Black-blood vessel wall imaging using SLR designed velocity selective RF pulse

Yunduo Li[1], Lirong Yan[2], Mayank Jog[2], Robert Smith[2], Karen Ying[3], Rui Li[4], Chun Yuan[4], and Danny JJ Wang[2]

[1]*Department of Biomedical Engineering, Tsinghua University, Beijing, Beijing, China,* [2]*Neurology, UCLA, CA, United States,* [3]*Department of Engineering Physics, Tsinghua University, Beijing, China,* [4]*Center for Biomedical Imaging Research, Tsinghua University, Beijing, China*

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

Purpose: Blood-suppressed (black-blood [BB]) MRI methods are widely used in various cardiovascular applications and particularly for vessel wall imaging. Several techniques have been proposed for suppressing the signal from flowing blood, including double inversion-recovery (DIR) and motion-sensitized driven-equilibrium (MSDE) techniques[1, 2]. Compared to conventional spatial inversion pulses, velocity-selective (VS) inversion RF pulse designed using the Shinnar-Le Roux (SLR) algorithm has the advantage of being independent on spatial location resulting in wider image coverage for abdominal and peripheral MR angiography (MRA) applications[3]. The purpose of the present study was to present a method for black-blood vessel wall imaging using SLR designed VS RF pulse to invert the spins of the flowing blood while leaving the static tissue undisturbed.

Methods:

RF Pulse Design: The Shinnar-Le Roux algorithm converts the problem of RF pulse design into that of FIR filter design[4], which allows the design of RF pulse to become a straightforward computational process and the inverse problem of non-linearity Bloch equations to be solved directly for any flip angles[4]. In the case of vessel wall imaging, a pulse which can invert the high-velocity spins is needed. We designed a high-pass inversion pulse using the Shinnar-Le Roux algorithm. Identical bipolar gradients of trapezoidal shapes are applied during each interval between two RF hard pulses to produce velocity encoding while satisfying the hard pulse approximation in Shinnar-Le Roux algorithm[4]. For imaging the aorta, the design targets were: Mz = 1 for velocities below $\pm$20cm/s and Mz = -1 for velocities between $\pm$20cm/s and $\pm$150cm/s. The total duration of the pulse was 15.86ms. A trade-off is considered between the pass-band ripples and the sharpness of the transition band. The pulse and gradient waveforms are shown in Fig.1. The simulated velocity selective profile is shown in Fig.2 (blue solid line).

Experiments: Flow phantom and in-vivo experiments were conducted on a 3T SIEMENS Tim Trio scanner. Single-shot Turbo-FLASH readout was used for data acquisition with the designed VS pulse as the magnetization preparation pulse. First, a flow-phantom study was conducted to test the velocity-selectivity of the designed pulse. A pump was used to generate the constant flow with different flow velocity. Phase contrast MRI (PC-MRI) scans were carried out to measure the actual flow velocities through the imaging plane. At the beginning of the human scan, the blood flow velocities across a cardiac cycle in ascending and descending aorta were measured using ECG-triggered multi-phase PC-MRI. The delay time at the peak systolic phase was identified. The same VS sequence was performed on human heart by synchronizing the VS pulse with the systolic cardiac phase. Different delay times from 100ms to 1500ms with a step of 100ms between VS and FLASH readout were chosen in the VS scans. A single 5mm-thickness axial slice was acquired to test the feasibility of the VS pulse. The other imaging parameters were: FOV=360ms, matrix=256*256, TE=1.2ms, TR=3s, iPAT=2. Centric readout ordering was applied for the data acquisition. The experimental velocity selective profile is compared with simulation result in Fig.2.

Results: Simulation results shown in Fig.2 demonstrate that the flip angle, the velocity selectivity, the pass-band ripples and the sharpness of transition-band all correspond well to the design targets. Results of flow phantom studies shown in Fig.2 verify that the designed pulse can: (1) invert flowing spins of high velocity; (2) leave static spins undisturbed and work relatively well in the low-velocity range. Results of in-vivo studies shown in Fig.3 indicate that (1) the signal of the blood was suppressed after the TI of 700ms; (2) the signal of the static tissue was bright so that the vessel wall of the aorta is clearly shown.

Discussion and Conclusion: In this proof of concept study, we presented a novel method for aortic vessel wall imaging using velocity-selective preparation pulse. Simulation and flow phantom results demonstrate the feasibility of VS inversion RF pulse using SLR algorithm. In-vivo studies showed that this novel method can be used to image the vessel wall of the aorta. In addition, our method enables the pulse designer to explicitly trade-off among important parameters such as pulse duration, cut-off velocity and pass-band ripples. Therefore it can be used for imaging other vasculatures such as carotid and peripheral arteries.

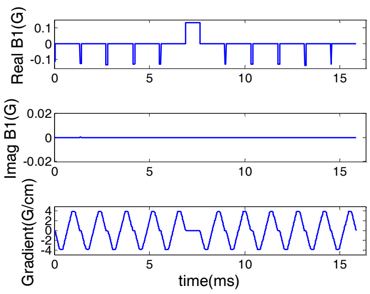

Figure 1. RF and gradient waveform. The 11 hard pulses together with bipolar gradients fulfill velocity selective inversion. RF and gradients have no overlap in time.

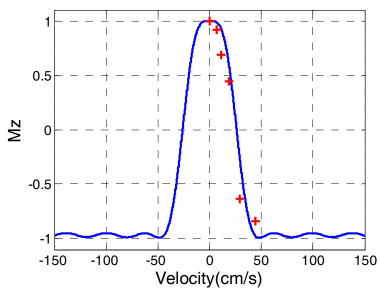

Figure 2. The real value of the signal intensity after generating the velocity selective pulse. Good agreement is shown between simulated (blue solid line) and experimentally measured (red dots) velocity selective profiles. A shift in the experimental profile is seen due to the off-resonance effect.

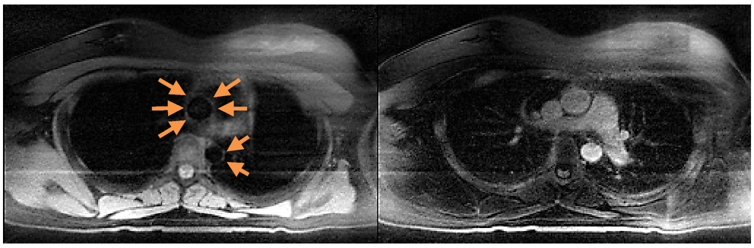

Figure 3. In-vivo experiment results (TI = 700ms). The vessel wall of both the ascending and descending aorta is shown (left, yellow arrows) and the bright-blood image of the aorta in which a global 180 degree inversion pulse is added (right). Both of images verify the velocity selectivity of the pulse.

References:

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