Imaging in diabetic ischemic foot

Dayananda Lingegowda, Srikant Moorthy, K. P. Sreekumar, Rajesh R. Kannan

Department of Radiology, Narayana Hrudayalaya, No. 258/A, Bommasandra Industrial Area, Anekal Taluk, Bangalore - 560 099, India

Introduction

Diabetes is an “iceberg” disease. There are an estimated 143 million diabetics worldwide, and the disease prevalence is estimated to be 4%. Diabetic microangiopathy largely affects the infrapopliteal vessels. Extensive infrapopliteal calcification and occlusions, without the presence of collaterals, are common in diabetic patients. The strengths and weaknesses of the various imaging modalities are discussed in this article with respect to diabetic patients.

Duplex sonography of lower limb extremity arteries

Hemodynamically significant stenosis (>50% stenosis) is characterized by a peak systolic velocity (PSV) ratio >2 (PSV ratio = PSV at the site of the lesion/PSV proximal to the lesion) [Figure 2A–D]. The absence of signal from show the characteristic triphasic velocity waveform [Figure 1A]. The initial high-velocity forward flow phase that results from cardiac systole is followed by a brief reverse flow phase in early diastole and a final low-velocity forward flow phase later in diastole. The reverse flow component reflects the elasticity of the arterial bed and the relatively high distal peripheral vascular resistance. Distal vasoconstriction (commonly due to a cold environment) can cause a biphasic pattern without the diastolic forward flow [Figure 1B]. Loss of elasticity due to calcification leads to a monophasic signal, with the absence of early diastolic reversal [Figure 1C]. Arterial lesions disrupt the laminar flow and produce a widened frequency band (filling of spectrum called “spectral broadening”) or turbulent flow [Figure 1C and D].

Figure 1: Spectral waveform: (A) triphasic waveform; (B) biphasic waveform; (C) spectral broadening; (D) turbulent flow; (E) waveforms are damped and monophasic, with flow only in systole; (F) low-resistance continuous flow is due to proximal obstruction and vasodilatation induced by ischemia; (G) prolonged early systolic acceleration and diminished amplitude are referred to as tardus-parvus; (H) arteriovenous fistula—spectral waveform from the artery showing high-amplitude, low-resistance, continuous flow.
arteries suggests occlusion [Figure 2E and F]. Vessels
distal to a significant stenosis may show low-amplitude
tsystolic signals (monophasic) or continuous antegrade
flow or a tardus-parvus pattern [Figure 1E–G]. False
positive for occlusion may result from vessel wall
calcification, which is common in diabetics [Figure 6;
Table I].

Evaluation of infrapopliteal vessels is technically
demanding due to the occurrence of multiple tandem
lesions.\[9\] The extensive calcifications commonly seen
in diabetic patients cause signal loss [Figure 3C]. This
problem is partially overcome by Doppler sampling
in between the calcifications by using power Doppler,
changing the angle of insonation, increasing gain, and
using low-flow settings [Figure 2A and B]. Proximal
lesions can be detected by the poststenotic waveform
[Figure 1E–G]. In a few cases, a vessel that is apparently
occluded on angiography may be found to be patent
on ultrasound Doppler examination\[10\] [Figure 4C–E].
In this subset of patients, color duplex ultrasound
appears to perform better than angiography. These
vessels invariably show a velocity of <15 cm/s. Failure
of a patent vessel to opacify on angiography may be
due to failure to acquire sufficiently delayed images or
because of dilution of contrast due to proximal injection
in the aorta (nonselective injection). Patency of the distal
vasculature is crucial for conducting a bypass procedure.
Vascular surgeons may perform a bypass procedure
on an angiographically nonvisualized vessel, if flow is
detectable on Doppler.\[11\]

Conventional percutaneous catheter angiography\[3\]

The use of the current gold standard, catheter
angiography, purely for diagnostic purpose is soon
likely to become a thing of the past as newer diagnostic
modalities gain ground. Diagnostic angiographies are
now recommended for evaluation of only those patients
who have peripheral vascular disease and in whom
revascularization is contemplated. This is because
angiogram is an invasive procedure and, potentially,
can result in complications such as hematoma,
pseudoaneurysm formation, wound infection, etc.
Other major complications such as plaque embolization,
and contrast nephrotoxicity are added risks in diabetic
patients. The high incidence of contrast-induced

---

Some observed flow patterns

<table>
<thead>
<tr>
<th>Pathologic correlate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occlusion likely proximal to the sampling, with distal vasodilatation</td>
</tr>
<tr>
<td>Arterial occlusion proximal to the sampling site</td>
</tr>
<tr>
<td>Calcification</td>
</tr>
<tr>
<td>Poor penetration and insufficient sensitivity of the Doppler device</td>
</tr>
<tr>
<td>Subtotal occlusion</td>
</tr>
<tr>
<td>Indicates likelihood of more distal occlusion</td>
</tr>
<tr>
<td>Arteriovenous fistula</td>
</tr>
</tbody>
</table>

---

Figure 2: (A–D) Right superficial femoral artery angiogram (A) showing tight stenosis. The waveform taken at the stenotic site shows PSV ratio >2 (C). The proximal (B) and distal wave forms (D) are damped and monophasic. Note that increased velocity at the stenosis is independent of proximal velocity. (E, F): Angiogram showing left popliteal artery occlusion (E). Color Doppler images from the same patient shows flow in the popliteal artery (F).
nephropathy in the diabetic population is because of the underlying renal insufficiency. Overnight hydration and minimization of the volume of contrast used are essential when an angiogram is performed on diabetics. When the plasma creatinine is more than 1.5 mg/dL, the patient should be premedicated with acetylcysteine; also, the use of a low-osmolar or iso-osmolar contrast agent (e.g., visipaque) may be beneficial for reducing the risk of contrast nephropathy. Contrast injection below the renal artery during the aortogram also decreases contrast toxicity since arterial injection is more likely to cause nephrotoxicity than intravenous injection.

In spite of being the reference standard, false-negative findings are known to occur in catheter angiography due to use of suboptimal techniques. Atherosclerotic lesions are often eccentric and the angiographic appearance may be misleading on a single view, especially in aortoiliac segments. Selective and superselective studies are necessary to avoid false-positive diagnosis of occlusion. Since the angiogram is a luminogram, extraluminal pathology can be easily overlooked. The false impression of a stenosis can be produced by extrinsic impression from underlying bone in plantar flexion (the “balletina defect”); this lesion disappears with a neutral position of the foot.

**CT angiography of the arterial system**

When vascular access is complicated by extensive occlusions, multidetector computed tomography (MDCT) angiogram is an alternative to catheter angiogram. Extraluminal pathologies such as aneurysm are evaluated better with MDCT. Anatomical variants are easily demonstrated using MDCT angiography. Because of higher contrast resolution, runoff vessel demonstration is better on MDCT angiography as compared to catheter angiography. Eccentric stenosis can be evaluated accurately with the use of cross-sectional MDCT angiography.

Extensive calcification in small-caliber tibio-peroneal vessels can cause difficulty in interpretation. Calcification in larger vessels can be overcome to some extent by evaluation of axial images. Early venous return in the affected limb is a problem unique to moving-table MRA. Early venous contamination in the affected limb results in nondiagnostic infrapopliteal studies in a significant number of cases. Therapeutic decisions on extensively calcified infrapopliteal vessels are difficult to make based on MDCT. Since diabetes and age above 80 years are independent predictors of infrapopliteal calcification, MDCT is not suitable in this subset of patients.

**Contrast-enhanced MR angiography**

Contrast-enhanced moving-table MR angiography has largely replaced noncontrast techniques. Early venous return in the affected limb is a problem unique to moving-table MRA. Early venous contamination in the affected limb results in nondiagnostic infrapopliteal studies in a significant number of cases.

---

Figure 4: (A, B) Left knee arteriogram shows apparently normal popliteal artery (A). Color Doppler study of the same patient shows a popliteal artery aneurysm with a concentric thrombus (B). (C–E) Apparently, occluded anterior and posterior tibial arteries on angiogram (C). Selective angiogram was not possible due to a long-segment proximal occlusion (not shown). Doppler shows patent anterior and posterior tibial arteries (D and E).

Figure 5: Web-like infrarenal aortic stenosis is demonstrated on MRA (A). The lesion is not clearly visible on angiogram (B). Spectral wave forms from the common femoral artery before stenting shows ischemic flow. Follow-up Doppler from the same site after aortic stenting shows normal triphasic flow, confirming the presence of a significant pressure gradient across the stenosis.
venous return in the affected limb can be explained by the combination of faster arterial flow and the presence of the arteriovenous fistula. Faster arterial flow in the affected limb is due to vasodilatation caused by ischemia. Microfistule formation is due to cellulitis, ulceration, and infection. A brief scan time may help catch the leg in the arterial phase. Reducing the field of view in the phase-encoding direction (coronal) just enough to cover the arteries, reduces the scan time without reducing the resolution. Since contrast-enhanced MRA is a subtraction technique, the final image will be free from wrap-around artifact caused by excluded anatomy. Increasing the slice thickness from 4 to 8 mm, or even to 10 mm, can dramatically shorten the acquisition time by 5–6 s at each station. However, the disadvantage of this approach is that there is a decrease in the spatial resolution and zigzag appearances in the rotary maximum intensity projection (MIP) reconstruction.

Figure 6: (A, B) Infrapopliteal angiogram showing posterior tibial artery spasm (“string of pearls” appearance in A) which was relieved after vasodilators (B). (C, D) Multiplanar reconstruction (MPR) images of MDCT angiogram, showing extensively calcified posterior tibial artery (C). The lesion could not be commented upon due to extensive calcification. Catheter angiogram showing two tandem long-segment occlusions (D) with poor runoff.

Figure 7: Patient with acute-on-chronic limb ischemia. Catheter angiogram was deferred in this case because of absent peripheral pulses. MDCT angiogram—axial (A) and coronal (B) images—showing an incidentally detected abdominal aortic aneurysm. Volume rendered technique (VRT) image (C) showing occluded right iliac and left common femoral arteries.

Figure 8: Axial section of MDCT angiogram showing the course of a partially thrombosed persistent sciatic artery. A thrombosed sciatic artery aneurysm is also identified (arrow in D). The whole course is demonstrated in a single image (G). VRT image showing only patent vessels (H). Catheter angiogram in this case may be misleading, since it will show only the patent vessels (H). CIA = common iliac artery; EIA = internal iliac artery; SA = sciatic artery; PA = popliteal artery.

Figure 9: Contrast-enhanced MRA images of aortoliac (A) and femoropopliteal segments (B). Infrapopliteal images on the symptomatic side (left) is of nondiagnostic quality due to venous contamination (C).
also helps to reduce venous contamination.\textsuperscript{[16,17]}

If the venous contamination persists in spite of all these techniques, the problem can be overcome by acquiring the tibio-peroneal stations as a separate study. Time-resolved imaging of contrast kinetics (TRICKS) sequences for the infrapopliteal region gives high temporal resolution without significant loss in spatial resolution.\textsuperscript{[16,17]} This application not only allows one to appreciate the flow dynamics in the diabetic foot, but also allows visualization of pure arterial phase [Figure 10E–H]. Alternatively, hybrid peripheral 3D contrast enhanced MR angiography can be used to obtain high-resolution images with out venous contamination.

The availability of safe MR contrast agents makes MRA to be preferred over conventional angiography and MDCT angiography in diabetic patients at risk for contrast-induced nephropathy.\textsuperscript{[18]} There is minimal interference from calcified vessels/bone with MRA compared to MDCT angiogram. Runoff demonstration in the MR angiogram is comparable with that of MDCT/USG.\textsuperscript{[16,17]}

Pseudostenosis on MRA can be due to susceptibility artifact from calcium because of the presence of calcium [Figure 11A and B] and high gadolinium concentration.\textsuperscript{[13]} Too rapid injection may result in ringing artifact, which may mimic dissection [Figure 11C]. Overestimation of lower grade stenosis as higher-grade stenosis may occur with MRA due to blooming artifact, and this may affect therapeutic decisions [Figure 12]. Overestimation may lead to the patient being subjected to unnecessary revascularization procedures.\textsuperscript{[15,19]}

**Conclusion**

Imaging modalities should be chosen carefully in the diabetic patient so that the maximum relevant information is obtained with minimum risk and inconvenience to the patient. When the diabetic patient presents with a nonhealing ulcer, the investigation of first choice should be duplex ultrasound. Ultrasound is not only safe and noninvasive, it also serves to guide further patient management. Since the ultrasound has high negative predictive value, no further investigation is required when duplex findings are normal. In a subset of patient in whom intervention is planned, catheter angiogram is the best choice; if the patient has diabetic nephropathy, MR angiogram is an alternative. MDCT
angiogram is not a preferred modality in the diabetic patient because there is likely to be extensive calcification in infrapopliteal vessels.

References


Source of Support: Nil, Conflict of Interest: None declared