A Practical Approach to Interpreting Lower Extremity Noninvasive Physiologic Studies

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KEYWORDS

• Peripheral arterial disease • Vascular laboratory • Ankle brachial index
• Segmental pressure measurements • Pulse volume recording

KEY POINTS

- Resting ankle brachial index (ABI) less than 0.90 is abnormal. Exercise ABI should be done in symptomatic patients with normal ABIs at rest.
- When rest and postexercise ABIs are normal, there is a low likelihood of an abnormal segmental pressure measurement or pulse volume recording (PVR).
- Toe brachial index (TBI) is especially helpful in patients in whom an ABI cannot be reliably obtained because of incompressibility of the calf arteries, often due to arteriolosclerotic mural calcifications. A TBI value less than 0.70 is abnormal.
- Segmental pressure measurements and pulse volume recording (PVR) studies help determine the level of obstruction. A pressure gradient more than 20 mm Hg between different levels, or between the 2 sides at the same level, is considered significant.
- PVR waveforms distal to a site of significant stenosis are characterized by loss of the dicrotic notch, smaller amplitude of the pulse wave, increased time-to-peak, a more rounded peak, and a downslope that is convex away from the baseline.

INTRODUCTION

Peripheral arterial disease (PAD) is an important manifestation of atherosclerosis, with an estimated age-adjusted prevalence of approximately 13% in people older than 50.[1] PAD affects men and women equally and is associated with an increased relative risk of death from cardiovascular causes that is approximately the same as in patients with a history of cardiovascular disease.[2] The major risk factors for PAD include age older than 40 years, smoking, diabetes, hyperlipidemia, hypertension, and hyperhomocysteinemia.[3–6] Because even asymptomatic individuals with PAD have an increased relative risk of death, screening of the at-risk population should be considered to identify the disease and begin treatment.[2] Early intervention with lipid-lowering therapy and antiplatelet drugs may delay disease progression and prevent premature death from cardiovascular causes.[7]

Ten percent to 30% of patients with PAD have symptoms of claudication.[8] Typical claudication is defined as pain in one or both legs on walking, primarily affecting the calves, that does not go

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away with continued walking and is relieved by rest. However, more than 50% of patients found to have PAD by ankle brachial index screening (ABI) do not have typical claudication or evidence of limb ischemia at rest.[9] Initial evaluation of a patient suspected of having PAD should include a careful history to determine whether the patient has a history of walking impairment or if the patient experiences discomfort at rest. In patients with a history of walking impairment, it is important to quantify the degree of impairment by documenting the degree of exertion (eg, the distance walked) before the development of symptoms. A thorough physical examination is also performed to assess for abnormal pulses, skin discoloration, skin integrity, and ulcerations.[2] PAD can be further classified using the Rutherford Classification Index or the Fontaine classification system.[10,11] The Rutherford Classification Index classifies patients according to the degree of sensory loss, muscle weakness, and arterial and venous measurements in acute and chronic PAD. The Fontaine classification index classifies patients into 1 of 4 disease states, ranging from asymptomatic (stage 1) to tissue necrosis, death, and gangrene (stage 4).

In this review, we focus on the physiologic noninvasive vascular laboratory methods for screening and follow-up of patients with PAD, such as ABI (without or with exercise), toe brachial index (TBI), segmental pressure measurements, and pulse volume recordings (PVRs), which are considered the mainstays for identifying and quantifying the degree of PAD. Noninvasive imaging of PAD with ultrasound, computed tomography angiography (CTA), or magnetic resonance angiography (MRA) is not included in this review.[12–14]

ABI

The ABI is an objective test that can be used as a screening tool in the initial evaluation of PAD and in differentiating vascular etiology from neurologic and musculoskeletal causes of lower extremity pain, such as nerve root compression (for example by a herniated disc), spinal stenosis, or hip arthritis.[8] ABIs are also helpful in the evaluation of patients with PAD after medical or interventional treatment. Furthermore, ABIs have been validated with angiography and have been shown to provide prognostic information regarding limb survival, wound healing, and even all-cause patient survival.[15–17]

Technique

The patient should rest in the supine position for at least 10 minutes before obtaining the ABI. Blood pressure cuffs that are appropriately sized to the limb circumference are placed on both arms and lower calves. Systolic blood pressure (BP_S) is obtained with the aid of a handheld 5-MHz to 10 MHz continuous wave Doppler scanning probe. BP_S from the brachial arteries in the right and left upper extremities and the dorsalis pedis and posterior tibial arteries in the bilateral lower extremities are obtained. The ABI on each side is then calculated to 2 decimal places by dividing the higher of the dorsalis pedis and posterior tibial artery BP_S on that side by the higher of the BP_S in the arms (left or right arm).

Interpretation

A difference in BP_S in the brachial arteries by more than 20 mm Hg may be observed in patients with aortic dissection or stenosis in the subclavian or axillary arteries, and further workup for this should be considered (**Fig. 1**). Pulse wave reflection in healthy individuals causes the ankle systolic pressure to be approximately 10 to 15 mm Hg (10%) higher than the brachial arterial systolic pressure, causing the ABI to be normally greater than 1.00. An ABI less than 0.90 is considered abnormal. Patients with claudication typically have ABIs ranging from 0.41 to 0.89, and patients with critical leg ischemia have ABI values of 0.40 or less (**Table 1**). Patients with heavily calcified arteries, including arteriolosclerotic calcifications in the tunica media (often found in patients with diabetes and chronic renal failure and elderly individuals), may demonstrate falsely elevated systolic pressure measurements or inability to completely occlude the arterial flow (ie, noncompressible vessels). An ABI value of greater than 1.30 or a systolic pressure measurement higher than 250 mm Hg (some use 200 mm Hg) is an indeterminate result, usually secondary to a noncompressible, calcified vessel that prevents measurement of true arterial pressure. Although vessel wall calcification limits ABI and segmental pressure measurements and interpretation, it usually does not affect pulse volume recording waveforms.[18]

With serial ABI measurements following medical, surgical, or percutaneous interventional treatment, a decrease in ABI of 0.10 or greater when associated with a change in clinical status or an isolated decrease in ABI of 0.15 or greater is considered significant.[19]

Pitfalls and Limitations

An abnormal ABI in itself is not a reliable predictor of symptom magnitude, extent, or location of disease, and should be used primarily to identify patients with PAD, and interpreted in conjunction with segmental pressure measurements and PVR

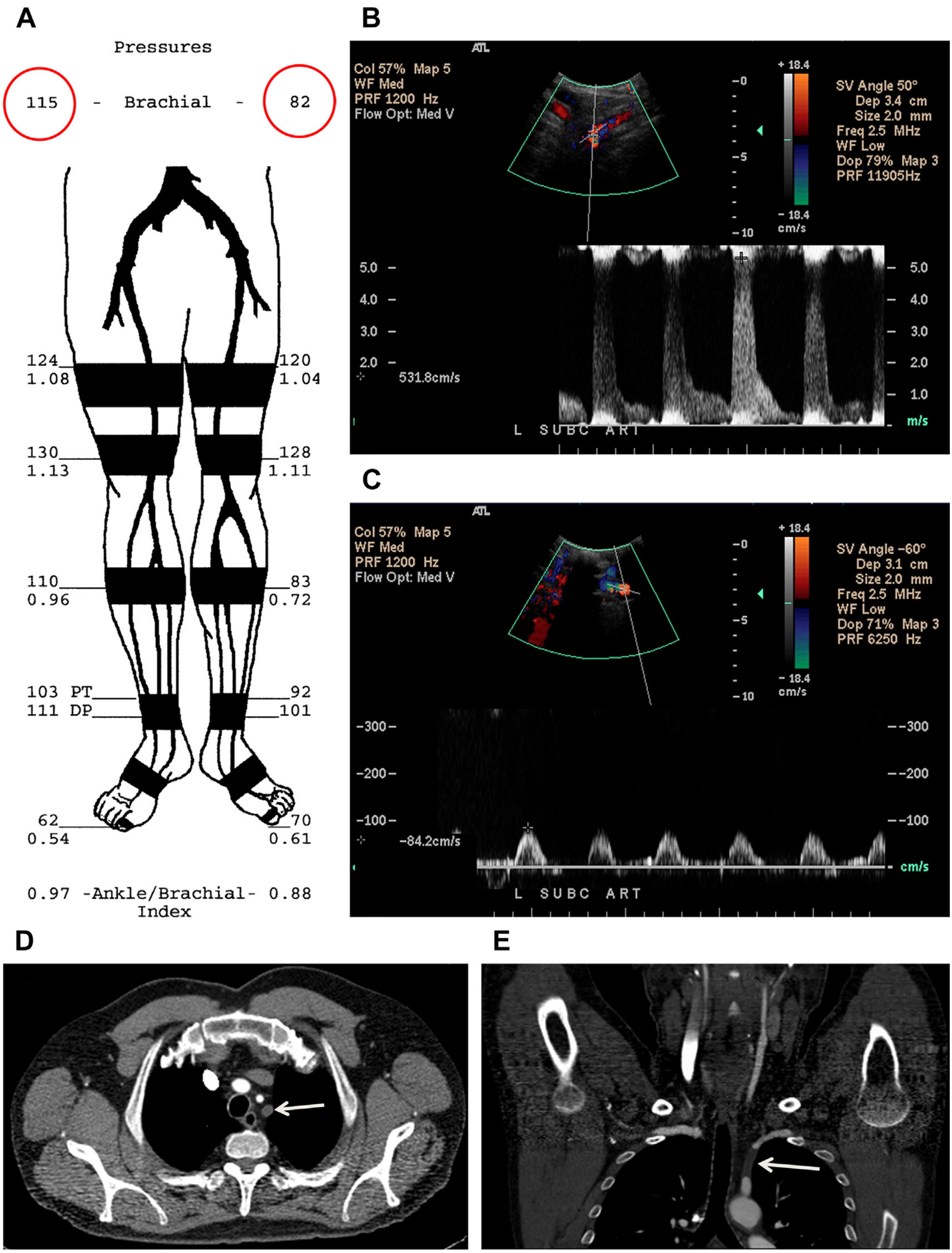

Fig. 1. A 50-year-old man with suspected lower extremity peripheral arterial disease. (*A*) There is a significant pressure difference of 33 mm Hg between the right (115) and left (82) brachial arteries. (*B*) Doppler ultrasound examination shows a markedly increased peak systolic velocity of 532 cm/s in the medial left subclavian artery. (*C*) Doppler ultrasound within the mid left subclavian artery shows tardus parvus waveforms and a relatively low peak systolic velocity of 84 cm/s. These findings are consistent with a high-grade left subclavian artery stenosis. (*D, E*) Axial and coronal reformatted CTA scan of the chest in a different patient shows complete occlusion of the left subclavian artery (*arrows*, *D, E*) with reconstitution of the distal artery from collaterals.

Table 1
Interpretation of resting ABI

ABI Value	
>1.30	Indeterminate result due to noncompressible artery
0.90–1.30	Normal
0.41–0.89	Mild to moderate peripheral arterial disease
<0.41	Severe peripheral arterial disease

Abbreviation: ABI, Ankle Brachial Index.

to further quantify and localize the extent of PAD.[10] Noninvasive localization of the level of obstruction can be attempted with segmental-limb pressures and PVR (see later in this article). In addition, in patients with severely stenotic or completely occluded iliofemoral arteries, the ABI may be normal at rest if sufficient collaterals are present. In symptomatic individuals with suspected PAD and normal resting ABIs, exercise (stress) ABI should be performed.[2]

It is important to carefully position the patient in the supine position at the time the blood pressures are taken. For each inch the ankle is positioned below the heart, there is a 1 mm Hg increase in systolic ankle blood pressure.[10]

EXERCISE ABI

In symptomatic patients who have a normal ABI at rest, an exercise ABI should be performed. Ideally, the patient is made to walk on a treadmill at 2 mph (3.2 km/h), at a 10% to 12% grade for 5 minutes or until the patient develops symptoms of claudication. If a treadmill is not available, the patient is asked to perform active pedal plantar flexion for approximately 5 minutes. A decrease in the postexercise ABI by 0.15 to 0.20 (15%–20%) of the resting ABI is concerning for significant PAD.

Contraindications to performing exercise ABI include uncontrolled hypertension, severe aortic stenosis, congestive heart failure, chronic obstructive pulmonary disease, or other comorbidities that prevent the patient from performing exercise. An alternative in nonambulatory patients is to inflate the thigh cuff above the BP_S for 3 to 5 minutes, and then deflate the cuff to cause reactive hyperemia. The ankle pressure 30 seconds after cuff deflation is approximately equivalent to the pressure obtained 1 minute after walking to the point of claudication.

If the rest ABI is indeterminate (>1.30) due to vascular calcifications, exercise ABI is unlikely to be helpful. Also, it is important to have a formally structured exercise protocol and not simply request that the patient "walk around" the vascular laboratory to elicit the symptoms of claudication, because those measurements tend to be less reliable.

TBI

The digital arteries are much less likely to be affected by the tunica media arteriolosclerotic calcifications that involve the calf arteries. Therefore, the TBI is especially helpful in cases of suspected false elevation of ankle pressures secondary to medial calcification or when PAD is suspected within the foot. A small pneumatic cuff is placed directly on the first or second digit. A photo electrode is then placed on the end of the digit and a photoplethysmographic waveform is recorded. The cuff is inflated until the arterial waveform is no longer seen and then deflated. The systolic pressure is recorded at the time of return of the arterial waveform. The normal toe pressure is 80% to 90% of the brachial artery pressure, so a normal TBI is 0.80 to 0.90. A TBI less than 0.70 is considered abnormal (**Fig. 2**). Patients with claudication typically have a TBI of 0.35 ± 0.15 (mean $\pm$ SD), and patients with ischemic rest pain typically have a TBI of 0.11 ± 0.10 (mean $\pm$ SD).[20]

SEGMENTAL PRESSURE MEASUREMENTS

Segmental pressure measurements and PVRs are used to attempt to localize the level of stenosis.

Technique

Similar to measuring the ABI, segmental pressure measurements are done with the patient in the supine position. A small cushion is placed under the patient's feet to elevate the ankles to approximately the same level as the heart. Blood pressures are obtained from the bilateral brachial arteries. Appropriately sized pneumatic cuffs are then placed around both lower extremities at the thigh, calf, and ankle levels. Both a 4-cuff technique (upper thigh, lower thigh, calf and ankle levels) as well as a 3-cuff technique (thigh, calf, and ankle) have been described. The ankle cuff is placed just above the malleoli. The calf cuff is placed around the widest portion of the calf. If 2 cuffs are placed in the thigh (4-cuff technique), the upper thigh cuff is positioned such that the upper edge of the cuff is at the highest possible level of the patient's inner thigh. The lower thigh cuff is positioned such that the lower edge of the cuff is just above the patella. Typical cuff bladder widths for an average adult in the upper thigh, lower thigh,

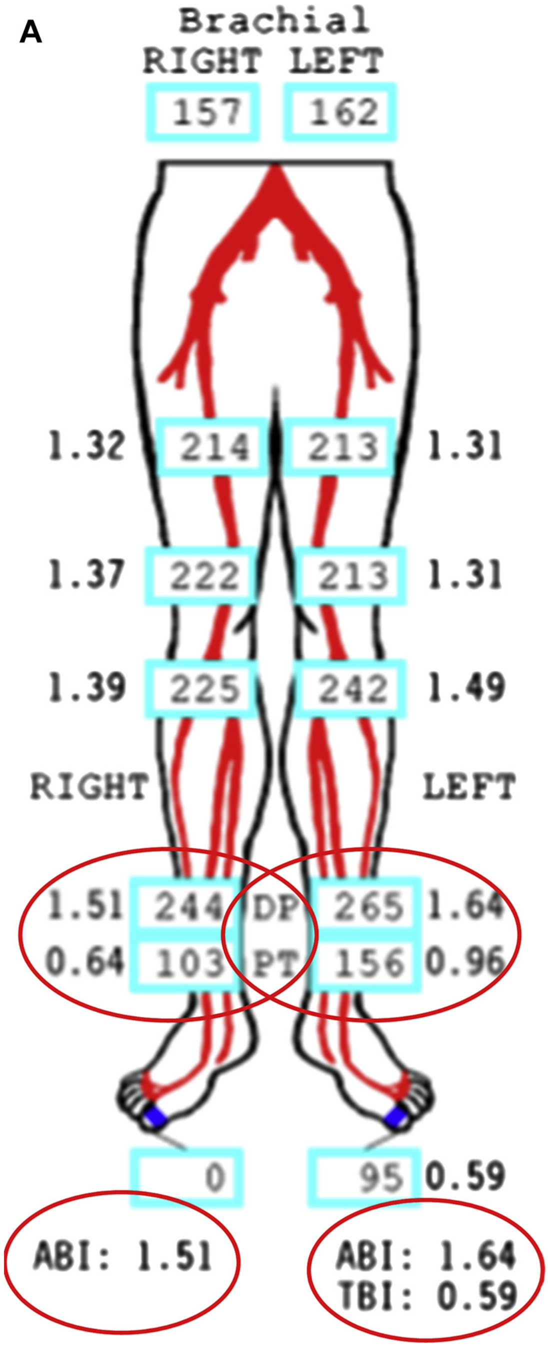

Fig. 2. A 67-year-old woman with diabetes and right great toe gangrene. (*A*) ABIs are indeterminate (>1.3) in bilateral dorsalis pedis arteries: 1.51 on right and 1.64 on left, likely due to arteriosclerotic calcifications associated with diabetes. The ABIs in the posterior tibial artery, 0.64 on right and 0.96, on left appear to be a more reliable indicator of the underlying arterial pressures. TBI is abnormal on left side (0.59) and could not be obtained on right side because of digital gangrene. (*B*) Radiograph of the right foot shows "tram-tracking" type of arterial tunica media calcifications in the anterior tibial (*single arrow*) and dorsalis pedis arteries. Note the lack of calcifications in the digital arteries (*double arrows*).

calf, and ankle are 11, 19, 12, and 10 to 12 cm respectively. The advantage of the 4-cuff method is better localization of the level of disease. Disadvantages include potentially longer time to complete the study, and additionally, in some patients with large thighs, it can be challenging to get a reliable pressure measurement or place the cuff high in the thigh.

Pressure measurements are taken sequentially starting at the ankle, followed by the calf and thighs. The cuff is inflated to well above the systolic BP and then slowly deflated at a rate of approximately 2 to 4 mm Hg per second while using a continuous-wave Doppler device to detect resumption of blood flow distally within the posterior tibial or dorsalis pedis arteries. Segmental pressure indices analogous to the ABI are computed at each level by dividing the pressure at that level by the higher of the right and left brachial artery pressures.

Interpretation

In a healthy individual, blood pressures increase slightly as one proceeds distally within a limb. The presence of a hemodynamically significant arterial stenosis or occlusion will result in a decrease in the segmental pressure measurements distally within that limb.

The normal pressure variation between limb segments should be no more than 20 to 30 mm Hg. To improve sensitivity, at our institution, we use a gradient between adjacent limb segments greater than 20 mm Hg as significant for a hemodynamically significant stenosis in the artery between the 2 segments. In cases of complete arterial occlusion, a gradient of 40 mm Hg or greater is expected. It is also useful to compare measurements in the right and left leg: a pressure difference greater than 20 mm Hg at the same level in the opposite limb is concerning for hemodynamically significant disease.[21]

Pitfalls and Limitations

The accuracy of segmental pressure measurements is significantly affected by the size of the blood pressure cuff that is used. If the cuff is too narrow, the pressure reading will be falsely elevated, and if the cuff is too wide, the pressure reading will be falsely low. For instance, inappropriate cuff sizing during the measurement of brachial artery blood pressures have been shown to produce an average error of 8.5 mm Hg.[22] The American Heart Association recommends that the width of the bladder (inflatable portion) of the pressure cuff be 40% of the circumference of the limb or 20% wider than the limb diameter.[23] Similar to the ABI, assessment of segmental pressure measurements is limited in arteries that are incompressible due to the presence of heavily calcified plaque or medial arteriosclerotic calcifications. A segmental pressure index greater than 1.30 or pressure greater than 250 mm Hg suggests that the pressure measurements are unreliable at that level. Segmental pressure measurements should not be attempted at the level of a previously placed stent or arterial bypass graft because of the risk of stent fracture or trauma to the underlying graft. Also, patients with wounds or cellulitis, or patients with critical limb ischemia may not be able to tolerate cuff inflation because of severe pain, leading to an incomplete study. Another contraindication is the presence of acute deep venous thrombosis.

PULSE VOLUME RECORDING (PLETHYSMOGRAPHY)

The volume of an extremity changes with each incoming arterial pulse and/or in response to temporary obstruction of the venous system. The commonly used air plethysmogram records the volume changes of an examined body part using a pulse volume recorder. PVR uses pneumatic cuffs placed at multiple levels along an extremity, which are inflated until the underlying veins (but not the arteries) are occluded. By standardizing the volume of air and pressure within the cuff, the subtle volume changes that occur in a limb lead to measurable pulsatile pressure changes within the cuff, which may be used to derive intra-arterial pressures and arterial flow. The contour and amplitude of the PVR waveforms provide a qualitative assessment of the degree of PAD.

Technique

Similar to segmental pressure measurements, pressure cuffs are placed around the limb and attached to the plethysmograph. Most modern plethysmography machines inject a known fixed quantity of air into the cuffs to achieve a preset pressure, after which PVR tracings are recorded over several cardiac cycles. It is important to avoid adjusting the amplitude gain and other settings on the plethysmography machine so as to achieve accurate and reproducible results and enable reliability in comparison between the different levels and follow-up studies on the same patient.

Interpretation

A normal pulse wave is characterized by a steep upslope, a narrow peak, the presence of a dicrotic notch in the downslope, and a downslope that is concave toward the baseline. Normally, the pulse wave amplitude should increase between the thigh and calf. This occurs because of differences in muscle mass, cuff volumes, and decrease in vessel diameter from the thigh to the calf.[24] Pulse wave contour and amplitude should be symmetric when comparing both limbs at the same level. In the presence of a proximal arterial stenosis or occlusion, loss of the dicrotic notch is usually the first observed sign. With increasing severity of atherosclerotic disease, the amplitude of the pulse wave diminishes progressively (**Figs. 3** and **4**). In addition to dampening of the pulse wave contour, the upslope becomes more gradual, the peak appears broader and more rounded, and the downslope becomes convex away from the baseline. If this continues to progress, the pulse wave contour will eventually flat line (**Figs. 5–8**). Note that the presence of a dicrotic notch in the waveforms at the ankle level makes significant proximal arterial occlusive disease unlikely.

Pitfalls and Limitations

The systolic pressure wave created by left ventricular contraction is modified by a number of variables, including stroke volume, vasoconstriction or vasodilation of small-caliber arteries and arterioles, vessel wall elasticity, arterial branching patterns, vascular stenosis or occlusion, presence of collateral vascular beds, arteriovenous shunts, and size and position of the limb.[25] Any of these variables may act as confounding factors, and limit the accuracy of PVR measurements. Specifically, the presence of aortic valvular stenosis, hypotension, tachycardia, patient motion, or a significant proximal arterial stenosis may mask the presence of distal disease due to decreased intra-arterial pressure.

SUMMARY

Noninvasive vascular laboratory physiologic studies are used in screening asymptomatic individuals with risk factors for PAD, helping establish an arterial etiology of a patient's symptoms, localizing the level of disease, determining prognosis, and performing surveillance after invasive therapy.

An algorithm that summarizes the noninvasive workup of patients with suspected PAD is provided in **Fig. 9**. In a new patient with suspected PAD, resting ABI is first done. If this is normal, an exercise ABI is done. If resting and exercise ABI are

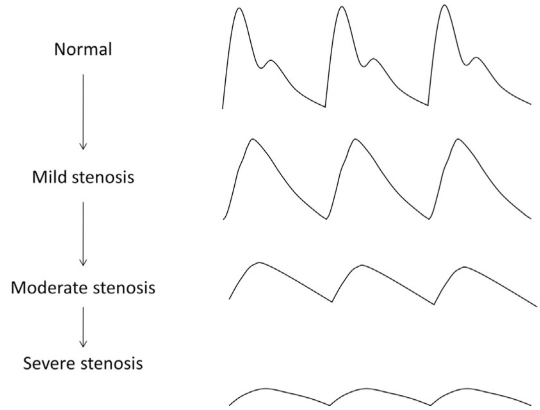

Fig. 4. Schematic diagram showing the changes in PVR waveforms with increasing severity of stenosis. Loss of the dicrotic notch is often the first observed sign. With further increase in stenosis severity, there is a progressive flattening of the waveforms, an increase in the time to peak, and the downslope becomes bowed away from the baseline.

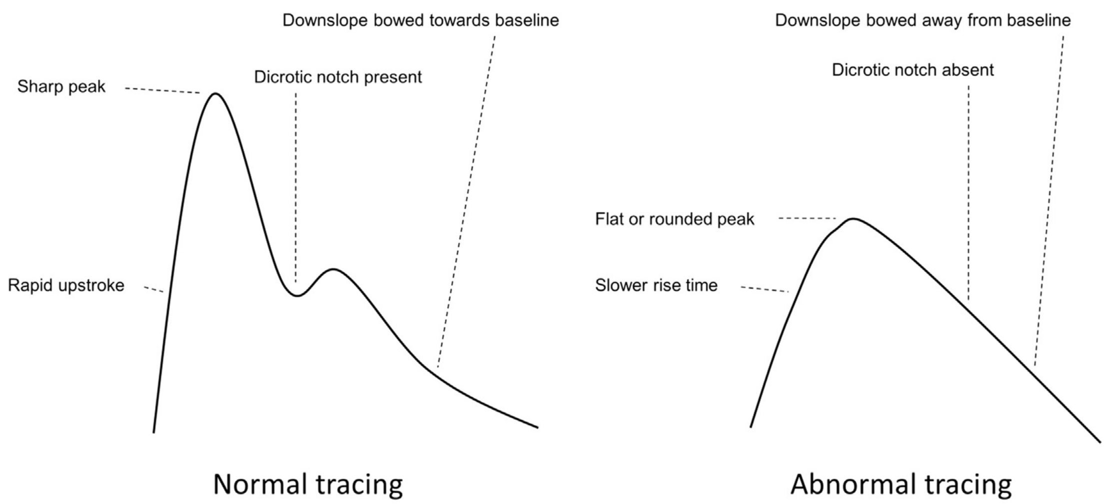

Fig. 3. Schematic diagram showing differences between a normal and abnormal PVR tracing. A normal tracing is characterized by a rapid upstroke, sharp peak, presence of a dicrotic notch, and a downslope that is bowed toward the baseline. An abnormal tracing demonstrates a slower rise time, a flat or rounded peak, absence of the dicrotic notch, and a downslope that is bowed away from the baseline.

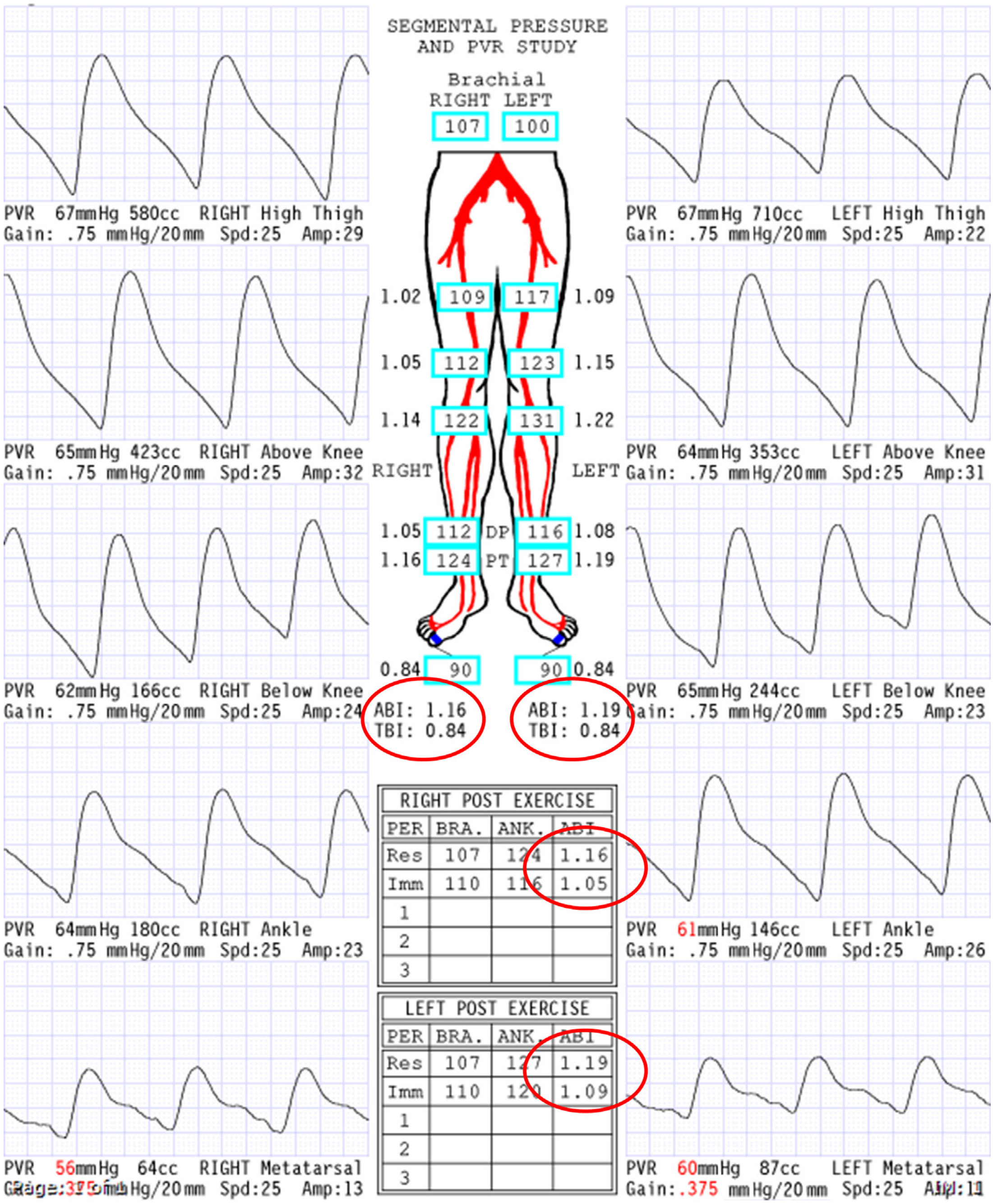

Fig. 5. A 51-year-old woman with bilateral lower extremity claudication. ABIs are normal bilaterally: 1.16 on right and 1.19 on left. TBIs are also normal bilaterally: 0.84 on right and 0.84 on left. Immediately after exercise, ABIs decreased slightly to 1.05 from 1.16 (–0.11) on the right side and decreased slightly to 1.09 from 1.19 (–0.10) on the left side, which are not significant. Therefore, this is a normal study, and there is likely a nonvascular cause of the patient's symptoms. With a normal rest and exercise ABI, there is a very low likelihood of an abnormal PVR study. Note that there are no significant segmental pressure gradients, and the PVR waveforms are symmetric throughout, with a preserved dicrotic notch through the level of the metatarsals.

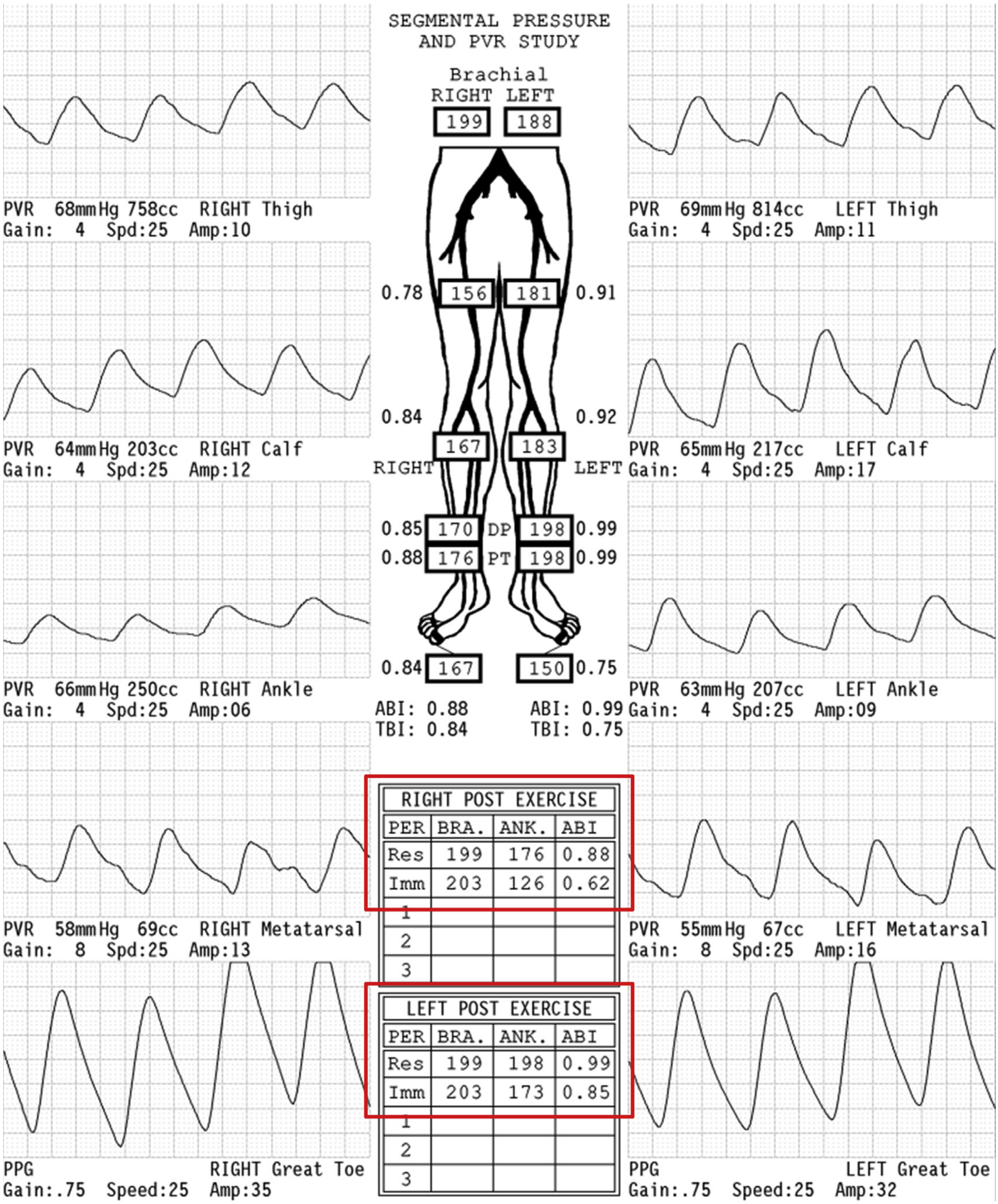

Fig. 6. A 62-year-old man with right lower extremity claudication. Rest ABI, TBI, segmental pressure measurements, and PVR are normal except for a slightly decreased right-sided ABI (0.88). After exercise, the ABI on the right decreased to 0.62, consistent with significant PAD. The patient underwent angiography, which demonstrated stenosis of the right external iliac artery that was treated with a stent (not shown). This case shows the utility of obtaining post exercise ABI.

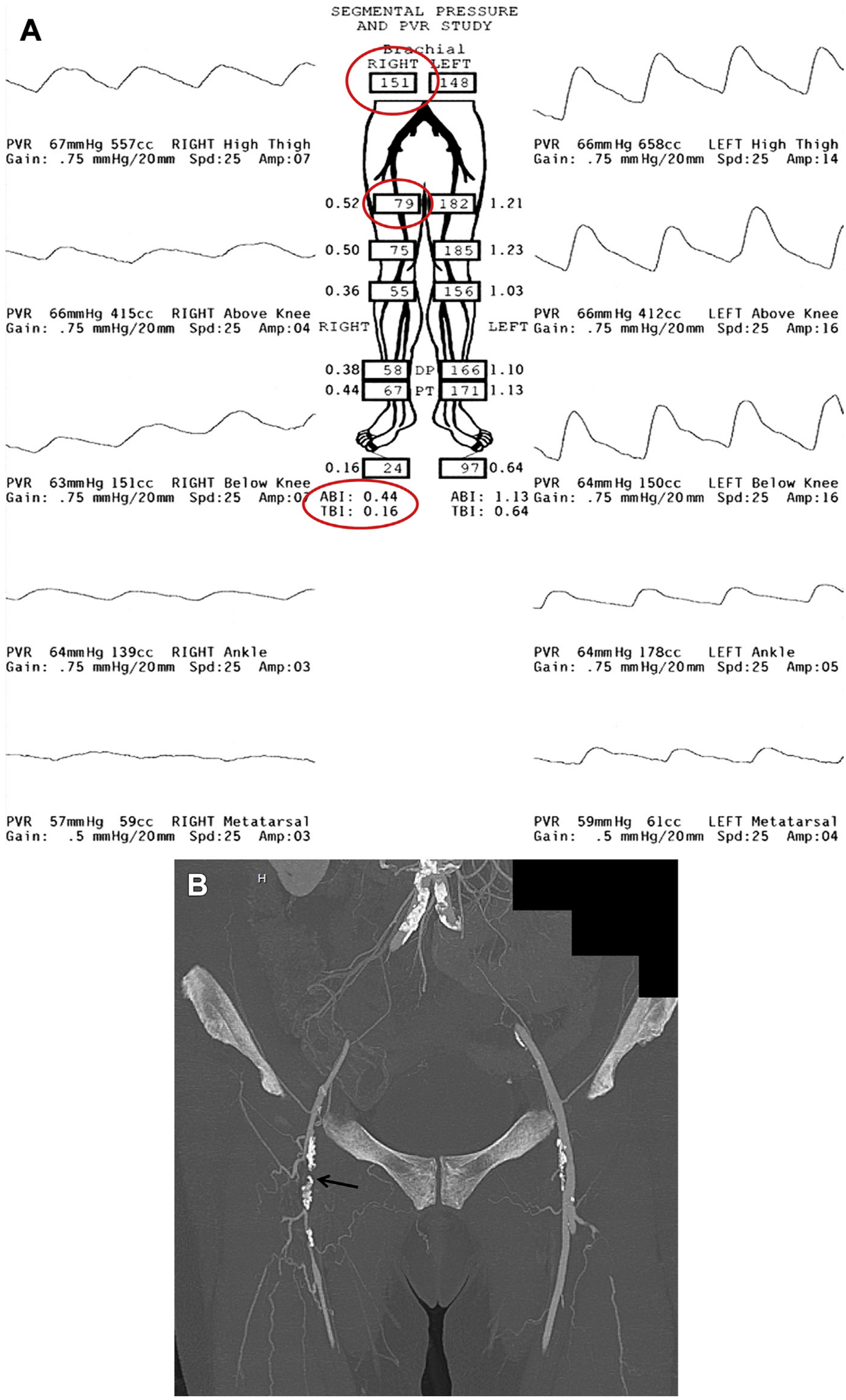

Fig. 7. A 61-year-old woman with right lower extremity claudication. (*A*) Note the markedly decreased ABI (0.44) and TBI (0.16) on the right side. Segmental pressure measurements show a significant gradient of 72 mm Hg between the right brachial artery (151 mm Hg) and right high thigh (79 mm Hg), but no other significant pressure gradients are observed. PVR demonstrates loss of dicrotic notch and dampened waveforms throughout the right lower extremity compared with the left side. These findings are consistent with right iliofemoral (inflow) disease. (*B*) Coronal maximum-intensity projection (MIP) reconstruction of a CT angiogram shows focal occlusion of the right common femoral artery (*arrow*) with reconstitution of the superficial femoral and profunda femoris arteries from collaterals. The patient underwent a right common femoral endarterectomy (not shown). (*C*) Postoperative study shows normal right ABI (1.02) and TBI (0.88). Note the marked improvement in the amplitude and appearance of the PVR waveforms on the right side, which are now very similar to the left.

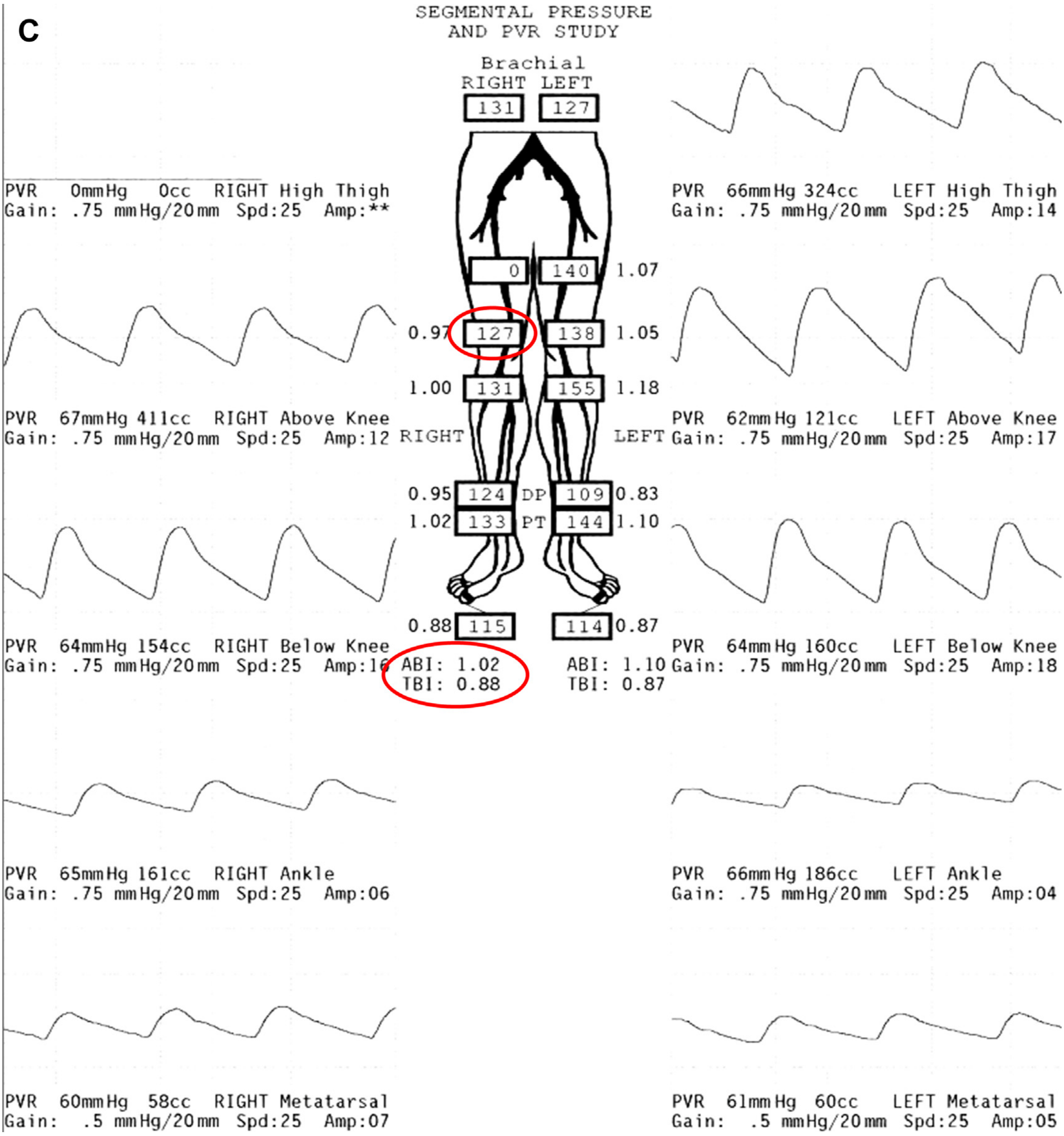

Fig. 7. (*continued*)

both normal, it is unlikely that PAD is the cause of patient's symptoms, and alternate (musculoskeletal or neurologic causes) should be considered. If the resting and/or exercise ABI is abnormal, segmental pressure measurements and PVR are done to localize the disease. If these studies are abnormal as well, further evaluation with Doppler ultrasound, CTA, MRA, or angiography should be done as appropriate. If the resting ABI is indeterminate (>1.30), TBI may be helpful. Please note, however, that because of differences in subspecialist versus primary care physician referral patterns and preferences, it is common in many practices, including our own, to initially perform resting ABI, TBI, segmental pressure measurements, and PVR in all patients with suspected PAD.

A practical approach to the interpretation of vascular laboratory physiologic studies is summarized in **Box 1**. After angiographic or surgical intervention, surveillance is done using review of symptoms, physical examination, noninvasive vascular studies, and/or Duplex ultrasound at regular intervals.[2]

Medical therapy is initially recommended in patients without critical limb ischemia (rest pain, skin changes, or tissue loss) who have abnormal

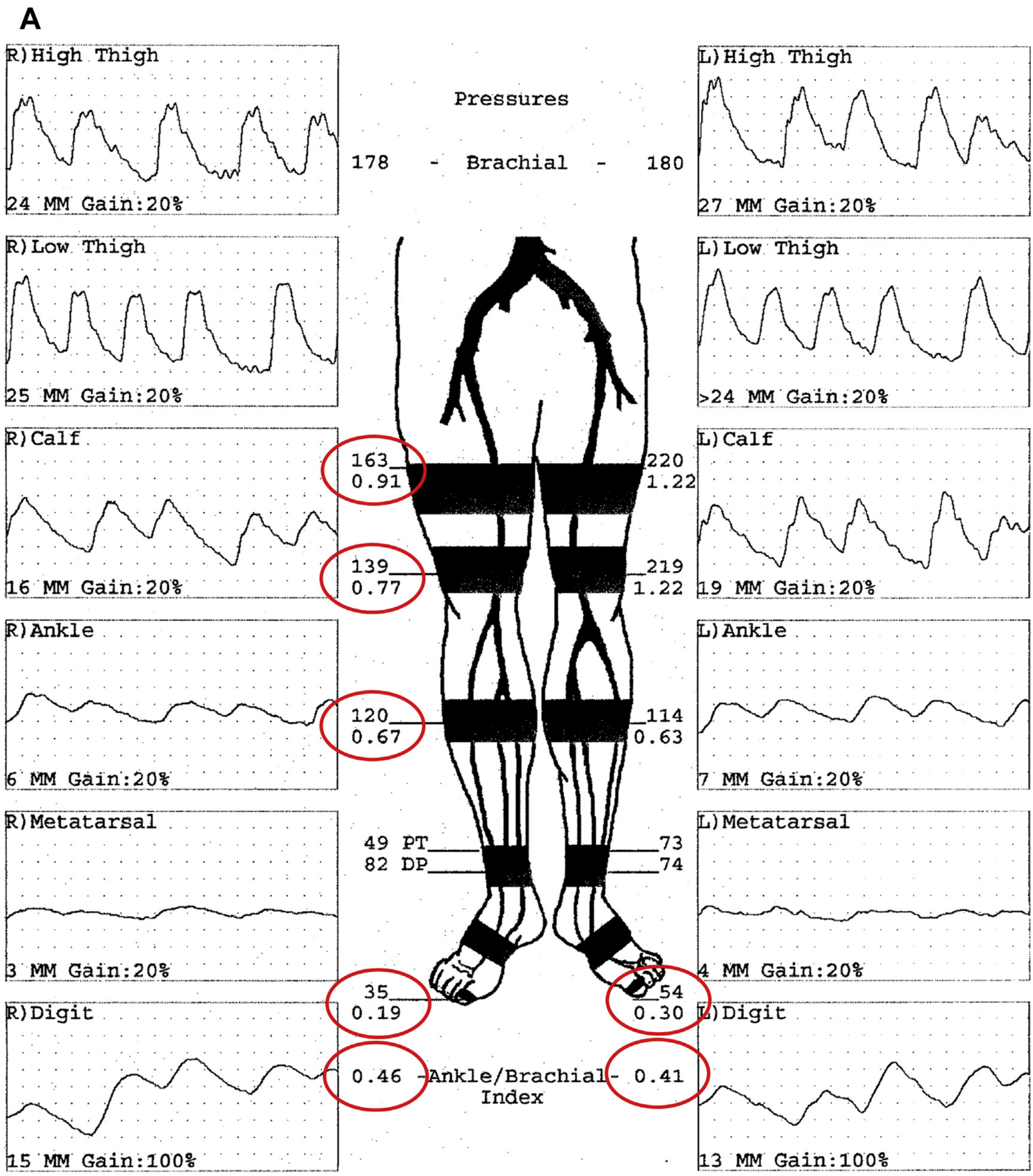

Fig. 8. A 75-year-old man with right leg rest pain. (*A*) The ABIs are decreased bilaterally (0.46 on right and 0.41 on left). There is a 24 mm Hg significant pressure gradient between the right upper thigh (163 mm Hg) and the lower thigh (139 mm Hg) and borderline 19 mm Hg gradient to the upper calf (120 mm Hg). Also note the dampening of waveforms between the right lower thigh to calf, and calf to ankle levels. The values 0.91, 0.77, and 0.67 represent the segmental pressure indices, which are analogous to the ABI. (*B*) CTA shows complete occlusion of the right distal superficial femoral and popliteal arteries (*arrows*). (*C*) Angiogram confirms the above CTA findings (*arrows*). (*D*) Note the complete occlusion of the right posterior tibial and distal peroneal arteries (*double arrows*). The anterior tibial artery (*arrow*) is widely patent to the level of the ankle joint.

vascular laboratory physiologic studies.[7] The patient may also undergo a treadmill test to define maximum walking distance and pain-free walking distance. Patients who have critical limb ischemia or have failed medical therapy will need to be further evaluated using ultrasound, CTA or MRA, and digital subtraction angiography. Ultrasound has the advantage of being inexpensive, widely available, and does not use contrast media or ionizing radiation; however, it may be limited in individuals with

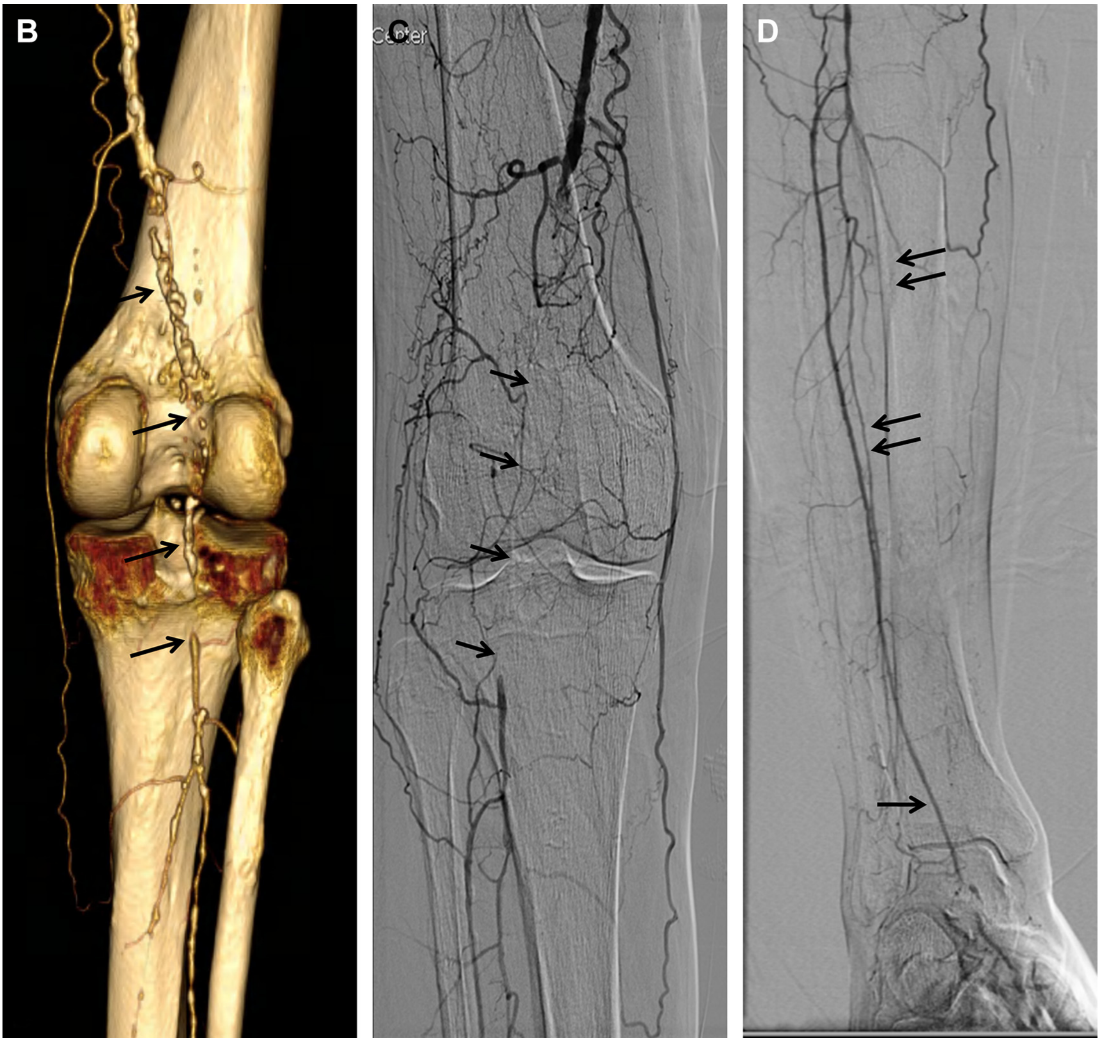

Fig. 8. (*continued*)

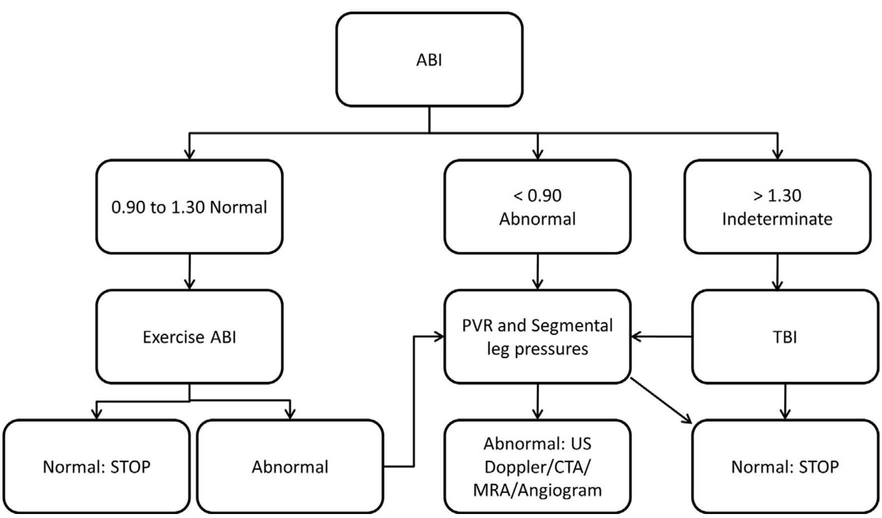

Fig. 9. Algorithm for the noninvasive vascular laboratory workup of patients with suspected peripheral arterial disease. Please note that because of variations in physician preferences, it is common to perform rest ABI, TBI, segmental pressure measurements, and PVR in all patients with suspected PAD. US, ultrasound.

Box 1
Checklist for interpreting ankle brachial index/pulse volume recording (ABI/PVR) studies

1. Brachial artery systolic blood pressures
   - If there is a systolic blood pressure difference between right and left brachial arteries greater than 20 mm Hg, consider possibility of thoracic aortic dissection or significant subclavian/axillary artery stenosis
2. ABI
   - Rest ABI less than 0.90: Abnormal
   - Rest ABI greater than 1.30: Indeterminate
   - Rest ABI ranging from 0.90 to 1.30: Normal
   - Exercise ABI (only done if rest ABI is normal): Decrease of 0.15 compared with the rest ABI is abnormal
   - Follow-up studies: Decrease in ABI by $\geq$0.15; (or) Decrease in ABI by $\geq$0.10 accompanied by change in clinical symptoms/signs is significant
3. Toe Brachial Index (TBI)
   - TBI less than 0.70: Abnormal
4. Segmental Pressure Measurements
   - More than 20 mm Hg difference in pressure between the 2 sides or between different levels on the same side is significant
5. PVRs
   - Compare amplitude of waveforms at the same level on both sides
   - Assess for abnormal features in waveforms, including
     - Loss of dicrotic notch
     - Increased time to peak
     - Smooth or rounded peak
     - Downslope bowed away from baseline

a large body habitus, those with extensive atherosclerotic or arteriosclerotic calcifications, and in the iliac and below-knee arteries. CTA provides excellent spatial resolution but has the disadvantages of being relatively expensive and using ionizing radiation and potentially nephrotoxic iodinated contrast media. Digital subtraction angiography is an invasive procedure, and with the exception of carbon dioxide angiography in patients with renal failure, is mostly done when there is a high likelihood of performing an intervention at the same time.

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