OFF-RESONANCE-ROBUST VELOCITY-SELECTIVE MAGNETIZATION PREPARATION FOR NON-CONTRAST-ENHANCED PERIPHERAL MRA

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Target audience MR physicists and vascular radiologists interested in non-contrast-enhanced (NCE) MR angiography (MRA).

Purpose Velocity-selective (VS) excitation is a promising magnetization preparation for NCE MRA due to its ability to generate positive angiographic contrast directly without subtraction [1]. A VS excitation pulse can be designed using the excitation k-space formalism [2,3], but this reference design suffers from excitation profile shifting in proportion to off-resonance (Figs. 1a and 1b). This study aimed to develop an off-resonance-robust VS excitation pulse and demonstrate its application to NCE peripheral MRA.

Methods The proposed VS pulse design is based on modifications of the reference k-space-based design (Figs. 1a and 1c). First, a composite pulse train of 90_x-180_y-90_x is inserted between two unipolars that are split from the original bipolar gradient. To compensate for the magnetization's rotation made by the 180° pulses, unipolar gradients and RF sub-pulses between odd-ordered 180° pulses and subsequent even-ordered 180° pulses (grey circles in Fig. 1c) are modified according to the following rules [1]: (i) $G_{uni}(t) \rightarrow -G_{uni}(t)$, and (ii) $RF_{sub}(\alpha, \psi) \rightarrow RF_{sub}(\alpha, \pi-\psi)$ where $G_{uni}(t)$ = unipolar gradient, $RF_{sub}(\alpha,\psi)$ = RF sub-pulse with a flip angle α and phase ψ. Second, potential excitation errors due to imperfect 180° rotations are further reduced in velocity and off-resonance ROIs (v_{ROI} and f_{ROI} ; white box in Fig. 1d) by numerically tailoring (i) a time delay between a unipolar gradient (T_d) and a 180° pulse (grey bars in Fig. 1c), and (ii) shifting of the excitation profile by multiples of the velocity FOV (Δv):

$$\underset{\Delta v, T_d}{\operatorname{argmin}} \max_{\substack{v \in v_{ROI} \\ f \in f_{ROI}}} \left| M_z(\Delta v, T_d; v, f) - M_z^{ref}(v) \right|$$

where M_z^{ref} is the reference profile obtained on resonance. The profile shifting is done by applying an RF phase that is proportional to the 1st moment of a VS gradient and the amount of velocity shifting Δv [1].

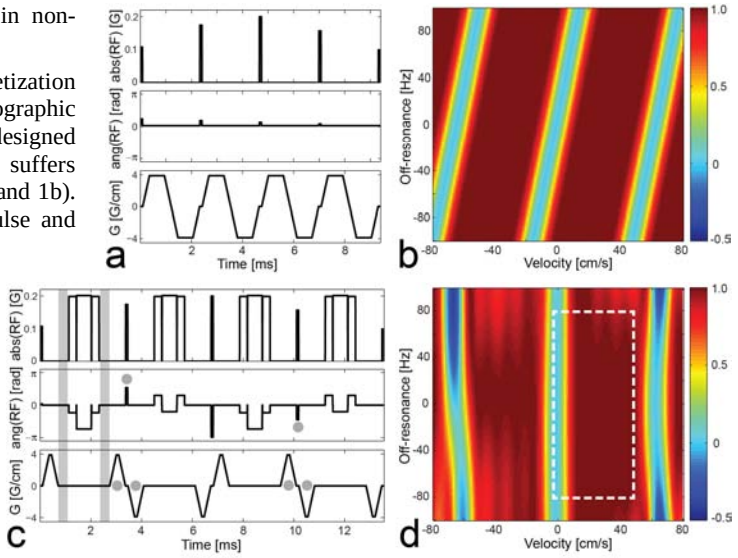

Figure. 1: Pulse sequence diagram and simulated M_z resulting from the reference (top) and proposed VS excitation pulse designs (bottom).

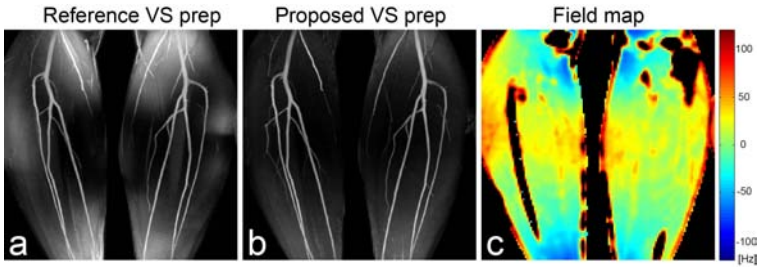

Figure 2: Reformatted MIP images of NCE MRA using the reference (a) and proposed (b) VS preparations, and a field map (c).

For imaging the calves, the velocity pass- and saturation-bands were [+5, +55] cm/s and [-4, 0] cm/s, respectively (Fig. 1d). For imaging the thighs, the upper bound of the velocity pass-band was 15% increased by scaling down the VS gradient. The NCE MRA pulse sequence was cardiac gated and consisted of VS preparation at the time of peak systolic flow, fat saturation and 3D balanced SSFP readout. Imaging parameters for the calves/ thighs were spatial resolution = 1.1×1.1×1.3 mm^3 / 1.3×1.3×1.8 mm^3, FOV = 30×32×8.3 cm^3/ 30×34×13.7 cm^3 , TR = 4.5 ms / 4.5 ms, view per segment = 73 / 65, scan time = 256 / 304 heart beats. A 1.5 T GE MR system and an 8-channel cardiac coil were used.

Results The reference and proposed VS preparations were compared by imaging the calves in four healthy volunteers. Figure 2 contains reformatted maximum-intensity-projection (MIP) angiograms, and the field map of the center coronal slice in a healthy subject. The MIP image from the proposed VS preparation shows much more uniform background suppression across the entire FOV due to the improved off-resonance immunity. The clinical feasibility of the proposed approach was tested by scanning the calves and thighs of a patient who was scheduled for a DSA examination. The mild narrowing of the right femoral artery and occlusion of the right popliteal artery are well identified on both the MR and DSA images (arrows in Fig. 3).

Discussion NCE MRA using the proposed VS preparation can create high angiographic contrast reliably in the presence of large field inhomogeneity. The VS magnetization-prepared MRA method is non-subtractive and robust to R-R variability (due to its dependence on systolic flow only), and can be used for imaging other vasculatures such as carotid and abdominopelvic arteries.

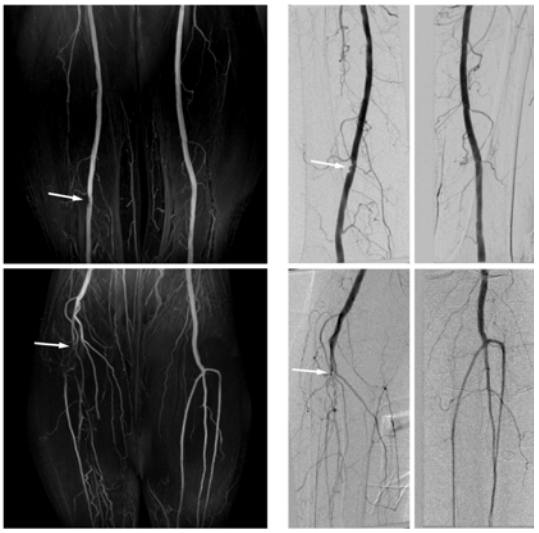

Figure 3: Proposed NCE peripheral MRA (left) compared with DSA (right) in a patient with stenosis (arrows).

References [1] T Shin et al. MRM in press (DOI: 10.1002/mrm.24356). [2] J Pauly et al. JMR 1989; 81:43-56. [3] L de Rochefort et al. MRM 2006;55:171-176.