Flow inversion-prepared Non-contrast Enhancement in the Steady State (FINESS): a novel SSFP-Dixon technique for non-contrast MR angiography of the renal arteries

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Purpose: Contrast-enhanced MR Angiography (CEMRA) is widely used for evaluation of vascular pathology. Recent concerns about nephrogenic systemic fibrosis (NSF) after administration of Gadolinium based contrast agents in patients with compromised renal function have spurred interest in non-contrast MRA methods. In addition to traditional methods such as 3D time of flight (TOF) and phase contrast imaging, newer methods like 3D ECG-gated Fast Spin Echo (FSE) [1] and variants of arterial spin labeling with balanced steady-state free precession (SSFP) and FSE [2,3] have been proposed recently. SSFP imaging has shown great promise due to its high SNR and short scan times and has been successfully used in coronary artery imaging. Robust fat suppression remains challenging at high field strengths due to B_0 and B_1 inhomogeneities. Furthermore, fat saturation pulses compromise the SSFP steady state, causing artifacts. We propose FINESS (**F**low **I**nversion-prepared **N**on-contrast **E**nhancement in the **S**teady **S**tate) a novel balanced SSFP-Dixon technique for non-contrast MRA of the renal vasculature.

Methods: Pulse sequence: A 3D dual-echo bipolar readout balanced SSFP pulse sequence was developed. A robust two-point Dixon reconstruction algorithm [4] was used for fat-water separation, eliminating the need for conventional fat suppression pulses. The elimination of fat suppression pulses enabled us to use novel efficient k-space segmentation schemes. A radial fan-beam segmentation in k_y-k_z space was employed, with k-space points acquired in the order of increasing k_r within each radial sector (fan beam). Each radial sector was acquired following a slab selective hyperbolic secant 180° pulse (inversion prep [5]). The inversion slab was offset in the inferior direction relative to the acquisition volume to simultaneously effect venous and background suppression [3]. The inversion time was chosen as an optimal trade-off between background/venous blood suppression and the in-flow arterial blood signal and was set to 900ms at 3T. The time efficient radial fan-beam k-space segmentation scheme minimized the number of inversion segments needed. This enabled us to acquire the 3D volume in a single breath-hold, eliminating the need for respiratory triggering which could be unreliable or prolong scan times, especially in sick and elderly patients.

Experiments- Imaging parameters for FINESS were as follows: 70° flip, $\pm$ 167 kHz bandwidth, $TR/TE_1/TE_2$ 6.2/1.4/2.8 ms, 256x224 matrix, 35 cm FOV, 2 mm thick, 32-40 slices, 300 k-space points per radial sector, TI=900ms. A self-calibrating hybrid space parallel imaging scheme [6] with an acceleration factor of 2.5 was used in the phase encoding direction. This resulted in an overall breath-holding time of 20-25s, depending on the inversion time chosen and number of slice partitions. All subjects were imaged on a GE Excite system (GE Healthcare, Waukesha, WI) using an 8-channel torso array coil under an IRB-approved protocol.

Results: Figure 1 shows representative slices from a subject obtained using conventional fat suppression (a) and using the Dixon reconstruction technique (b). Note the uniformity and degree of fat suppression in (b) compared to (a). Figure 2 shows a reformatted volume rendering and a MIP of the renal vasculature obtained from a healthy subject in a 23s breath-hold at 3T demonstrating the high image SNR and contrast achievable using the proposed sequence. Figure 3 shows a reformatted MIP of the renal arteries obtained FINESS (a) on a patient with suspected renal hypertension at 1.5T. A first pass Gadolinium CEMRA MIP obtained using a 3D SPGR sequence is also shown for comparison (b). Note the excellent visualization of the vasculature afforded by FINESS, obtained in a 22s breath-hold.

Discussion: The proposed FINESS technique yields excellent fat suppression, high SNR and contrast and excellent visualization of the renal vasculature, especially at 3T where conventional fat saturation techniques are often suboptimal. While we restricted the slab thickness to limit the acquisition time to reasonable breath-hold times, the method can also be combined with respiratory triggering and the radial fan-beam segmentation can help reduce motion artifacts by dispersing them in much the same way as radial under-sampling. Multiple thinner slabs could also be acquired in short breath-holds to increase coverage and inflow signal contrast. The addition of a breath-held 3D SSFP sequence to respiratory-triggered non-contrast renal MRA protocols may prove useful in patients with irregular respiratory rhythms, in whom respiratory gating is frequently suboptimal.

References: [1] Miyazaki et al. JMRI 12:776–783 (2000) [2] Katoh et al. Kidney Int 66:1272–1278 (2004) [3] Takei et al. Proc ISMRM, p3420 (2008) [4] Ma et al. MRM. 52:415-419 (2004) [5] Nishimura et al. MRM 7:472-484 (1988) [6] Beatty et al. Proc ISMRM, p1749 (2007)

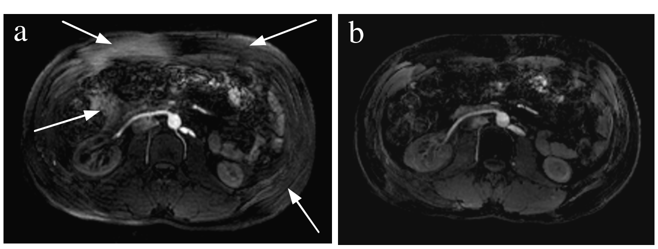

Figure 1. Comparison of representative slices obtained using conventional fat suppression (a) and the 2-point Dixon reconstructed (b) balanced 3D SSFP sequence at 3T. Note the uniformity of fat suppression in (b) compared to (a).

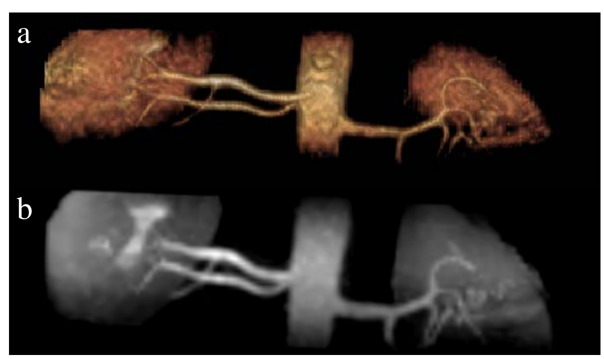

Figure 2. Reformatted volume rendering (a) and MIP (b) of a data set obtained using the proposed balanced SSFP-Dixon FINESS technique in a 23s breath-hold from a healthy subject at 3T.

Figure 3. Reformatted MIP from a dataset obtained using the proposed FINESS pulse sequence (a) on a patient with suspected renal hypertension. A MIP from a first-pass contrast enhanced MRA obtained using a 3D SPGR sequence is shown in (b) for comparison.