Non-Contrast Enhanced MR Angiography (NCE-MRA) of the Foot Using Flow Sensitive Dephasing (FSD) Prepared Steady-State Free Precession (SSFP) in Patients with Diabetes

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Introduction: Contrast-enhanced MR angiography (CE-MRA) has been used as a routine procedure for imaging limb arteries and offers advantages over computed tomography angiography in that patients are not exposed to ionizing radiation or to potentially nephrotoxic iodinated contrast media [1]. However, the use of gadolinium-based agents has been limited in patients with renal insufficiency because of the concerns regarding nephrogenic systemic fibrosis. Furthermore, short contrast first-pass window in arteries often limits imaging coverage or spatial resolution and venous contamination may be present at distal run-off vessels. Peripheral noncontrast (NCE)-MRA techniques such as FBI, QISS have previously been developed to image lower extremity arteries in patients with impaired renal function [2, 3]. A new peripheral NCE-MRA technique using steady-state free precession (SSFP) and flow-sensitive dephasing (FSD) magnetization preparation has been recently proposed for the purpose. [4]. With the flow insensitivity nature of SSFP and more flexible suppression of flow signal by using the strength- and direction-tunable FSD preparation, the technique allows high image quality for tortuous and small distal extremity arteries and demonstrate clinical potential in the depiction of hands [5, 6]. To our knowledge, no study has been reported to systematically evaluate the clinical application of the NCE-MRA technique in the foot. **The purpose of this study was to prospectively assess the diagnostic performance of NCE-MRA using FSD-prepared SSFP in patients with diabetes, using conventional CE-MRA as the reference standard**.

Methods: Thirty-eight healthy volunteers and 38 diabetic patients (type II) who underwent lower extremity contrast-enhanced MR angiography (CE-MRA) were recruited for NCE-MRA study on a 1.5T MR system (Avanto, Siemens) equipped with a 12-element phased-array head coil for pedal arteries acquisition. CE-MRA was performed with bolus-chase three-station technique from thigh to feet using a 3D gradient-echo fast low-angle shot pulse sequence. NCE-MRA was performed using ECG-triggered 3D segmented SSFP coupled with an FSD magnetization preparation. Imaging parameters included: TE/TR = 1.9/3.8 ms, receiver bandwidth = 965 Hz/pixel, FOV = $300\times200\times80\sim90$ mm^3, voxel size = $0.9\times0.9\times0.9$ mm^3, flip angle = 90^o, parallel imaging (GRAPPA) acceleration factor = 2 in the phase-encoding direction, 60 lines per heart beat, acquisition time = 2～4 min per scan (depending on the heart rates) including two consecutive measurements of bright-artery and dark-artery. The m_1 value of the FSD gradient were individually optimized using a scout approach (100～150 mTms^2). Maximum intensity projection images of the calf and foot arteries were created. Only foot arteries images were used for image analysis. The calf arterial images of CE-MRA were used as a reference if an occlusive disease was suspected in the distal calf arteries. Image quality on a 1-4 point scale (2 or more was defined as diagnostic) on five foot arterial segments (dorsal pedal artery, medial plantar artery, lateral plantar artery, pedal arch, and metatarsal arteries), SNR, and CNR on three main pedal arteries (dorsal pedal artery, lateral plantar artery, and pedal arch) were assessed in consensus by two experienced radiologists and statistically compared between the two techniques. Diagnostic accuracy of NCE-MRA for detecting more than 50% arterial stenosis was assessed in the three main pedal arteries by the same two readers independently using the diagnostic arterial segments of CE-MRA as a standard reference based on the arterial segments of diagnostic image quality.

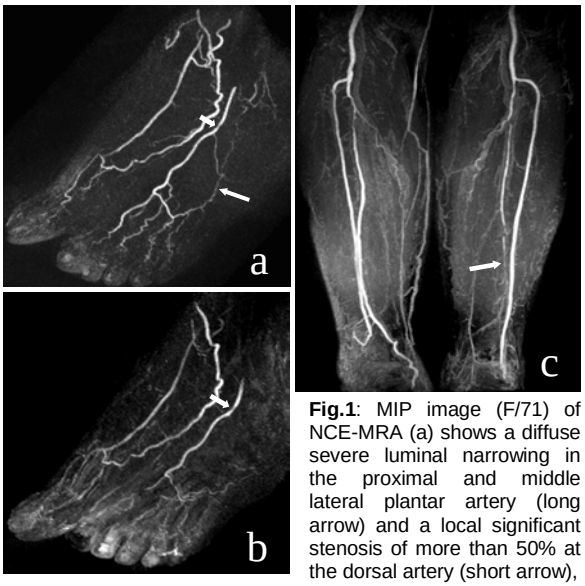

Fig.1: MIP image (F/71) of NCE-MRA (a) shows a diffuse severe luminal narrowing in the proximal and middle lateral plantar artery (long arrow) and a local significant stenosis of more than 50% at the dorsal artery (short arrow), This is confirmed by CE-MRA (b) at the corresponding site of the artery. CE-MRA f**ails** to depict the lesion in the lateral plantar artery. MIP image of NCE-MRA in the calf shows an occlusion in the distal posterior tibia artery (c).

Results: All subjects successfully underwent foot NCE-MRA study within an imaging time of 2～4 minutes. The average percentage of diagnostic arterial segments in all subjects on NCE-MRA was 99%, 92%, 93%, 91%, and 98% in dorsal artery, lateral plantar artery, medial plantar artery, pedal arch, and metatarsal arteries, respectively. In the patients with diabetes, the overall image quality of NCE-MRA was significantly higher than that of CE-MRA with few venous contaminations and high isotropic spatial resolution (3.2±0.8 vs. 2.5±0.8, $p < 0.001$) **(Fig. 1)**. There was no difference in SNR and CNR between the two techniques in dorsal artery (96.7 ± 37.3 vs. 99.6 ± 41.0, p=0.59 for SNR, 93.7 ± 35.4 vs. 94.8 ± 39.6, p=0.82 for CNR) and lateral plantar artery (93.1 ± 42.4 vs. 83.6 ± 34.4, p=0.086 for SNR, 84.8 ± 34.3 vs. 77.6 ± 33.2, p=0.13 for CNR). Using CE-MRA with standard multi-station technique as a standard reference, NCE-MRA demonstrated comparable diagnostic accuracy for the detection of significant arterial stenosis **(Fig. 2)** and a good inter-observer agreement (k=0.83). The average sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of NCE-MRA for assessing significant stenosis were 89%, 93%, 82%, 96%, and 92%, respectively.

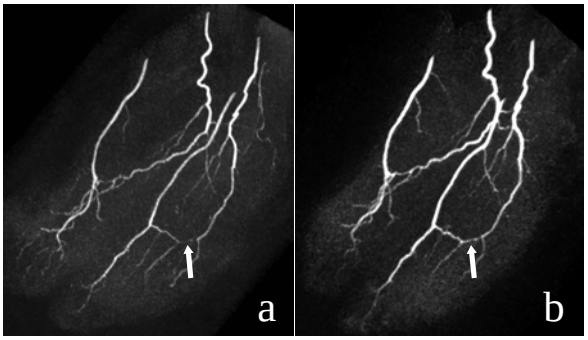

Fig.2: MIP image (43/F) of NCE-MRA (a) shows a pedal circulation of co-dominance by dorsal artery and lateral plantar artery (LPA). A significant stenosis (arrow) is suspected at the pedal arch, which is normal at the corresponding arterial segment on CE-MRA (b).

Discussion: NCE-MRA using FSD-prepared SSFP allowed for precise depiction of complete pedal arterial tree in an acceptable acquisition time in healthy volunteers and diabetic patients. The percentage of diagnostic arterial segments and image quality of the NCE-MRA technique were significant greater than that of CE-MRA in both healthy volunteers and diabetic patients. Excellent diagnostic accuracy was shown in this study. On the other hand, without contrast agent, NCE-MRA was unable to detect enhancement of soft tissue associated with inflammatory complications in diabetic foot. Nevertheless, the present study indicates that the NCE-MRA technique has potential to be used as a clinical tool for the evaluation of foot arteries in diabetic patients, especially in the patients with renal insufficiency.

References: 1. Pomposelli F. J Vasc Surg 2010; 52(3 Suppl):81S-91S. 2. Miyazaki M, et al. Radiology 2008;248:20. 3. Hodnett PA, et al. Radiology 2011;260:282. 4. Fan Z, et al. Magn Reson Med 2009;62:1523. 5. Fan Z, et al. Invest Radiol 2011;46:515. 6. Sheehan JJ, et al. Radiology 2011;259:248.