Arterial flow characteristics in the presence of vascular disease, and implications for non-contrast MRA

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Introduction: Concerns about nephrogenic systemic fibrosis (NSF) have spurred a search for alternatives to first-pass gadolinium-enhanced MRA in patients with renal insufficiency. Among the proposed alternatives for peripheral MRA are non-contrast ECG-gated techniques [1-3] that exploit differences in flow velocity between diastole and systole. Due to flow-related dephasing, arteries appear dark in systole when the flow is fast, but brighter in diastole, when the flow is slow. Bright-blood images of the arteries can therefore be obtained by subtraction. These techniques are capable of providing highly detailed angiograms in healthy subjects. The goal of this work was to examine the performance of ECG-gated 3D FSE [1,2] in patients with vascular disease, who may have atypical flow patterns. It has earlier been shown that the flow sensitivity of FSE increases as the flip angle of the refocusing pulses decreases [4]. This provides some ability to adapt to individual flow patterns. However, it is not yet known whether it provides sufficient control to obtain accurate depiction of vascular pathology over a wide range of disease states.

Methods: Imaging was performed on a Siemens 1.5T Avanto system using a peripheral phased array coil. 26 patients and 9 healthy subjects were included in the study, of whom 15 patients were enrolled prospectively (8 men, 7 women, ages 68.5±17.5 years, range 22–88). Retrospective analysis was conducted on data from an additional 11 patients (6 men, 5 women, ages 69.5±12.1 years, range 51–92) and 9 healthy subjects (6 men, 3 women, ages 34.1±13.7 years, range 23–63). All subjects provided written informed consent. Patients were recruited from among those scheduled for a routine contrast-enhanced MRA. Reasons for the exam included claudication (21 patients), non-healing ulcers (2), DVT (2) and Leriche syndrome (1). The contrast-enhanced MRA included time-resolved imaging of the calves followed by a multi-station bolus-chase. Non-contrast sequences were run prior to contrast administration. In the prospective study, an ECG-gated 3D FSE-based MRA was performed in two stations (calf and thigh) using the following parameters: FOV=450mm, in-plane voxel size 1.7x1.4mm^2, nominal slice thickness 1.5mm (calf) or 2mm (thigh), slice resolution 75%, echo spacing 2.76ms, 2 echo trains per partition, GRAPPA 2, constant FA of 60°–120°, TE 19–104 ms. Phase-contrast imaging was conducted in multiple axial planes to calculate appropriate trigger delays for the MRA acquisition and to document flow characteristics. Data were also analyzed retrospectively from 11 patients enrolled in a study to compare ECG-gated FSE with diffusion-prepared SSFP-based MRA [3] in the calf. Diffusion weighting was applied only during the systolic acquisition; during diastole a 90°-180°-90° preparation with identical timing but without the diffusion gradients was used. Phase-contrast and FSE-based MRA data from the calves of 9 healthy subjects were also analyzed retrospectively. Images from the prospective patient study were read by a board-certified radiologist, who graded vessel visualization in the non-contrast FSE-based MRA as compared to contrast-enhanced MRA on a 5-point scale: better/same/worse/much worse/not visualized. Separate grades were assigned to each of the following arterial segments in the calves: popliteal, tibioperoneal trunk, and proximal and distal segments of the anterior tibial, peroneal, and posterior tibial. In the thighs, the following arteries were graded: common femoral, superficial femoral (proximal and distal segments), profunda femoris and proximal popliteal. Average grades were also assigned to collaterals and small branch arteries.

Results: In the healthy subjects, peak systolic flow in the popliteal arteries was 43.8±7.8cm/s. Mean diastolic flow was 1.8±2.9cm/s (including negative values). The highest diastolic flow measured in any of the healthy subjects was 6.5±3.1cm/s; for this subject, optimal arterial conspicuity over both large and small vessels in the calves was achieved with FA=120°. Results from the prospective patient study are shown in Fig. 1. Non-contrast FSE-based MRA performed better or the same as contrast-enhanced MRA in 73% and 52% of named arterial segments in the calves and thighs respectively. Reasons for poor vessel visualization included patient motion and vessel orientation perpendicular to the frequency-encoding direction. Signal loss in the right groin, probably due to B_1 inhomogeneity [5], contributed to the inferior overall performance in the thigh compared to the calf station. However, faster flow in the thigh may also warrant flip angles higher than 120°.

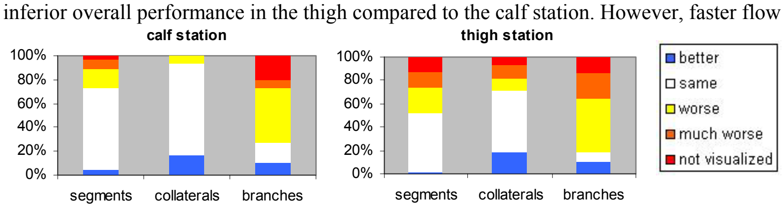

Figure 1. Visualization of arteries in 15 patients with non-contrast 3D FSE-based MRA as compared to first-pass contrast-enhanced MRA in the calf and thigh stations. Results are shown separately for named segments, collaterals and small branch arteries.

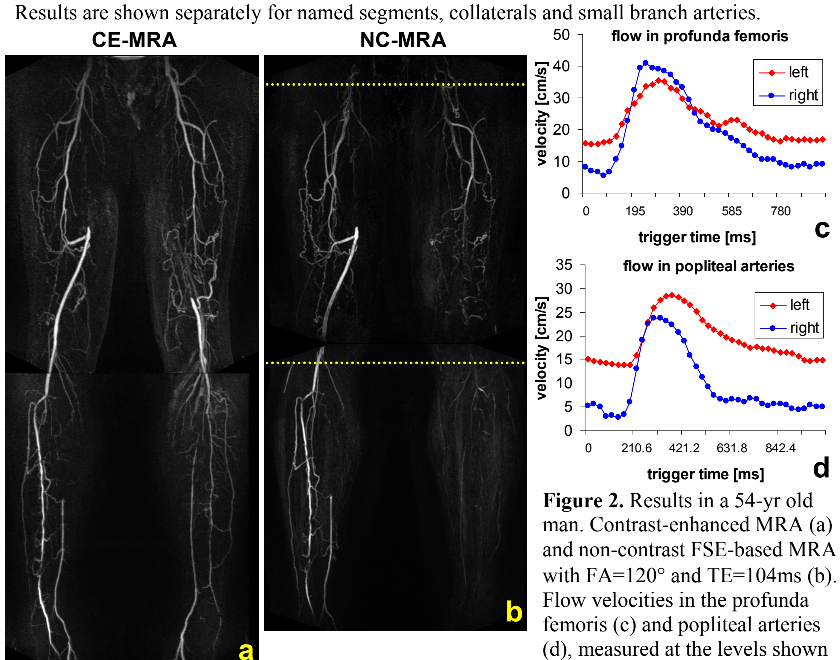

Figure 2. Results in a 54-yr old man. Contrast-enhanced MRA (a) and non-contrast FSE-based MRA with FA=120° and TE=104ms (b). Flow velocities in the profunda femoris (c) and popliteal arteries (d), measured at the levels shown by the dotted lines in (b).

Two patients in the prospective study were notable in having particularly high diastolic flow due to their pathology. One was a 22 year-old man with a non-healing wound. Diastolic flow velocity measured in the tibioperoneal trunk in this patient was 14.8cm/s. Vessel visualization on the non-contrast FSE-based MRA was poor despite a high FA (120°). A second patient (54-year old man) had reduced pulsatility and high diastolic flow ('tardus parvus' waveform) distal to an occlusion of the superficial femoral artery (Fig 2). The flow pattern in the profunda femoris, which supplied the collateral vessels, was also affected. Both the profunda femoris and the arteries distal to the occlusion were poorly visualized on the non-contrast FSE-based MRA despite a high FA (120°). Hypothesizing that the diffusion-prepared SSFP-based sequence [3] might be better adapted to this flow pattern, since it is flow-sensitive only in systole, we retrospectively analyzed data from a study that compared FSE- and SSFP-based non-contrast MRA. One patient (a 59-year old man) from that study also exhibited reduced pulsatility and increased diastolic flow distal to a severe stenosis, which correlated with poor visualization of the distal segments on FSE-based MRA. As predicted, the SSFP-based sequence provided improved visualization of these segments, although the images exhibited venous contamination.

Discussion: While we have highlighted flow patterns that resulted in poor performance of the FSE-based MRA sequence, there were many cases in which it accurately depicted pathology. The patients in whom we observed the tardus parvus waveform were both relatively young, and presumably had fairly compliant vessels. We did not observe this phenomenon in any of the much older patients, despite the presence of severe disease. Further studies will be necessary to determine whether better arterial depiction in the presence of altered flow patterns can be obtained with the existing FSE-based sequence by more judicious parameter choices.

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References: [1] Radiol 2003; 227:890 [2] ISMRM 2008, 730 [3] Fan, MRM Oct 2009 [4] ISMRM 2009, 423 [5] ISMRM 2009, 426