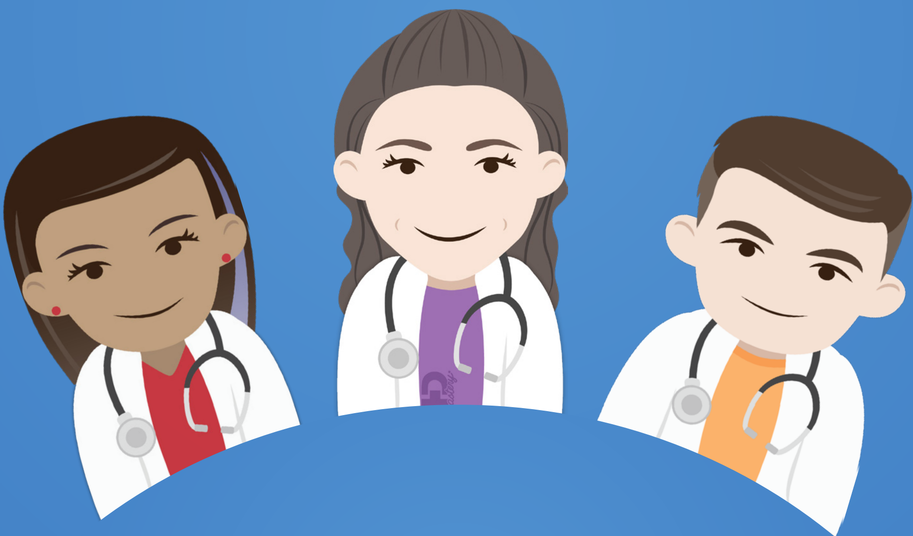
ULTRASOUND MASTERCLASS: ARTERIES OF THE LEGS

HANDBOOK



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Abbreviations

2D	two-dimensional
AAA	abdominal aortic aneurysm
ABI	ankle-brachial index
ALI	acute limb ischemia
ATA	anterior tibial artery
BP	blood pressure
BPG	bypass graft
CFA	common femoral artery
CFV	common femoral vein
CLI	chronic limb ischemia
CT	computed tomography
DP	dorsalis pedis
DPA	dorsalis pedis artery
GSV	great saphenous vein
PAD	peripheral artery disease
PFA	profunda femoris artery
PPG	photoplethysmography
PSV	peak systolic velocity
PT	posterior tibial
PTA	posterior tibial artery

PW	pulsed-wave
SFA	superficial femoral artery
SFJ	saphenofemoral junction
TBI	toe-brachial index
TPT	tibioperoneal trunk

Chapter 1

REMEMBERING THE SPECIFICS

Reviewing normal anatomy on ultrasound

To appreciate how helpful ultrasound is in evaluating the lower extremities for abnormalities, it is important to be proficient in the basic anatomy of the lower extremity arteries.

There are five arteries in each leg that you'll examine in a routine ultrasound study:

1. Common femoral artery (CFA)
2. Superficial femoral artery (SFA)
3. Popliteal artery
4. Posterior tibial artery (PTA)
5. Dorsalis pedis artery (DPA)

The lower extremities' deep veins run adjacent to arteries of the same name which can help identify the arteries on ultrasound.

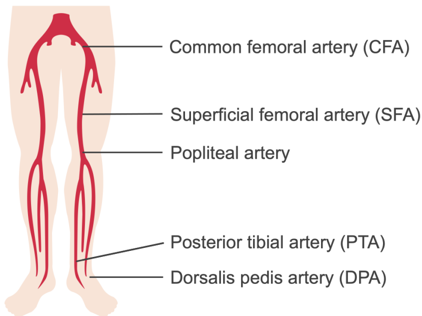


Figure 1. The five lower extremity arteries that are routinely examined on ultrasound include the common femoral artery (CFA), the superficial femoral artery (SFA), the popliteal artery, the posterior tibial artery (PTA), and the dorsalis pedis artery (DPA).

The common femoral artery (CFA)

The saphenofemoral junction (SFJ) in the groin area is adjacent to the CFA. On ultrasound, you can find the SFJ next to the CFA with the common femoral vein (CFV) just inferior. This appearance is referred to as the Mickey Mouse sign.

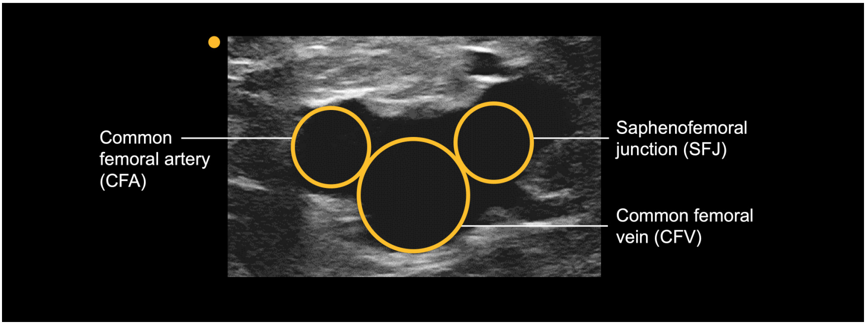


Figure 2. Ultrasound image of the Mickey Mouse sign, which consists of the saphenofemoral junction (SFJ) adjacent to the common femoral artery (CFA), and the common femoral vein (CFV) just inferior.

The CFA is inferior to the inguinal ligament and receives aortoiliac inflow. On ultrasound, a normal CFA has smooth walls and a black lumen.

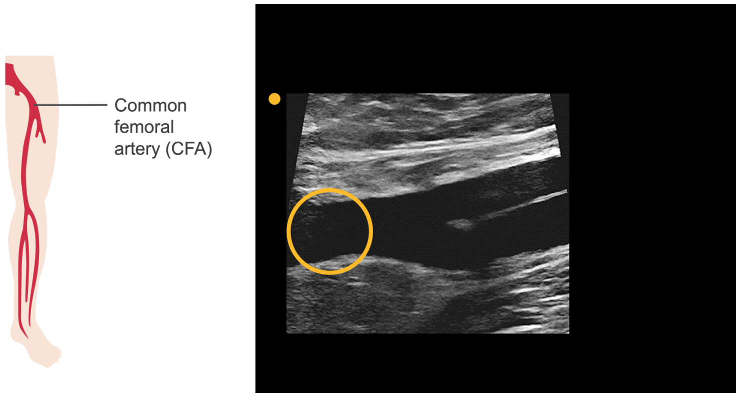


Figure 3. The common femoral artery (CFA) is located just inferior to the inguinal ligament. On an ultrasound image of a normal CFA using a longitudinal (e.g., lengthwise) view, the walls appear smooth and the lumen appears black.

At the CFA bifurcation, the CFA divides into two branches:

1. Profunda femoris artery (PFA)
2. Superficial femoral artery (SFA)

The profunda femoris artery (PFA)

The PFA, formerly known as the deep femoral artery, dives deep off of the CFA bifurcation and branches into collaterals in the thigh. Due to its deep anatomical location, it is not routinely examined on ultrasound past the CFA bifurcation. The PFA and its branches are better evaluated by computed tomography (CT), if needed.

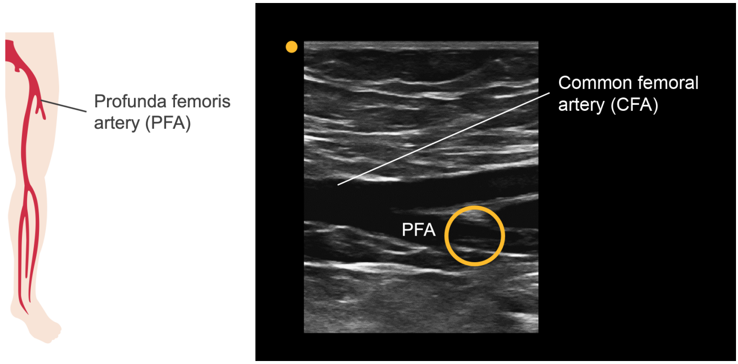


Figure 4. The profunda femoris artery (PFA) is a branch of the common femoral artery (CFA).

The superficial femoral artery (SFA)

The other branch off of the CFA bifurcation, the SFA, is also known as the femoral artery. Rather than use the general terminology, it is more useful to clarify whether you're referring to the common femoral artery, the profunda femoris artery, or the superficial femoral artery. The SFA travels from the CFA bifurcation down the medial thigh to the knee.

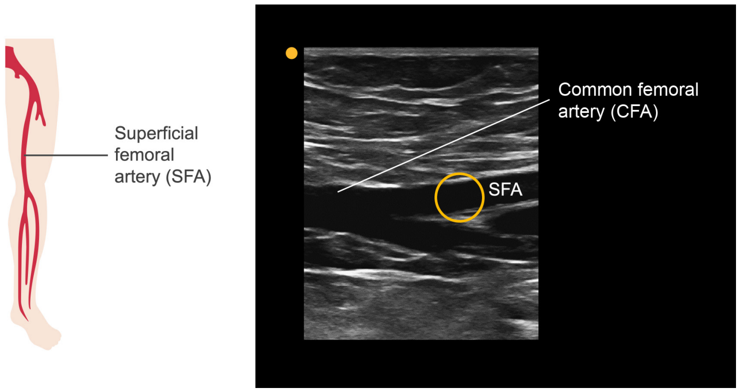


Figure 5. The superficial femoral artery (SFA), a branch of the common femoral artery (CFA), travels down the medial thigh to the knee.

The popliteal artery

The SFA becomes the popliteal artery at the posterior knee. The above-knee popliteal artery starts at the distal adductor canal (where the thigh becomes the knee), and the below-knee popliteal artery extends to the bifurcations of the calf arteries at the distal popliteal fossa.

The popliteal is the only artery where you regularly see the vein located above the artery on the ultrasound screen.

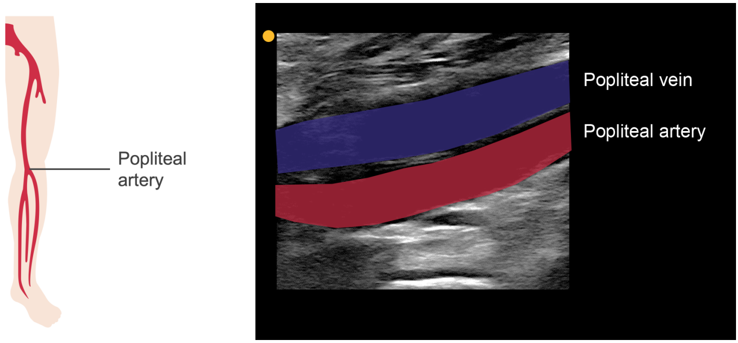


Figure 6. The superficial femoral artery (SFA) becomes the popliteal artery at the posterior knee. On ultrasound, the popliteal vein is often oriented superior to the popliteal artery.

The posterior tibial artery (PTA)

The distal popliteal artery splits into the anterior tibial artery (ATA) and the tibioperoneal trunk (TPT) at the distal popliteal fossa. The TPT immediately splits into the peroneal artery and PTA, which both travel the length of the inner calf to the ankle.

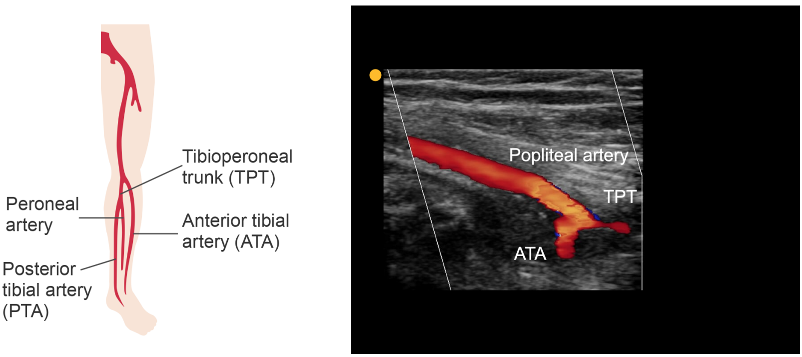


Figure 7. The distal popliteal artery branches into the anterior tibial artery (ATA) and the tibioperoneal trunk (TPT). The TPT immediately branches into the peroneal artery and posterior tibial artery (PTA).

The dorsalis pedis artery (DPA)

The ATA follows the lateral shin and becomes the DPA at the ankle. Then, it forms the pedal arch of the foot. The DPA can be evaluated in an ankle-brachial index test, known as the ABI test.

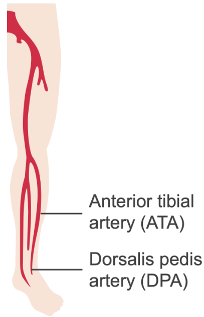


Figure 8. The anterior tibial artery (ATA) becomes the dorsalis pedis artery (DPA) at the ankle.

The three-vessel runoff

The peroneal artery, the PTA, and the ATA are commonly referred to as the three-vessel runoff. The three-vessel runoff isn't typically examined throughout the entire calf with ultrasound.

By comparing the ultrasound duplex findings at the popliteal artery to the waveforms obtained at the ankle, we can determine the presence and severity of a disease in the calf. If there is a concern from this comparison, a CT scan is ordered for a more efficient and detailed assessment of the runoff vessels.

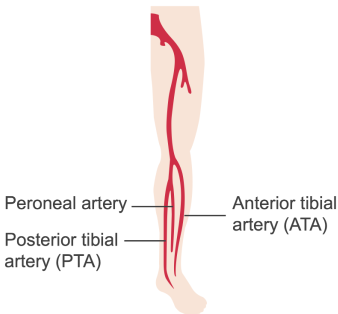


Figure 9. The arteries that form the three-vessel runoff include the peroneal artery, posterior tibial artery (PTA), and anterior tibial artery (ATA).

Recognizing risk factors and clinically diagnosing atherosclerosis

There are three types of peripheral arterial disease (PAD) in the lower extremities:

1. Atherosclerosis
2. Aneurysm
3. Trauma

First, let's dive into atherosclerosis. Atherosclerosis involves the deposit of fatty materials that form plaque on arterial walls. This results in chronic wall damage and lumen blockage due to the plaque buildup.

At severe stages, atherosclerosis can lead to chronic limb ischemia (CLI). Chronic limb ischemia increases the risk of infection and can eventually lead to amputation.

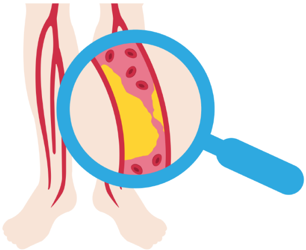
It is important to note that CLI can refer to chronic limb ischemia, but it can also mean critical limb ischemia. Make sure to differentiate the two. Critical limb ischemia can also result from acute obstructive processes, whereas atherosclerosis (with resultant CLI) is a chronic disease.

What are the risk factors for atherosclerosis?

There are three key risk factors for atherosclerosis that chronically contribute to arterial wall damage:

1. Diabetes
2. Smoking
3. Hypertension

Diabetes plays a large part in the development of arterial wall calcification and rigidity, which promote plaque collection. Smoking and hypertension are modifiable risk factors which also cause significant stress. Atherosclerosis is a long-term process and is commonly seen in older adults.



Risk factors for atherosclerosis

- Diabetes
- Smoking
- Hypertension

Figure 1. Risk factors for atherosclerosis include diabetes, smoking, and hypertension.

What are the symptoms of atherosclerotic PAD?

Claudication

The first symptom a patient feels that indicates atherosclerotic PAD is claudication. Claudication is pain with activity that is relieved with rest. Claudication usually begins in the calf, but if the disease involves the aortoiliac system, the pain can be felt in the buttock and the thigh as well.

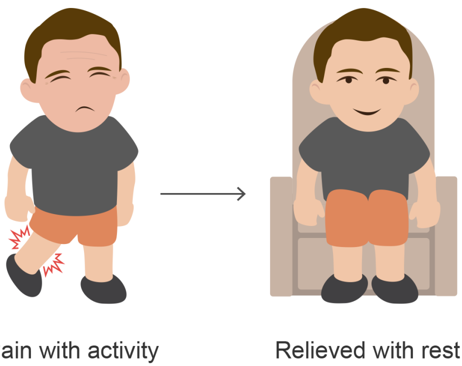


Figure 2. Claudication, a symptom of atherosclerotic peripheral arterial disease, involves pain with activity that is relieved with rest.

Rest pain

As mentioned previously, chronic and untreated atherosclerosis can evolve into advanced stages of CLI. The advanced stage typically presents with a constant, severe pain at rest which is referred to as rest pain. Rest pain usually occurs in the forefoot, heel, and toes.

These patients are urgent surgical candidates. If left untreated, they are at risk for necrosis and amputation of the affected limb.

Typically, it is obvious when a patient is suffering from rest pain. The patient appears uncomfortable, as the pain is very severe. Often, the patient dangles their leg over the side of the bed, which helps alleviate the pain by increasing blood flow to the foot.

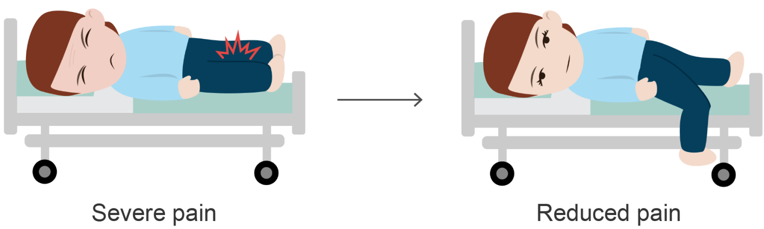


Figure 3. In patients suffering from rest pain due to chronic and untreated atherosclerosis, the severe pain can be reduced when the patient dangles their leg over the side of the bed.

How to assess a patient for atherosclerosis of the lower extremities

There are three steps to assessing a patient who presents with symptoms of lower extremity atherosclerosis:

1. Assess pedal pulses
2. Inspect the feet and lower legs
3. Perform an ankle-brachial index (ABI) test

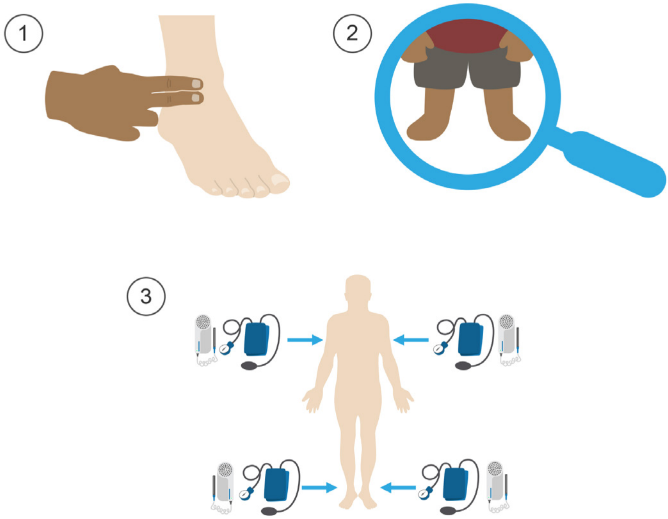


Figure 4. The three steps to assessing a patient with symptoms of lower extremity atherosclerosis include, 1) assess pedal pulses, 2) inspect the feet and lower legs, and 3) perform an ankle-brachial index test.

Let's get into each of these steps in more detail.

Step 1: Assess pedal pulses

The first step in the evaluation is to assess for pulses at the ankles. Remember that the posterior tibial artery (PTA) and dorsalis pedis artery (DPA) are the main runoff vessels. The PTA and anterior tibial artery (ATA) branch off of the distal popliteal artery, and then the ATA becomes the DPA at its distal end.

The PTA and the DPA are routinely checked for pulse strength at the ankle level.

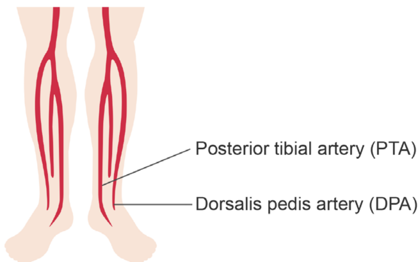


Figure 5. Pedal pulses are assessed by checking the pulse strength of the posterior tibial artery (PTA) and the dorsalis pedis artery (DPA).

When assessing pedal pulse strength, the handheld Doppler pen is extremely helpful for hearing the volume intensity of the blood flow. It can also help you hear the blood flow sound (e.g., phasicity) which can tell you if there is a proximal disease.

The Doppler should be readily available in most hospitals and clinics.
To use the Doppler, you need gel, so don't forget it!

Diminished pedal pulses can be a sign of PAD. Sometimes these vessels naturally decrease in size as they reach the ankle and can become difficult to palpate, but the pulses aren't technically diminished. This challenge increases when the extremity is edematous (where fluid accumulates in the extravascular tissue). Edema can interfere with palpation for a pedal pulse as well as with a Doppler pen.

Could it just be peripheral neuropathy?

It's important to remember that diabetes is a risk factor for PAD. However, diabetes increases a patient's risk for both PAD and peripheral neuropathy.

Peripheral neuropathy can cause decreased sensation in the extremities, painful burning in the feet, or a pins-and-needles sensation in the feet. These symptoms are very similar to PAD symptoms. The similarity in symptoms can cause confusion and delays in the diagnosis of PAD.

Since the symptoms of PAD and peripheral neuropathy are similar, make sure to diligently palpate the pedal pulses. If the pulses are strong, then the symptoms are not likely from PAD.

Possible causes of decreased sensation, burning, or pins-and-needles symptoms	**Pedal pulse strength**
Peripheral neuropathy	Strong
Peripheral arterial disease (with or without peripheral neuropathy)	Diminished
Edema	Diminished

Table 1. Distinguishing between three potential causes of decreased sensation, burning, or pins-and-needles in the lower extremities using pedal pulse strength.

Step 2: Inspect the feet and lower legs

As you perform the exam, you may recognize that some patients not only present with pain, but also have obvious signs of advanced disease. Ulcers and necrosis are the most severe signs of CLI and are visually obvious. Arterial ulcers usually occur over the tibia and feet. These ulcers are usually very painful.

Inspect both feet thoroughly!

Peripheral neuropathy involves a loss of sensation in the extremities. Patients who have both peripheral neuropathy and peripheral artery disease (PAD) will not be able to feel the pain that is typically present with ulcers and necrosis, so it's important to thoroughly inspect both feet.

Step 3: Perform an ankle-brachial index (ABI) test

If the pedal pulses are diminished, it may be helpful to assess for arterial obstruction with an ABI test. An ABI is performed by obtaining blood pressure readings in the arms and the ankles and comparing them.

An index for each leg is calculated from the readings. The calculation represents the amount of appropriate blood flow reaching the ankles from the heart.

Ideally, the ratio should be one, meaning that 100% of the blood flow is reaching the ankles. If the ratio is 0.5, then 50% of the blood flow is reaching the ankles and 50% is being blocked by PAD.

Differentiating ulcers

Discerning the cause of a patient's foot or lower leg ulcer can be difficult. However, there are ways to differentiate between arterial, venous, and diabetic ulcers. This is great news since ordering arterial and venous insufficiency studies for every wound is expensive and a waste of resources.

Sometimes the cause of an ulcer is a combination of arterial disease, venous disease, and diabetes. However, ulcers often have one primary cause, and there are ways to tell these types of ulcers apart.

There are three steps to follow when you begin to evaluate a patient with a foot or lower leg ulcer:

1. Check pedal pulses
2. Ask if the wound is painful
3. Inspect the ulcer

Step 1: Check pedal pulses

Start your evaluation with a pedal pulse check. You can begin the check with manual palpation. Ideally, you'll want to check for a pulse with a Doppler pen, especially if you can't manually palpate the pulses.

If the pulses sound strong in volume and you can hear two or three separate sounds (e.g., phases) per pulse, the arteries are patent. This means that the wound is not due to arterial limb ischemia, and you can move on to venous disease and diabetic ulcer differentiation.

The waveform sounds from the Doppler will also give you a general idea of the presence or absence of peripheral arterial disease (PAD).

Step 2: Ask if the wound is painful

Typically, arterial ulcers are extremely painful. Venous ulcers can present with dull and achy pain in the entire leg, but the wound area itself usually doesn't hurt unless it's infected. Diabetic ulcers may present with the pins-and-needles pain or a loss of sensation that is associated with peripheral neuropathy.

Step 3: Inspect the ulcer

It's also important to inspect the ulcer and note the border, depth, and location. A quick trick to watch for is that arterial and diabetic ulcers look alike and occur in tandem, but venous ulcers are usually identified by clinical examination.

Figure 1. The steps for evaluating a foot or leg ulcer include, 1) check pedal pulses, 2) ask if the wound is painful, and 3) inspect the ulcer.

Now, let's get into more detail on how to differentiate between the three types of ulcers.

Signs and symptoms of arterial ulcers

Typically, arterial ulcers are extremely painful. However, it's important to remember that patients who also experience peripheral neuropathy may not feel them at all.

Chronic arterial ulcers look like deep, round hole punches with regular, well-defined, raised borders. The area around the ulcer will feel dry and cold and the skin may be cracked. The pedal pulses will be weak or absent.

Arterial ulcers are mostly located on the toes, between the toes, around the lateral ankle, or on the tibia. Severe late-stage arterial ulcers can present as gangrenous chronic limb ischemia (CLI) involving the toes.

Chronic arterial ulcers are due to arteries that are slowly blocked over time. These ulcers are usually seen in older adults. The progressive blockage of the arteries decreases blood flow to an area which causes the tissue to die. The pain that is associated with these arterial blockages can be improved by dangling the leg, which increases blood flow to the area.

Not all people with severe peripheral arterial disease (PAD) have ulcers!

The slow process of plaque buildup allows for the development of collateral arteries, which are new arterial branches that can provide additional blood flow to the area. Identifying the presence of collateral flow can help you decide the need for an intervention.

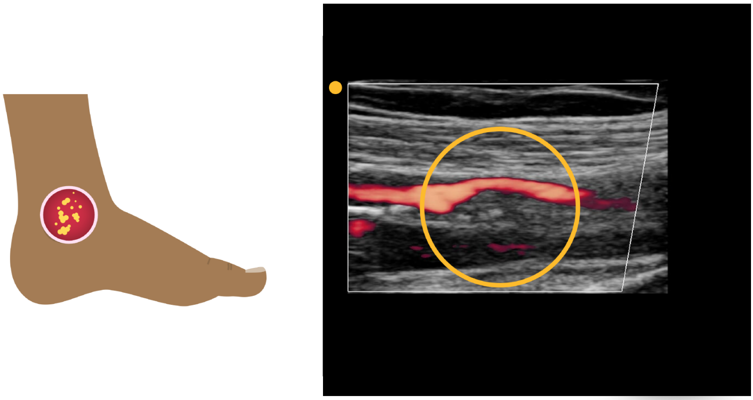


Figure 2. Arterial ulcers are typically deep with round, regular, and well-defined borders. On ultrasound, you can visualize plaque buildup within an artery that has led to the appearance of a chronic arterial ulcer.

If you suspect an arterial ulcer based on clinical findings and the patient's presentation, order an ankle-brachial index (ABI).

Signs and symptoms of venous ulcers

Most lower extremity ulcers are venous ulcers. These ulcers are due to weak valves in the veins which create increased pressure in the leg tissues. They are associated with edema, varicose veins, and scaly alligator-like skin.

Chronic venous ulcers weep fluid and have irregular, shallow borders. Some patients note that their socks or pant legs are wet from unwrapped wound discharge.

Venous ulcers are generally located in the distal medial calf and ankle. Arterial pedal pulses will be strong. But, don't be fooled! The pulses may be difficult to find if the patient has edema.

Pain caused by venous ulcers is a dull, achy pain that is improved by elevating the leg, as opposed to dangling, like in arterial blockages.

Figure 3. Venous ulcers typically weep fluid and have irregular, shallow borders.

> If you suspect a venous ulcer, a venous insufficiency ultrasound should be ordered, not an arterial ultrasound.

Signs and symptoms of diabetic ulcers

Diabetic ulcers are caused by hyperglycemia. Notably, most nontraumatic amputations are due to diabetic ulcers.

The borders of diabetic ulcers are usually raised and round. They are often located on the bottom of the feet and are associated with skin cracks, blisters, and sores. They appear red and warm in the earlier stages and then progress to eschar and gangrene in the later stages.

Patients with diabetes frequently present with peripheral neuropathy (pins-and-needles pain or total loss of sensation) due to nerve damage. The patients will also have strong pedal pulses, and their arterial and venous tests are typically normal.

Remember, strong pedal pulses are usually present with venous or diabetic ulcers, whereas weak or absent pedal pulses are present with arterial ulcers. This is an extremely important differentiation that can be determined at the beginning of the exam.

Figure 4. Diabetic ulcers typically occur at the bottom of the foot and are usually raised and round.

You can quickly differentiate all three ulcer etiologies by comparing their clinical presentations.

		Arterial ulcers	Venous ulcers	Diabetic ulcers
Step 1: Pedal pulse		• Weak or absent	• Strong • May seem weak due to edema	• Strong
Step 2: Pain		• Typically severe (but absent if the patient also has peripheral neuropathy) • Improved by dangling the leg (increasing blood flow)	• Possibly dull and achy • Improved by elevating the leg	• May also present with peripheral neuropathy (pins-and-needles pain or loss of sensation)
Step 3: Inspect	Location	• On or between toes • Lateral ankle • Tibia	• Distal medial calf and ankle	• Bottom of the foot
	Depth	• Deep	• Shallow	• Usually deep
	Border	• Round • Raised • Regular, well-defined	• Irregular	• Round • Raised
	Skin	• Cracked • Dry • Cold • May present as gangrenous chronic limb ischemia (CLI) involving the toes in severe, late stages	• Alligator-like • Scaly • Edema • Weepy wound • Varicose veins	• Cracked • Blistered • Sores • Red and warm in early stages • Eschar and gangrene in later stages

Table 1. Summary of typical findings with arterial, venous, and diabetic ulcers.

How to tell if a patient with diabetes also has arterial CLI

A patient with diabetes can have diabetic ulcers in conjunction with arterial CLI. Thus, if the patient's pulses are weak and the wound has arterial CLI characteristics, it warrants a quick ABI test.

If the pulses are bounding, the arterial ultrasound will likely reveal arterial wall calcification rather than atherosclerosis. Arterial wall calcification will show up as black acoustic shadowing on ultrasound. Depending on which wall the plaque is on, the shadowing can happen over the whole artery (if on the anterior wall), or under the artery alone (if on the posterior wall).

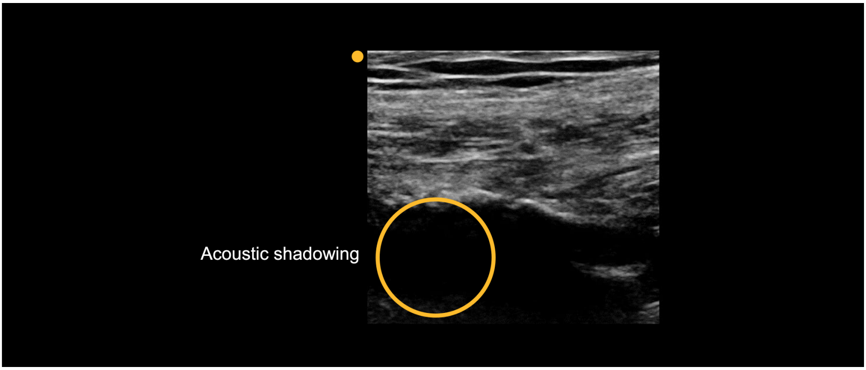


Figure 5. Arterial wall calcification can be identified on ultrasound by the appearance of black acoustic shadowing either over the whole artery or under the artery alone.

Managing atherosclerosis

Atherosclerotic peripheral arterial disease (PAD) can be treated with medication and / or surgery. Let's review both of these treatment options and when each option is indicated.

Medication use for atherosclerotic PAD

The management of mild atherosclerosis with medication mainly consists of statin drug therapy. Statins lower cholesterol which reduces plaque buildup on the artery walls that leads to blockage. In 2006, statins were reported to clear plaque out of coronary arteries, and have been used with similar hopes in patients with atherosclerosis in the lower extremities.

If the patient's symptoms are not bothersome, management with medication can be an effective way to prevent further plaque buildup and potentially clear plaque out of the arteries. As well, it avoids an invasive surgical intervention.

With mild atherosclerosis, surgeons employ a watchful waiting practice which includes serial visits to clinically track symptoms and perform ultrasounds. Ultrasounds provide information on the severity of the disease and its pace of advancement.

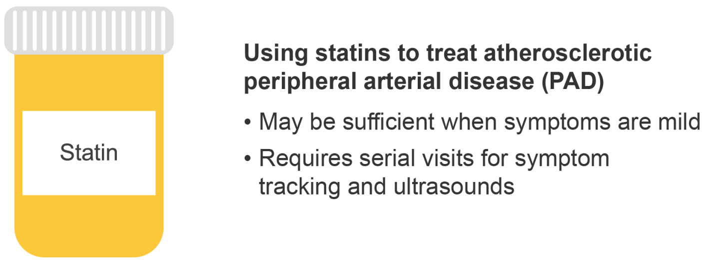


Figure 1. Using statins to treat atherosclerotic peripheral arterial disease (PAD) may be sufficient when symptoms are mild. This approach requires serial appointments to track symptoms and perform ultrasounds.

Sometimes, even with complete femoropopliteal occlusion, the symptoms are not severe enough for surgery. Collateral artery growth in response to chronic arterial blockage can provide adequate flow to the calf and foot, which prevents rest pain and ulcers. Collaterals act as a great collection of naturally grown bypass grafts.

During the watchful waiting period, frequent and purposeful walking can help promote collateral circulation growth.

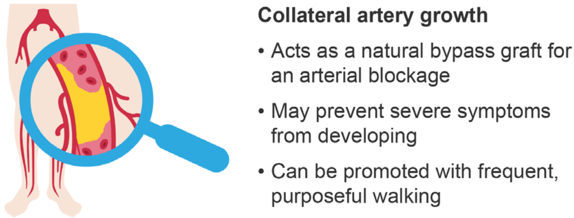


Figure 2. Collateral artery growth acts as a natural bypass graft for an arterial blockage, may prevent severe symptoms from developing, and can be promoted with frequent, purposeful walking.

Surgical treatment options for atherosclerotic PAD

Treatment to reopen or bypass the artery is usually elective until the patient experiences rest pain or ulcers, or if the ankle-brachial index (ABI) drops to 0.5 or less (regardless of symptoms).

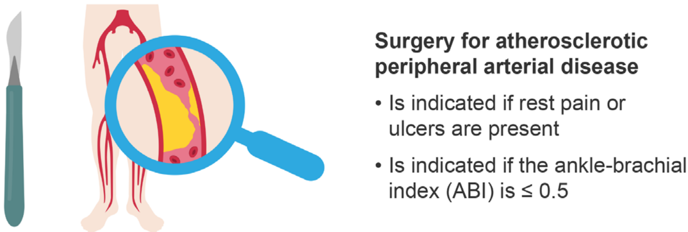


Figure 3. Surgery for atherosclerotic peripheral arterial disease (PAD) is indicated if the patient experiences rest pain or ulcers, or has an ankle-brachial index (ABI) of 0.5 or less.

Surgical treatment for severe atherosclerosis consists of four options:

1. Endarterectomy
2. Angioplasty
3. Stent placement
4. Bypass graft

Endarterectomy is the surgical removal of part of an artery's inner lining along with the obstructive plaque. This procedure is also referred to as a roto-rooter procedure. On the other hand, angioplasty is the unblocking of a vessel using an expandable balloon catheter that pushes plaque up against the artery walls.

If a bypass graft surgery is anticipated, usually lower extremity ultrasound vein mapping is requested to measure the great saphenous vein (GSV) diameter. This helps you decide if the GSV is viable as an autologous graft to bypass the diseased artery.

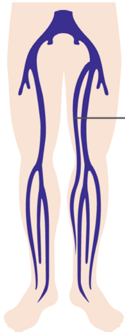


Figure 4. The great saphenous vein (GSV) runs along the length of the lower leg. It can be used as the source of an autologous graft to bypass a diseased artery.

Material for an autologous bypass graft is taken from the patient's body, as opposed to an allogenic bypass graft which is taken from donated material. Autologous grafts are preferred over allogenic grafts because there is a lower risk of infection.

Note that post-surgical patients will return for long-term follow-ups with serial ultrasounds after their surgery.

It is very useful to perform a preoperative ABI as a baseline so that later ABI tests can be used to evaluate the surgery's success and the healing progress. A preoperative ABI can be done alongside the ultrasound vein mapping.

Unfortunately, sometimes advanced damage has already been done to the tissue that wasn't receiving adequate blood flow. In this case, a surgical repair or bypass will not help, and amputation is unavoidable.

Evaluating aneurysms

When peripheral arterial disease (PAD) occurs in the lower extremities, the causes can include atherosclerosis, aneurysm, or trauma. Let's review the risk factors of lower extremity arterial aneurysms as well as symptoms and potential treatments for this type of PAD.

With true aneurysms, the artery wall layers become weak and balloon out. A vessel is considered aneurysmal when it is dilated at least 1.5 times the size of the proximal segment.

> Note that on ultrasound, arteries are measured from the outermost part of the walls.

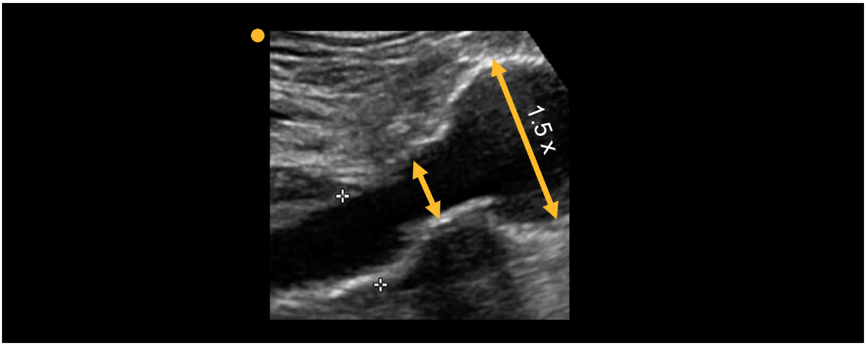


Figure 1. A bulge in a vessel is considered to be an aneurysm if it measures 1.5 times the size of the proximal segment.

Risk factors for lower extremity arterial aneurysms

There are seven known risk factors for lower extremity aneurysms:

1. Male sex
2. Disorders involving weak connective tissue
3. Congenital vessel wall weakness
4. Hypertension
5. Nicotine use
6. Repetitive arterial compression
7. Trauma

True aneurysms are more prevalent in biological males but can develop in anyone with weak connective tissue, such as Marfan's syndrome. It can also occur in weak vessel walls, which is largely due to congenital disorders.

Hypertension and nicotine use are risk factors for aneurysms that develop over time. As well, repetitive compression, such as popliteal artery entrapment, can increase the risk of aneurysms. Aneurysms can also acutely occur from trauma.

Risk factors for lower extremity aneurysms

- Male sex
- Disorders involving weak connective tissue
- Congenital vessel wall weakness
- Hypertension
- Nicotine use
- Repetitive arterial compression
- Trauma

Figure 2. Risk factors for a lower extremity aneurysm include male sex, disorders involving weak connective tissue, congenital vessel wall weakness, hypertension, nicotine use, repetitive arterial compression, and trauma.

Here's a good tip regarding aneurysms.

If the patient has a known abdominal aortic aneurysm (AAA), they should be scanned for lower extremity arterial aneurysms. These most often occur in the popliteal artery but can be seen in the common femoral artery (CFA) as well.

Signs and symptoms of a lower extremity aneurysm

Signs and symptoms of a lower extremity arterial aneurysm can vary, depending on the patient's situation:

- Pain and bulging or no symptoms
- Blue toe syndrome or acute ischemia

Pain and bulging or no symptoms

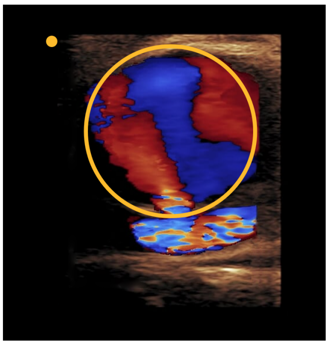
A patient with a lower extremity arterial aneurysm can present with pain and / or bulging in the area of the aneurysm. Aneurysms are usually painful if thrombotic or ruptured but are often otherwise asymptomatic.

Even if the patient is asymptomatic, a thorough and routine exam of the common femoral artery (CFA) and the popliteal artery can reveal a pulsating mass in the groin or behind the knee. Aneurysms can also be found incidentally on imaging of the CFA and the popliteal artery areas that was ordered for unrelated indications.

Asymptomatic aneurysms will likely have a normal ankle pedal pulse check and a normal ankle-brachial index (ABI) test. Normal pedal pulse checks and ABI results indicate that the aneurysm is not disrupting blood flow (yet).

Note that pseudoaneurysms look like true aneurysms on ultrasound, but they are not part of the actual artery.

Pseudoaneurysms occur when there is a puncture through the artery wall and blood leaks into the tissue.



Blue toe syndrome or acute ischemia

Occasionally, mural thrombus can occur with a true aneurysm. Mural thrombus, a coagulation of blood along the inner wall of an aneurysm, is associated with an increased risk of rupture and an embolism.

Aneurysms become symptomatic when a mural thrombus lodges in any number of toe arteries. This is referred to as blue toe syndrome, which is very painful and reflects sudden cyanosis.

Large embolic showers can block runoff arteries, causing acute limb ischemia of the calf and foot. A mural thrombus can also expand to occlude the aneurysm and completely block blood flow to the lower leg. These symptoms are emergencies, not only because of the risk of aneurysmal rupture but also because the lower extremities are at risk of irreparable damage that could result in amputation.

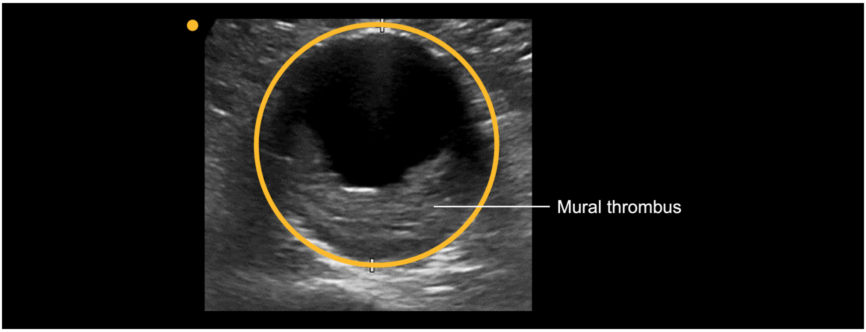


Figure 3. Blood coagulation along the inner wall of an aneurysm is called a mural thrombus, and is associated with an increased risk of rupture and embolism.

How to assess a lower extremity arterial aneurysm

If you palpate a pulsating mass or encounter blue toe syndrome, order an arterial duplex ultrasound rather than an ABI test. An ABI will show you the overall circulation in the lower extremities by providing waveforms and calculations. If a large aneurysm exists but is patent and allows normal blood flow to the ankles, it will not be detected by an ABI.

The arterial duplex ultrasound will obtain images of the artery and locate the aneurysm, which can then be examined and measured. For example, if a patient with a history of AAA was found to have a CFA aneurysm when they were scanned with a duplex ultrasound, the ABI for that patient would be normal.

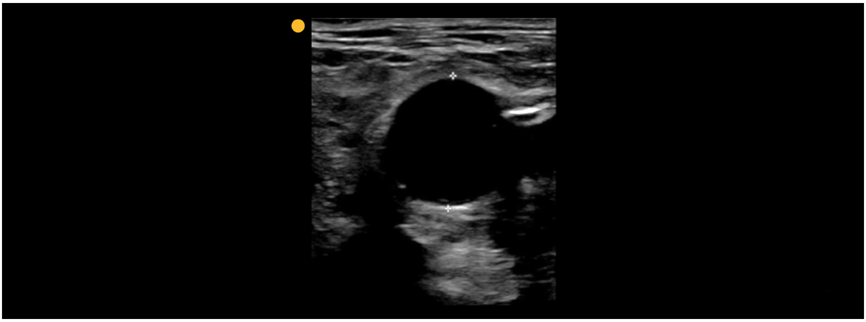


Figure 4. An arterial duplex ultrasound can be used to locate an arterial aneurysm, which can then be examined and measured.

When and how to treat a lower extremity aneurysm

Asymptomatic lower extremity aneurysms smaller than 2 cm can be followed on serial duplex ultrasounds. When the aneurysm becomes larger than 2 cm, elective treatment is an option. If the aneurysm becomes symptomatic, treatment is necessary.

Symptomatic?	Size	Treatment recommendations
No	< 2 cm	Follow with serial duplex ultrasounds
	> 2 cm	Elective treatment is an option
Yes		Treatment is necessary

Table 1. Treatment recommendations for lower extremity arterial aneurysms based on size and symptoms.

Once a diagnosis has been made, three treatment options exist for true lower extremity aneurysms:

1. Tie off the aneurysm and create a bypass.
2. Cut the aneurysm out of the vessel and insert a bypass graft to reconnect the artery.
3. Place a stent-graft through the arterial aneurysm so that blood directs through the stent only (e.g., excluding the aneurysm).

Assessing peripheral artery disease

Peripheral arterial disease (PAD) in the lower extremities can be caused by atherosclerosis, aneurysm, or trauma. This article will cover the assessment and treatment of trauma-related arterial damage.

Traumatic arterial wall damage can be caused by a laceration or puncture from a broken bone that occurred during a fall or a motor vehicle accident. Another example is trauma from a knife or gunshot wound. Unfortunately, sometimes traumatic arterial damage is iatrogenic, meaning that it is caused by a physician during a procedure.

Let's review the assessment and treatment of two potential outcomes of trauma-related arterial injury:

1. Acute limb ischemia (ALI)
2. Pseudoaneurysms

Acute limb ischemia (ALI)

Traumatic arterial damage can cause ALI, which is clinically diagnosed with the five Ps:

1. Pain
2. Pallor (e.g., unhealthy, pale skin)
3. Pulselessness
4. Paresthesia (e.g., pins-and-needles sensation)
5. Paralysis

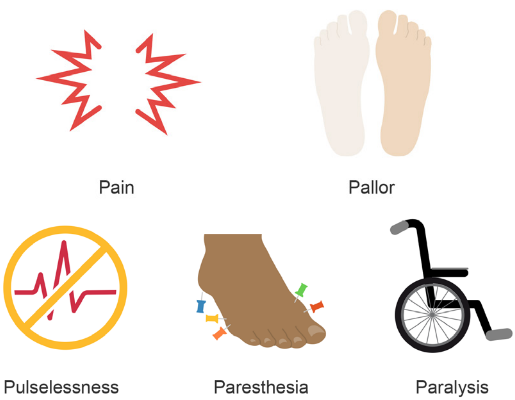


Figure 1. The five Ps of acute limb ischemia include pain, pallor, pulselessness, paresthesia, and paralysis.

How to treat ALI

Acute limb ischemia is a surgical emergency because it can result in sudden necrosis. Usually, there is no time to obtain an ultrasound.

Confirmation of absent peripheral pulses on palpation can be performed with a portable Doppler pen. But, the patient is likely to go straight to the catheterization laboratory or the operating room.

Figure 2. Because acute limb ischemia (ALI) can result in sudden necrosis, it is considered a surgical emergency.

Pseudoaneurysms

Iatrogenic arterial wall trauma can occur during a procedure such as vessel catheterization. The catheter can accidentally penetrate the arterial wall causing blood to leak out into the surrounding tissue. This contained rupture is called a pseudoaneurysm.

A common iatrogenic pseudoaneurysm results from catheterization of the common femoral artery in the groin. It usually presents as a pulsatile mass in one side of the groin.

With a pseudoaneurysm, blood flows from the artery through the puncture and forms into a round collection of active blood flow. This blood collection is connected to the artery by a neck (e.g., a trail of blood between the artery and the blood collection).

The blood flow swirls within the pseudoaneurysm, creating a yin-yang color effect on an ultrasound. The neck is characterized by to-and-fro flow, meaning that the blood actively flows back and forth from the artery to the pseudoaneurysm.

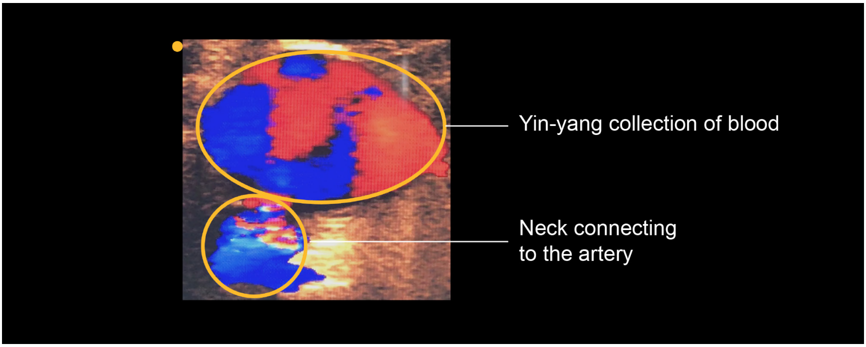


Figure 3. On ultrasound, a pseudoaneurysm takes on a yin-yang appearance, which is caused by a round collection of active blood flow that is connected to an artery by a neck.

Arterial duplex ultrasounds are useful for diagnosing pseudoaneurysms because they provide a direct image of the pseudoaneurysm that can be used for further evaluation.

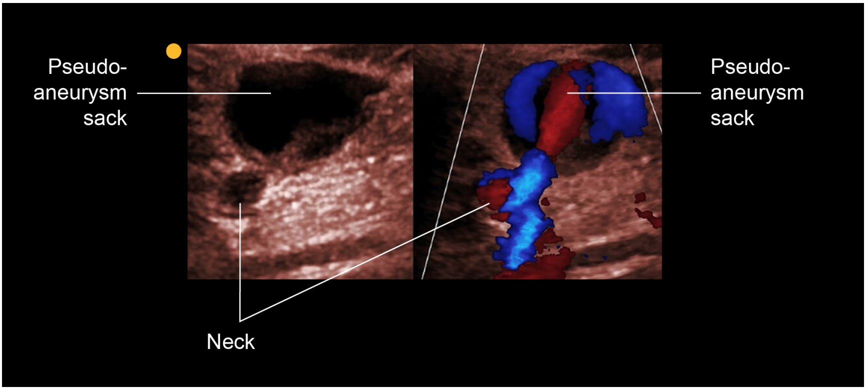
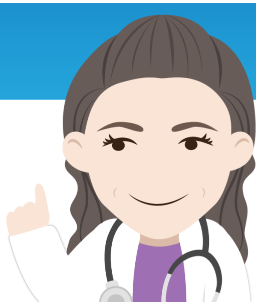


Figure 4. Obtaining an arterial duplex ultrasound of a pseudoaneurysm can be helpful because the images can facilitate further evaluation.

Expect the ankle-brachial index (ABI) to be normal with a pseudoaneurysm.

Even a large pseudoaneurysm does not usually steal enough blood flow to affect the amount that gets to the ankle. For this reason, ankle-brachial indexes are typically normal and do not provide any useful information about whether the patient has a pseudoaneurysm or not.



How to treat pseudoaneurysms

In most cases, a small pseudoaneurysm that is not quickly expanding isn't a surgical emergency. Most physicians wait and watch to see if the pseudoaneurysm becomes thrombotic on its own over the next one to two days.

If the pseudoaneurysm does not clot, there is the option of performing a 20-minute manual compression of the pseudoaneurysm's neck. This procedure attempts to cut off blood flow from the artery and causes thrombosis of the pseudoaneurysm. Sometimes, the compression is done with the ultrasound probe to track progress.

Recently, the standard of care for pseudoaneurysms has become an injection of thrombin under ultrasound guidance. Thrombin causes the blood in the pseudoaneurysm to clot. Ultrasound is used to confirm the needle placement, visualize the injection, and ensure that there is no extension into the native artery (which can cause embolism).

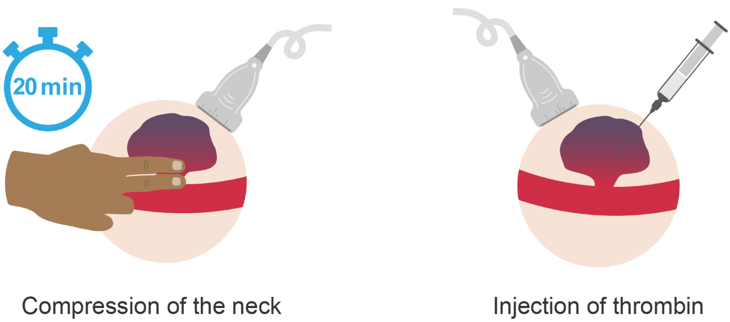


Figure 5. Two options for the treatment of a non-thrombotic pseudoaneurysm include a 20-minute manual compression of the pseudoaneurysm's neck or injection with thrombin.

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Chapter 2

ORDERING AND INTERPRETING THE ANKLE-BRACHIAL INDEX (ABI)

Recognizing when to order an ABI

An ankle-brachial index (ABI) test provides a lot of useful information and is a quick, noninvasive way to check for obstructive peripheral arterial disease (PAD). Before we get into what the ABI represents and when ordering one might be useful, you should be aware that there are two components of an automated ABI report:

1. The quantitative portion consisting of the ABI ratio.
2. The qualitative portion consisting of the audible and analog waveforms.

The quantitative portion consists of a ratio of the systolic blood pressure taken in the ankle over the systolic blood pressure taken in the arm. This calculation creates the index value.

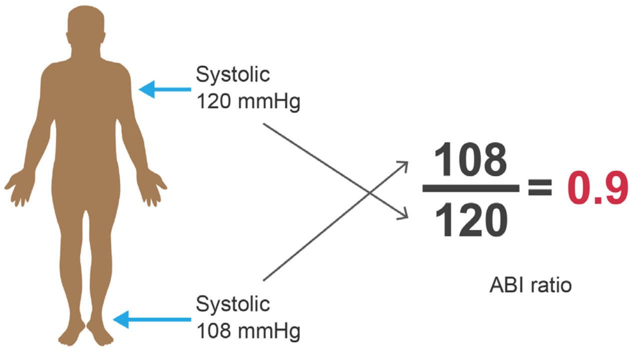


Figure 1. The quantitative portion of an automated ankle-brachial index (ABI) report consists of a ratio which is calculated by dividing the systolic blood pressure in the ankle by the systolic blood pressure in the arm.

The qualitative component of an ABI test consists of the audible and analog waveforms produced by the Doppler on an automated ABI machine. These waveforms, in conjunction with the ratio, are used to classify the presence and degree of blockage.

It's important to note that there's a key difference between manual ABIs (which only require a Doppler pen and blood pressure cuff and pump) and automated ABIs (which require an automated ABI machine). Both the manual and automated methods provide us with ratios and audible waveforms. But, only an automated ABI machine can provide us with analog waveforms.

The most useful part of analog waveforms is that they can be printed in a report and shared. The waveforms are then correlated with the ABI ratios to help with diagnosis.

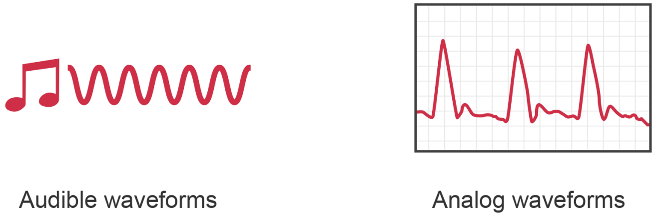


Figure 2. The qualitative portion of an automated ankle-brachial index (ABI) report consists of audible waveforms, which can only be heard, and analog waveforms, which can be printed in a report.

What does the ABI test mean?

The ABI represents the percentage of blood flow that is traveling from the heart to the ankles. Ideally, the index should be 1, which means that 100% of the blood is reaching the ankles. In fact, the index can be slightly greater than 1 due to hydrostatic pressure that naturally increases from standing during the day.

On the other hand, an ABI of 0.5 means that only 50% of the blood is reaching the ankles, and 50% is blocked by PAD.

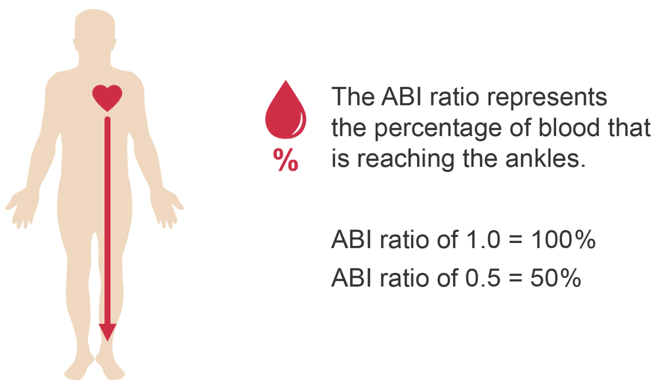


Figure 3. When performing an ankle-brachial index (ABI) test, the ABI ratio represents the percentage of blood that is reaching the ankles.

When is an ABI indicated?

An ABI can be used to evaluate a patient for suspected occlusive PAD, but not for a patent aneurysm without obstructive mural thrombus. As well, it would be rare to have enough mural thrombus to show up on an ABI unless an aneurysm was occluded by mural thrombus (then acute limb ischemia would happen).

Keep in mind that PAD is not ruled out by a normal ABI. Rather, the ABI results help differentiate what type of PAD the patient may have.

For example, patients with PAD due to a true aneurysm or even an active pseudoaneurysm will usually have normal ABI results. However, patients who have PAD that is of an occlusive etiology will have abnormal ABI results. Thus, the ABI is mostly used when an occlusive disease is suspected, such as atherosclerosis.

With a patient who has atherosclerotic PAD, one would expect abnormal ABI ratios and abnormal ABI waveforms.

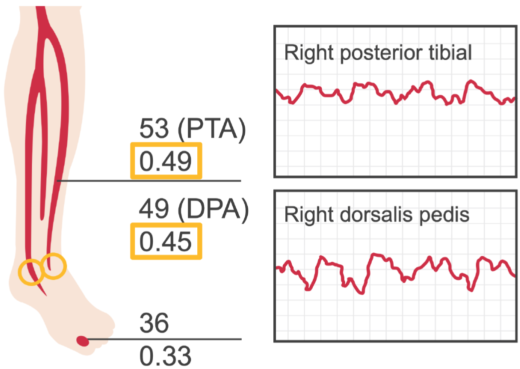


Figure 4. A patient with atherosclerotic peripheral arterial disease would be expected to show abnormal ankle-brachial index (ABI) ratios and abnormal waveforms.

Interpreting ABI waveforms

During an automated ankle-brachial index (ABI) test, ABI ratios are calculated and included in the patient report. While waveforms are only audible when using Doppler during a manual ABI, an automated ABI machine's Doppler probe also provides analog waveforms, which form an important component of the report.

Understanding how to interpret both the audible and analog waveforms of an automated ABI machine is especially important in circumstances where the ABI ratios are inaccurate and irrelevant. For example, some vessels are so calcified that they resist compression and falsely elevate the ABI ratio.

How to position the Doppler probe

Before we get into how to interpret audible and analog waveforms, let's review how to position the Doppler probe when performing an ABI. Pulse sounds (e.g., audible waveforms) and analog waveforms are qualitative data produced by the Doppler probe. The sound is crucial, but it is not recorded. Only the analog waveforms are recorded, and their quality is dependent on the skill of the person using the Doppler probe.

It is easy to make a healthy vessel look diseased, but it is not easy to make a diseased vessel look healthy. In other words, audible and analog waveforms may overestimate the presence of disease if the technique is poor.

Good technique comes with practice and experience. Ideally, the pen is held at 45° (or less) to the vessel or skin, and is pointed towards the heart. The more perpendicular you are to the vessel, the more you will overestimate the severity of disease.

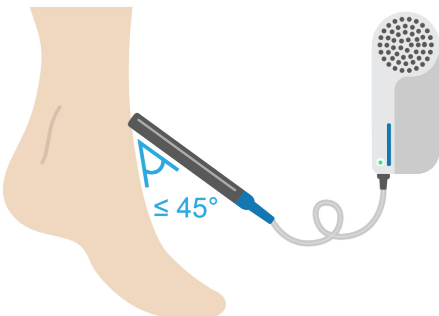
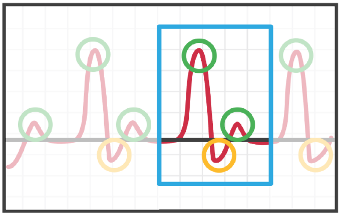


Figure 1. Good technique for a Doppler probe involves holding the pen at 45° or less to the vessel or skin and pointing towards the heart.

Waveforms are named by the number of times they cross the baseline.

Another way to understand it is waveforms are named by the number of peaks and pits around the baseline. Ideally, an analog waveform should be triphasic with two peaks and one pit.



How to avoid waveform artifacts

Artifacts can appear on analog waveforms as multiple tiny peaks and pits. Artifacts are errors, not true peaks and pits, and they can make waveforms difficult to classify.

There are two reasons why artifacts may be introduced:

1. The user has a shaky hand.
2. There is venous flow interference.

A tip to avoid venous flow interference is to press gently on the vein with the probe. Since the vein has lower pressure, it will collapse. The venous flow will pause and allow for a clear arterial Doppler reading without artifacts.

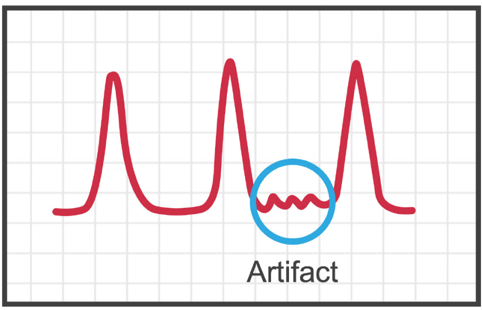


Figure 2. An artifact on a waveform appears as multiple tiny peaks and pits, which can make the waveforms difficult to interpret and classify.

How to interpret audible and analog waveforms

In general, waveforms that consist of two peaks and one pit are ideal and considered normal. These are called triphasic waveforms.

As peripheral arterial disease (PAD) worsens from mild to severe, the waveforms change. First, they decrease in the number of peaks and pits, then they develop rounded upstrokes or humpback peaks (e.g., wide peaks without pits), and finally, all peaks and pits become absent.

There are five stages of waveform degradation that occur with worsening PAD:

1. Biphasic (mild)
2. Weak biphasic (moderate)
3. High monophasic (moderate)
4. Dampened monophasic (severe)
5. Absent (critical)

First, let's cover what triphasic waveforms look and sound like. Then, we will describe each stage of waveform degradation so you can master how to interpret both audible and analog waveforms across PAD stages.

Triphasic waveforms (normal)

The healthiest waveforms are called triphasic, meaning they have two peaks and one pit that are both audible and visible. A triphasic waveform indicates that a shift of direction in blood flow is occurring, which reflects normal vessel flexibility.

A triphasic waveform features a sharp incline to the tallest peak; the upstroke represents an acceleration of blood flow to a peak systole. The pit is early diastole, which is the reversal of flow. The second peak is late diastole, which is the forward flow. Essentially, triphasic waveforms represent blood flow that is normal at rest.

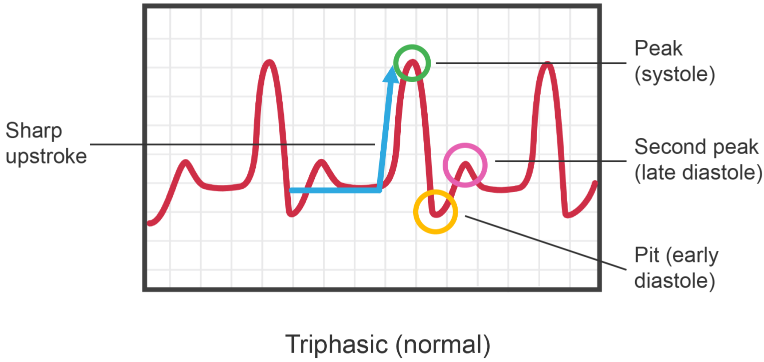


Figure 3. Normal, triphasic ankle-brachial index (ABI) waveforms feature a sharp upstroke to the tallest peak (blood flow acceleration during systole), a pit (reversal of flow during early diastole), and a second peak (forward flow during late diastole).

With audible triphasic waveforms, you'll notice three distinct sounds that follow the pattern peak-pit-peak (e.g., one pit and two peaks).

Biphasic waveforms (mild)

Artery walls lose elasticity as they become diseased, which is reflected in a loss of humps in the ABI waveforms. Audible biphasic waveforms only have two sounds, and visually (e.g., on analog) have only one peak and one pit. Notably, biphasic waveforms still have a sharp upstroke to the tallest peak.

The loss of the second peak can sometimes be due to an asymptomatic loss of elasticity in the artery. This is due to wall calcification, which is worse with atherosclerosis and diabetes but can also develop naturally with age. Wall calcification can become severe at a younger age in patients with diabetes.

Patients with biphasic waveforms usually present with symptoms of intermittent claudication. However, biphasic waveforms can also be found in patients with mild to moderate arterial insufficiency. Correlating the waveforms with the ABI ratios helps decipher the cause of the biphasic waveforms. For example, if the ABI is 1.0 and the waveform is biphasic, there could be mild calcification in the vessels but no significant atherosclerosis. Biphasic waveforms obtained with an ABI of 0.7 indicate mild to moderate PAD.

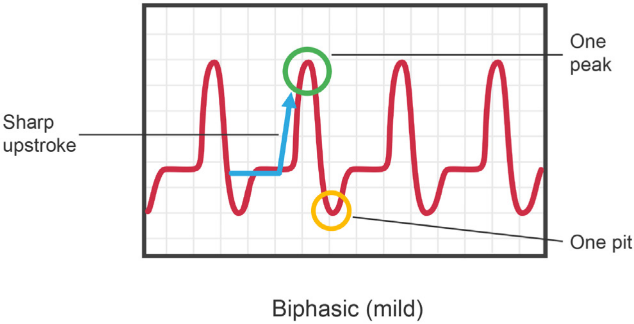


Figure 4. Biphasic ankle-brachial index (ABI) waveforms caused by mild peripheral arterial disease (PAD) features a sharp upstroke, one peak, and one pit.

When listening to biphasic waveforms, you'll notice only two distinct sounds. As long as the waveforms are multiphasic, biphasic, or triphasic (e.g., not monophasic), the situation is not an immediate surgical concern.

Weak biphasic waveforms (moderate)

Waveforms with a sharp upstroke and shallow pits are called weak biphasic. They are found when there is moderate arterial insufficiency.

Weak biphasic waveforms are best analyzed using analog (not audible) waveforms. Similar to the biphasic waveforms, you can still expect to hear one peak and one pit. But, the difference with weak biphasic waveforms is that the upstroke (e.g., peak) is usually louder than the pit.

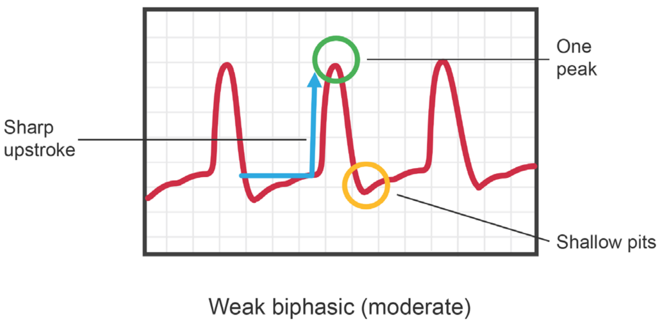


Figure 5. Weak biphasic ankle-brachial index (ABI) waveforms caused by moderate peripheral arterial disease (PAD) features a sharp upstroke, one peak, and shallow pits.

High monophasic waveforms (moderate)

When the waveforms have no pits but still have one peak with a sharp upstroke, they are called high monophasic. These waveforms also represent moderate arterial insufficiency.

Distinguishing between high monophasic and dampened monophasic waveforms can be difficult. It involves a subjective component which is dependent on the experience of the operator. Experienced operators can appreciate the sharp upstroke found with high monophasic—as opposed to the dampened waveforms that are seen with more severe forms of PAD.

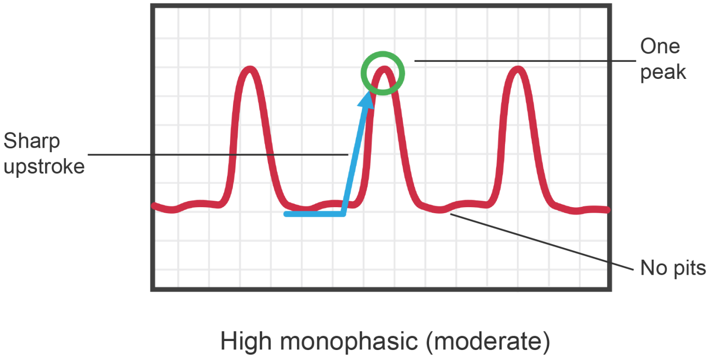
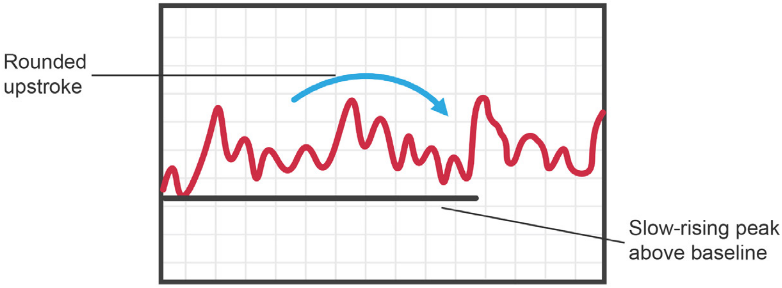


Figure 6. High monophasic ankle-brachial index (ABI) waveforms caused by moderate peripheral arterial disease (PAD) features a sharp upstroke, one peak, and no pits.

Dampened monophasic waveforms (severe)

Dampened humpback monophasic waveforms indicate severe PAD. There is a slow-rising peak above the baseline and the upstroke is rounded—not sharp. Dampened monophasic waveforms can be seen with non-healing ischemic ulcers.

Note that dampened monophasic waveforms are also commonly called *tardus parvus waveforms*.



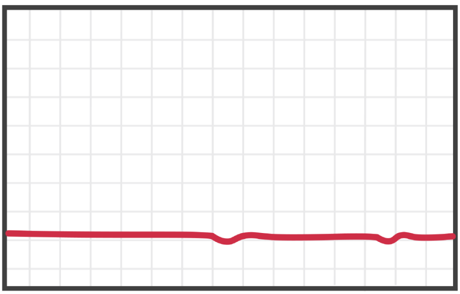
Dampened monophasic / tardus parvus (severe)

Figure 7. Dampened monophasic ankle-brachial index (ABI) waveforms caused by severe peripheral arterial disease (PAD) features a slow-rising peak above the baseline and a rounded upstroke.

When listening to dampened monophasic waveforms, you'll hear only one peak and continuous flow throughout the cardiac cycles.

Absent waveforms (critical)

Absent ABI waveforms are due to a lack of peripheral pulses. They are found in patients with rest pain and critical limb ischemia.



Absent (critical)

Figure 8. The absence of ankle-brachial index (ABI) waveforms is caused by a lack of peripheral pulses from critical peripheral arterial disease (PAD).

Interpreting ABI numbers

An ankle-brachial index (ABI) report consists of two parts—the qualitative and quantitative data. The quantitative portion includes the ABI ratios and the patient's blood pressure measurements from both arms and both ankles. Let's go over which pressures are measured, how they are used to calculate the ABI ratios, and how to interpret these numbers.

Which blood pressures are measured to calculate the ABI?

To calculate the ABI ratios, the patient's blood pressure must be measured in both arms and both ankles. But, the only numbers recorded are for systolic blood pressure. Six values are typically recorded:

1. Right brachial systolic pressure
2. Left brachial systolic pressure
3. Right posterior tibial artery (PTA) systolic pressure
4. Left posterior tibial artery (PTA) systolic pressure
5. Right dorsalis pedis artery (DPA) systolic pressure
6. Left dorsalis pedis artery (DPA) systolic pressure

Brachial artery pressures are chosen because they are the closest to the heart. As well, two ankle systolic pressures are recorded on each side of the body (PTA and DPA).

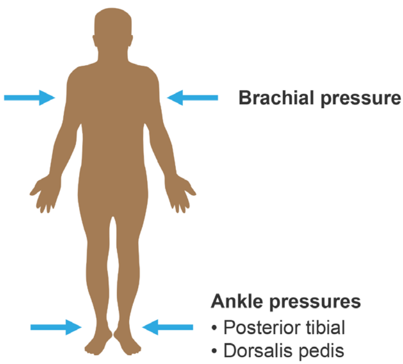


Figure 1. To calculate ankle-brachial index ratios, record the patient's brachial systolic pressure, posterior tibial artery systolic pressure, and dorsalis pedis artery systolic pressure on each side of the body.

An automated ABI machine will automatically save the blood pressure values and calculate the patient's ratios. It will also print analog waveforms. If you are performing a manual ABI, you will need to write all six systolic pressure values down one at a time.

Both the left and right brachial pressures are measured because sometimes there is a contralateral pressure gradient that may indicate subclavian steal syndrome. This is a unilateral occlusion in the subclavian artery that blocks blood flow to the brachial artery and causes lower blood pressure in the affected arm. Usually, this is not considered significant unless there is a 10–20 mmHg difference.

There are circumstances where only a unilateral brachial pressure can be taken, such as the presence of a dialysis shunt, a mastectomy, a lumpectomy, or lymphadenopathy. Always ask the patient if it's okay to take their blood pressure in both arms. Although unilateral pressure values are not as ideal as bilateral values, it still provides valuable information.

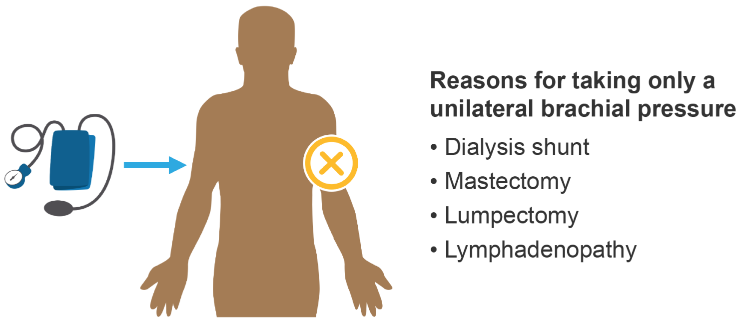


Figure 2. A patient's brachial blood pressure may only be obtained on one side of the body because of a dialysis shunt, a mastectomy, a lumpectomy, or lymphadenopathy.

How to calculate ABI ratios

Ankle-brachial index ratios are always performed bilaterally but calculated one leg at a time. There are three steps to calculating the ABI ratio for each leg:

1. Determine the highest brachial pressure (left or right).
2. Determine the highest ankle pressure for each leg (PTA or DPA).
3. Divide the highest ankle pressure on each side by the highest overall brachial pressure.

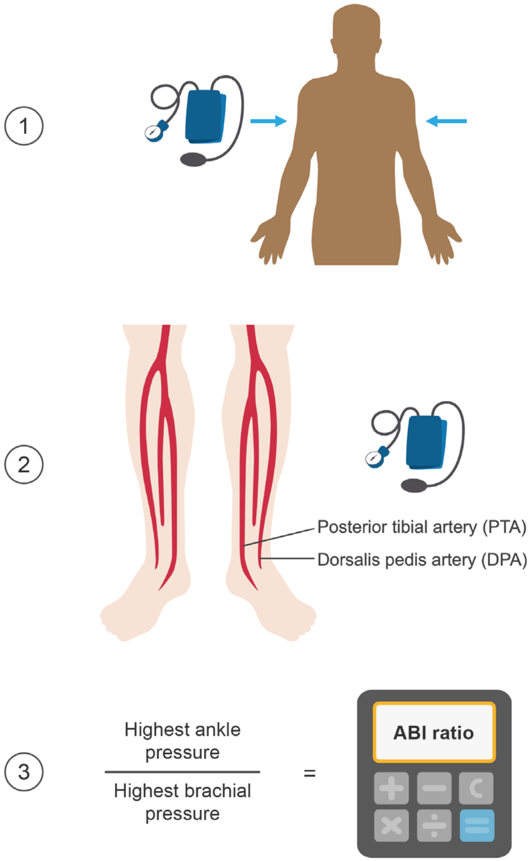


Figure 3. Steps for calculating ankle-brachial indices include, 1) determine the highest brachial pressure, 2) determine the highest ankle pressure for each leg, and 3) divide the highest ankle pressure on each side by the highest overall brachial pressure.

Step 1: Determine the highest brachial pressure

Choose the highest brachial pressure (regardless of which side it is from) and use that value for both the left and right ABI calculations.

Step 2: Determine the highest ankle pressure for each leg

Two measurements are required for each ankle—the PTA and DPA systolic pressure values. From the ankle pressures recorded, select whichever pressure is higher between the PTA and DPA on each side. These are the values that will be used for the ABI calculations.

Step 3: Divide the highest ankle pressure on each side by the highest brachial pressure

To calculate the left ABI ratio, divide the highest ankle systolic pressure from the left leg by the highest overall brachial systolic pressure. Repeat this process with the highest ankle pressure recorded from the right side to calculate the ABI ratio for the right leg.

If there is a large pressure difference between the brachial and ankle pressures, we can assume there is an obstruction occurring between the two locations.

How to interpret ABI ratios

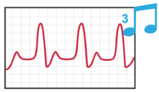
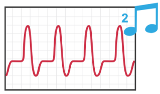
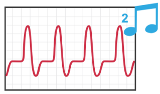
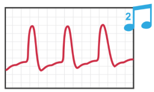
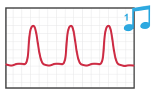
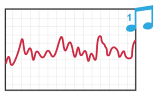
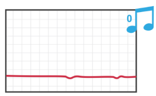
Once the ABI ratios have been calculated, you can compare these findings with the obtained audible waveforms (e.g., qualitative portion of the ABI report). The sound of the flow you hear from the Doppler probe can help characterize the degree of proximal obstruction.

An ABI ratio between 0.9–1.4 that is correlated with a multiphasic waveform (e.g., triphasic or mild biphasic) is consistent with a patient who does not have arterial occlusion.

An ABI between 0.7–0.9 should correlate with biphasic waveforms (e.g., mild or weak biphasic). These waveforms have a sharp upstroke to the peak and one pit. The findings represent mild to moderate arterial insufficiency. These patients typically present with claudication.

An ABI between 0.3–0.5 represents severe peripheral arterial disease (PAD) and usually correlates with a monophasic waveform (e.g., high or dampened monophasic). These patients typically present with pain and ulcers.

A critical ABI range is less than 0.3 to absent, which correlates with an absent waveform and represents critical PAD. In this case, there is no flow in the DPA or PTA; patients with no flow to the feet typically present with advanced ulcers and gangrene.

	ABI range	Signs and symptoms	Waveforms
Normal	0.9–1.4	• Not applicable	Multiphasic: • Triphasic  • Mild (strong) biphasic 
Mild to moderate	0.7–0.9	• Claudication	Biphasic: • Mild (strong) biphasic  • Weak biphasic 
Severe	0.3–0.5	• Pain • Ulcers	Monophasic: • High monophasic  • Dampened monophasic 
Critical	< 0.3	• Advanced ulcers • Gangrene	Absent 

ABI = ankle-brachial index

Table 1. Degrees of arterial perfusion and associated ankle-brachial index (ABI) ranges, signs and symptoms, and waveforms. Lower arterial perfusion is associated with more severe peripheral arterial disease.

Example demonstrating how to calculate and interpret ABI ratios

Let's say that you have a patient whose highest right ankle pressure is 139 mmHg and their highest overall brachial pressure is 126 mmHg. The right ABI ratio is calculated by dividing 139 mmHg by 126 mmHg, which equals 1.10 (a normal ABI).

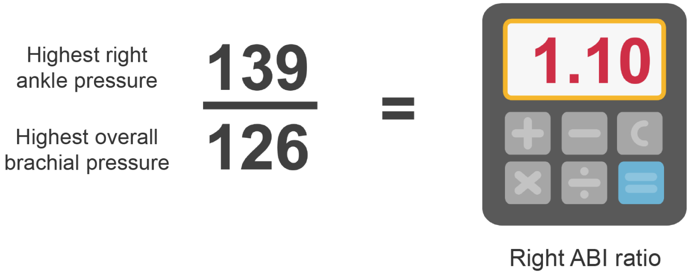


Figure 4. To calculate the right ankle's ankle-brachial index (ABI), divide the highest ankle pressure on the right by the highest overall brachial pressure.

Next, you listen to the patient's audible waveforms and find them to be triphasic, which correlates with the finding of a normal right ABI and represents normal flow.

Keep in mind that if the patient's ABI ratio is in the normal range, but the corresponding waveform is found to be monophasic, a further investigation would be needed.

Continuing with our example, let's say that you had access to the patient's report from an ABI machine. Automated ABI reports calculate the ratios for you.

In this case, let's say that the patient's ABI report shows that the highest ankle pressure on the right is the DPA at 134 mmHg. The ABI machine automatically chooses the patient's highest ankle pressure and highest overall brachial pressure, which is 126 mmHg, to calculate the ABI ratio. So, the right ABI is calculated by dividing 134 mmHg by 126 mmHg, which equals 1.06 (a normal ABI).

This finding should be correlated with the analog waveforms shown on the patient's ABI report. If the analog waveforms are triphasic (which is normal), then the patient has normal flow.

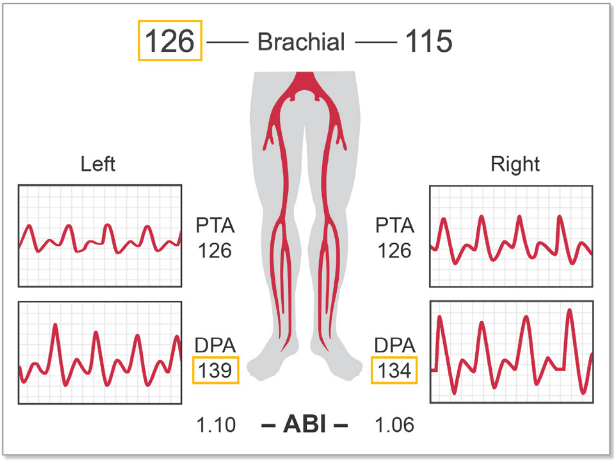


Figure 5. An automated ankle-brachial index (ABI) report showing the ABI ratios for each side of the body.

Going beyond ABI

Three scenarios require further evaluation beyond obtaining an ankle-brachial index (ABI):

1. When a pedal vessel is not compressible above 220 mmHg.
2. When a patient with normal or mildly reduced ABI ratios presents with claudication.
3. When an ABI ratio falls outside of the normal range (e.g., outside a 0.9–1.4 range).

We'll get into the recommended testing for when an ABI falls outside the normal range, but first, let's dive into the first and second scenarios in a little more detail.

Scenario 1: A pedal vessel is not compressible above 220 mmHg

When you have at least one pedal vessel that is not compressible at a pressure above 220 mmHg, this indicates medial calcinosis. Medial calcinosis is a hardening of the arterial walls rather than a collection of plaque within the lumen, and it is often seen in patients with diabetes.

If a pedal vessel is not compressible above 220 mmHg, the next step is to obtain a toe-brachial index (TBI). This requires a machine that can produce an analog waveform.

Obtain a TBI

A TBI can determine the presence or absence of blood flow in the toes and gives a ratio similar to an ABI. We use TBIs when the dorsalis pedis artery (DPA) or the posterior tibial artery (PTA) are not compressible, as often seen in patients with diabetes. If there is good blood flow to the toes, then the leg arteries are patent.

A TBI does not directly reflect the degree of peripheral arterial disease (PAD) in the legs; doctors use it as a baseline for serial ultrasound follow-up exams if the ankle vessels are not compressible. Toe-brachial indices focus on feet perfusion by taking pulse recordings of the toes with photoplethysmography (PPG) and taking systolic pressure readings of the big toes.

Foot perfusion can be easily influenced by factors such as room temperature or microvessel disease. For this reason, TBIs are not always as useful as ABIs for determining general PAD.

But, a TBI is better than not having any quantitative information, especially if the concern is a foot ulcer. As well, a PPG waveform can be used to determine the presence or absence of blood flow in the toe digit without strictly depending on the pressure.

A TBI is performed with small PPG light sensors and small toe-sized blood pressure cuffs. The cuff is wrapped around the base of the big toe and the sensor is applied to the toe pad by either a clip, tape, or Velcro strap. From the sensor on each big toe, you receive an analog waveform on the screen. The waveform is just a light sensor, so there is no sound for this reading.

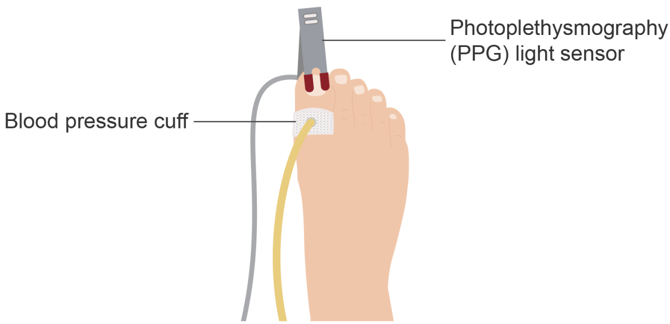


Figure 1. When obtaining a toe-brachial index, a small photoplethysmography (PPG) light sensor takes pulse recordings, and a small blood pressure cuff measures the blood pressure of the big toe.

Photoplethysmography waveforms do not follow the peaks and pits spectrum, and are instead judged mostly by their amplitude. The higher the amplitude, the better the patient's circulation.

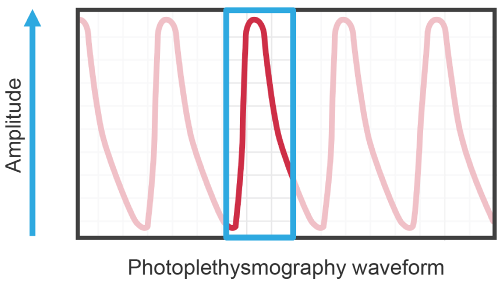


Figure 2. Photoplethysmography (PPG) waveforms are judged mostly by their amplitude. The higher the amplitude, the better the patient's circulation.

A TBI is calculated in the same way as an ABI, with toe pressure over the highest brachial systolic pressure. A normal TBI often settles around 0.7 but can vary between laboratories.

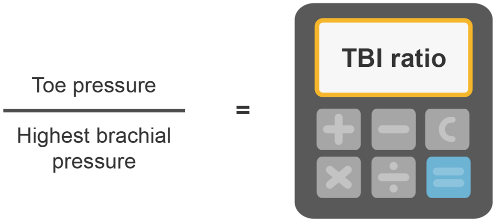


Figure 3. A toe-brachial index (TBI) is calculated by dividing the patient's toe pressure by their highest brachial systolic pressure (left or right arm).

Patient case where a TBI was indicated

On a patient's ABI report, the PTA and DPA pressures were labeled as noncompressible (NC). Since the pedal vessels were noncompressible, a TBI was performed and the indices were normal.

When looking at the report, you can see that the ABI Doppler waveforms are multiphasic. This indicates normal resting arterial perfusion at the ankles. With at least one vessel that is not compressible above 220 mmHg, we can predict some medial calcinosis, but we know from the TBI that the feet are well perfused.

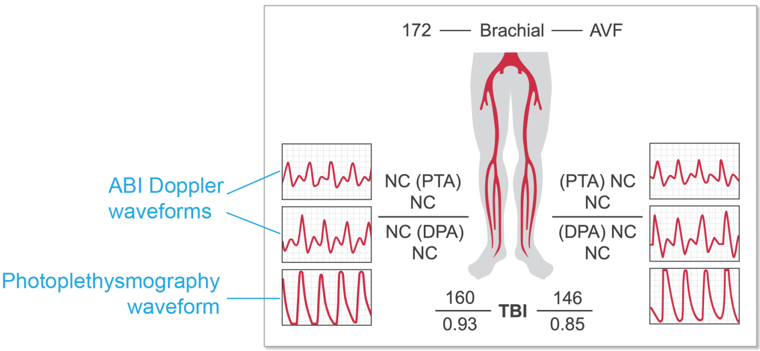


Figure 4. On the ankle-brachial index (ABI) and toe-brachial index reports from a patient with noncompressible pedal pulses, the ABI Doppler waveforms are multiphasic and the photoplethysmography waveforms have a high amplitude, which indicates that the feet are well perfused. The patient likely has medial calcinosis.

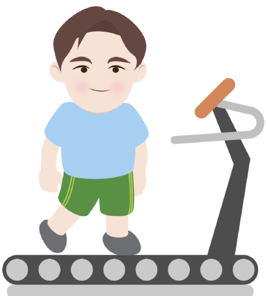
Scenario 2: A patient with normal or mildly reduced ABI ratios presents with claudication

The second scenario that requires further evaluation beyond ABIs is when a healthy patient with normal or mildly reduced ABIs (such as 0.8) presents with claudication symptoms. In this scenario, pre- and post-exercise ABIs are indicated.

Perform exercise ABIs

Ankle-brachial index testing is normally performed when the patient is at rest. But, testing of a patient with normal ABIs with claudication symptoms should include blood pressures taken before and after exercise. Exercise such as a treadmill walk or repetitive heel raises is sufficient.

A drop in ABI greater than 0.15 between pre- and immediate post-exercise pressure readings indicates PAD. Remember, depending on where the disease is located, this can be a unilateral or bilateral drop.



Exercise ABI facts

- Ankle and brachial pressures are taken before and immediately after exercise
- A drop in ABI ratio that is > 0.15 after exercise indicates peripheral arterial disease (PAD)

Figure 5. When an exercise ankle-brachial index (ABI) is performed, ankle and brachial pressures are taken before and immediately after exercise. A drop in ABI that is greater than 0.15 after exercise indicates the presence of peripheral arterial disease (PAD).

Both waveform and pressure readings are obtained before exercise, but only pressure readings are recorded after exercise. Waveforms are not recorded after exercise because they naturally become more monophasic as the limb vessels expand for more blood flow. So, they do not reflect the true extent of disease.

Another reason waveforms aren't recorded after exercise is that there isn't sufficient time. The stress test requires you to record the highest ankle vessel pressure on each side (PTA or DPA) plus the higher brachial pressure (left or right) all within one minute since the values are most accurate immediately after exercise.

Patient cases where exercise ABIs were indicated

Bilateral iliac disease

A patient had normal ABIs and multiphasic waveforms, which indicates normal resting arterial perfusion at the ankle for this patient. However, after exercising, this patient's bilateral ABI ratios dropped to a level indicating critical arterial insufficiency. The patient was found to have bilateral iliac disease.

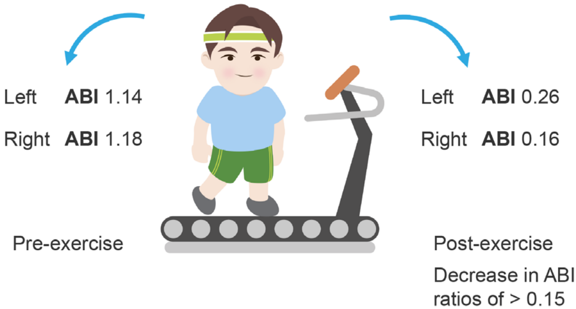


Figure 6. A patient who had normal ankle-brachial index (ABI) ratios before exercise experienced a significant drop in both ratios after exercise and was found to have bilateral iliac disease.

Popliteal artery entrapment

Exercise ABI testing is also indicated for more rare forms of PAD, such as popliteal artery entrapment. This testing is especially useful in younger, athletic patients where this condition may occur.

Popliteal artery entrapment syndrome involves the repetitive compression of the popliteal artery by hypertrophic calf muscles which can cause claudication in younger, athletic, and otherwise healthy patients. These patients usually have normal resting ABI ratios that will drop with exercise.

When popliteal artery entrapment is suspected, PPG waveforms should also be obtained. They are recorded during maneuvers of dorsiflexion and plantar flexion with knee hyperextension.

In this case, the patient's PPG waveforms were normal at rest. However, with maneuvers they became flat, which is indicative of popliteal artery entrapment.

> Keep in mind that if photoplethysmography (PPG) is unavailable, exercise ABIs are also diagnostic of popliteal entrapment.

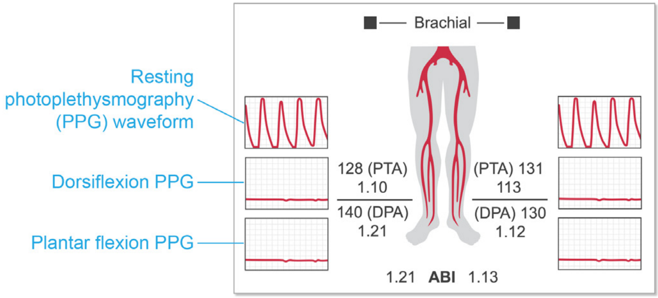


Figure 7. A toe-brachial index (TBI) report from a patient with popliteal artery entrapment syndrome. The resting photoplethysmography (PPG) waveforms are normal, but the waveforms become flat with dorsiflexion and plantar flexion.

Scenario 3: An ABI ratio falls outside of the normal range

The flow of testing to perform when an ABI falls outside of the normal range follows this simple algorithm:

- If an ABI is greater than 1.4, obtain a TBI.
- If an ABI is between 0.9–1.4, you're either done or perform exercise ABIs.
- If an ABI is less than 0.9, perform duplex and / or exercise ABIs.
- If an ABI is 0.6 or less, perform duplex, but not exercise ABIs.

ABI ratio	Testing indicated
> 1.4	• Obtain a toe-brachial index (TBI)
0.9–1.4	• No further action required if the patient is asymptomatic • Perform exercise ABIs if the patient has claudication symptoms
< 0.9	• Perform duplex and / or exercise ABIs
≤ 0.6	• Perform duplex (NOT exercise ABIs)

ABI = ankle-brachial index

Table 1. Summary of additional testing to perform after an ankle-brachial index (ABI) ratio falls outside of the normal range.

It's important to note that you should not exercise the patient if the ABI is 0.6 or less, as there is obviously disease present. Just duplex instead!

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Chapter 3

PERFORMING A BASIC ABI

Choosing a method

In fact, ABI ratios can be even be calculated without the use of a Doppler pen. In an emergency situation when an ABI machine or a Doppler pen is not available, you can simply grab a portable blood pressure (BP) machine. Put the cuff on each limb and take the patient's systolic pressures to manually calculate the ABI ratios.

This is less accurate because without the Doppler you will not hear the waveforms. Doppler waveforms are more sensitive and are typically faster at detecting the earliest pulse. However, blood pressure cuffs can give you a general idea if a disease is present—especially if you see a big drop between the arm and ankle, which is helpful in an emergency.

Pro tip: start by taking blood pressure readings from the leg of concern.

If the patient's blood pressure cannot be detected in the leg of concern, you already know that blood flow is severely restricted. Try placing the blood pressure cuff's artery marker over the dorsalis pedis artery (DPA) and then over the posterior tibial artery (PTA) and compare the two readings.

If a manual ABI is performed, there is still the option of using an older photoplethysmography (PPG) portable recorder to perform digit PPG and toe-brachial index (TBI) testing. The results can be printed and scanned into the patient's chart.

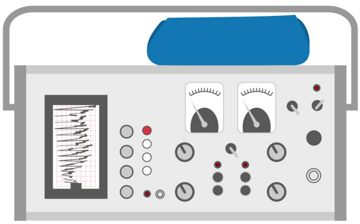


Figure 2. An older photoplethysmography (PPG) portable recorder can be used to perform digit PPGs and toe-brachial index (TBI) testing in conjunction with a manual ankle-brachial index (ABI).

Advantages of using an automated ABI machine

Of course, when one is available, an automated ABI machine has several advantages:

- Automated protocols
- Automated calculations
- Ease of TBI testing
- Ability to print / transfer a report with analog waveforms

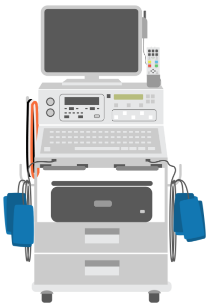


Figure 3. Advantages of using an automated ankle-brachial index (ABI) machine include automated protocols, automated calculations, ease of toe-brachial index (TBI) testing, and the ability to print or transfer a report with analog waveforms.

As you can see, an automated ABI machine may be preferable, but a manual ABI still provides information that is reliable and useful for diagnostic purposes.

Performing a manual ABI

To perform a manual ankle-brachial index (ABI), you'll need to measure bilateral systolic blood pressures at three specific locations:

1. Right and left brachial arteries
2. Right and left dorsalis pedis arteries
3. Right and left posterior tibial arteries

When taking systolic pressures in each of these areas, you follow four basic steps:

1. Apply the blood pressure cuff.
2. Listen for waveforms with the Doppler pen.
3. Pump up the cuff (20 mmHg above when you hear the last arterial beat).
4. Slowly release the pressure and record when the first arterial beat returns.

Let's cover these steps again in each specific arterial location.

Four steps for recording brachial systolic pressures

1. With the patient lying supine, apply the cuff (or cuffs) to each arm, starting with the brachial artery in the right arm.
2. Hold the Doppler pen as if it's a real pen. The strongest signal is at a 45° angle to the artery with the pen pointing towards the heart. Using this technique, find the right radial artery at the thumb side of the inner wrist. Balance your wrist (or ring and pinky fingers) on the patient's arm or bed to keep a steady hand.
3. Inflate the cuff, watch the pressure gauge, and listen for the point at which you stop hearing arterial beats with the Doppler pen. Keep inflating to a pressure that is 20 mmHg higher than the pressure was at the time when you heard the last arterial beat.
4. Slowly release the pressure from the cuff and record the pressure when the first arterial beat returns, which is the right brachial systolic pressure. Remember, only the systolic pressure is obtained for ABI tests. Allow three beats to ensure that the sound is not an artifact.

Repeat these steps to obtain and write down the left brachial pressure. The highest brachial pressure (from the left or right arm) is the denominator for the ABI ratio equation.

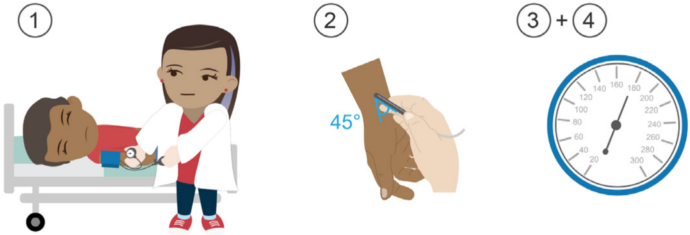


Figure 1. The steps for recording the right brachial systolic pressure include, 1) apply the blood pressure cuff to the right arm with the patient in the supine position, 2) hold the Doppler pen at a 45° angle to the brachial artery, 3) pump up the blood pressure cuff to 20 mmHg above when you hear the last arterial beat, 4) slowly release the pressure from the cuff and record the pressure when the first arterial beat returns.

Four steps for recording the dorsalis pedis artery (DPA) pressures

1. Apply the cuff to the right ankle just above the malleolus.
2. Find the dorsalis pedis artery (DPA) by sliding the Doppler from the inner to the outer ankle across the anterior ankle. The Doppler will cross the DPA. If you have trouble finding the DPA at the anterior ankle, start between the big toe and the second toe and slide proximally in between the bones to find the pedal arch. Adjust the Doppler pen at a 45° angle to the skin and listen for how many peaks and pits you hear. This is your first clue to the presence of a disease.
3. Pump up the cuff (as you did for the brachial pressures) to 20 mmHg above when you hear the last arterial beat with the Doppler pen on the DPA.
4. Slowly release the pressure from the cuff and record the pressure when the first arterial beat returns. Again, only record the systolic portion. This is the right systolic DPA pressure.

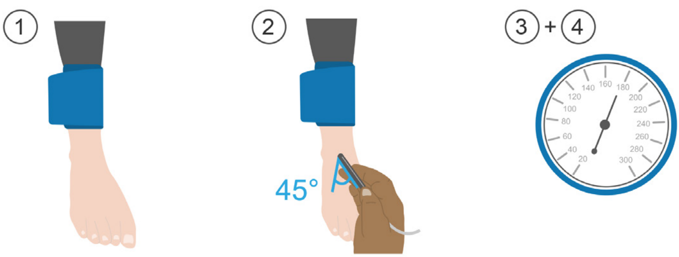


Figure 2. The steps for recording the right dorsalis pedis artery (DPA) pressure include, 1) apply the blood pressure cuff to the right ankle just above the malleolus with the patient in the supine position, 2) hold the Doppler pen at a 45° angle to the DPA, 3) pump up the blood pressure cuff to 20 mmHg above when you hear the last arterial beat, 4) slowly release the pressure from the cuff and record the pressure when the first arterial beat returns.

Four steps for recording the posterior tibial artery (PTA) pressure

1. Keep the blood pressure cuff in place on the right ankle.
2. Position the Doppler pen just behind the right medial malleolus (e.g., inner ankle bone) at a 45° angle and slide posteriorly towards the Achilles tendon. You will cross the posterior tibial artery (PTA). Use enough gel to get good contact with the skin. Listen for the auditory waveforms.
3. Pump up the cuff to 20 mmHg above when you hear the last arterial beat.
4. Slowly release the pressure from the cuff and record when the first arterial beat returns. This is the right systolic PTA pressure.

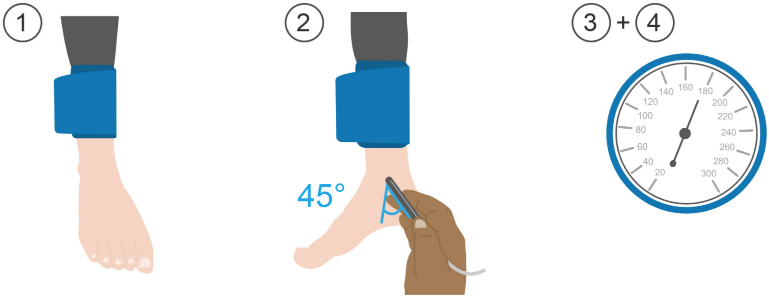


Figure 3. The steps to recording the right posterior tibial artery (PTA) pressure include, 1) keep the blood pressure cuff on the right ankle just above the malleolus, 2) hold the Doppler pen at a 45° angle to the PTA, 3) pump up the blood pressure cuff to 20 mmHg above when you hear the last arterial beat, 4) slowly release the pressure from the cuff and record the pressure when the first arterial beat returns.

Remember, the highest systolic number of the two arteries (DPA or PTA) is used to calculate the right ABI ratio. This number will be the numerator for the ABI equation.

Repeat the steps on the left ankle to obtain the left DPA and PTA blood pressures, and listen to the Doppler waveforms. In the interest of ergonomics, try using your left hand to hold the Doppler when obtaining the left PTA data.

As with the right side, the highest reading from the left DPA and PTA pressures is the numerator for the left ABI equation.

Mastering the ABI machine

An ankle-brachial index (ABI) machine consists of a pump, blood pressure cuffs, Doppler pen, photoplethysmography (PPG) sensors, a remote control, and a printer—all in one machine. Before we get into the steps involved in performing an automated ABI test, let's get a bit familiar with the ABI machine.

Getting to know the ABI machine

Hoses and blood pressure cuffs

The hoses on the ABI machine are color-coded and hook up to the cuff attachments. For example, the brachial pressure hoses may be white, the ankle hoses may be orange, and the toes hoses may be black. These colors can be different with different machines.

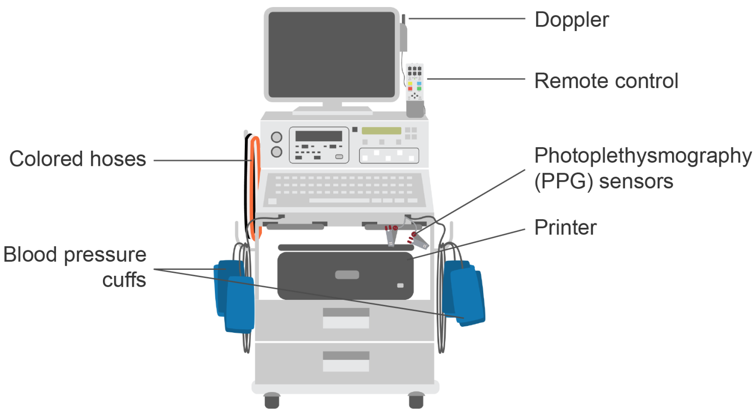


Figure 1. An automated ankle-brachial index (ABI) machine includes blood pressure cuffs with colored hoses, a Doppler pen, a remote control, photoplethysmography (PPG) sensors, and a printer.

For a basic ABI machine, there is a set of four cuffs. A blood pressure cuff is placed on each upper arm and each ankle (just above the malleolus) during an ABI test. Typically, a 10 cm cuff is used on each extremity. But, a 12 cm by 40 cm cuff may be needed if the patient is obese.

The remote control

The remote control for the ABI machine has three main parts:

1. Sound
2. Cuffs
3. Waveform

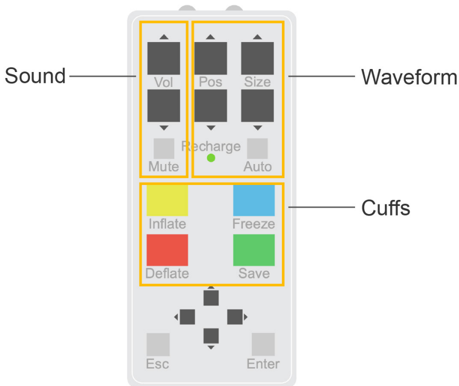


Figure 2. Although the appearance may vary from machine to machine, the automated ankle-brachial index (ABI) machine's remote control has sound, waveform, and cuff buttons.

The sound control buttons

Sometimes, the machines start without the volume on, so the volume will need to be turned up when starting the ABI machine. However, there is often an unpleasant static sound that occurs between obtaining pulses and pressures, so it's helpful to use the mute button.

The mute button helps to avoid extraneous static noise that may occur from the pen movement or from a lack of gel. Always hit the mute button between recordings and then unmute when actively listening for a pulse. It's also a good idea to warn your patient that the Doppler microphone can be noisy.

The cuff control button

The cuff inflation button controls the cuff pressure. When you stop pushing this button, it stops inflating the cuff and starts slowly deflating. Like a manual ABI, the pressure is pumped to 20 mmHg above the last arterial beat, and then the cuff is allowed to deflate until a return beat is heard.

Press the freeze button once you hear the first three arterial beats. Then, use the arrows at the bottom of the remote to scroll back to the pressure reading of the first returning arterial beat. Hit the save button to save the data.

The waveform control buttons

The buttons used to adjust waveforms are to the right of the volume buttons on the remote. The auto button will optimize your waveforms.

For the best analysis, manually adjust the baseline (e.g., position) and scale (e.g., size) of the waveform to take up about 3/4 of the screen height in the center of the screen. Most protocols optimize the dorsalis pedis artery (DPA) waveform and then do not change the waveform's size thereafter so the vessels' waveform amplitude can be accurately compared.

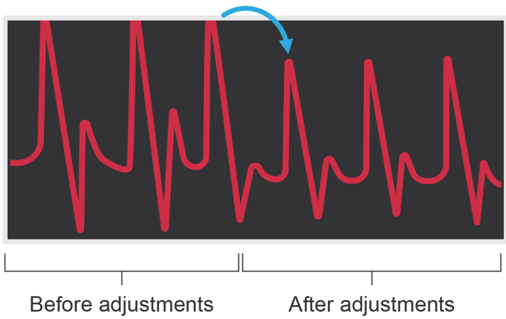


Figure 3. Adjust baseline and scale using the position and size buttons on the ankle-brachial index (ABI) machine remote control until the waveform on the screen is centered and takes up about 3/4 of the height of the screen.

Remember, the focus is on the lower extremities, thus the brachial waveforms are not recorded. Keep your waveform focus on the ankles.

Once an accurate waveform (that is 3/4 the size of the screen) is obtained, press the freeze button and then use the scroll buttons at the bottom of the remote to find the optimal waveform and save it. The machine will then prompt which waveform to obtain next.

How to use the ABI machine to record pressures and capture waveforms

Now that the details of how to use the machine are clear, let's review the flow of the arterial evaluation. To begin, let's go through the steps involved in performing automated ABI testing.

Start by obtaining brachial pressures

1. Place the blood pressure cuff on the right upper arm.
2. Place the Doppler probe at the antecubital fossa (to find the right brachial artery) or the thumb side of the wrist (to find the radial artery).
3. Brace your ring finger or pinky on the patient's arm or bed to steady your hand and avoid artifacts. Keep in mind that the upper extremity waveforms are never recorded for an ABI test, so don't worry about optimizing them. Just try to make the Doppler pen line up with the vessel to get the clearest signal.
4. To capture brachial pressures, press and hold the inflate button until the pressure reaches 20 mmHg above the last arterial beat. Then, release the inflate button and allow the pressure to slowly deflate.
5. Press freeze when you hear the first three arterial beats return.
6. Use the arrow buttons at the bottom of the remote to scroll the recording back to the pressure reading of the first returned arterial beat.
7. Press the green save button to save the data.
8. Repeat these steps to obtain the left brachial pressure.

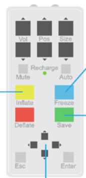
Obtain Doppler waveforms and pressures for the ankles

1. Wrap the blood pressure cuff just above the malleolus on the right ankle.
2. Position the Doppler pen on the appropriate artery. Most protocols start with the DPA pulse and pressure recordings before proceeding to the posterior tibial artery (PTA).
3. Find the right DPA pressure using the same technique for brachial pressures (steps 4–7).
4. To capture the pulse waveforms, start by adjusting the baseline (e.g., position button) and scale (e.g., size button) of the waveform so it is in the center and takes up about 3/4 of the screen height.
5. Press the freeze button once an accurate waveform is obtained.
6. Scroll to the optimal waveform and press save.
7. Repeat steps 2–7 to record the right PTA pressure and pulse waveforms.
8. Repeat this process for the left ankle.

Steps involved in performing automated ankle-brachial index (ABI) testing

Start by obtaining brachial pressures:

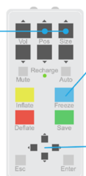
1. Place the blood pressure cuff on the right upper arm.
2. Place the Doppler probe at the antecubital fossa (for the right brachial artery) or at the thumb side of the wrist (for the radial artery).
3. Brace your ring finger or pinky on the patient's arm or bed to steady your hand and avoid artifact.



4. Press the inflate button and hold until the pressure reaches 20 mmHg above the last arterial beat, then release and allow the pressure to slowly deflate.
5. Press freeze when you hear the first three arterial beats returning.
6. Use the arrow buttons at the bottom of the remote to allow you to scroll the recording back to the pressure of the first returning arterial beat.
7. Press the green save button to save the data.
8. Repeat steps 1–7 for the left arm.

Obtain Doppler waveforms and pressures for the ankles next:

1. Wrap the blood pressure cuff just above the malleolus on the right ankle.
2. Position the Doppler pen on the dorsalis pedis artery (DPA).
3. Find the right DPA pressure using the same technique as you did for brachial pressures (**steps 4 to 7**).



4. To capture pulse waveforms, start by adjusting the baseline (position button) and scale (size button) of the waveform so it is in the center and takes up about ¾ of the height of the screen.
5. Press the freeze button once an accurate waveform is obtained.
6. Scroll to the optimal waveform and press save.
7. Repeat steps 2–7 to record the right PTA pressure and pulse waveforms.
8. Repeat this process for the left ankle aswell.

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Chapter 4

ORDERING AND INTERPRETING A BASIC ARTERIAL DUPLEX

Differentiating tests

Duplex ultrasound is named as such because it produces two components: images and waveforms. Technically, it's a triplex because it can also be performed live!

The two-dimensional (2D) imaging component of duplex ultrasound is in black and white, and allows visualization of arterial plaque. Color Doppler imaging confirms that plaque is not an artifact. As well, the velocities measured within the Doppler waveforms give a percentage of obstruction.

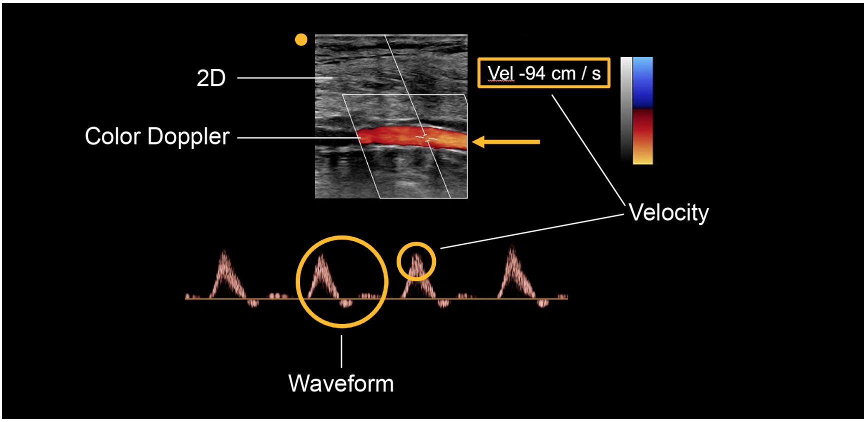


Figure 1. On a duplex ultrasound screen, arterial plaque can be assessed with two-dimensional (2D) black and white imaging, color flow, waveforms, and velocity.

When should you order an arterial duplex ultrasound?

There are three main reasons for ordering an arterial duplex ultrasound:

1. In the case of an abnormal ankle-brachial index (ABI).
2. If there is suspicion of an aneurysm.
3. If there is suspicion of a pseudoaneurysm.

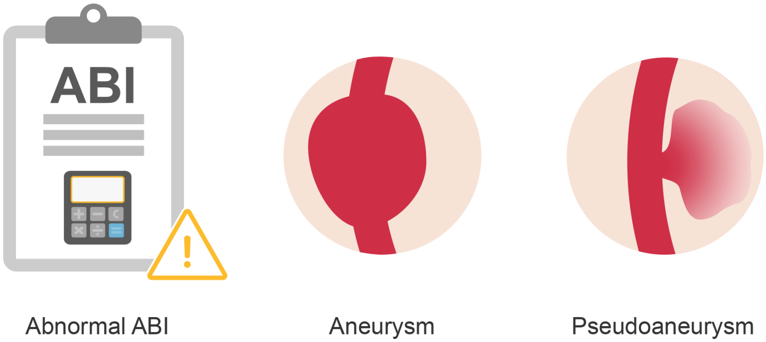


Figure 2. Three reasons for ordering arterial duplex ultrasound testing include an abnormal ankle-brachial index (ABI), suspicion of an aneurysm, and suspicion of a pseudoaneurysm.

Arterial duplex ultrasound allows you to view the arterial walls and lumen. It also records waveforms and velocities of blood flow to determine the level and extent of arterial disease. In contrast, an ABI test only gives you information about a circulation problem and the degree of disease—but not the location.

What will you see on duplex ultrasound?

Before we get into the different available modes, let's review what a healthy artery looks like on a duplex ultrasound. On a 2D image of a normal artery, the lumen will be black and the walls will be smooth. Color imaging can be used to confirm that the vessel is healthy; on a healthy vessel, the color should fill the lumen from wall to wall with no aliasing (e.g., bright spots), and you should see no evidence of plaque.

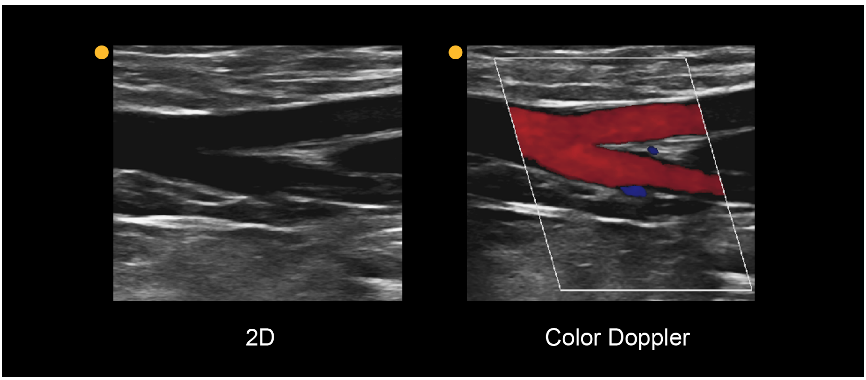


Figure 3. Two-dimensional (2D) and color Doppler duplex ultrasounds of a healthy common femoral artery bifurcation. Note that the arterial lumen is black and the walls are smooth. On the color flow image of the same bifurcation, note that the color fills the artery from wall to wall with no aliasing (e.g., bright spots) or plaque.

Next, the transducer is moved distally along the vessel to look for plaque. If plaque is present, it can be visualized as changes within the lumen.

Calcific plaque is echogenic (e.g., bright) and has acoustic shadowing, which is a black shadow that is produced because ultrasound cannot penetrate plaque. Some patients with diabetes and atherosclerosis have calcification that can also produce acoustic shadowing.

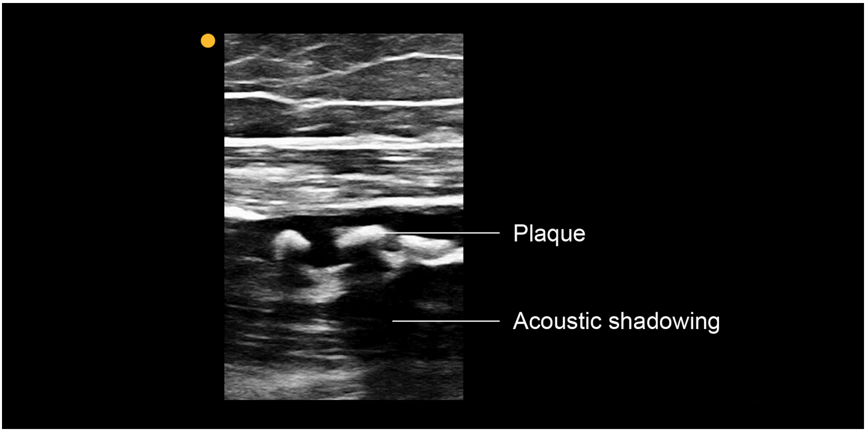


Figure 4. On a duplex Doppler ultrasound, calcific plaque will appear echogenic (e.g., bright) and will be accompanied by acoustic shadowing (e.g., black shadow).

How to use different duplex ultrasound modes

Using the color flow Doppler mode

If any plaque is seen protruding into the lumen, the area is further examined with color flow Doppler imaging. Color flow provides a visual representation of blood flow around arterial stenosis. Aliasing occurs as blood velocity increases within stenosis, and is visualized as bright areas within the color flow.

Color aliasing in the presence of stenosis can appear as a few spots on ultrasound. However, as stenosis worsens, it will present in multiple areas.

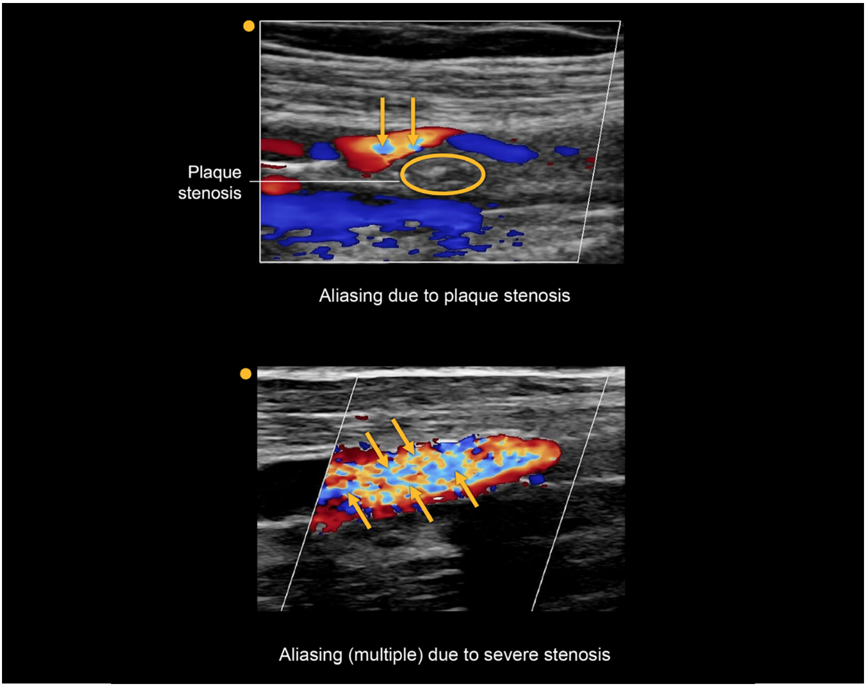


Figure 5. Aliasing, or bright areas on a color flow duplex Doppler ultrasound, occurs in areas where blood flow is at an increased velocity, which is often due to plaque stenosis. Multiple areas of aliasing indicate severe stenosis.

A string sign is a classic sign on color flow imaging which indicates that minimal flow is getting through arterial stenosis. Often, a color bruit can be seen above the string sign. This is produced by massive vibrations from tight stenosis.

A Doppler bruit is also possible. Both Doppler and color bruits are similar to audible bruits which can be heard with a stethoscope over stenotic carotid and femoral arteries.

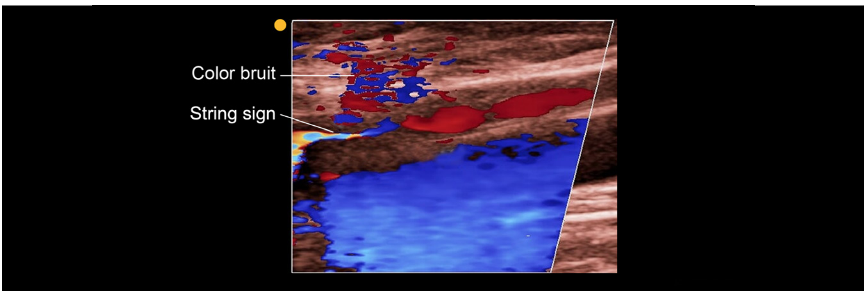


Figure 6. A string sign and color bruit on a color flow duplex ultrasound are indications that minimal blood flow is getting through tight arterial stenosis.

Using the power Doppler mode

An additional feature called the power mode can be used to detect blood flow in tight areas of stenosis. It is sensitive enough to differentiate tight stenosis from occlusion. As well, the color maps for a power Doppler ultrasound are adjustable with each machine.

Power Doppler ultrasounds can be used to investigate if there is a presence of flow around the plaque, which would prove that the vessel is not occluded.

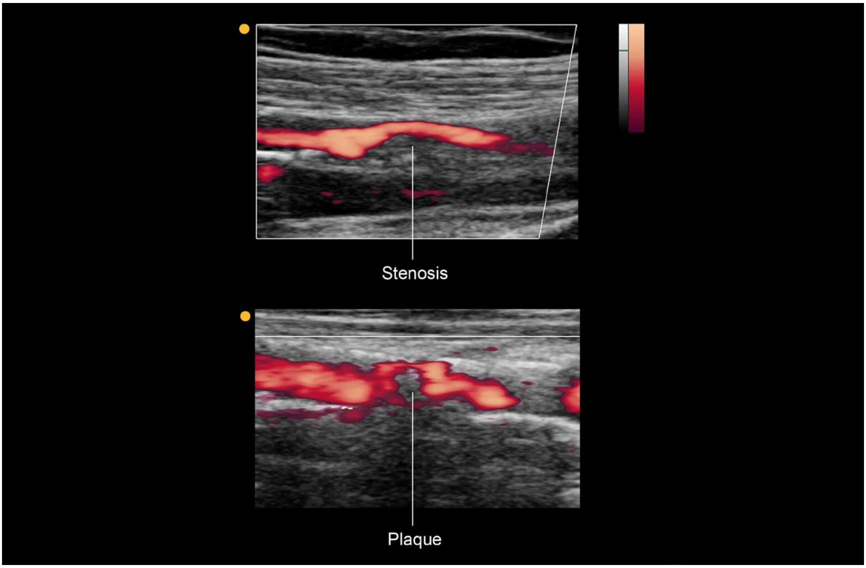
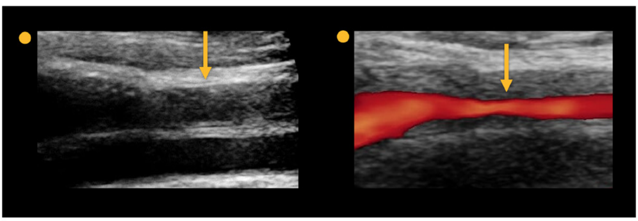


Figure 7. The power mode on duplex Doppler ultrasound can detect flow in tight areas of stenosis, and can help confirm the presence of flow around plaque.

It's important to utilize all your options!

Non-calcific plaque can be difficult to see without the color flow mode. For a thorough evaluation, be sure to use all the modes available to you when performing a duplex ultrasound.



Interpreting duplex waveforms

Duplex ultrasound waveforms are obtained in segments throughout the leg and compared for degradation from triphasic to biphasic or monophasic waveforms. The waveforms are then correlated with velocities to confirm stenosis.

The concept of ankle-brachial index (ABI) Doppler phasicity, or peaks and pits, holds true for duplex ultrasound waveforms as well. For example, triphasic waveforms look and sound triphasic on duplex ultrasound.

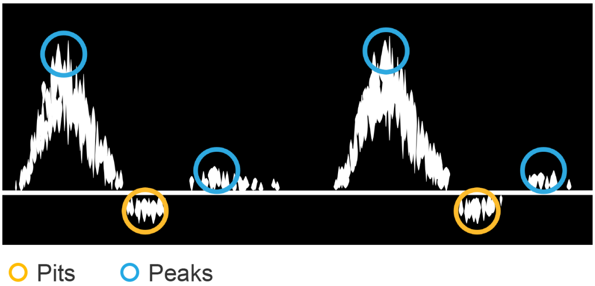


Figure 1. Triphasic waveforms on duplex ultrasound consist of two peaks and one pit.

However, duplex ultrasound is different from ABI because if there is stiffening and degradation of phasicity, you can image the area and identify if the degradation is due to plaque build-up or wall calcification. With duplex ultrasound, you can see the vessel and confirm if it is widely patent. Duplex ultrasound also records the waveforms on a velocity scale, which helps grade the percentage of stenosis.

The stages of waveform degradation on duplex ultrasound

A loss of phasicity occurs in stages; each stage represents different severities of disease. These stages of waveform degradation are clearly seen on duplex and fall into one of three categories:

1. Pre-stenosis
2. Intra-stenosis
3. Post-stenosis

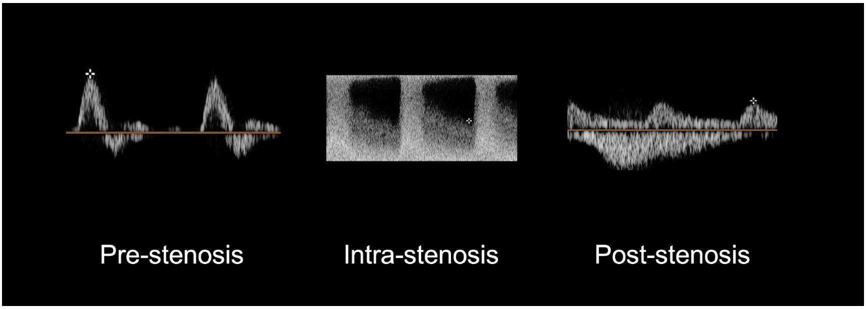


Figure 2. The three stages of waveform degradation include pre-stenosis, intra-stenosis, and post-stenosis.

Identifying stages of waveform degradation on duplex ultrasound

When performing duplex ultrasound, the technologist will begin at the common femoral artery (CFA) and move distally down the leg to thoroughly evaluate all the main arteries. Similar to ABIs, multiphasic waveforms are considered normal. If there is a blockage in the leg from significant stenosis, triphasic waveforms will only be obtained proximal to the blockage.

Let's take a look at a patient case to demonstrate how to interpret duplex waveforms and identify stages of degradation.

Pre-stenosis waveforms

On ultrasound, the patient's CFA waveforms are triphasic which indicate normal aortoiliac inflow since the CFA is distal to the aorta and iliac arteries. As mentioned, arteries distal to significant stenosis will not be triphasic.

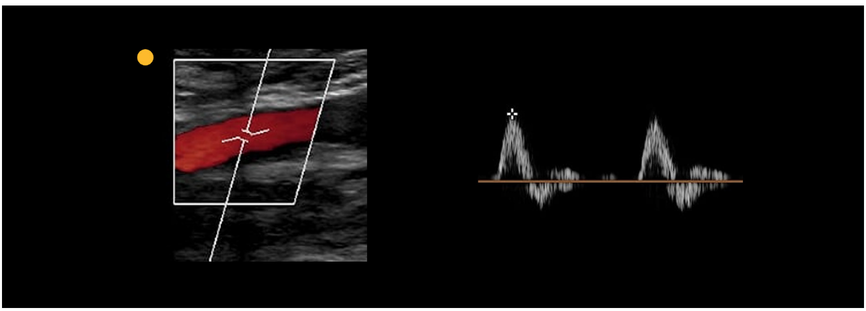


Figure 3. A normal color flow duplex ultrasound and triphasic waveforms at the common femoral artery (CFA) indicate normal aortoiliac flow since the aorta and iliac arteries are proximal to the CFA.

Intra-stenosis waveforms

Further down the leg at the mid-superficial femoral artery (SFA), the patient's waveforms are still multiphasic which indicate normal blood flow. However, the waveforms at the popliteal artery show spectral broadening (e.g., snowy filling of the waveform window due to turbulence produced by stenosis). This is categorized as an intra-stenosis popliteal artery waveform.

With this patient, you can also see an increase in velocity at the popliteal artery in comparison to the velocity at the SFA (Fig. 4). This happens because the lumen diameter decreases from stenosis which causes the blood velocity to increase.

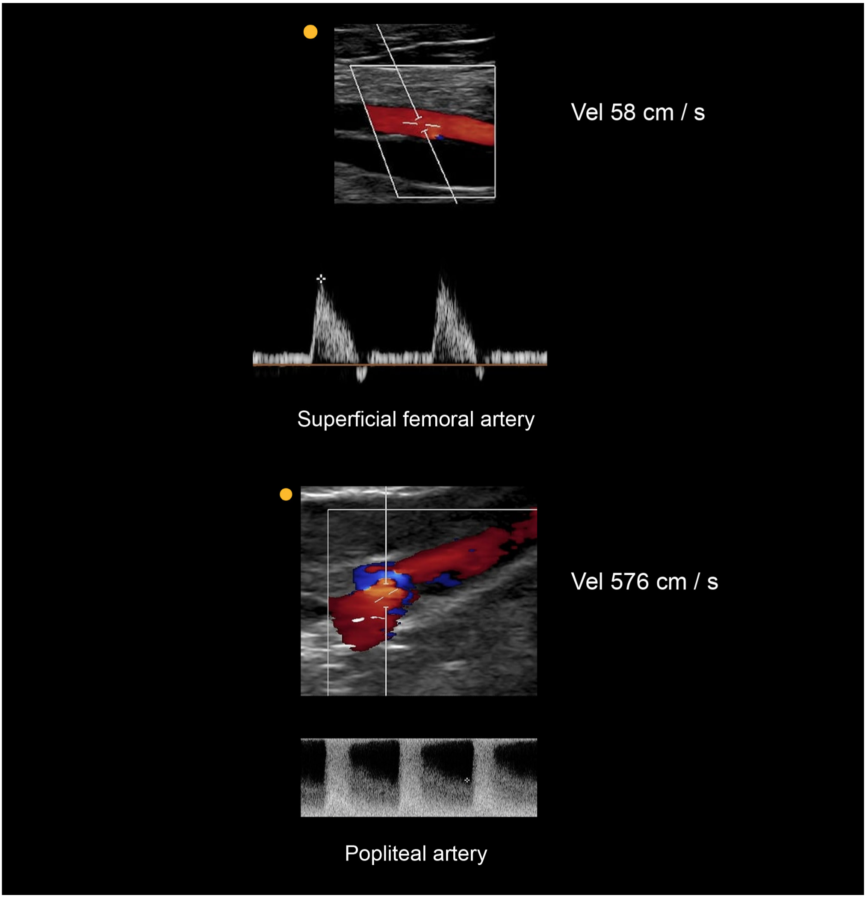


Figure 4. A patient with a normal color flow duplex ultrasound and multiphasic waveforms at the level of the superficial femoral artery (SFA). However, waveforms at the popliteal artery show spectral broadening and the blood velocity (vel) has increased to 576 cm / s which indicates that stenosis is present in the popliteal artery.

Post-stenosis waveforms

Arterial waveforms distal to significant stenosis are usually monophasic. Keep in mind that waveforms can sometimes occur below the baseline simply because of phasic vein Doppler interference—which is blood flow in the veins.

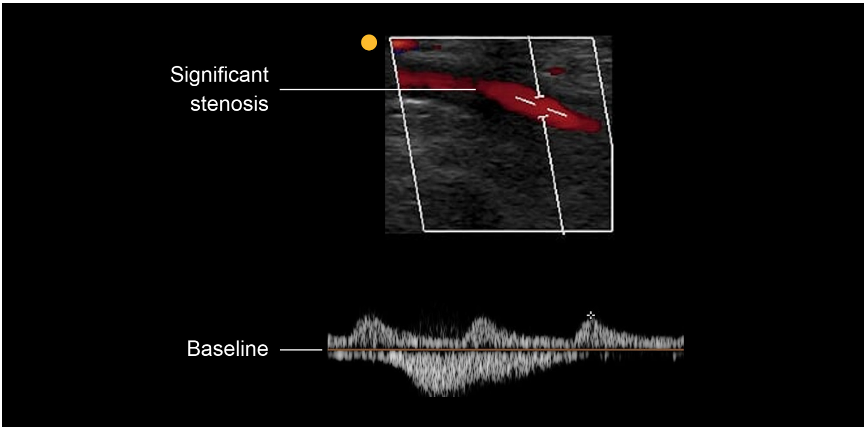


Figure 5. Arterial waveforms distal to significant stenosis are typically monophasic. The waveform area beneath the baseline is due to phasic vein Doppler interference.

Comparing ABI and duplex ultrasound findings

For the patient case featuring popliteal artery stenosis, compare the patient's ABI test to their duplex ultrasound findings. The dampened monophasic ankle waveforms and abnormal ratios suggest stenosis. But, the findings don't give any information about the location. The duplex ultrasound confirmed that the blockage location was in the popliteal artery.

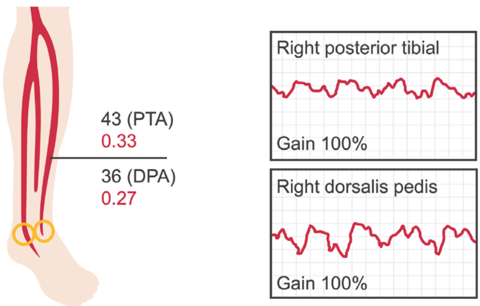


Figure 6. The ankle-brachial index (ABI) from a patient with popliteal artery stenosis showed dampened monophasic ankle waveforms and abnormal ratios.

Recognizing a Doppler bruit on duplex ultrasound

Occasionally, a Doppler bruit will occur on a duplex ultrasound. This is from the vibration of a severely stenotic vessel. If this is seen, but the velocities are not elevated, keep searching nearby since the vibration is usually coming from a stenotic artery.

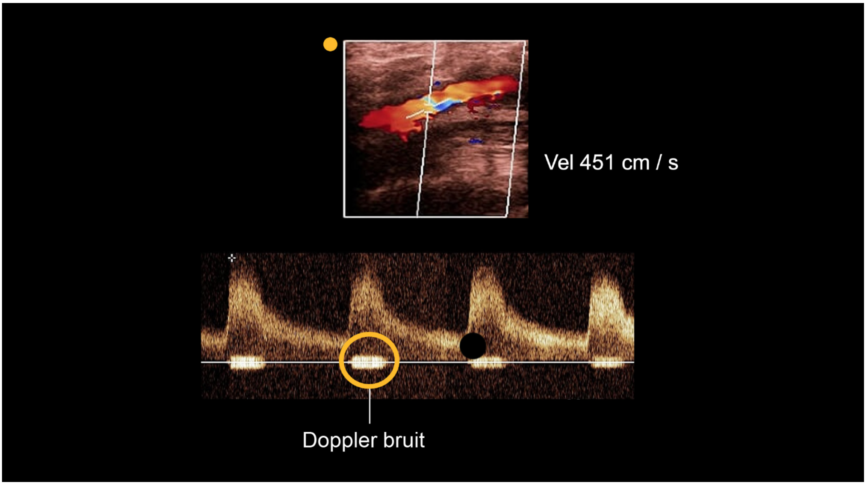


Figure 7. A Doppler bruit on a duplex ultrasound waveform indicates that stenosis is nearby.

Calculating duplex velocities

A benefit of duplex ultrasound is that the velocities are obtained in segments throughout the leg using the Doppler. Let's go over the steps that are used to capture duplex velocities and how they can be used to calculate the degree of obstruction within a vessel.

Four steps for capturing duplex velocities

There are four basic steps for capturing duplex velocities:

1. Angle the cursor in the direction of blood flow in the middle of the vessel.
2. Adjust the Doppler angle line so it is parallel to the vessel walls.
3. Capture the Doppler waveform.
4. Press the measure / caliper button with the cursor at the tallest peak.

Let's go over those steps again in a little more detail.

Step 1: Angle the cursor in the direction of blood flow in the middle of the vessel

To capture duplex velocities, start by angling the cursor (known as steering) in the direction of the blood flow for the vessel being examined. The center of the cursor contains a sample volume and Doppler angle. Place the sample Doppler in the middle of the vessel that you want to examine.

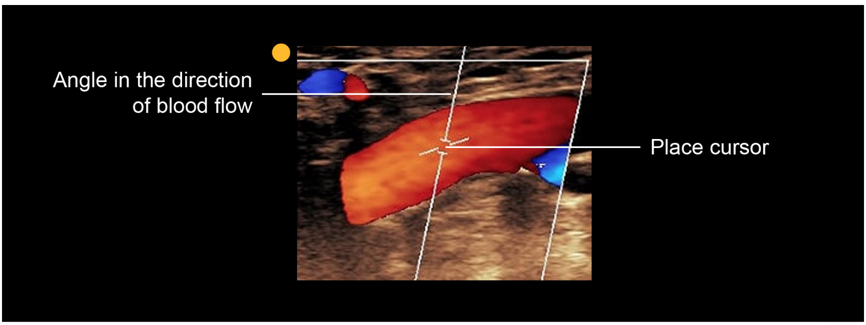


Figure 1. When capturing duplex velocities, begin by angling the cursor in the direction of the blood flow and placing the cursor in the middle of the vessel that you want to examine.

Step 2: Adjust the Doppler angle line so it is parallel to the vessel walls

While keeping the Doppler cursor angle at 60°, move the probe's angle to get the Doppler angle line as parallel to the vessel walls as possible. If the vessel is too steep, you can adjust the Doppler angle between 0–60° and still be accurate. Angles greater than 60° overestimate the velocity and the degree of stenosis.

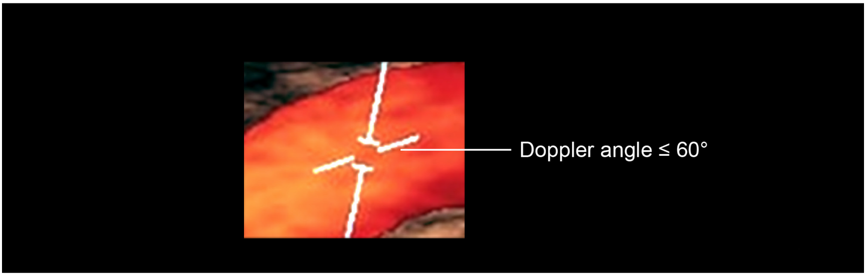


Figure 2. When capturing duplex velocities, move the Doppler cursor angle parallel to the vessel walls without exceeding 60° for accurate readings.

Step 3: Capture the Doppler waveform

Next, obtain the Doppler waveform and freeze it by pressing the freeze button on the keyboard.

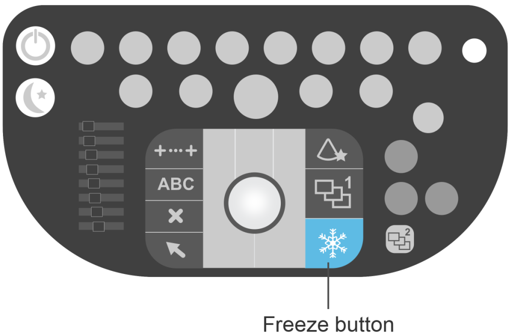


Figure 3. When capturing duplex velocities, obtain the Doppler waveform by pressing the freeze button on the keyboard.

Step 4: Press the measure / caliper button with the cursor at the tallest peak

Press the measure / caliper button so that the cursor appears, and then place the cursor at the tallest peak of the waveform to record the peak systolic velocity (PSV).

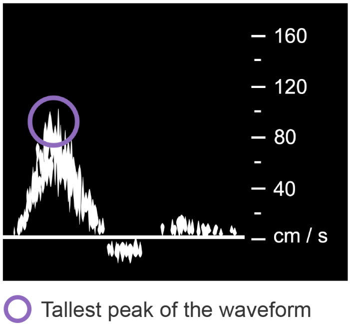


Figure 4. When capturing duplex velocities, press the measure / caliper button and place the cursor at the tallest waveform peak to record the peak systolic velocity (PSV).

How to calculate the percentage of obstruction caused by stenosis

Remember, the ultrasound machine does not calculate or compare the obstruction percentage. Instead, you must do manual calculations using the PSV values.

The patient's age and natural hemodynamic state can affect their vasculature. Thus, velocities in the peripheral arteries will vary. To calculate the percentage of obstruction, the differences in velocities from different arterial segments are compared.

This categorizes the degree of obstruction into four ranges:

1. 0–50% obstructed
2. 50–75% obstructed
3. 75–99% obstructed
4. 100% obstructed (e.g., occluded)

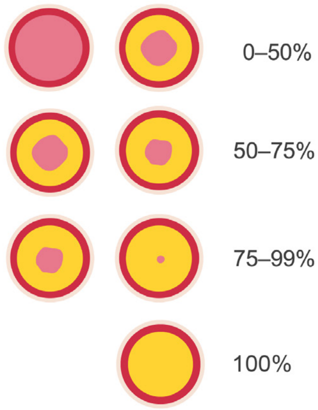


Figure 5. The degree of obstruction of a vessel is categorized into four ranges, 0–50% obstructed, 50–75% obstructed, 75–99% obstructed, and 100% obstructed (e.g., occluded).

To calculate the obstruction percentage, measure the velocity proximal to stenosis and the velocity within stenosis. Then, confirm that there are monophasic waveforms with diminished flow distal to stenosis. Next, compare the proximal PSV to the PSV within the stenotic artery:

- A PSV less than two times the proximal PSV suggests that the vessel is less than 50% blocked.
- A PSV two times the proximal PSV indicates that the vessel is approximately 50% obstructed.
- A PSV four or more times the proximal PSV indicates that the vessel is at least 75% blocked.

PSV of the obstructed vessel (compared to PSV of the proximal vessel)	**Degree of blockage**
< 2 x greater	< 50%
2 x greater	≈ 50%
≥ 4 x greater	≥ 75%

PSV = peak systolic volume

Table 1. Calculating the degree of obstruction in a vessel by comparing peak systolic velocities (PSV) within stenosis and proximal to stenosis.

Sample calculation

In our sample patient, the area of concern is the proximal superficial femoral artery (SFA). Take the velocity from the segment just proximal to the SFA, the common femoral artery (CFA), and then compare it to the velocity in the SFA:

- CFA PSV is 125 cm / s
- SFA PSV is 398 cm / s

The PSV of the SFA is double, but does not increase over four times the CFA velocity. So, the range, in this case, is between 50–75% of lumen diameter reduction.

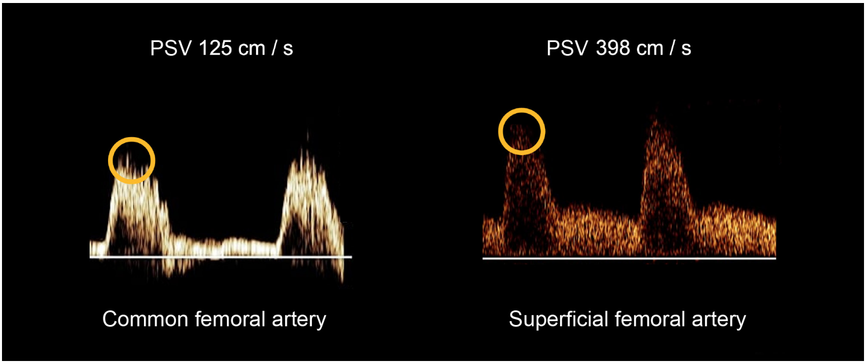


Figure 6. A patient has a peak systolic velocity (PSV) of 125 cm / s in the common femoral artery and a PSV of 398 cm / s in the superficial femoral artery (SFA). The percentage of SFA obstruction is between 50–75% since the PSV is between two to four times greater than the proximal segment.

An important exception!

Popliteal artery

Stenotic PSV > 400 cm / s =
> 75% reduction in diameter

In the popliteal artery, a stenotic peak systolic velocity (PSV) greater than 400 cm / s automatically suggests a diameter reduction greater than 75%, regardless of the proximal segment velocity. This is because the proximal segment may also be obstructed, so the calculation is not applicable.

What if you can't obtain a velocity?

If you are unable to obtain a PSV value in a vessel, it may be occluded. The occlusion is usually well-visualized with color flow duplex ultrasound, but it may be obscured by calcific shadowing. In this case, you can rely on the ankle-brachial index (ABI) and the duplex waveforms distal to the occlusion to determine the presence and extent of the disease.

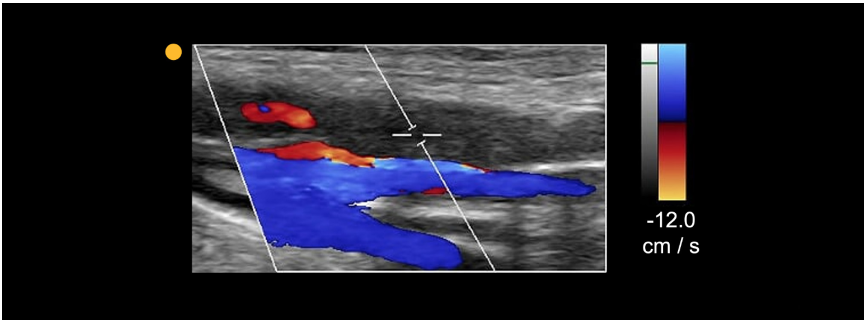


Figure 7. An occlusion can usually be well-visualized with color flow duplex ultrasound.

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Chapter 5

PERFORMING AN ARTERIAL DUPLEX

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Identifying the basics

The duplex ultrasound machine may look complex, but only a few buttons are used for a basic lower extremity arterial study:

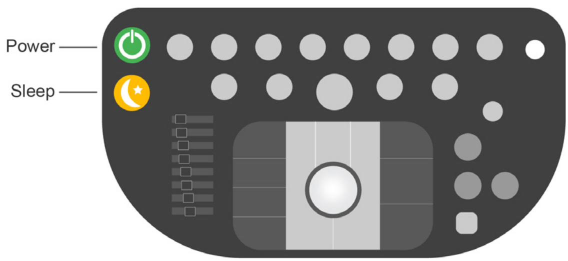
- Power and sleep
- Probe and preset
- Trackball, freeze, and save (e.g., acquire 1)
- Caliper and depth
- Doppler gain, two-dimensional gain, and color gain
- Color scale
- Steering
- Pulsed-wave

Let's get familiarized with each of these buttons so that you can feel confident using a Doppler probe.

Power and sleep functions on duplex ultrasound

As is true for all the buttons covered in this article, the power button will be located in different places depending on the machine. We'll demonstrate examples of where each button may be found on the keyboard. But, keep in mind that their locations vary.

There is usually a sleep button next to the power button that can be used when the machine needs to be transported. Sleep mode decreases battery use, and the power usually lasts about 20–30 minutes for off-outlet scanning time.



Picking a probe and preset on duplex ultrasound

As you get started, you will be prompted to pick a probe and a preset. Choose the 12 MHz linear transducer and the arterial lower extremity preset.

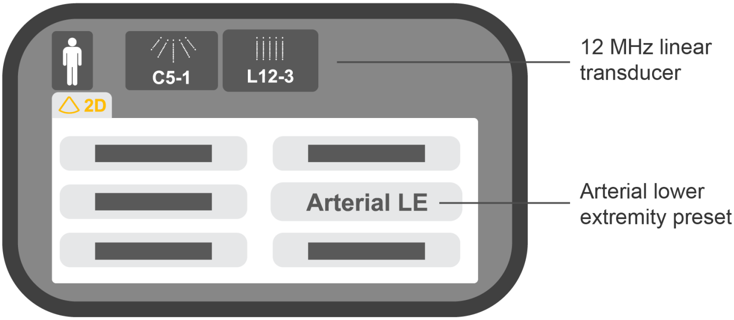
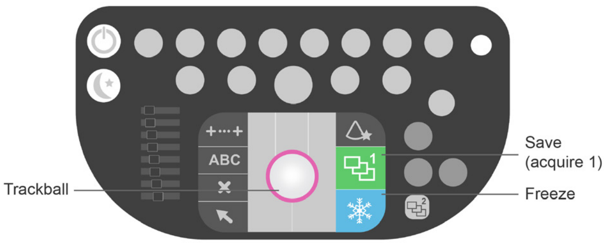


Figure 1. To perform a duplex ultrasound of the lower extremities, choose the 12 MHz linear transducer and the arterial lower extremity preset.

Trackball, freeze, and save (e.g., acquire 1) functions on duplex ultrasound

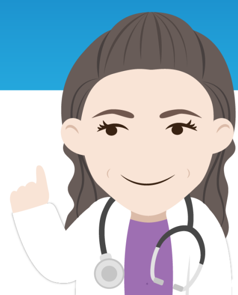
Most machines have a trackball in the middle of the keyboard with freeze and save buttons around it. Save is labeled as the acquire 1 button.

The freeze button is used to freeze images, which are then scrolled back with the trackball to get an optimal image, and then saved with the acquire 1 button.



Pro tip:

The acquire 1 and acquire 2 buttons can be programmed to capture a few seconds of cine clip. If this function is used, the freeze button is not required.



Caliper and depth functions on duplex ultrasound

Once an image is frozen, you can use the caliper button on the main keyboard to measure the distance between the arterial walls to diagnose an aneurysm, or to measure the peak systolic velocity (e.g., the highest peak on the waveform) to diagnose an obstruction.

The depth button will allow you to increase the image depth to see deeper vessels and decrease the image depth to more clearly see superficial vessels.

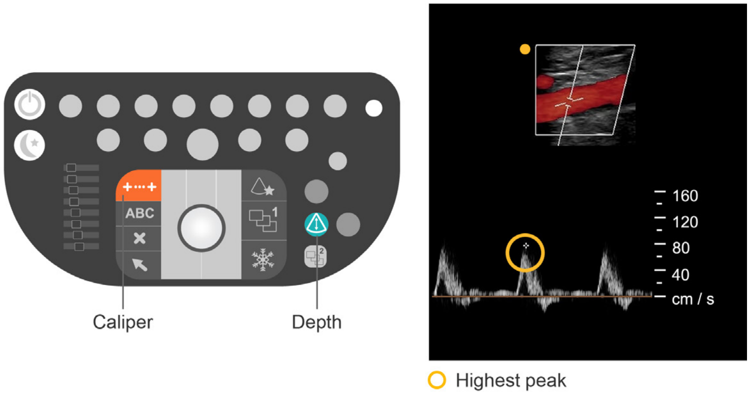
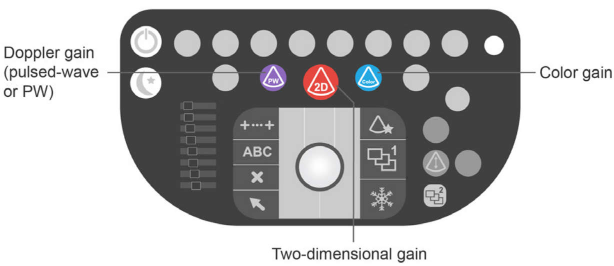


Figure 2. Use the caliper button to measure the distance between arterial walls or measure the peak systolic velocity during a lower extremity arterial ultrasound. Use the depth button to increase or decrease the image depth.

Doppler gain, two-dimensional gain, and color gain functions on duplex ultrasound

An additional set of buttons frequently used during a lower extremity examination are the gain buttons. These consist of two-dimensional (2D) gain, color gain, and Doppler gain (pulsed-wave or PW button). Gain buttons control the brightness of an image and can be adjusted throughout the exam.



Adjusting the Doppler gain will affect the brightness of the ultrasound. Changing the Doppler gain can affect the brightness so much that, at some levels, the waveforms can completely disappear. A slight adjustment will bring it into view again—but too much of an adjustment will create background changes!

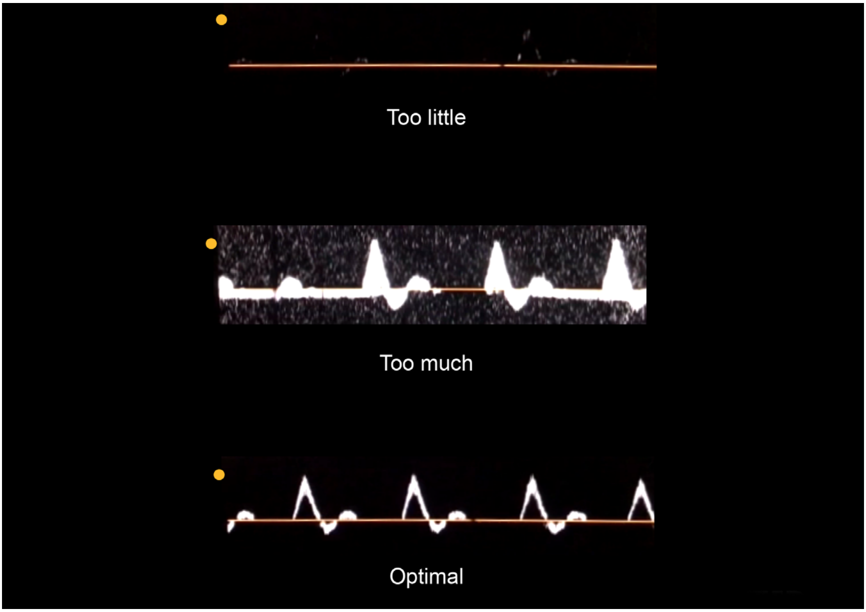


Figure 3. When adjusting the Doppler gain, too much will cause the waveforms to disappear; too little will cause background distortion.

Two-dimensional gain adjusts the visual volume of the black-and-white screen. Keep in mind that if the gain is too high, you can sometimes get artifacts that can affect the image quality.

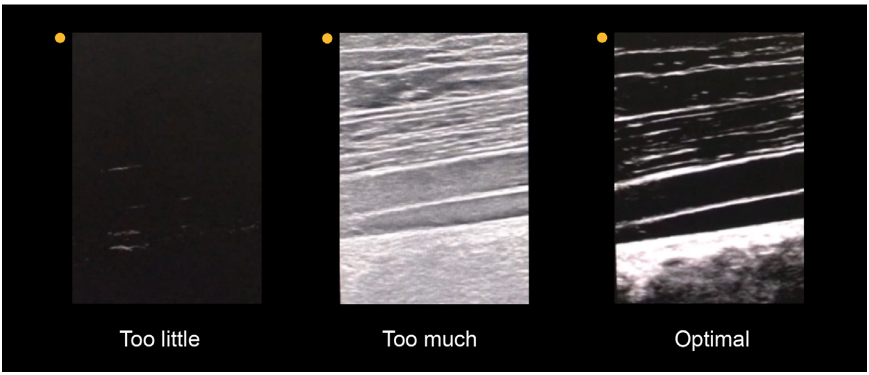


Figure 4. When adjusting two-dimensional gain, too little will cause the image to disappear and too much will cause artifacts that can affect the image quality.

As color gain is adjusted, the color appearance changes. It can fade away so that no color flow is seen or becomes so bright that it overwhelms the image, which makes the duplex difficult to evaluate. Fine adjustments to the color gain will affect how well you see the color flow.

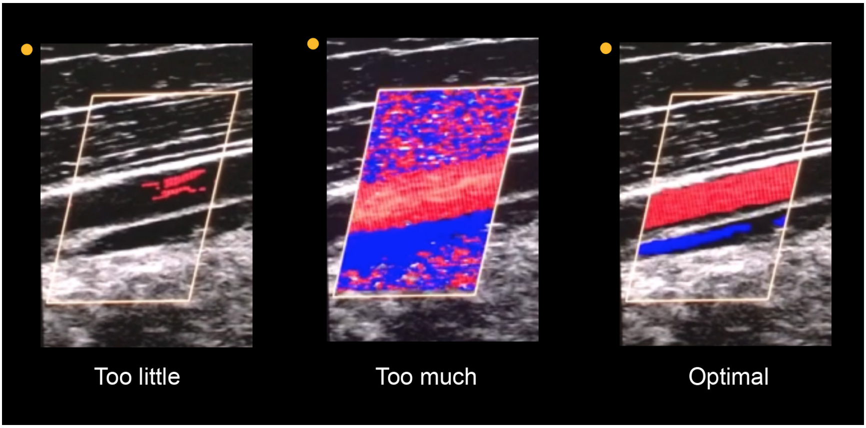
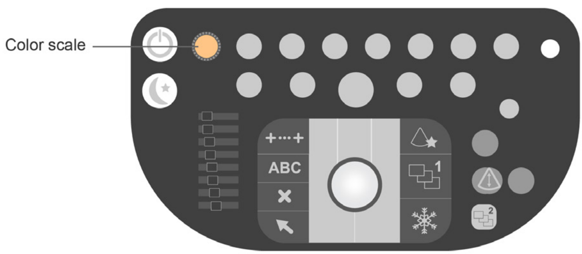


Figure 5. When adjusting color gain on a duplex ultrasound, too little causes the color to disappear, and too much causes color to overwhelm the image.

Color scale function on duplex ultrasound

Another color gain function is color scale, which can also be adjusted as you examine a vessel. Initially, it should be set around 30–40 cm / s. Color scale controls the color sensitivity, meaning that it allows a specific range of blood flow velocities to be translated into color. The gain helps amplify this data.



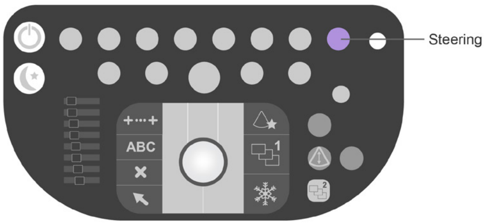
A lower color scale reads slower blood flow and must be adjusted. It can be adjusted along with gain throughout the examination. You can turn the color scale up or, if you are not seeing color very well in what seems like a patent artery, you can turn it down and increase your color gain. This is especially helpful if the area of concern is distal to significant stenosis and only has a trickle of blood flow.

If the scale is appropriately low but the gain is also too low, you still won't see the blood flow. Thus, gain and scale are often adjusted depending on the need at each particular vessel.

In contrast, you can turn the color scale up to exclude low velocities and focus on high velocities, such as velocities that create aliasing and bruits. Turning the color scale up should make the color less sensitive to stenotic vibrations, decrease artifacts, and give better color fill.

Steering function on duplex ultrasound

The Doppler angle should be set at 60° with the angle parallel to the vessel wall. The steering button is used to make this adjustment.



If the vessel is at a slant where the Doppler angle cannot be parallel to the walls at 60°, then the angle can be adjusted to less than 60° for an accurate measurement. But, you ideally want to keep a 45–60° angle. If the Doppler angle is over 60°, the machine overestimates the velocity and thus the degree of stenosis.

As you measure the velocities, turn the direction of the color box so that it follows the slant of the vessel. The steering button controls the slant of the color box and the sample volume. Knowing how to maneuver these controls is helpful when measuring velocities.

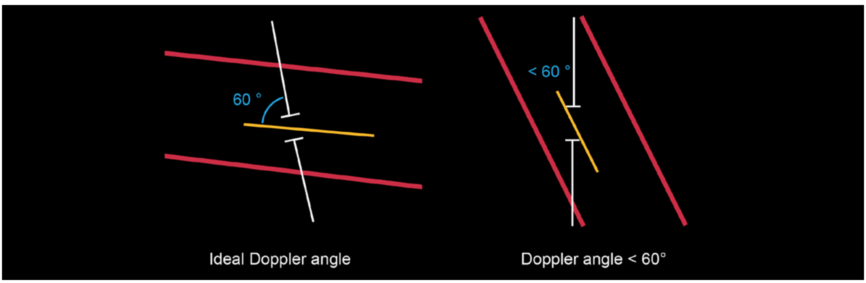


Figure 6. An ideal Doppler angle on a duplex ultrasound is 60°, but if the vessel is at an increased slant, the steering function can be adjusted to keep the angle parallel with the vessel walls as long as it does not exceed a 60° angle.

Pulsed-wave function on duplex ultrasound

When measuring velocities, press the PW button. This is the same PW button as mentioned under Doppler gain.

In addition to controlling gain (e.g., darkness or brightness), the PW button controls the waveform scale (e.g., size of the waveforms) on the velocity graph. This is extremely helpful for more accurate measurements of velocity. Keep in mind that you may have to increase your PW scale to accommodate high velocities in stenosis.

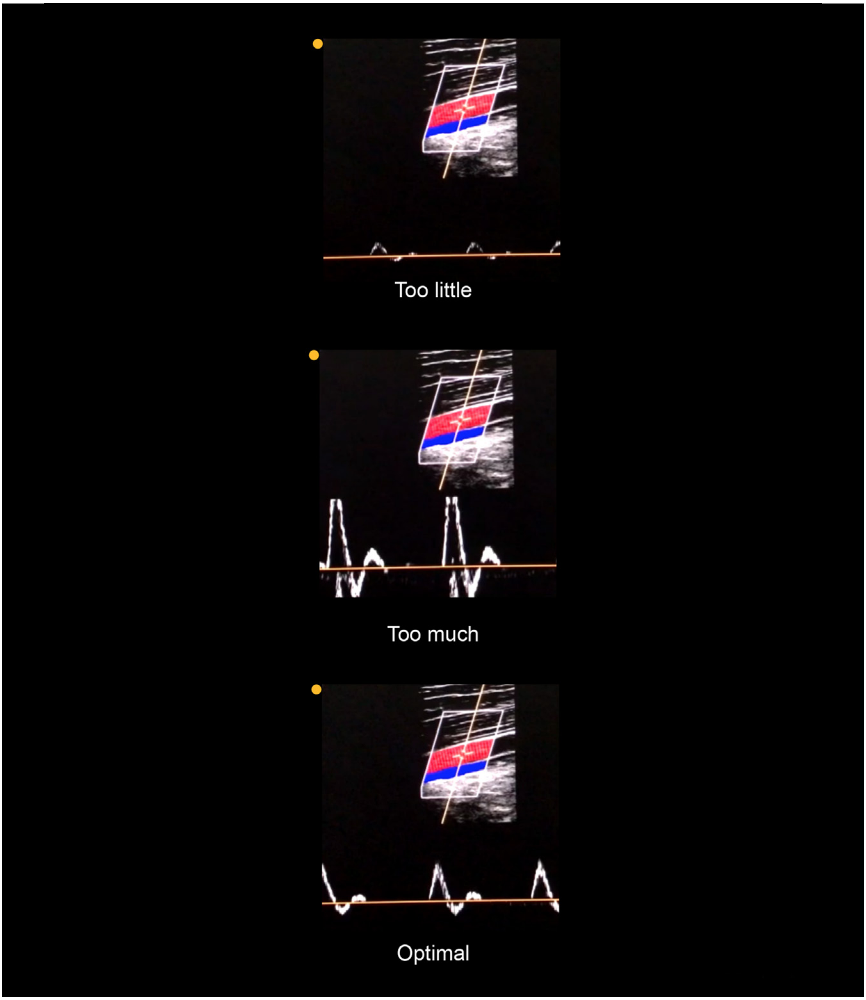


Figure 7. Use the pulsed-wave button to adjust the size of the waveforms. This is especially helpful when examining stenosis since it allows you to accommodate for high velocities.

Choosing the appropriate ultrasound probe

Typically, a duplex ultrasound machine has two probes:

1. A 12–18 MHz linear probe
2. A 5–6 MHz curved probe

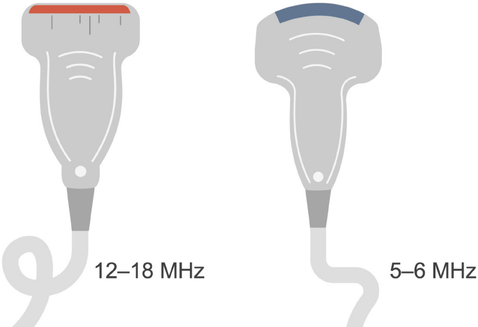


Figure 1. A duplex ultrasound machine has a 12–18 MHz linear probe and a 5–6 MHz curved probe.

The curved probe uses lower frequencies to see deeper vessels, whereas the linear probe uses higher frequencies to see more superficial vessels. The difference between the probes is just the depth of penetration.

The 12–18 MHz linear probe

Most peripheral arterial studies are performed with the linear probe because most of the lower extremity vessels are typically superficial.

The 5–6 MHz curved probe

The curved probe is usually reserved for deep abdominal arteries. However, it can be used in obese or swollen lower extremities where there is increased vessel depth.

It's really that simple!

Positioning the probe

Positioning the probe during a duplex ultrasound is simple. Every probe has an orientation notch that is a small marker or grooved line on one side of the probe. Begin by holding the probe with the thumb side of your hand near the orientation notch or groove.

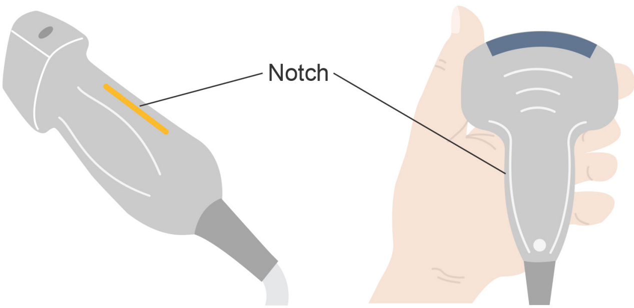


Figure 1. The duplex ultrasound probe has an orientation notch on one side. When holding the probe, this notch should be oriented towards the thumb side of your hand.

Next, it's important to realize that there are two planes used for peripheral arterial duplex studies:

1. Longitudinal
2. Transverse

On longitudinal ultrasound images, the artery looks like a horizontal tube. On the other hand, transverse ultrasound images are a cross-section of the artery.

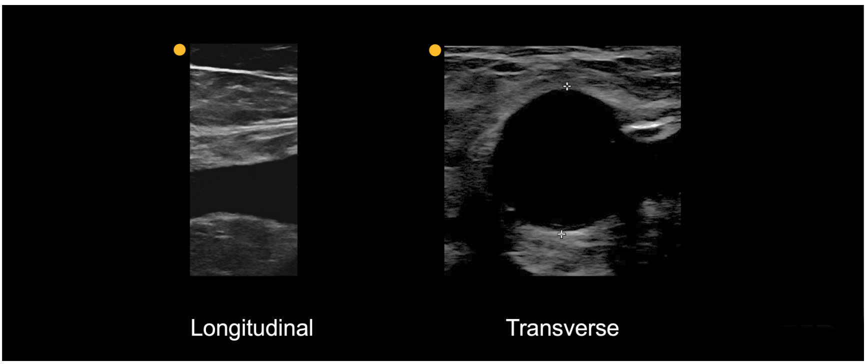


Figure 2. On duplex ultrasound images, the artery looks like a horizontal tube in the longitudinal view. In the transverse view, the artery is cross-sectioned.

How to orient the ultrasound probe

When using the longitudinal orientation, hold the probe so that the orientation notch is pointing towards the patient's head. When using the transverse orientation, the notch should be towards the patient's right side. This will orient your screen to the corresponding plane.

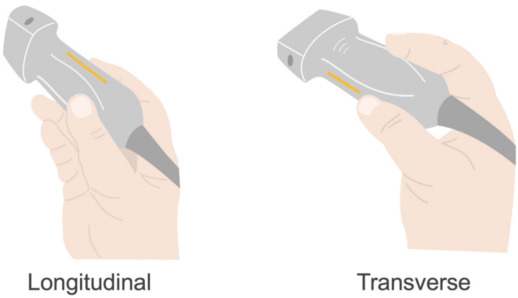


Figure 3. When using a longitudinal view, hold the probe so that the orientation notch is towards the patient's head. When using a transverse view, keep the notch pointed towards the patient's right side.

Duplex ultrasound screen orientation

Longitudinal plane

When looking at the ultrasound screen in the longitudinal orientation, the patient's head will be to the left of the image and their legs will be to the right. Longitudinal ultrasound images are taken parallel to the vessel—which is why the artery looks like a horizontal tube.

Keep in mind that velocities are only taken in the longitudinal view.

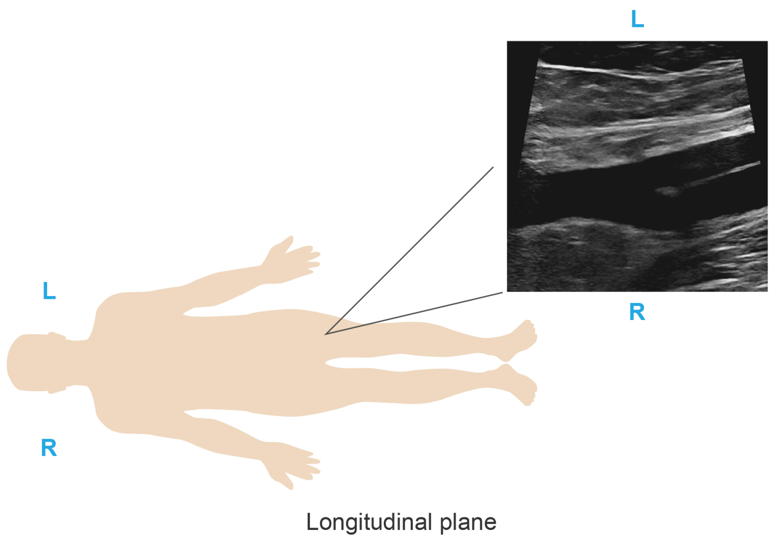


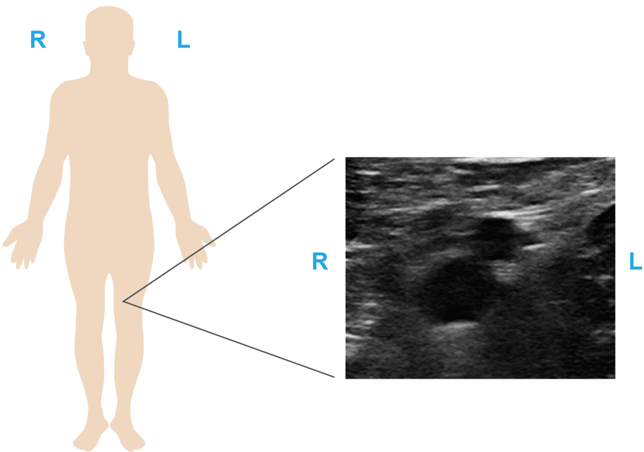
Figure 4. In the longitudinal view of a common femoral artery, the duplex ultrasound screen is oriented so that the right of the image is cranial, the left is caudad, the top of the image is the patient's left, and the bottom is the patient's right.

> Remember, when performing a duplex ultrasound with a longitudinal view, the probe's orientation notch should be pointing toward the patient's head.

Transverse plane

In transverse images, the artery looks like a cross-sectional circle. As such, any plaque jutting out into the lumen can be easily seen. Transverse views are also useful for finding a vessel's location.

The probe is held perpendicular to the vessel, which provides the sharpest image. The notch is to the patient's right when using the transverse view.



Transverse plane

Figure 5. In the transverse view of a superficial femoral artery, the duplex ultrasound screen is oriented so that the top of the image is cranial, the bottom is caudad, the right of the image is the patient's left side, and the left of the image is the patient's right side.

Quick tip to help you find a vessel if you get disoriented:

If you are in longitudinal view and you lose track of a vessel, go back into transverse view. It's much easier to locate a vessel in transverse than it is in longitudinal view.

Identifying landmarks

Arteries are difficult to identify without labels; however, there are a few tricks to keep you on track while evaluating them. First, there are two easy ways to differentiate between veins and arteries on duplex ultrasound:

1. Compression (or the lack of compression)
2. Color

To differentiate arteries from veins on duplex ultrasound, try to compress the vessel. Veins are easily compressible, but arteries are not.

Veins are also a different color than arteries on color flow duplex ultrasound. Veins are blue while arteries are red. It's important to note that this color setting can be changed, so be sure to check the ultrasound settings when you start!

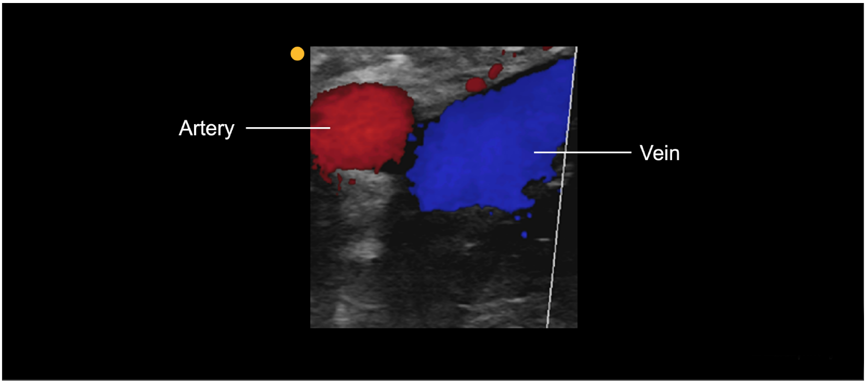


Figure 1. On color flow duplex ultrasound, arteries appear red while veins appear blue.

Next, let's cover a few tips and tricks for finding specific lower extremity arteries.

Tips for finding the common femoral artery

To find the common femoral artery (CFA) in a transverse view, look for what is referred to as the *Mickey Mouse view*. It consists of the CFA, the common femoral vein (CFV), and the saphenofemoral junction (SFJ), with the great saphenous vein in the groin.

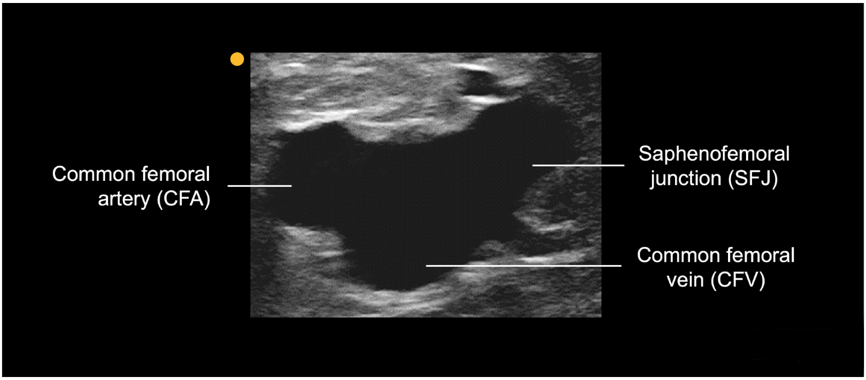


Figure 2. The Mickey Mouse view on a transverse duplex ultrasound consists of the common femoral artery (CFA), the common femoral vein (CFV), and the saphenofemoral junction (SFJ).

When looking for the CFA in a longitudinal view, look for what is commonly referred to as the tuning fork view. The tuning fork view shows the CFA as it bifurcates into the profunda femoris artery (PFA) and superficial femoral artery (SFA) in the groin.

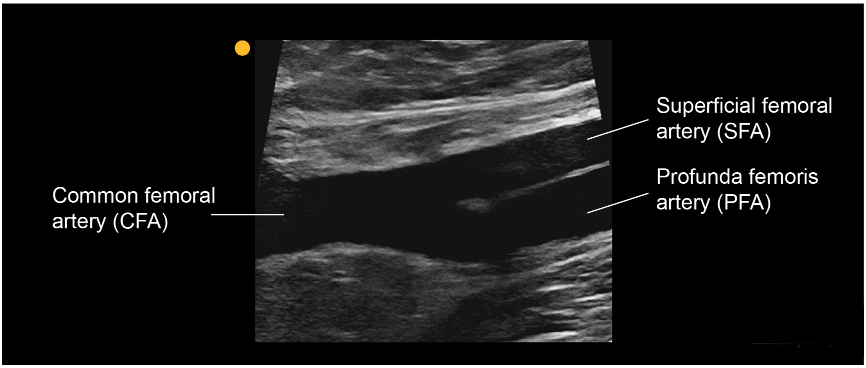


Figure 3. The tuning fork view on a longitudinal duplex ultrasound consists of the common femoral artery (CFA) bifurcating into the profunda femoris artery (PFA) and superficial femoral artery (SFA).

Tips for finding the superficial femoral artery

The presence of the femoral vein helps identify the SFA. In a transverse view, the vein is below the artery on the ultrasound screen.

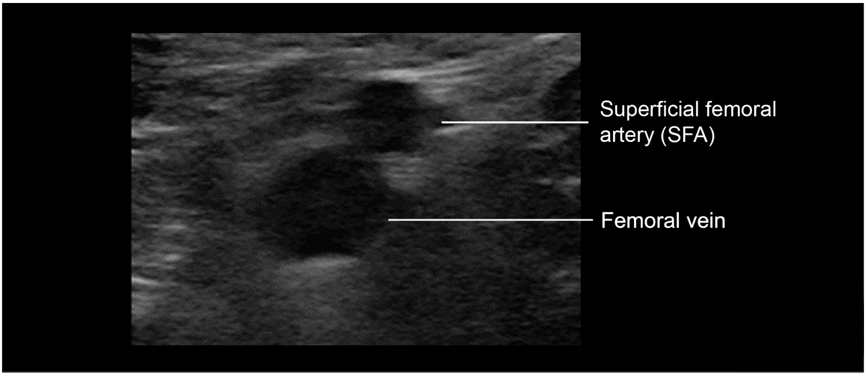


Figure 4. The superficial femoral artery (SFA) is located just above the femoral vein on transverse duplex ultrasound.

Remember, blue is typically assigned to veins, and red is assigned to arteries on color flow duplex ultrasound. There may be duplicated femoral veins—but they are easy to tell apart from the SFA. As we've already covered, not only is the color assignment different, but veins are easily compressible while arteries are not.

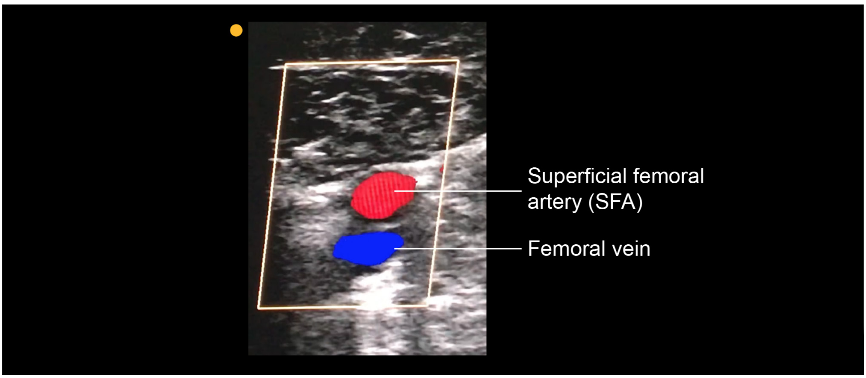


Figure 5. On color flow duplex ultrasound with a transverse view, the femoral vein appears blue and is typically located below the superficial femoral artery (which appears red).

In a longitudinal view on ultrasound, a healthy SFA appears as an unremarkable tube. It is recognized by its anatomical location along the length of the medial thigh.

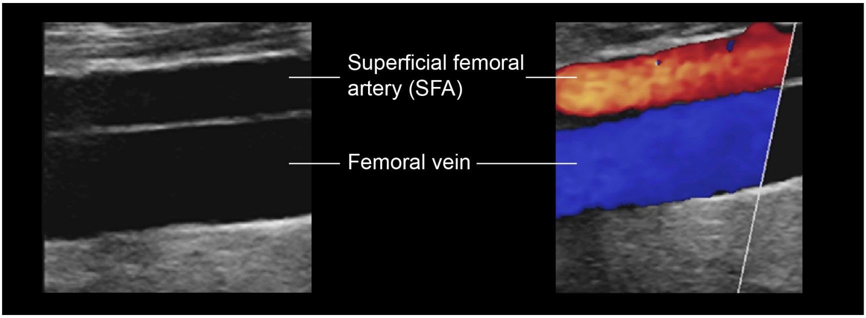


Figure 6. The superficial femoral artery (SFA) on a longitudinal duplex ultrasound is typically positioned above the femoral vein. The artery appears red on color flow while the vein appears blue.

Tips for finding the popliteal artery

In contrast to the other lower extremity vessels, the popliteal vein appears above the artery on the duplex ultrasound screen, for both the longitudinal and transverse views.

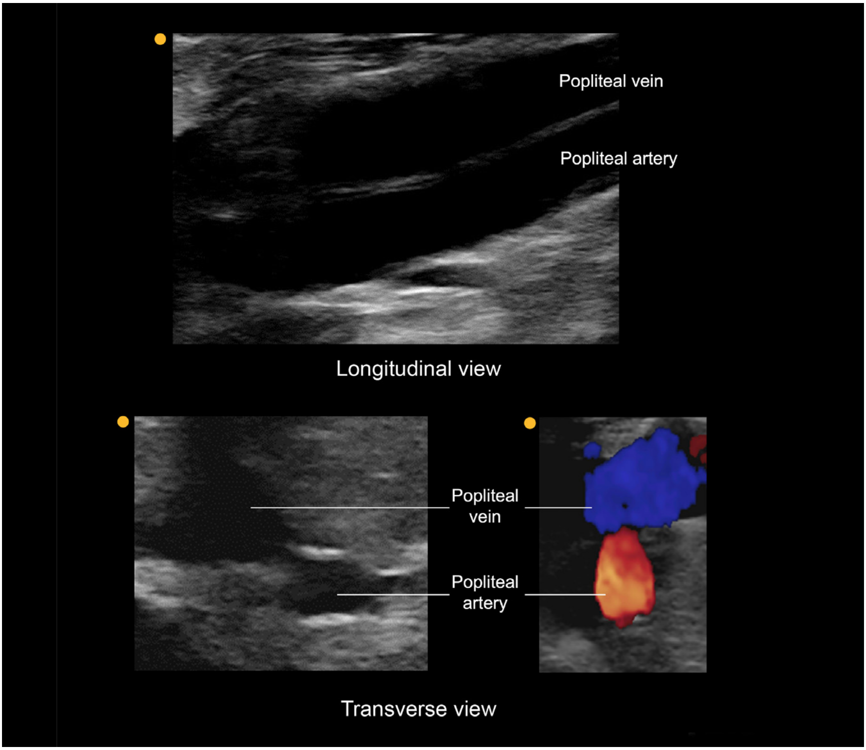


Figure 7. The popliteal artery appears below the popliteal vein in both the longitudinal and transverse views.

To summarize, to find the CFA, we look for the Mickey Mouse view. To find the SFA, look for the vein underneath the artery. To find the popliteal artery, look for the vein above the artery on ultrasound.

Lower extremity artery	**What to look for on ultrasound**
Common femoral artery (CFA)	Mickey Mouse view
Superficial femoral artery (SFA)	Vein below artery
Popliteal artery	Artery below vein

Table 1. What to look for on duplex ultrasound to find the common femoral artery (CFA), superficial femoral artery (SFA), and popliteal artery.

Tips for finding the anterior tibial artery and the tibioperoneal trunk

To find the anterior tibial artery (ATA) and the tibioperoneal trunk (TPT), keep moving the probe down the patient's leg. The distal popliteal artery can be seen as it bifurcates into the ATA and TPT, with the popliteal vein above the artery.

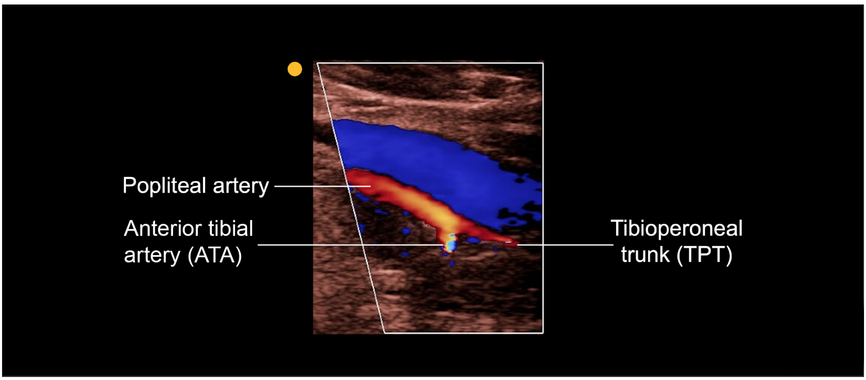


Figure 8. The popliteal vein is located above the arteries on color flow duplex ultrasound when the popliteal artery bifurcates into the anterior tibial artery (ATA) and tibioperoneal trunk (TPT).

Tips for finding the dorsalis pedis artery

The calf arteries at the ankle are the dorsalis pedis artery (DPA) and the posterior tibial artery (PTA). They are very small arteries that can be identified by two or more compressible deep veins traveling parallel to them.

To find the DPA, place the probe on the anterior ankle and move laterally. If you have trouble finding the artery, try following the same path as an ankle-brachial index (ABI) Doppler pen by starting between the bones of the first two toes and moving proximally. On ultrasound, the DPA will appear very superficial with calcific shadowing underneath, which is caused by an underlying bone.

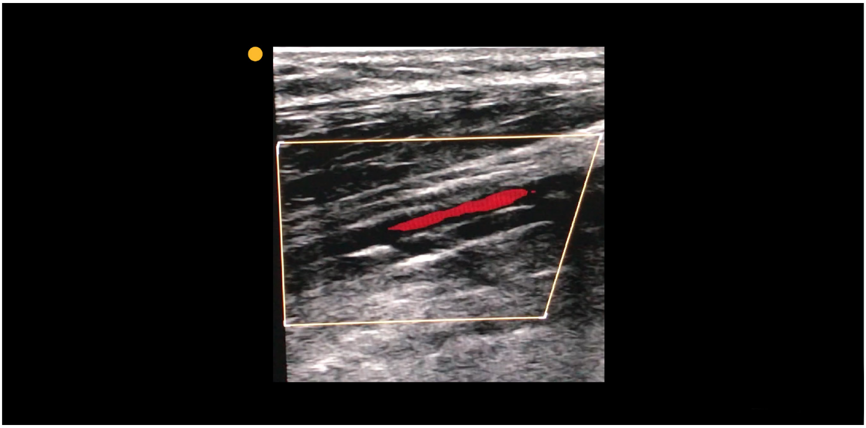


Figure 9. The dorsalis pedis artery (DPA) can be found by placing the probe on the anterior ankle. The DPA will appear superficial with calcific shadowing underneath, which is caused by an underlying bone.

If you are unable to find the pedal pulses while doing ABIs, you can use duplex ultrasound at the ankle to visualize the arteries and confirm an occlusion.

Tips for finding the posterior tibial artery

Similar to the Doppler pen, you can find the PTA behind the medial malleolus. If you cannot see the PTA very well, perform a distal augment, which is a squeeze of the foot. Blood flow in the vein is accelerated by squeezing distally. The veins can be identified by a blue flash on the duplex created by the blood movement. Where there is a vein, an artery is nearby.

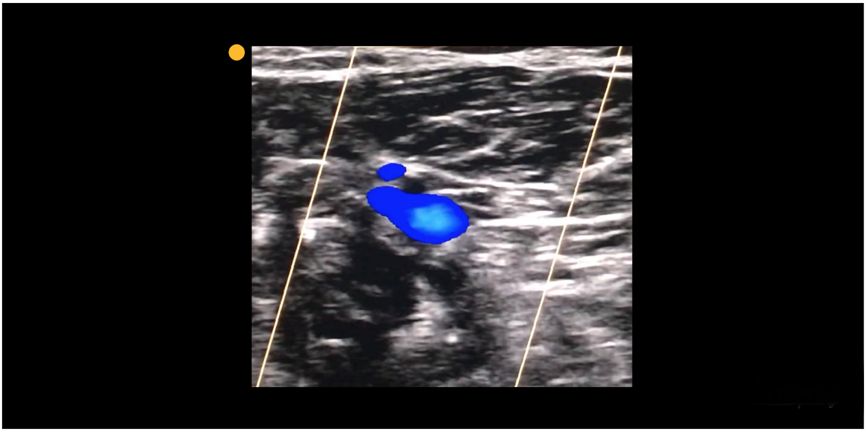


Figure 10. To view the posterior tibial artery (PTA) in a transverse view, squeeze the foot, and look for a blue flash created by the movement of blood in the nearby vein.

The PTA is also superficial and can be easily seen at the ankle level—especially because of the two or more accompanying veins.

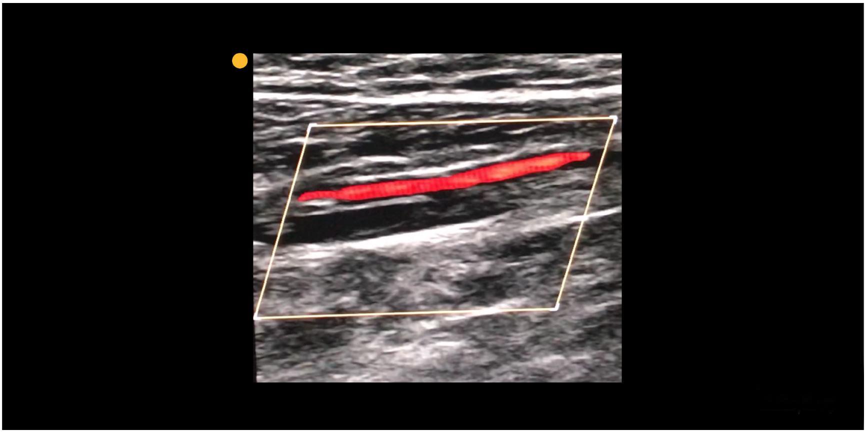


Figure 11. The posterior tibial artery (PTA) is easy to find because it is superficial and is located beside two or more veins.

Mastering an arterial duplex protocol

There are five steps to performing a basic lower extremity arterial duplex ultrasound:

1. Prepare and position the patient for the examination.
2. Locate the Mickey Mouse view in the transverse plane.
3. Examine the common femoral artery (CFA) in the longitudinal view.
4. Examine the profunda femoris artery (PFA) and superficial femoral artery (SFA).
5. Examine the popliteal artery.

Let's take a look at each of these steps in a little more detail.

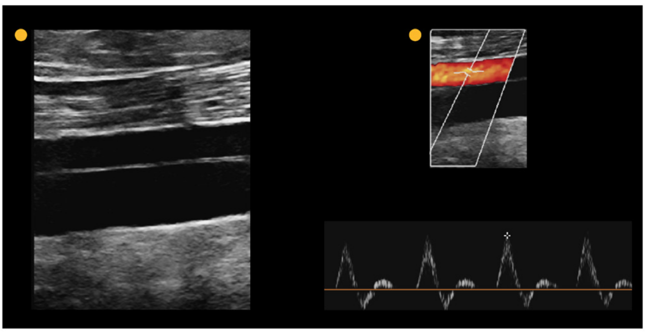
Step 1: Prepare and position the patient for the examination

Start by warning the patient that the exam initially requires the probe to be placed in their groin. Then, have the patient lie supine on the table and tuck a towel or washcloth into their underwear to keep the gel off of it.

Next, ask the patient to relax and bend their knee out to the side in a frog-legged position. Keep in mind that too much of a bend can make it difficult to find the popliteal artery.

Capture two-dimensional (2D) longitudinal images, color flow images, and Doppler waveforms

Keep in mind that every formal image is required to include a two-dimensional (2D) longitudinal image, color flow image, and Doppler waveforms. Thus, at each arterial segment, you will be performing those steps. Remember, duplex ultrasound machines allow color and Doppler on the same screen.



Step 2: Locate the Mickey Mouse view in the transverse plane

As you begin the examination, the first thing you'll be looking for is the Mickey Mouse view of the common femoral artery (CFA) in the transverse plane. Start by placing your probe in the middle of the slightly lateral inguinal crease. Slide the probe in the crease medially towards the inner thigh and you will cross the CFA.

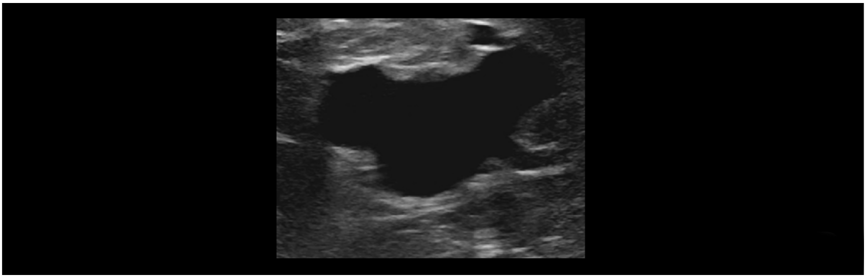


Figure 1. To locate the common femoral artery (CFA) on an arterial duplex ultrasound, start by finding the Mickey Mouse view in the transverse plane.

Remember, transverse images are not recorded on an arterial duplex ultrasound. They are simply used to locate arteries as well as aneurysms.

Step 3: Examine the CFA in the longitudinal view

Turn your probe 90° clockwise. Remember, this will move the notch towards the patient's head so that you can obtain a longitudinal view of the artery. In the longitudinal view, look for plaque and aneurysms on two-dimension (2D) and color modes. Then, Doppler for a waveform.

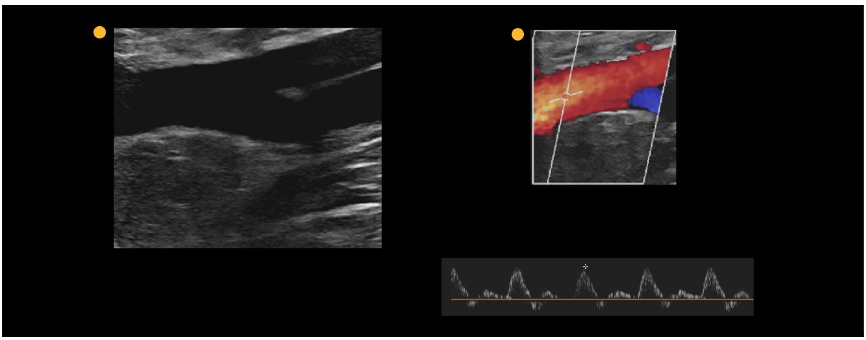


Figure 2. In a longitudinal view on duplex ultrasound, examine the common femoral artery (CFA) bifurcation and obtain black and white two-dimensional images, color images, and Doppler waveforms.

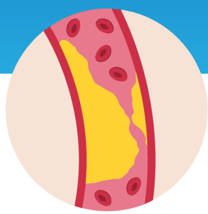
Step 4: Examine the profunda femoris artery (PFA) and superficial femoral artery (SFA)

Evaluate the PFA off of the CFA bifurcation, and then the proximal, middle, and distal SFA. Ideally, you want to slowly track the arteries in the longitudinal view (with color) to continuously evaluate the entire artery. This takes practice because you can easily slide off the artery and miss a segment. But, it's the most effective way to locate stenosis. If you slide off, you can go back into the transverse view and locate the artery again.

If there is a blockage, waveforms can help you locate the blockage even if you don't actually see it on the duplex ultrasound.

Pro tip:

When performing an arterial ultrasound, do not simply spot-check the upper, middle, and distal thigh. Stenosis can be missed between the segments that you checked.



Step 5: Examine the popliteal artery

Next, evaluate further down the leg by placing the probe behind the knee. Evaluate the entire popliteal artery behind the knee by moving the probe down the calf until the vessels bifurcate. Again, this action will produce the black and white 2D images, color images, and Doppler waveforms.

It's as simple as that!

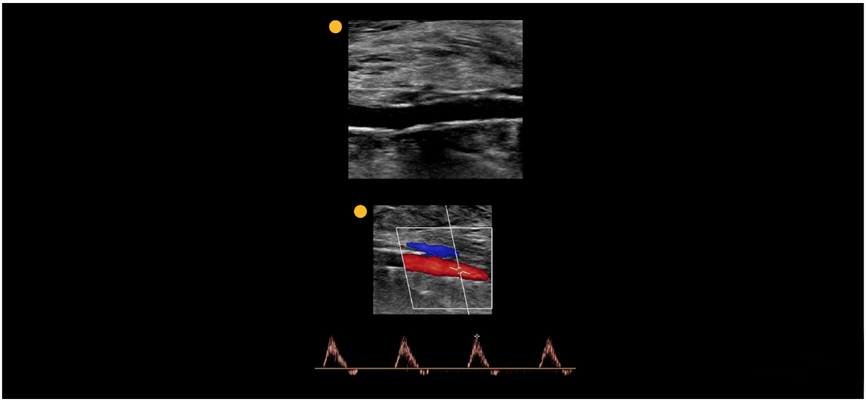


Figure 3. When examining the popliteal artery on a duplex ultrasound, you will capture two-dimensional black and white images, color images, and Doppler waveforms.

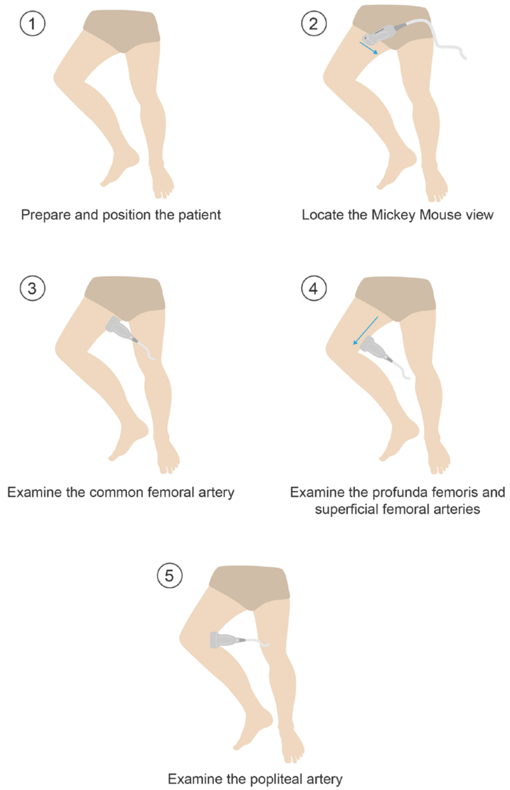


Figure 4. The five steps to performing a basic lower extremity arterial duplex ultrasound include, 1) prepare and position the patient, 2) locate the Mickey Mouse view, 3) examine the common femoral artery, 4) examine the profunda femoris and superficial femoral arteries, 5) examine the popliteal artery.

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Chapter 6

INTERPRETING ANOMALIES AND SURGICAL CASES

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Evaluating stents and bypass grafts

Oftentimes, patients will have stents or bypass grafts placed as part of a treatment, so it's important to be able to recognize them on ultrasound. Let's dive into how to find and evaluate stents and bypass grafts on duplex ultrasound.

Lower extremity stents on duplex ultrasound

Finding stents

On ultrasound, stents appear with bright and echogenic borders. Stents are most easily recognized at their proximal attachment.

Occasionally, it can be difficult to find and evaluate stents for patency due to the presence of calcific shadowing. The calcific shadowing is from atherosclerotic plaque that is pushed up against the walls of the artery.

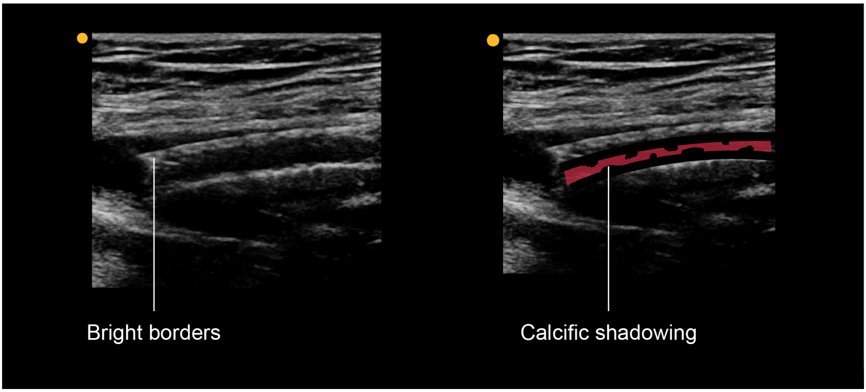


Figure 1. Stents can be recognized on ultrasound by their bright and echogenic borders. Sometimes, calcific shadowing from atherosclerotic plaque can make stents difficult to identify, as demonstrated in this superficial femoral artery stent.

When off-axis, you can usually recognize a stent on ultrasound by its mesh pattern.

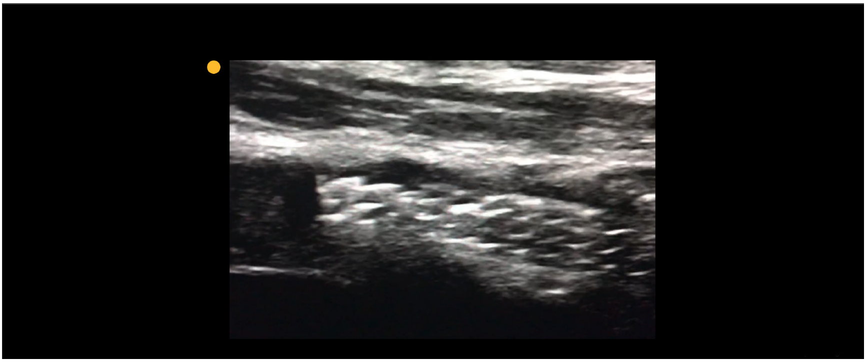


Figure 2. A stent can often be recognized on ultrasound by its characteristic mesh pattern.

Evaluating stents

The evaluation of a stent follows a standard protocol where a series of velocities are measured in seven key locations:

1. Just proximal to the proximal attachment (e.g., inflow).
2. Within the proximal attachment.
3. In the proximal portion of the stent.
4. In the middle of the stent.
5. In the distal portion of the stent.
6. Within the distal attachment.
7. Just distal to the distal attachment (e.g., outflow).

The inflow velocity taken just proximal to the proximal attachment serves as the reference velocity. The velocities are then used to assess the degree of obstruction within the stent.

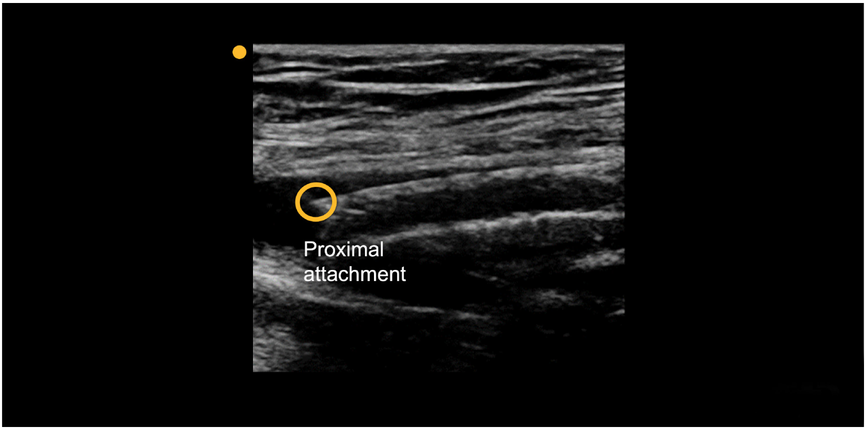


Figure 3. When evaluating a stent on ultrasound, start by taking the velocity just proximal to the proximal attachment of the stent.

Lower extremity bypass grafts on duplex ultrasound

Finding synthetic bypass grafts

Synthetic bypass grafts (BPGs) are usually easy to recognize on ultrasound. A synthetic BPG looks like a vessel with the same color fill and waveforms as a normal, healthy artery. But, it has patterned edges. Bypass grafts in the superficial femoral artery (SFA) often have a more superficial path compared to the SFA.

Bypass grafts are examined the same way as stents. The only difference is that we use slightly different terminology. Instead of attachments, we use the terms proximal anastomosis and distal anastomosis for the ends of the graft.

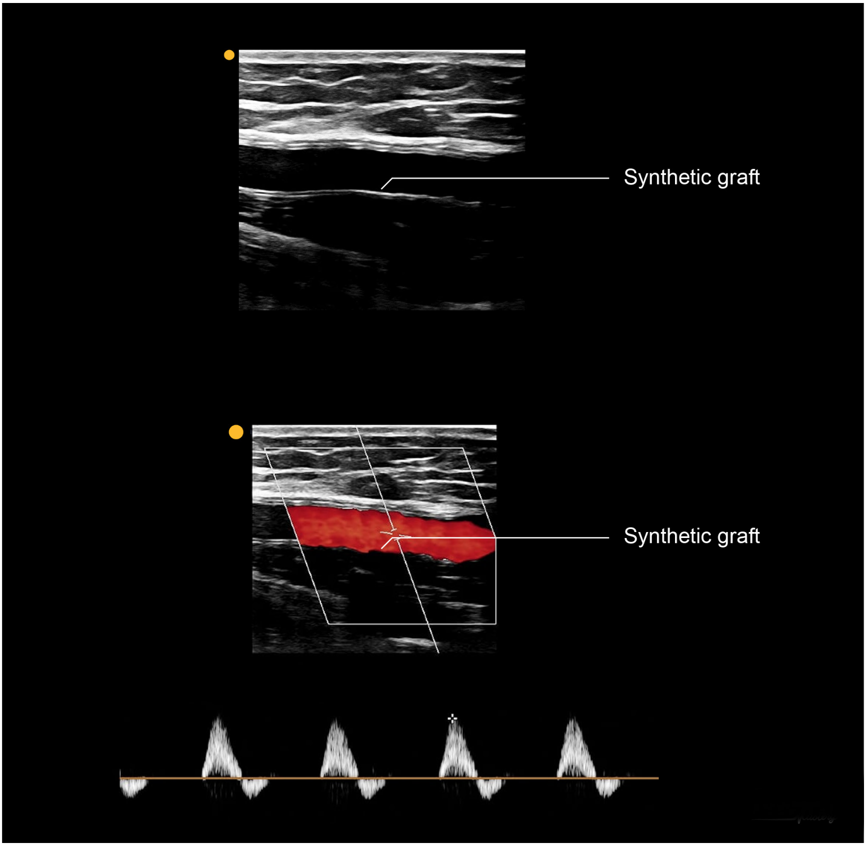


Figure 4. A synthetic bypass graft looks like a healthy vessel on duplex ultrasound and has normal waveforms. But, it can be identified by its patterned edges.

Finding autologous bypass grafts

If the graft is autologous (e.g., taken from the patient's body) from a reversed saphenous vein, there is nothing remarkable about the wall's appearance. In this case, it is best identified by its pulsating color and location down the length of the medial thigh. In some rare cases, bypass grafts can run down the outer thigh to the anterior tibial artery.

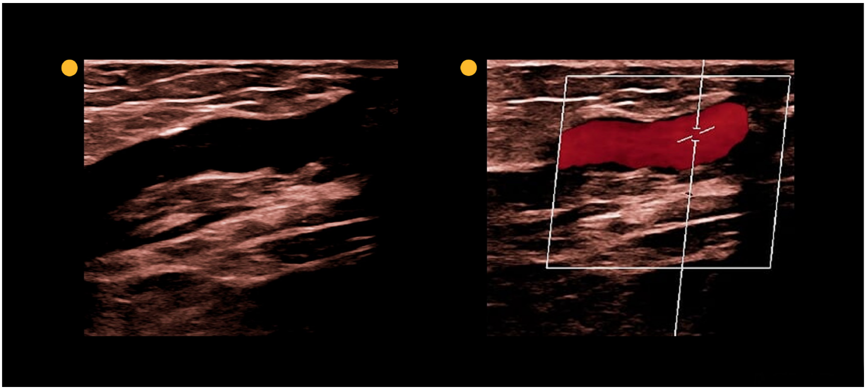


Figure 5. An autologous bypass graft looks just like a normal, healthy vessel on two-dimensional and color flow ultrasound images. It can be identified by its pulsating color and location down the length of the medial thigh.

Pro tip:

When looking for a bypass graft, keep in mind that it passes beside a very diseased vessel. If you're in the area of a known graft and you find an artery that looks widely patent, it's likely that you're imaging the bypass graft.

Some surgeons tend to place the graft in the native artery's anatomical location—which can be confusing at first. Sometimes you can see the diseased vessel, but it might be difficult to see if the vessel is chronically occluded.

It's easiest to locate the bypass graft at its proximal anastomosis, which is often in the groin. Once identified, follow the graft continuously like you would with a non-bypassed artery. If you get lost, go back in into a transverse orientation with color to relocate the vessel.

Evaluating bypass grafts

The evaluation of a bypass graft follows the same standard protocol that is used for stents. Measure a series of velocities in seven key locations:

1. Just proximal to the proximal anastomosis.
2. Within the proximal anastomosis.
3. In the proximal portion of the graft.
4. In the middle of the graft.
5. In the distal portion of the graft.
6. Within the distal anastomosis.
7. Just distal to the distal anastomosis.

The inflow velocity taken just proximal to the proximal anastomosis is the reference velocity. The velocities are then used to assess the degree of obstruction within the bypass graft.

Investigating true aneurysms

During the ultrasound evaluation of a patient, it's important to check for aneurysms. Lower extremity arterial aneurysms are seen more often in the popliteal artery and less often in the common femoral artery (CFA).

Genetic disorders (such as Marfan's syndrome) increase the chance of an aneurysm in other vessels. In patients without a genetic predisposition, the popliteal artery and the CFA are the most commonly affected vessels. This is believed to be because these two vessels are located in joint creases. So, they undergo frequent compression and can incur wall damage from repetitive microtrauma.

If a patient is found to have an abdominal aortic aneurysm, you'll also want to spot check the CFA and popliteal artery for any evidence of aneurysms.

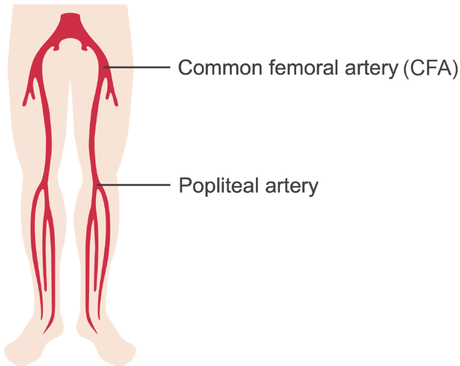


Figure 1. The two most common locations where a lower extremity arterial aneurysm can occur are within the popliteal artery and the common femoral artery (CFA).

Guidelines for defining an aneurysm on ultrasound

Aneurysms can be defined in two different ways on ultrasound:

1. Comparison
2. Direct measurement

The most important way to define an aneurysm is by comparison. In the lower extremities, arteries are considered aneurysmal if the vessel's diameter increases by 1.5 times compared to the segment proximal to the suspected aneurysm.

With the direct measurement method, 10 mm is considered aneurysmal for the popliteal artery and 15 mm is considered mildly aneurysmal for the CFA.

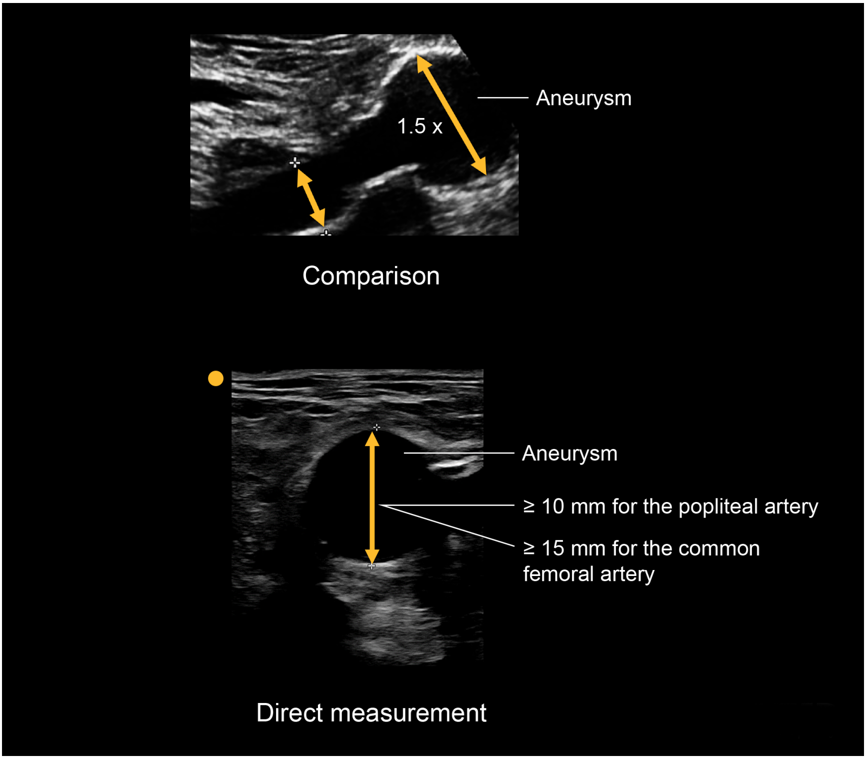


Figure 2. Aneurysms can be identified on ultrasound by comparison or direct measurement. With the comparison method, a bulge is considered an aneurysm if it is 1.5 times greater in diameter than the proximal segment. With direct measurement, a bulge is considered an aneurysm if it is greater than or equal to 10 mm in the popliteal artery or 15 mm in the common femoral artery.

Steps for measuring an aneurysm on ultrasound

There are four steps for measuring an aneurysm on ultrasound:

1. Make the aneurysm as circular as possible in the transverse view.
2. Place the calipers from the outer wall to the opposite outer wall and include all of the mural thrombus. Measure the diameter of the aneurysm from anterior to posterior.
3. Measure the nearest normal proximal segment for comparison.
4. Switch to a longitudinal view and measure the aneurysm to confirm the transverse measurement.

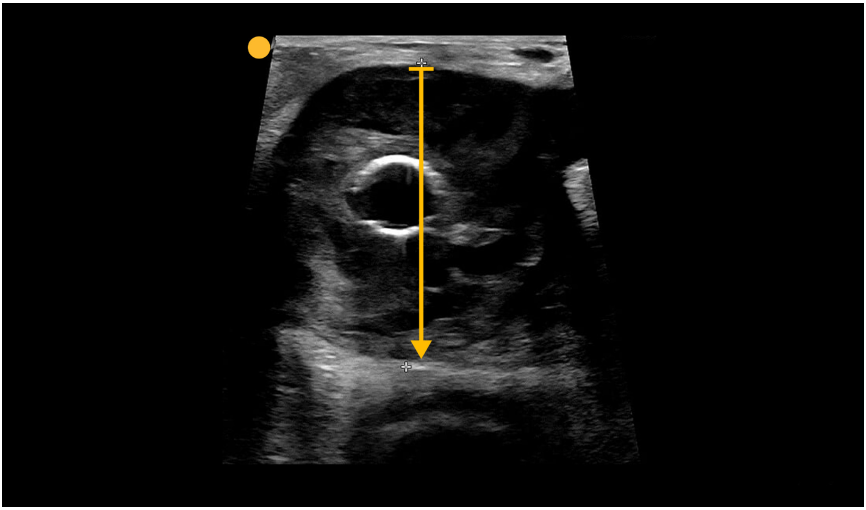


Figure 3. When measuring an aneurysm on ultrasound in a transverse view, measure anterior to posterior from outer wall to outer wall and include the mural thrombus, if present.

When an artery has a stent graft placed to exclude a thrombotic aneurysm, you should still measure the aneurysm from the outer wall to the opposite outer wall in the transverse view. Also, check for an endoleak (a leak through the graft or at the graft end), which allows blood flow into the excluded aneurysm sac. An endoleak continually increases the size of the aneurysm and the risk of rupture.

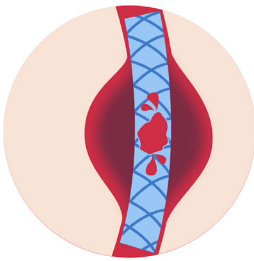


Figure 4. An artery with a stent graft that has been placed to exclude a thrombotic aneurysm should be checked with ultrasound for an endoleak. Endoleaks allow blood flow into the aneurysm sac and increase the chance of rupture.

When taking measurements in a longitudinal view, also take anterior to posterior measurements (e.g., from the top of the screen to the bottom). The measurements should be taken as perpendicular as possible to the vessel walls to get the most accurate diameter.

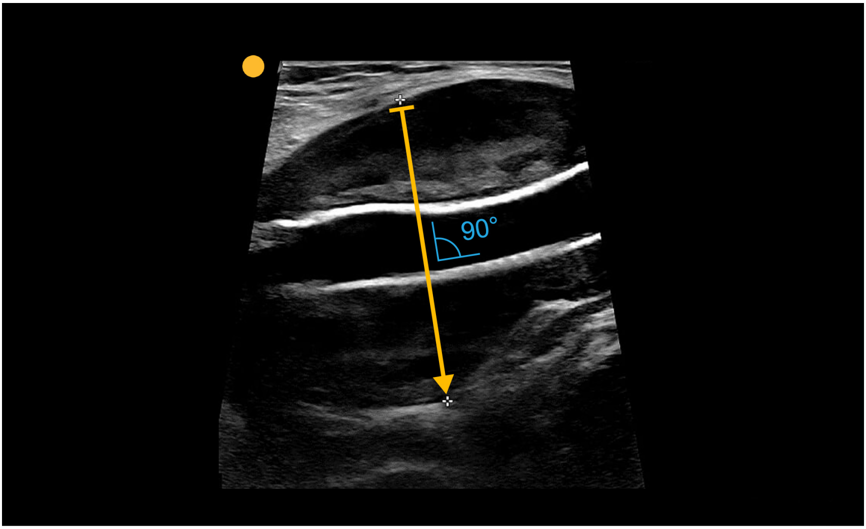


Figure 5. When measuring an aneurysm in a longitudinal view, measure from top to bottom (e.g., anterior to posterior) and take the measurement as perpendicular to the vessel walls as possible.

Diagnosing pseudoaneurysms

Pseudoaneurysms are caused by a penetrating injury to the arterial wall. This causes blood to leak from the artery and pulsate into the surrounding tissues.

One cause of a pseudoaneurysm is an iatrogenic puncture during catheterization. Suspect a pseudoaneurysm if a pulsatile groin mass appears after surgery involving groin catheterization.

Thankfully, pseudoaneurysms are easily evaluated on ultrasound. Let's take a look at how to examine, treat, and perform follow-ups for a pseudoaneurysm.

How to examine and measure a pseudoaneurysm on ultrasound

Measurement of a pseudoaneurysm, similar to stents, follows a standard protocol:

1. Measure the pseudoaneurysm sac using a transverse two-dimensional (2D) view.
2. Turn on color Doppler and look for the yin-yang sign and neck.
3. Measure the length and width of the neck.
4. Capture Doppler waveforms at the neck.

Step 1: Measure the pseudoaneurysm using the transverse 2D view

In a transverse 2D view, measure the pseudoaneurysm from the outer wall to the opposite outer wall and note any thrombus.

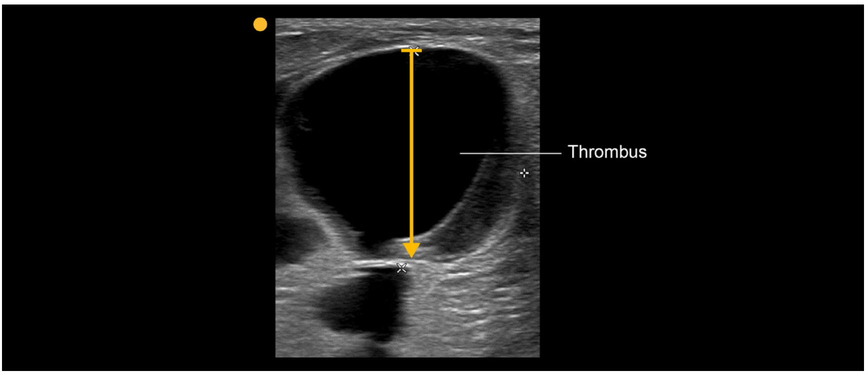


Figure 1. Measure the pseudoaneurysm from the outer wall to the opposite outer wall using a transverse two-dimensional view and note any thrombus.

Step 2: Turn on color Doppler and look for the yin-yang sign and neck

The pseudoaneurysm's appearance on color Doppler is referred to as the yin-yang sign. This represents the swirling flow of color from the blood jetting through the neck of the pseudoaneurysm. The leaking artery and the blood collection can be visualized on ultrasound.

You can also visualize the pseudoaneurysm neck, which is the length of blood flow between an artery and a pseudoaneurysm sac.

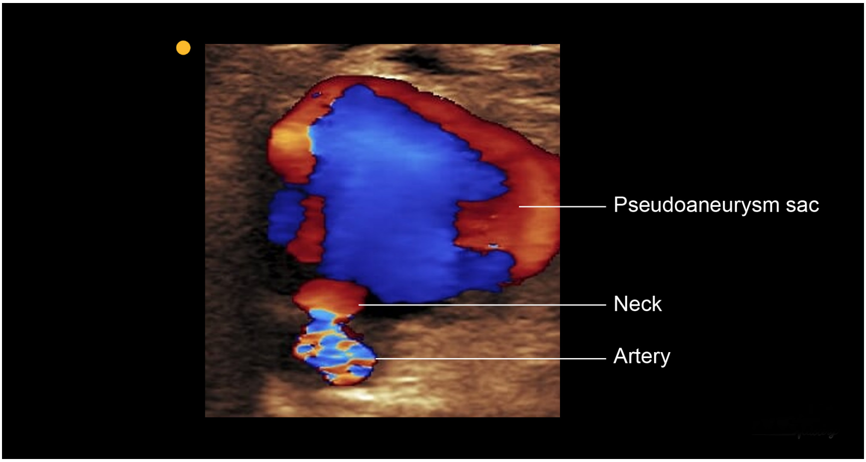


Figure 2. When examining a pseudoaneurysm on ultrasound, turn on color Doppler and look for the characteristic yin-yang sign of the pseudoaneurysm sac. As well, note the pseudoaneurysm neck and the leaking artery.

Step 3: Measure the length and width of the neck

The pseudoaneurysm neck can vary in length and width, and occasionally there won't be a discernable neck separating the pseudoaneurysm from the artery. When measuring the neck, keep in mind that the measurements are more accurate without color. This is because color can bleed over the edges of the vessel walls on the ultrasound screen. However, if the pseudoaneurysm neck is difficult to see without color, you may need to measure the neck with the color on.

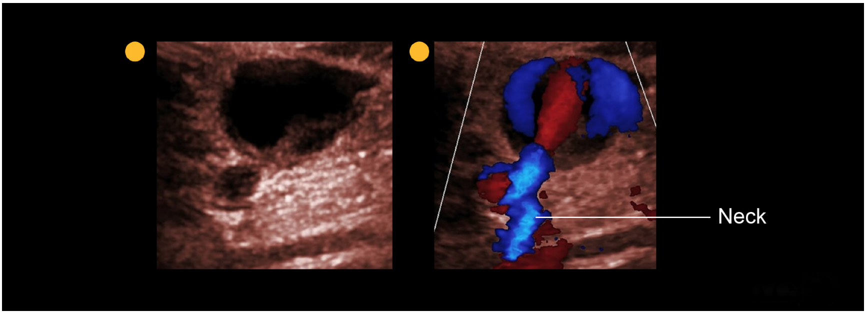


Figure 3. A pseudoaneurysm neck on duplex ultrasound is easier to see in the color Doppler mode than in the black and white mode.

Step 4: Capture Doppler waveforms at the neck

When assessing Doppler waveforms of the neck, the to-and-fro flow will be apparent on the waveforms since it pulses above and below the baseline.

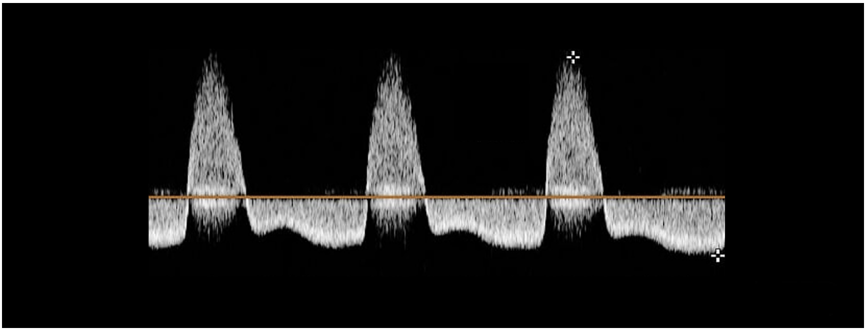


Figure 4. The Doppler waveforms of a pseudoaneurysm neck demonstrate to-and-fro flow with waveforms above and below the baseline.

Pseudoaneurysm treatment and follow-up

Watch-and-wait approach

The treatment of a pseudoaneurysm consists of a few options. If the pseudoaneurysm is not quickly expanding, a watch-and-wait approach with serial follow-up visits is appropriate.

Twenty-minute compression

If it does not clot on its own, then a twenty-minute compression of the pseudoaneurysm neck can be performed with the ultrasound probe in an attempt to achieve thrombosis. This method is not frequently used because it causes pain for the patient, is strenuous for the ultrasound technologist, and is time-consuming.

After this treatment, the common femoral artery should be examined for evidence of pseudoaneurysm clot extension.

Injection of thrombin

Another option is an injection of thrombin into the pseudoaneurysm sac. This is the preferred method to treat pseudoaneurysms because it is relatively fast, not as difficult for the operator, and not as uncomfortable for the patient.

The injection of thrombin is ultrasound-guided, which helps confirm needle placement, visualize the injection, and ensure there is no clot extension into the native artery. Clot extension can cause an occlusion of the native artery (e.g., clot embolism) from the pseudoaneurysm sac into the legs.

What to look for on follow-up ultrasounds of a pseudoaneurysm

Pseudoaneurysms can clot on their own, which is why a watch-and-wait method is often a reasonable option. During this period, serial ultrasounds help track spontaneous thrombosis.

On color flow duplex ultrasound, a partially thrombotic pseudoaneurysm will demonstrate diffuse blood flow within the thrombus.

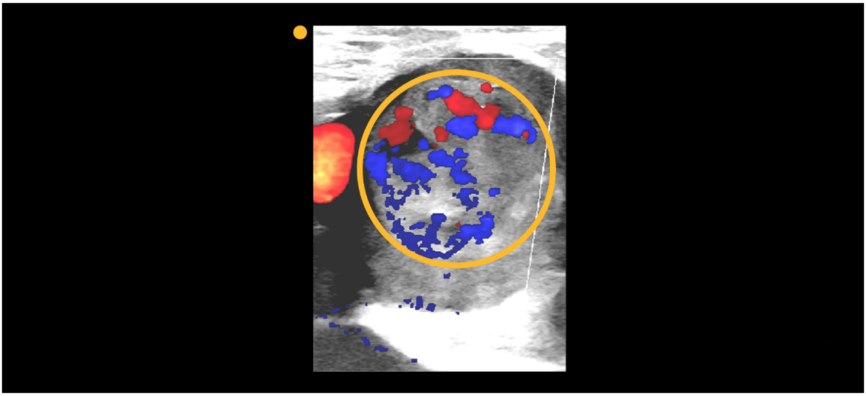


Figure 5. A partially thrombotic pseudoaneurysm demonstrating diffuse blood flow within the thrombus on color flow duplex ultrasound.

When a pseudoaneurysm is mostly clotted, you can see varying gray tones in a 2D view which represent clotted blood. Any remaining active bleeding will show up as an anechoic (e.g., completely black) section.

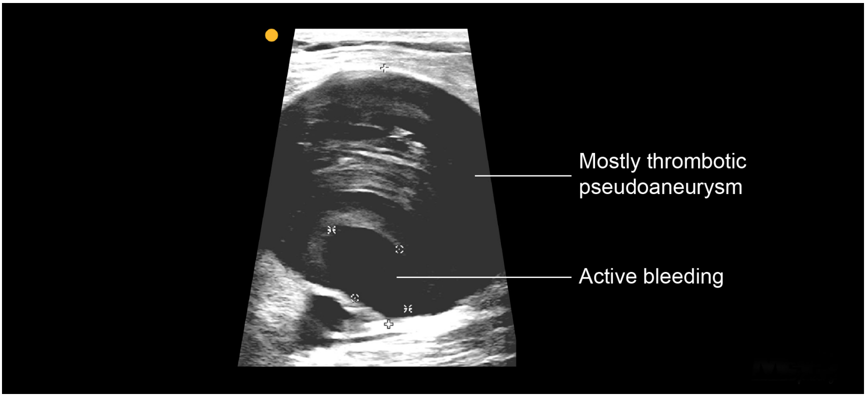


Figure 6. This pseudoaneurysm is mostly clotted, as seen by varying gray tones representing clotted blood. The anechoic (e.g., completely black) section on the bottom is the remaining active bleeding.

Manual compression of the neck, or a thrombin injection into the pseudoaneurysm sac, speeds complete thrombosis of a pseudoaneurysm. With a fully thrombotic pseudoaneurysm, the pseudoaneurysm sac should show no flow, which can be confirmed by color Doppler.

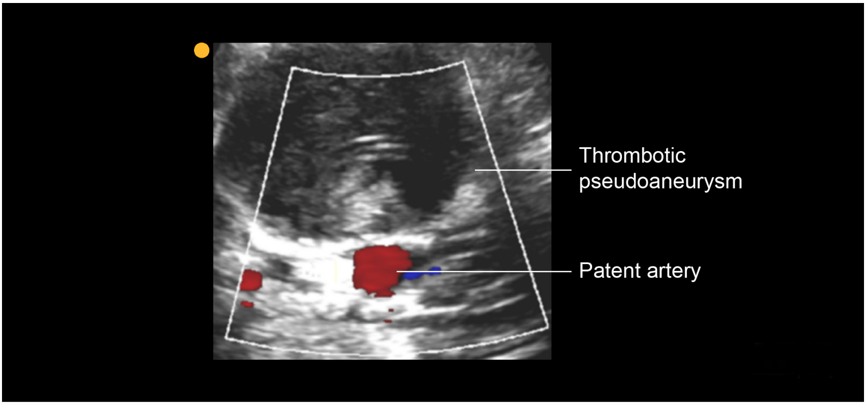


Figure 7. A fully thrombotic pseudoaneurysm shows no characteristic yin-yang flow on color Doppler and a fully patent artery.

After the successful treatment of a pseudoaneurysm, you should be able to compare the pre- and post-treatment images. To confirm a successful thrombosis, note that the pseudoaneurysm sac no longer has blood flow on examination with color Doppler. The thrombotic pseudoaneurysm is now referred to as a hematoma.

The neck (if there still is one) should not show any to-and-fro flow. As well, its waveforms should only show pulses above the baseline.

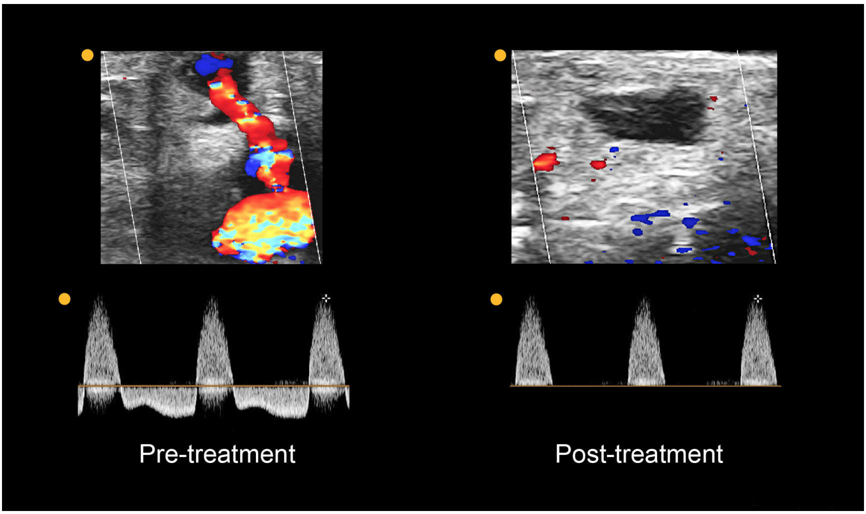
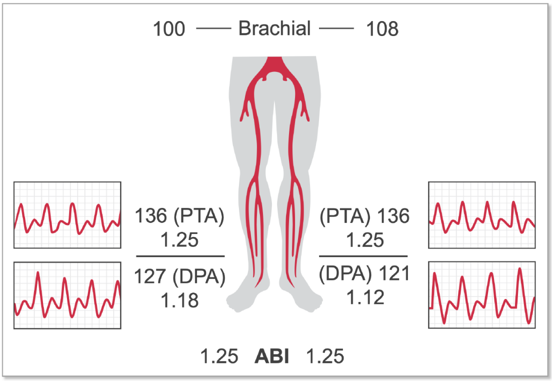


Figure 8. Pre- and post-treatment images of a small pseudoaneurysm with a long neck after ultrasound-guided compression. The pre-treatment Doppler waveforms from the neck show pulses above and below the baseline; the post-treatment waveforms are all above the baseline.

Case demonstrating a pseudoaneurysm found on duplex ultrasound after a normal ABI

Remember, a patient with a pseudoaneurysm will have a normal ankle-brachial index (ABI). At first, an ABI report can be confusing to look through—but don't let it intimidate you! Start by looking at the ABI calculations.

In this case, the patient's ABI ratios were 1.25 for the right posterior tibial artery (PTA) and 1.18 for the dorsalis pedis artery (DPA), which are considered normal. However, when a duplex ultrasound was performed in the right groin, a pseudoaneurysm was found with its characteristic yin-yang appearance and neck.



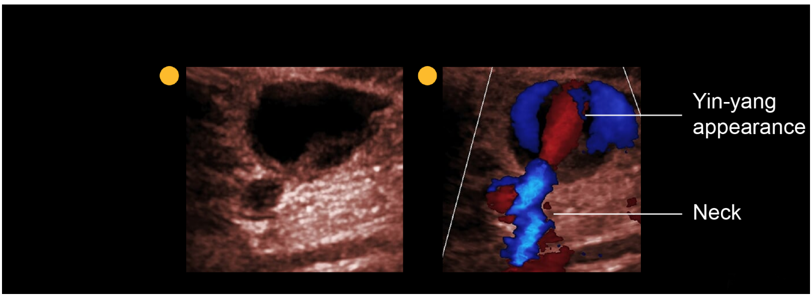


Figure 9. A patient case presenting with a pseudoaneurysm and normal ankle-brachial index (ABI) ratios. The pseudoaneurysm with its characteristic yin-yang appearance and neck was found on duplex ultrasound.

If you suspect a pseudoaneurysm, all you need is a duplex ultrasound!

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APPENDIX

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