CONTRAST-PREPARED STEADY-STATE FREE PRECESSION FOR VISUALIZING VASCULAR MALFORMATION IN INTERVENTION

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Introduction: Low-flow vascular malformations (VMs) are congenital lesions of the venous or lymphatic system, with an overall incidence of 4.5%.[1] Typically, VMs are treated by injecting sclerosing agents guided by real-time imaging via ultrasound and/or X-ray fluoroscopy.[2] However, the use of MR for image guidance would be advantageous due to reduced radiation exposure to both patient and interventionalist. This is of particular interest in pediatric and multiple treatment sessions cases. Due to the presence of fluid, VMs are best identified on T_2-weighted images such as those obtained with Half Fourier Acquired single Shot Turbo spin Echo (HASTE).[2,3] However, HASTE images can be blurry and are sometimes sensitive to motion due to limited temporal resolution[4], and hence HASTE is not ideal for real-time imaging. Alternatively, balanced steady-state free precession (bSSFP) has shown flexible contrast with the addition of contrast preparation pulses such as T_2-Prep.[5] Here, we present a contrast-prepared bSSFP (cpSSFP) imaging sequence specifically designed for the visualization of fluid during interventional procedures. The cpSSFP sequence exhibits the following features: (1) tunable T_2-weighting achieved by variable TE T_2-preparation pulses,[5] (2) tunable degree of fat saturation with the use of spectrally selective suppression using bSSFP (S5FP)[6], and (3) efficient acquisitions for fast imaging during free-breathing.

Theory: The proposed sequence is presented in Figure 1. The standard bSSFP steady-state is interrupted periodically to insert T_2-Prep pulses. To avoid artifacts during the re-entry into imaging, a ramped flip-angle train ($N_{RAMP}\approx5$) is applied at the start of the imaging train of RF pulses. To maintain imaging efficiency, data is acquired during all TRs except for the first, which is applied at TR/2 using an arbitrary flip angle θ. During the generalized flip angle ramp, $\alpha[i]$ (the flip angle of the i^{th} RF) is determined by: $\alpha[0]=\theta; \alpha[i]=2\theta+(2i-1)d\xi, 0<i<N_{RAMP}$. Where, $d\xi$ - increment of the angle to z-axis, $d\xi=\frac{\alpha/2-\theta}{N_{RAMP}-1}$. A centric-phase encode ordering is used to maximize T_2-contrast, acquiring the center of k-space as early as possible after contrast preparation (during the flip angle ramp up). Tunable fat suppression is achieved with the use of a closing ramp of increasing flip angles, which increases the separation of fat and water in adjacent bands of the bSSFP frequency spectrum.[6] Maximum fat sat is achieved by ramping the flip angle smoothly from α to 90°. Finally, after z-storing the water magnetization with a 45° pulse, a crushing gradient and train-to-train phase cycling[6] are applied to avoid inter-train coherences. The speed of the imaging sequence is adapted by changing the number of RF pulses applied per imaging train. To facilitate the transition into steady-state, dummy trains are used at the start of imaging for a particular slice. To increase overall efficiency, data is acquired during the ramps and scaled appropriately during reconstruction.

Methods: Under informed consent and with IRB approval, normal subjects (N=4) were imaged on a wide-bore 1.5T system (MAGNETOM Espree, Siemens Healthcare) using the standard body matrix and spine coils. All images were acquired with the same resolution, 1.17x1.17x5mm^3. To visualize fluids in preparation for imaging VMs in patient studies, transverse images were acquired at the level of the bladder or at the level of the liver with a view of the CSF (used here as a long T_2 signal) in the spinal canal. ROIs were used to measure signals. HASTE imaging parameters: acquisition matrix 256x128, time per slice 1.2 sec, effective TR/TE 3500/86 ms, inter-echo spacing 4-5 ms; and 3 slices were interleaved continuously as is typically used during a real-time interventional procedure. cpSSFP imaging parameters: matrix 256x256, time per slice 0.93 sec, TR/TE 3.2/1.6 ms, flip angle 70°, 128 imaging TRs per train, 1-2 dummy startup trains, 16 and 40ms T_2Prep echo times (TE), 60° and 90° water-fat separation angles (WFA). CNR efficiency (CNR divided by square root of the scan time) was used to compare images. **Results:** Tunable T_2 weighting and fat-sat with cpSSFP are demonstrated in Fig. 2. A comparison between cpSSFP and HASTE is shown in Fig. 3. CNR efficiencies: CSF-liver: 34±20.1 (HASTE) and 59±14.5 (cpSSFP); bladder-muscle: 39±0.3 (HASTE) and 44±1.0 (cpSSFP).

Conclusion: Compared with HASTE, cpSSFP shows higher CNR efficiency, superior delineation of small (vessels) and moving structures (liver) and higher imaging speed (~2.6 times faster). With cpSSFP, T_2 weighting and fat-sat are tunable; an advantage when tailoring sequence performance to maximize the visibility of needles or lesions during intervention. Therefore, cpSSFP shows the potential for real-time guidance of the interventional VM procedure on free-breathing patients. Finally, cpSSFP is amenable to the integration of image acceleration with parallel imaging, providing a means achieving higher frame rates as required during many interventional procedures. **Funding:** This work was funded in part by Grant Number UL1 RR 025005 from the National Center for Research Resources and the NIH Roadmap for Medical Research and Siemens Healthcare.

References: [1] Greene et al, Clin Plastic Surg 2011 38: 1; [2] Legiehn et al, Semin Intervent Radiol 2010 27: 209; [3] Weiss et al, ISMRM 2011: 3759; [4] Coates et al, JMRI 1998: 642; [5] Brittain et al, MRM 1995 33: 689; [6] Derbyshire et al, MRM 2005 54: 918;

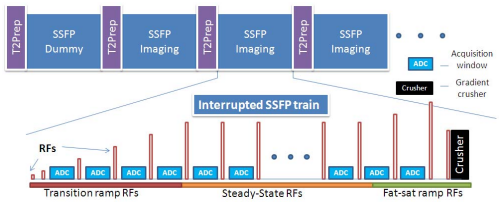

Figure 1: The standard bSSFP sequence is partitioned into short trains interleaved with T_2-prep pulses for contrast preparation. Each train is composed of an opening sequence (transition ramp RFs), steady state component, and a closing sequence (ramp to 90° for fat suppression). RF phase spoiling and a large crusher gradient are used to suppress artifacts due to the interruption of steady state between the adjacent trains.

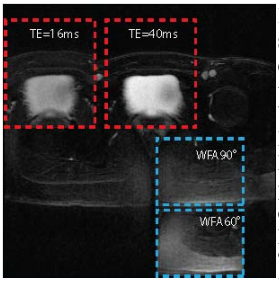

Figure 2(Left bottom): Insets (TE=16ms and WFA60°, respectively) are superimposed on a background image with TE=40ms and WFA90°. The comparison between the insets and background image shows that T_2 weighting and fat-sat are tunable with cpSSFP by adjusting T_2-prep TE and WFA. WFA – water fat separation angle.

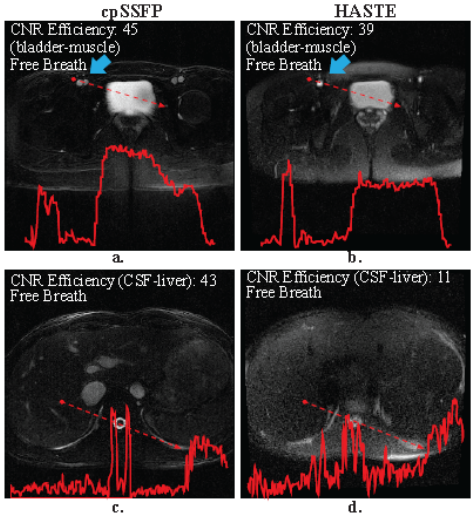

Figure 3(Right): Normal subject images acquired with cpSSFP (a&c) and HASTE (b&d) are displayed at same window/level. The blue arrows in pelvic images of a female volunteer (a,b) show that cSSFP delineates two distinct vessels (2 peaks in the red intensity profile) instead of one (1 peak) in HASTE. Abdominal images of a male volunteer (c,d) demonstrate enhanced T_2 contrast between background tissue (liver) and fluid (CSF) for cpSSFP. Moreover, the intensity profile of cpSSFP also shows 2 distinct CSF peaks.