3D Fluid-Suppressed T2-Prep Flow-Independent Angiography using Balanced SSFP

N. K. Bangerter[1], B. A. Hargreaves[1], J. H. Brittain[2], B. Hu[3], S. S. Vasanawala[4], D. G. Nishimura[1]

[1]Department of Electrical Engineering, Stanford University, Stanford, CA, United States, [2]ASL-West, GE Medical Systems, Menlo Park, CA, United States, [3]Palo Alto Medical Foundation, Palo Alto, CA, United States, [4]Department of Radiology, Stanford University, Stanford, CA, United States

INTRODUCTION: Recent work has shown that the high SNR, short scan times, and flow properties of balanced steady-state free precession (SSFP) make it an excellent candidate for flow-independent angiography (FIA), particularly where high spatial resolution is required [1,2]. However, the characteristic bright fluid signal of balanced SSFP can obscure vascular structure when long-T1 fluids, such as edema or sinovial fluid, are present in the region of interest. Balanced SSFP angiograms of the hand and foot, for example, suffer from bright sinovial fluid signal in the joints. Balanced SSFP angiograms of the extremities in patients with peripheral swelling may be obscured by bright signal from edema.

In this work, we present a fast, magnetization-prepared 3D SSFP sequence for creating high-resolution flow-independent angiograms with long-T1 fluid suppression. The sequence exploits inversion-recovery/T2-prep combined with square-spiral centric phase encode ordering for contrast generation, and achieves fat suppression through phase-sensitive SSFP reconstruction [2]. Only a modest increase in scan time over a simple 3D SSFP acquisition is required.

METHODS: A diagram of the sequence is shown in Figure 1. A non-selective 180°$_x$ inversion pulse is followed by an inversion time TI chosen to attenuate long-T1 fluids (usually about 2 s). At this point, both the blood (T1 ≈ 1 s) and muscle (T1 ≈ 850 ms) signals have recovered to near-equilibrium values. A T2-preparation (90°$_x$, 180°$_y$, 180°$_y$, -90$_x$) [3] follows to suppress muscle signal and further enhance blood/muscle contrast, after which a ramp catalyzation is performed to reduce transient signal oscillations [4]. SSFP data acquisition then begins, with a square-spiral phase encode ordering to capture the prepared contrast at low spatial frequencies [5]. A related approach has been proposed for 3D CSF-suppressed brain imaging using an MP-RAGE acquisition [6].

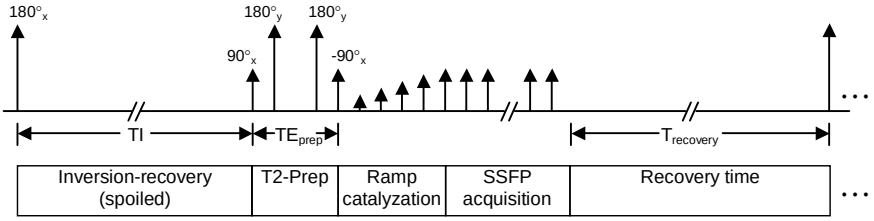

Figure 1: Pulse sequence diagram. A spoiled non-selective inversion is followed by an inversion time TI, after which a T2-preparation sequence is applied. Immediately following the T2 preparation, a linear ramp catalyzation is performed to reduce transient signal oscillations, after which SSFP acquisition begins with a centric phase-encode ordering.

The above series (IR, T2-prep, catalyzation, balanced SSFP acquisition) may be repeated several times, depending on the total number of phase encodes in the scan and the degree of fluid-suppression required. When multiple repetitions are used, the square-spiral phase encodes are interleaved as shown in Figure 2. This effectively increases the extent of low-frequency *k*-space acquired before signal levels evolve from their magnetization-prepared state to the steady state. A recovery time of at least several seconds is required between each set of acquisitions to allow the volume to reach near equilibrium prior to the next inversion.

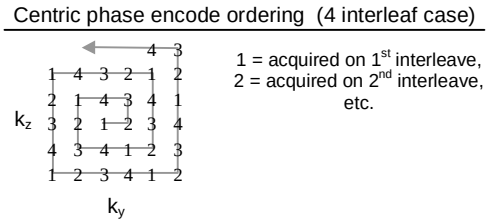

Figure 2: Centric phase-encode ordering. If more than one magnetization preparation is required for the volume, square-spiral phase encodes are interleaved (as shown for the four-interleaf case).

RESULTS: The sequence was implemented on a 1.5 T GE scanner with CV/i gradients. A protocol suitable for the lower leg and foot was prescribed with the following scan parameters: TR/TE = 4.6/2.3 ms, α = 70°, 384x128x128 matrix, 1 mm isotropic resolution, TI = 2 s., TE_{prep} = 80 ms, and a 10 excitation linear ramp catalyzation. Four interleaves were performed (i.e., four magnetization preparations were applied over the course of the scan). Total scan time was 1:55 (including a long $T_{recovery}$ of 10 s to avoid gradient overheating), compared with a normal balanced SSFP scan time with the same parameters of 1:15 s.

Figure 3 shows results in a normal foot. The image on the left (Figure 3a) was acquired with only the T2-prep pulse, eliminating the inversion-recovery preparation. Bright sinovial fluid signal is seen in the joints of the foot, obscuring vascular structure. Figure 3b shows the corresponding result when both the inversion-recovery and T2-prep were applied. Sinovial fluid signal is well suppressed, allowing much better visualization of the vessels. High arterial/venous contrast is also achieved.

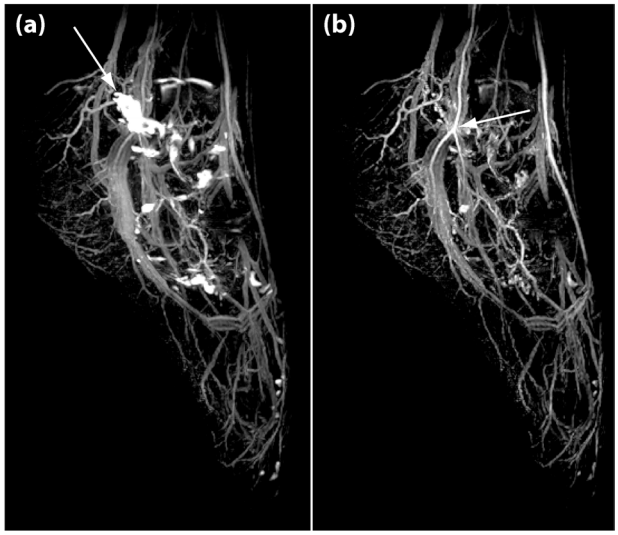

Figure 3: Maximum-intensity projection of 3D balanced SSFP flow-independent angiograms (1.5 T) of the foot with 1 mm isotropic resolution. (a) Centric T2-prep 3D SSFP *without* the IR preparation, showing high signal from sinovial fluid in the foot joints (arrow). (b) Centric IR/T2-prep 3D SSFP, showing good sinovial fluid suppression and high arterial/venous contrast (arrow). Scan times were 1:47 for (a) and 1:55 for (b), with a matrix size of 384x128x128 in both cases.

CONCLUSION: A combination IR/T2-prep 3D balanced SSFP sequence with square-spiral centric phase encode ordering can be combined with phase-sensitive fat suppression to produce high-resolution flow-independent angiograms in the presence of long-T1 fluids. Good long-T1 suppression can be achieved with as few as four magnetization preparations for the entire 3D volume, only modestly increasing the scan time over a simple 3D balanced SSFP acquisition.

REFERENCES:

[1] J. BRITTAIN *et al., Proc. Soc. Magn. Reson. Med.*, 2003, p. 1710
[2] B. HARGREAVES *et al.*, *Magn. Reson. Med.*, **50**:210, 2003.
[3] J. BRITTAIN *et al., Magn. Reson. Med.*, **33**:689, 1995
[4] D. NISHIMURA *et al.*, *Proc. Soc. Magn. Reson. Med.*, 2000, p. 301.
[5] H. KORIN *et al.*, *J. Magn. Reson. Imaging*, **2**:687, 1992.
[6] F. EPSTEIN *et al.*, *J. Magn. Reson. Imaging*, **4**:463, 1995.