3D Non-Contrast-Enhanced MRA Using Flow-Sensitive Dephasing (FSD) Prepared Balanced SSFP: Identification of the Optimal First-Order Gradient Moment

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Introduction: A non-gadolinium-enhanced MRA technique using ECG-triggered 3D balanced SSFP with flow-sensitive dephasing (FSD) preparation has recently been developed and validated in the distal lower extremities of healthy volunteers [1]. The FSD's first-order gradient moment, m_1, is shown to be the most important parameter to determine angiographic quality. A suboptimal m_1 may result in venous contamination or incomplete arterial delineation. This work aimed to develop an m_1-scout approach to rapidly identify the optimal m_1 for FSD-based noncontrast MRA.

Materials and Methods:
- Theory: FSD-induced flow signal suppression is voxel size-dependent as its underlying mechanism is the intravoxel velocity variation [2]. For FSD-based 3D isotropic-resolution MRA with major flows in the readout direction, we hypothesized that the same imaging sequence can be switched to a 2D mode to rapidly identify the optimal m_1 to be applied in the readout direction during the 3D dark-artery measurement. This requires the 2D imaging plane to be perpendicular to the major vessel of interest, the FSD gradient pulses to be applied in the slice-select direction, and the in-plane resolution to be identical to that of 3D imaging. Theoretically, the larger-sized pixel in 2D imaging has approximately the same phase dispersion as in the smaller-sized voxel in 3D imaging. This is because the velocity variation along the vessel course can be neglected and the phase dispersion should be independent of the 2D slice thickness. Therefore, the choice of the m_1-value by this 2D scout scan could directly translate to 3D imaging.
- Validation of m_1-scout
(a) Flow phantom study. Gd-doped water (0.25mM, T_1 = 670 ms) was pumped through a silicone tube (4.8-mm ID) in a water bath. Various flow rates (15, 20, 30, 40, 50, 60 cm/s) were tested at 1.5T (Espree, Siemens). 2D FSD-bSSFP scan was performed for m_1-scout, acquiring 11 cross-sectional images at the center of the tube in the bath with incremental m_1-values (0.94-mm in-plane resolution and 5-mm slice thickness) (**Fig. 1**). Six selected m_1-values were respectively used in a 3D FSD-bSSFP coronal scan (0.94-mm isotropic resolution) to acquire dark-flow datasets. The readout direction was parallel to the tube's long axis. Simulated heart period = 1000 ms. Signal intensity (SI) was measured in the lumen on the matched 3D (averaged from three locations) and 2D images and analyzed using Pearson correlation.
(b) Volunteer study (3 males, 2 females). Left and right thighs (popliteal artery) were scanned separately (**Fig. 2**). 2D m_1-scout imaging acquired 11 cross-sectional images using m_1 = 0, 5, …, 50 $mT\cdot ms^2/m$, respectively. 3D FSD-bSSFP oblique sagittal imaging was repeated with 7 selected m_1 values to acquire dark-artery datasets. Both 2D and 3D scans used the same ECG trigger delay time (i.e. peak flow) determined by the phase contrast flow scan. The same spatial resolution and signal analysis as described in flow phantom study were used.
- FSD MRA study using m_1-scout: FSD MRA was performed in the healthy lower legs and hands with m_1-scout providing the optimal m_1-value. 3D MRA datasets and MIP images were reviewed by a radiologist on a 4-point scale [1] (1, poor, 4 excellent).

Fig 1. Schematic of the 2D m_1-scout approach. A total of 11 images were collected within 1 min. The first image uses m_1 = 0, while the others use incremental m_1 values (user specified.)

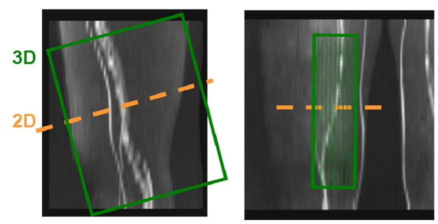

Fig 2. Prescription of the imaging volume in the volunteer study.

Tab. 1. Signal intensity Pearson correlation in 5 healthy volunteers.

Volunteer (Left/Right)	1 (L)	1 (R)	2 (L)	2 (R)	3 (L)	3 (R)	4 (L)	4 (R)	5 (L)	5 (R)
Pearson Correlation	0.941	0.955	0.974	0.984	0.990	0.992	0.947	0.960	0.924	0.950
p-value	0.002	0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.001	0.001	0.003	0.001

Results: 2D scout imaging time was <1 min. In the phantom study, the lumen SI from the 2D and 3D images were significantly correlated at all velocities tested (Pearson correlation = 0.988±0.011, $p<0.001$) (**Fig. 3**). Similar results were observed in volunteer studies (**Fig. 4** & **Tab. 1**). The optimal m_1 value determined by the 2D scout consistently provided high-quality (score = 3 or 4) MRA at calves and hands (**Fig. 5 & 6**), even though the scout plane was not perfectly perpendicular to some artery segments.

Discussion and Conclusions: m_1-scout is an efficient approach to predict the optimal m_1 for each individual subject, which could potentially improve FSD-based MRA and vessel wall imaging [3]. Patient studies are required to test its effectiveness in clinical situations.

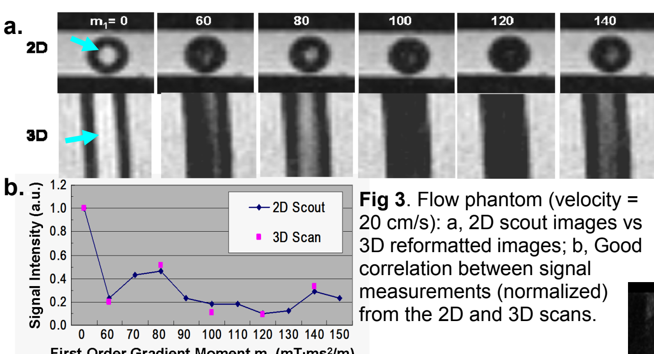

Fig 3. Flow phantom (velocity = 20 cm/s): a, 2D scout images vs 3D reformatted images; b, Good correlation between signal measurements (normalized) from the 2D and 3D scans.

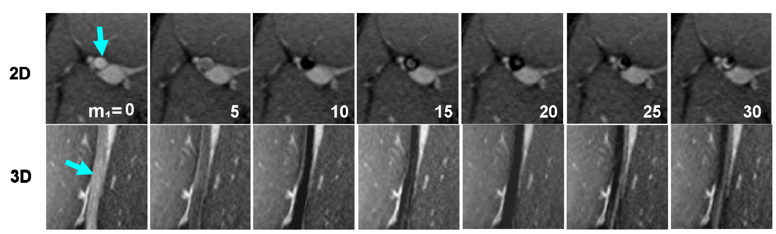

Fig 4. 2D scout vs. 3D reformatted images of the popliteal artery from a volunteer

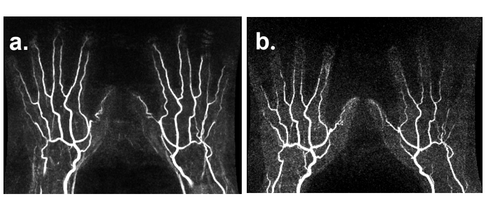

Fig 5. Noncontrast hand MRA (a) has better arterial depiction than contrast MRA (b).

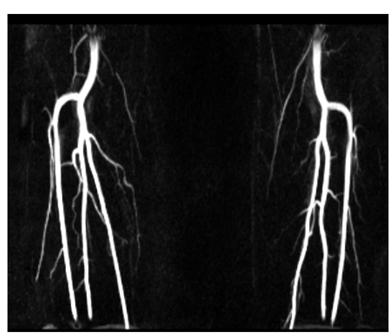
Fig 6. Noncontrast calf MRA offers superior angiographic quality (score = 4).

References:
1. Fan Z, et al. MRM 2009; 62
2. Nguyen TD et al. JMRI 2008; 28(5):1092-100
3. Koktzoglou I, et al. JCMR 2007;9:33.