

Non-contrast-enhanced abdominal MRA using velocity-selective saturation and multiple inversion recovery

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Target Audience MR physicists and engineers interested in MR angiography (MRA)

Purpose For non-contrast-enhanced (NCE) MRA in the abdomen, two recent methods have proposed the use of magnetization preparation sequences based on either velocity-selective (VS) excitation [1] or multiple inversion recovery (MIR) [2]. VS preparation eases the in-flow requirements to attain arterial contrast over a wide region but background suppression levels are constrained. MIR offers a high level background suppression but requires sufficient in-flow of arterial blood. In this work, we propose a hybrid VS-MIR method that accrues the benefits of both preparation sequences for NCE abdominal MRA.

Methods The original MIR sequence (SP-MIR) consists of spatially selective (SP) pulses that saturate the region of interest (ROI, typically an axial slab), followed by multiple non-selective inversion pulses that substantially null (down to $\sim 10^{-3}$) a wide range of background T_1 species in the ROI after an inflow period Q (Fig. 1a). To ensure B_1 -robust background suppression, a train of several saturation pulses is applied. To maximize the inflow of arterial blood during Q , the trigger delay (TD) is adjusted to place the SP saturation module at the onset of systolic flow. The readout portion is an alternating-TR (ATR) balanced SSFP sequence that gives high blood signal while maintaining fat suppression [3]. The imaging sequence can be 2DFT (single-heartbeat projective), 3DFT with few slice encodings (breath-hold), or 3DFT with full encoding (respiratory triggered). High-contrast vessel signals appear to the extent that unsaturated arterial blood flows into the ROI during Q .

To extend the craniocaudal angiographic coverage, the new method (VS-MIR) replaces the SP saturation with VS saturation (Fig. 1a). The VS module saturates stationary tissues and venous blood flowing in the inferior-to-superior direction, while not perturbing arterial blood flowing in the superior-to-inferior direction. Hence, arterial blood in the abdominal and iliac arteries remains fully magnetized at the start of the inversions, and will appear with high contrast in the resultant angiogram regardless of the length of the ensuing inflow period. For imaging the renal arteries, which extend in the left-right direction, fully magnetized blood need only travel from the origin of the renal branch, as opposed to the superior edge of a spatial saturation volume as in SP-MIR. To help differentiate between arterial blood and static materials, the VS preparation is placed at the time of peak arterial flow. The VS saturation module consists of two VS 90° excitation pulses that were designed using the generalized excitation k-space formalism and Shinnar-Le-Roux transform (Figs. 2a, 2b) [1,4]. Each of the VS pulses had a velocity pass-band of $[-115, -25]$ cm/s and an inversion-band of $[-9, 29]$ cm/s where a negative value indicates the direction of arterial flow (Fig. 2c). Because the VS excitation profile has a dependence on off-resonance frequency (Figs. 2c, 2d), a separate fat-saturation pulse is applied at the end of the VS saturation module.

Results The VS-MIR sequence was implemented on a GE 1.5T scanner and compared with SP-MIR. An 8-channel cardiac array was used. The ATR-SSFP sequence parameters were $TE/TR_1/TR_2 = 1.72/3.44/1.16$ ms; flip angle = 50° ; in-plane resolution = 1.25×1.25 mm²; FOV = $30 \times 32 \times 10.8$ cm³; inflow period (Q) = 350-425 ms. The breath-hold scans (24 heartbeats) used 6 slice partitions in the S/I direction (18-mm sections) while the respiratory triggered scan (7.2 min) used 54 partitions (2-mm sections). In Fig. 3, the coronal maximum-intensity-projections (MIPs) demonstrate the large S-I vessel coverage of VS-MIR compared to SP-MIR. Because SP-MIR depends on the flow of upstream arterial blood into the volume of spatial saturation, the craniocaudal extent of visible arteries is limited (Fig. 3b). With VS-MIR, we are able to visualize all of the abdominopelvic arteries using the same inflow time (Figs. 3a, 3c). Vessel contrast of breath-hold VS-MIR (Fig. 3c) is comparable to its fully encoded counterpart (Fig. 3a) as the background suppression afforded by MIR gives high contrast despite the relatively thick slices.

Discussion & Conclusion This work demonstrates the potential of VS-MIR for NCE abdominal MRA. VS-MIR achieves high vessel contrast over a larger spatial extent than SP-MIR. VS-MIR also provides better background suppression with flexible choice of inflow time as compared to VS preparation alone. Due to the limited period of high systolic flow, VS preparation with only 2 saturation pulses was possible (vs. 6 with SP-MIR to compensate for B_1 nonuniformities). The resultant suppression level is somewhat compromised with VS-MIR; however, the level of suppression remains sufficient to tolerate relatively large slice thickness, thereby enabling short scan times down to a breath-holding interval.

References [1] Shin T., *et al.*, MRM early view, 2012. [2] Dong HZ, *et al.*, MRM early view, 2012. [3] Leupold J, *et al.*, MRM 55:557-65, 2006. [4] de Rochefort L, *et al.*, MRM 55:171-176, 2000.

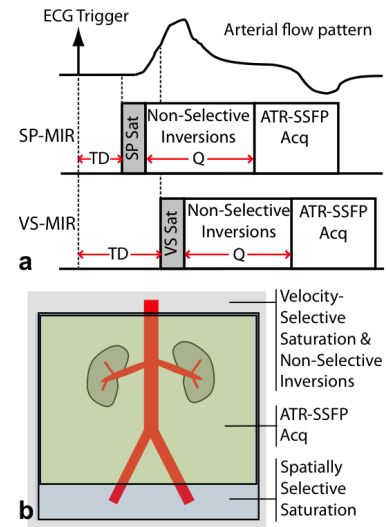


Figure 1: (a) Timing diagram – SP-MIR and VS-MIR. (b) Excited regions for different modules. The SP sat region includes the ROI and venous supply region.

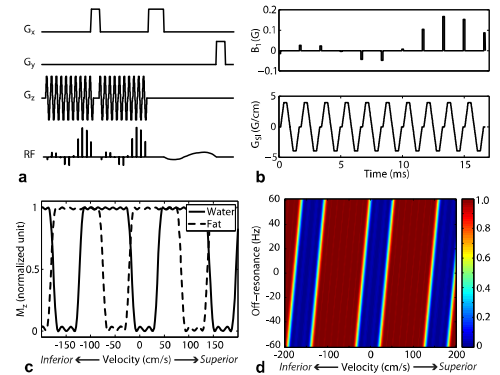


Figure 2: (a) VS-sat module consists of 2 VS-sat pulses. (b) VS-sat pulse. (c) M_z profile for VS-sat pulse. “+” and “-” indicate superior and inferior flow directions, respectively. (d) VS-sat pulse performance over a typical off-resonance frequency range.

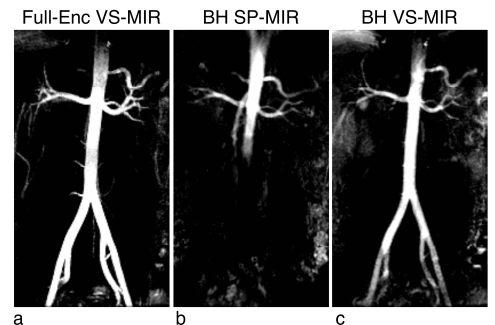


Figure 3: (a) Respiratory-triggered VS-MIR with full slice encoding shows large S-I extent due to VS saturation preserving the M_z of arterial blood. (b) Breath-hold (BH) SP-MIR based on inflow from above. (c) BH VS-MIR with fewer slice partitions shows good background suppression despite the thicker slices.