Rapid Non-Contrast-Enhanced Renal Angiography using Multiple Inversion Recovery

H. Z. Dong[1], P. W. Worters[2], H. H. Wu[1,3], T. Çukur[1], B. A. Hargreaves[2], D. G. Nishimura[1], and S. S. Vasanawala[2]
[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]Radiology, Stanford University, Stanford, CA, United States, [3]Cardiovascular Medicine, Stanford University, Stanford, CA, United States

Introduction: Non-contrast-enhanced MR angiography (NCE-MRA) [1] has gained salience due to the association of gadolinium contrast agents with nephrogenic systemic fibrosis (NSF). Multiple inversion recovery (MIR) preparatory pulses [2] combined with 3D balanced SSFP (bSSFP) has been shown to offer good renal vessel contrast without subtraction or breath-holding [3]. However, the rapid recovery of fat after contrast preparation led to confounding high-frequency signals. In this work, we first propose an alternating TR (ATR) [4] version of the MIR 3D bSSFP sequence to address this issue, and demonstrate the superb ability of MIR to suppress a wide range of background tissues. The excellent suppression opens up the possibility of rapid projective angiography, which is robust against respiratory motion. We proceed to investigate the use of MIR with 2D ATR-bSSFP and alternatively, 2D half-Fourier single-shot FSE (SSFSE), with the goal of providing high-contrast renal angiograms in one heartbeat.

Methods: MIR preparation consists of selective spatial saturation followed by nonselective inversions (Fig. 1) to suppress a range of background T_1 species (e.g. fat, muscle, and slow blood). Spatial saturation comprises of six 90° excitations and a pair of crusher gradients applied in each direction for maximum signal dephasing. Saturation region was extended distally beyond the imaging volume to remove venous signal. The MIR inflow period is adjustable (via optimization of the inversion times) to achieve a balance between the extent of arterial inflow and vessel SNR. One combination used was a 400-ms inflow period and inversions placed at 26, 21, 256, 362 ms after saturation [3].

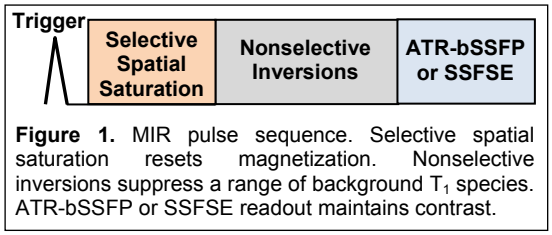

Figure 1. MIR pulse sequence. Selective spatial saturation resets magnetization. Nonselective inversions suppress a range of background T_1 species. ATR-bSSFP or SSFSE readout maintains contrast.

Two readout approaches were chosen: ATR-bSSFP to provide good blood SNR with added fat suppression; SSFSE to fully capture the MIR contrast preparation and maintain it throughout the readout train. MIR ATR-bSSFP parameters were: $TE/TR_1/TR_2$=1.72/3.44/1.16 ms; flip angle=45°; in-plane resolution=1.25×1.25 mm^2; in-plane FOV=32×32 cm^2; slab thickness/number of slices (3D)=40 mm/20 slices, slice thickness (2D)=30 mm; RF phase cycling 0°-90°-180°-270°; centric acquisition with bSSFP train length of 128; scan time 3D/2D=1:08 min avg./3 heartbeats. MIR SSFSE parameters were: TE/TR=39/1127 ms; echo spacing=5 ms; refocusing flip=130°; matrix=256×96; FOV=32×19 cm^2; slice thickness=30 mm; readout flow compensation; scan time=1 heartbeat. Plethysmograph triggering was used in all MIR sequences to ensure a diastolic readout. 3D ATR-bSSFP without MIR or gating (scan time=24 s) was performed for anatomical comparison. Renal angiograms of 5 volunteers were acquired on a 1.5 T GE Signa scanner using an 8-channel cardiac coil.

Results and Discussion: Figure 2 shows representative results. MIR 3D ATR-bSSFP (2b) demonstrates the ability of MIR to achieve strong background suppression while maintaining a high level of vessel signal. The 3D dataset can be reformatted to arbitrary orientations. The high vessel contrast enabled rapid projective angiography. MIR 2D ATR-bSSFP (2c), acquired in 2 shots/3 heartbeats, offered higher vessel SNR and sharpness than SSFSE. Some high-frequency background signals remained due to an imperfect ATR fat profile and signal recovery after the MIR null point. Acquisition can be reduced to a single shot (1-heartbeat scan time) by using partial k-space and/or parallel imaging. Near-perfect background suppression was obtained with MIR 2D SSFSE (2d), acquired in 1 shot/1 heartbeat, as the MIR null point was fully captured by the initial 90° excitation and maintained throughout readout. Vessel blurring in the phase encode direction due to FSE T_2 decay effects can be mitigated by using parallel imaging. The two projective methods can be easily applied in other orientations such as coronal.

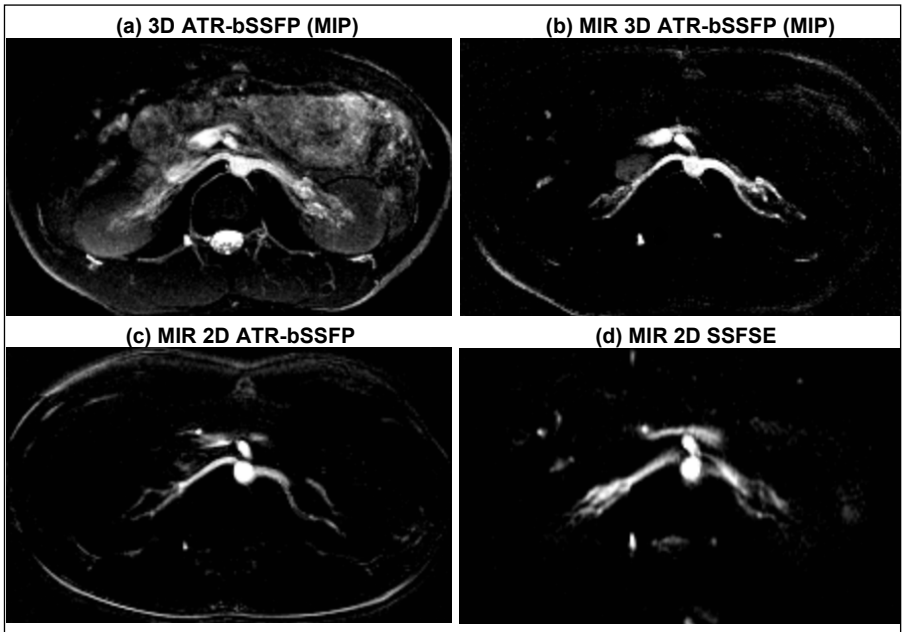

Figure 2. Renal angiograms with the same zoom. **(b)** MIP of MIR 3D ATR-bSSFP (1:08 min) demonstrates excellent background suppression compared to **(a)** the same sequence without MIR or gating (24 s). Superb suppression enabled rapid projective scans. **(c)** MIR 2D ATR-bSSFP (2 shots/3 heartbeats) achieved higher vessel SNR and sharpness than SSFSE. **(d)** MIR 2D SSFSE (1 shot/1 heartbeat) realized near-perfect background nulling. Note: Due to thinner imaging volume, part of right renal artery in **(c)** and **(d)** was out of slab.

Flexibility of the MIR inflow time combined with the fast scan times of the proposed methods facilitates real-time sequence tuning based on patient physiology. Moreover, MIR allows reduced-FOV imaging as the superb background suppression removes the restriction imposed by aliasing in the phase encode direction. Because of the sparsity of the angiograms, compressed sensing can be used for further reduction of readout length.

Conclusion: The excellent ability of MIR to suppress a wide range of background T_1 species enables rapid 2D projective renal angiography. We presented two sequences: MIR ATR-bSSFP and MIR SSFSE, with which high-contrast renal angiograms were reliably produced in 3 and 1 heartbeat(s) without contrast agents, image subtraction, or breath-holding.

References: [1] Miyazaki M, Radiology 248:20, 2008. [2] Mani S, MRM 37:898, 1997. [3] Dong H, ISMRM, p.1875, 2009. [4] Leupold J, MRM 55:557, 2006.