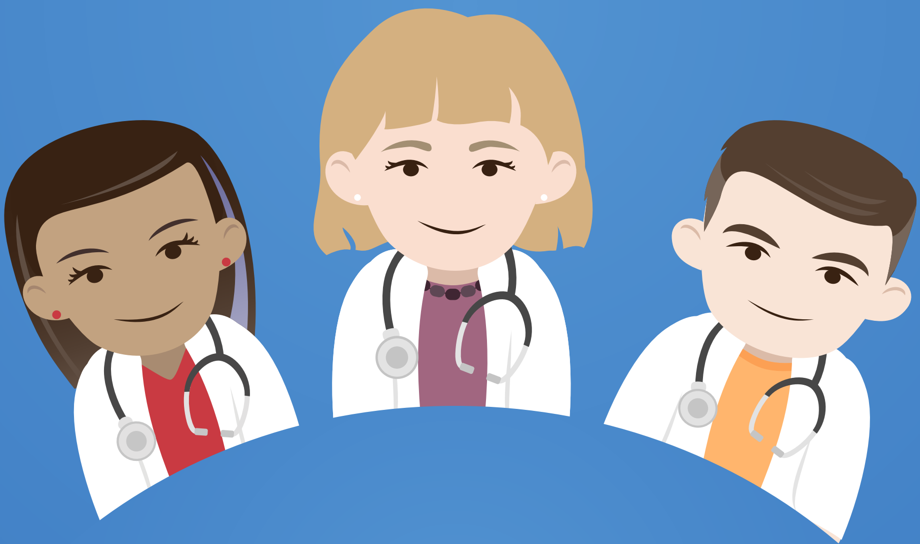
ULTRASOUND MASTERCLASS: THE CAROTID ARTERY

HANDBOOK



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Abbreviation list

ALARA	as low as reasonably achievable
CCA	common carotid artery
ECA	external carotid artery
ECST	European Carotid Surgery Trial
EDV	end-diastolic velocity
ICA	internal carotid artery
MI	mechanical index
NASCET	North American Symptomatic Carotid Endarterectomy Trial
PACS	picture archiving and communications system
PRF	pulse repetition frequency
PSV	peak systolic velocity
PSVR	peak systolic velocity ratio
TGC	time gain compensation
TI	thermal index
TIA	transient ischemic attack

Chapter 1

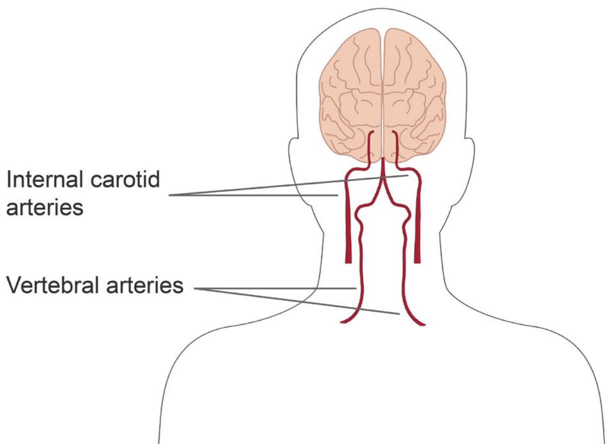
SETTING THE SCENE

Reviewing essential cerebrovascular anatomy

A carotid, vertebral, and subclavian ultrasound scan plays an important role in the assessment of arterial disease. Before we learn how to image these arteries, we need to review some essential cerebrovascular anatomy.

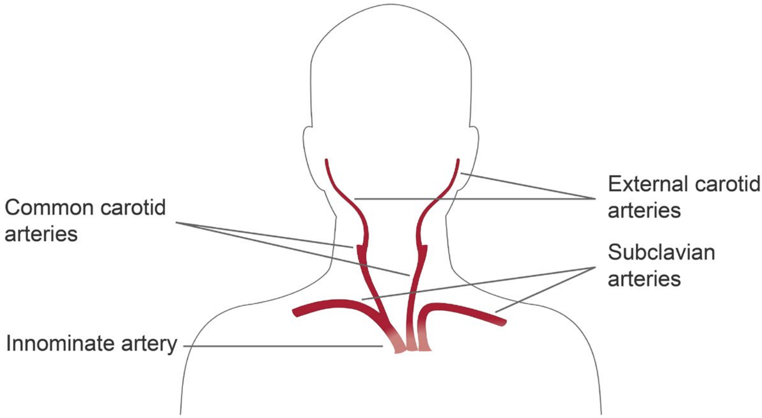
So, let's start with the brain. The brain receives blood from four arteries:

1. Left internal carotid artery
2. Right internal carotid artery
3. Left vertebral artery
4. Right vertebral artery



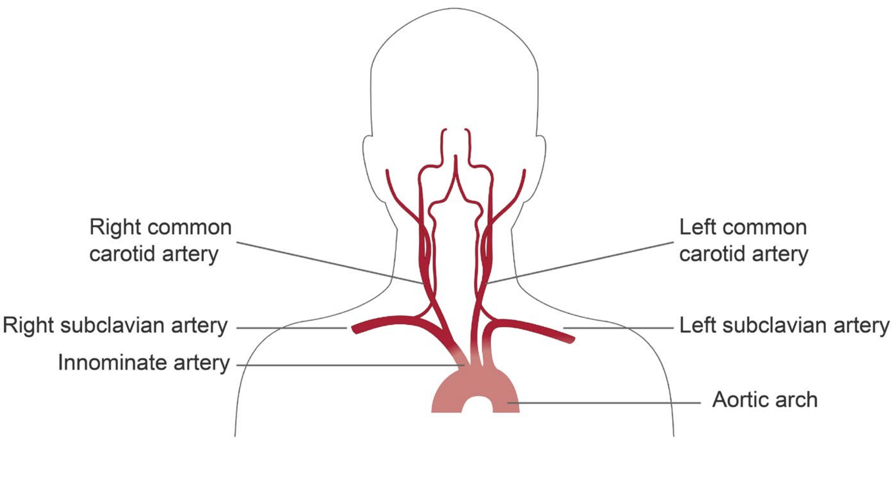
Other arteries supply blood to the head, neck, and upper extremities:

- Innominate (or brachiocephalic) artery
- Subclavian arteries
- Common carotid arteries
- External carotid arteries



The term extracranial cerebral arteries refers to all of the arteries carrying blood up from the heart to the base of the skull. During a carotid ultrasound investigation, you will image and report on the extracranial cerebral arteries.

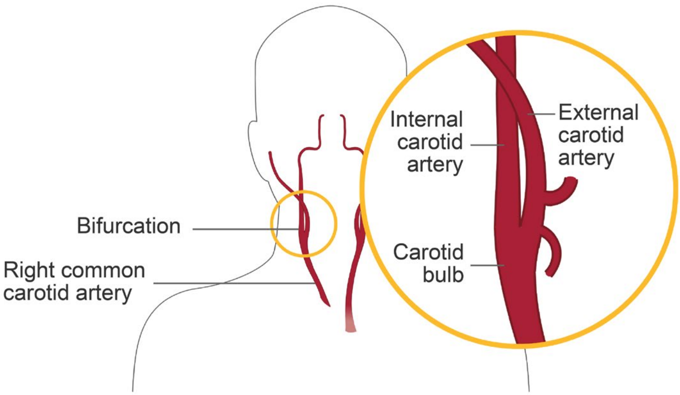
The origin of all of these arteries is found at the base of the neck, but their anatomy is not symmetrical. On the right side of the body, the innominate artery (also known as the brachiocephalic artery) arises directly from the aortic arch and then divides into the right subclavian artery and common carotid artery. However, on the left side of the body, the common carotid artery and subclavian artery both extend directly from the aortic arch.



Carotid arteries

The main arteries of the neck are the carotids, which serve as the anterior blood supply of the brain. The common carotid artery (or CCA) has no branches and widens at the bifurcation, which is known as the carotid bulb.

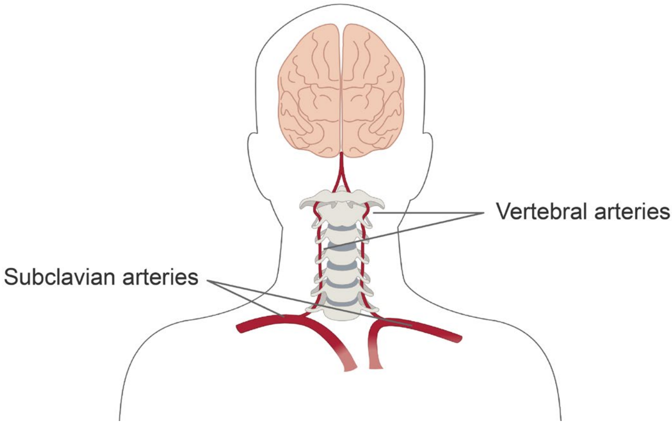
The bulb usually includes the origin of the internal carotid artery (or ICA), which lies posterior and lateral to the external carotid artery (or ECA) and is larger in caliber. The ECA is typically anterior and medial to the ICA at its origin and has multiple extracranial branches.



It is important to know that the level of the carotid bifurcation is variable, but it is typically located at the angle of the mandible (or lower jaw).

Vertebral arteries

The other main arteries of the neck are the vertebral arteries, which supply most of the posterior circulation to the brain. These usually arise from the subclavian arteries and then ascend vertically through the transverse processes. The left vertebral artery is typically larger in caliber than the right, and the vertebral arteries lie lateral and posterior to the carotid arteries at their origin.



Anatomical variations in cerebrovascular anatomy

There are three anatomical variations in this territory for you to be aware of:

1. In rare cases, the left common carotid artery and subclavian artery may actually share a common origin instead of both arising directly from the aortic arch.
2. The left vertebral artery can arise directly from the aortic arch instead of from the subclavian artery, but this is particularly rare on the right side.
3. The right vertebral artery origin may be at the distal end of the innominate artery instead of arising from the subclavian artery.

As you can see, the anatomy here is complex. Therefore, having a good understanding of cerebrovascular anatomy and possible anatomical variations is important when performing extracranial ultrasound investigations.

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Understanding the purpose of a carotid ultrasound scan

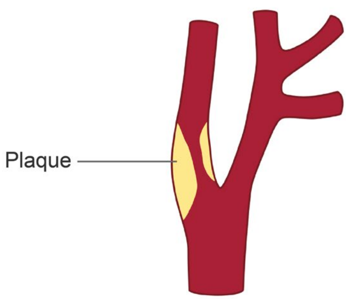
A carotid ultrasound scan is an imaging test performed to visualize the extracranial arteries. It is primarily used to assess patients who are at risk of stroke, and in particular, those who have experienced a transient ischemic attack (or TIA). These patients are investigated for suspected atherosclerotic disease in the extracranial arteries in order to determine the best treatment approach for the patient.

Let's go over five reasons why a carotid ultrasound scan might be indicated:

1. Carotid disease
2. Carotid artery dissection
3. Carotid aneurysm
4. Carotid body tumor
5. Disease in the subclavian or vertebral arteries

Carotid disease

Carotid disease is highly associated with stroke. Ischemic strokes occur when there is insufficient blood flow to the brain. Most ischemic strokes and TIAs are caused by plaque buildup at the carotid bifurcation.



Carotid bifurcation

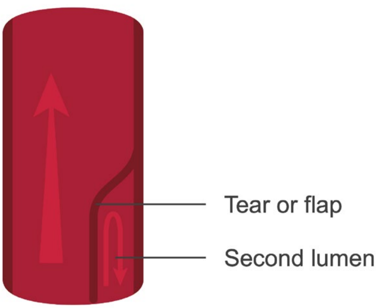
If there is significant disease at the bifurcation, the plaque can be removed surgically. Therefore, the most common purpose for performing a carotid ultrasound scan is to investigate for the presence of atherosclerotic disease in the extracranial carotid arteries, and in particular, at the carotid bifurcation.

Carotid artery dissection

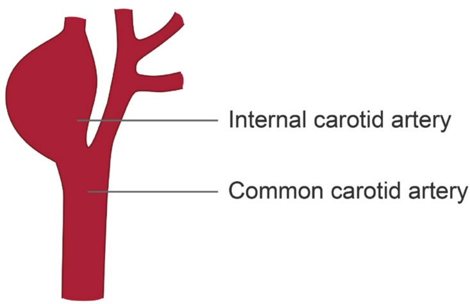
Additionally, you may perform a carotid ultrasound scan to investigate much less common, non-atherosclerotic conditions, such as a carotid artery dissection. This usually results from trauma and causes a tear or flap in the intimal wall of the carotid artery, thereby creating a second lumen with flow and potentially leading to the formation of a blood clot.

Carotid aneurysm

Alternatively, you may be asked to assess a patient for the presence of a carotid aneurysm, which is a bulge in the wall of one of the carotid arteries. This is typically found in the distal common carotid artery and proximal internal carotid artery.



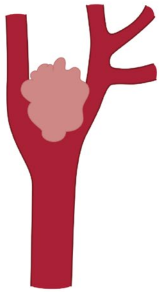
Carotid artery dissection



Carotid aneurysm

Carotid body tumor

Although very rare, you may perform a carotid ultrasound to assess a patient with a suspected carotid body tumor, which typically grows around the bifurcation and causes splaying or spreading apart of the internal and external carotid arteries.



Carotid body tumor

Disease in the subclavian or vertebral arteries

Lastly, a carotid ultrasound scan can be performed to investigate the presence of disease in the subclavian and vertebral arteries. For example, an occlusion in the vertebral artery can cause vertebrobasilar disease characterized by poor blood flow to the posterior part of the brain.

Vertebral artery occlusion

What information can a scan reveal?

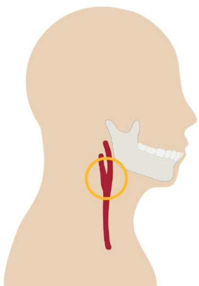
In each case, the referring clinician will want to know specific information from every scan. Here are a few examples of what they might want to know:

- Is any disease present?
- Which arteries are affected by this disease?
- Are the arteries stenosed or completely occluded?
- What is the actual degree of any narrowing?
- If a plaque is present, what are its characteristics?

Aiding with decisions related to surgical interventions

Finally, anatomical information obtained from the scan can help the surgeon decide whether a carotid endarterectomy, which is the removal of plaque build-up, is a feasible treatment option. This includes the level of the carotid bifurcation relative to the mandible, as a very high carotid bifurcation may make surgery much more difficult or even not feasible. Many centers will use ultrasound to mark the position of the bifurcation on the neck immediately before surgery.

Other useful anatomical information includes if the vessels are tortuous or coiled. This will make the surgery more complex, so it is helpful for the surgical team to know this in advance.



Level of the carotid bifurcation relative to the mandible

Tortuous or coiled vessels

It is important to remember that all patients referred with suspected stroke or TIA will have a full carotid ultrasound scan. This includes the carotid, subclavian, and vertebral arteries. All arteries must be investigated as they are interlinked and connected, so significant disease in one artery will have an effect on the others.

Recognizing the indications for a carotid ultrasound scan

So, how do I know if my patient requires a carotid ultrasound scan? Well, there are several indications for a carotid ultrasound investigation, which, as we learned previously, includes imaging of the carotid, vertebral, and subclavian arteries.

Let's dive into two categories of arterial disease that require a carotid ultrasound scan:

1. Carotid artery disease
2. Vertebral and subclavian artery disease

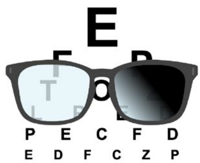
Carotid artery disease

Carotid artery disease is characterized by plaque buildup inside the carotid arteries. Let's start with three indications for carotid artery disease:

1. Transient ischemic attacks (this is the most common indication for an ultrasound investigation of the carotid arteries)
2. Strokes (i.e., cerebrovascular accidents)
3. Amaurosis fugax, which is defined as the sudden loss of vision in one eye (this is a less common indication for disease in the carotid territory)

Ischemic attack

Stroke or accident



Amaurosis fugax

Transient ischemic attacks and strokes
There are several symptoms associated with carotid artery disease. Typically, the symptoms are focal, meaning that they only affect one side of the body, and they are usually attributed to complications in the contralateral hemisphere of the brain. So, if the left side of the body is affected, you would suspect disease in the right carotid arteries.

For transient ischemic attacks and strokes, symptoms can have one of three presentations:

1. Hemisensory, which includes numbness, a pins-and-needles sensation, or impaired sensation on one side of the body
2. Hemiparesis, which is a mild weakness affecting one side of the body
3. Hemiplegia, meaning complete paralysis of half of the body

Hemisensory

Hemiparesis

Hemiplegia

All of these deficits might involve one side of the face, one arm, one leg, or a combination of these.

Patients may also present with these additional symptoms:

- Slurred speech
- Speech disturbances
- Aphasia, which is the total loss of the ability to speak

Speech is typically controlled by the dominant side of the brain; for a right-handed person, speech will be controlled by the left side of the brain. Therefore, if altered speech is a symptom in a right-handed patient, you would suspect disease in the left carotid artery.

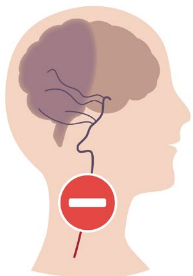
Amaurosis fugax

With amaurosis fugax (i.e., a loss of vision due to a lack of blood flow), patients often describe the symptom of a curtain drawing across their eye, typically lasting for a few minutes. Here, the symptoms are related to the ipsilateral (or same side) carotid artery, so if the patient experienced a loss of vision in their left eye, you would suspect disease in the left carotid artery.

> It is also important to note that some asymptomatic patients may be referred for a carotid scan when a loud carotid bruit, which is an abnormal vascular sound heard with a stethoscope, has been noted, and the patient has associated risk factors.

Vertebral and subclavian artery disease

The most common indication for an ultrasound of the vertebral and subclavian arteries is suspected vertebrobasilar insufficiency, which is characterized by poor blood flow to the posterior part of the brain.



Vertebrobasilar insufficiency

Here are a few symptoms that are associated with disease in the vertebral or subclavian arteries:

- Vertigo or dizziness and light-headedness
- Ataxia (i.e., a loss of coordination, stumbling, or falling)
- Nausea
- Dysphagia (i.e., difficulty swallowing)
- Diplopia (i.e., disturbances affecting both eyes)

As you can see, vertebrobasilar-type symptoms are less likely to lead to stroke. On the other hand, carotid territory symptoms are more concerning because they may be a warning sign of a more significant stroke, which is why you must always investigate these symptoms in a timely manner.

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Chapter 2

THE BASICS

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Analyzing hemodynamics in the carotid territory

Hemodynamics is the physical principles of how blood flows through the vessels of the body. In this Medmastery lesson, we will review some of the basic principles. This will help us understand how the flow patterns in extracranial arteries arise and how they change in the presence of disease.

Blood is a sticky or viscous fluid. As it is pumped away from the heart, it experiences changes in pressure and resistance.

The walls of the arteries are highly elastic, so they can stretch as the pulse wave from the heart moves through the arteries. In the presence of atherosclerosis, the elasticity of the artery walls is reduced, and this changes the speed at which the pulse wave from the heart travels through the arteries, which will affect the flow patterns you see on the ultrasound scan.

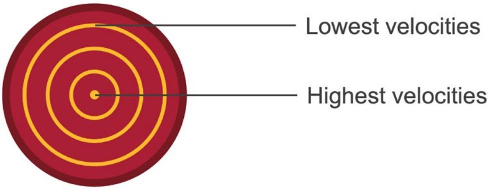
Elastic vessel

Vessel expands with pulse wave

Diseased vessel

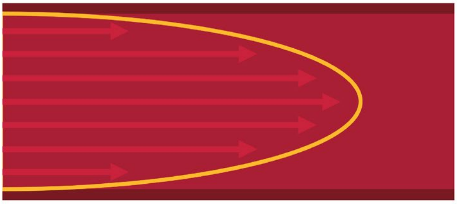
Expansion is reduced

The velocity of blood flow is also not uniform throughout the vessel lumen. This is because concentric layers of fluid are formed within the vessel. The lowest velocities occur next to the vessel wall, and the highest velocities are observed in the center of the vessel.



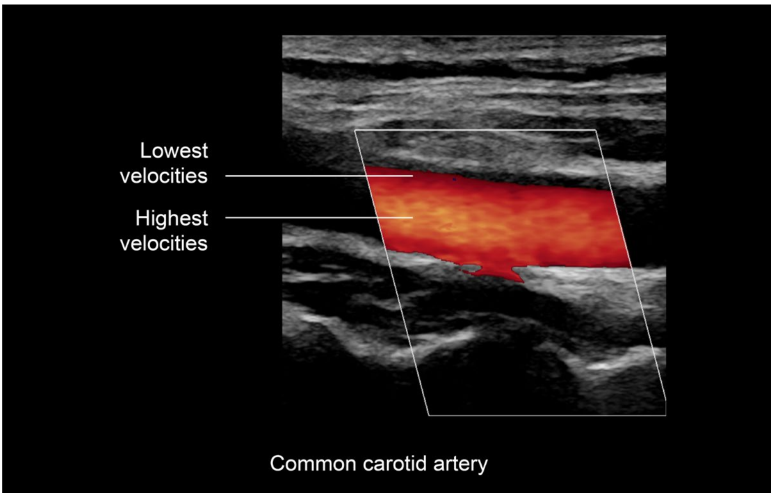
Blood flow in normal, straight arteries

Blood flow in normal arteries is usually laminar (meaning it travels smoothly), and in the middle of a relatively long, straight segment, the blood flow profile is symmetrical and parabolic.



Symmetrical, parabolic blood flow in a normal, straight artery

The ultrasound image shown next is from a common carotid artery (CCA) that demonstrates laminar, parabolic flow. The lowest velocities in the vessel are identified by darker shades of red at the edge of the vessel and the highest velocities are indicated by lighter shades of red in the center of the vessel.

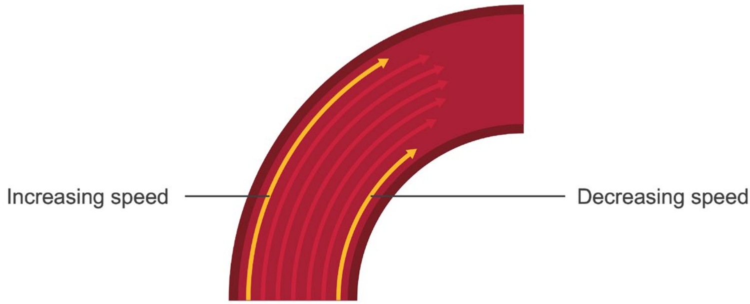


Common carotid artery

Blood flow where arteries curve, widen, or divide

But what happens to this flow profile when an artery curves, widens, or divides, all of which occur in the carotid bifurcation? Well, the parallel lines of laminar flow can be altered, which disturbs the flow of blood.

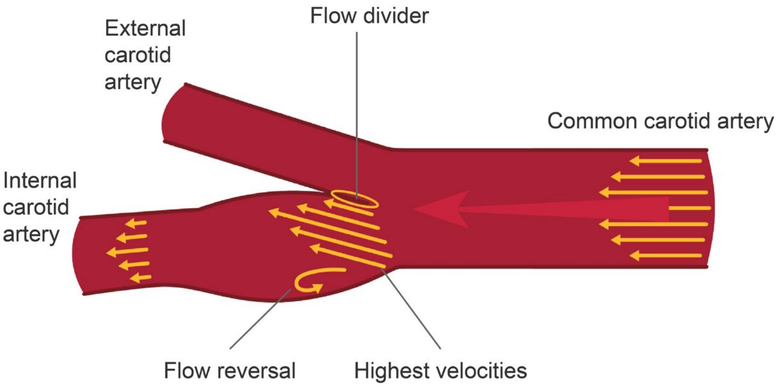
When we have a curve in the vessel, the speed of the blood flow increases on the outside of the curve but decreases on the inside. In other words, the profile becomes asymmetrical.



Asymmetrical blood flow in a normal, curved vessel

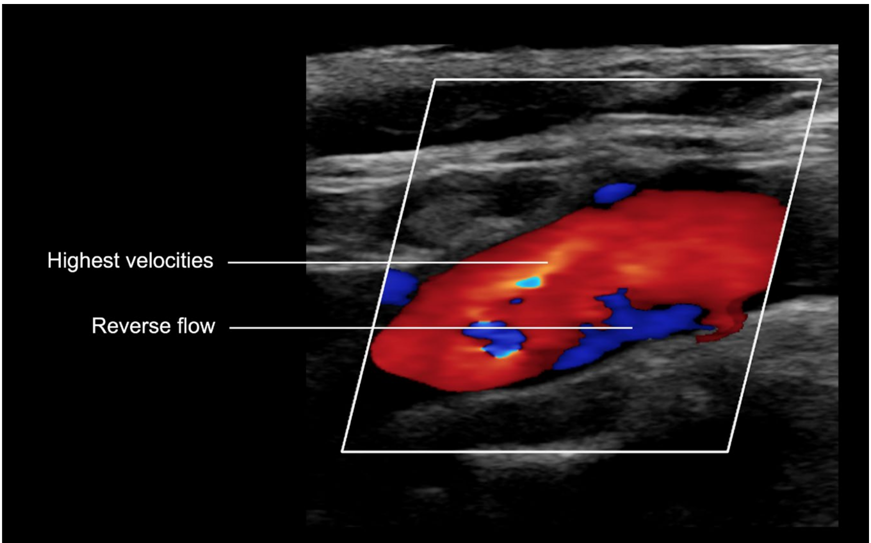
Flow at the carotid bifurcation is complex and has been extensively studied. In the CCA, the flow profile is symmetrical. In the proximal internal carotid artery (ICA), the flow profile becomes asymmetric, with the highest velocities observed towards the flow divider.

On the opposite edge to the flow divider, there is flow separation with flow reversal. This is a result of the combination between the geometry of the arteries and the presence of pulsatile flow. However, further into the ICA, the flow profile will become symmetrical again.



Normal flow at the carotid bifurcation

The flow pattern in the ultrasound image shown next reflects these profile changes. The highest velocities in the proximal ICA occur at the side of the vessel closest to the external carotid artery (ECA) and are shown in the lighter shades of red. At the opposite side of the vessel, the flow is reversed, as shown in blue.



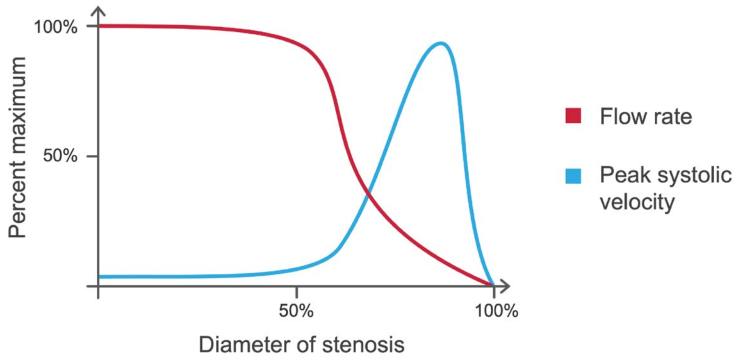
Proximal internal carotid artery

Blood flow in the presence of arterial disease

So, what happens to the flow and velocities in the presence of disease? Well, narrowing or stenosis will affect the resistance of flow through the arteries.

As blood travels through a significant stenosis where the diameter of the artery is reduced by approximately 50%, the flow rate starts to decrease, and the peak systolic velocity then increases rapidly, indicating that the stenosis has become hemodynamically significant.

As the degree of stenosis increases further, the resistance increases, and there becomes a point at which the flow drops to such an extent that the velocity begins to decrease. This is known as a subocclusion, and the flow is described as trickle flow.



This means that the velocities measured from ultrasound waveforms can be used to accurately estimate the degree of narrowing for hemodynamically significant stenoses.

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Reviewing ultrasound basics

When performing a carotid ultrasound investigation, you will need to use several ultrasound modalities. Here are four common modalities used in carotid ultrasound investigation:

1. B-mode
2. Pulsed Doppler
3. Color flow
4. Power Doppler

Other modalities, including harmonic imaging, contrast imaging, and B-flow, are available on some scanners but are likely only needed in more complex cases. In this Medmastery lesson, we will review the most commonly used ultrasound modalities.

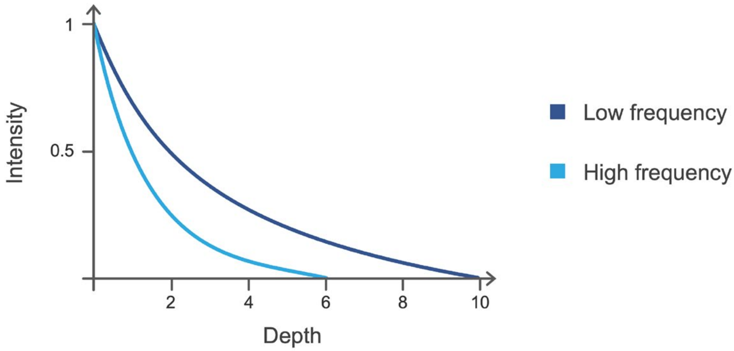
B-mode

Let's start with the brightness mode (or B-mode) and look at how ultrasound is used to build the 2-dimensional gray scale B-mode image.

Frequency and resolution

Ultrasound is a high-frequency sound wave with all of the expected physical properties of a wave. The higher the frequency of the ultrasound, the better the resolution of the image. On the other hand, a lower frequency will result in a poorer resolution.

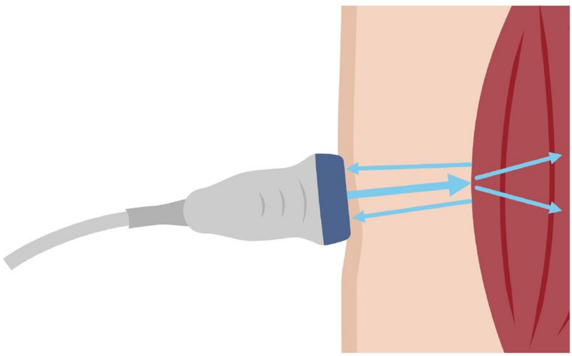
As the beam travels through the tissue, its energy or intensity is reduced. The rate of this reduction increases with higher frequency probes. So, to image deeper structures, lower frequencies will be needed, which will also result in a poorer resolution.



Fortunately, the carotid arteries are relatively close to the skin's surface, so high-frequency ultrasound can be used to produce high-resolution images.

Acoustic impedance

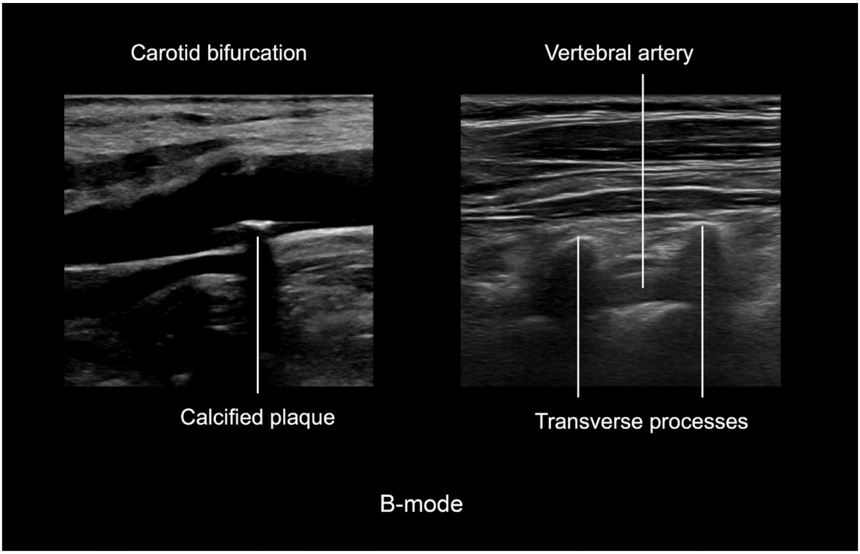
The ultrasound wave is generated by the ultrasound transducer, which is placed on the surface of the patient's body. When the wave hits a surface interface within the body, some of the energy will be reflected back towards the probe, and some will continue through to the next layer.



The proportion of energy reflected and transmitted depends on the acoustic impedance of the layers, or in other words, the level of resistance to the ultrasound wave as it passes through the tissues. The larger the difference in acoustic impedance between the layers, the stronger the reflected signal will be.

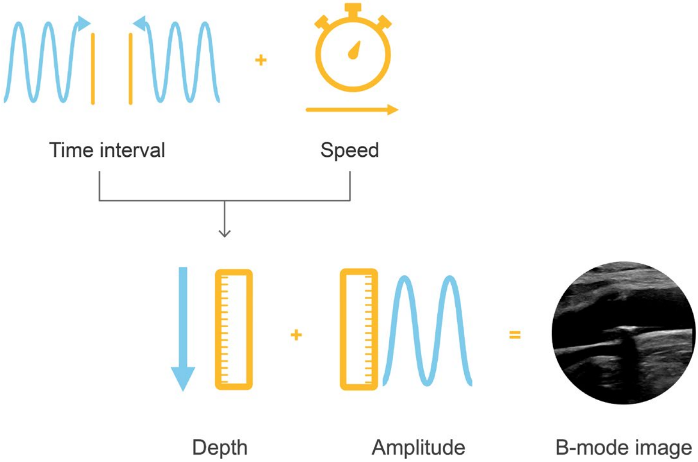
There is a large difference between the acoustic impedance of soft tissue and bone, so when the ultrasound beam travels from soft tissue to bone, most of the ultrasound beam energy will be reflected, and little will pass through. This is why we lose the ultrasound image beyond calcified vessels and bone.

For example, most of the ultrasound beam energy will be reflected when there is a calcified plaque at the carotid bifurcation, or when we are imaging the vertebral artery, which travels through the bone of the transverse processes in the neck.



Time, speed, and amplitude
An ultrasound image is generated by sending wave pulses. Once one pulse of the ultrasound wave has been transmitted, the transducer switches to receiving the reflected waves.

Knowing the time interval between the transmitted and returning waves and the speed at which the ultrasound wave travels through tissues allows the signals to be processed to provide the depth of the signal. This, together with the amplitude of the echoes received by the transducer, allows a 2-dimensional gray scale or B-mode image to be built and structures within the body to be identified.

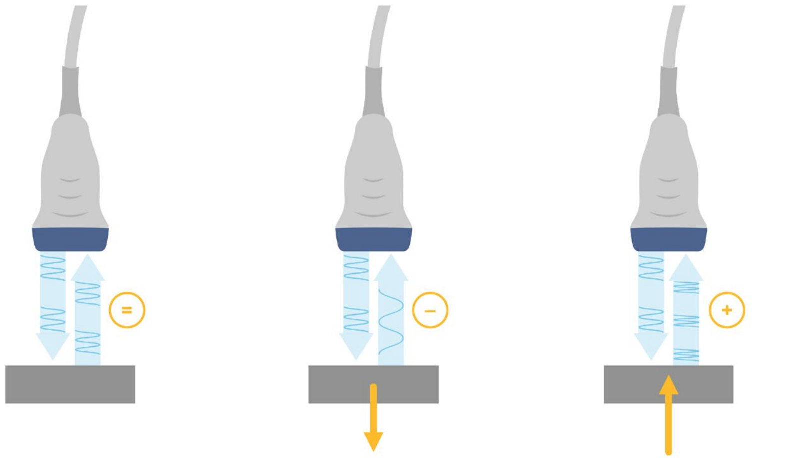


Pulsed Doppler

The Pulsed Doppler modality is fundamental to all vascular ultrasound investigations as it allows us to study blood flow. Pulsed Doppler uses the Doppler principle, which is a change in the frequency of a sound is caused by the movement of the source or the observer.

Three results are possible when using pulsed Doppler:

1. When an ultrasound wave hits a stationary surface, the frequency of the reflected beam will be unchanged.
2. When the wave hits a surface that is moving away from the probe, the reflected wavefronts are stretched apart, resulting in a decreased frequency.
3. When the surface is moving towards the probe, the reflected wave will be compressed, resulting in increased frequency.



In vascular ultrasound, the moving target is the red blood cells, and once again three results are possible:

1. When an ultrasound wave hits a stationary surface, the frequency of the reflected beam will be unchanged.
2. When the red blood cells are moving towards the probe, the returning frequency is increased, or in other words, there is a positive Doppler shift.
3. When the red blood cells are moving away from the probe, the returning frequency is reduced, meaning there is a negative Doppler shift.

So right away, we can identify the direction of blood flow relative to the probe!

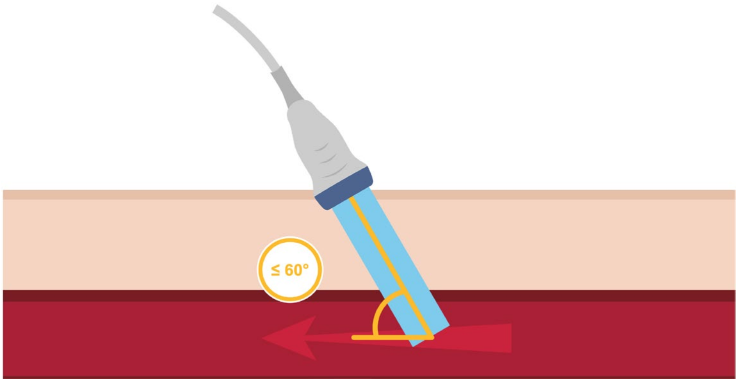
Watch how you hold the probe!

It's important to know that if the probe is held perpendicular to the flow, then no Doppler shift will be detected.

Velocity of flow

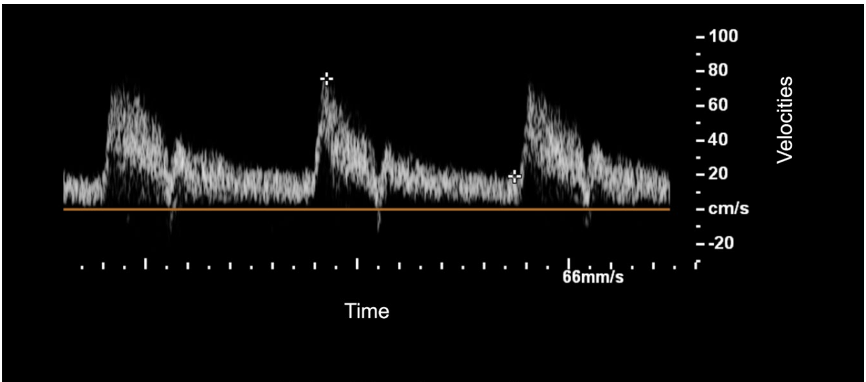
Determining the velocity of flow is also important for carotid ultrasound investigations. As the velocity of red blood cells increases, the Doppler frequency will also increase proportionally, allowing changes in velocity to be detected.

To obtain accurate measurements, you must ensure that the angle between the direction of the flow and the ultrasound beam is 60° or less. This is because as the Doppler angle increases, the potential for error in velocity calculations increases.



Doppler waveforms

The Doppler ultrasound beam is also sent out as a pulse, and this is known as pulsed Doppler. The ultrasound scanner then processes the Doppler signals, and the output is displayed as a Doppler waveform. The velocities are indicated on the y-axis against time on the x-axis.

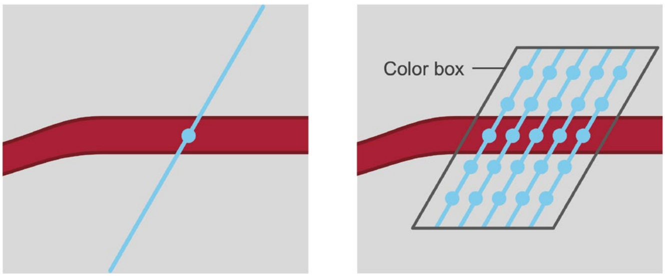


Pulsed Doppler waveforms

Doppler waveforms are complex, as the velocity of the red blood cells will vary throughout the vessel. Flow in the arteries is pulsatile, so the velocities will also vary with time and be dependent on the cardiac cycle. As a result, Doppler waveforms from different vessels will be different, and these will be altered in the presence of significant disease.

Color flow

The next modality we will cover is the color flow, which also uses the Doppler principle. In pulsed Doppler, there is one sample volume, but in color flow, Doppler shifts are determined from multiple sites within a specified region, known as the color box. At each site, the direction of flow relative to the probe is determined and the mean velocity is calculated at each point in time.

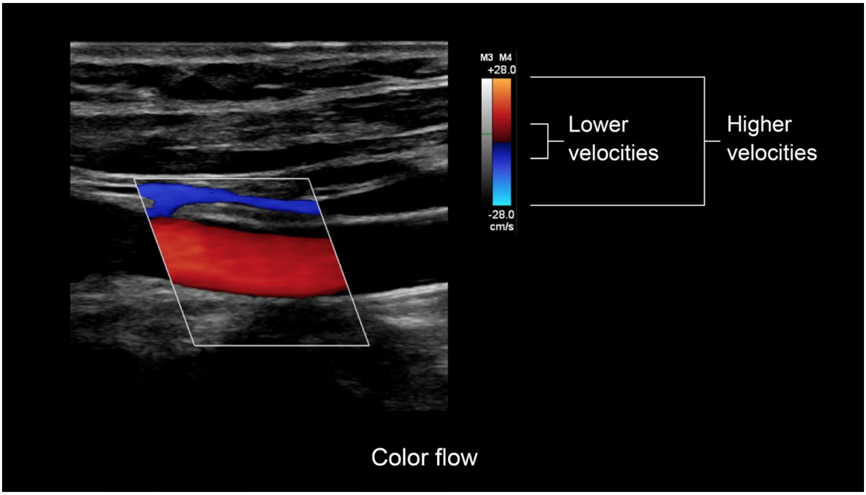


Pulsed Doppler   Color flow

Flow direction and colors

This information is then superimposed onto the B-mode image, with the color scale in the top right-hand corner. Flow towards the probe is typically indicated in red, and flow away from the probe in blue.

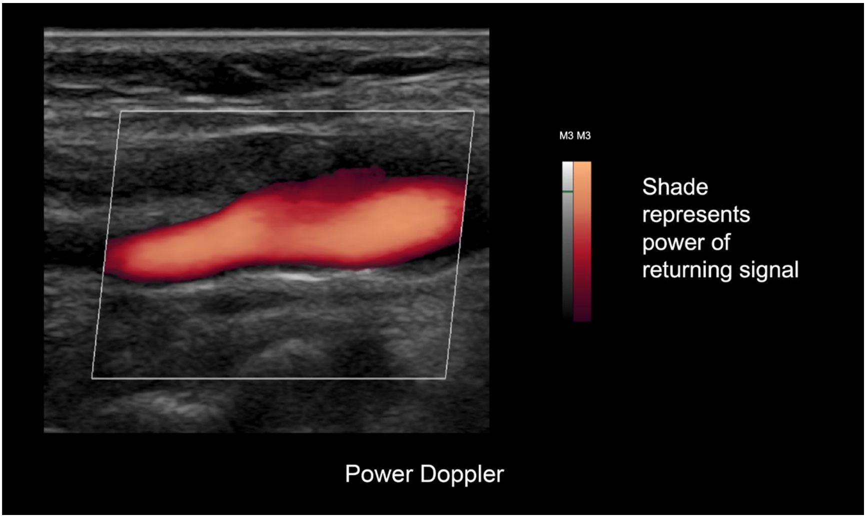
Flow velocity and shading
The shade of the color represents the mean velocity detected in that pixel; darker shades usually represent lower velocities, and lighter shades represent higher velocities.



A key difference between the pulsed Doppler and color flow is that the color flow gives the overall picture because only the mean velocity is calculated in each sample volume at each point in time. On the other hand, pulsed Doppler is used for the detailed analysis of vessels and to quantify blood flow velocities.

Power Doppler

The last modality that you will often use is the power Doppler. Power Doppler is more sensitive than color flow in detecting low blood flow, but it does not provide information related to the direction or velocity of the flow. Instead, the shade of the color assigned is related to the power of the returning Doppler signal.



As power Doppler is particularly sensitive to detecting very low flow, it can be really useful to help detect flow where an internal carotid artery occlusion is suspected.

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Identifying flow directions in color flow

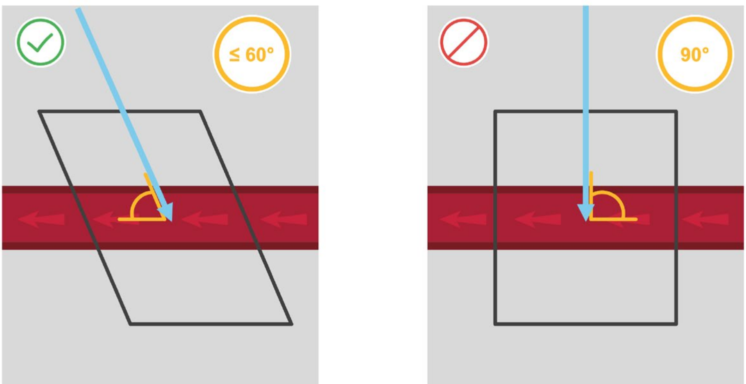
Color flow is a valuable qualitative tool in carotid ultrasound investigations. In this Medmastery lesson, you will learn how to identify flow directions in color flow, which is an important skill to be able to recognize pathologies.

Color flow allows you to quickly locate vessels and identify stenoses. It is also really important in establishing the direction of flow, which can often be confusing in the carotid territory, particularly when vessels are tortuous.

Steering the color box

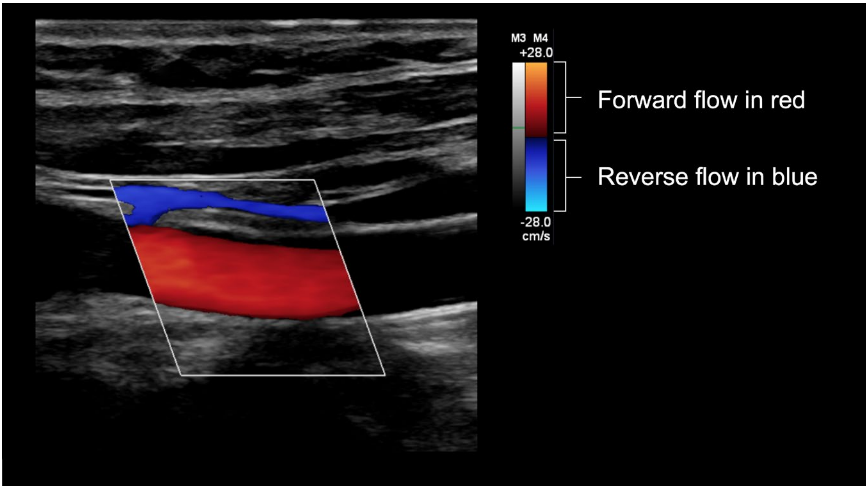
Most ultrasound systems will allow the color box to be steered between the left, the center, and the right. You will need to steer the color box to get a good Doppler angle of 60° or less.

Make sure that the color box is not parallel to the direction of the flow because if the angle between the direction of the flow and the ultrasound beam is 90°, then no Doppler shift will be detected.



Setting up the color flow

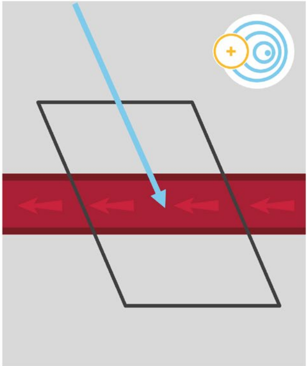
When setting up the color flow, the conventional way is to use red to indicate flow moving towards the probe and blue for flow moving away from the probe. This is shown on the color scale, with positive or forward flow in red and negative or reverse flow in blue.



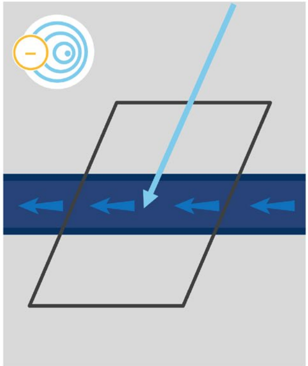
Angling the color box towards the direction of flow

You should then angle the color box towards the expected direction of flow so that forward flow is being detected, which will give a positive Doppler shift, and flow will then be shown in red on the ultrasound image.

If you angle the box to the left (or away from the direction of the flow), the flow is still in the same direction in the vessel but will be shown in blue, because the Doppler shift will now be negative.

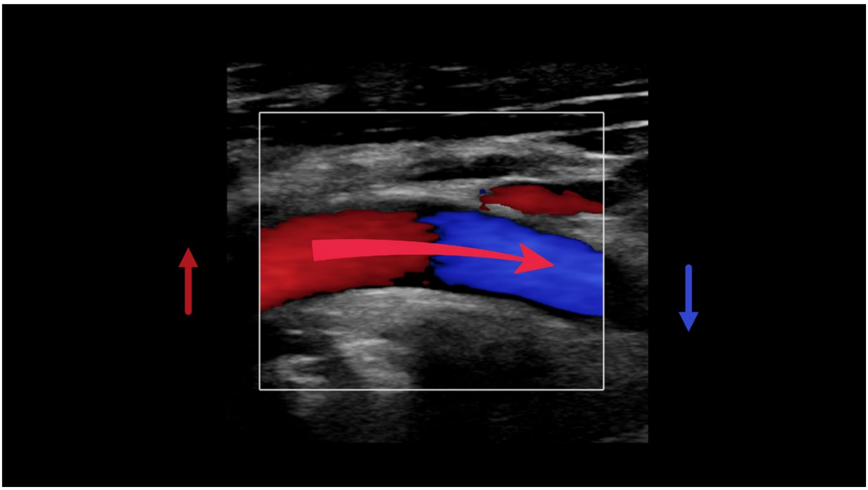


Angled towards flow



Angled away from flow

Typically, vessels don't run parallel to the surface. In the ultrasound image shown next, the flow is moving from left to right. In the first section of the vessel, the flow is moving up towards the probe and is shown in red. In the second section, it is moving down away from the probe and is shown in blue. Blood flow in the vessel is in the same direction throughout, but it may be necessary to steer the box in more than one direction to assess all parts of a vessel.

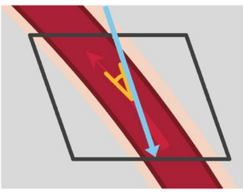


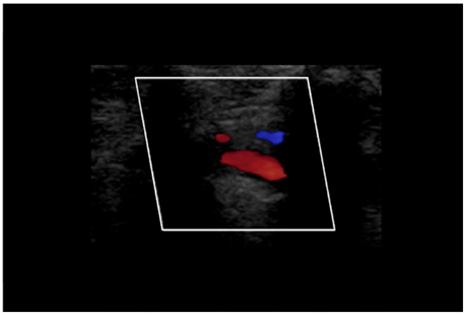
Color flow is useful in extracranial ultrasound investigations to confirm that flow in the vertebral artery is antegrade or towards the head. Retrograde flow or flow going away from the brain may indicate vertebrobasilar disease, characterized by poor blood flow to the posterior part of the brain, and this would require further investigation.

How to confirm anterograde flow in the vertebral artery

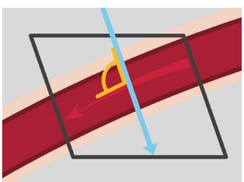
Let's go through an example of how to confirm anterograde flow in the vertebral artery.

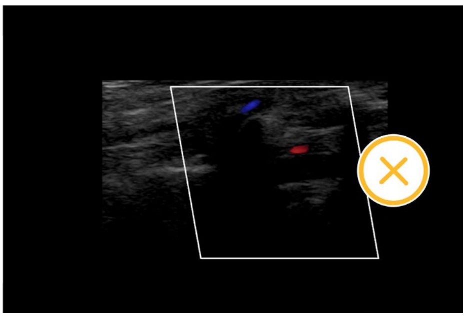
In the ultrasound image shown next, the vertebral artery is reaching up towards the surface. To get a good Doppler angle, the color box is steered to the right. Antegrade flow is moving towards the probe and is shown in red on the color flow image.



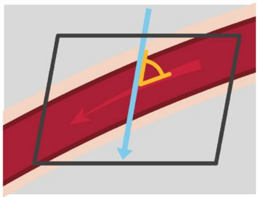


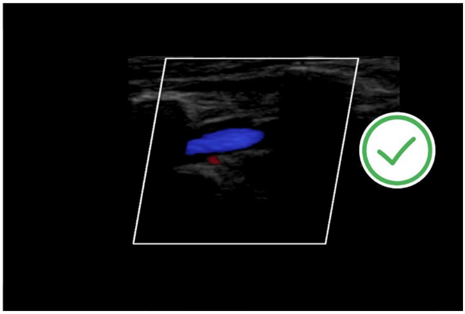
In this next ultrasound image, the vertebral artery is diving down away from the surface. The box was kept angled to the right, so the Doppler angle is close to 90°, resulting in a poor color signal.





To create a good Doppler angle, the box must be steered to the left, as it has been in the next ultrasound image. Flow is still antegrade, but it is now going away from the probe and, therefore, is shown in blue.





It is sometimes confusing to determine the direction of the flow, and it takes practice and experience. However, you can make it simple for yourself with these two tips:

1. Start by checking the direction on the color flow scale, and consistently use red to indicate flow towards the probe.
2. Always optimize the angle of the color box to the flow, making sure there is a good Doppler angle, which will provide a good color signal.

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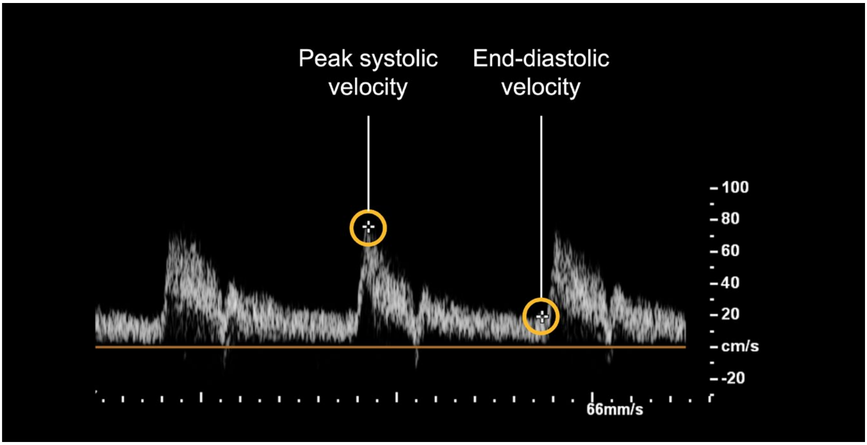
Ensuring a correct pulsed Doppler angle

During a carotid ultrasound investigation, you will need to measure the peak systolic and end-diastolic velocities from the pulsed Doppler waveforms. These will be used to grade the severity of any hemodynamically significant internal carotid artery disease, so these measurements must be as accurate as possible.



The key error in velocity measurements is having an incorrect Doppler angle. In this Medmastery lesson, we will look at why it is so important for the pulsed Doppler angle to be 60° or less.

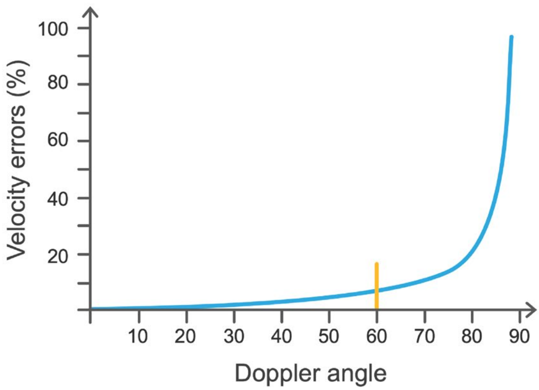
How to set up pulsed Doppler

When making velocity measurements, you will be using the pulsed Doppler. The B-mode and color flow should also be used to help determine the direction of flow.

To set up the pulsed Doppler, the angle correction cursor is used to get an accurate estimate of the angle between the pulsed Doppler beam and the direction of the flow. As you rotate the angle correction cursor, the Doppler angle will be shown on the ultrasound screen.

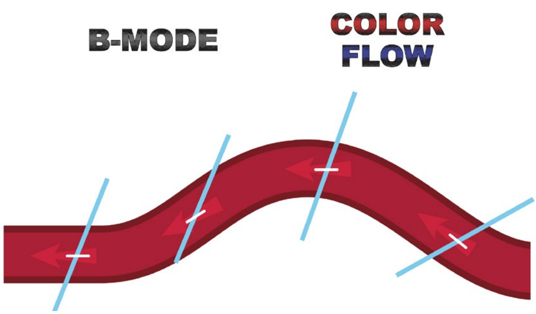
The angle correction cursor should be aligned to the direction of the flow. Once the angle is known, the signals can be processed using the Doppler equation to calculate velocities.

It is important to keep this angle at 60° or less. As you can see in the graph below, the potential for errors in the calculated velocities increases significantly for angles above 60°.

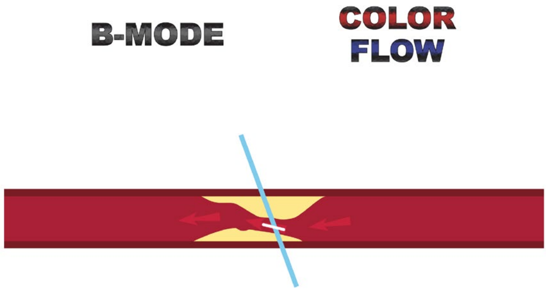


How to use B-mode and color flow to align the cursor

To create a good Doppler angle, the B-mode and color flow images should be used to help you align the angle correction cursor to the direction of the flow, which is usually shown going from right to left in the carotid ultrasound image. Typically, this means aligning the cursor to be parallel to the vessel walls as you move through the vessel.



However, where there is tight stenosis created by a plaque, the jet flow in the remaining lumen may not be parallel to the vessel walls. In this case, it is important to align the angle correction cursor parallel to the jet rather than to the vessel walls.



How to use steer control or positioning to align the cursor

The pulsed Doppler beam can be steered to help with aligning the angle of the cursor. You can also use the *heel and toe* method to rock the probe on the patient's neck by pushing very gently at one end to create a better Doppler angle.

In most circumstances, you will be able to create a Doppler angle of exactly 60° using the pulsed Doppler steer control or by adjusting the probe on the patient's neck. However, when this isn't possible, it is recommended that the angle is kept between 45 and 60° to ensure that any errors due to the angle are kept small and consistent. Using an angle greater than 60° isn't acceptable, as the errors in the velocity calculations will be too large.

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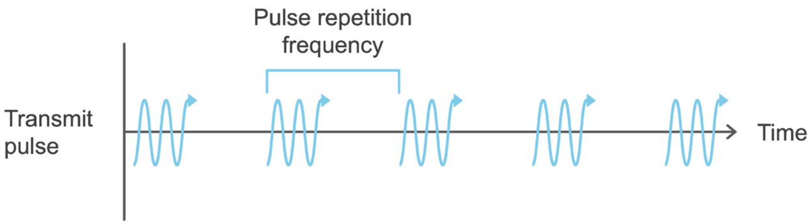
Recognizing aliasing

When using ultrasound, aliasing is a signal processing effect inherent to Doppler modalities. In this Medmastery lesson, we will learn how it can be both problematic and helpful when performing a carotid ultrasound scan.

So, what exactly is aliasing and what causes it?

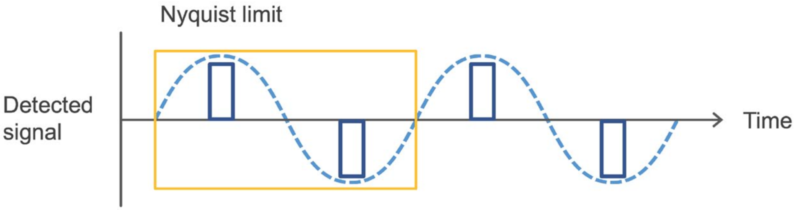
Aliasing is an imaging error that occurs because of insufficient sampling rates, resulting in an inability to accurately record direction and velocity. This happens when we are imaging an event that is occurring faster than the rate at which the ultrasound is sampling it.

In both pulsed Doppler and color flow, the ultrasound waves are sent out in pulses rather than continuous waves. The sampling rate at which the pulses are sent out is known as the pulse repetition frequency (PRF).

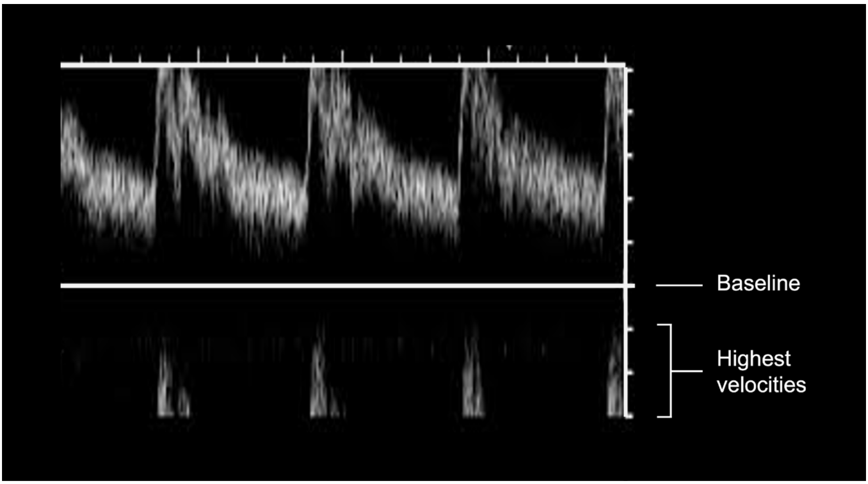


The returning signals are sampled in a time interval between two pulses. This means that the processed Doppler signal is not known at every point in time, so it is estimated from the samples of the returning signal received.

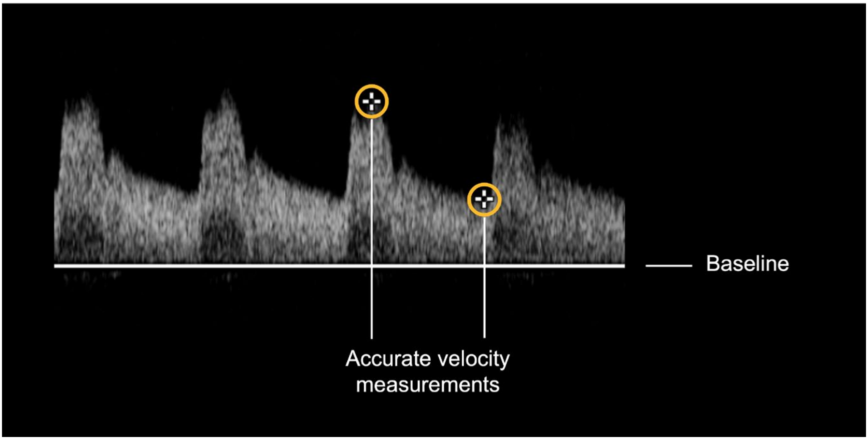
To be able to correctly estimate the Doppler signal, at least two samples are needed per cycle. This is known as the Nyquist limit. If the PRF is set below the Nyquist limit, then aliasing may occur.



The image shown next depicts an example of aliasing in pulsed Doppler. The highest Doppler velocities have been underestimated and are displayed as low-frequency signals below the baseline. Aliasing is easy to recognize as the peak velocities have been *wrapped around* the scale, resulting in an inability to accurately measure velocities.



It is important to adjust the pulsed Doppler controls to get an accurate representation of the velocities present because these measurements are used to grade hemodynamically significant internal carotid artery disease.



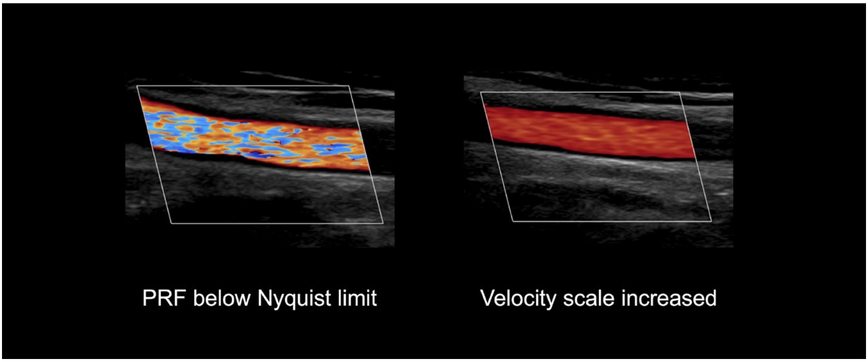
How to correct aliasing

In tight stenoses, Doppler velocities can become very high, and aliasing may occur, so let's learn how to correct this. Here are four ways:

1. **Increase the velocity scale or PRF.** This is the simplest adjustment. It will increase the velocity range, allowing the waveform to be displayed correctly.
2. **Move the baseline down.** Alternatively, the zero or baseline of the velocity scale can be moved down, allowing an increased range of positive velocities to be displayed.
3. **Reduce the Doppler transmit frequency.** Another strategy is to reduce the transmitted frequency, which will decrease the Doppler frequencies and allow higher velocities to be displayed accurately.
4. **Increase the Doppler angle.** This will result in a decreased Doppler frequency and thus will reduce the sampling rate required for accurate representation.

Aliasing also occurs in color flow if the PRF is below the Nyquist limit. As a result, very high velocities are not accurately represented, and the color assigned to these high velocities will be opposite to the color expected.

On the first ultrasound image shown below, the highest velocities are shown in blue instead of red. Similar to the techniques that we learned for pulsed Doppler, the velocity scale can be increased to eliminate the aliasing. On the ultrasound on the right, you can see the results after the velocity scale has been increased to eliminate aliasing.

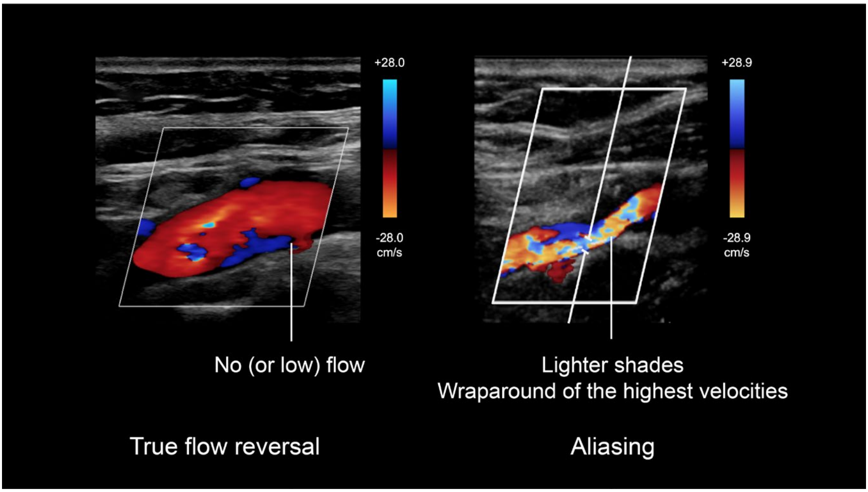


How to distinguish between true flow reversal and aliasing

Because color flow is used qualitatively, aliasing isn't such a problem like it is in pulsed Doppler, but it is still important to be able to differentiate between true flow reversal, where the flow is also shown in blue, and aliasing.

As we learned previously, flow reversal in the carotid bifurcation is expected. In the ultrasound image on the left shown below, the colors are at the lower end of the scale (i.e., the darker shades), and the point where no flow or very low flow is detected appears black. This represents true flow reversal in the carotid bifurcation.

Where aliasing is present, as shown in the image on the right, the colors will be at the higher end of the scale (i.e., the lighter shades), and there will be wraparound of the highest velocities, which will be shown in the opposite color.

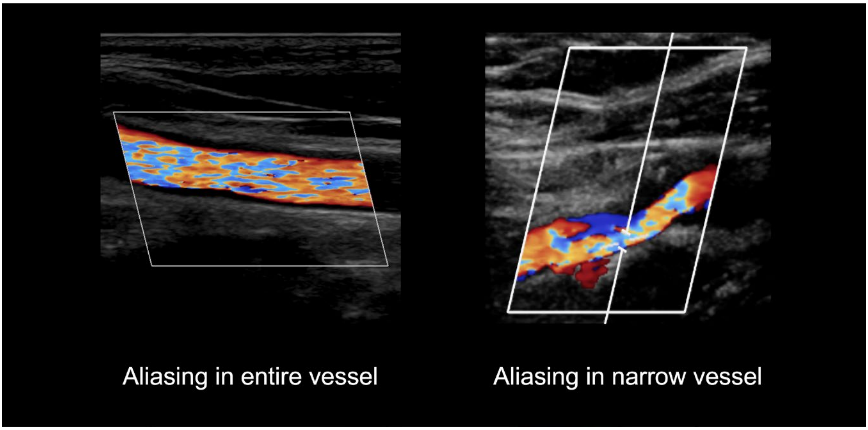


This wraparound can actually be helpful because the highest velocities stand out, so they are much easier to identify. High velocities will be found in significant stenoses, so aliasing can help with identifying stenoses and positioning the pulsed Doppler sample volume to make important velocity measurements.

How do we tell the difference between helpful and unhelpful aliasing?

So, how do we tell the difference between aliasing that needs to be corrected and aliasing that is helpful?

Well, in pulsed Doppler, aliasing should always be corrected, as the velocity measurements need to be accurate because they are used to quantify disease. In color flow, if the aliasing extends across the entire vessel, then it should be corrected so that the image is optimized. But, if aliasing occurs just in a narrowed part of a vessel, then the aliasing can be used to help position the pulsed Doppler sampling volume to identify the highest velocities.



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Identifying safety issues

Ultrasound is one of the safest and most effective diagnostic tools in healthcare. It has been widely used for many years with no reported evidence of harmful effects.

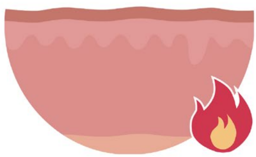
However, there are some safety issues that you should be aware of:

1. Risks associated with energy transmission
2. Risk of infection
3. Risk of sonographer injury
4. Risk of misdiagnoses

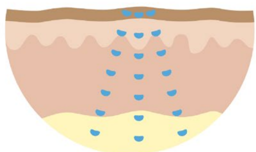
Risks associated with energy transmission

During the ultrasound scan, energy is transmitted into the patient. There are two potential harmful effects of this:

1. Tissue heating
2. Cavitation (i.e., where small gas-filled cavities are created)



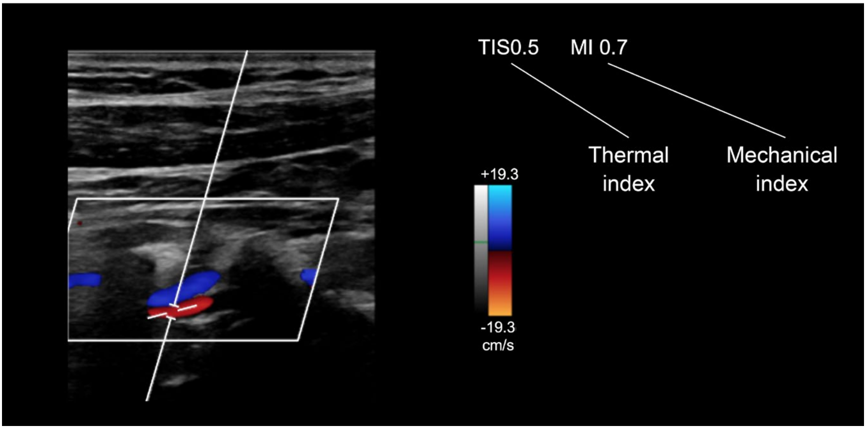
Tissue heating



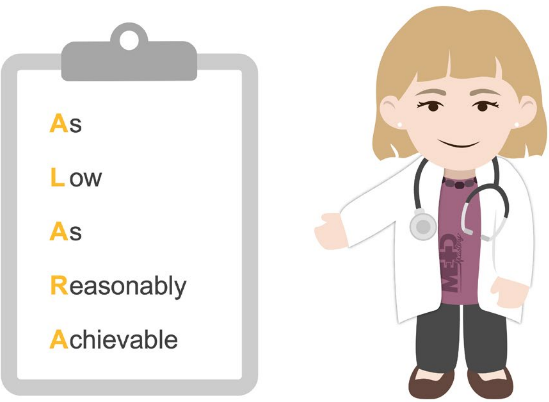
Cavitation

Two parameters are used to indicate the risk of these effects, and these are displayed in real-time on the screen of the scanner:

1. Thermal index (or TI), which indicates the heating effects
2. Mechanical index (or MI), which indicates the cavitation effects



You need to be aware of these parameters and keep in mind the ALARA principle, which stands for as low as reasonably achievable, as the risk increases with the number of ultrasound modalities being used simultaneously during a carotid investigation.



Risk of infection

Another safety concern you should be aware of is the control of infection. The cross-infection of patients by the ultrasound transducer is a real risk. Therefore, it must be thoroughly cleaned and disinfected between patients.

Ultrasound probes can be damaged by some cleaning agents, so you must always follow the manufacturer's specifications. The surface of the front of the transducer is delicate, and particular care is needed.

If you are asked to perform a carotid scan on a patient immediately after surgery, make sure you use a transducer sheath if there is likely to be contamination with blood or other tissue discharges.

Transducer sheath

Risk of sonographer injury

There are also safety concerns regarding the clinicians performing ultrasound. Sonographers are at risk of developing musculoskeletal injuries. Back, shoulder, and wrist injuries are quite common.

However, scanners are now ergonomically designed with many additional features to reduce repetitive strain injuries. Lots of guidance is available to help minimize these risks, including specially designed operator chairs and examination couches.

Risk of misdiagnoses

Finally, misdiagnosis is perhaps the biggest risk. All scans need to be of good quality, and when this isn't possible, any factors limiting the scan should be clearly documented in the report.

Ultrasound is highly operator-dependent. Extensive training and experience are needed to acquire the skills necessary to perform a high-quality scan. Therefore, it is essential that you get the time and support needed to learn this new skill.

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Chapter 3

ADJUSTING THE ULTRASOUND SCANNER CONTROLS

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Setting up the scanner

To carry out a carotid investigation, you will need a high-performance Duplex ultrasound scanner. The scanner should be able to store images and transfer them to a digital archiving system.

In this Medmastery lesson, we will look at the key scanner requirements and learn how to set up the ultrasound before you start your scan.

How to set up the ultrasound scanner

To investigate the extracranial arteries, you will need to use all of the ultrasound modalities that we talked about previously. Let's go over a few things you'll need to consider.

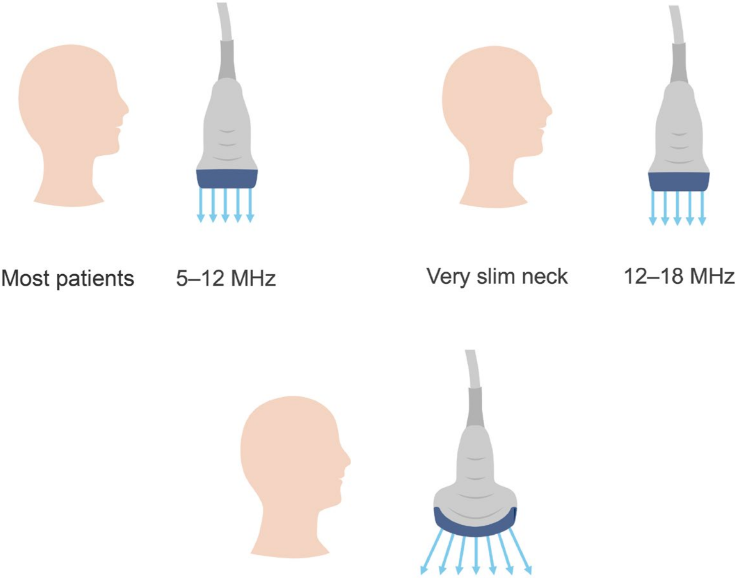
Probe type and frequency

When imaging the carotid arteries in most patients, choose the following probe type and frequency:

- A medium to high frequency flat linear array probe
- In the range of 5–12 MHz (the higher the frequency, the better the resolution)

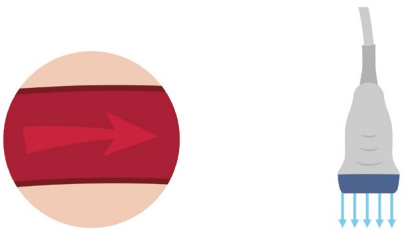
However, there are exceptions:

- Patients with very slim necks:
  - a probe with a higher range of frequencies can be used to acquire even higher resolution images
- Patients with thick necks or a high carotid bifurcation:
  - may need to use a curvilinear array probe
  - may need to switch to using a lower frequency (the lower frequency beam will undergo less energy loss, allowing the deep-lying arteries to be imaged, although the resolution will be reduced)



Doppler carrier frequency

Typical blood flow velocities in most normal and diseased carotid arteries are high in the range of 80–400 cm / s. For the scanner to detect and process these high-velocity signals, a Doppler carrier frequency of 3–5 MHz is required.

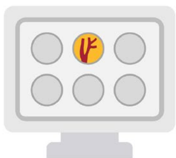


Carotid examination preset

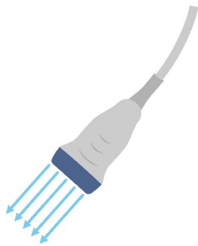
The scanner should have a vascular package that includes vascular presets with a specific carotid examination preset. When this is selected, it will be indicated at the top left of the ultrasound image. The carotid examination preset will be suitable for most carotid investigations, but adjustments will be needed throughout the scan to optimize each modality.

As such, you should start your scan with the following settings:

1. With the carotid examination preset selected
2. Using a linear array probe



Carotid examination preset



Linear array probe

The settings in the preset are a good starting point to image and assess flow in the extracranial vessels. If you have any concerns about the preset, you can make the changes yourself, but you may find it helpful to contact the applications specialist who will be able to come in and work with you to make any adjustments that are needed.

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Optimizing the B-mode image

B-mode imaging is the first modality used in carotid ultrasound investigations to get a good idea of the anatomy, how the vessels lie, and to determine if any pathology is present.

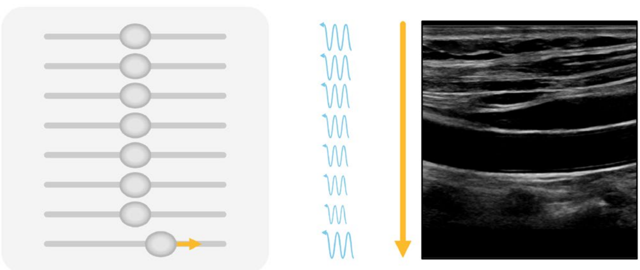
In this Medmastery lesson, we will focus on the B-mode controls and learn how to use these to optimize images of the extracranial arteries. The carotid examination preset will be a good starting point, but you will need to make adjustments throughout the scan to keep the image optimized.

The terminology for different scanner controls can be confusing as it often varies between manufacturers, so you should familiarize yourself with the controls and terminology on the scanner you will be using.

Time gain compensation control

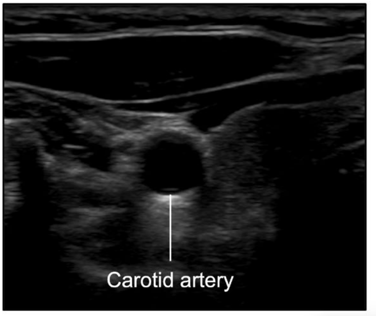
Let's start with the time gain compensation (TGC) control. This is usually a set of sliders on the scanner's control panel. Each slider controls the gain of the image at a particular depth. Weaker echoes will be expected from greater depths, and the TGC allows you to increase the gain from greater depths if needed.

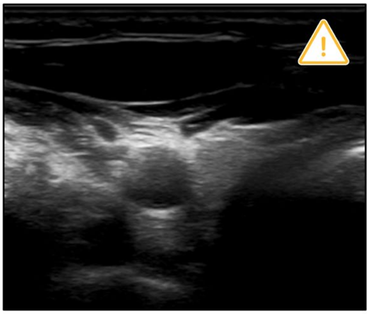
Start with all of the sliders set in the middle, and then look at your image. Adjust the sliders if necessary, so that the image clearly shows the vascular structure being assessed, and the brightness reflecting the strength of the returning echoes is relatively uniform across the image.



Time gain compensation control

A non-diseased carotid artery should appear black with no echoes. Increasing the gain at this depth would start to introduce noise or speckle and reduce the quality of the image.





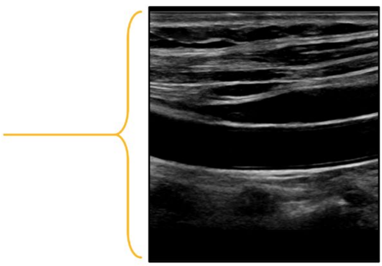
Too much gain

However, one example where you may need to increase the gain in this particular area is a suspected soft thrombus, which can be difficult to see.

Overall gain control

There is also an overall gain control, which is a rotary knob that may be called the master, 2D knob, or B-mode gain. This control allows the level of amplification of the returning echoes to be adjusted for the entire image or field of view. Together, the gain and the TGC should be adjusted to give the best possible image of the vascular structure being imaged.

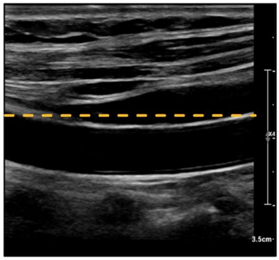
Gain control



Depth control

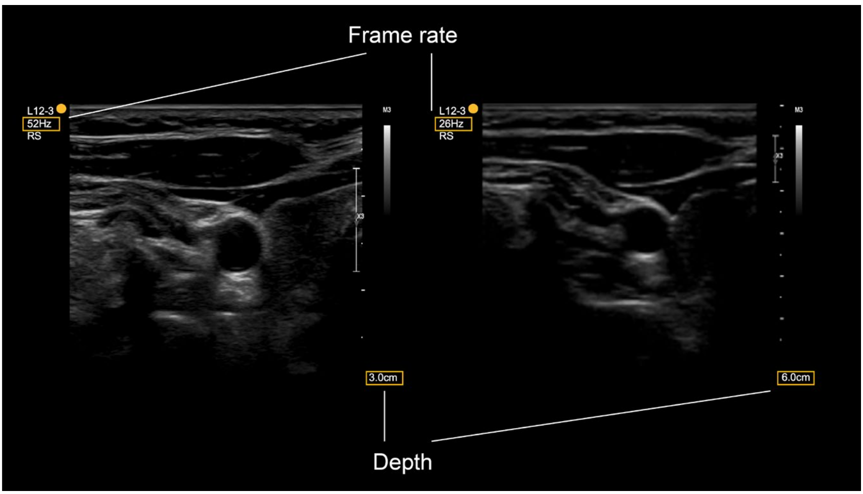
The depth of the image or field of view can be increased or decreased using the depth control. The depth scale can be found on the bottom right-hand side of the ultrasound image. Aim to keep the artery of interest in the middle or just below the middle of the image.

Depth control



One example where you will need to increase the depth is when imaging the internal carotid artery, which typically dives down deep as it moves up the neck away from the bifurcation. Be aware that increasing the depth will decrease the frame rate, which may reduce the clarity of the image.

The next set of images show an example of where the depth was increased from 3.0–6 cm, and the frame rate, which is shown in the top left corner, was reduced from 52–26 Hz. As you can see, the clarity of the image was reduced.

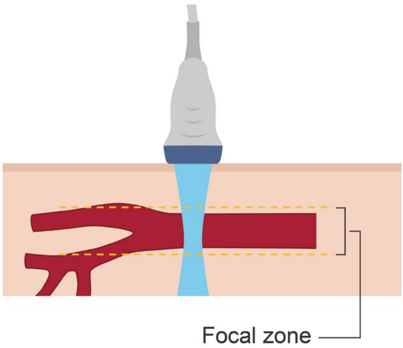


So, it is important to remember to decrease the depth wherever possible, which will increase the frame rate and result in a clearer and smoother image.

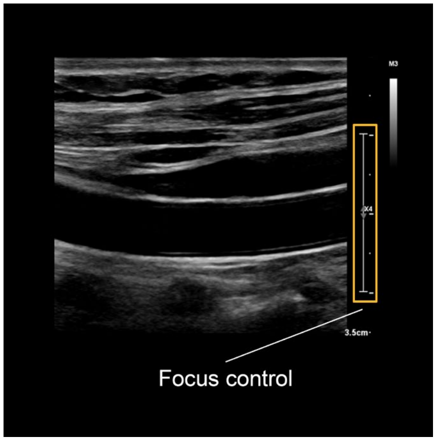
Focus control

The focus control is also used to optimize the B-mode image. The transmitted ultrasound beam is focused so that the image quality is optimized within a short range, known as the focal zone.

The position and extent of the focal zone are usually indicated next to the depth scale found on the right-hand side of the image.



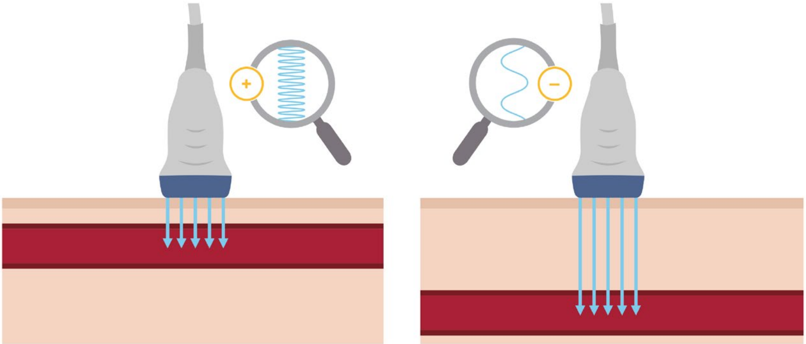
Focus control



The focus control should be adjusted so that the focal zone appears at the level of interest or just below this level. Some scanners may also use dual or multiple focal zones.

Probe operating frequency range control

Lastly, the probe will be operating over a range of transmitted frequencies. To improve the resolution of a near structure, the probe operating frequency range can be increased. Similarly, to optimize the image for a deep-lying artery, the probe operating frequencies can be reduced.



Probe operating frequency

The way the probe is held and used to insonate the vessel or area of interest also impacts the quality of the B-mode image. Insonating the vessel at 90° will give the highest levels of reflection and the best definition of the vessel wall and any plaque present.

All extracranial arterial ultrasound investigations should start with B-mode imaging. Adjusting the controls using the techniques learned in this lesson will produce the best possible images of these vessels before you move on to the color flow and pulsed Doppler.

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Optimizing the color flow

After scanning along the carotid arteries using the B-mode, you will have a good idea of the anatomy, how the vessels lie, and any pathology that may be present. Next, the color flow should be switched on for a more detailed investigation.

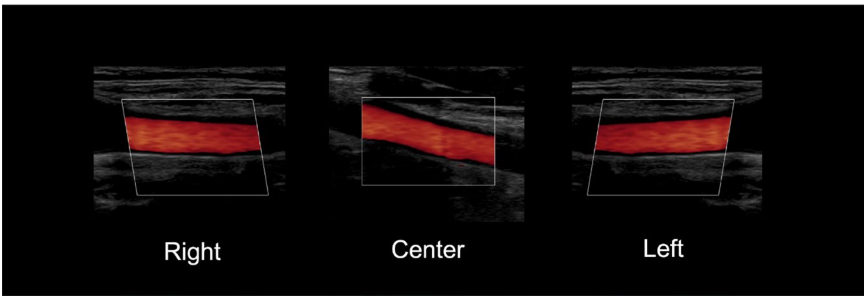
Remember that some manufacturers use different terminology for these controls, so you will need to refer to the specific manual of your scanner. In this Medmastery lesson, we will cover the most commonly used controls for the color flow.

Similar to the B-mode, the carotid examination preset will be a good starting point for the color flow image, but the controls will need to be adjusted throughout the scan.

Color steer

Let's start with the color steer, which is the control that you will use the most. The color steer changes the angle of the color box.

Most machines allow the box to be steered between the right, center, and left to create a good Doppler angle of 60° or less and help give a good color filling of the artery being imaged. If the vessel is diving away from the surface, then the box can be steered straight because there will already be a good Doppler angle.

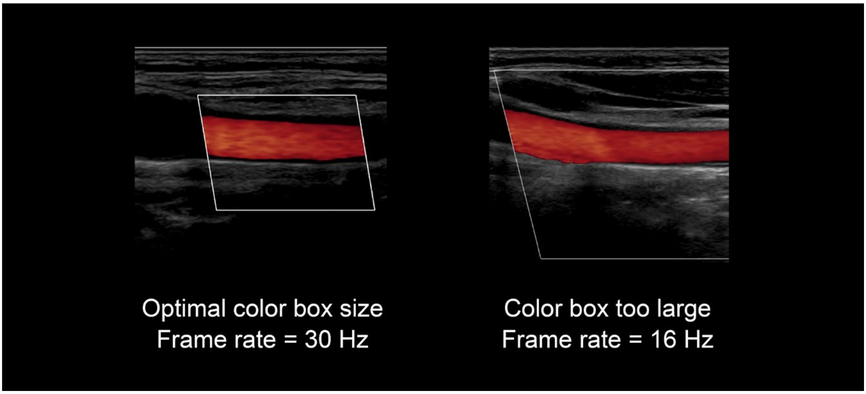


As you move along the length of the vessels, you will need to use the *heel and toe* method to rock the probe together with the steer control to keep the image optimized.

Color box position and size

Typically, there is a control that switches between changing the position and size of the color box. The color box should be positioned over the artery being assessed, and the size of the color box should be adjusted to cover the area of interest and optimize the frame rate to obtain a clear image.

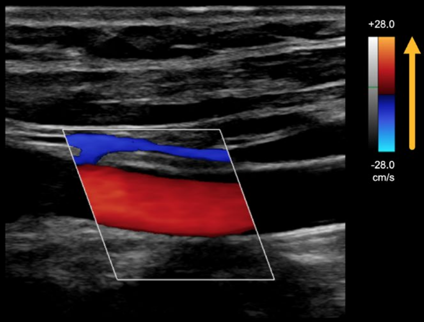
It is important to keep the size of the color box as small as possible. If the color box is too large, this will decrease the frame rate and quality of the image.



Velocity scale

Once the angle, position, and size of the color box are optimized, the velocity scale should be considered. The carotid preset will have a relatively high default velocity scale setting. This should be sufficient to detect the relatively high mean velocities expected in normal carotid arteries.

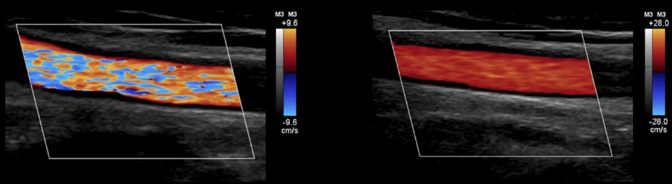
However, you will need to decrease the velocity scale to detect lower flows, such as those expected beyond tight an area of stenosis or where occlusion is suspected. Additionally, the velocities in the carotid, vertebral, and subclavian arteries tend to be different, so adjustments will be needed as you move from vessel to vessel.



Velocity scale

It is important to know that although aliasing can help identify the presence of a stenosis, there may be cases where velocities are high overall, and if the velocity scale is set too low, this will lead to aliasing across the image.

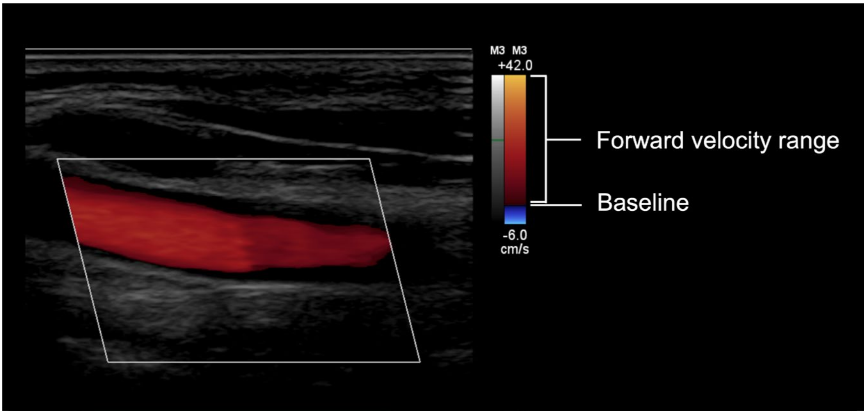
In the example featured next, increasing the velocity scale allowed for a meaningful color flow image to be obtained.



Velocity scale too low

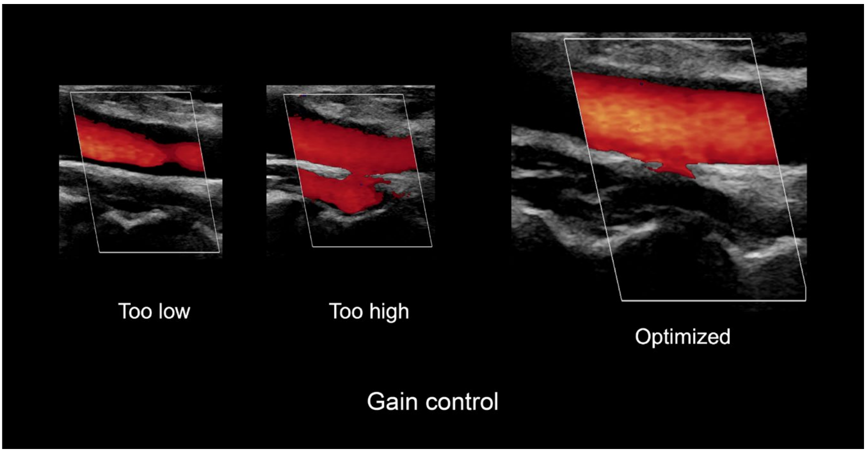
Velocity scale increased

Alternatively, you can change the baseline of the velocity scale to increase the velocity range in one direction.



Gain control

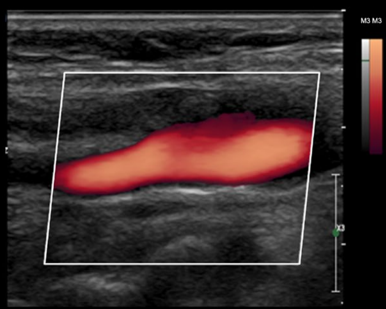
Similar to the B-mode, there is also a gain control for the color flow. If this is set too low, the artery will have a poor color filling. If set too high, the color inside the vessel will bleed to the outside. If either of these occurs, you will need to adjust the gain to get the optimal filling of the vessel.



It is important to know that for a vessel that is diving deeply away from the surface, such as the distal internal carotid artery, you will need to increase the gain.

Power Doppler

As a special type of color flow, power Doppler can be really useful in carotid studies. Remember this has no directional or velocity information but is very sensitive to low flow, so it can be helpful when an internal carotid artery (ICA) occlusion is suspected.



Power Doppler

To optimize the power Doppler, you will need to keep the probe very still as the power Doppler is extremely sensitive to any movement. The scale and gain controls can then be used, similar to the color Doppler.

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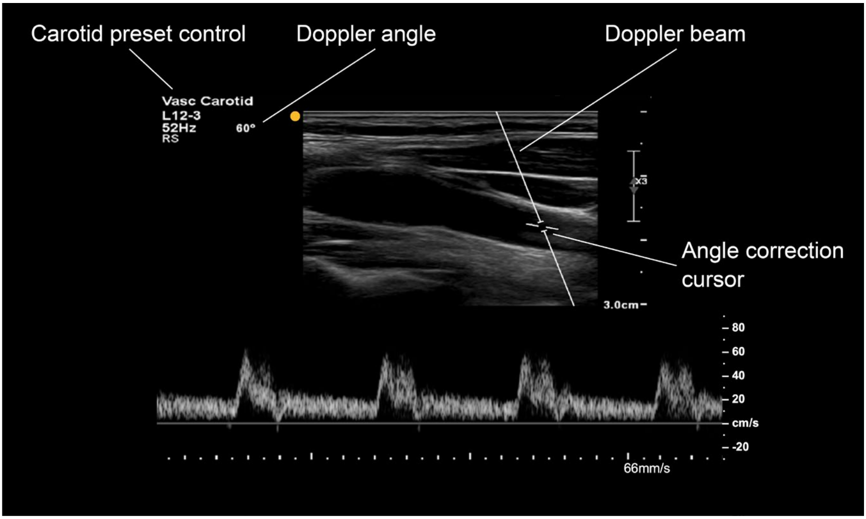
Optimizing the pulsed Doppler

In carotid ultrasound investigations, the pulsed Doppler waveforms must be clear and accurate. This is because the quantitative measurements taken from these waveforms (which are also referred to as spectral Doppler waveforms) are used to grade the extent of any hemodynamically significant disease present.

In this Medmastery lesson, we will review how to use the pulsed Doppler controls to optimize these waveforms.

When you switch on the pulsed Doppler, the screen will appear as depicted in the image shown next . The carotid preset controls will be selected, but adjustments will have to be made throughout the scan.



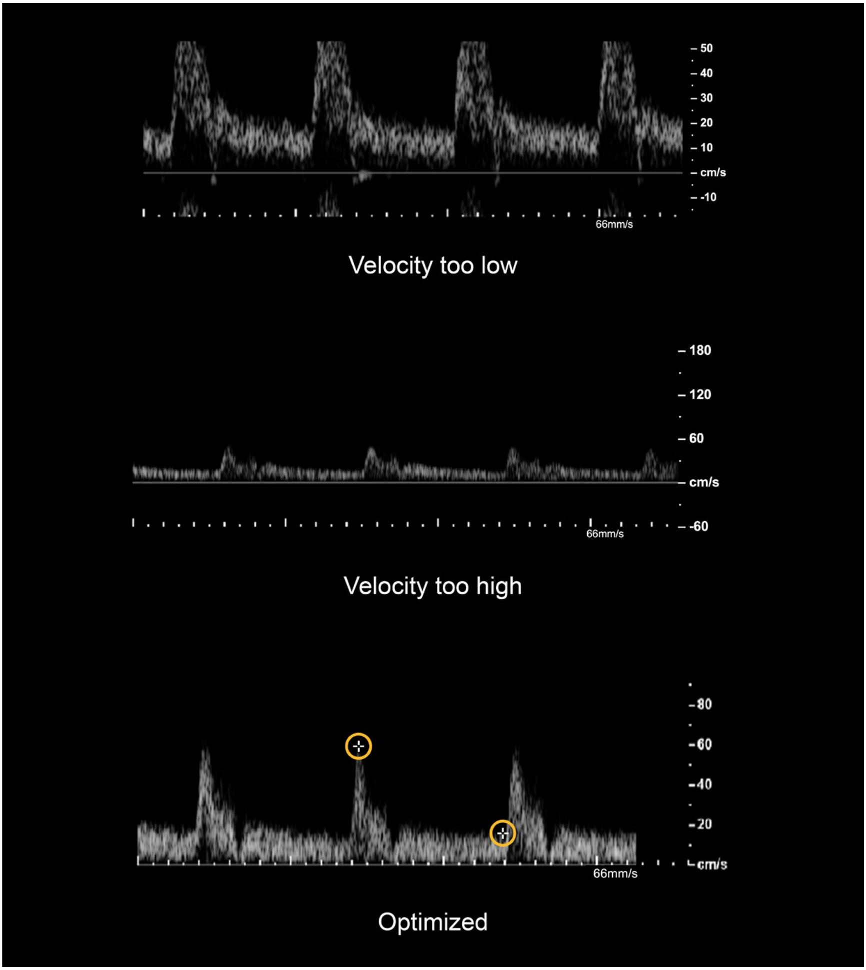
Doppler steer control

To keep the Doppler angle close to 60° or less, the Doppler beam is steered using the Doppler steer control or by rocking the probe. The angle correction cursor control should be used to align the cursor with the direction of the flow, and you should keep checking this to make sure that the angle is kept at 60° or less throughout the scan.

Pulsed Doppler velocity scale

The velocity scale will also have to be adjusted. If the pulsed Doppler velocity scale is set too low, the waveform may be cut off at the top, and a peak systolic velocity measurement won't be possible. If the scale is set too high, the waveform will appear small, and the accuracy of velocity measurements will be reduced as the positioning of the calipers is less sensitive.

The scale should be adjusted so that the waveform fills most of the space, which will allow the calipers to be carefully positioned, making the velocity measurements as accurate as possible.

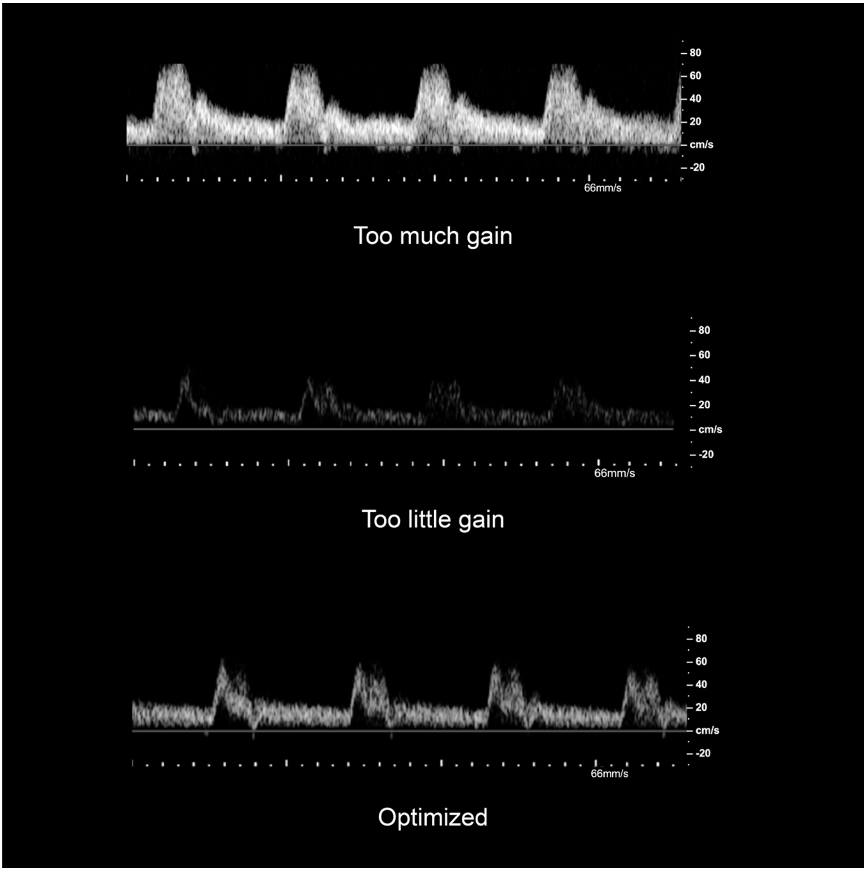


Gain control

Next, check the gain adjustment. If the gain is set too high, the waveform will appear overly bright. If too low, it will be difficult to see the waveform.

The gain should be adjusted so that the waveform just reaches peak white at its brightest part. A clean Doppler waveform is required to make accurate velocity measurements and prevent an under- or over-estimation of the peak systolic velocity.

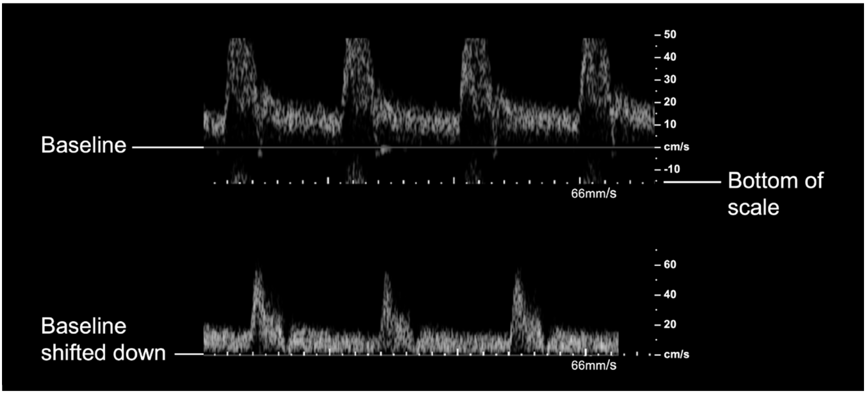
For deeper-lying arteries, such as the vertebral artery, the gain will need to be increased.



Baseline

Next, you may need to adjust the baseline. For extracranial studies, the baseline will be set close to the bottom of the scale, giving most of the velocities in the forward direction but still allowing any reverse flow to be visualized.

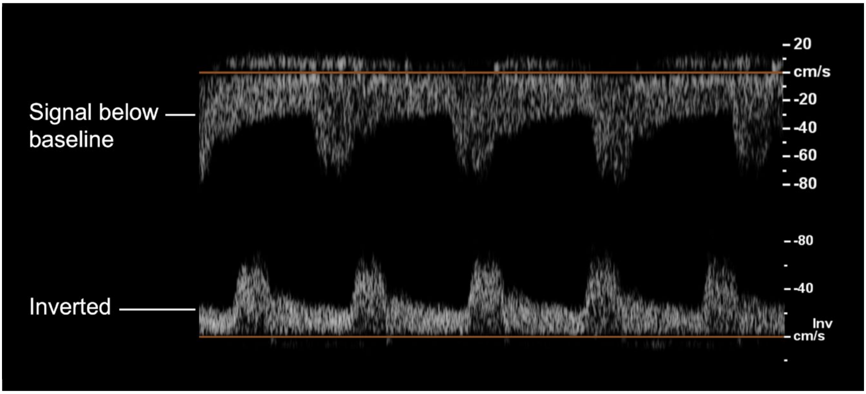
If aliasing occurs with the highest velocities appearing below the baseline, and the velocity scale has already been adjusted to the maximum, the baseline can be shifted down further to increase the velocity range in the forward direction.



Where both the artery and flow are diving away from the probe, which often occurs in the distal internal carotid artery, the Doppler signal will be negative and will be shown below the baseline.

Invert control

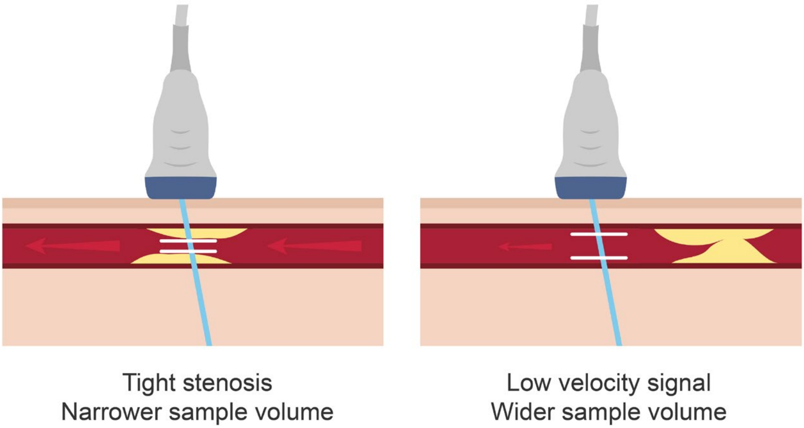
The invert control can be used to switch the flow in the negative scale to above the baseline, and the scale markings will reflect this. In both cases, the scale will be negative, indicating flow moving away from the probe.



Doppler positioning control

The Doppler positioning control should be used to move the sample volume to the center of the artery or stenotic jet.

The width of the sample volume can also be adjusted. A smaller sample volume is required when investigating an area of tight stenosis, whereas a wider sample volume is needed when trying to detect a very low-velocity signal, such as that from a suspected internal carotid artery occlusion.

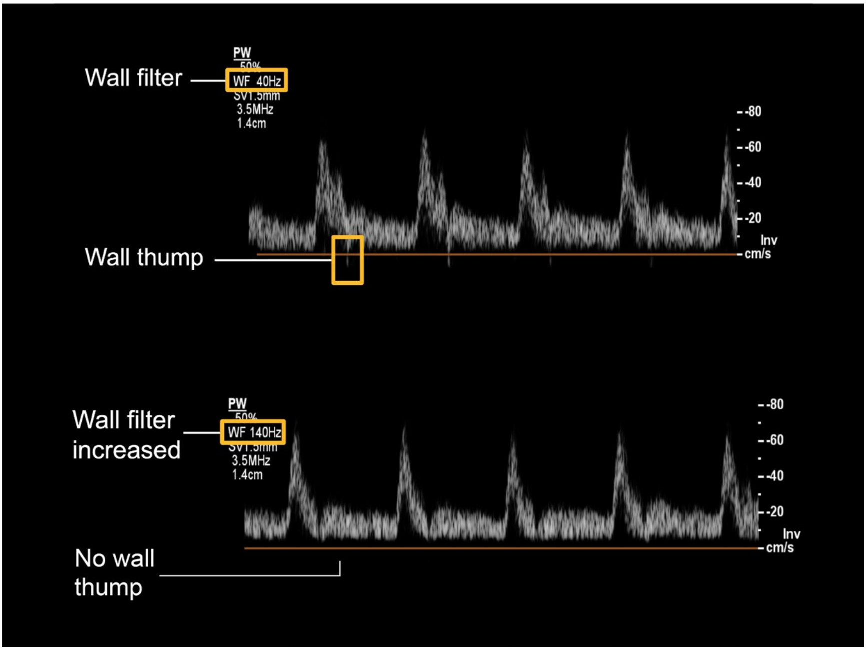


Wall filter

The wall or thump filter is a high-pass filter used to remove high-level noise around the baseline. It is set quite high in the carotid default settings, which may be a problem if you are looking for very low-velocity signals such as those in an almost totally occluded internal carotid artery. In this case, the level of the filter should be reduced to ensure that low-velocity signals are detected.

The walls of normal carotid arteries are strongly elastic, and that fact, together with the sharply pulsatile flow, can produce a *wall thump*, which is a strong, audible, and visible thump-like low-velocity signal around the baseline.

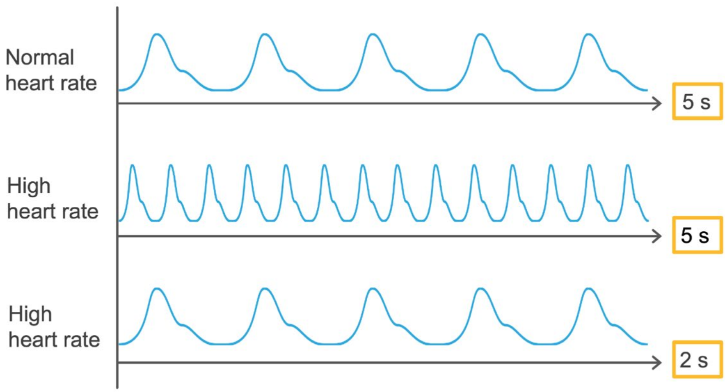
This low-velocity signal can interfere with the Doppler waveform because much of the gain automatically goes to this part of the signal, preventing other parts from being accurately represented. The frequency of the wall filter shown on the top left of the ultrasound image should be increased to remove the wall thump.



Timescale

Lastly, the default carotid setting for the time along the x-axis of the graph will work well for typical heart rates, but for a particularly high or low heart rate, this may need to be adjusted to get good enough Doppler waveforms to make accurate measurements.

For example, with a high heart rate, the waveforms may appear compressed with a preset timescale of 5 seconds and will be difficult to make measurements on. In this case, the time along the x-axis should be decreased to about 2 seconds. Typically, you want to see 4–6 waveforms along the x-axis.



Audible signal

Finally, remember that the Doppler signal is audible and that your ears are very sensitive. Therefore, the signal may be heard before it can be seen on the screen. The audible signal can help to detect and optimize the Doppler signal. This is particularly useful when the sample volume is being moved along a vessel to detect low or high velocities in an area of tight stenosis.

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Chapter 4

PERFORMING A SCAN

Positioning the patient

In this Medmastery lesson, we will look at how to position the patient for an extracranial artery scan. Before positioning the patient, we need to keep the following considerations in mind:

- What positioning (of the patient) will minimize the risks of repetitive strain injury or work-related upper limb disorders for the sonographer?
- Will this positioning still ensure there is good access to the patient's neck?
- Will the position be comfortable or at least tolerable for the patient?

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

Minimizing repetitive strain

Over 80% of healthcare workers who use ultrasounds have reported work-related musculoskeletal disorders affecting their upper limbs. Vascular ultrasound, in particular, requires a lot of twisting, turning, and stretching. However, scanners, scanning chairs, and examination couches are now ergonomically designed with several adjustable features that a sonographer should use when setting up the equipment to suit their requirements and minimize the risk of injury.

When positioning the patient, one option is to sit behind the patient's head with the scanner to the side. This option is highly recommended because it allows easy access to the patient's neck while the sonographer rests their scanning arm on the examination couch. To alleviate excessive stretching, the scanner can be positioned so that the controls are easily accessible, and the height of the scanner and scanning chair can be adjusted.

In some cases, sitting behind the patient won't be possible. For example, the design of some rooms may make this option difficult. An alternative is for the sonographer to face the patient and reach across to scan both sides of the patient's neck. Again, the position and height of the examination couch, chair, and scanner controls should all be optimized to minimize stretching and twisting.

Optimizing access and comfort

When performing the scan, the patient should be laying in the supine position. Patients with breathing difficulties will need to be elevated slightly from fully supine. Occasionally, it may be necessary to scan the patient while seated in a chair, but it's important to make sure that the patient's head is supported.

The patient should be asked to extend their head back and turn their chin away from the side being scanned. This will allow good access to the carotid arteries. The patient should also be instructed to relax their shoulder to improve access in the area of the clavicle when the subclavian artery is being investigated.

Remembering these key points will allow good access to the patient's neck while minimizing the amount of twisting and stretching as much as possible.

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Scanning the extracranial arteries

The carotid, subclavian, and vertebral arteries should be imaged according to a set protocol. This ensures a systematic approach and reduces the variability between sonographers.

In this Medmastery lesson, we will go through a step-by-step protocol for performing a comprehensive examination of the extracranial arteries using different planes, approaches, and ultrasound modalities.

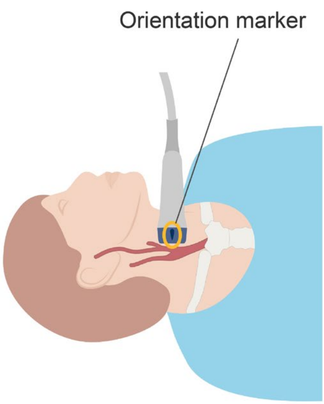
Investigate the common carotid artery, bifurcation, internal carotid artery, and external carotid artery

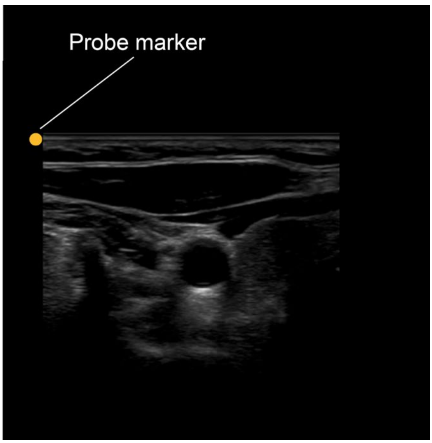
B-mode

The first step is to scan the right-hand side of the patient's neck. Using a good amount of gel, position the probe on the patient's neck. Be careful not to exert too much pressure, particularly around the bifurcation where the vessels are very close to the skin and can be easily compressed.

Starting with the B-mode, the carotid arteries should be scanned in the transverse plane. There will be an orientation marker on one side of the probe. For a transverse scan, this should be pointed to the patient's right side.

The marker at the top left of the B-mode image will then represent the right side of the patient. In this course, the probe marker is usually represented by a yellow dot.



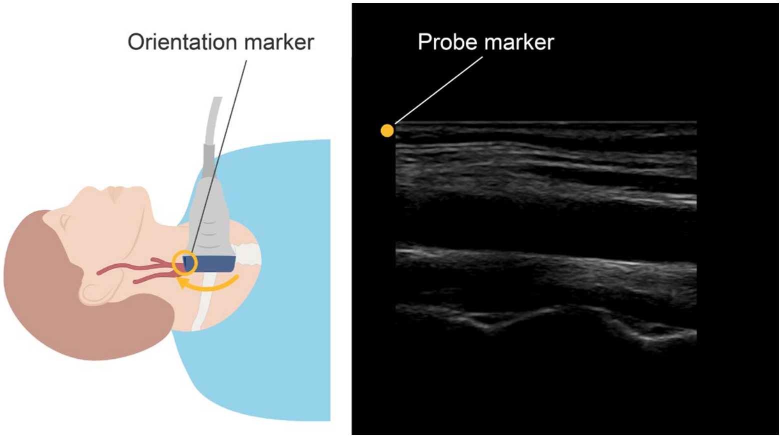


A lateral approach through the sternocleidomastoid muscle in the neck provides a good ultrasonic window. To begin, identify the common carotid artery (CCA), and then starting at the base of the neck near the clavicle, move up slowly past the bifurcation and towards the mandible. This provides a good overall picture that will help identify the level and orientation of the bifurcation and the location and extent of any disease present.

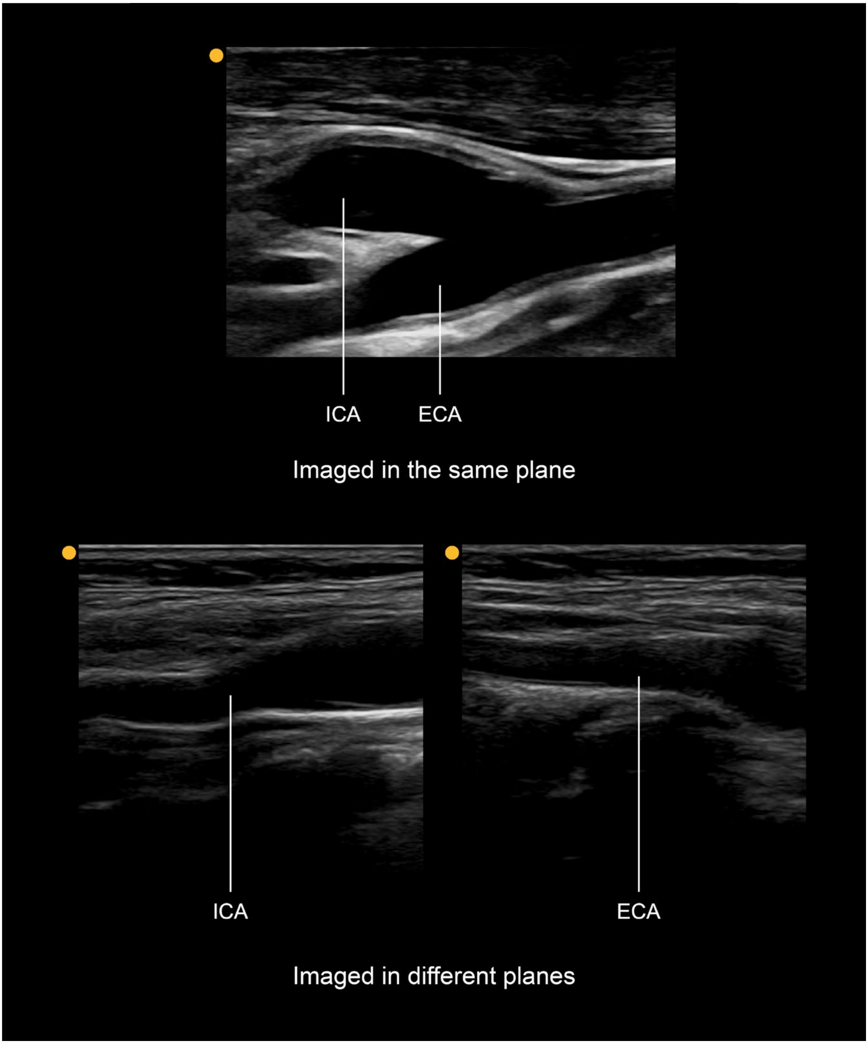
In some cases, such as when there is extensive disease or heavy calcification, switching on the color flow may help to identify the vessels and the presence of disease.

Next, move back to the base of the neck and rotate the probe to image the proximal CCA in the longitudinal plane. The orientation marker should be pointing towards the patient's head. Here, the marker at the top left of the image will indicate the *head end* of the patient.

Move up the neck using the knowledge gained from the transverse scan to help orientate the probe as you go.



In some cases, it will be possible to image the bifurcation with the internal carotid artery (ICA) and external carotid artery (ECA) in the same plane, but they will often have to be imaged separately in a different plane. These two vessels usually lay very close together, so only small movements of the probe are required.



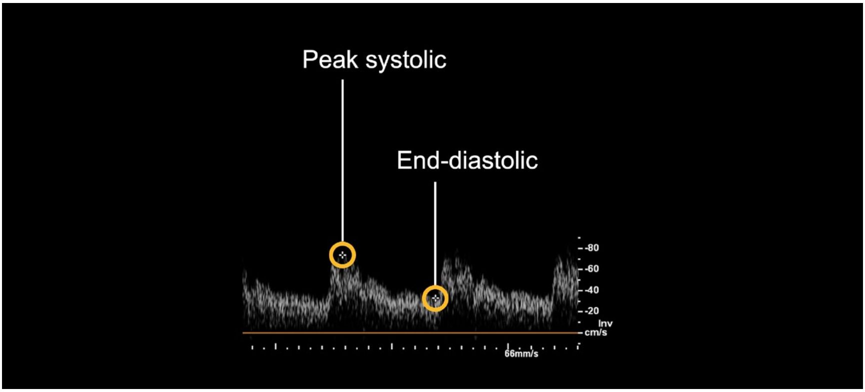
Color flow and pulsed Doppler
Still scanning in the longitudinal plane, move back down towards the base of the neck and switch on the color flow. Then, travel back up the neck to help identify areas of high velocity and aliasing.

If significant disease is identified in the ICA, it is really important to image as high up as possible into the distal ICA to confirm that it is patent (or unobstructed) and of good caliber.

Next, the pulsed Doppler should be used to obtain quantitative measurements, including the peak systolic and end-diastolic velocities. These should be measured in the following locations:

- Distal CCA
- Proximal ICA
- Distal ICA
- Proximal ECA

Any areas of suspected narrowing or stenosis should then be investigated.



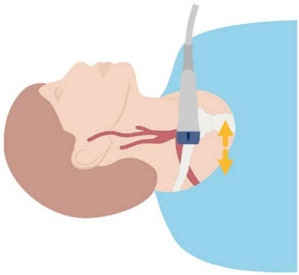
Investigate the subclavian artery

B-mode

Having completed the assessment of the carotid arteries, move down to the base of the neck towards the subclavian artery. Scanning the subclavian arteries can be challenging due to their close proximity to the clavicle.

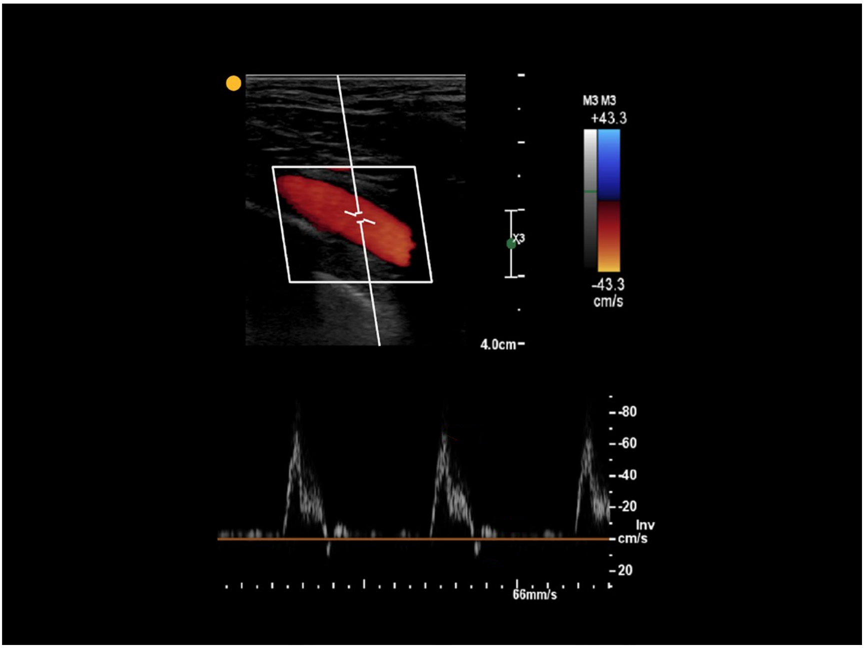
To help with this, ask the patient to relax their shoulder down and turn their head a little further to the left, away from the side that is being scanned. Using plenty of gel, position the probe in the supraclavicular notch, and adjust the position of the probe to obtain a longitudinal view of the subclavian artery.

Move the probe medially to image the subclavian artery as proximally as possible and then laterally to image the distal subclavian artery.



Color flow and pulsed Doppler

Use the color flow to help identify the vessel and any areas of stenosis, and then make sure to obtain a pulsed Doppler waveform, which should have triphasic flow, to help identify the presence of significant disease.

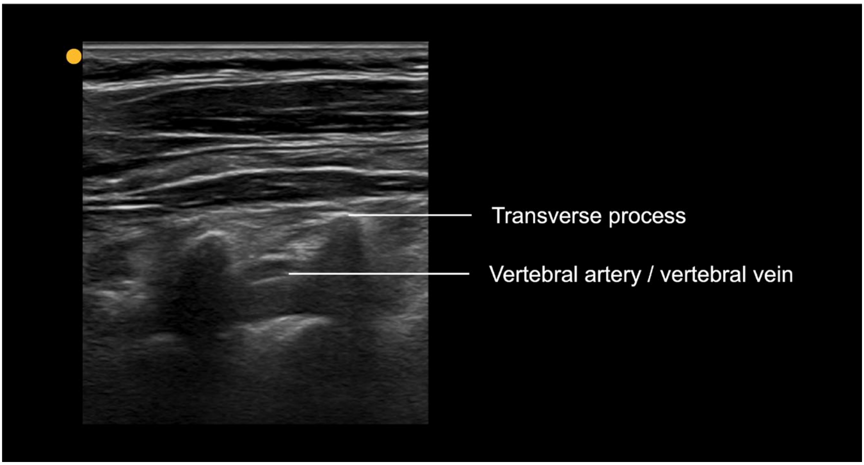


Investigate the vertebral artery

B-mode

To complete the investigation, the vertebral artery needs to be assessed. This is usually best scanned with the patient's head positioned straight and using an anterior or lateral approach. The vertebral artery can be located by first imaging the mid-CCA in the longitudinal plane.

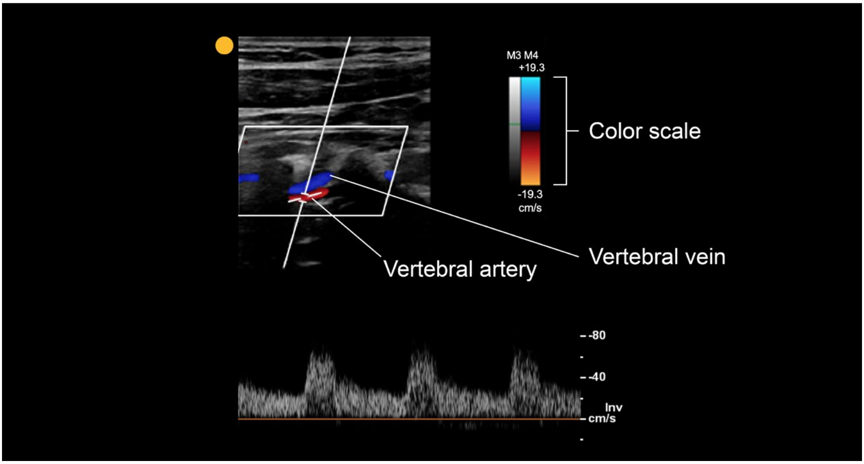
The transverse processes and vertebral artery should then come into view just lateral and posterior to the CCA. The transverse processes will be visualized as bright echoes with shadows behind them. In between each transverse process, a short segment of the vertebral artery and vertebral vein will be seen. The other segments of these vessels lie behind the bone of the transverse processes and cannot be visualized with ultrasound. The probe position should be adjusted to optimize the view of the vertebral artery.



Color flow and pulsed Doppler

For the color flow image, the color scale will usually need to be reduced and the gain increased to get a good filling of the artery. The vertebral vein will be seen just above the artery.

A pulsed Doppler signal from the vertebral artery should also be obtained to confirm the direction of flow, which should be anterograde.



Once the scan of the right side is complete, the patient should be asked to turn their head to the right, and the left side of the neck should be investigated following the same steps.

As you can see, following a set protocol and using a methodical approach will ensure that you have performed a detailed investigation of each vessel.

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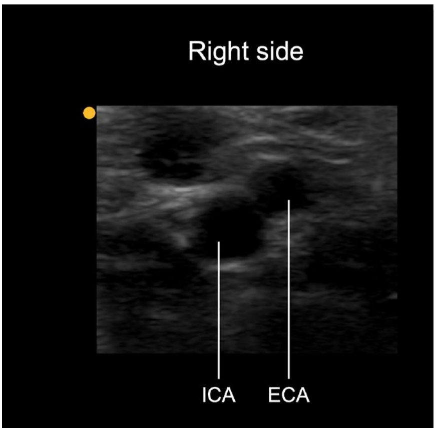
Distinguishing the internal carotid artery from the external carotid artery

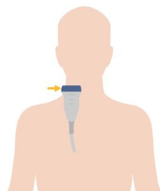
As we learned previously, the carotid bifurcation is a typical site for atherosclerosis. The presence of a stenosis in the ICA is a likely cause of the patient's symptoms, whereas significant stenosis in the ECA is far less worrisome.

Therefore, being able to distinguish between the ICA and ECA is an important skill. In some cases, it is very straightforward, but in other cases, it can be more challenging, and you will need to apply everything that you learn from this lesson.

Orientation for the right versus the left side

Remember that the probe marker at the top left of the image should always represent the right side of the patient when imaging the carotid arteries in the transverse mode. So, when imaging the right side of the neck, the larger, deeper artery on the left side of the image, that is the lateral side of the neck, is the ICA. The artery on the right side of the image, that is the medial side of the neck, is the ECA.

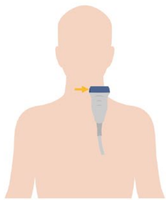


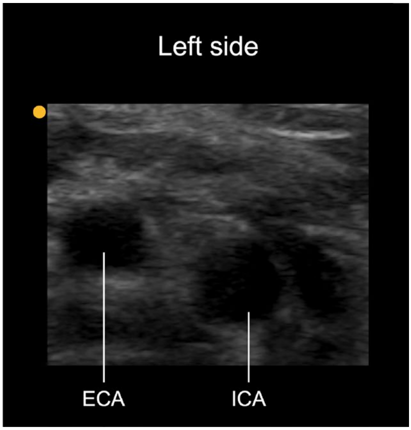


Transverse mode

Left side

When performing an ultrasound on the left side of the neck, the larger, deeper artery on the right of the image, that is the lateral side of the neck, is the ICA. Again, the artery on the left side of the image, that is the medial side of the neck, is the ECA.

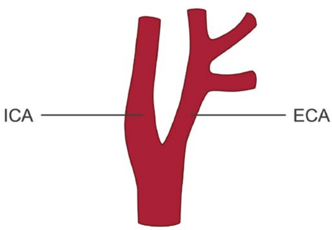


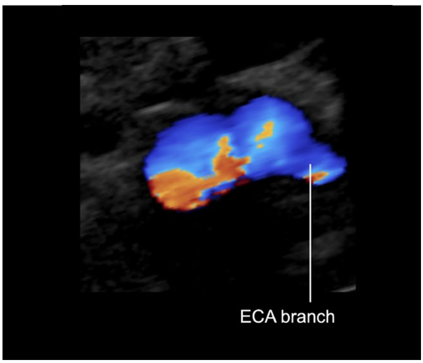


Look for ECA branches

To help identify these arteries, first look at the right side of the patient's neck. Keep the probe in transverse and try to locate the ECA. One key difference between the ECA and ICA is that the ECA has branches, whereas the ICA doesn't.

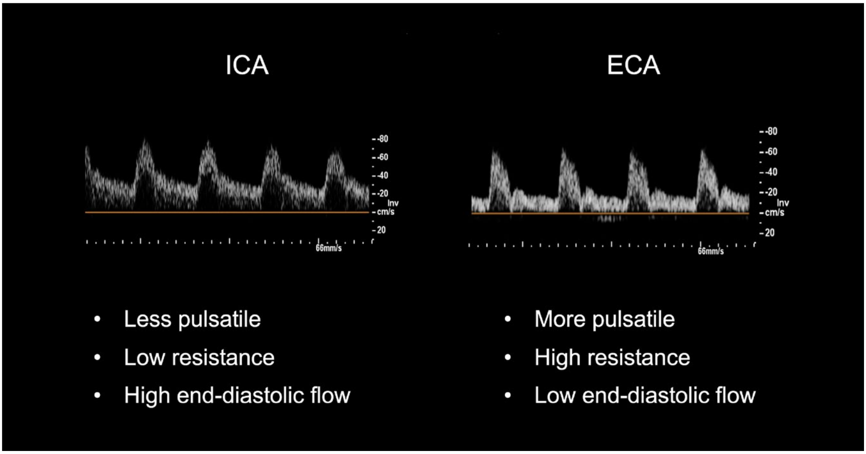
The color flow can be used to help identify the branches of the ECA. You may also be able to see ECA branches in the longitudinal plane.





Pulsed Doppler differences

The ICA and ECA also have different flow patterns, which can be identified using the pulsed Doppler. The ICA is less pulsatile and has a lower resistance waveform, which means it has a higher end-diastolic flow. In comparison, the ECA is more pulsatile and has a higher resistance waveform, which means lower end-diastolic flow.

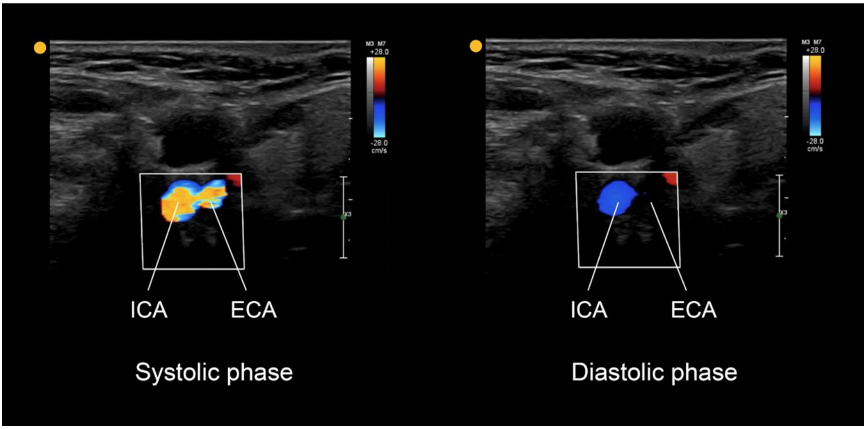


As you can see, the differences in their waveforms are clear, but they also sound very different too. The ICA sounds less pulsatile and more continuous. In contrast, the ECA sounds much sharper, and the pulse is more pronounced. You should learn to recognize these differences, so don't forget to listen too, because your hearing can be more sensitive!

Color flow differences

Similarly, the color flow patterns reflect the differences between flow in the ICA and ECA, although the differences are more subtle than those for the pulsed Doppler. Color flow in the ICA will appear more continuous and less pulsatile, so the color appears to fill the vessel throughout each cardiac cycle.

In the ECA, the color flow will appear more pulsatile and almost reach zero between each pulse. Often, there is very little color filling at the end of each cardiac cycle with the vessel almost appearing black.

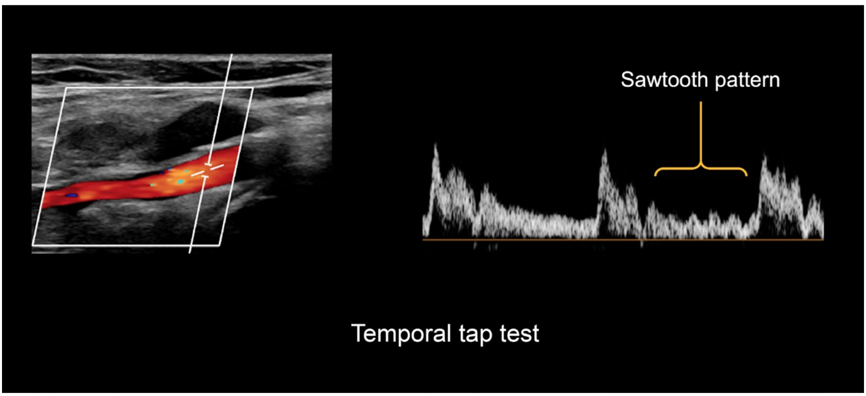


The temporal tap test

Remembering these key differences will help you clearly identify the ICA and ECA in most cases, but sometimes, distinguishing between these two arteries is more difficult. This is because the orientation of the vessels may be different, or the arteries might be very close together with minimal differences in size or flow patterns.

In these situations, the temporal tap test can be used to help identify the ECA. To perform this test, position the Doppler sample volume in what you think is the ECA, and switch on the pulsed Doppler.

Once you have a clear pulsatile waveform, use a finger from your other hand to locate the temporal artery in front of the patient's ear. Light tapping here while keeping the probe very still should produce a *sawtooth* pattern in the ECA waveform but will have no effect on the ICA waveform.



This technique requires a lot of practice and experience, but it can also be really useful in difficult situations when disease is suspected. For example, it can be helpful when there is a longstanding ICA occlusion, and you can only see one vessel going up into the distal part of the neck in both the transverse and longitudinal sections. In this case, the ECA may be acting as a collateral vessel and have higher than expected diastolic flow. Using the temporal tap will confirm that it is the ECA.

As a helpful tip, practicing this test in cases where you have already confidently identified each artery will help you develop this highly useful skill!

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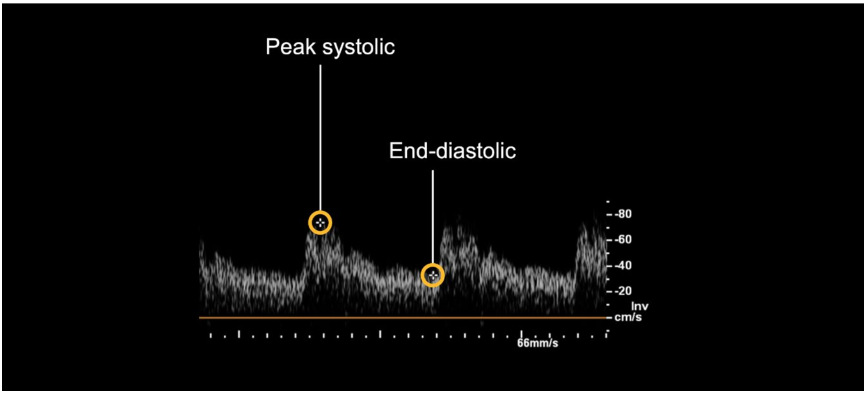
Making accurate velocity measurements

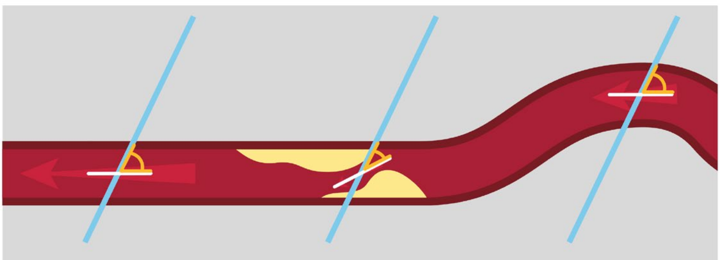
During the scan, you will measure and record peak systolic and end-diastolic velocities from the pulsed Doppler waveforms. These measurements will be used in calculations to grade the degree of any hemodynamically significant stenosis present, so they must be as accurate as possible.



Optimizing your settings

Position the angle correction cursor

To ensure accurate velocity measurements, first remember that the angle correction cursor should be aligned to the direction of the flow, which is normally parallel to the vessel walls. However, in the case of a jet within a stenosis, the cursor should be aligned to the jet, and where the vessel is tortuous, the angle cursor should be aligned to the tangent of the flow.

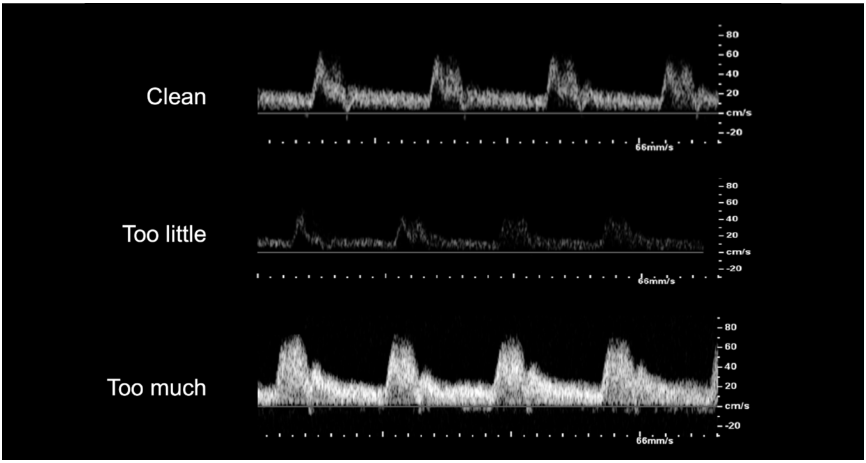


Check the Doppler angle

Second, check that your Doppler angle is between 45 and 60° but as close as possible to 60°. If not, steer the Doppler beam or manipulate the probe to obtain this angle.

Capture a clean Doppler waveform

Third, a clean Doppler waveform is required for accurate velocity measurements. Too little or too much gain can cause an under- or over-estimation of the peak systolic velocity.

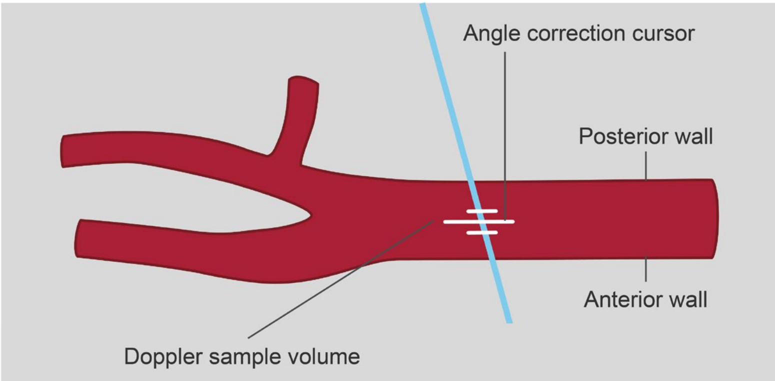


Making velocity measurements

CCA velocity

So once the settings are optimized, where should we make the velocity measurements? Well, the peak systolic velocity varies along the length of the CCA. Therefore, to ensure consistent velocity measurements, the guidelines recommend that the velocities are measured within 2 cm of the bulb.

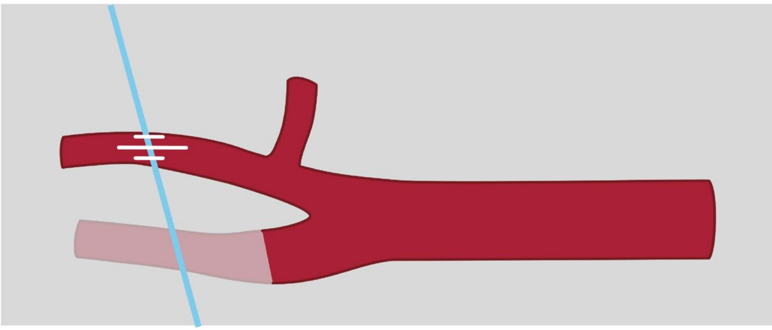
All measurements should be made in the longitudinal section with a good length of the vessel in the image. The image should clearly show the anterior and posterior walls, which will allow the sample volume to be positioned in the middle of the vessel and the angle correct cursor to be aligned with the vessel walls.



Common carotid artery

ECA velocity

Most centers will also measure and record the peak systolic and end-diastolic velocities from the ECA. Again, these should be measured away from the origin and where a good length of the vessel can be visualized together with the anterior and posterior walls.

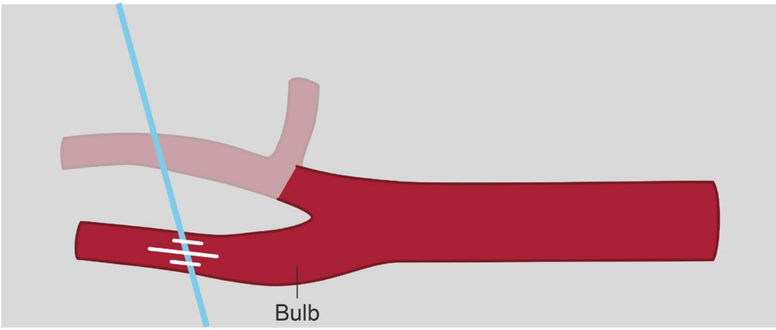


External carotid artery

ICA velocity

In the ICA, we have already looked at flow patterns and learned that flow separation with flow reversal occurs in the bulb. Waveforms here are likely to be unusual, and this is actually reassuring as this flow pattern is expected in a normal bifurcation.

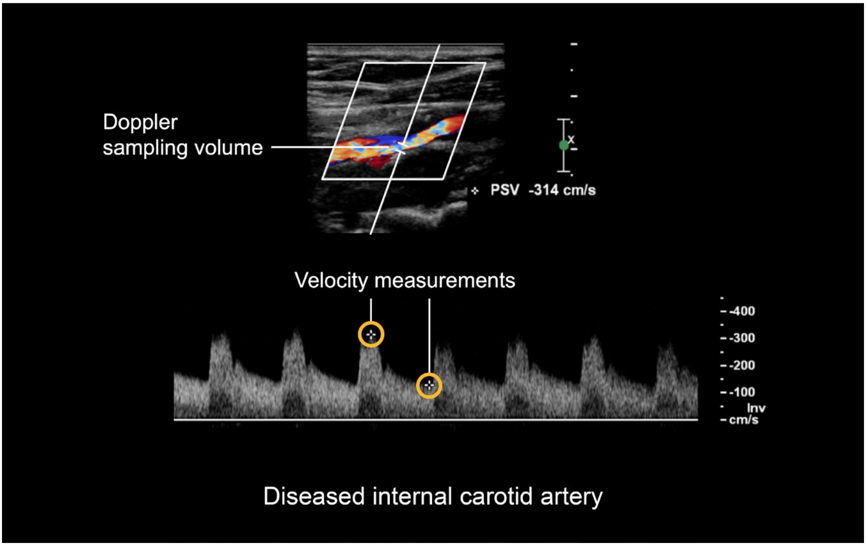
Therefore, in a normal ICA, the proximal ICA velocity measurements should be made just beyond the bulb, where the waveform has typical ICA characteristics, and the vessel has a uniform diameter. This is where the highest velocities will be found.



Internal carotid artery

In a diseased ICA, the highest peak systolic velocity is typically observed at the tightest point of the stenosis or in the jet just distal to the stenosis. The color flow image should be optimized to allow this area to be visualized clearly, which will help with the placement of the Doppler sampling volume.

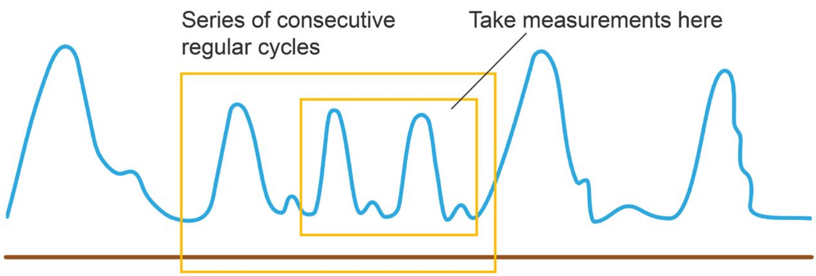
The Doppler sampling volume should be moved through the area of highest velocities shown by the color flow, and the Doppler waveforms should be continuously monitored. In this way, the highest peak systolic velocity (or PSV) can be located. This takes care and patience. Once the highest velocity is located, the gain and angle should be corrected to optimize the signal and ensure the accuracy of velocity measurements.



Diseased internal carotid artery

Taking challenging velocity measurements

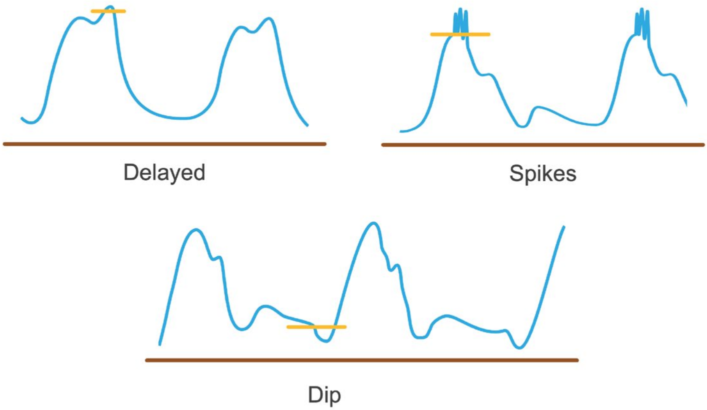
Irregular heartbeats
Making accurate velocity measurements is challenging when the patient has an irregular heartbeat because it is difficult to know which beat to make the measurements on. It is recommended to wait for a series of consecutive regular cycles and then measure on the second or third beat. Importantly, you must be consistent with your set of measurements.



Velocity measurements with irregular heartbeats

Atypical waveforms
Velocity measurements can also be challenging when the shape of the waveform is atypical—for example, when the peak is delayed or there are spikes above the peak due to turbulence. Then, it is recommended that the cursor is positioned over the main peak.

It can also be difficult to decide where to position the cursor to measure the end-diastolic velocity because there may sometimes be a dip at the end of the cycle. In this case, it is recommended that the cursor is positioned at the velocity level before the dip.



Velocity measurements with atypical waveforms

Finally, it is important to take care and be consistent when positioning the velocity measurement cursor to ensure accurate velocity measurements!

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Documenting the scan

It is very important that your scan is well documented. In this Medmastery lesson, we look at which images should be recorded during a carotid ultrasound scan.

Storing easily accessible images

First, you need to understand how images are stored at your hospital. Most ultrasound scanners now use digital archiving. Images will be stored on the scanner and moved to a picture archiving communications system (PACS) at the end of the examination. This allows them to be retrieved easily and reviewed across the hospital or shared with other hospitals.

Here are four reasons why it is really important that your images are easily accessible:

1. It's important for your protection in any litigation since the stored images can support and defend your report.
2. It allows your images to be reviewed at multidisciplinary team meetings, both in your hospital and at other sites.
3. It allows the images to be reviewed and compared with images from any previous and future scans.
4. The images can be used for quality assurance and audits.

Including the right details

All images must be of good quality, and they should accurately represent what you have observed. They should be correctly labeled and include information about the patient's identification and examination date, as well as the hospital and department in which the ultrasound was performed.

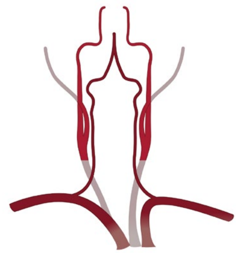
Capturing the right images

The images should also support the report you will be writing later. For example, if you are going to mention a specific type of plaque in a particular vessel, then you should have an image of it.

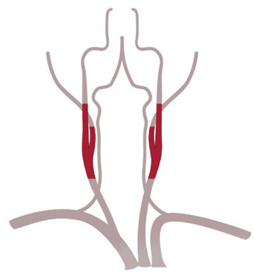
The list of images that are documented, recorded, and stored will vary between departments. Your departmental protocol will detail which images are expected.

As a minimum, the stored images should include:

- Pulsed Doppler waveforms with the peak systolic and end-diastolic velocities measured in the following locations:
  - distal CCAs (approximately 2 cm below the bifurcation)
  - proximal and distal ICAs
  - proximal ECAs
  - subclavian arteries
  - vertebral arteries (the direction of flow in the recorded vertebral artery image should be clear)

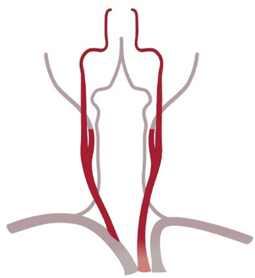


- B-mode images in the longitudinal and transverse planes showing the following locations:
  - bifurcation
  - proximal ICA



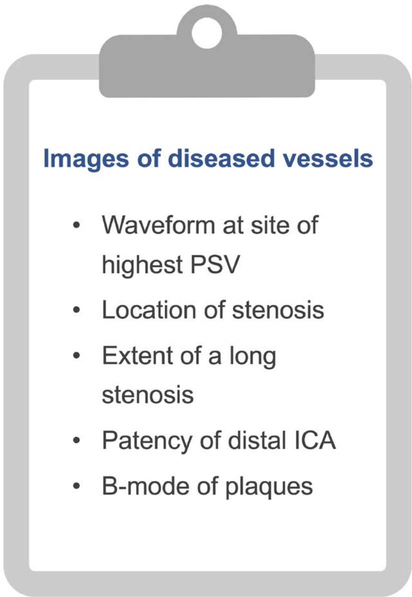
Some protocols will require additional B-mode with color flow images showing the following in the transverse and longitudinal planes:

- CCA
- Bifurcation
- ICA



If disease is present, then further images should be recorded:

- A pulsed Doppler waveform at the site of the maximum increase in the peak systolic velocity (or PSV) in any areas of a suspected stenosis
- An image documenting the location of the stenosis and the extent of a long stenosis
- An image documenting the presence of a plaque or otherwise a clear distal lumen in the ICA
- B-mode images of any plaques showing their location, nature, and extent (transverse and longitudinal images may be needed to document this sufficiently)



Remembering to record these images will ensure that your scan is well documented, but don't forget you will need to refer to and follow your local protocol.

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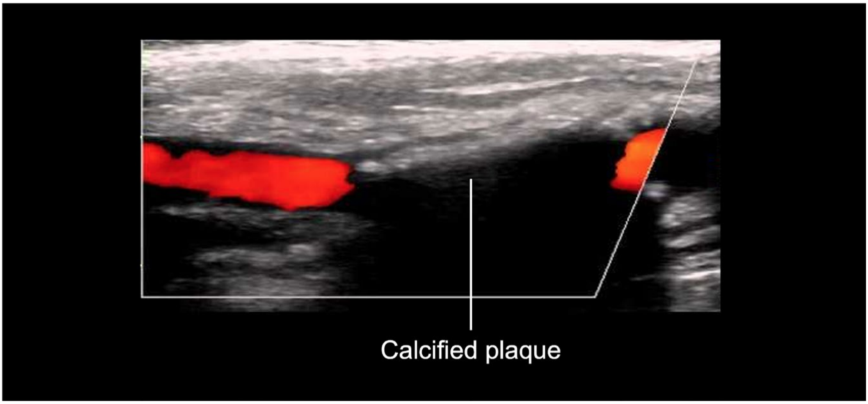
Tackling difficult scans

We know that not all ultrasound investigations will be straightforward, so in this Medmastery lesson, we will look at some of the challenges you are likely to encounter and learn some helpful tips that you can use to overcome them.

Calcified plaques

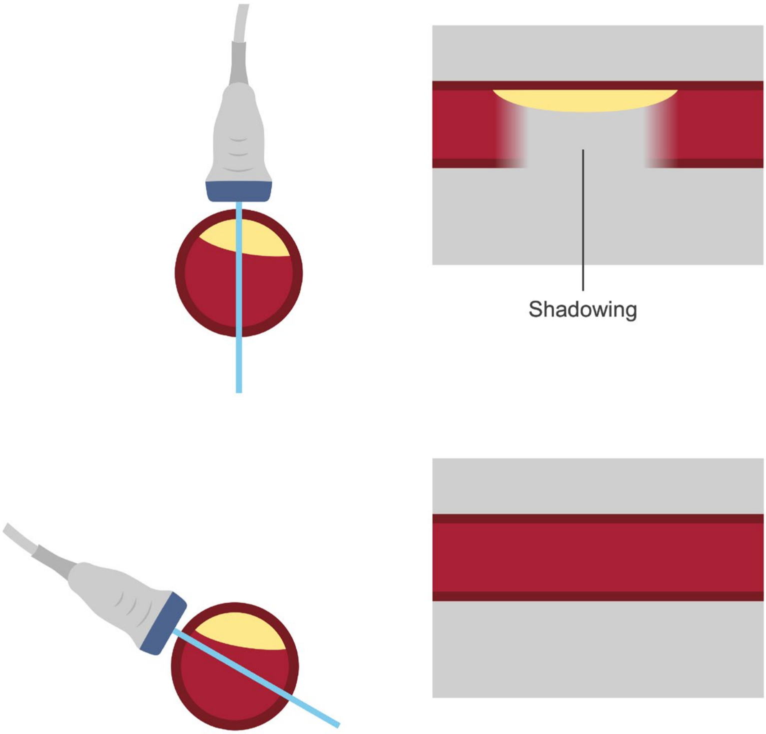
One of the difficult scans you may encounter is when your patient has a calcified plaque. It typically lies around the carotid bifurcation and in the proximal ICA and ECA. This causes acoustic shadowing and may obscure a particular area of interest, preventing the color flow and acquisition of the Doppler waveform at a site where a suspected stenosis lies.



Changing the scanning plane

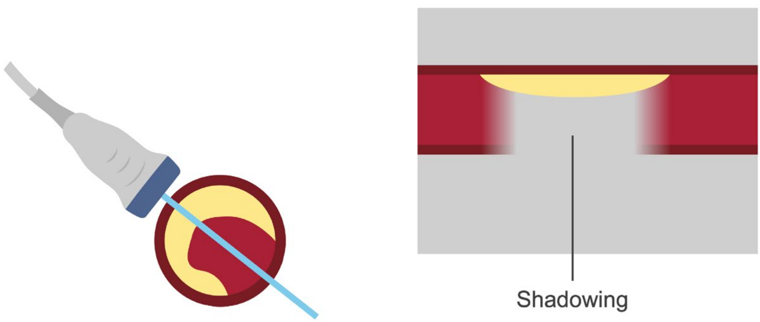
If the plaque is predominately on the anterior wall and acoustic shadowing is observed on the B-mode image, it may still be possible to obtain a good view by changing the scanning plane.

Moving the probe slightly may allow for a good section of the artery to be imaged, and then the color flow and pulsed Doppler can be used to assess the flow and significance of the plaque.



B-mode longitudinal image

However, if the plaque is more severe and extends to more of the walls, scanning from a different plane won't help.



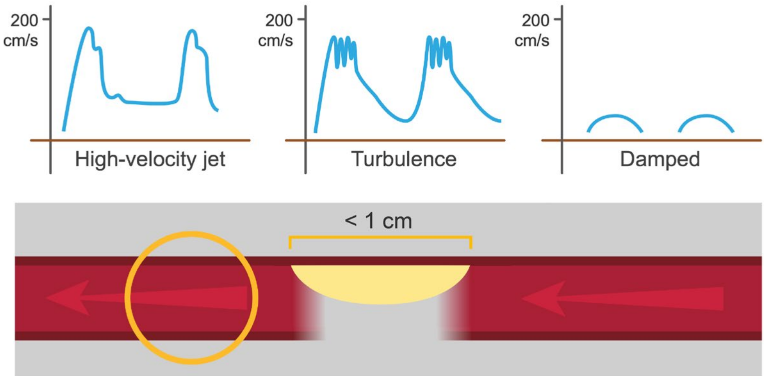
B-mode longitudinal image

Assessing color flow and pulsed Doppler

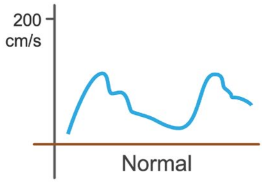
In the case of a more severe plaque that extends around to more of the vessel walls, the information that you can obtain from the scan may be limited. However, the assessment of the color flow and pulsed Doppler waveforms proximal and distal to the calcified area will provide useful information, particularly if the length of the gap or calcified area is less than 1 cm.

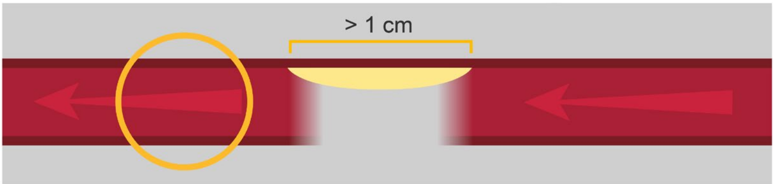
A normal Doppler waveform just distal to a short gap suggests the absence of significant stenosis, whereas an abnormal Doppler waveform suggests the presence of significant disease.

For example, a high-velocity jet may extend from the calcified area, giving a high peak systolic and end-diastolic waveform distal to the stenosis. Alternatively, the waveform might show turbulence or appear damped with low velocities. All of these types of waveforms suggest the presence of significant disease in the calcified area.



If the length of the calcified area is longer than 1 cm, the distal waveform may have recovered from changes caused by a stenosis and appear normal. In this case, you will not be able to report the presence or absence of disease with any degree of certainty.





Tortuous arteries

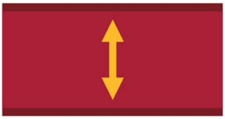
Identifying and reporting the presence of any plaque will be particularly challenging when the arteries are tortuous. The arteries may not be in a single plane, and it will be difficult to image sections of the vessel walls where they are in the same direction as the ultrasound beam.

In this case, the color flow may be difficult to interpret, because even though the flow is going in the same direction, at some points it will be moving towards the probe, then parallel to the probe, and then away from the probe.

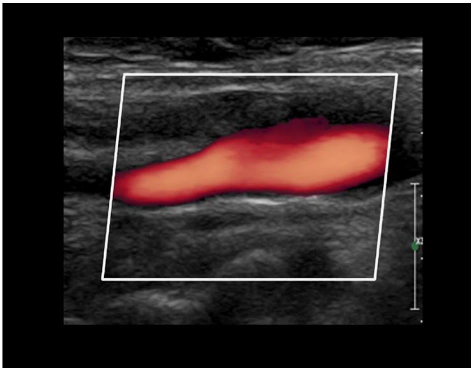
Aligning the angle correction cursor will also be difficult, so obtaining accurate velocity measurements from the pulsed Doppler waveform will be challenging.

Scanning in the transverse plane and using power Doppler

Scanning in the transverse plane will often help to clarify the path of the vessel. Using the power Doppler instead of color flow may help identify any filling defects associated with a plaque. It may also help with the placement of the Doppler sample volume and angle correction cursor.



Transverse plane



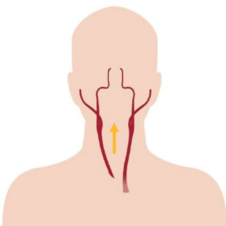
Power Doppler

Tortuosity should be mentioned in the report, including whether it has limited the scan.

High carotid bifurcation

A high carotid bifurcation will also provide a challenge. For a high bifurcation, first, ensure that the patient's head is extended as far back as possible and tilted away from the side being scanned. This movement may be enough to allow the visualization of more of the vessels distal to the bifurcation.

If positioning is not helpful, then a curvilinear probe can be used. This can be rocked or tilted to allow longer sections of the ECA and ICA to be observed.



High bifurcation

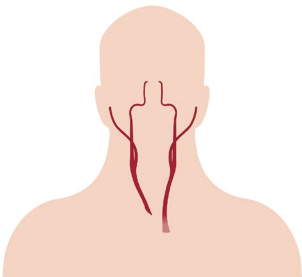
Curvilinear probe

Deep-lying vessels

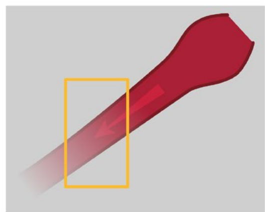
For deep-lying vessels in a patient with a thick neck, it can be difficult to obtain sufficient color filling and a good pulsed Doppler signal. For example, the ICA sometimes dives away steeply.

One option is to steer the color box straight. This is because the direction of the artery relative to the color box already gives an adequate angle, and importantly, the path of the ultrasound beam is shorter with the box steered straight. This will result in a stronger returning signal and thus a stronger color flow and pulsed Doppler signal.

If this doesn't help, try switching to the curvilinear probe. The resolution will be compromised, but enhanced color filling may help confirm whether the distal vessel is patent and of good caliber.



Thick neck



Steer the color box straight

Try a curvilinear probe

Internal carotid artery occlusion

Probably the most critical and difficult situation to image is a suspected ICA occlusion. In this case, it is really important to distinguish between total occlusion of the ICA where no flow is detected on the ultrasound and a tight stenosis with residual trickle flow.

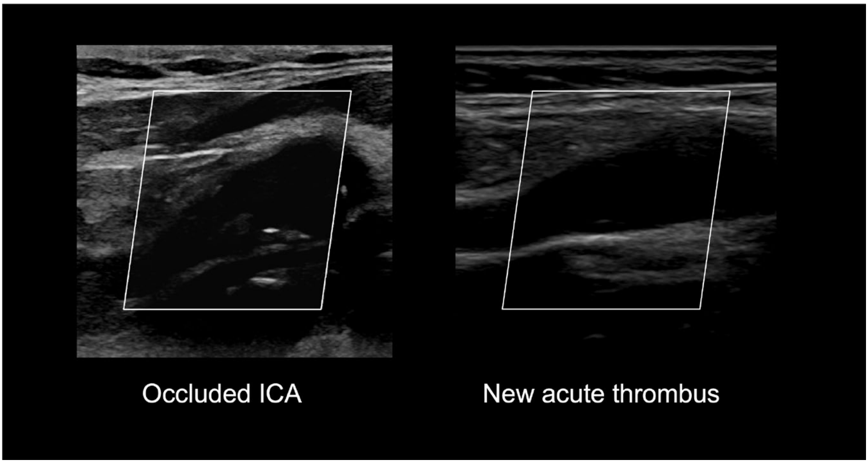
If no flow can be detected with the color flow, pulsed Doppler, or power Doppler, then an occlusion is suspected.

There are also three additional features that can help confirm an ICA occlusion:

1. Echoes
2. CCA resistance and flow
3. Thump at the stump

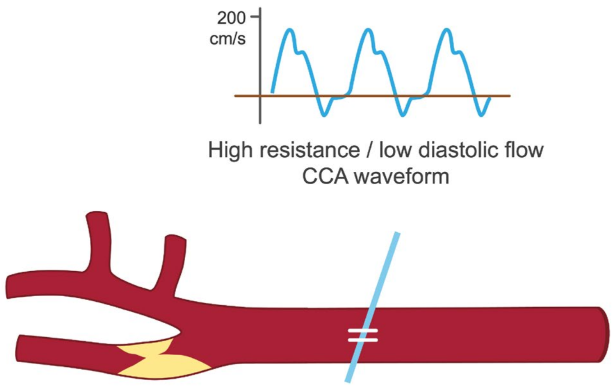
Echoes

On the B-mode image, an occluded ICA will usually be filled with echoes, but if the occlusion is the result of a new acute thrombus, the lumen of the vessel will appear echo-free or black. However, if the ICA occlusion is longstanding, it may have shrunk and could be difficult to image.



CCA resistance and flow

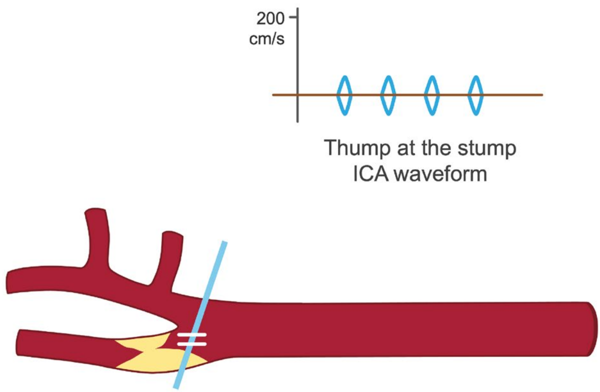
In the presence of an occlusion in the ICA, the CCA waveform will show high resistance. There will be low or no flow in diastole, and there may even be a reverse flow component.



ICA occlusion

Thump at the stump

A high-amplitude, low-velocity signal at the ICA origin, known as the *thump at the stump*, can help confirm an ICA occlusion.



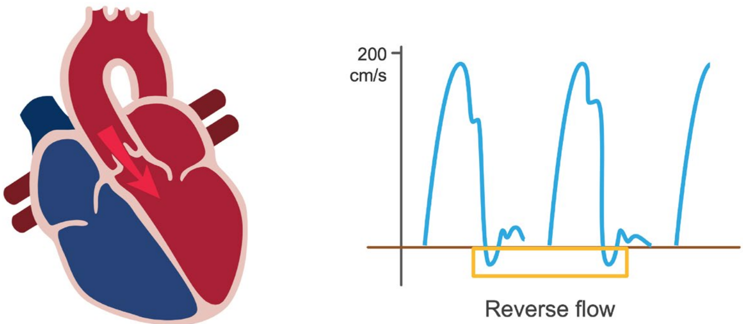
ICA occlusion

In a very tight ICA stenosis, the peak systolic velocity falls rapidly, and flow can be very slow, trickling through a tiny residual channel. This can be difficult to detect with color flow, even with the velocity scale and high-pass filter reduced and the gain increased.

In this situation, the power Doppler is more sensitive and should be switched on. The probe will need to be kept very still, and the pulsed Doppler with the settings optimized for low velocities may help confirm the presence or absence of flow.

Aortic regurgitation

Lastly, aortic regurgitation, which occurs when the aortic valve doesn't close tightly, may also significantly affect the carotid, subclavian, and vertebral waveforms. In this case, the flow during diastole is reduced in the CCA and may even be reversed.



Aortic regurgitation

However, we just saw that there can also be reverse flow in the CCA when an ICA occlusion is suspected. Therefore, it is important to confirm whether this reverse diastolic flow in the CCA is due to an ICA occlusion or aortic regurgitation.

If it is aortic regurgitation, then the effect should be bilateral, so observed in the carotid arteries on both sides. Aortic regurgitation will also hopefully be reported in the patient's history.

So, there you have it! By keeping these helpful tips in mind, you will be more confident when tackling challenging ultrasound investigations.

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Chapter 5

RECOGNIZING PATHOLOGY

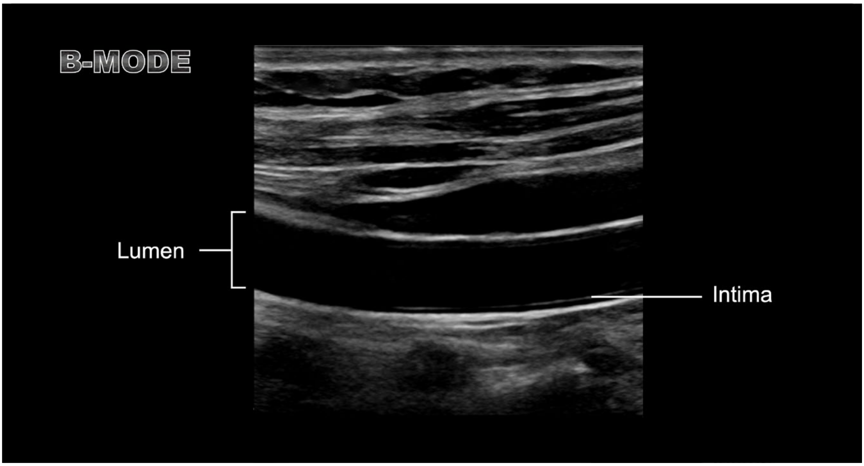
Identifying normal findings

Having a good understanding of normal artery findings will help you recognize pathologies when you come across them. In this Medmastery lesson, we will review what is expected on the B-mode, color flow, and pulsed Doppler images during a normal ultrasound investigation.

What to expect on B-mode

B-mode imaging provides a good overall picture for the common carotid artery (CCA), but beyond the bifurcation and in the vertebral and subclavian arteries, the images will be less clear, so you will need to depend more on the color flow and pulsed Doppler.

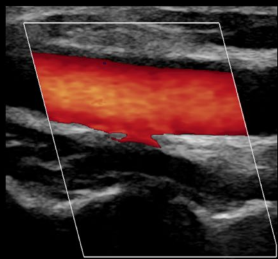
Let's start with the B-mode image of a normal CCA. Here, the lumen should appear echo-free throughout in both transverse and longitudinal planes. When scanning in the longitudinal plane, the image should clearly show the intima, which is the innermost layer.



What to expect on color flow

Color filling

For the color flow image, good wall-to-wall color filling should be observed throughout the carotid arteries from the base of the neck to the level of the mandible when the settings are optimized.

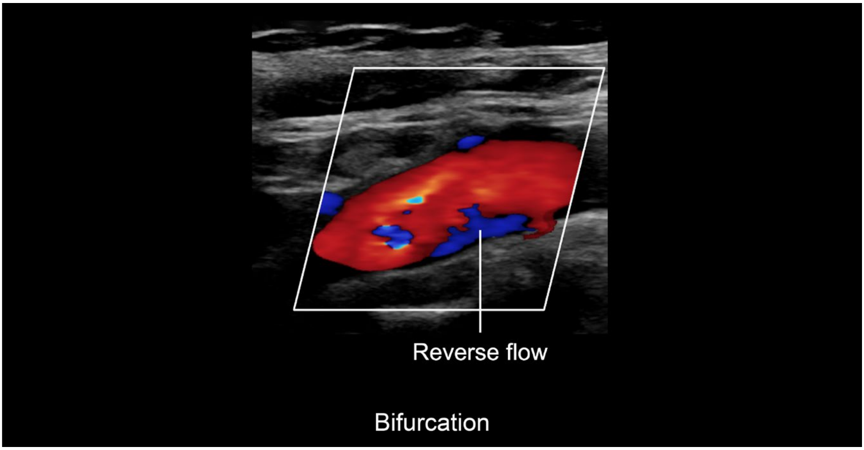


Color filling (carotid artery)

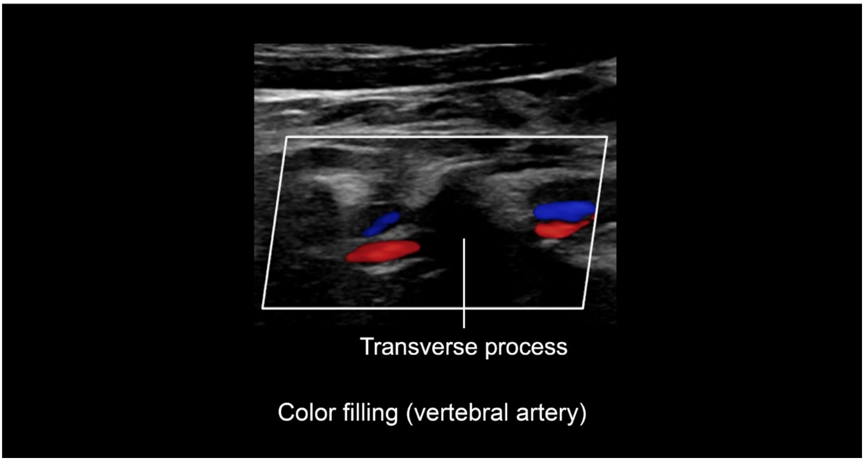
Color flow

Flow should be pulsatile, with the flow in the external carotid artery (ECA) appearing more pulsatile than that in the internal carotid artery (ICA) and CCA.

At the bifurcation, reverse flow is expected, which will be shown in the opposite color. Color filling should also be evident in the subclavian arteries. The flow will be very strongly pulsatile with a reverse flow component during each cycle, indicated by a flash of blue.



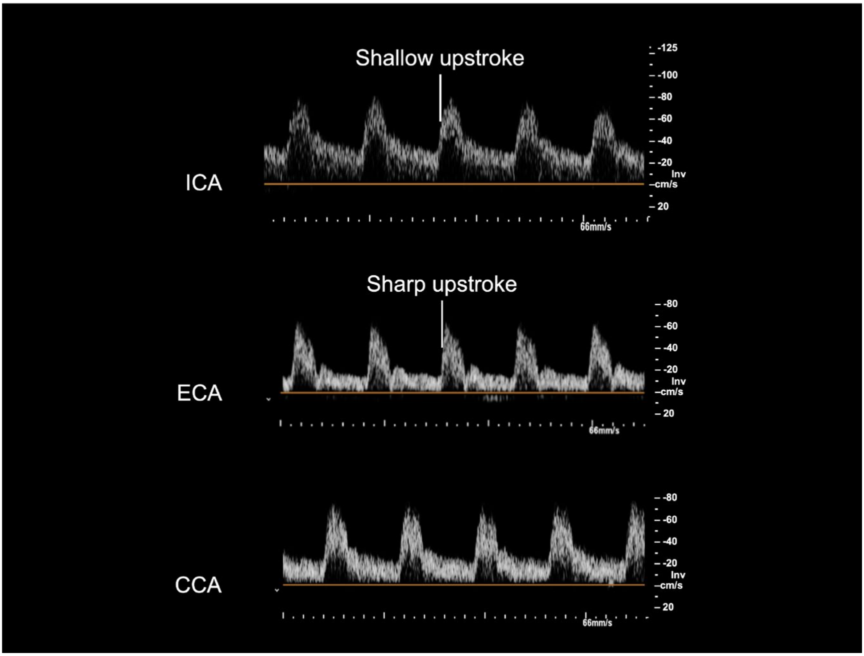
For the vertebral artery, only short segments will be observed between the transverse processes. The color flow should be used to confirm that the direction of flow is antegrade. The velocity scale will usually need to be reduced and the color gain increased. Typically, the vertebral vein with the flow in the opposite color will be seen above the vertebral artery.



What to expect on pulsed Doppler

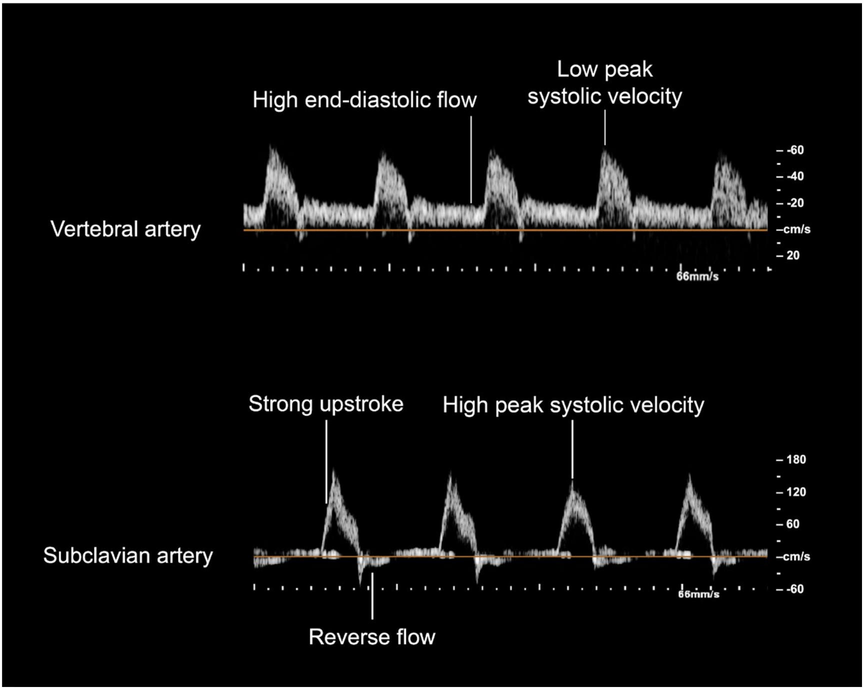
In addition to normal color filling and flow direction, the pulsed Doppler waveforms should also show typical characteristics. In the ICA, a normal Doppler waveform should have relatively high end-diastolic flow, generating a shallow upstroke. The peak systolic velocity should be less than 125 cm / s but will typically be much less than this.

In comparison, a normal ECA waveform will have lower end-diastolic flow and a sharper upstroke, and the Doppler waveform from the CCA should appear as a mix of these two patterns.



The normal vertebral artery Doppler waveform will look and sound similar to the ICA. It will have high end-diastolic flow, but the peak systolic velocities will be much lower, typically in the range of 40–60 cm / s. Keep in mind that one vertebral artery will usually appear much larger than the other, and higher velocities may be observed on one side.

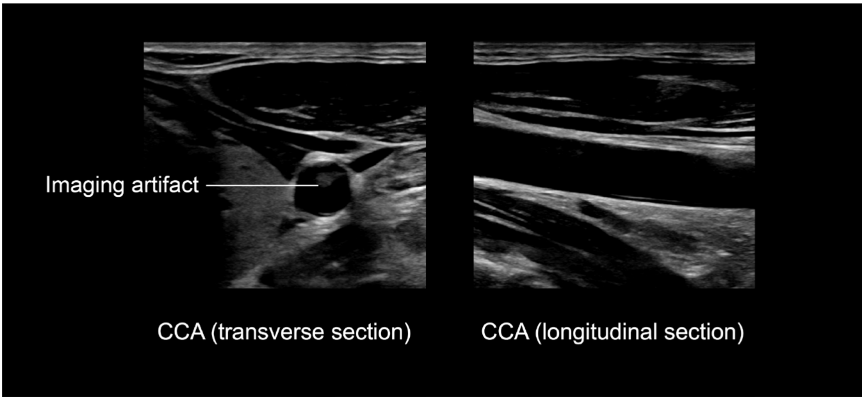
Lastly, the normal subclavian artery waveform should have a strong upstroke and be very pulsatile. It will be tri- or biphasic with a strong second reverse flow component. The expected peak systolic velocities can be high, typically between 80 and 150 cm / s.



Imaging artifacts on normal scans

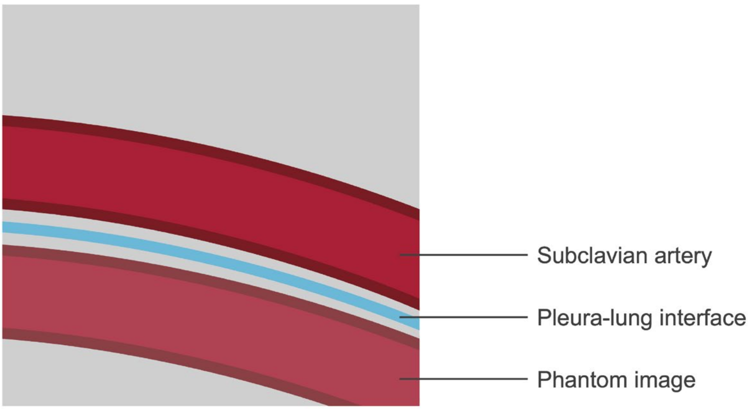
It is important to know that during normal scans, imaging artifacts may occur. These are caused by the inherent nature of ultrasound interactions with tissues and interfaces, resulting in a false structure or artifact in the image. You should be aware of these, so they are not misinterpreted as pathological findings.

The artifacts will sometimes be observed within the lumen on the B-mode image. Imaging from a different plane should remove the artifact and confirm that it is not a true structure. This is important as the artifact could be misinterpreted as something more harmful, such as a carotid dissection.



Additionally, the subclavian artery is an area where mirror artifacts can occur in both the B-mode and color flow images. This can be confusing and lead to misinterpretations if not understood properly.

When there is a strong reflecting surface present, a mirror image of a structure can be produced. For example, the pleura-lung interface can act as a strong reflector to the subclavian artery. The result is a *ghost* or *phantom image* of the subclavian artery lying below the pleura.



It is important to understand that these imaging artifacts are not pathologies, and they are something you will come across during normal scans and need to be able to recognize as artifacts.

Identifying carotid artery disease

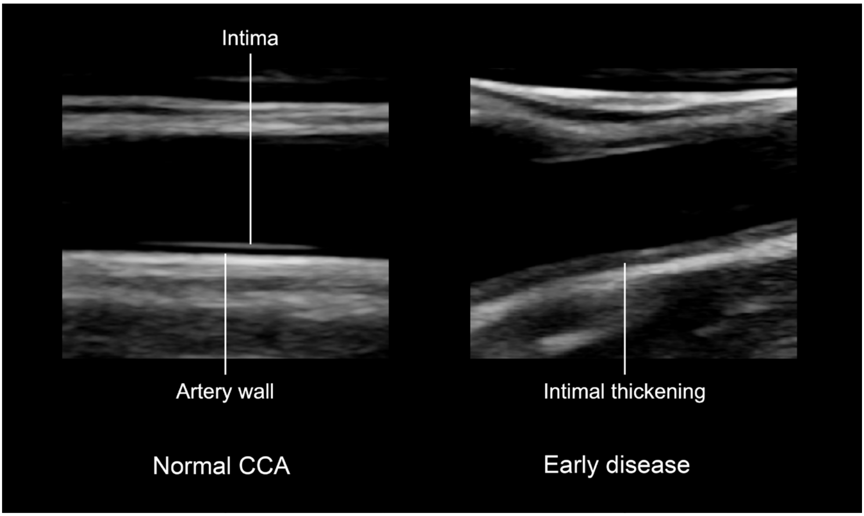
In this Medmastery lesson, you will learn how to recognize pathology in the carotid arteries.

Pathology in the common carotid artery

The typical site for atheroma is the carotid bifurcation. It's less common for atheroma or plaque buildup to occur in the CCA, but it's important to check the entire length of the CCA in both the transverse and longitudinal planes using B-mode and document any areas of irregularity or plaque. Alternative imaging planes should be used to distinguish between a plaque and an imaging artifact.

B-mode

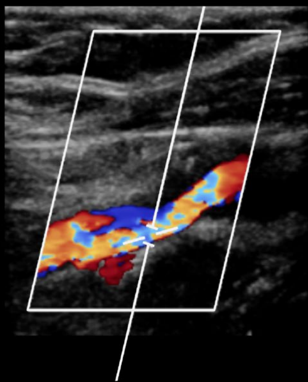
The B-mode image provides a lot of useful information. In the normal CCA, we saw that there is a clear gap between the intima and the media in the walls of the artery. Early disease in the carotid territory can be recognized by thickening of the intimal layer, which causes the clear gap to disappear. This can be visualized and documented with a high-frequency probe.



Color flow and pulsed Doppler

If the atheroma is more significant, meaning that it causes a greater than 50% reduction in the diameter of the lumen, then this should be apparent with color flow and pulsed Doppler. When the diameter is reduced by 50%, velocities will start to increase through the narrowing and will be shown in lighter shades of red on the color flow image.

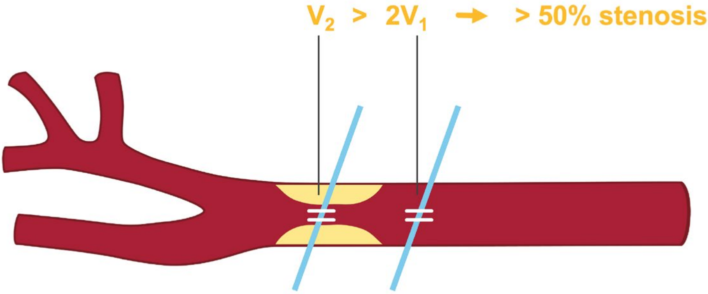
A tight stenosis or high-velocity jet just beyond a stenosis may also cause aliasing to occur in the color flow image. The marked change from reds to blue associated with aliasing will make tight stenoses easy to identify.



Aliasing

The pulsed Doppler waveforms and velocity measurements should then confirm the findings from the B-mode and color flow.

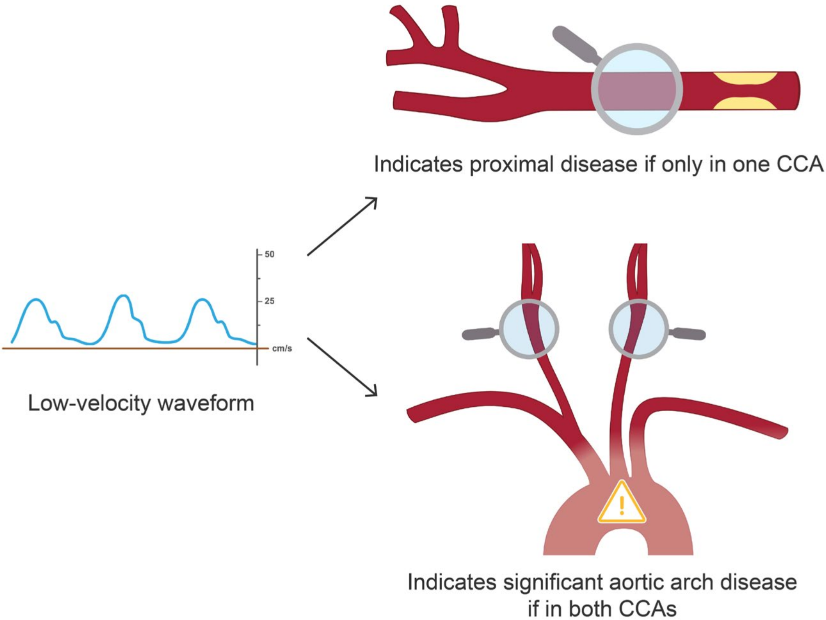
For example, a raised peak systolic velocity in the CCA is rare, but it may indicate significant stenosis in the CCA. A peak systolic velocity in the narrowed area that is more than double the velocity just proximal to this site would indicate a greater than 50% stenosis in the CCA. If this is the case, then narrowing should have been observed on the B-mode and color flow images.



V_1 = peak systolic velocity in the narrowed area

V_2 = peak systolic velocity just proximal to the narrowed area

Additionally, a very low-velocity waveform in the CCA may be observed. Proximal disease would be suspected if this occurs in one artery only. However, if observed in both CCAs, then this may indicate significant aortic arch disease.



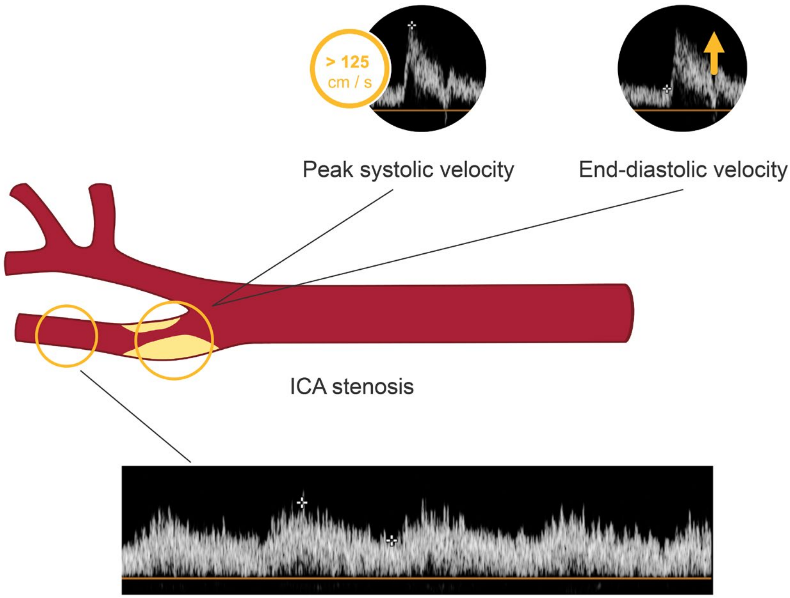
Pathology in the external carotid artery

It is more difficult to quantify the degree of narrowing in the ECA as this usually occurs close to the origin, so obtaining an accurate proximal velocity measurement for comparison isn't possible. However, significantly raised peak systolic velocities, together with plaque found on the B-mode image, suggest significant stenosis, and this is enough information to include in the report.

Pathology in the ICA

In the ICA, peak systolic velocities greater than 125 cm / s and increased end-diastolic velocities indicate the presence of significant disease. It is important to *walk* the Doppler sampling volume through the area of the stenosis to ensure that the highest velocities are detected, which may occur in a jet just distal to the stenosis.

In addition, a waveform demonstrating turbulent flow may be observed in the ICA distal to a significant stenosis. If a stenosis hasn't been found on the B-mode and color flow images but a turbulent waveform is detected, you must go back and confirm that a stenosis hasn't been missed.



Waveform showing turbulent flow

Reporting unusual waveforms

You may also come across some unusual waveforms. It is important to remember that if a waveform doesn't have the normally expected characteristics, there is an underlying reason for this. You must report this finding and be able to suggest possible causes.

For example, we have already learned that a high resistance waveform in the CCA may be observed when the ICA is occluded.

It is rare, but a high resistance waveform with no flow in diastole may also be observed throughout the ICA. In this case, a more distal obstruction is suspected. This might be in an intracranial part of the ICA or above, which can't be assessed with ultrasound.

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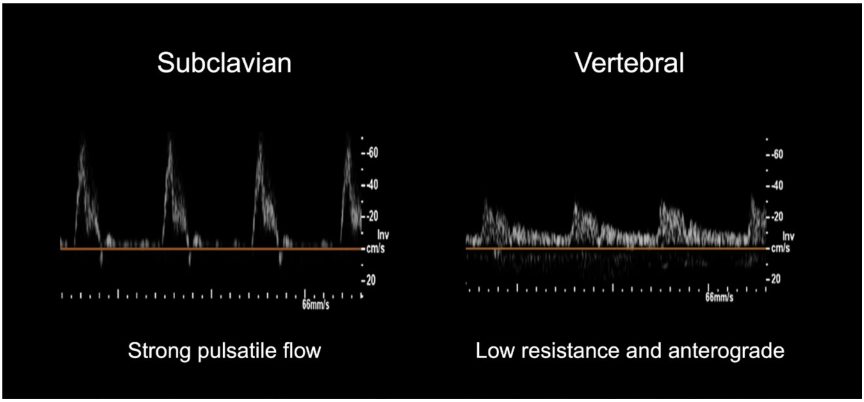
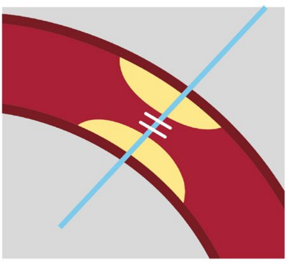
Identifying subclavian and vertebral artery pathology

We know that the subclavian arteries should have strongly pulsatile bi- or triphasic flow and that the flow in the vertebral arteries should be low resistance and antegrade. Disease in these arteries is relatively rare, but it is important to be able to recognize any irregularities.

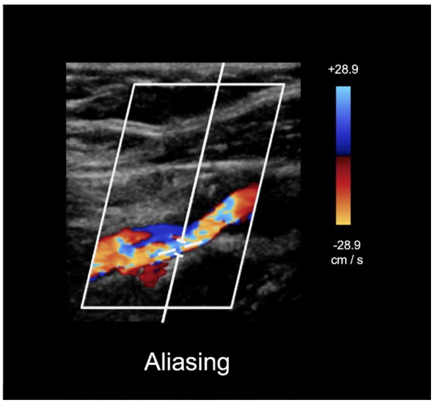


Pathology in the subclavian arteries

Let's begin with disease in the subclavian artery. In these arteries, the color flow image should help identify any pathology. Very high-velocity flow in a narrowing will be shown by aliasing or the lighter color shades.



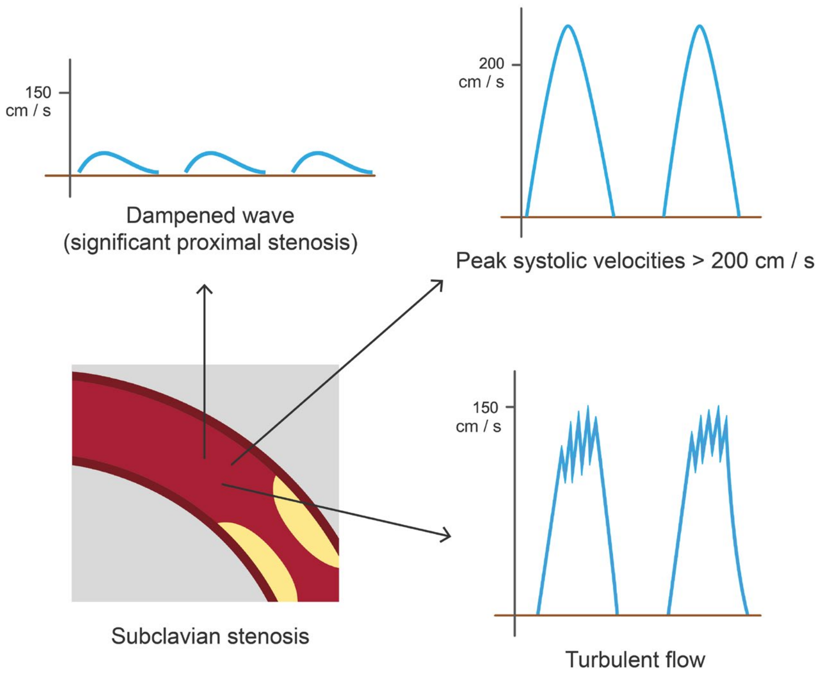
Subclavian narrowing



Pulsed Doppler waveforms can help confirm the stenosis. The peak systolic velocities in the subclavian artery are often quite high, but a velocity greater than 200 cm / s would suggest significant stenosis is present.

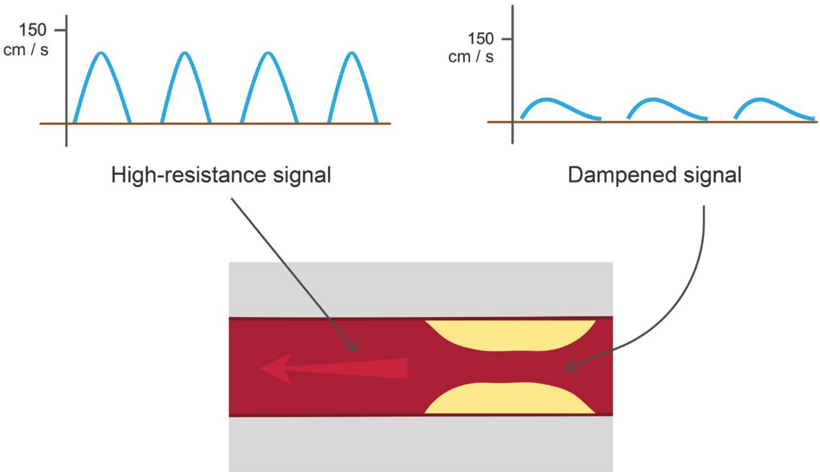
Imaging the subclavian artery can be quite challenging as it dives up from the aortic arch and then down under the clavicle, so a stenosis lying close to the limit of the area that can be assessed with ultrasound may be difficult to identify. However, a turbulent flow pattern on the color flow image suggests the presence of stenosis just proximal to the site of turbulence.

The pulsed Doppler can be used to confirm the presence of turbulence, and it may be possible to locate the stenosis with the Doppler sampling volume. Lastly, a low-velocity, dampened Doppler waveform in the subclavian artery indicates significant proximal stenosis.



Pathology in the vertebral arteries

We know that the vertebral arteries can't be fully assessed with ultrasound as the vertebral artery can only be viewed in the gaps between the transverse processes, but the same rules apply as with the carotid and subclavian arteries. A very dampened signal may suggest more proximal disease, and a high-resistance signal indicates more distal disease.



Vertebral artery stenosis

To confirm a suspected occlusion in the extracranial portion of the vertebral artery, clear images of several sections are needed. The absence of flow on the color flow, pulsed Doppler, and power Doppler confirms the presence of an occlusion.

Vertebral artery pathological findings may be secondary

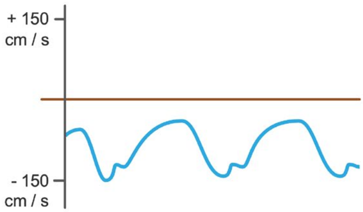
It is important to be aware that pathological findings in the vertebral arteries may also suggest the presence of disease in other arteries.

High peak systolic velocity with a wide diameter

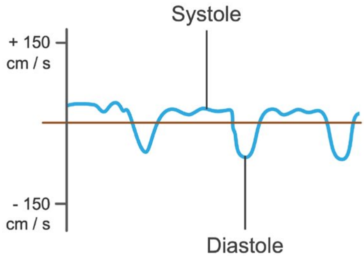
For example, a high peak systolic velocity measurement, together with a wide diameter vessel, may indicate that the vertebral artery is acting as a collateral vessel to increase blood flow to the brain. In this case, a high-grade stenosis or occlusion might be suspected elsewhere, such as in the ICA.

Retrograde flow

In addition, retrograde flow may be detected in the vertebral artery, where the flow is moving down the neck and away from the head. In some cases, the flow may be anterograde during systole and then move away from the head during diastole.

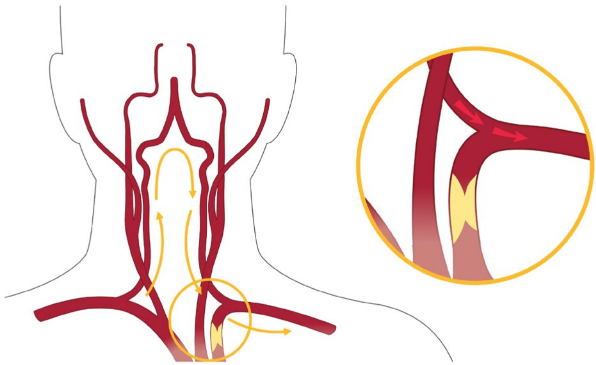


Retrograde flow



Anterograde / retrograde flow

In both cases, a subclavian steal is suspected. This happens when there is significant stenosis or an occlusion proximal to the origin of the ipsilateral vertebral artery, typically in the subclavian artery. The drop in pressure across the stenosis causes flow to be *stolen* from the other subclavian artery via the contralateral vertebral and then away from the head down the vertebral artery on that side.



Subclavian steal

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Identifying unusual pathologies

In addition to atherosclerotic disease, there are also non-atherosclerotic pathologies that occur in the carotid arteries. These are all rare, but it is important to be able to recognize them. The clinical history of the patient will usually highlight suspicion of a specific pathology, but it can also be identified coincidentally during the scan.

In this Medmastery lesson, you will learn what to expect on ultrasound images for these rare pathologies.

Pulsatile swelling in the neck

An example of a typical non-stroke referral is a patient with a pulsatile swelling in the neck, which usually occurs just above the clavicle. A pulsatile swelling may have one of three causes:

1. Potentially non-pathological causes
2. Carotid aneurysm
3. Carotid body tumor

Potentially non-pathological causes

This pulsatile swelling is often related to a combination of factors that may make the vessels easily palpable:

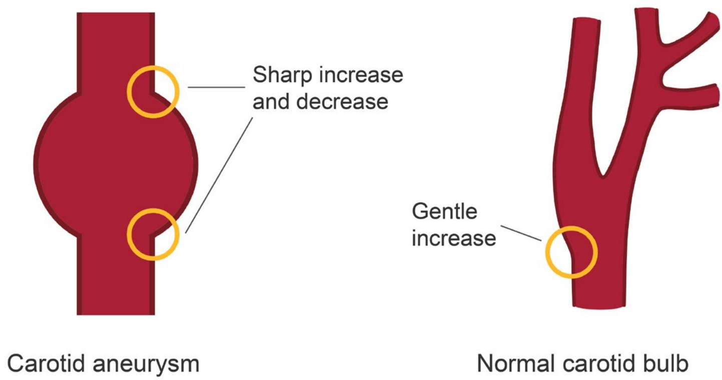
- A particularly superficial innominate artery or carotid bifurcation
- Dilated vessels
- Tortuous vessels

These factors will be evident on the ultrasound image and should be documented and recorded.

Carotid aneurysm

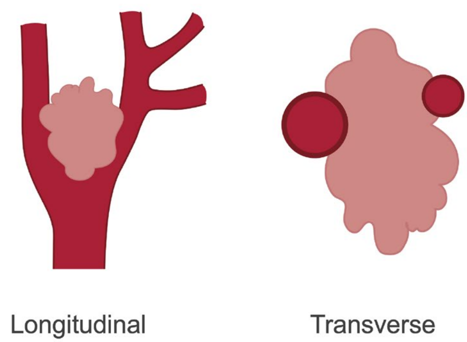
Alternatively, the pulsatile swelling may be related to a carotid aneurysm, which is the enlargement of an artery due to muscle weakness in the arterial wall. A doubling in size at the site of dilatation compared with a nearby normal section of the artery indicates an aneurysm. In this case, documenting accurate diameter measurements is important.

It can be challenging to distinguish between an aneurysm and the carotid bulb where the artery normally widens. A key difference to remember is that an aneurysm often shows a sharp increase and decrease in size, whereas the diameter of the bulb increases more subtly.



Carotid body tumor

The pulsatile swelling may also be caused by a carotid body tumor situated at the bifurcation. On the B-mode image, in both the longitudinal and transverse planes, a carotid body tumor will appear as a moderately echogenic structure between the ICA and ECA. The structure will appear to force or splay apart these arteries, the appearance of which is often described as a *wine glass* shape.

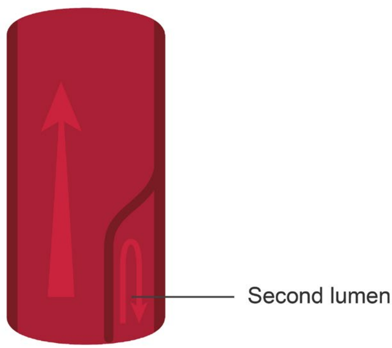


The tumor is typically highly vascular, and the flow within it can be visualized with the color flow. Additionally, because the flow in the tumor is usually fed by the ECA branches, the Doppler waveform in the ECA will have a much higher flow in diastole than expected in a normal ECA waveform.

Carotid dissection

Another example of an unusual pathology is a carotid dissection or tear in the wall of a carotid artery, which can create a false patent lumen. This is usually due to trauma and can happen in relatively young patients—for example, those involved in motorbike accidents when the helmet causes injury to the neck.

The dissection can be identified on the B-mode image, and the color flow will show a double lumen with flow in both. When this is suspected, it will normally be indicated in the patient's clinical history.



Carotid dissection

So, next time you're performing a carotid ultrasound investigation, it is important to keep these less common pathologies in mind.

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Chapter 6

REPORTING THE SCAN

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Evaluating carotid artery grading criteria

In this Medmastery lesson, you will learn how to grade a significant internal carotid artery (ICA) stenosis.

Stenoses that reduce the diameter of the artery by less than 50% are not hemodynamically significant and will not cause a change in flow or increase in Doppler velocities. For these low-grade stenoses, you will need to use the B-mode image alone to estimate the level of disease. These are typically classified as minor or moderate.

When the disease reduces the diameter by 50%, it becomes hemodynamically significant, increasing Doppler velocities. For these high-grade ICA stenoses, pulsed Doppler velocity measurements are used to determine the level of disease.

Mild or moderate ICA stenosis

High-grade ICA stenosis

Disease in the ICA is particularly difficult to assess compared to disease in a long relatively straight artery with parallel sides, such as the femoral artery. Because the geometry around the ICA is complex with the bifurcation and branches of the external carotid artery (ECA), there are different flow patterns and velocities. In the presence of hemodynamically significant ICA disease, these flow patterns will change further, and in particular, the velocities will increase.

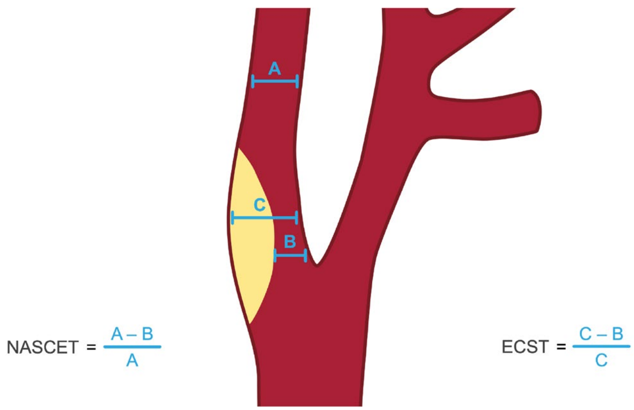
Because of this complex anatomy, the criteria used to grade ICA stenoses are not straightforward. Over time, several different criteria have been published, which has caused confusion. It is important for you to understand these different criteria and be able to justify the ones that you use. To help you with this, we're going to review the history of these guidelines, and then provide you with simple criteria that use Doppler velocity measurements to give an accurate, evidence-based measure of narrowing in the ICA.

History of internal carotid artery grading criteria

Much of the misunderstanding stems back to the early 1990s when two large carotid surgery trials were published: one from North America named the North American Symptomatic Carotid Endarterectomy Trial (NASCET) and one from Europe named the European Carotid Surgery Trial (ECST).

Both studies showed the benefits of surgery for ICA stenoses, but the degree of stenosis found to benefit from surgical intervention was very different. This was because the method used to report the narrowing from angiograms, which was the gold standard at the time, was very different between the two studies.

In the NASCET trial, the residual lumen was compared with the diameter of the distal ICA. However, in the European ECST study, the residual lumen was compared with an estimate of the ICA diameter at the point of the stenosis. This led to significant differences of up to 30% in the grading of the same stenosis.



A = Diameter of the distal ICA
B = Residual lumen
C = Diameter of the ICA at the point of stenosis

Additionally, the original studies that developed the ICA stenosis velocity grading criteria used angiogram-reported stenoses for comparison. However, this caused confusion as it wasn't always clear whether the North American or European method had been used.

A further source of confusion was that several studies published different criteria. These criteria were all based on ICA and CCA velocity measurements and ratios, but the values for the same degree of stenosis varied between these studies. As a result, there were no clear standard criteria.

Coming to a consensus

In a hospital, carotid ultrasound investigations are performed in different departments, ranging from general imaging to specialist vascular labs. Different departments, and sometimes even those in the same hospital, may use different grading criteria and even different measurement methods based on either the NASCET or ECST method.

This confusion has inevitably resulted in unnecessary repeat testing and missed opportunities for surgical intervention. Consequently, working groups were set up to agree on a consensus in both North America and the United Kingdom (UK).

Grading criteria agreed upon by the United Kingdom consensus group

In this lesson, we're going to review the grading criteria agreed upon by the UK consensus group. These criteria use the NASCET measuring method and are in broad agreement with the North American recommendations.

Four pulsed Doppler velocity measurements

Both the NASCET and ECST methods are based on the four pulsed Doppler velocity measurements obtained during a scan:

1. Peak systolic velocity (PSV) in the ICA and common carotid artery (CCA)
2. End-diastolic velocity (EDV) in the ICA and CCA

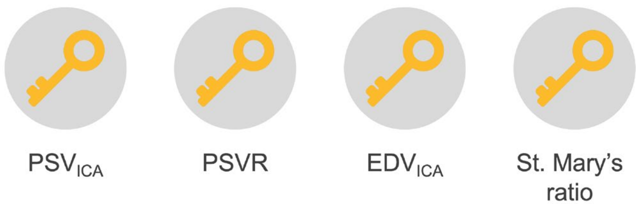
	Peak systolic velocity	End-diastolic velocity
ICA	PSV_{ICA}	EDV_{ICA}
CCA	PSV_{CCA}	EDV_{CCA}

Four key diagnostic criteria

These four pulsed Doppler velocity measurements then form the four key diagnostic criteria that have gained consensus for grading an ICA stenosis:

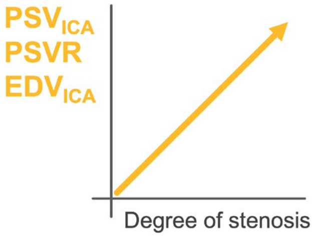
1. Peak systolic velocity in the ICA
2. PSVR, which stands for peak systolic velocity ratio and is the ratio of the peak systolic velocity in the ICA to the peak systolic velocity in the CCA
3. End-diastolic velocity in the ICA
4. St. Mary's ratio, which is the ratio of the peak systolic velocity in the ICA to the end-diastolic velocity in the CCA

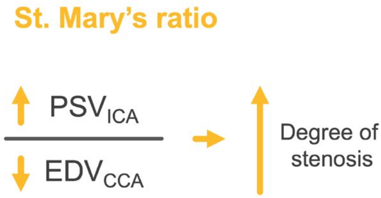
When two or more of these criteria agree, the diagnostic confidence increases.



The peak systolic velocity in the ICA, the PSVR, and the end-diastolic velocity in the ICA all increase with increasing degrees of stenosis. The last parameter, the St. Mary's ratio, enables the grading of stenoses in deciles.

As the degree of the ICA stenosis increases, the resistance presented by the ICA increases, causing the diastolic flow in the CCA to decrease. So, with increasing levels of stenoses, the nominator increases, but the denominator decreases. This results in an overall increase in the ratio.





When introducing the St. Mary's ratio in my lab, we audited it against other imaging parameters and surgical findings. We found good accuracy and determined that splitting the grading into 10% deciles really helped with surgical decision-making.

Handy summary of all the criteria

The table that appears next features all the diagnostic criteria together with the percentage of stenosis in the left column followed by each of the four key criteria. You'll want to keep this table somewhere at your reporting desk.

<table>
<tr><th>% stenosis (NASCET)</th><th>PSV$_{ICA}$</th><th>PSVR</th><th>EDV$_{ICA}$</th><th>St. Mary's ratio</th></tr>
<tr><td>< 50</td><td>< 125</td><td>< 2</td><td>< 40</td><td>< 8</td></tr>
<tr><td>50–59</td><td rowspan="2">> 125</td><td rowspan="2">2–4</td><td rowspan="2">40–100</td><td>8–10</td></tr>
<tr><td>60–69</td><td>11–13</td></tr>
<tr><td>70–79</td><td rowspan="2">> 230</td><td rowspan="2">> 4</td><td rowspan="3">> 100</td><td>14–21</td></tr>
<tr><td>80–89</td><td>22–29</td></tr>
<tr><td>> 90</td><td>> 400</td><td>> 5</td><td>> 30</td></tr>
</table>

Criteria do not apply for really tight stenoses much greater than 90%.

We will go through an example using these criteria in the next lesson.

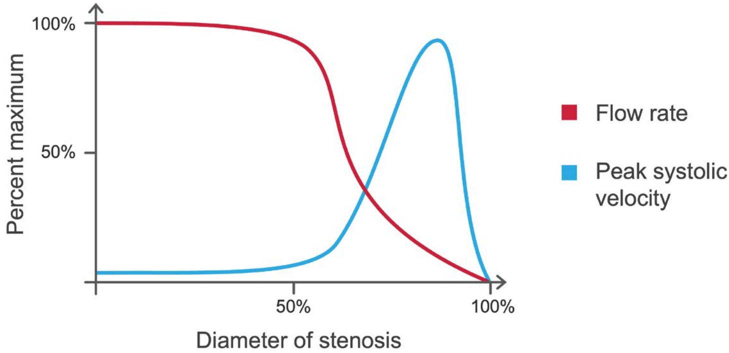
Why the criteria don't apply to really tight stenoses

These criteria do not apply for really tight stenoses much greater than 90% or total occlusions, because the velocities may be too low or undetectable.

For a really tight stenosis or subocclusion, you will likely see trickle or string flow with very low velocity in the ICA, which should be included in your report.

The grading criteria won't apply at this degree of stenosis because the flow has dropped to such an extent that the velocity begins to decrease.

Of course, for an occlusion, you won't detect any flow in the ICA with either color flow, power Doppler, or pulsed Doppler.



Know and document which criteria your department uses

Your department will likely use velocity and ratio criteria based on the published studies, or they may use a variation of these. Whatever the case, it is important that you understand where the criteria that your department uses came from. More importantly, the following should be true of the criteria you use:

- It should be evidence-based.
- It should be aligned with referring clinicians.
- It should be shared with other local diagnostic departments to avoid any unnecessary confusion or repeat testing.

It is also important to clearly indicate which measuring method (NASCET / ECST) is being used.

Finally, as a word of warning, there are several situations in which caution is required when applying these criteria, particularly the St. Mary's ratio. These scenarios will be covered in the next lesson.

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Categorizing carotid artery disease

In this Medmastery lesson, our focus will be on how to apply the key criteria for grading an ICA stenosis, and we will look at situations in which caution is required when categorizing carotid disease from your scan.

Although the velocities from the pulsed Doppler waveforms are used to grade an ICA stenosis, remember that the B-mode and color flow images also need to be evaluated. Visually, these should match the grading from the velocity criteria. If not, the potential reasons should be investigated and commented on in the report.

Start with peak systolic velocity in the internal carotid artery and confirm with other key criteria

Of the four diagnostic criteria, the PSV in the ICA should be the starting point because this measurement is reliable and reproducible, and the levels set for different categories of disease are now well established.

To increase the confidence in the findings, it is important to use the other key criteria to confirm the grading determined based on the PSV in the ICA. The grade of stenosis determined from the other criteria will usually agree with the level indicated by the PSV in the ICA.

Example of using diagnostic criteria to grade an internal carotid artery stenosis

Let's look at an example where the calculated PSV in the ICA is 157 cm / s, and the EDV in the CCA is 18 cm / s. The PSV is applied first, and according to the diagnostic criteria that we learned in the previous lesson, a PSV in the ICA greater than 125 cm / s puts the degree of stenosis into a wide range of 50–69%.

% stenosis (NASCET)	PSV_{ICA}	PSVR	EDV_{ICA}	St. Mary's ratio
< 50	< 125	< 2	< 40	< 8
50–59	> 125	2–4	40–100	8–10
60–69				11–13
70–79	> 230	> 4	> 100	14–21
80–89				22–29
> 90*	> 400	> 5		> 30

Next, the St. Mary's ratio is calculated:

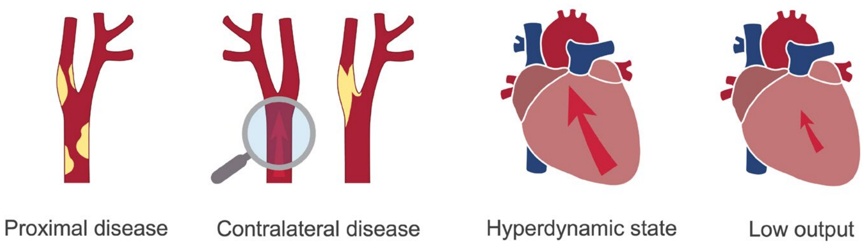
$$\frac{PSV_{ICA}}{EDV_{CCA}} = \text{St. Mary's ratio} \qquad \frac{157\ \text{cm / s}}{18\ \text{cm / s}} = 8.7$$

A St. Mary's ratio between 8 and 10 indicates a degree of stenosis of 50–59%. As you can see, this value is in a decile that sits within the wider range given by the PSV.

When the peak systolic velocity in the internal carotid artery may not be reliable

It is important to know that there will be circumstances in which the PSV in the ICA may not accurately represent the degree of ICA stenosis. Here are four examples:

1. **The presence of significant proximal disease.** For example, a significant CCA narrowing can cause a reduced PSV distally.
2. **The presence of severe disease on the contralateral side.** For example, a tight ICA stenosis or occlusion on the opposite side can cause an increase in flow and PSVs on the side being investigated.
3. **A hyperdynamic cardiac state.**
4. **Low cardiac output.** Both a hyperdynamic cardiac state and low cardiac output may increase or decrease the PSV, and as a result, the velocity criteria may not fit with what is being observed visually.

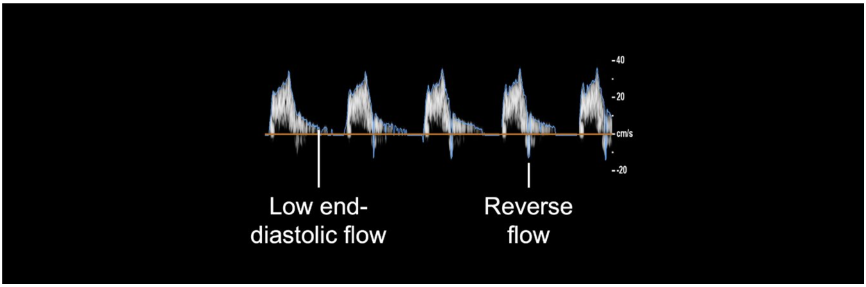


In these cases, it is particularly important to use the additional key criteria to obtain a representative value for the stenosis. Applying the PSVR, which is the ratio of the peak systolic velocities in the ICA and CCA, is likely to give a more accurate measure of the stenosis.

If the PSV in the ICA is not being used, this fact, together with the rationale behind it, should be documented in the report.

When to avoid using the St. Mary's ratio

Although the St. Mary's ratio is extremely useful, one situation in which it should not be used is when there is low end-diastolic flow or reverse flow bilaterally in the CCAs.



The low end-diastolic flow is likely to be associated with aortic valve disease and regurgitation. If the end-diastolic velocity in the CCA is less than 10 cm / s, then St. Mary's ratio shouldn't be used, and this should be noted in the report.

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Evaluating plaque characteristics

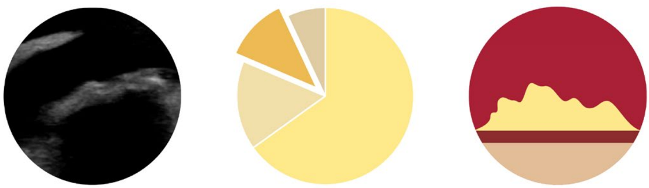
Evidence suggests that particular types of plaques are more dangerous than others, so it is important to be able to recognize the different plaque characteristics on an ultrasound image.

Studies indicate that the differences in plaque characteristics are related to the histology and symptoms of patients. However, despite the development of various methods and software programs to characterize plaques, the role that ICA plaque characterization plays in carotid disease remains poorly understood.

What we do know is that there are three key characteristics that can be used to describe plaques:

1. Echogenicity, which is the density of the echoes on the B-mode image
2. Composition
3. Surface contour, which is the appearance of the plaque's surface

Reporting these characteristics can help in decision-making about treatment options, including surgical intervention.

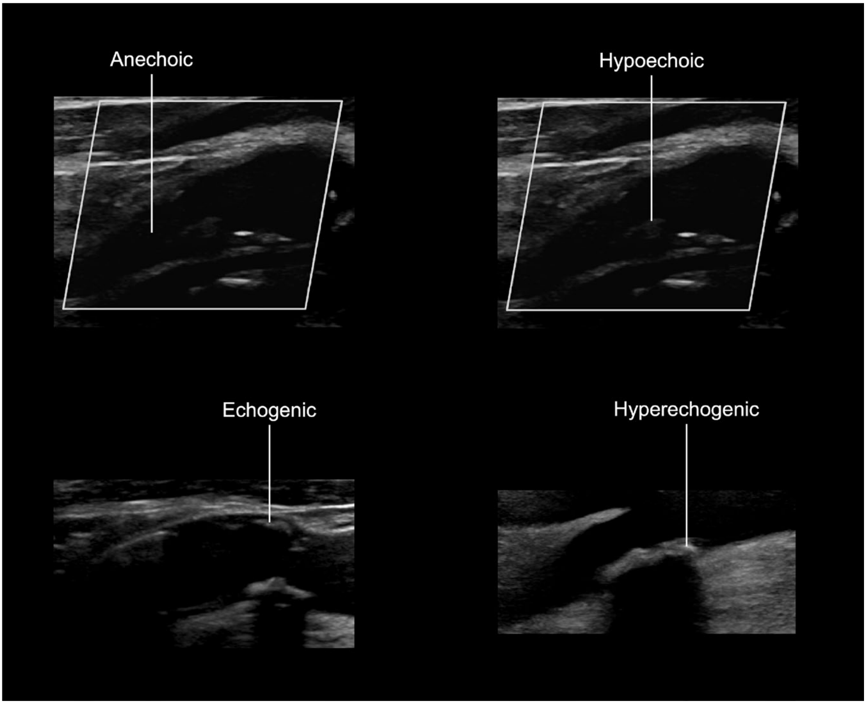


Echogenicity Composition Contour

Echogenicity

There are four categories of plaque echogenicity:

1. Anechoic
2. Hypoechoic
3. Echogenic
4. Hyperechogenic



Anechoic

If plaques are anechoic, no echoes are detected. As a result, these types of plaque are easy to miss. Anechoic plaques are regarded as very high risk, so it is important to be able to identify them. Research has shown a significantly increased rate of high-risk plaques in men than in women.

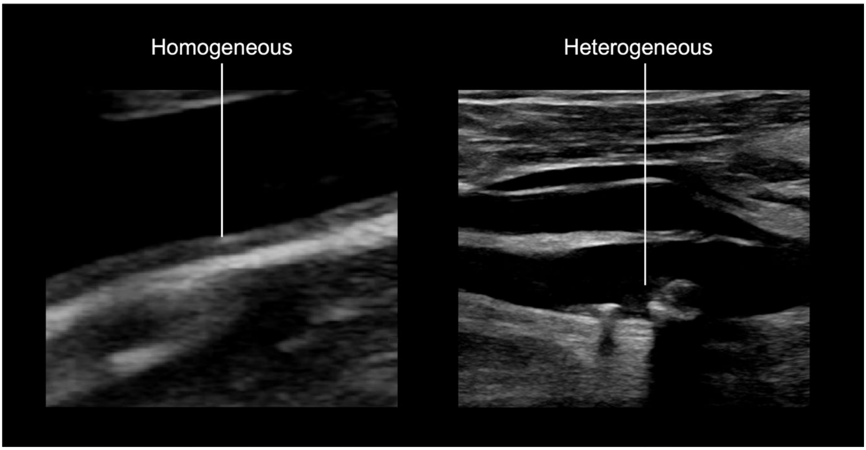
These plaques sometimes have a fibrous cap, which can be visualized on the B-mode image. The color flow should also help confirm the presence of this type of plaque.

Hypoechoic
Hypoechoic plaques produce a low level of echoes. Similar to anechoic plaques, they are associated with a high lipid concentration and a high risk of embolizing.

Echogenic
Echogenic plaques produce stronger echoes, so they are more clearly visualized on the B-mode image. They are associated with more dense fibrous tissue and are believed to be more stable.

Hyperechogenic
Much brighter echoes are produced with hyperechogenic plaques. This type of pattern is associated with calcified plaques that create acoustic shadowing.

Composition
The next characteristic is plaque composition, of which there are two categories:
1. Homogeneous
2. Heterogeneous



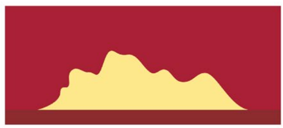
Homogeneous
Homogeneous plaques have a uniform gray scale appearance on the B-mode image.

Heterogeneous
In contrast, heterogeneous plaques have a mixed appearance on the image, producing strong echoes in some places and weaker echoes in others.

Surface contour
The final plaque characteristic is the surface contour, or in other words, *what does the surface of the plaque look like?*

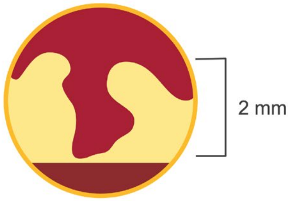
There are two possibilities when it comes to surface contour:
1. Smooth
2. Irregular


Smooth


Irregular

Smooth
Smooth plaques have a flat, even surface and tend to be hypoechoic, and therefore, produce a low level of echoes.

Irregular
Irregular plaques have uneven, broken surfaces. They can also be associated with ulceration (i.e., indentation or erosion on the surface). Ulcerated plaques have a very high risk of causing emboli, and they are difficult to identify with ultrasound. Typically, they will have a crater-like appearance, and the depth of the crater will be a least 2 mm.



Ulceration

Plaque characterization isn't easy, and it takes a lot of practice. Remember that the location and extent of any plaque identified must be included in your report.

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Completing a report

Once you have performed your scan, reviewed your images, and calculated the velocity ratios, you are now ready to write your report.

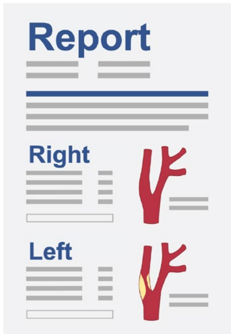
The patient's treatment will be based on your report, and vascular surgeons may decide to operate based on your findings. Therefore, the ultrasound investigation report must be accurate, clear, and concise. This isn't always easy as you have gathered a lot of information, both quantitative and qualitative, so you will need to follow a structured and logical approach.

What to include in your report

There are specific items that every report must include, although the format and style of the report will vary between organizations.

For the carotid arteries, the following components should be included in your report:

1. Velocity measurements
2. Degree of stenosis and calculation method used
3. Plaque location, length, and appearance
4. Limitations encountered
5. Any other abnormalities
6. ICA disease-specific findings
7. Vertebral and subclavian artery findings
8. Conclusion



Velocity measurements

The following velocity measurements should be reported:

- Peak systolic velocity and end-diastolic velocity in the CCA 1–2 cm below the bifurcation
- Peak systolic velocity and end-diastolic velocity in the ICA at the point of the highest velocity

Degree of stenosis and calculation method used

From the velocity measurements, the degree of stenosis and calculation method used (NASCET or ECST) should be included. The report should also note when particular grading criteria haven't been applied and include the rationale for this exclusion, such as low EDV in the CCA values or severe contralateral disease.

Plaque location, length, and appearance

If a plaque is present, its location and length, plus its appearance or characteristics must be described in your report.

Limitations encountered

Any limitations, such as a calcified plaque that is causing acoustic shadowing, need to be included. It is particularly important to report the extent of the limitation. For example, you would want to report if the shadowing in the proximal ICA extends for 1 cm or greater and is located where significant disease is suspected.

Any other abnormalities

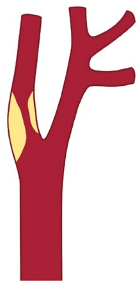
Here are a few other findings that are important to document in your report:

1. Any abnormalities in the carotid waveforms, such as low end-diastolic or reverse flow in the ICA, which may indicate a distal intracranial occlusion
2. Carotid dissection
3. Carotid body tumor
4. Carotid aneurysm
5. Carotid tortuosity

Internal carotid artery disease-specific findings

When there is significant ICA disease, be sure to include the following in your report:

- Patency of the distal ICA and whether or not it is free from disease
- Level of the carotid bifurcation (if the patient is likely to be considered for surgical intervention)



Vertebral and subclavian artery findings

The report should also include the following findings from the vertebral and subclavian arteries:

- Vertebral arteries patency and direction of flow
- Subclavian arteries patency and shape of the waveforms

Conclusion
A clear, concise conclusion that answers the clinical question is always required.

How to format the report

As you can see there is a lot to include in the report. This may be an entirely written or diagrammatic report. In the United Kingdom, surgeons prefer a diagrammatic report. This allows them to quickly see the velocity measurements, together with the location and extent of any disease.

Alerting the referring clinician and saving the report

Any critical findings should be reported to the referring clinician immediately or as soon as possible.

Ideally, the report should be saved in a system that allows it to be stored together with the images. This allows both to be easily retrieved and reviewed together.

So, next time you're ready to write your report, remember to follow a structured and logical approach to ensure that your ultrasound investigation report is accurate, clear, and concise!

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APPENDIX

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Reference list

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