Non-contrast-enhanced peripheral venography using velocity-selective magnetization preparation and transient balanced SSFP

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Target Audience: MR engineers and clinicians interested in peripheral venography.

Purpose: Accurate diagnostic imaging of deep venous thrombosis (DVT) is crucial due to the risk of pulmonary embolism and hypertension [1]. Non-contrast-enhanced (NCE) MR venography (MRV) poses advantages including the absence of ionizing radiation and the risk of nephrogenic systemic fibrosis, and large 3D anatomic coverage. Several methods have shown great promise, but are based on multiple acquisitions [2-4] or 2D multi-slice acquisition [5]. This study aims to develop an NCE MRV method which generates 3D encoded venograms directly using a single acquisition.

Methods: The proposed MRV sequence employs a velocity-selective (VS) magnetization preparation module, which inverts arterial blood while barely affecting stationary tissues and venous blood. The VS module is followed by a delay time (TI) during which the inverted arterial blood magnetization becomes close to zero while other tissue magnetizations are recovered to the equilibrium states. After a spectrally selective fat inversion pulse, a 3D balanced SSFP sequence is played, which consists of dummy excitations and data acquisition with centric view order. The VS module consists of a VS inversion pulse with an inversion band targeting stationary tissues and venous blood, immediately followed by a global inversion pulse. The VS pulse was designed through the excitation *k*-space formalism combined with refocusing pulses as described in [6]. The delay period (TI) and the number of dummy excitations (N_{dum}) were optimized to 350 ms and 40, respectively for maximizing vein-to-background contrast through Bloch simulations. In-vivo experiments were performed on a 1.5 T scanner (Avanto; Siemens Medical Solutions). To demonstrate the effects of TI and N_{dum}, the MRV sequence was applied to the thigh of a subject using 9 sets of the two parameters chosen around their optima. To demonstrate the visualization of the entire lower extremity venous system, MRV was performed in 6 subjects using 4 stations. Imaging parameters included flip angle = 90°, spatial resolution = 1.3×1.3-1.8×2.0 mm^3, FOV = 34×13-22×22.8 cm^3, TR = 4.3 ms, 2-fold parallel imaging, and scan time = 290 heart beats (~4.5 min) per station.

Results: The in-vivo testing with various N_{dum} confirms that the optimal vein-to-muscle contrast occurs after 40 dummy excitations rather than the steady-state (Figs. 3a and 3c). As N_{dum} deviates from 40, fat signal also increases due to insufficient or excessive inversion recovery (arrows in Fig. 3a). TI affects almost exclusively arterial blood, best suppressing it with 350 ms (open arrow heads; Figs. 3b and 3d). Figure 4 shows representative venograms of the entire peripheral system in partial coronal MIP formats. All the major veins are well visualized from the iliac to the tibial and peroneal veins while background tissues are well suppressed except in the bladder due to high T_2/T_1 ratio. Relative vein contrast ratios, defined as $(S_{vein}-S_{background})/S_{vein}$ were 0.83±0.06, 0.76±0.07 and 0.84±0.07 against artery, muscle and fat, respectively across 4 stations and 6 subjects.

Discussion and Conclusion: The proposed MRV method generates vein contrast directly in a single acquisition without subtraction by combining VS magnetization preparation and transient bSSFP acquisition in an optimal manner that maximizes venous signal and obviates other tissue signals. Visualization of the entire peripheral venous system using 4-station acquisitions was feasible, as demonstrated by excellent image quality and high relative vein contrast ratios. Although technical feasibility was shown in healthy subjects, the performance of the proposed technique needs to be further investigated in DVT patients.

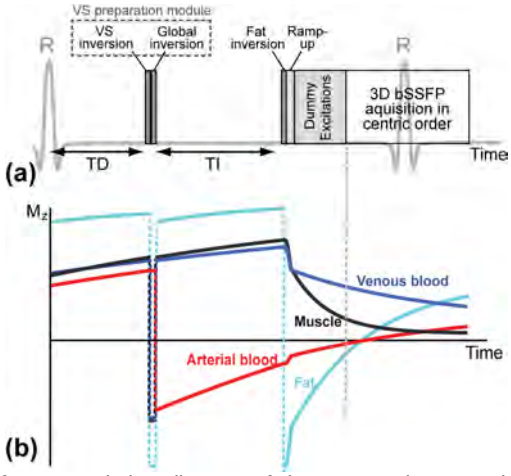

Figure 1. *Timing diagram of the proposed MRV pulse sequence (a) and corresponding Mz evolutions of arterial blood, venous blood, muscle and fat (b).*

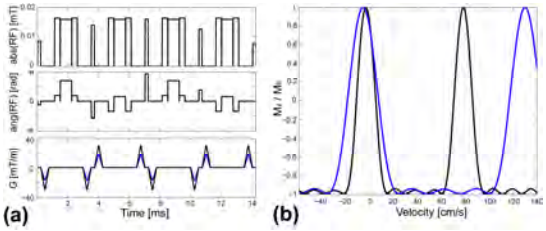

Figure 2. *VS inversion pulse sequence (a) and simulated M_z after both VS and global inversions (b).*

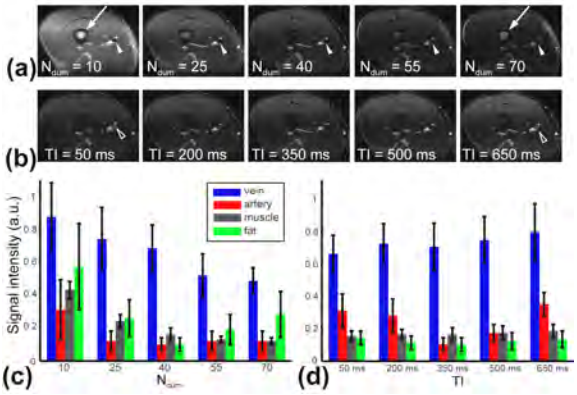

Figure 3. *Axial MRV images (a) and ROI analysis (c) from various N_{dum}. Axial images (b) and ROI analysis (d) from various TI.*

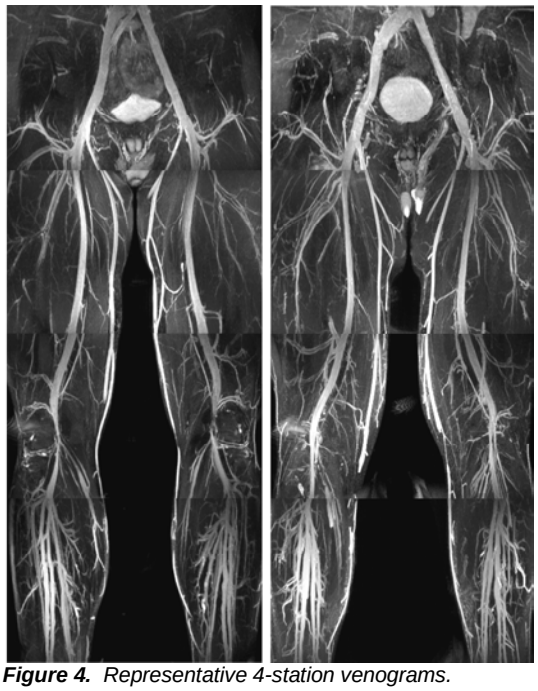

Figure 4. *Representative 4-station venograms.*

References: [1] Kearon C, *et al.*, Circ 107:I22-30, 2003. [2] Edelman RR, *et al.*, Radiology 250: 236-245, 2009. [3] Ono A, *et al.*, MRM 61: 907-917, 2009. [4] Priest AN, *et al.*, ISMRM2011: 1289. [5] Litwiller DV, *et al.*, ISMRM2013: 1286. [6] Shin, *et al.*, MRM 70: 1229-1240, 2013.