce poor slice profile and other artifacts. The RF pulses used in the T_2-TIDE opening sequence are improved by narrowing BW and increasing the TBP at a small expense of RF duration and ultimately TR. Optimum BW and TBP were chosen based on simulations (Matlab, Natick, MA) yielding thin slice profiles. ***Fat suppression:*** Standard S^5FP achieves fat saturation in single slice SSFP by taking advantage of the out of phase nature of fat spins.[7] However, fat signals recover quickly in interleaved multi-slice acquisitions, yielding insufficient suppression. Using an inversion-recovery modification to S^5FP (IR-S^5FP), which includes ramping the flip angle to 180^o during closing, fat is suppressed in the next imaging period for a given slice.

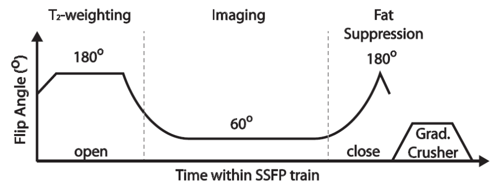
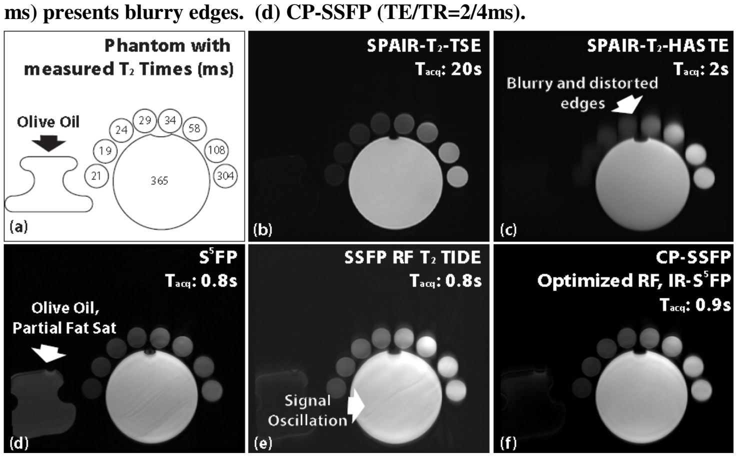


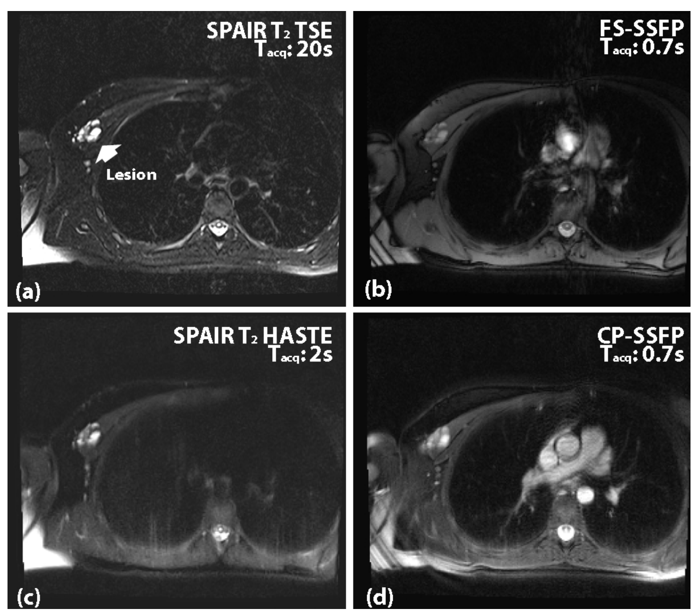
Fig 1. Illustration of one SSFP train used during CP-SSFP. As in T_2 TIDE[6], 180° RF pulses at the opening of the train provides T_2 weighting. A smooth transition in flip angle into SSFP permits rapid imaging without significant transition towards steady-state artifacts during single shot acquisitions. Ramping flip angles to 180° during closing enables spectrally selective inversion recovery, a technique derived from S^5FP[7].

METHODS: All experiments were performed at a 1.5T wide-bore scanner (Espree, Siemens Healthcare). ***Phantom testing:*** Gel phantoms with clinically relevant T_1/T_2 were scanned; olive oil was used to examine fat suppression. ***Patient validation:*** Low-flow vascular malformations (VMs) are clinically diagnosed by T_2 weighted fat suppressed images[1]. In this study, patients with VMs scheduled for either therapeutic or diagnostic imaging with IRB approval. The characteristic long T_2 observed in lesions provide an excellent substrate for CP-SSFP imaging. Subjects were scanned using HASTE, fat-sat SSFP (FS-SSFP) and CP-SSFP; TSE was used as the reference of VM lesion detection. For TSE and HASTE, SPAIR[8] was used for fat suppression. For FS-SSFP, a 90^o fat saturation pulse was used before each readout train. To evaluate the sequence's performance in patients, CNR efficiency (CNR of VMs vs. muscle divided by the square root of acquisition time) and image sharpness (the reciprocal of mean edge width in mm)[9] were used.

Fig 2 (bottom). Phantom images acquired by thin-slice (5mm) interleaved 3-slice protocols. (a) Depiction of the phantom. (b) Reference SPAIR-T_2-TSE (Echo spacing/TE/TR=7.4/82/2000 ms), (c) SPAIR T_2 HASTE, (d) S^5FP (TE/TR=1.8/3.6ms), (e) T_2 TIDE-SSFP with standard RF pulses (BW=1.5kHz, TBP=1.2, TE/TR=1.8/3.6ms), and (f) CP-SSFP with optimized RF pulses (BW=2.7kHz, TBP=4, TE/TR=2/4ms) and IR-S^5FP.

Fig 3 (right). Images from a patient with a lesion (VM) in the right shoulder. (a) Reference image from SPAIR T_2 TSE. (b) FS-SSFP offers inferior image contrast to visualize the lesion. (c) SPAIR T_2 HASTE (ES/TE/TR=7.4/82/2000 ms) presents blurry edges. (d) CP-SSFP (TE/TR=2/4ms).





RESULTS: Phantom images are shown in Fig 2. All real-time images are windowed/leveled equally. Using TSE images as a reference, comparisons on the phantom were performed (Fig 2). In patients, CNR efficiency: 27±8(HASTE), -1±7(FS-SSFP), 37±4(CP-SSFP); and image sharpness (mm^{-1}): 0.07±0.02(HASTE), 0.2±0.03(FS-SSFP), 0.2±0.03(CP-SSFP). Example images from a patient are shown in Fig 3.

CONCLUSION: CP-SSFP provides efficient imaging with T_2 contrast and image sharpness ideal for lesion and critical structure visualization during real-time imaging. Optimized RF pulses present reduced artifacts for thin slice high flip angle SSFP imaging. T_2 weighting achieved with CP-SSFP is sufficient for interventional guidance and the addition of IR-S^5FP yields improved fat suppression in multi-slice acquisition protocols.

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