REVIEW ARTICLE

Imaging in diabetic ischemic foot

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Diabetic microangiopathy largely affects the infrapopliteal vessels. Extensive infrapopliteal calcification and occlusions, without the presence of collaterals, are common in diabetic patients. 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. 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. Multidetector computed tomography angiogram is not a preferred modality in the diabetic patient because there is likely to be extensive calcification in infrapopliteal vessels.

KEY WORDS: Angiogram, diabetic foot, Doppler

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Introduction

Diabetes is an "iceberg" disease.[1] There are an estimated 143 million diabetics worldwide, and the disease prevalence is estimated to be 4%. Diabetic microangiopathy largely affects the infrapopliteal vessels.[2] Extensive infrapopliteal calcification and occlusions, without the presence of collaterals, are common in diabetic patients.[3,4] 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[5-8]

Duplex scan of normal lower extremity arteries 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].

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

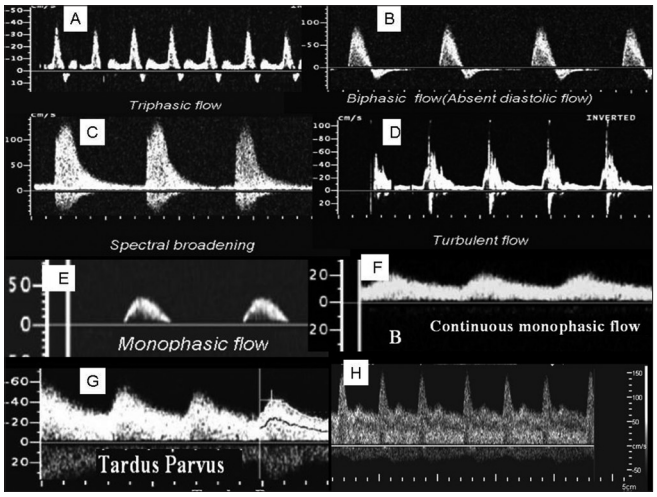

Figure 1: Spectral waveform: (A) triphasic waveform; (B) biphasic waveform; (C) spectral broadening; (D) turbulent flow; (E) waveforms are damped and monophasic, with flow only in systole; (F) low-resistance continuous flow is due to proximal obstruction and vasodilatation induced by ischemia; (G) prolonged 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.

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arteries suggests occlusion [Figure 2E and F]. Vessels distal to a significant stenosis may show low-amplitude systolic 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 1].

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]

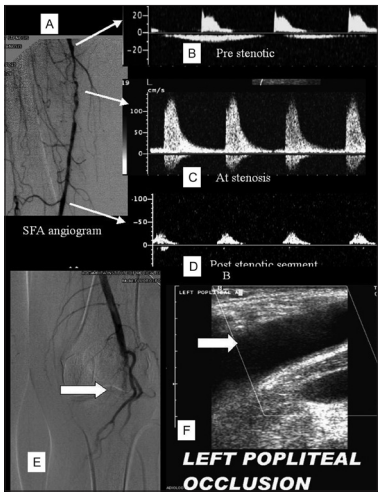

Figure 2: (A–D) Right superficial femoral artery angiogram (A) showing tight stenosis. The waveform taken at the stenotic site shows PSV ratio >2 (C). The proximal (B) and distal wave forms (D) are damped and monophasic. Note that increased velocity at the stenosis is independent of proximal velocity. (E, F): Angiogram showing left popliteal artery occlusion (E). Color Doppler images from the same patient shows flow in the popliteal artery (F).

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

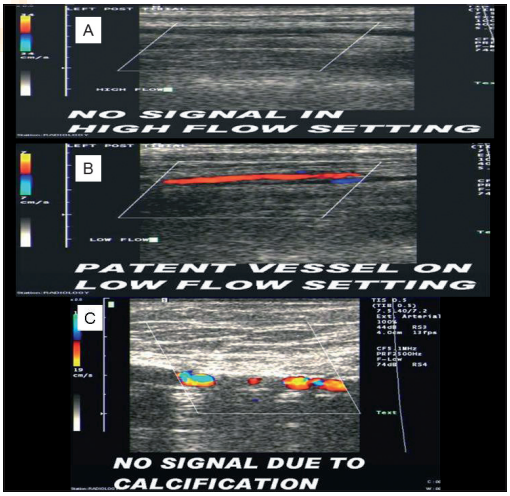

Figure 3: False-positive occlusion due to improper technique. Apparently, occluded vessel on high-flow setting (A) is patent in low-flow setting (B). (C) Color Doppler images showing loss of signal due to calcification, mimicking occlusion.

Some observed flow patterns	Pathologic correlate
Low-amplitude and persistent antegrade flow during systole and diastole [Figure 1F]	Occlusion likely proximal to the sampling, with distal vasodilatation
Tardus-parvus pattern [Figure 1G]	Arterial occlusion proximal to the sampling site
Absent flow signals (false positive for occlusion, false negative for stenosis) [Figure 3A–C]	Calcification
Large collateral branches seen during color flow imaging	Poor penetration and insufficient sensitivity of the Doppler device
Low-resistance waveform with elevated velocity in artery and an arterial pulse in the vein [Figure 1H]	Subtotal occlusion
	Indicates likelihood of more distal occlusion
	Arteriovenous fistula

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.[12] 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.[12]

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[3] [Figure 5]. Measuring the pressure gradient across the lesion is not always practical or anatomically possible. Selective and superselective studies are necessary to avoid false-positive diagnosis of occlusion [Figure 4C–E]. Since the angiogram is a luminogram, extraluminal pathology can be easily overlooked [Figure 4A and B]. The false impression of a stenosis can be produced by extrinsic impression from underlying bone in plantar flexion (the "ballerina defect"); this lesion disappears with a neutral position of the foot.[3] Transient arterial spasm in response to stimulation by catheter or contrast appears as a "string of pearls" or as "standing waves" [Figure 6A and B].

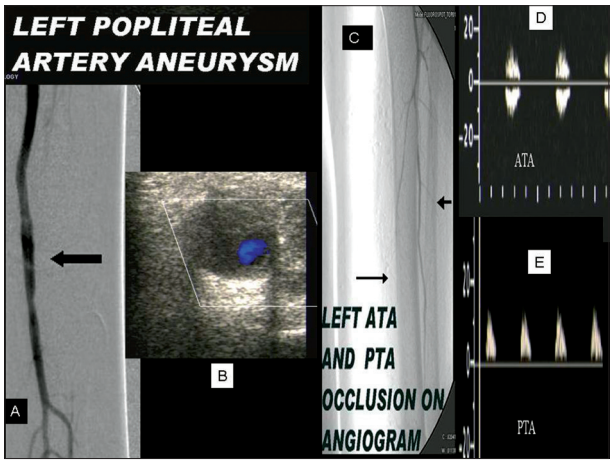

Figure 4: (A, B) Left knee arteriogram shows apparently normal popliteal artery (A). Color Doppler study of the same patient shows a popliteal artery aneurysm with a concentric thrombus (B). (C–E) Apparently, occluded anterior and posterior tibial arteries on angiogram (C). Selective angiogram was not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

CT angiography of the arterial system[13,14]

When vascular access is complicated by extensive occlusions, multidetector computed tomography (MDCT) angiogram is an alternative to catheter angiogram [Figure 7]. Extraluminal pathologies such as aneurysm are evaluated better with MDCT [Figure 7]. Anatomical variants are easily demonstrated using MDCT angiography [Figure 8]. 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. It is difficult to visualize the lumen through the blooming caused by calcification in a small-caliber vessel, and an occluded vessel may appear patent [Figure 6C and D]. 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.[14]

Contrast-enhanced MR angiography

Contrast-enhanced moving-table MR angiography has largely replaced noncontrast techniques.[15] Early venous return in the affected limb is a problem unique to moving-table MRA[16,17] [Figure 9]. Early venous contamination in the affected limb results in nondiagnostic infrapopliteal studies in a significant number of cases [Figure 9]. Early

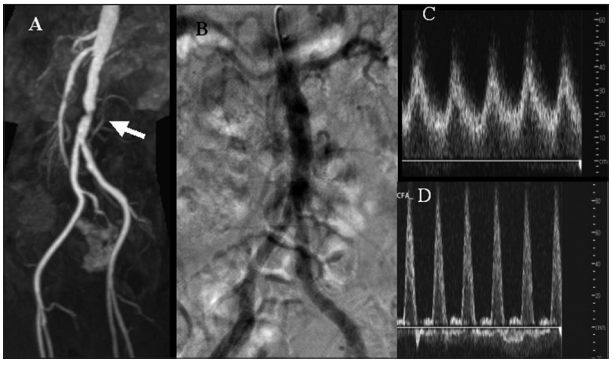

Figure 5: Web-like infrarenal aortic stenosis is demonstrated on MRA (A). The lesion is not clearly visible on angiogram (B). Spectral wave forms from the common femoral artery before stenting shows ischemic flow. Follow-up Doppler from the same site after aortic stenting shows normal triphasic flow, 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.[16,17] 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 [Figure 10A–C]. 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. Venous compression over the thigh

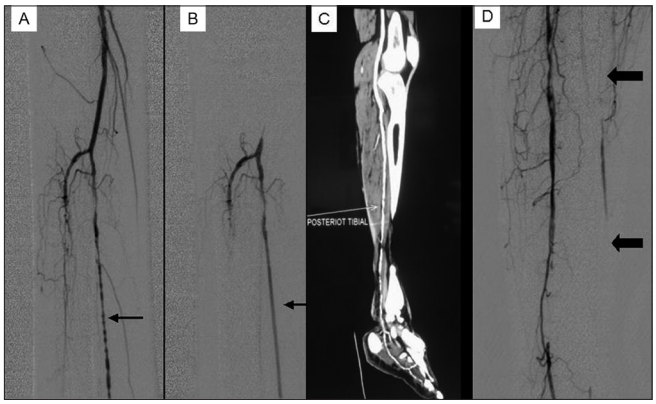

Figure 6: (A, B) Infrapopliteal angiogram showing posterior tibial artery spasm ("string of pearls" appearance in A) which was relieved after vasodilators (B). (C, D) Multiplanar reconstruction (MPR) images of MDCT angiogram, showing extensively calcified posterior tibial artery (C). The lesion could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

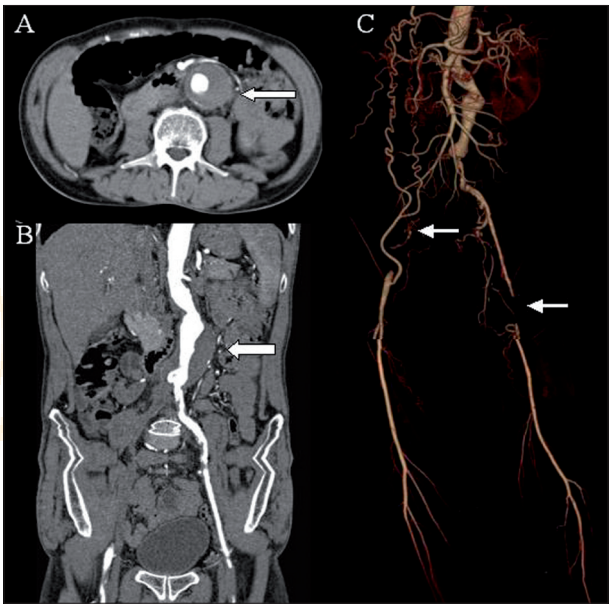

Figure 7: Patient with acute-on-chronic limb ischemia. Catheter angiogram was deferred in this case because of absent peripheral pulses. MDCT angiogram—axial (A) and coronal (B) images—showing an incidentally detected abdominal aortic aneurysm. Volume rendered technique (VRT) image (C) showing occluded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

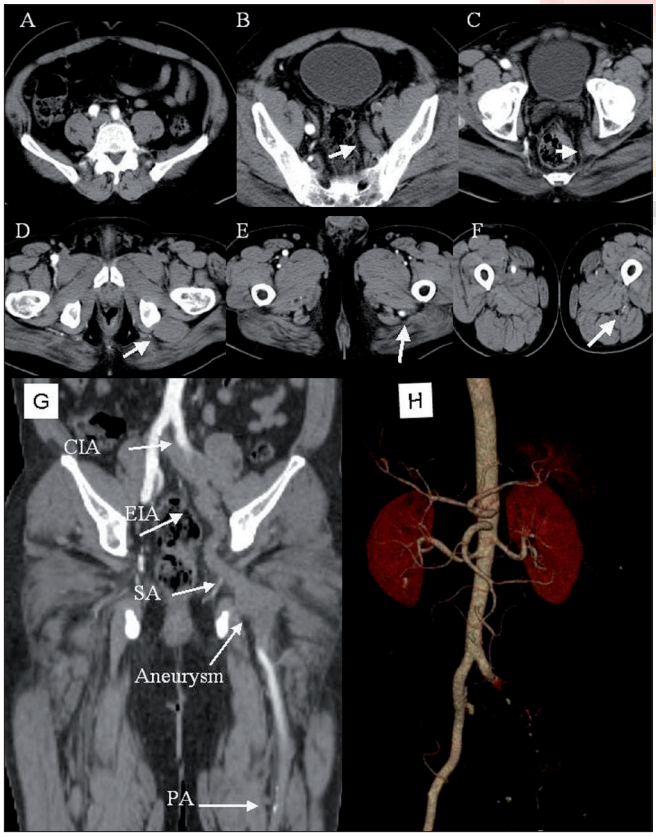

Figure 8: Axial section of MDCT angiogram showing the course of a partially thrombosed persistent sciatic artery. A thrombosed sciatic artery aneurysm is also identified (arrow in D). The whole course is demonstrated in a single image (G). VRT image showing only patent vessels (H). Catheter angiogram 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.

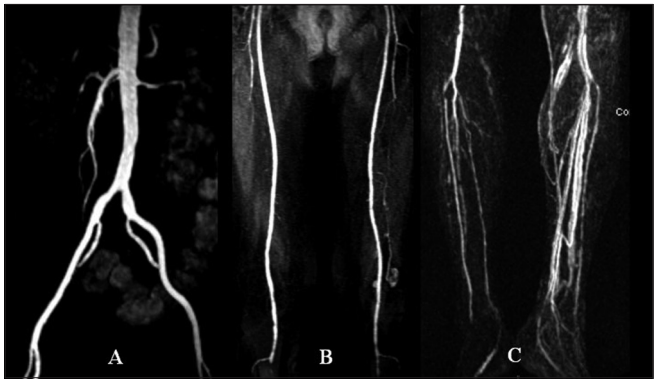

Figure 9: Contrast-enhanced MRA images of aortoliac (A) and femoropopliteal segments (B). Infrapopliteal images on the symptomatic side (left) is of nondiagnostic quality due to venous contamination (C).

also helps to reduce venous contamination.[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.[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.[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.[9,17]

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.[15] 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 revacularization procedures.[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

Figure 10: (A–C) Wrap-around artifact in precontrast mask image (A) and postcontrast source image (B). Final images are free from the wrap-around artifact due to subtraction (C). (D–H) Contrast-enhanced TRICKS acquisition images of infrapopliteal segments showing asymmetric passage of blood. Right leg shows faster arterial flow and early venous return as compared to the left side (asymptomatic limb). This patient exemplifies why temporal resolution is so important.

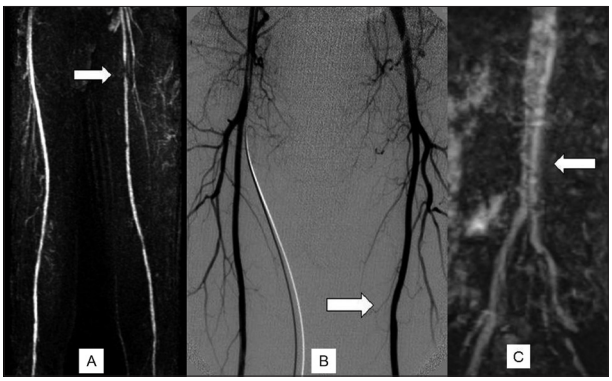

Figure 11: (A, B) Contrast-enhanced MRA showing left superficial femoral artery stenosis (A). No lesion is detected on catheter angiogram (B). Pseudostenosis on MRA is assumed to be due to blooming artifact because of presence of calcium. (C) Coronal MIP images from abdominal contrast-enhanced MRA shows ringing artifact, simulating dissection. Dramatic alteration in concentration of contrast material at the time of imaging is the cause of this artifact. It is also called "Maki" artifact.

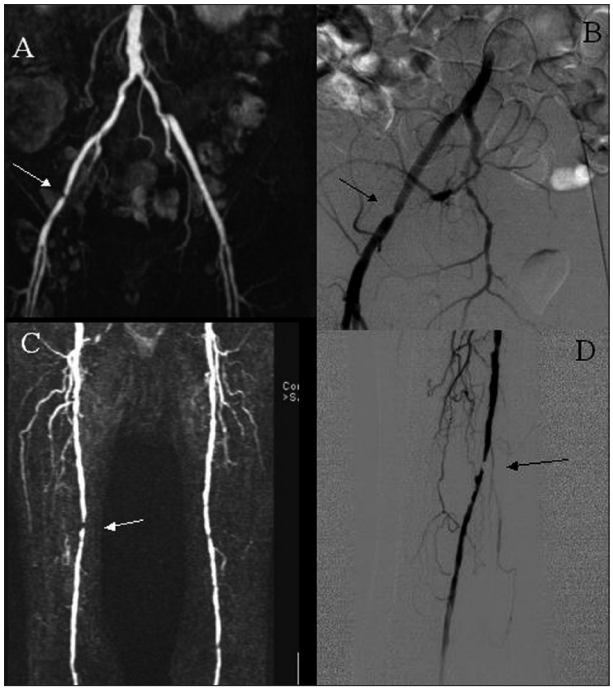

Figure 12: Overestimation of a lesion on MRA. Moderate-grade right iliac stenosis on MRA (A). Only minimal eccentric plaque is observed on catheter angiogram (B). Similarly, high-grade (D) superficial femoral artery stenosis is overestimated as occlusion on MRA (C).

angiogram is not a preferred modality in the diabetic patient because there is likely to be extensive calcification in infrapopliteal vessels.

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