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

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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\textsuperscript{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\textsuperscript{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\textsuperscript{1}, 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\textsuperscript{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\textsuperscript{4}. For imaging the aorta, the design targets were: $M_z = 1$ for velocities below $\pm20$cm/s and $M_z = -1$ for velocities between $\pm20$cm/s and $\pm150$cm/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).

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.

References: