Velocity Selective RF pulse prepared Inversion Recovery (VSIR) for carotid artery vessel wall imaging

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Target audience: MR scientists and clinicians interested in vessel wall imaging.

Introduction: Velocity Selective (VS) RF pulse has been used in renal and abdominal MR angiography, which null static tissue by inversion recovery[1]. In this study, we use VS RF pulse in an opposite way by suppressing blood signal with high pass Velocity Selective RF pulse prepared Inversion Recovery (VSIR). Its feasibility was evaluated in the application for carotid artery vessel wall imaging.

Methods:

Velocity Selective RF Pulse sequence: Velocity selective RF pulse using Shinnar-Le Roux algorithm converts RF pulse design into a FIR filter design[2]. In the case of carotid artery vessel wall imaging, a high pass inversion pulse is wanted to invert the high-velocity spins. The first solution is to invert a low pass velocity selective inversion pulse (LPVS, Fig.1a) by adding a 90x-180y-90x composite pulse ahead. The RF pulse design parameters included cut-off velocity = ±12.90cm/s (velocity at full-width-half-maximum) and total pulse duration = 17.54ms. Alternatively, we directly designed a high pass velocity selective inversion pulse (HPVS, Fig.1b) to compensate the signal dropout of static tissue caused by off-resonance effect. The parameters included cut-off velocity = ±26.90cm/s and total pulse duration = 16.04ms. Identical bipolar gradients of trapezoidal shapes are applied during each interval between two adjacent RF hard subpulses to produce velocity encoding using a gradient amplitude of 3G/cm and a gradient slew rate of 120G/cm/ms with 1.66ms (LPVS) and 1.6ms (HPVS) duration. The simulated velocity selective profiles of LPVS and HPVS are shown in Fig.1c and Fig.1d, respectively. 3D Spoiled Gradient echo (SPGR) was employed as acquisition sequence with spectrum selective fat suppression after VSIR pulse. (Fig. 2).

Experiments: To evaluate the feasibility of the new techniques, 3D images of carotid were obtained from three healthy volunteers (male, ages 21-23 years) with iMSDE[3], LPVS and HPVS preparations at identical anatomic locations in coronal view on a 3.0T MR system (Achieva, TX, Philips) with an eight-channel carotid coil. To facilitate fair comparison, the only difference between three sequences is preparation module. For iMSDE, m1 = 231mT·ms^2/m. For VS, we selected TI = 400ms. The parameters for SPGR acquisition were: Spatial resolution = 0.7 × 0.7 × 0.35 mm^3, FOV = 250 × 160 × 32 mm^3, TR/TE = 10ms/4.9ms, flip angle = 10^o, TFE factor = 90, acquisition matrix = 356 × 229.

Image analysis: Images acquired at the same location with different blood suppression techniques were analyzed using ImageJ. SNR and CNR measurements were performed in regions of interests (ROIs), which were manually delineated in the lumen and wall area. The standard deviation (SD) of noise was measured from areas free from the signal and artifacts. The CNR_{wl} (wl = wall - lumen) was calculated from SNR differences between wall and lumen. Analysis was performed on images at carotid bifurcation (BIFU), common carotid artery (CCA) and internal carotid artery (ICA). Statistical analysis for all data was performed in SPSS (version 16.0, Chicago, IL).

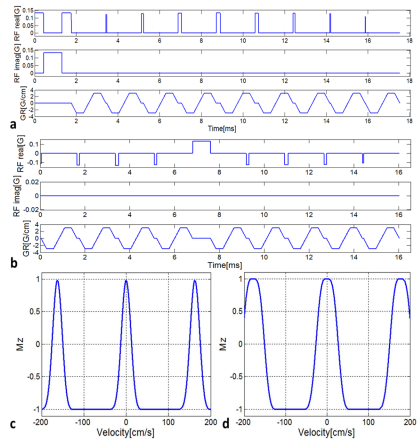

Figure 1. RF and gradient waveform of LPVS (a) and HPVS (b). The hard pulses together with bipolar gradients fulfill velocity selective profile (c, d).

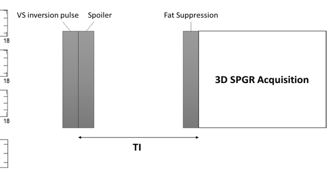

Figure 2. Timing diagram of VSIR vessel wall imaging sequence.

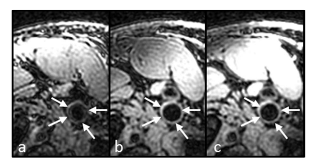

Figure 3. Left CCA images of different imaging techniques: (a) iMSDE, (b) LPVS, and (c) HPVS.

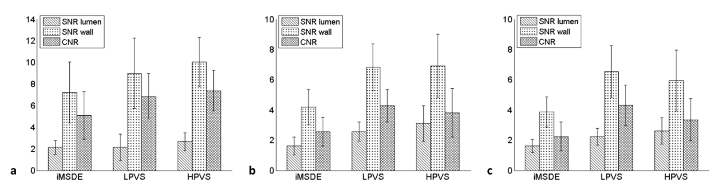

Figure 4. Comparison between iMSDE, LPVS and HPVS techniques. SNR lumen, SNR wall and CNR_{wl} of CCA (**a**), BIFU (**b**) and ICA (**c**) were plotted respectively.

Results: Comparison between iMSDE, LPVS and HPVS techniques are shown in Fig.3. Comparing to iMSDE, obvious image quality improvement can be observed visually in LPVS and HPVS (white arrows). Quantitative measurements with statistical results are summarized in Fig.4. As shown in Fig.4, both LPVS and HPVS produced a higher signal in the carotid vessel wall and higher CNR_{wl} than iMSDE. The lumen SNR values for both LPVS and HPVS are higher than iMSDE method except for CCA (Fig.4a).

Discussion and Conclusion: In this study, we presented a Velocity Selective RF pulse prepared Inversion Recovery (VSIR) technique for carotid artery vessel wall imaging. Simulation results demonstrate the feasibility of VS inversion pulse using SLR algorithm. In-vivo experiments showed that the VSIR can be used for carotid vessel wall imaging. As VS pulse retains the signal of static tissue, the VSIR technique provides better SNR of the vessel wall and CNR between lumen and vessel wall than iMSDE. However, VS provides higher lumen SNR than iMSDE except for CCA, probably because VS sacrifices blood suppression efficiency at BIFU and ICA, in which the flow is not exactly along the velocity encoding direction. More applications on other vascular bed such as femoral artery will be evaluated in the further study.

References: [1] Shin T, et al. MRM 2013; 69: 1268-1275. [2] Pauly J, et al. IEEE TMI 1991; 10(1): 53-65. [3] Wang J, et al. JMRI 2010; 31: 1256-1263.