Pedal Artery Imaging – A Comparison of Selective Digital Subtraction Angiography, Contrast Enhanced Magnetic Resonance Angiography and Duplex Ultrasound

W. J. Hofmann*, R. Forstner, B. Kofler, K. Binder, A. Ugurluoglu and H. Magometschnigg

Objective: to evaluate selective digital subtraction angiography (DSA), contrast-enhanced magnetic resonance angiography (CE-MRA) and duplex ultrasound (duplex) in preoperative pedal artery imaging.

Material and Methods: DSA, CE-MRA and duplex were studied prospectively in 37 patients suffering from critical leg ischaemia. Two radiologists independently reviewed both the CE-MRA and DSA images. The pedal vessels were scored on a scale from 0 to III (0 = vessel not visualised, I = vessel faintly visualised, II = stenosis > 50%, III = vessel without relevant stenosis). Duplex ultrasound was performed by an angiologist blind to both the DSA and MRA findings and the pedal arteries were scored 0–III according to their diameter.

Each examiner named the pedal artery best suitable for bypass surgery. Agreement in artery assessment was expressed as kappa values.

Patency of the bypass at 30 days was used as validation of the artery’s suitability as the run-off vessel.

Results: interobserver agreement for DSA (weighted Kappa 0.63, CI 0.53–0.73 and CE-MRA (weighted kappa 0.60, CI 0.5–0.7) was moderate to substantial. CE-MRA depicted significantly more vascular segments than DSA (p ≤ 0.0001).

In the prediction of the distal outflow vessel duplex and CE-MRA proved to be superior to DSA.

Conclusion: because of the moderate inter-observer agreement it may be questionable to regard selective DSA as gold standard imaging procedure in preoperative pedal artery imaging. CE-MRA and duplex are very helpful in assessing the pedal artery morphology and should be used if selective DSA does not sufficiently depict the pedal vasculature.

Key Words: Pedal artery; Digital subtraction angiography; Magnetic resonance angiography; Duplex ultrasound.

Introduction

Restoration of a pulsatile blood-flow is the fundamental goal in the treatment of the critically ischaemic foot. Even in severe multilevel occlusive disease the pedal arteries often remain patent in many patients and may serve as run-off vessels.¹

Consequently, bypass grafts to the foot arteries have been established as effective limb salvage procedures.²,³ For that reason an appropriate evaluation of the pedal arteries seems to be mandatory in the case of critical limb ischaemia (CLI) due to tibial or femorotibial occlusive disease.

Traditionally, selective angiography has been considered the gold standard for the evaluation of the tibial and pedal vessels.⁴,⁵ Recently, non-invasive techniques such as magnetic resonance angiography (MRA) and duplex sonography have attracted more interest.

Examination times in non-contrast MRA techniques can be fairly long. In addition, there is a risk of false-negative findings and overestimation of stenoses resulting mainly from turbulent or retrograde blood flow and signal loss from in-plane saturation.⁶ Contrast-enhanced MRA (CE-MRA) allows very short examination times and has been widely accepted for imaging of peripheral vessels.⁷

With regard to duplex ultrasound, the development of high frequency (10–13 MHz) probes has enabled the examination of smaller vessels like the pedal arteries.

The aim of this prospective study was to compare selective DSA, CE-MRA and duplex ultrasound in the preoperative depiction of potential pedal run-off vessels.

Material and Methods

Patients were eligible for the study if they met the following criteria: non-healing pedal ulcer or toe gangrene (CLI grade III category 5 according to the recommended standards for reports dealing with
lower extremity ischaemia\(^9\), non invasive testing (physical examination, segmental oscillometry, duplex ultrasound) indicating tibial or femoro-tibial occlusive disease, potential candidate for a pedal artery revascularisation. Exclusion criteria were missing informed consent and contraindications to one of the imaging techniques such as chronic renal failure or a cardiac pacemaker.

**DSA**

Selective digital subtraction angiography (DSA) was defined as angiographic imaging after injecting the contrast agent in the ipsi-lateral common femoral artery or distal to this puncture site. An antegrade puncture was used in 7 of 39 cases.

Examinations were performed using a DV 1.2 Digital Vascular Imaging Unit (Philips Medical System, Eindhoven, The Netherlands). To avoid moving artefacts, patients were positioned comfortably and the knees and heels were supported by cushions.

Non-ionic contrast medium (Iopromid [Ultravist, Schering-Vienna; Austria]) was administered by mechanical injection with a constant flow rate of 10 ml/sec. The total amount of contrast material ranged from 25 to 170 (median 80) ml. The variation in contrast medium given results from the fact that 18 of the 37 patients had bilateral aortic flush angiography prior to the selective run. Bi-planar projections of the forefoot were obtained at the discretion of the angiographer. Vasodilating drugs or hyperthermia were not applied. The duration of imaging depended on the on-line visualisation of the vessels on the screen. Filming was continued until either the pedal run-off vessel had been opacified, collateral vessels were clearly demonstrable or at least a soft tissue blush had appeared.

**CE-MRA**

CE-MR angiography was performed on a standard 1.0 Tesla imager (Siemens Harmony, Siemens Medical Systems, Erlangen; Germany) equipped with high performance gradients (\(\geq 20 \text{mT/m}, \text{min. rise time} \leq 400 \mu\text{s}\)). A quadrature head or knee coil was placed to include the entire foot to be examined. A flash 3D sequence (TR 6.2/TE 2.24) was performed with four consecutive sagittal slabs (slab thickness 90 mm). Acquisition time was 27 seconds per slab. Twenty ml of gadolinium were administered with a flow rate of 2.5 ml/sec starting with the first set of imaging. Data were processed using the MIP algorithm and a three dimensional image of the pedal arteries was created. Matrix size was 126:526, Voxel size was 1.52 \(\times\) 0.76 \(\times\) 1.13 mm.

**Image analysis of DSA and CE-MRA studies**

Two radiologists independently reviewed – in random order – both the DSA and CE-MRA images without knowledge of the result of the concurrent imaging technique. Usual delay between presentation of CE-MRA images and DSA images was approximately two weeks. In case of disagreement, a final consensus interpretation of the images was performed.

The pedal vessels were divided into four segments (dorsal pedal artery proximal, dorsal pedal artery distal, retromalleolar artery and plantar pedal artery) and their morphology was scored on a scale from 0 to III (0 \(\hat{=}\) vessel not visualised, I \(\hat{=}\) vessel faintly visualised, II \(\hat{=}\) stenosis > 50\%, III \(\hat{=}\) vessel without relevant stenosis).

**Duplex**

The examinations were carried out only once (because of limited facilities) by an experienced angiologist who was blind to both the DSA and MRA results. The above-mentioned four pedal vascular segments were examined, using a highly sensitive 13 MHz ultrasound probe (GE LOGIQ 700, GE Medical Systems, Solingen, Germany). The colour flow mode was used to identify the vessel and to place the sample volume. To avoid difficulties in grading a stenotic lesion based on peak systolic velocity (PSV) ratios in case of severe in-flow disease, the minimal and maximal diameter in the specific segment were recorded. According to these findings vessels were scored 0–III (score 0 \(\hat{=}\) vessel not visualised, score I \(\hat{=}\) diameter < 1 mm, score II \(\hat{=}\) diameter 1–1.4 mm, score III \(\hat{=}\) diameter > 1.5 mm). In addition the grade of calcification was scored on a scale of 1–3 (score 1 \(\hat{=}\) vessel without relevant calcification, score 2 \(\hat{=}\) non-circumferential calcified plaques, score 3 \(\hat{=}\) circumferential calcification).

Based on their findings (score > I) the radiologists and the angiologist identified the pedal run-off vessel best suitable for a bypass procedure.

**Data analysis**

Data analysis comprised the calculation of inter-observer agreement (DSA and CE-MRA studies) and
agreement between the imaging techniques (duplex, DSA and CE-MRA consensus reading) by means of weighted kappa statistics. In order to compute the 95% confidence interval, the bootstrap method was applied with a bootstrap sample size of B = 1000, whereby the BCa (bias-corrected-accelerated) algorithm was used. Symmetric disagreement weights \(v_{ij}\) (with i and j ranging from 1 to 4 for four categories) were defined in the following way: \(v_{ii} = 0\), for all i, \(v_{12} = 3\), \(v_{13} = 7\), \(v_{14} = 10\), \(v_{23} = 7\), \(v_{24} = 7\) and \(v_{34} = 3\). Data were interpreted according to Landis and Koch: below 0.0: poor, 0.00–0.20: slight, 0.21–0.41: fair, 0.42–0.60: moderate, 0.61–0.80: substantial, 0.81–1.00: almost perfect. Since the estimations are done on the same individuals, the Bonferroni correction was applied.

A log-linear model was applied to compare the distributions of pedal vessels scoring (scored with 0, I, II, III) for (a) DSA vs CE-MRA, (b) DSA vs duplex and (c) CE-MRA vs duplex. The Z-test was used to compare the probabilities that a pedal artery segment was scored as 0 or I for these three comparisons. The significance level of \(\alpha = 0.05\) was adjusted by the Bonferroni method. In patients who underwent pedal artery surgery, early (30 days) patency of a bypass to a specific pedal artery (assessed by means of pulse palpation and additional duplex) served as a validation of the artery’s suitability for pedal reconstruction. Intra-operatively, a vessel was rated suitable for surgery if it demonstrated a diameter of at least 1 mm. Calcification was managed by fracture technique and did not exclude the patient from a pedal bypass procedure. In uncertain cases additional on-table angiography was used to assess the run-off. In case of probatorial dissection or early graft failure (30 days), the pedal vessel was rated as not suitable for surgery.

For the comparisons of conditional probabilities in those patients who underwent pedal artery surgery (DSA vs CE-MRA, DSA vs duplex, CE-MRA vs duplex), simultaneous 95% confidence intervals were used (Pearson–Clopper intervals). All computations were done with STATISTICA 5.5 and MATHEMATICA 3.0.1.

### Results

During a 14-month-period 37 patients, 29 men and 8 women (age ranged 47–89 years median 70 years) were included in the study. Two men had both legs treated, thus 39 extremities have been examined. Surgical treatment consisted of pedal artery grafting in 26 cases, another two patients had surgical exploration of a pedal artery that proved to be unsuitable for a bypass procedure. Two patients had a femoro-crural bypass and another two had PTA of the popliteal artery. Seven patients were treated conservatively.

Regarding the entire 156 examined pedal artery segments, inter-observer agreement was moderate to substantial for DSA as well as CE-MRA. Kappa value was 0.63 (CI 0.53–0.73) in the DSA studies and 0.6 (CI 0.5–0.7) in the CE MRA studies, respectively (Tables 1, 2). Regarding scoring of the pedal artery segments (DSA and CE-MRA consensus reading and duplex ultrasound – Table 3), the distributions proved to be statistically different for DSA vs CE-MRA (\(p \leq 0.000007\) and DSA vs duplex (\(p \leq 0.00004\). No significant difference could be detected for the

### Table 1. Inter-observer agreement for DSA studies of 38 patients (156 vascular segments). Cross table comparing results of reader one to results of reader two.

<table>
<thead>
<tr>
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### Table 2. Interobserver agreement for CE-MRA studies of 38 patients (156 vascular segments). Cross table comparing results of reader one to results of reader two.

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<td>61</td>
<td>156</td>
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</table>

### Table 3. Comparative between results of DSA and CE-MRA consensus reading and results of duplex scanning.

<table>
<thead>
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<th>DSA</th>
<th>CE-MRA</th>
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</tr>
<tr>
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<td>34</td>
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comparision of CE-MRA vs Duplex \((p \geq 0.85)\). The probability that a vessel was not or was faintly visualised was larger for DSA than for CE-MRA \((p \geq 0.0001)\), larger for DSA than for duplex \((p \geq 0.0008)\), but there was no statistical significant difference between CE-MRA and duplex \((p \geq 0.46)\). Table 4 demonstrates the grade of calcification in the examined pedal arteries segments as determined by duplex ultrasound. Calcification can not be assessed by means of DSA and CE-MRA. However, this additional information determined the selection of the distal site of anastomosis.

Duplex ultrasound and CE-MRA proved to be superior to DSA (duplex kappa \(-0.82\) (CI 0.5–1), CE-MRA kappa 0.82 (CI 0.46–1), DSA kappa 0.6 (CI 0.28–0.83)) in predicting the distal site of anastomosis (pedal artery segment proposed by the three different methods vs definitive site of anastomosis).

Table 4. Grade of calcification in the different pedal arteries segments, score 1–3.

<table>
<thead>
<tr>
<th>Score 1 not calcified</th>
<th>Score 2 not circumferential calcification</th>
<th>Score 3 circumferential calcification</th>
</tr>
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<tbody>
<tr>
<td>Dorsal pedal artery prox.</td>
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</tr>
<tr>
<td>Dorsal pedal artery dist.</td>
<td>7</td>
<td>24</td>
</tr>
<tr>
<td>Retromalleolar artery</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>Plantar artery</td>
<td>4</td>
<td>20</td>
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</table>

Table 5 compares the results of the three imaging techniques in the 28 patients that underwent pedal artery surgery. Comparisons of the confidence intervals of the conditional probabilities showed no evidence for a statistical significant difference among these three imaging techniques.

### Discussion

Planning of pedal artery reconstructions requires sufficient visualisation of the pedal vasculature to exclude relevant stenoses distal to the planned site of anastomosis. The vessel diameter and grade of calcification are additional relevant factors.

This prospective study was planned to compare CE-MRA and duplex ultrasound to selective DSA which we regarded as gold standard imaging procedure in the depiction of pedal run-off vessels. However, inter-observer agreement for grading vascular disease at the level of the pedal arteries was moderate to substantial for selective DSA and CE-MRA studies, respectively. This observation confirms the report by Koelemay et al.\(^{12}\) In their study, four observers reviewed 48 selective digital angiograms with only moderate over-all agreement for grading the pedal arteries (kappa 0.39).

As it may be questionable to regard selective DSA as gold standard of pedal artery imaging in the setting of CLI we compared the results of the different imaging techniques to intra-operative findings and
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early postoperative results. However, statistically there was no difference between these three methods.

CE-MRA depicted significantly more vascular segments than selective DSA. As described by other authors this is mainly a consequence of superior contrast-enhanced resolution.

Unlike DSA, timing of contrast agent can be difficult in CE-MRA studies and superimposition of venous signals may lead to misinterpretation. Although the scanning time in our protocol was short (27 s), venous superimposition was considered the main cause for false-positive findings.

The basic limitation of the MRA technique used in this study is that only one foot is covered. A complete evaluation of the vessels from the abdominal aorta to the tibial vessels would require a second examination. Several reports describe different approaches to complete imaging of one or both extremities by CE-MRA including bolus-chase and moving table technique. Whether these techniques will provide an adequate depiction of the foot vessels is currently unresolved.

Although the recipient pedal vessel’s diameter is a crucial information for surgical planning, this information is usually not obtained from DSA or MRA images. Current MR machines provide an in-plane resolution of up to 0.8 mm (voxel size 0.74 mm³). The in-plane resolution on DSA studies can be up to 0.3 mm – depending on the matrix and the image intensifier used. However, the accuracy of determining a small artery’s diameter on DSA studies is limited by the parallactic error.

Highly sensitive duplex probes provide high axial resolution of up to 0.1 mm and duplex scanning may therefore serve best to evaluate a pedal artery’s diameter. In addition, duplex ultrasound is the only method from which direct information about the grade of vessel calcification can be obtained. On the other hand severe calcification of the artery may lead to signal extinction and was the main cause for false-negative duplex findings in our study.

Comparing the three imaging techniques by one scoring system may be problematic, as the type of information provided by the different methods is not the same. Whereas DSA and CE-MRA findings depend on local contrast agent concentration, duplex findings depend on the anatomy, the grade of calcification and the examiner’s experience.

As the duplex examinations were carried out by only one angiologist we are not able to report on inter-observer variation. Recently, a moderate interobserver agreement for pedal artery evaluation based on PSV ratios was reported. In this study the pedal arteries were assessed using a 7.5 MHz probe. Because of superior in-plane resolution, we speculate that inter-observer agreement could be improved by using a highly sensitive 13 MHz probe.

Angiography in this study was performed without use of vasodilating drugs on the basis that there is no vasodilating potential in severely calcified small vessels is critically ischaemic feet.

Antegrade angiography provides a detailed map of the entire extremity with superior spatial resolution (compared to CE-MRA). Bi-dimensional selective DSA is still our preferred technique for preoperative pedal artery evaluation. Occlusion of a named pedal artery is only presumed if collateral vessels along its course are clearly visualised. In case DSA does not sufficiently visualise the foot vessels, non-invasive CE-MRA with superior contrast resolution is a worthwhile supplementary tool. MRA with additional slices offers the possibility to gain information about potential sites of infection in the plantar region, which may be difficult to detect by means of physical examination.

Duplex remains the preferred method of evaluating a pedal artery’s diameter and morphology because of its superior spatial resolution.

References


