Optimized and Accelerated Non-contrast-enhanced MRA of the Lower Extremities using iMSDE Prepared bSSFP Acquisition

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Introduction: A bSSFP based non-contrast-enhanced (NCE) MRA technique using motion-sensitized driven equilibrium (MSDE or iMSDE) or flow-sensitive dephasing (FSD) preparation has recently been shown to provide excellent arterial visualizations for anatomic regions including distal lower extremities, hand and foot [1-3]. To guarantee excellent image quality, an ECG gated 2D phase contrast sequence and a rapid m1 (first gradient moment) scout scan are required to provide systolic/diastolic time point and optimal m1 for blood suppression respectively [4]. For imaging of lower extremities, each station would require 4 scans resulting in a total of 12 scans covering all the three stations, which is complicated and poses great difficulties for the radiologists to follow clinically.

This study optimized and accelerated the iMSDE prepared NCE-MRA technique in three aspects (detailed in the following section) to facilitate easier and faster scans in clinical practice.

Materials and Methods:

Pulse sequence: The iMSDE prepared dark-artery imaging and the bright-artery imaging with T2 preparation are combined in a single scan with an interval of one R-R wave (**Fig. 1**). In the systolic scan, a low-high bSSFP acquisition scheme is adopted and the iMSDE module is followed immediately by linear sweep up preparation pulses prior to acquisition, thus the best arterial blood suppression can be achieved. In the diastolic scan, iMSDE module is replaced by T2 preparation to introduce the same T2 weighting so that the signals from venery and static tissues can be effectively subtracted.

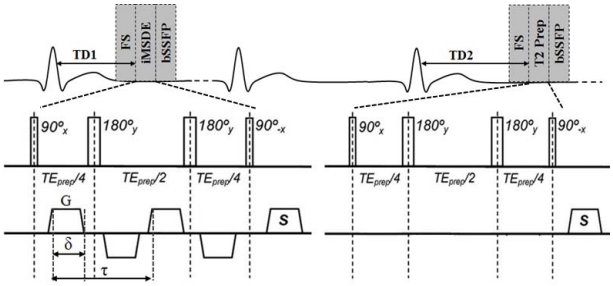

Fig 1. Diagram of the iMSDE prepared NCE-MRA sequence. The systolic scan and the diastolic scan are separated by one R-R interval. iMSDE or T2 Prep module is placed between Fat suppression and bSSFP acquisition.

m1 optimization: For spins experiencing the iMSDE module, the phase dispersion (φ) caused by intra-voxel velocity variation (Δv) can be expressed as $\varphi = \gamma m_1 \Delta v$, where $m_1 = 2G\delta\tau$. Considering a small enough pixel where the velocity variation is approximately linear as described by Haacke et al. [5] (**Fig. 2**) for laminar flow: $\Delta v / \Delta v \approx d(v(y))/dy = -2yv_{\max}/a^2$, where Δy is the pixel size. To avoid obvious venous suppression, the condition $|\varphi|_v \le \pi$ should be met for all pixels, namely $y \in [-a, a]$. Thus $m_1 \le \pi/(2\gamma \Delta y v_{v,\max}/a)$ (1), where $v_{v,\max}$ is the maximum venous velocity. To suppress arterial pixels, a minimal phase dispersion of 2π is required, which induces an infinite m1 for signal dephasing at y=0. A feasible assumption would be that $|\varphi|_a \le 2\pi$ be satisfied for pixels located at $a/2 \le |y| \le a$, which gives $m_1 \ge \pi(\gamma \Delta y v_{a,\max}/2a)$ (2), where $v_{a,\max}$ is the maximum arterial velocity.

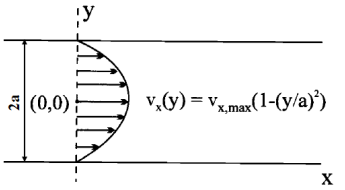

Fig 2. Laminar flow model.

Theoretically, the value in equation (1) would be the optimal m1 for best arterial visualization without venous contamination. If the value in equation (2) exceeds that in (1), then we suggest using the derived lowest m1 in (2), which gives adequate arterial suppression, though the tradeoff of certain venous contamination would be introduced.

Acceleration with keyhole: Keyhole is most frequently used in dynamic scans where only one dynamic scan (reference scan) data is fully acquired. The rest dynamic scans shared the same high frequency k-space data with the reference scan to significantly reduce the scan time [6]. In theory, either the systolic or the diastolic scan can be used as reference scan. However, it's more advisable to use the diastolic scan as a reference because it is often evaluated together with the subtracted images to facilitate diagnostic decisions [7].

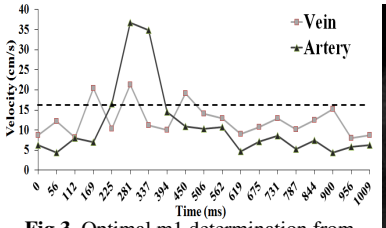

Fig 3. Optimal m1 determination from phase contrast sequence.

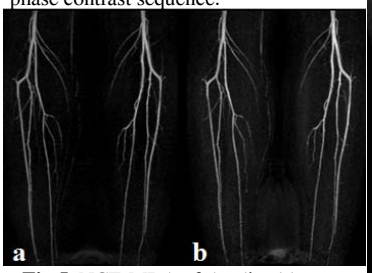

Fig 5. NCE-MRA of the distal lower extremities without (a) and with keyhole technique (b) (score = 4).

Fig 4. Three stations of the lower extremities by iMSDE prepared NCE-MRA using the m1 derived from phase contrast sequence (score = 4).

Volunteer study: Two healthy volunteers were studied with the proposed sequence using the optimal m1 derived from a 2D phase contrast sequence at Multiva 1.5T (Philips Healthcare, Suzhou, China). Imaging parameters for bSSFP acquisition were: TR/TE = 4.8/2.4 ms, TFE factor = 50, SENSE factor = 2. The spatial resolution varies slightly so that the scan time for each station was 4-5 min (distal: 1.0x1.0x1.0 mm^3; middle: 1.2x1.2x1.2 mm^3; proximal: 1.5x1.5x1.5 mm^3). We also tested the accelerated scan employing keyhole technique in the distal lower extremities. The diastolic scan was used as reference and 60% of k-space data was acquired for the systolic scan with the same imaging parameters as above. All images were reviewed by two radiologists on a 4-point scale [1] (1 to 4: poor to excellent).

Results: Optimal m1 was determined from 2D phase contrast scan (**Fig. 3**) and high image quality with scores 3 or 4 was achieved for all the three stations of lower extremities using the derived m1 (**Fig.4**). The number of scans for imaging the lower extremities was reduced from 12 to 6. By using the keyhole technique, a further 20% scan time was reduced without apparent image quality degradation (**Fig. 5**).

Discussion & Conclusions: An optimized and accelerated iMSDE prepared NCE-MRA technique was proposed, which allows for easier and faster scans in practice. Further studies involving patients are required to evaluate the clinical effectiveness of this technique.

References:

[1] Fan Z, et al. MRM 2009;62:1523-32. [2] Fan Z, et al. Invest Radiol 2011;46:515-23. [3] Liu X, et al. Radiology 2014;272: 885-94. [4] Fan Z, et al. MRM 2011;65:964-72. [5] Haacke EM, et al. Wily-Liss 1999;23: 673-5. [6] Jones RA, et al. MRM 1993;29:830-4. [7] Nakamura K, et al. MRM 2011;65:595-602.