Magnetic Resonance Imaging-derived Arterial Peak Flow in Peripheral Arterial Disease: Towards a Standardized Measurement

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WHAT THIS PAPER ADDS

Arterial peak flow is a quick and simple functional magnetic resonance imaging-derived measure that can be used to objectively quantify vascular status and to monitor therapy in patients with peripheral arterial disease. In clinical practice, it would be desirable to have a standardized arterial segment to measure the arterial peak flow, comparable to, for example, ankle-brachial index measurements, independent of the location of obstructive arterial lesions, but with the greatest likelihood to differentiate between a diseased and healthy arterial vasculature and with well-known normative values.

Objective: To determine the best location to measure the arterial peak flow (APF) in patients with peripheral arterial disease in order to facilitate clinical standardization.

Methods: Two hundred and fifty-nine patients with varying degrees of peripheral artery disease (PAD) and 48 patients without PAD were included. All patients underwent magnetic resonance phase-contrast imaging of the common femoral artery (CFA), superficial femoral artery (SFA), and popliteal artery (PA). APF values of patients with PAD were compared with patients with no PAD. The discriminative ability to identify PAD was evaluated by means of receiver—operator characteristic curves and the corresponding areas under the curve (AUC).

Results: Mean APF values in patients with PAD were reduced by 42%, 55% and 59% compared with non-PAD patients for the CFA, SFA, and PA, respectively ($p < .01$). The AUC's were 0.84, 0.92, and 0.93 for the CFA, SFA, and PA, respectively.

Conclusion: The APF measured at the level of the PA shows the largest differences between patients with PAD and patients with no PAD and the best discriminative ability compared with the APF acquired in the CFA or SFA. The PA seems to be the most suitable level for standardized flow measurements in patients with PAD in order to obtain relevant functional information about the vascular status.

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INTRODUCTION

Magnetic resonance angiography (MRA) is a highly accurate noninvasive diagnostic imaging method for the morphological evaluation of the peripheral arteries in patients with peripheral arterial disease (PAD).[1—4] Clinically, owing to high costs and limited availability, MRA is mainly applied in the setting of treatment planning and/or therapy monitoring. Nevertheless, given the progressive nature of PAD, increasing numbers of patients undergo multiple MRA examinations during their lifetime for treatment planning and/or therapy monitoring. For these patients, a fast and simple functional magnetic resonance imaging (MRI)-derived measure, such as the arterial peak flow (APF), which is suitable to objectively quantify the vascular status and to monitor the progression of PAD over time, might be a valuable addition to MRA.[5—7] Numerous other noninvasive functional diagnostic tools are available for this purpose, such as ankle-brachial pressure index (ABI), duplex ultrasonography, and laser Doppler measurements.[8—11] However, APF measurements have the advantage of being quick, reproducible, and highly automated, with acquisition times well below 1 minute, and can easily be added to existing MRA protocols to obtain the functional vascular status together with morphologic information during the same examination.[5,6,12—14]

Previous studies have demonstrated good reproducibility for APF measurements and lower APF values in patients with PAD compared with healthy controls.[5—7] For clinical

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practice, it would be desirable to have a standardized arterial location to measure the APF, comparable to ABI measurements, independent of the location of obstructive arterial lesions, but with good ability to differentiate between a diseased and healthy arterial vasculature, and with well-known reference values. Therefore, in this preliminary study the APF was acquired at three distinctive and standardized arterial positions in a large group of patients with PAD and patients without PAD with the purpose of determining the optimal location that best differentiates between patients with PAD and those without.

METHODS

Study population

MR cine phase-contrast imaging flow measurements are a standard addition to contrast-enhanced MRA (CE-MRA) at Maastricht University Medical Center (MUMC) in all patients scheduled for CE-MRA of peripheral arteries. The ethics committee of MUMC waived the need for informed consent from patients, as flow measurements are part of the standard imaging protocol at MUMC. Data were retrospectively analyzed anonymously. Patients with (partial) lower extremity amputations were excluded from the study. Otherwise, there were no exclusion criteria. Patients referred for CE-MRA of the peripheral arterial tree to rule out deep vein thrombosis (DVT) or in the preoperative workup for reconstructive surgery using lower extremity tissue flaps with no clinical symptoms of PAD or signs of PAD on CE-MRA were used as the reference. Patient characteristics were retrieved from the patient records and are summarized in Table 1.

MRI protocol

All patients underwent a three-station CE-MRA protocol of the peripheral arteries,[15] followed by quantitative MR cine phase-contrast imaging flow measurements at three distinctive arterial positions as described below. Flow data were used to obtain the APF in patients with PAD and in those without it.[16] All examinations were performed using a 1.5-T MRI system (Intera, Philips Medical Systems, Best, the Netherlands). Patients were imaged in the supine position and were in this position for approximately 30 minutes before the flow measurements were started. During this period, the CE-MRA examination was performed using a fixed dose of 10-mL gadofosveset trisodium (Ablavar®; Lantheus Medical Imaging, Billerica, MA, USA) as contrast agent.[6,17]

CE-MRA. A three-station three-dimensional gradient-echo (fast field echo) MRA sequence was performed as previously described.[2,15]

Flow MRI. For quantitative cine phase-contrast imaging a two-dimensional gradient-echo (fast field echo) scan technique was used. Measurements were performed at the level of the proximal common femoral artery (CFA), the proximal superficial femoral artery (SFA), and the P2-segment of the popliteal artery (PA) (Fig. 1). Parallel imaging (sensitivity encoding, SENSE) was applied to reduce scan time (SENSE acceleration factor 2 in the anterior-posterior direction).[18] At a mean heart rate of 60 beats per minute, the nominal acquisition time was 1 minute.

Table 1. Patient characteristics.

	Patients with PAD	Patients without PAD
Number	259	48
Men (%)/women (%)	147 (57)/112 (43)	23 (48)/25 (52)
Age, years (mean ± SD)	67 ± 13.1	53 ± 16.4*
Heart rate, bpm (mean ± SD)	71 ± 13	75 ± 14
Bodyweight, kg (mean ± SD)	77.1 ± 15.1	75.7 ± 16.4
IC/CI (%)	137 (53)/122 (47)	–
Diabetics (%)	120 (54)[b,a]	5 (13)[b]

Note. PAD = peripheral arterial disease; bpm = beats per minute; IC = intermittent claudication; CI = critical ischemia.*$p < .01$.

[a] Diabetic status could only be retrieved in 221/259 patients with PAD.

[b] Diabetic status could only be retrieved in 38/48 patients without PAD.

Angiographic reading

All CE-MRA datasets were analyzed by a well-trained radiologist with over 5 years of experience in MRA of the peripheral vasculature. For this study, CE-MRA data were used to determine the presence and severity of obstructive arterial lesions in PAD and to exclude the presence of obstructive arterial lesions or arterial malformations in the group of patients with no PAD.

Flow analysis

A quantitative flow analysis package (QFlow) included with the software release (R11.4.14; Philips Medical Systems) of the MRI hardware was used to analyze the flow data directly after acquisition. Using this software, a region of interest (ROI) covering the entire visible cross-section of the artery of interest was accurately drawn manually using a modulus image at peak systole and then automatically propagated to the remaining cardiac phases using an active contour algorithm. In general, the PA had the smallest caliber, covering approximately 6 pixels in diameter (i.e., approximately 28 pixels in cross-sectional area).[7] Although the peak systolic phase only is sufficient to calculate the APF, ROIs were propagated to the remaining cardiac phases to obtain flow wave forms, which were visually analyzed to ensure that the chosen cardiac phase was, indeed, at peak systole and to detect possible aliasing effects. If detected, the measurement was repeated with a sufficiently higher phase encoding velocity.

APF analysis

APF was determined in the most symptomatic leg, according to the request form completed by the vascular surgeon