

**American College of Radiology
ACR Appropriateness Criteria®
Lower Extremity Arterial Revascularization-Post-Therapy Imaging**

Variant: 1 Previous infrainguinal endovascular therapy or bypass. Asymptomatic. Surveillance.

Procedure	Appropriateness Category	Relative Radiation Level
US duplex Doppler lower extremity	Usually Appropriate	○
Arteriography lower extremity	Usually Not Appropriate	⊗ ⊗
MRA lower extremity without and with IV contrast	Usually Not Appropriate	○
MRA lower extremity without IV contrast	Usually Not Appropriate	○
CTA lower extremity with IV contrast	Usually Not Appropriate	⊗ ⊗ ⊗

Variant: 2 Previous infrainguinal endovascular therapy or bypass. Claudication or CLI. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US duplex Doppler lower extremity	Usually Appropriate	○
MRA lower extremity without and with IV contrast	Usually Appropriate	○
CTA lower extremity with IV contrast	Usually Appropriate	⊗ ⊗ ⊗
Arteriography lower extremity	May Be Appropriate	⊗ ⊗
MRA lower extremity without IV contrast	May Be Appropriate	○

Variant: 3 Previous infrainguinal endovascular therapy or bypass, presenting with cold, painful extremity and diminished pulses (acute limb ischemia). Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US duplex Doppler lower extremity	Usually Appropriate	○
Arteriography lower extremity	Usually Appropriate	⊗ ⊗
CTA lower extremity with IV contrast	Usually Appropriate	⊗ ⊗ ⊗
MRA lower extremity without and with IV contrast	May Be Appropriate (Disagreement)	○
MRA lower extremity without IV contrast	May Be Appropriate	○

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Summary of Literature Review

Introduction/Background

Lower extremity peripheral arterial disease (PAD), defined as an ankle-brachial index (ABI) measurement ≤ 0.90 [1], affects >8 million people in the United States alone [2]. Approximately 9%

to 23% of patients older than age 55 are believed to suffer from the condition, of which more than 40% are asymptomatic [3]. The principal cause of PAD is atherosclerosis, and thus risk factors for PAD closely parallel those for atherosclerosis elsewhere in the body (eg, smoking, diabetes, hypertension, hyperlipidemia, family history, postmenopausal state, hyperhomocysteinemia, etc.) [4]. Patients with PAD are at an increased risk for cardiovascular death and all-cause mortality [1]. PAD may present as claudication, ischemic rest pain, nonhealing ulcers, or gangrene; without treatment, many patients will go on to require some degree of amputation ranging from loss of one or more digits to major limb loss (below-knee or above-knee amputation).

Over the past several decades, a paradigm shift away from surgical treatment and toward endovascular therapy for PAD has occurred, with many now advocating surgical treatments only after one or more failed endovascular revascularization attempts. The BASIL trial demonstrated that patients with critical limb ischemia (CLI) presenting with rest pain, ulceration, and gangrene of the leg due to infrainguinal disease had similar amputation-free survival and quality-of-life outcomes whether they were randomized to a surgery-first or angioplasty-first treatment strategy. Furthermore, first-year costs associated with bypass surgery were about one-third higher than those associated with angioplasty [5]. The long-term outcomes following surgical and endovascular therapy in the setting of CLI are the subject of the ongoing BEST-CLI trial, which has an estimated primary endpoint completion date in December 2018.

Whether endovascular or surgical revascularization is used, restenosis is a pervasive issue. As target lesion restenosis and adjacent segment disease typically precede frank occlusion and CLI, surveillance has been advocated for many years in the setting of bypass, and there is increasing evidence to support its use following angioplasty and stenting. Additionally, there has been a steady increase in the investigative tools available to the vascular specialist to diagnose and stratify lesions in the lower extremity arteries. Because of the plethora of testing options available, it can be difficult for physicians to determine the most appropriate test to obtain in the setting of recurrent symptoms after therapy.

Overview of Imaging Modalities

Noninvasive Hemodynamic Testing

Noninvasive testing (NIVT), both before and after intervention, has been used for decades as a first-line investigatory tool in the diagnosis and categorization of PAD. It is widely available and provides a large amount of information at low cost without the use of ionizing radiation [6]. NIVT can consist of one or more of the following components: the ABI, segmental pressure measurements (SPMs), pulse-volume recordings (PVRs), photoplethysmography (PPG), and transcutaneous oxygen pressure measurement (TcPO₂).

The ABI is defined as the ratio between the higher of the brachial artery pressures and the higher of the dorsalis pedis or posterior tibial artery pressures in each leg at the level of the ankle [7]. The ABI is performed after 10 minutes of rest in the supine position for the most reliable and accurate measurement [8]. An ABI between 0.9 and 1.31 is normal [9]; measurements <0.9 are suggestive of PAD, while values >1.3 indicate noncompressible vessels (frequently present in patients with longstanding diabetes mellitus and chronic renal insufficiency). The toe-brachial index (TBI) has been shown to provide a more accurate estimation of the presence of PAD in these subgroups, with a TBI ≤0.7 considered abnormal [10]. A major strength of ABI is the ability to simulate real-world conditions through the use of pre- and post-exercise determinations; a drop in ABI of 0.15

or more is suggestive of at least moderate arterial occlusive disease, even if the resting ABI is in the normal range [11]. The ABI is limited in its usefulness, as it does not allow for the localization of disease, distinction between single level and multilevel disease, or the characterization of arterial occlusive lesions.

SPMs compare systolic pressures at sequential levels in the extremities to evaluate for significant drops between one level and the next. A pressure drop of ≥ 20 mmHg between adjacent measurements suggests one or more hemodynamically significant stenoses between them [9]. SPMs allow the reader to distinguish the approximate level of disease, although the precise severity and number of lesions cannot be determined. Similar to the ABI, SPMs are limited in patients with noncompressible vessels.

PVRs provide a qualitative (rather than quantitative) measurement of limb perfusion. PVRs are created by inflating pneumoplethysmography cuffs to a specified pressure at predetermined levels on each limb. Each cuff measures the miniscule change in the volume of the limb under the cuff with each pulse, creating a tracing of volume versus time. The resultant waveforms can be compared to determine segmental disease, providing insight into the quality of arterial blood flow at each station simultaneously. PVRs are also useful in patients with noncompressible vessels, as this modality relies on limb volume change rather than the pressure required impeding flow through the vessel being interrogated.

PPG involves the detection of a transmitted infrared signal through each of the digits. The degree of transmitted signal varies depending on blood volume within the digit, blood vessel wall movement, and the orientation of red blood cells [12]. PPG is useful for detection of disease below the knee as well as disease isolated to the forefoot and digits. As such, it has been demonstrated to be a complementary test to ABI, which has limited use in these segments.

TcPO₂ measurement allows the determination of the oxygen tension within tissue. An improvement in the TcPO₂ value postintervention compared with preintervention has been validated as an excellent marker of tissue reperfusion [13]. TcPO₂ values >40 mmHg in the area surrounding the ulcer or amputation site are considered predictive of successful healing. This test is not limited by noncompressible vessels, and, in patients without pedal Doppler signals, it is one of the few NIVTs that is helpful [14]. The test is limited by its availability in the office setting, patient resistance to avoiding smoking and caffeine prior to the test, as well as the time and cost constraints associated with providing the temperature-controlled environment required to standardize the test.

US

Peripheral duplex ultrasound (DUS) imaging, which consists of grayscale 2-D imaging, color Doppler, and spectral waveform analysis, has been a mainstay of vascular imaging for decades. This technology is widely available, portable, does not require contrast agents, and can be used in the angiography suite or operating room. DUS has been validated as a screening tool [15], a first-line study for clinically suspected PAD [16], and as a tool to plan the approach for both endovascular and surgical intervention [17]. In most situations, it is complimentary to NIVT, such as the ABI [18]. US has a high sensitivity for the detection of patent tibial arteries but is less accurate in detecting complete occlusions, particularly in the peroneal artery [19]. DUS has also been used to quantify the firmness of occlusions to determine the degree of chronicity to some success [20].

More recently, DUS has become a tool in the follow-up of prior endovascular interventions. Several papers recommend DUS as the first-line study following lower-extremity angioplasty. If initial follow-up is normal, further surveillance has been shown to be essentially no better than clinical follow-up and NIVT alone. However, in patients with persistent or recurrent disease seen on the initial study, a more aggressive surveillance program every 2 to 3 months is often warranted [21]. Duplex has been validated for follow-up of prior angioplasty, stenting, and covered stenting/stent grafting [22] but is of less utility in surveillance below the knee [23]. Several papers argue toward immediate postintervention duplex as a "new baseline," often identifying lesions not identified angiographically, which may require more aggressive follow-up [24,25]. Systolic velocity ratios ≥ 2.5 correlate well with symptom recurrence [26]. When planning interventions, the anticipated intervention based on US alone was unchanged after angiogram in femoropopliteal and iliac lesions in >80% of patients, but only 59% in lesions below the knee [27]. In critical limbs, close surveillance shows significant improvement in limb salvage rates over clinical follow-up alone [28].

Unfortunately, of all the noninvasive imaging techniques, US is also the most operator dependent and time consuming [29]. The DIPAD trial, which evaluates the cost-benefit ratio of DUS compared with computed tomography angiography (CTA) and contrast-enhanced magnetic resonance angiography (CE-MRA), showed that although the initial cost of US is lower, this does not take into account the time-related expense and operator experience required to produce satisfactory imaging. Additionally, practitioner confidence in the results is often lower than with the more advanced techniques, leading to a greater number of follow-up studies prior to intervention [30].

CTA

Modern CTA has been demonstrated to be comparable to the gold standard (catheter-based angiography) for the detection of hemodynamically significant stenoses (>50%) with sensitivity, specificity, and accuracy of 99%, 98%, and 98%, respectively [31]. Refinements in CT protocols have also compared favorably to MRA with no statistically significant difference between the two modalities in the evaluation of claudication or CLI [32]. Arterial opacification is significantly improved by using high-density compact contrast boluses, which is rapidly becoming the standard of care with equivalent iodine dose to previous standard bolus technique [33].

Potential drawbacks of CTA include the exposure to ionizing radiation and the use of iodinated contrast, which presents the potential for allergic reaction or contrast-induced nephropathy, particularly in those patients who already possess some degree of renal impairment. Metallic streak artifact is often problematic in patients with postsurgical changes or implanted hardware. Additionally, in extremely obese patients, the signal-to-noise ratio becomes somewhat prohibitive. Evaluation of densely calcified vessels can be difficult with CTA because of the similar density between plaque and contrast and the blooming artifact created by the former, leading to overestimation of the degree of stenosis in many cases, as well as the inability to determine patency in stented vessels. Because of the density of calcified plaque in relation to the relatively small lumen of the tibial vessels, CTA has traditionally suffered in the infrageniculate distribution [34].

Multiple studies have now validated dual-energy CTA as a practical and effective method for subtraction of calcified plaque and soft tissues, allowing for simultaneous creation of conventional CTA data sets and angiogram-like composite images of the vasculature alone. These subtraction

images have been demonstrated to be nearly equivalent in diagnostic accuracy to those of conventional angiograms, with similar or less radiation using newer protocols [35]. This technique has been improved at some institutions by subtracting the extravascular tissues in multiple segments rather than the entire study at once [36]. Relatively recent advances in CTA technology include the use of dynamic (time-resolved) imaging of the tibial arteries [37], selective ultra-low-dose intra-arterial contrast-enhanced CTA [38], and CO₂-enhanced high-pitch CTA [39], all of which show promise in certain circumstances.

MRA

MRA has been used for many years in patients with PAD for both treatment planning and assessment of procedural success. Continued evolution of this technology and imaging protocols has improved image quality and increased the potential applications. Most MRA protocols provide both source images with excellent soft-tissue differentiation and subtracted images demonstrating the vasculature in 2-D and 3-D representations similar to those provided during conventional angiography.

In the current era, the accuracy of CTA and CE-MRA for the detection of hemodynamically significant PAD has become essentially equivalent, with an edge for CTA in the aortoiliac segment and for MRA in the infrageniculate distribution [32]. In diabetics, MRA is considered particularly helpful for runoff evaluation because of its superior ability to detect flow in small, calcified vessels, approaching the sensitivity of digital subtraction angiography (DSA) [40].

Venous contamination tends to decrease diagnostic accuracy, particularly in the runoff distribution. In the past, cuff compression had been used to increase venous pressure and therefore delay filling of the outflow, improving arterial opacification and diagnostic confidence [41]. Reliance on this technique has decreased in recent years through advances in time-resolved techniques, so called "4-D MRA." This method allows evaluation of flow into a segment of tissue over time, simulating conventional angiography and allowing readers to select the time point at which each segment is optimally opacified [42]. This technique increases sensitivity, specificity, and accuracy for PAD in all segments of the lower extremity arteries, but most importantly below the knee [43,44]. Time-resolved imaging of the whole limb has also been reported [45]. MRA provides imaging quality similar to DSA for the evaluation of lower extremity bypass conduits [46,47]. It also allows for excellent evaluation of previously angioplastied segments and has a high specificity for in-stent patency; however, sensitivity for occlusion is still poor because of blooming artifact, particularly in stainless steel stents [48]. Newer generation nitinol stents are less affected by this limitation.

There are several important limitations of MRA. Patients with most types of defibrillators, spinal cord stimulators, intracerebral shunts, cochlear implants, and other devices are excluded, as are patients affected by claustrophobia that is not overcome by sedation. Open-field 1.0T MRA has been used for claustrophobic patients, with imaging quality approaching that of DSA above the knee; however, below the knee, the technology is still quite limited [49]. It takes longer to acquire images with MRA than with CTA, and the studies themselves are considerably more expensive. However, with MRA, patients are not exposed to ionizing radiation, and the risk of nephrotoxicity from gadolinium-based contrast is considerably less than that of iodinated contrast agents.

For a time, CE-MRA was considered an alternative to CTA in patients with renal impairment; however, since the association between renal failure and nephrogenic systemic fibrosis after

gadolinium administration was discovered, it fell out of favor [50]. This led to copious research of noncontrast MRA. Time-of-flight imaging is one such method, which, with current technology, provides images with equivalent accuracy to CE-MRA for popliteal and runoff assessment, but still lags behind in the aortoiliac and femoral segments [51,52]. It is less expensive than CE-MRA, and has been proposed as a potential PAD screening test [53]. Quiescent-interval single-shot MRA and flow-spoiled fresh-blood imaging are newer techniques, which may show promise in combination with conventional time-of-flight techniques [54-56]. Quiescent-interval single-shot currently provides similar imaging quality and diagnostic accuracy to CE-MRA in runoff vessels of diabetics, suggesting that perhaps a combination of noncontrast MRA techniques may provide equivalent whole-body vascular imaging to those provided by CE-MRA [57].

Many newer techniques in MRA show excellent promise in certain circumstances. Perfusion imaging using arterial spin labeling has been used to quantify arterial flow in the thigh and calf musculature, which has been shown to have equal or greater sensitivity for PAD compared with ABI, independent of the amount of preimaging exercise time [58,59]. Arterial peak flow velocity measurements can be obtained using phase-contrast techniques, comparing well to those obtained using spectral Doppler [60,61]. The vessel wall itself can be evaluated using blood-suppression, allowing for quantification and characterization of plaque and restenosis [62]. Continuous table movement MRA is a newer method that promises similar imaging quality to conventional multi-station MRA, with 30% faster imaging acquisition [63].

Arteriography

DSA is the reference standard to which CTA and MRA are compared. DSA can localize and quantify obstructive lesions, permits physiological evaluation by the determination of pressure gradients, and allows for intervention at the time of diagnosis. In high-acuity settings, such as a thrombosed bypass graft, where immediate catheter-based intervention is likely to be indicated, direct referral to catheter angiography is a valid option. However, DSA is an invasive technique with a small but definite risk in every patient. Access-site hematoma, arterial dissection, thrombosis, and limb loss are known complications that can result from the procedure and occur in up to 2.0% of patients in this population [64]. These occur less frequently with increasing operator experience. For this document, it is assumed the procedure is performed and interpreted by an expert. Serious systemic complications are also possible, with increased risk in patients with severe widespread vascular disease, diabetes, renal insufficiency, or other contraindications to the use of iodinated contrast media. Carbon dioxide angiography may be of value in these patients. In light of the risk of nephrogenic systemic fibrosis in patients with severe renal disease, gadolinium chelates serve a very limited role as DSA contrast agents. Although DSA remains the gold standard for diagnosing PAD at the time of intervention, it generally plays no role in the surveillance of arterial segments previously treated with endovascular methods and in grafts without clinical evidence of malfunction

Discussion of Procedures by Variant

Variant 1: Previous infrainguinal endovascular therapy or bypass. Asymptomatic. Surveillance.

The most important indicator of restenosis or occlusion in the setting of previous revascularization is recurrence of symptoms. There is limited data to suggest that treatment of asymptomatic patients after endovascular therapy provides any long-term benefit [65]. As such, patients

presenting to the clinic for follow-up of previous endovascular therapy or bypass for PAD should be evaluated for symptoms of claudication and rest pain, and should be examined closely for evidence of lower extremity ulceration or gangrene. ABI should be determined at each follow-up visit in all previously treated patients with PAD [66]. PVRs can provide insight into subtle changes in arterial flow quality between segments, often preceding detectable anatomic changes on other modalities; however, they are fraught with reader subjectivity, poor patient cooperation, and baseline abnormalities in poor cardiac output [9]. A recent paper has also called into question whether they provide any benefit over ABIs and SPMs alone [67].

Variant 1: Previous infrainguinal endovascular therapy or bypass. Asymptomatic.

Surveillance.

A. Arteriography

As an invasive test, lower extremity arteriography is completely inappropriate for surveillance of asymptomatic patients. There is no evidence to support its use in this setting.

Variant 1: Previous infrainguinal endovascular therapy or bypass. Asymptomatic.

Surveillance.

B. CTA

Because of availability, the use of ionizing radiation and the risks inherent to iodinated contrast, CTA is not recommended for routine follow-up of asymptomatic patients with nonaneurysmal PAD.

Variant 1: Previous infrainguinal endovascular therapy or bypass. Asymptomatic.

Surveillance.

C. MRA

Although both CE-MRA and nonenhanced MRA have been proposed as potential screening tests for PAD, particularly in patients in whom NIVT is limited (ie, diabetics) and time constraints remain prohibitive [77], there is no convincing evidence in the literature arguing for the use of CE-MRA or nonenhanced MRA for surveillance of previously treated PAD, either with endovascular or surgical methods. False positives suggesting recurrent disease in asymptomatic patients could lead to unnecessary procedures.

Variant 1: Previous infrainguinal endovascular therapy or bypass. Asymptomatic.

Surveillance.

D. US

DUS demonstrates a high correlation between elevated PSV at sites of previous treatment and recurrence of symptoms, although this argues that symptoms alone could be used to determine recurrent disease [26]. Following endovascular therapy, DUS is indicated for an initial follow-up, but several studies have found no benefit in repeated US in the absence of an abnormality on the initial examination [21]. US surveillance of lower extremity bypass grafts (both vein grafts and synthetic) has been commonplace since the 1980s, when it was determined that a PSV within a graft of <40 to 45 cm/s was consistent with a graft at risk of failure [68]. An end-diastolic velocity ≤ 5 cm/s at the conclusion of a bypass procedure is a strong predictor of early graft occlusion [69]. Poor compliance with bypass surveillance has been demonstrated as an independent risk factor for acute graft thrombosis [22]. This is particularly true of vein grafts, which are more likely to develop a stenosis prior to occlusion than a synthetic graft, which often occludes without warning [70]. Duplex has been shown to be more useful in the evaluation of femorotibial than femoropopliteal grafts [71]. DUS speckle tracking has been used to detect early neointimal hyperplasia in vein

grafts prior to anatomically detectable stenosis [72]. However, several other authors have found no significant change in disease endpoints for vein grafts with surveillance [73,74]. One study found that primary-assisted patency was “significantly” higher in patients undergoing surveillance than those only followed clinically; however, the margin of benefit was relatively minimal [75]. Another paper suggested that >10% of patients with a detectable graft stenosis on initial imaging will occlude in the next 3 to 6 months [76].

Variant 2: Previous infrainguinal endovascular therapy or bypass. Claudication or CLI. Initial imaging.

NIVT is an ideal first test to evaluate patients presenting with symptoms of lower extremity arterial insufficiency. NIVT allows rapid delineation between vascular and neurogenic or musculoskeletal causes of lower extremity pain [78], as well as determining the likelihood of an ischemic component of ulcerations. A significant drawback of these tests is the inability to determine whether the previously treated segment or a new segment is the cause for the patient’s symptoms, although comparison between the abnormal segment on NIVT and previous imaging can provide some insight. TBI, PVR, and TcPO₂ determinations are of particular use in diabetic patients, in which the ABI and SPM are often misleading [14]. Should some degree of amputation be required, TcPO₂ measurements have been shown to help guide the highest necessary level of tissue removal by predicting the likelihood of postsurgical healing [13]. Although these tests allow determination of the likely cause of the patient’s symptoms, they are of relatively little use in procedural planning, particularly for patients where previous angiography or cross-sectional imaging is not available.

Variant 2: Previous infrainguinal endovascular therapy or bypass. Claudication or CLI. Initial imaging.

A. Arteriography

Given the similar sensitivity and specificity of MRA and CTA compared with DSA, this invasive modality is generally reserved for immediate pretreatment evaluation of PAD and is rarely used solely for diagnostic purposes. The ability to acquire pressure measurements can help determine whether a previously identified stenosis is truly hemodynamically significant, which can sometimes be difficult to determine with NIVT and DUS in the setting of multilevel disease. It is occasionally used to determine surgical targets for infrageniculate bypass in patients with densely calcified runoff vessels who are deemed to be poor endovascular candidates, although noninvasive cross-sectional imaging has essentially replaced angiography for this indication as well.

Variant 2: Previous infrainguinal endovascular therapy or bypass. Claudication or CLI. Initial imaging.

B. CTA

In the era of modern CTA, vascular imaging quality is similar to that of DSA, albeit with a modest limitation in the infrageniculate distribution due to contrast-timing issues and the frequency of tibial calcification. Through the acquisition of isotropic voxels on new scanners, images can be reconstructed in any plane, including curved planar reformats along the lumen of the vessel [80]. Particularly suited for aortoiliac and femoropopliteal evaluation, CTA is an excellent choice for the evaluation of claudicants, in which tibial disease is both less frequently present and less frequently treated. Similar to MRA, it is best suited in combination with tests providing data on the hemodynamic significance of identified lesions (NIVT and DUS).

Variant 2: Previous infrainguinal endovascular therapy or bypass. Claudication or CLI. Initial imaging.

C. MRA

MRA provides excellent-quality imaging of all arterial segments approaching that of DSA even in the tibial vessels, particularly when combined with time-resolved methods. In the hands of an experienced operator, DUS can provide detailed arterial maps prior to intervention; however, in the setting of multi-segmental disease, it can become difficult to determine the patient's TransAtlantic Inter-Society Consensus classification, which often guides decision making between endovascular and surgical treatments [9]. For this document, it is assumed the procedure is performed and interpreted by an expert. MRA carries a Level 1A recommendation for MRA from the ACC/AHA for the definition of the precise anatomic relationships of arterial stenotic lesions; however, it is subject to overestimation of the degree of stenosis [4]. This suggests that it is best used in combination with tests that provide insight into the hemodynamic significance of lesions, such as NIVT and DUS. MRA can be used effectively to guide therapy in patients who have undergone both a previous angioplasty with or without stenting as well as patients with bypass grafts. MRA can decrease procedure times, radiation and contrast doses, and can provide better assessment of risk and the likelihood of procedural success prior to undergoing intervention [80].

Although nonenhanced MRA can provide imaging quality and diagnostic confidence levels similar to that from CE-MRA, protocols and image quality vary significantly between institutions. Additionally, the lack of time-resolved imaging limits evaluation in the infrageniculate segment. Its use is generally reserved for patients who require evaluation of suspected aortoiliac and femoropopliteal lesions in the setting of renal insufficiency. The use of this modality is likely to evolve over the next decade given the vast amount of research in this area over the past few years.

Variant 2: Previous infrainguinal endovascular therapy or bypass. Claudication or CLI. Initial imaging.

D. US

DUS has a very high correlation with clinical deterioration after both endovascular therapy and bypass for lower-extremity PAD [26]. Following angioplasty, DUS has been validated as accurate for determining the specific levels of hemodynamically significant disease, although it often underestimates the extent of disease beyond the first significant stenosis. The aortoiliac segment can be evaluated in some patients, although obesity and bowel gas artifact are a pervasive problem. In combination with spectral Doppler, inflow disease can often be excluded and can guide the interventional approach (ie, retrograde contralateral versus antegrade ipsilateral access). Duplex is valuable in the determination of flow within and beyond stented and stent-grafted segments, and is slightly less limited than CTA and MRA, particularly in smaller-caliber stents [22]. The identification and treatment of symptomatic restenosis associated with a previously treated segment has been shown to provide improved long-term outcomes and patency in both endovascular and surgical patients [79]. In many cases, patients can proceed directly to intervention with Duplex arterial mapping alone [16,17]. In the setting of bypass, Duplex can determine whether the graft is patent, threatened, or occluded, and often can identify specific segments of disease to guide either endovascular repair or surgical revision.

Variant 3: Previous infrainguinal endovascular therapy or bypass, presenting with cold, painful extremity and diminished pulses (acute limb ischemia). Initial imaging.

Physical examination is critical in suspected acute limb ischemia/threatened limb, which is, at its core, a clinical diagnosis. The temperature and appearance of the limb, absence of palpable pulses or arterial signals by Doppler, loss of sensation, and decreased or absent strength in the affected extremity all provide insight into the urgency of the event. There is little evidence regarding the use of imaging in the setting of a threatened limb, and no tests should be performed that would

significantly delay therapy in a patient with impending limb loss. Patients with severe ischemia, as indicated by motor loss or severe sensory deficits (Rutherford class IIb or III), should likely proceed directly to definitive therapy, usually surgical thromboembolectomy or bypass [81]. Although a full spectrum of NIVT may be too time consuming in an acutely threatened limb, the determination of the ABI and SPM can assist in the determination of both the etiology of the symptoms and can also guide the level of necessary intervention.

Variant 3: Previous infrainguinal endovascular therapy or bypass, presenting with cold, painful extremity and diminished pulses (acute limb ischemia). Initial imaging.

A. Arteriography

Immediately threatened limbs (Rutherford class IIb and early presentations of class III) require rapid definitive therapy, and generally should proceed directly to emergency thromboembolectomy to prevent limb loss [84]. In the setting of viable or marginally threatened limbs (Rutherford class I or IIa), immediate arteriography for the evaluation of anatomic relationships between diseased segments is the preferred procedure [85]. Angiography provides detailed and accurate information regarding the etiology and extent of the insult that has caused acute limb ischemia and may allow a catheter-based treatment in some patients [86]. This can allow patients to be appropriately triaged to either surgery or endovascular therapy, the latter of which may involve thrombolysis or percutaneous thrombectomy, angioplasty, stenting, etc. If performed without prior NIVT or US, there is the potential for longer procedure times, increased contrast use and possibly multiple access sites to provide definitive therapy.

Variant 3: Previous infrainguinal endovascular therapy or bypass, presenting with cold, painful extremity and diminished pulses (acute limb ischemia). Initial imaging.

B. CTA

In patients with acute limb ischemia and viable or marginally threatened limbs, CTA may be considered for preprocedural evaluation given its near-equivalent accuracy compared to diagnostic angiography [36]. CTA is a rapid modality that can provide insight into the precise location of vessel occlusion, and in some centers it is supplanting arteriography as the test of choice prior to intervention [87]. It is particularly useful in patients who present with bilateral symptoms where inflow disease is suspected. However, its use should not delay definitive therapy. Additionally, the use of iodinated contrast agent for this modality can limit the ability to provide subsequent angiographic therapy because of the risk of contrast-induced nephropathy [88].

Variant 3: Previous infrainguinal endovascular therapy or bypass, presenting with cold, painful extremity and diminished pulses (acute limb ischemia). Initial imaging.

C. MRA

MRA is a time-consuming procedure, and its use in patients with acute limb ischemia should be reserved for those in whom motor and sensory function are preserved and the determination between endovascular and surgical therapy remains obscure. There are no studies to date independently comparing MRA with CTA or angiography in this patient population; however, given the length of the procedure, it is likely not an appropriate test in patients who require revascularization emergently (ie, within the next 3–6 hours), such as patients with Rutherford IIb or III ALI.

Similar to CE-MRA, nonenhanced MRA is time consuming and should only be used in patients with renal insufficiency where the determination between endovascular and surgical therapy remains obscure.

Variant 3: Previous infrainguinal endovascular therapy or bypass, presenting with cold,

painful extremity and diminished pulses (acute limb ischemia). Initial imaging.

D. US

DUS may provide the ability to determine whether the patient has an acute event associated with a previously treated segment or not. Brief evaluation of the venous system can also exclude other potential causes for acute lower extremity ischemia, such as phlegmasia cerulea dolens. Limited US evaluation for the evaluation of bilateral common femoral patency, the determination of inflow quality, and the patency of lower extremity bypass conduits can help guide expeditious treatment. Given portability and ubiquity in the hospital system, this can potentially be performed by physicians in the emergency department to triage patients to appropriate vascular specialists [82]. For this document, it is assumed the procedure is performed and interpreted by an expert. There is increasing focus on training vascular specialists to perform point-of-care DUS to quickly determine the etiology and extent of limb ischemia during the initial consultation [83]. This is particularly true for bypass conduits, which are generally located superficially and easily assessed sonographically. However, these tests should not delay definitive therapy if it is immediately available.

Summary of Highlights

- The combination of longitudinal clinical evaluation and comparisons of noninvasive hemodynamic testing, particularly the ABI, provides a large degree of information and can appropriately frame the patient's presentation.
- In patients who are asymptomatic post revascularization, DUS is the mainstay examination given the high correlation between abnormal findings and recurrence of symptoms. Initial post-treatment DUS can determine a baseline for future follow-up.
- In patients presenting with claudication or chronic limb ischemia post revascularization, noninvasive hemodynamic testing in combination with DUS and CTA or contrast-enhanced MRA can guide therapy in patients who have undergone both a previous angioplasty with or without stenting, as well as patients with bypass grafts.
- In patients presenting with symptoms of acute limb ischemia, time is of the essence, particularly if motor and sensory deficits are noted and redundant examinations should not delay definitive therapy. DUS, CTA, and arteriography are all rapid examinations that can delineate the level of acute abnormality and help guide treatment.

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at <https://acsearch.acr.org/list>. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at <https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria>.

Appropriateness Category Names and Definitions






Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in

		the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® [Radiation Dose Assessment Introduction](#) document.

Relative Radiation Level Designations

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
0	0 mSv	0 mSv
	<0.1 mSv	<0.03 mSv
	0.1-1 mSv	0.03-0.3 mSv
	1-10 mSv	0.3-3 mSv
	10-30 mSv	3-10 mSv
	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

References

1. Natsuaki C, Inoguchi T, Maeda Y, et al. Association of borderline ankle-brachial index with mortality and the incidence of peripheral artery disease in diabetic patients. *Atherosclerosis*.

2014;234(2):360-365.

2. Goodney PP, Beck AW, Nagle J, Welch HG, Zwolak RM. National trends in lower extremity bypass surgery, endovascular interventions, and major amputations. *J Vasc Surg.* 2009; 50(1):54-60.
3. Alahdab F, Wang AT, Elraiyah TA, et al. A systematic review for the screening for peripheral arterial disease in asymptomatic patients. [Review]. *J Vasc Surg.* 61(3 Suppl):42S-53S, 2015 Mar.
4. Hirsch AT, Haskal ZJ, Hertzner NR, et al. ACC/AHA 2005 Practice Guidelines for the management of patients with peripheral arterial disease (lower extremity, renal, mesenteric, and abdominal aortic): a collaborative report from the American Association for Vascular Surgery/Society for Vascular Surgery, Society for Cardiovascular Angiography and Interventions, Society for Vascular Medicine and Biology, Society of Interventional Radiology, and the ACC/AHA Task Force on Practice Guidelines (Writing Committee to Develop Guidelines for the Management of Patients With Peripheral Arterial Disease): endorsed by the American Association of Cardiovascular and Pulmonary Rehabilitation; National Heart, Lung, and Blood Institute; Society for Vascular Nursing; TransAtlantic Inter-Society Consensus; and Vascular Disease Foundation. [Review] [1308 refs]. *Circulation.* 113(11):e463-654, 2006 Mar 21. *Circulation.* 113(11):e463-654, 2006 Mar 21.
5. Adam DJ, Beard JD, Cleveland T, et al. Bypass versus angioplasty in severe ischaemia of the leg (BASIL): multicentre, randomised controlled trial. *Lancet.* 2005;366(9501):1925-1934.
6. Kim ES, Wattanakit K, Gornik HL. Using the ankle-brachial index to diagnose peripheral artery disease and assess cardiovascular risk. *Cleve Clin J Med.* 2012;79(9):651-661.
7. Hyun S, Forbang NI, Allison MA, Denenberg JO, Criqui MH, Ix JH. Ankle-brachial index, toe-brachial index, and cardiovascular mortality in persons with and without diabetes mellitus. *J Vasc Surg.* 2014;60(2):390-395.
8. Chuter VH, Casey SL. Effect of premeasurement rest time on systolic ankle pressure. *J Am Heart Assoc.* 2013;2(4):e000203.
9. Cao P, Eckstein HH, De Rango P, et al. Chapter II: Diagnostic methods. [Review]. *Eur J Vasc Endovasc Surg.* 42 Suppl 2:S13-32, 2011 Dec.
10. Hoyer C, Sandermann J, Petersen LJ. The toe-brachial index in the diagnosis of peripheral arterial disease. *J Vasc Surg.* 2013;58(1):231-238.
11. McCann TE, Scoutt LM, Gunabushanam G. A practical approach to interpreting lower extremity noninvasive physiologic studies. *Radiol Clin North Am.* 2014;52(6):1343-1357.
12. Ro du H, Moon HJ, Kim JH, Lee KM, Kim SJ, Lee DY. Photoplethysmography and continuous-wave Doppler ultrasound as a complementary test to ankle-brachial index in detection of stenotic peripheral arterial disease. *Angiology.* 2013;64(4):314-320.
13. Andrews KL, Dib MY, Shives TC, Hoskin TL, Liedl DA, Boon AJ. Noninvasive arterial studies including transcutaneous oxygen pressure measurements with the limbs elevated or dependent to predict healing after partial foot amputation. *Am J Phys Med Rehabil.* 2013;92(5):385-392.
14. Pardo M, Alcaraz M, Bernal FL, et al. A solution to ankle-brachial index limitations in peripheral transluminal angioplasty. *Radiol Med.* 2013;118(8):1373-1378.

15. van Zitteren M, Vriens PW, Heyligers JM, et al. Self-reported symptoms on questionnaires and anatomic lesions on duplex ultrasound examinations in patients with peripheral arterial disease. *J Vasc Surg.* 2012;55(4):1025-1034 e1022.
16. Wong TH, Tay KH, Sebastian MG, Tan SG. Duplex ultrasonography arteriography as first-line investigation for peripheral vascular disease. *Singapore Med J.* 2013;54(5):271-274.
17. Marti X, Romera A, Vila R, Cairols MA. Role of ultrasound arterial mapping in planning therapeutic options for critical ischemia of lower limbs in diabetic patients. *Ann Vasc Surg.* 26(8):1071-6, 2012 Nov.
18. Sultan S, Tawfick W, Hynes N. Ten-year technical and clinical outcomes in TransAtlantic Inter-Society Consensus II infrainguinal C/D lesions using duplex ultrasound arterial mapping as the sole imaging modality for critical lower limb ischemia. *J Vasc Surg.* 57(4):1038-45, 2013 Apr.
19. Mustapha JA, Saab F, Diaz-Sandoval L, et al. Comparison between angiographic and arterial duplex ultrasound assessment of tibial arteries in patients with peripheral arterial disease: on behalf of the Joint Endovascular and Non-Invasive Assessment of Limb Perfusion (JENALI) Group. *J Invasive Cardiol.* 2013;25(11):606-611.
20. Takimura H, Hirano K, Muramatsu T, et al. Vascular elastography: a novel method to characterize occluded lower limb arteries prior to endovascular therapy. *J Endovasc Ther.* 2014;21(5):654-661.
21. Arvela E, Dick F. Surveillance after distal revascularization for critical limb ischaemia. *Scand J Surg.* 2012;101(2):119-124.
22. Troutman DA, Madden NJ, Dougherty MJ, Calligaro KD. Duplex ultrasound diagnosis of failing stent grafts placed for occlusive disease. *J Vasc Surg.* 60(6):1580-4, 2014 Dec.
23. Shrikhande GV, Graham AR, Aparajita R, et al. Determining criteria for predicting stenosis with ultrasound duplex after endovascular intervention in infrainguinal lesions. *Ann Vasc Surg.* 2011;25(4):454-460.
24. Humphries MD, Pevec WC, Laird JR, Yeo KK, Hedayati N, Dawson DL. Early duplex scanning after infrainguinal endovascular therapy. *J Vasc Surg.* 53(2):353-8, 2011 Feb.
25. Wilson YG, Davies AH, Currie IC, et al. The value of pre-discharge Duplex scanning in infrainguinal graft surveillance. *Eur J Vasc Endovasc Surg.* 1995;10(2):237-242.
26. Jones DW, Graham A, Connolly PH, Schneider DB, Meltzer AJ. Restenosis and symptom recurrence after endovascular therapy for claudication: does duplex ultrasound correlate with recurrent claudication?. *Vascular.* 23(1):47-54, 2015 Feb.
27. Fontcuberta J, Flores A, Orgaz A, et al. Reliability of preoperative duplex scanning in designing a therapeutic strategy for chronic lower limb ischemia. *Ann Vasc Surg.* 2009; 23(5):577-582.
28. Gargiulo M, Maioli F, Ceccacci T, et al. What's next after optimal infrapopliteal angioplasty? Clinical and ultrasonographic results of a prospective single-center study. *J Endovasc Ther.* 2008; 15(3):363-369.
29. Owen AR, Roditi GH. Peripheral arterial disease: the evolving role of non-invasive imaging. *Postgrad Med J.* 2011;87(1025):189-198.
30. Ouwendijk R, de Vries M, Stijnen T, et al. Multicenter randomized controlled trial of the

costs and effects of noninvasive diagnostic imaging in patients with peripheral arterial disease: the DIPAD trial. *AJR*. 2008;190(5):1349-1357.

- 31.** Fotiadis N, Kyriakides C, Bent C, Vorvolakos T, Matson M. 64-section CT angiography in patients with critical limb ischaemia and severe claudication: comparison with digital subtractive angiography. *Clin Radiol*. 66(10):945-52, 2011 Oct.
- 32.** Jens S, Koelemay MJ, Reekers JA, Bipat S. Diagnostic performance of computed tomography angiography and contrast-enhanced magnetic resonance angiography in patients with critical limb ischaemia and intermittent claudication: systematic review and meta-analysis. *Eur Radiol* 2013;23:3104-14.
- 33.** Meyer BC, Klein S, Krix M, Aschoff AJ, Wacker FK, Albrecht T. Comparison of a standard and a high-concentration contrast medium protocol for MDCT angiography of the lower limb arteries. *Rofo*. 2012;184(6):527-534.
- 34.** Ouwendijk R, Kock MC, van Dijk LC, van Sambeek MR, Stijnen T, Hunink MG. Vessel wall calcifications at multi-detector row CT angiography in patients with peripheral arterial disease: effect on clinical utility and clinical predictors. *Radiology*. 2006;241(2):603-608.
- 35.** Huang SY, Nelson RC, Miller MJ, et al. Assessment of vascular contrast and depiction of stenoses in abdominopelvic and lower extremity vasculature: comparison of dual-energy MDCT with digital subtraction angiography. *Academic Radiology*. 19(9):1149-57, 2012 Sep. *Acad Radiol*. 19(9):1149-57, 2012 Sep.
- 36.** Lee IJ, Chung JW, Hong H, et al. Subtraction CT angiography of the lower extremities: single volume subtraction versus multi-segmented volume subtraction. *Acad Radiol*. 2011;18(7):902-909.
- 37.** Sommer WH, Bamberg F, Johnson TR, et al. Diagnostic accuracy of dynamic computed tomographic angiographic of the lower leg in patients with critical limb ischemia. *Invest Radiol*. 2012;47(6):325-331.
- 38.** Swanberg J, Nyman R, Magnusson A, Wanhainen A. Selective intra-arterial dual-energy CT angiography (s-CTA) in lower extremity arterial occlusive disease. *Eur J Vasc Endovasc Surg*. 48(3):325-9, 2014 Sep.
- 39.** Penzkofer T, Slebocki K, Grommes J, et al. High-pitch carbon dioxide contrasted CT angiography: pilot study. *Cardiovasc Intervent Radiol*. 2014;37(2):362-370.
- 40.** Healy DA, Boyle EM, Clarke Moloney M, et al. Contrast-enhanced magnetic resonance angiography in diabetic patients with infra-genicular peripheral arterial disease: systematic review. *Int J Surg*. 2013;11(3):228-232.
- 41.** Li J, Zhao JG, Li MH. Lower limb vascular disease in diabetic patients: a study with calf compression contrast-enhanced magnetic resonance angiography at 3.0 Tesla. *Acad Radiol*. 2011;18(6):755-763.
- 42.** Hadizadeh DR, Marx C, Gieseke J, Schild HH, Willinek WA. High temporal and high spatial resolution MR angiography (4D-MRA). [Review]. *ROFO Fortschr Geb Rontgenstr Nuklearmed*. 186(9):847-59, 2014 Sep.
- 43.** Kinner S, Quick HH, Maderwald S, Hunold P, Barkhausen J, Vogt FM. Triple-TWIST MRA: high spatial and temporal resolution MR angiography of the entire peripheral vascular system using a time-resolved 4D MRA technique. *Eur Radiol*. 2013;23(1):298-306.

44. Knobloch G, Gielen M, Lauff MT, et al. ECG-gated quiescent-interval single-shot MR angiography of the lower extremities: initial experience at 3 T. *Clin Radiol*. 2014;69(5):485-491.
45. Ko SF, Sheu JJ, Lee CC, et al. TRICKS magnetic resonance angiography at 3-tesla for assessing whole lower extremity vascular tree in patients with high-grade critical limb ischemia: DSA and TASC II guidelines correlations. *ScientificWorldJournal*. 2012;2012:192150.
46. Bertschinger K, Cassina PC, Debatin JF, Ruehm SG. Surveillance of peripheral arterial bypass grafts with three-dimensional MR angiography: comparison with digital subtraction angiography. *AJR*. 2001;176(1):215-220.
47. Hakyemez B, Koroglu M, Yildiz H, Erdogan C, Atasoy S, Yurdaeken K. Table-moving contrast-enhanced magnetic resonance angiography in the evaluation of lower extremity peripheral arterial bypass grafts. *JBR-BTR*. 2006;89(2):67-71.
48. Link J, Steffens JC, Brossmann J, Graessner J, Hackethal S, Heller M. Iliofemoral arterial occlusive disease: contrast-enhanced MR angiography for preinterventional evaluation and follow-up after stent placement. *Radiology*. 1999; 212(2):371-377.
49. Suttmeier B, Teichgraber U, Thomas A, et al. Non-invasive ECG-triggered 2D TOF MR angiography of the pelvic and leg arteries in an open 1.0-tesla high-field MRI system in comparison to conventional DSA. *Biomed Tech (Berl)*. 2014;59(1):29-37.
50. Ersoy H, Rybicki FJ. Biochemical safety profiles of gadolinium-based extracellular contrast agents and nephrogenic systemic fibrosis. *J Magn Reson Imaging*. 2007;26(5):1190-1197.
51. Liu X, Zhang N, Fan Z, et al. Detection of infragenual arterial disease using non-contrast-enhanced MR angiography in patients with diabetes. *J Magn Reson Imaging*. 2014;40(6):1422-1429.
52. Thierfelder KM, Meimarakis G, Nikolaou K, et al. Non-contrast-enhanced MR angiography at 3 Tesla in patients with advanced peripheral arterial occlusive disease. *PLoS One*. 2014;9(3):e91078.
53. Diop AD, Braidy C, Habouchi A, et al. Unenhanced 3D turbo spin-echo MR angiography of lower limbs in peripheral arterial disease: a comparative study with gadolinium-enhanced MR angiography. *AJR Am J Roentgenol*. 2013;200(5):1145-1150.
54. Atanasova IP, Kim D, Storey P, Rosenkrantz AB, Lim RP, Lee VS. Sagittal fresh blood imaging with interleaved acquisition of systolic and diastolic data for improved robustness to motion. *Magn Reson Med*. 2013;69(2):321-328.
55. Hansmann J, Morelli JN, Michaely HJ, et al. Nonenhanced ECG-gated quiescent-interval single shot MRA: image quality and stenosis assessment at 3 tesla compared with contrast-enhanced MRA and digital subtraction angiography. *J Magn Reson Imaging*. 2014;39(6):1486-1493.
56. Kassamali RH, Hoey ET, Ganeshan A, Littlehales T. A comparative analysis of noncontrast flow-spoiled versus contrast-enhanced magnetic resonance angiography for evaluation of peripheral arterial disease. *Diagn Interv Radiol*. 2013;19(2):119-125.
57. Hodnett PA, Ward EV, Davarpanah AH, et al. Peripheral arterial disease in a symptomatic diabetic population: prospective comparison of rapid unenhanced MR angiography (MRA)

with contrast-enhanced MRA. *AJR Am J Roentgenol* 2011;197:1466-73.

58. Grozinger G, Pohmann R, Schick F, et al. Perfusion measurements of the calf in patients with peripheral arterial occlusive disease before and after percutaneous transluminal angioplasty using MR arterial spin labeling. *J Magn Reson Imaging*. 40(4):980-7, 2014 Oct.
59. Pollak AW, Meyer CH, Epstein FH, et al. Arterial spin labeling MR imaging reproducibly measures peak-exercise calf muscle perfusion: a study in patients with peripheral arterial disease and healthy volunteers. *JACC Cardiovasc Imaging*. 2012;5(12):1224-1230.
60. Versluis B, Nelemans PJ, Brans R, et al. Functional MRI in peripheral arterial disease: arterial peak flow versus ankle-brachial index. *PLoS ONE*. 9(2):e88471, 2014.
61. Versluis B, Nelemans PJ, Wildberger JE, Schurink GW, Leiner T, Backes WH. Magnetic resonance imaging-derived arterial peak flow in peripheral arterial disease: towards a standardized measurement. *Eur J Vasc Endovasc Surg*. 2014;48(2):185-192.
62. Langham MC, Li C, Englund EK, et al. Vessel-wall imaging and quantification of flow-mediated dilation using water-selective 3D SSFP-echo. *Journal of Cardiovascular Magnetic Resonance*. 15:100, 2013 Oct 30. *J Cardiovasc Magn Reson*. 15:100, 2013 Oct 30.
63. Koziel K, Attenberger UI, Lederle K, Haneder S, Schoenberg SO, Michaeli HJ. Peripheral MRA with continuous table movement: imaging speed and robustness compared to a conventional stepping table technique. *Eur J Radiol*. 2011;80(2):537-542.
64. Eggin TK, O'Moore PV, Feinstein AR, Waltman AC. Complications of peripheral arteriography: a new system to identify patients at increased risk. *J Vasc Surg*. 1995;22(6):787-794.
65. Lin JS, Olson CM, Johnson ES, Whitlock EP. The ankle-brachial index for peripheral artery disease screening and cardiovascular disease prediction among asymptomatic adults: a systematic evidence review for the U.S. Preventive Services Task Force. *Ann Intern Med*. 2013;159(5):333-341.
66. Hartmann A, Gehring A, Vallbracht C, et al. Noninvasive methods in the early detection of restenosis after percutaneous transluminal angioplasty in peripheral arteries. *Cardiology*. 1994; 84(1):25-32.
67. Eslahpazir BA, Allemang MT, Lakin RO, et al. Pulse volume recording does not enhance segmental pressure readings for peripheral arterial disease stratification. *Ann Vasc Surg*. 2014;28(1):18-27.
68. Bandyk DF, Cato RF, Towne JB. A low flow velocity predicts failure of femoropopliteal and femorotibial bypass grafts. *Surgery*. 1985;98(4):799-809.
69. Scali ST, Beck AW, Nolan BW, et al. Completion duplex ultrasound predicts early graft thrombosis after crural bypass in patients with critical limb ischemia. *J Vasc Surg*. 54(4):1006-10, 2011 Oct.
70. Carter A, Murphy MO, Halka AT, et al. The natural history of stenoses within lower limb arterial bypass grafts using a graft surveillance program. *Ann Vasc Surg*. 2007;21(6):695-703.
71. Calligaro KD, Doerr K, McAfee-Bennett S, Krug R, Raviola CA, Dougherty MJ. Should duplex ultrasonography be performed for surveillance of femoropopliteal and femorotibial arterial prosthetic bypasses? *Ann Vasc Surg*. 2001;15(5):520-524.
72. Weitzel WF, Kim K, Henke PK, Rubin JM. High-resolution ultrasound speckle tracking may

detect vascular mechanical wall changes in peripheral artery bypass vein grafts. *Ann Vasc Surg.* 2009;23(2):201-206.

- 73.** Adam DJ, Gillies TE, Kelman J, Allan PL, Chalmers RT. Vascular surgical society of great britain and ireland: duplex surveillance does not enhance infrainguinal prosthetic bypass graft patency. *Br J Surg.* 1999;86(5):705.
- 74.** Davies AH, Hawdon AJ, Sydes MR, Thompson SG. Is duplex surveillance of value after leg vein bypass grafting? Principal results of the Vein Graft Surveillance Randomised Trial (VGST). *Circulation.* 2005;112(13):1985-1991.
- 75.** Hobbs SD, Pinkney T, Sykes TC, Fox AD, Houghton AD. Patency of infra-inguinal vein grafts-effect of intraoperative Doppler assessment and a graft surveillance program. *J Vasc Surg.* 2009;49(6):1452-1458.
- 76.** Ferris BL, Mills JL, Hughes JD, Durrani T, Knox R. Is early postoperative duplex scan surveillance of leg bypass grafts clinically important?. *J Vasc Surg.* 2003 Mar;37(3):495-500.
- 77.** Bosma J, Montauban van Swijndregt AD, Vahl AC, Wisselink W. The utility of contrast enhanced MR angiography as a first stage diagnostic modality for treatment planning in lower extremity arterial occlusive disease. *Acta Chir Belg.* 111(2):73-7, 2011 Mar-Apr.
- 78.** Jeon CH, Han SH, Chung NS, Hyun HS. The validity of ankle-brachial index for the differential diagnosis of peripheral arterial disease and lumbar spinal stenosis in patients with atypical claudication. *Eur Spine J.* 2012;21(6):1165-1170.
- 79.** Hodgkiss-Harlow KD, Bandyk DF. Interpretation of arterial duplex testing of lower-extremity arteries and interventions. *Semin Vasc Surg.* 2013;26(2-3):95-104.
- 80.** Iglesias J, Pena C. Computed tomography angiography and magnetic resonance angiography imaging in critical limb ischemia: an overview. [Review]. *Tech Vasc Interv Radiol.* 17(3):147-54, 2014 Sep.
- 81.** Rutherford RB. Acute limb ischemia. In: Cronenwett JL, Rutherford RB, eds. *Decision Making in Vascular Surgery.* Philadelphia, PA: WB Saunders; 2001:168-171.
- 82.** Rolston DM, Saul T, Wong T, Lewiss RE. Bedside ultrasound diagnosis of acute embolic femoral artery occlusion. *J Emerg Med.* 2013;45(6):897-900.
- 83.** Normahani P, Standfield NJ, Jaffer U. Sources of Delay in the Acute Limb Ischemia Patient Pathway. *Ann Vasc Surg.* 2017;38:279-285
- 84.** Rutherford RB. Clinical staging of acute limb ischemia as the basis for choice of revascularization method: when and how to intervene. *Semin Vasc Surg.* 2009;22(1):5-9.
- 85.** Creager MA, Kaufman JA, Conte MS. Clinical practice. Acute limb ischemia. *N Engl J Med.* 2012;366(23):2198-2206.
- 86.** Walker TG. Acute limb ischemia. *Tech Vasc Interv Radiol.* 2009;12(2):117-129
- 87.** Met R, Bipat S, Legemate DA, Reekers JA, Koelemay MJ. Diagnostic performance of computed tomography angiography in peripheral arterial disease: a systematic review and meta-analysis. *JAMA.* 2009; 301(4):415-424.
- 88.** Shue B, Damle RN, Flahive J, et al. The increased use of computed tomography angiography and magnetic resonance angiography as the sole imaging modalities prior to infrainguinal bypass has had no effect on outcomes. *Ann Vasc Surg.* 2015;29(6):1245-1254.

89. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: <https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/Clinical/Appropriateness-Criteria/ACR-Appropriateness-Criteria-Radiation-Dose-Assessment-Introduction.pdf>.

Disclaimer

The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.

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