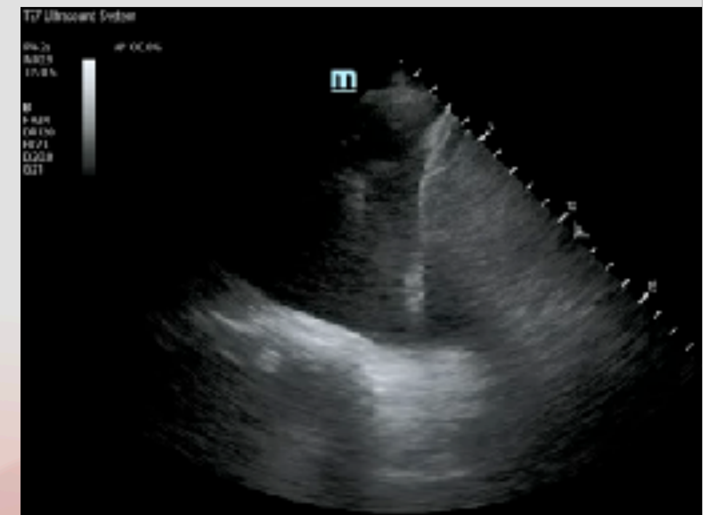
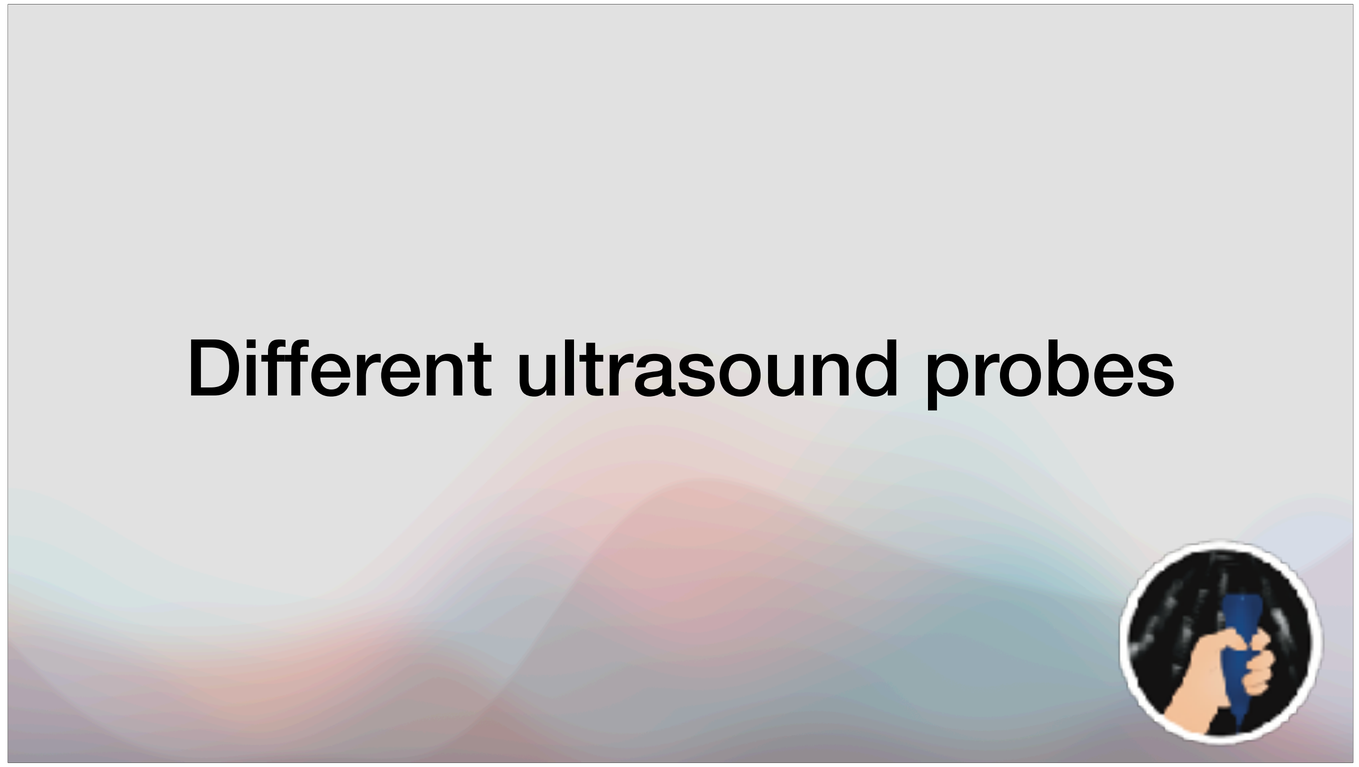

Welcome back to our point-of-care ultrasound course. As I mentioned previously, I will take this slowly and ensure that we get our basics straight so we can develop the course more effectively. I am Christian Espana Schmidt, your POCUS instructor.  I hope you get all that you can from this talk today.

## Conflicts of interest

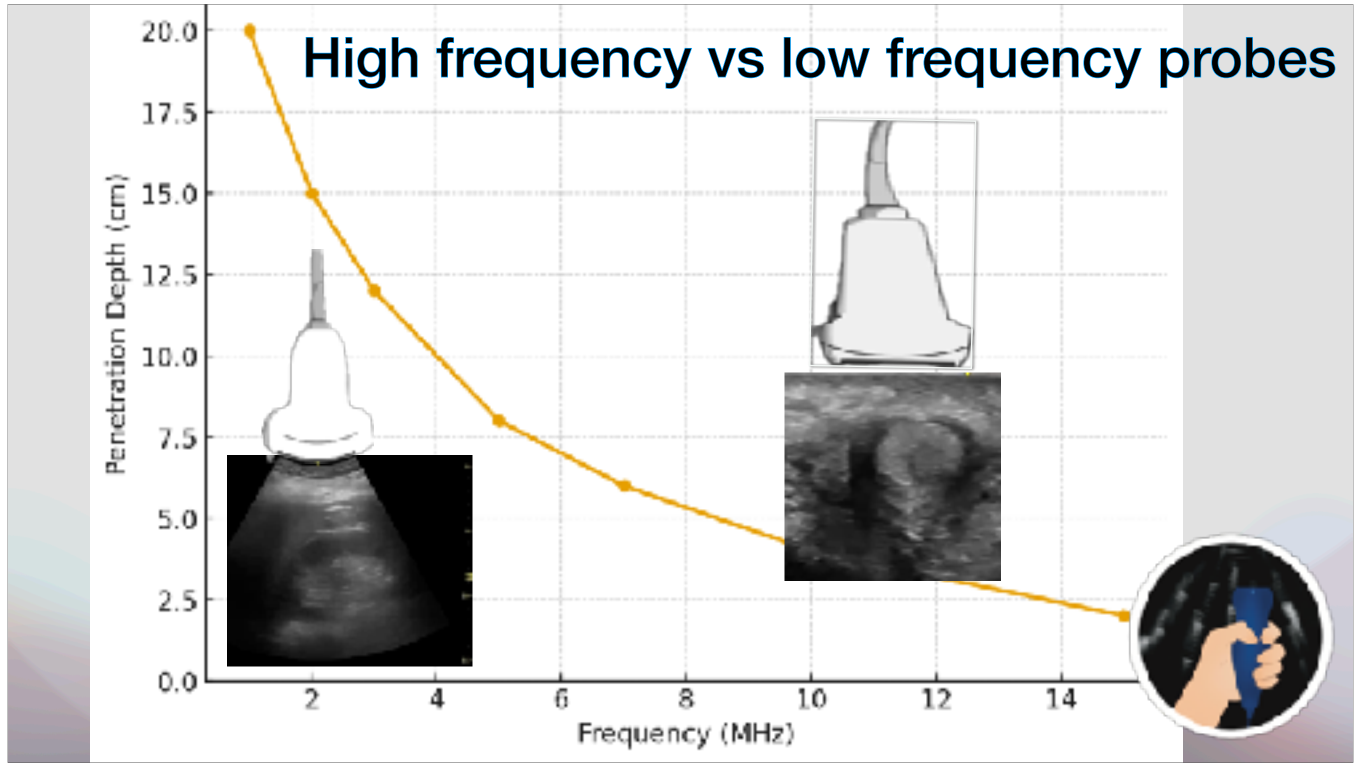
No pertinent conflicts of interest to disclose



I have no conflict of interest. You may know I am the point-of-care ultrasound director at CIFC.
In this ultrasound, we see area 4 of the frontal chest. There is a large pleural effusion, and a catheter is visible in the middle of the image with some probable fibrin. This catheter was not functioning properly and needed to be replaced. The objective of this ultrasound was to confirm the presence of pleural effusion. And to confirm that the catheter was in place. The pleural effusion is large, and you can see a kidney in the far field; there is also fluid below the diaphragm, secondary to ascites.
As you can see, the far field of the ultrasound looks brighter than the rest, and this is because of acoustic enhancement. We will discuss ultrasound artifacts in this chapter.



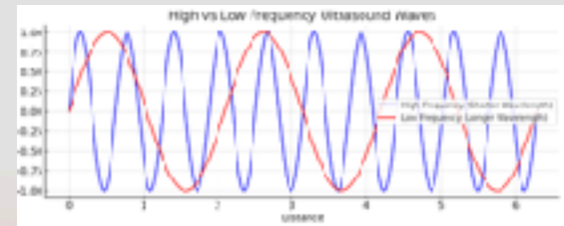

It is essential to be aware of the various probes we have. We will discuss the frequency of the probes and why this is important, as well as the array of ultrasound probes and their various applications.  Choosing the right probe for the right test is of the utmost importance.




In this graph, we see how the penetration decreases with the frequency. At 1 MHz, the penetration depth is approximately 25 cm, making it ideal for deep structures. At 11 MHz, the penetration is shallow, about a few centimeters, and the detail is great for shallow structures.   The linear array probe is evaluating a tendon of the middle finger of the hand. We can appreciate the tendon, specifically the A1 pulley, which is clearly inflamed in a case of trigger finger.
The ultrasound using the curved array probe is evaluating the kidney, approximately 10 to 15 cm deep. Curved array probes are better suited for deep and large organs. Higher-frequency transducers are better suited for shallow structures that require more detail, while low-frequency transducers are more suitable for deeper structures and larger organs.

# High frequency vs low frequency probes

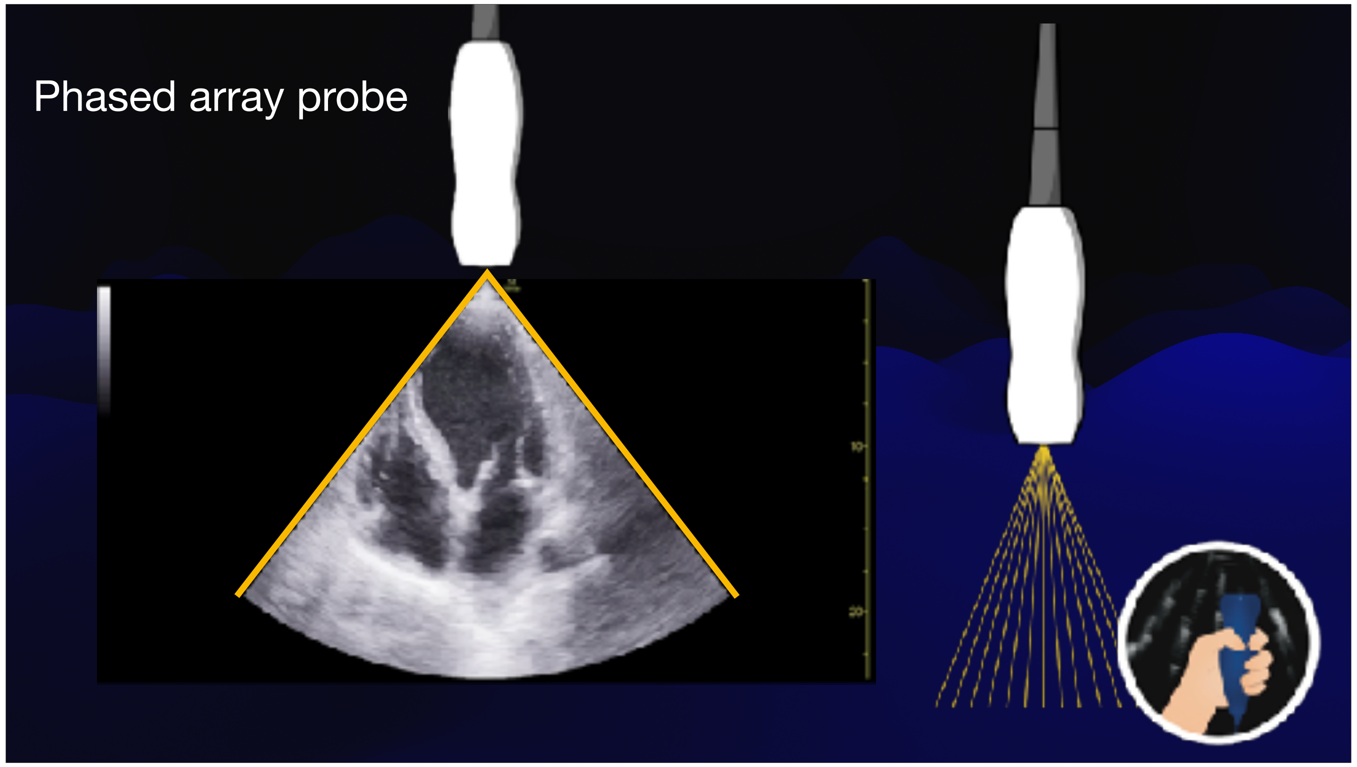
- High-frequency probes have high detail and lower penetration of tissues.
- Low-frequency probes have lower detail but increased penetration.
- High-frequency probes are ideal for shallow structures where one needs more detail
- Lower frequencies are ideal for deep structures.



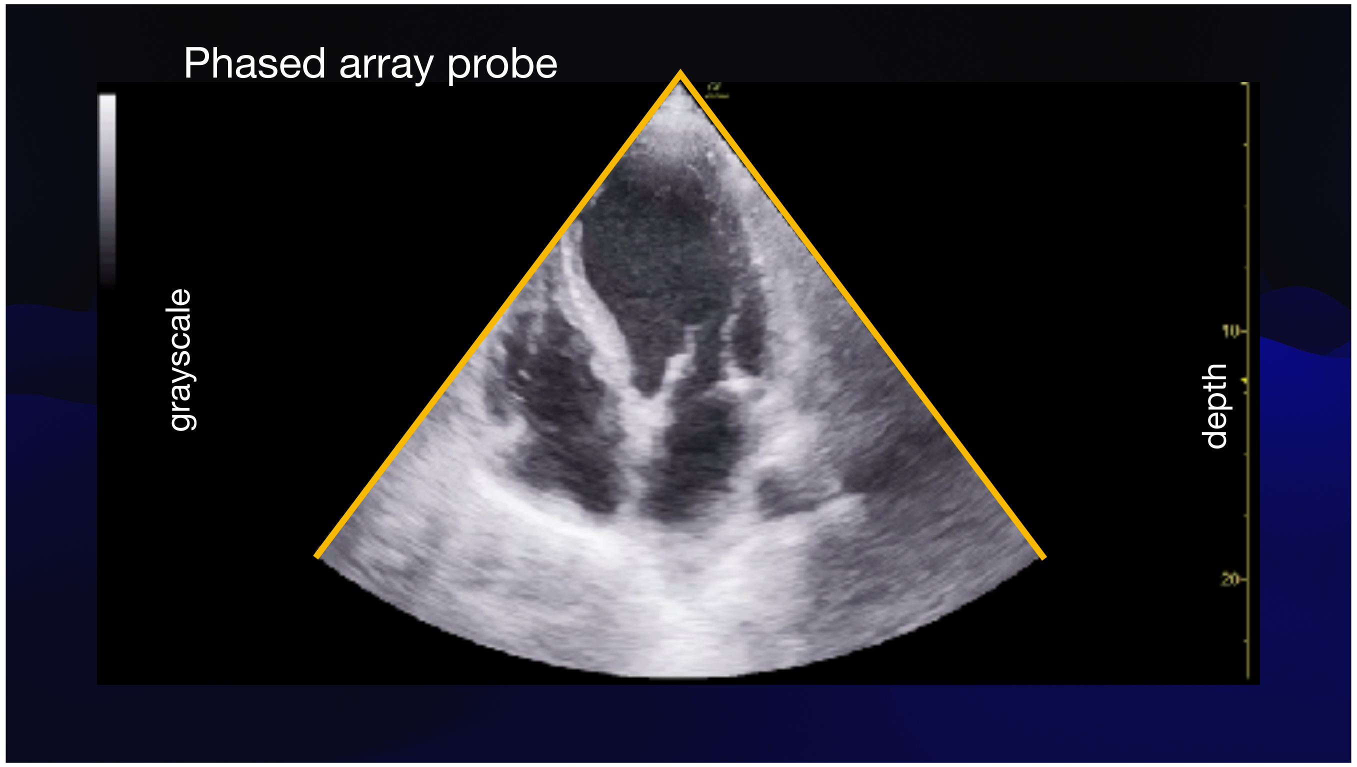
Here, we have three ultrasound probes: one linear, one curved, and one phased array.  The linear array transmits at a very high frequency, which is best suited for shallow structures where more detail is needed. This is a probe that we will use, for example, in placing a central line.  The abdominal probe, or curvilinear transducer, transmits a lower frequency, which provides better penetration at the expense of detail. The phased array or cardiac probe also transmits at a lower frequency, which provides deeper penetration.

# Common arrays of medical probes

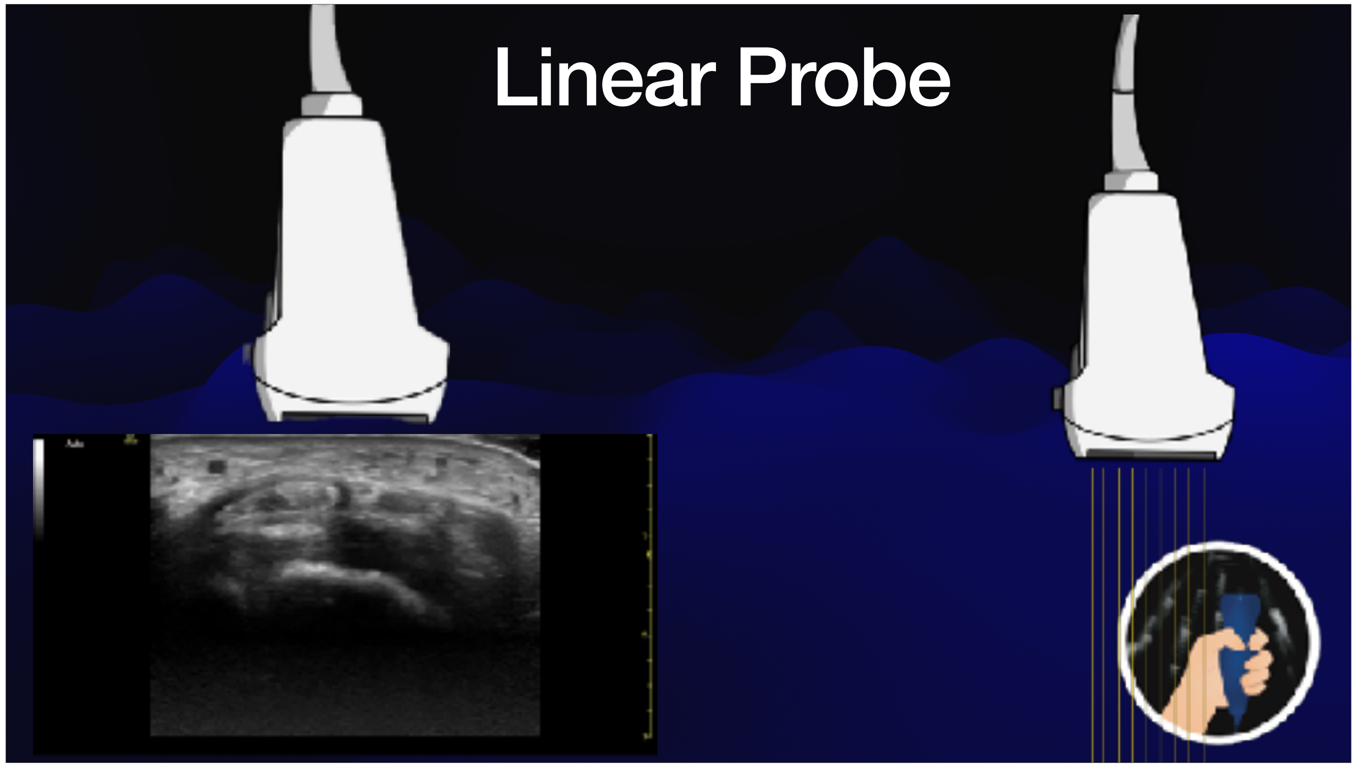
Different transducers are used in medicine. The phased array, the curved array, the micro curvilinear array, the linear array, and the intra-cavitary probes.  It is essential to understand how each of these transducers operates. We will only discuss the most common transducers used in internal medicine.




1. Structure
A phased array transducer contains dozens to hundreds of tiny piezoelectric crystals lined up in a row (linear array) or in a grid.
Each crystal can transmit and receive ultrasound independently.
2. Beam Steering
Instead of firing all crystals simultaneously, the system applies precise time delays (phase shifts) to each element.
By exciting elements sequentially with microsecond delays, the emitted wavefront tilts, steering the ultrasound beam without moving the probe mechanically.
3. Beam Focusing
By varying the pattern of delays (shorter in the middle, longer at edges), the waves converge at a chosen depth, creating a focal point.
Dynamic focusing can also be performed during reception, sharpening resolution at different depths.
4. Imaging Result
This electronic control allows sector-shaped images, sweeping the beam across an arc.
Widely used in echocardiography, because it produces a large field of view through a small acoustic window (like between ribs).




The result of the sector image is a triangular image that allows us to use small spaces like in between the ribs two ultrasound structures like the heart.
In this case, you can see the typical shape of a phased array transducer, as well as the depth, which is approximately 25 cm, in the grayscale. The heart being imaged has a very low ejection fraction and exhibits a phenomenon that we will discuss later, known as spontaneous contrast.




A linear array transducer is one of the most common types of ultrasound probes, particularly in internal medicine, vascular studies, and musculoskeletal imaging. Here's a structured overview:

Structure and Design

Crystal arrangement: Multiple piezoelectric elements (often 128–256) are arranged side by side in a straight line (linear geometry).

Shape: The footprint (contact surface) is flat and rectangular.

Beam steering: Each element is fired in sequence, producing parallel sound beams that create a rectangular field of view, producing a rectangular image with uniform width from near field to far field.

High axial and lateral resolution in the near field due to high frequencies.

Limited penetration compared to lower-frequency curvilinear or phased-array probes.

Depth: Typically effective for superficial structures (0–6 cm), though some probes reach ~10 cm.

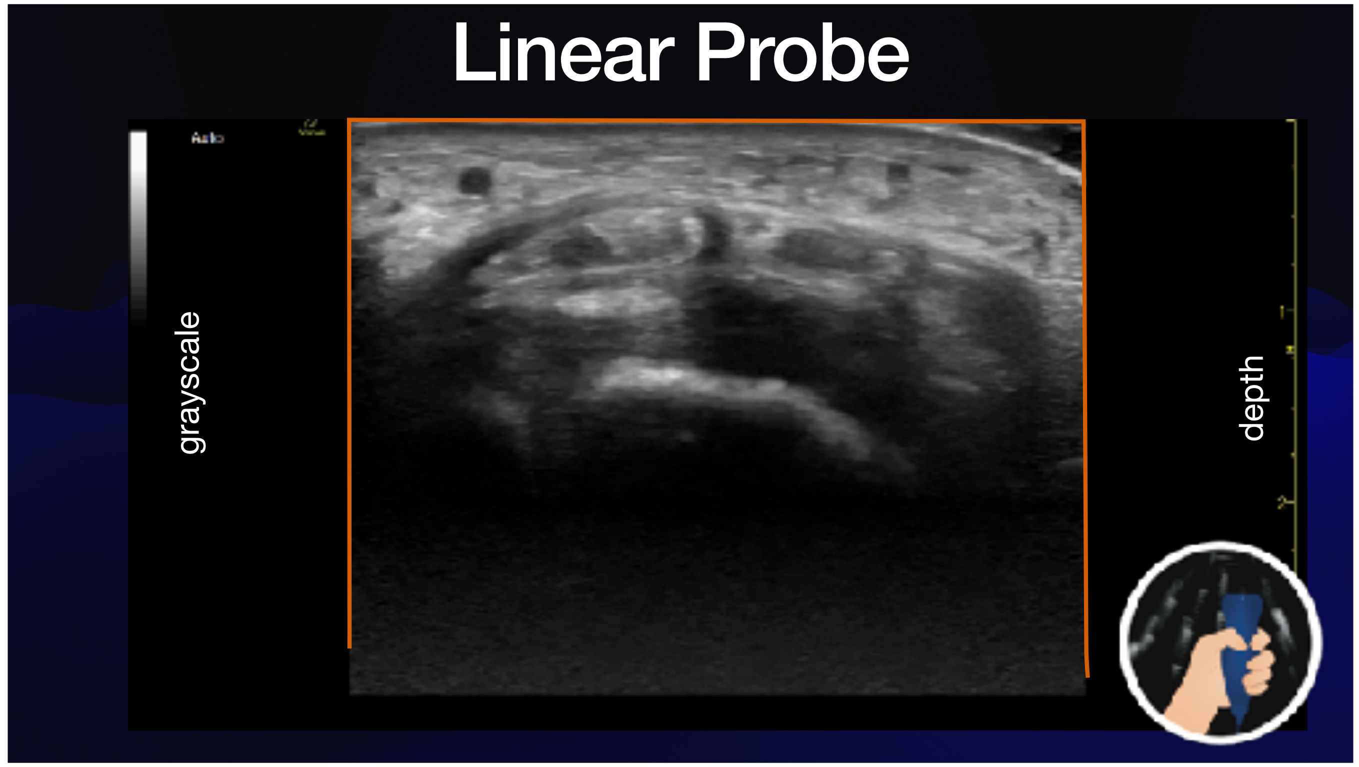
Clinical Applications

This transducer is ideal for vascular imaging, musculoskeletal imaging, such as tendons, ligaments, and joints. This is the probe that we would use for procedures.

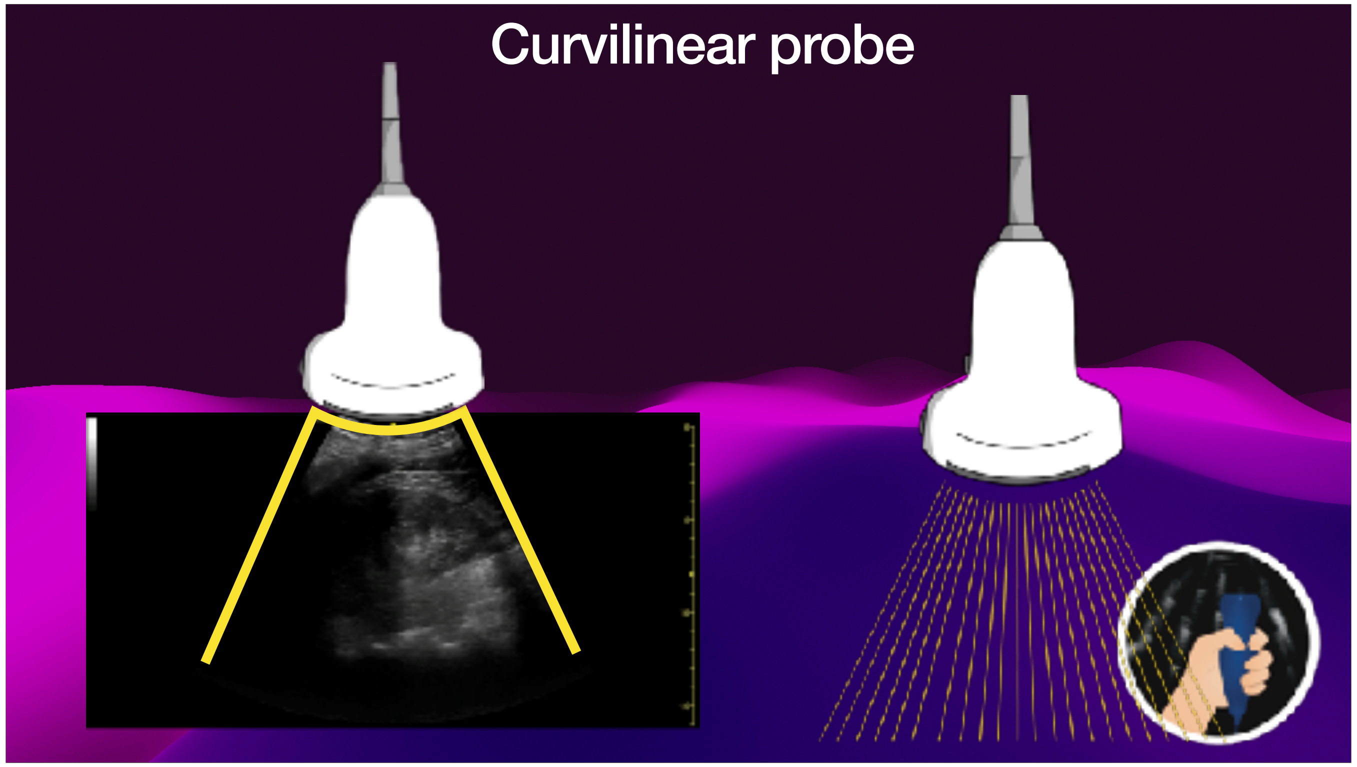
It is also ideal for small organs, such as lymph nodes, testicles, and thyroid.

Typically 7–18 MHz (high-frequency), optimized for shallow depth and fine detail.

Some "hockey-stick" or mini-linear probes are even higher frequency for very superficial targets (e.g., <2 cm).




Here we see a typical Picture from a linear array transducer. You can see that in the form of a square, the contact of the lens to the surface of the skin is horizontal. In this specific picture, we see a right wrist with effusion, edema around the extensor tendon, and some cobblestoning of the skin in a case of proven pseudo gout.  To your right, you can see the depth; to your left, a grayscale, and the indicator on the probe side. The linear probe is giving us a large amount of detail over a shallow structure.




A curvilinear array transducer (also called a convex array) is another key ultrasound probe, widely used for abdominal and obstetric imaging. Here's a structured breakdown:

Structure and Design:

Crystal arrangement: Piezoelectric elements are arranged in an arc (curved line) instead of a straight line.

Footprint: Larger, convex shape that conforms to the abdominal surface.

Beam formation: Elements are activated sequentially, but because they are curved, the beams diverge outward, producing a sector-shaped image.

Field of view:

Near field: wider footprint than phased array, but narrower than linear probe.

Far field: progressively widens due to curved geometry → "fan-shaped" or sector image.

Resolution and depth:

Uses lower frequencies (typically 1–5 MHz), which allows greater penetration (up to 25–30 cm).

Resolution is lower compared to high-frequency linear probes.

Clinical Applications

Abdominal ultrasound: Liver, gallbladder, pancreas, kidneys, aorta.

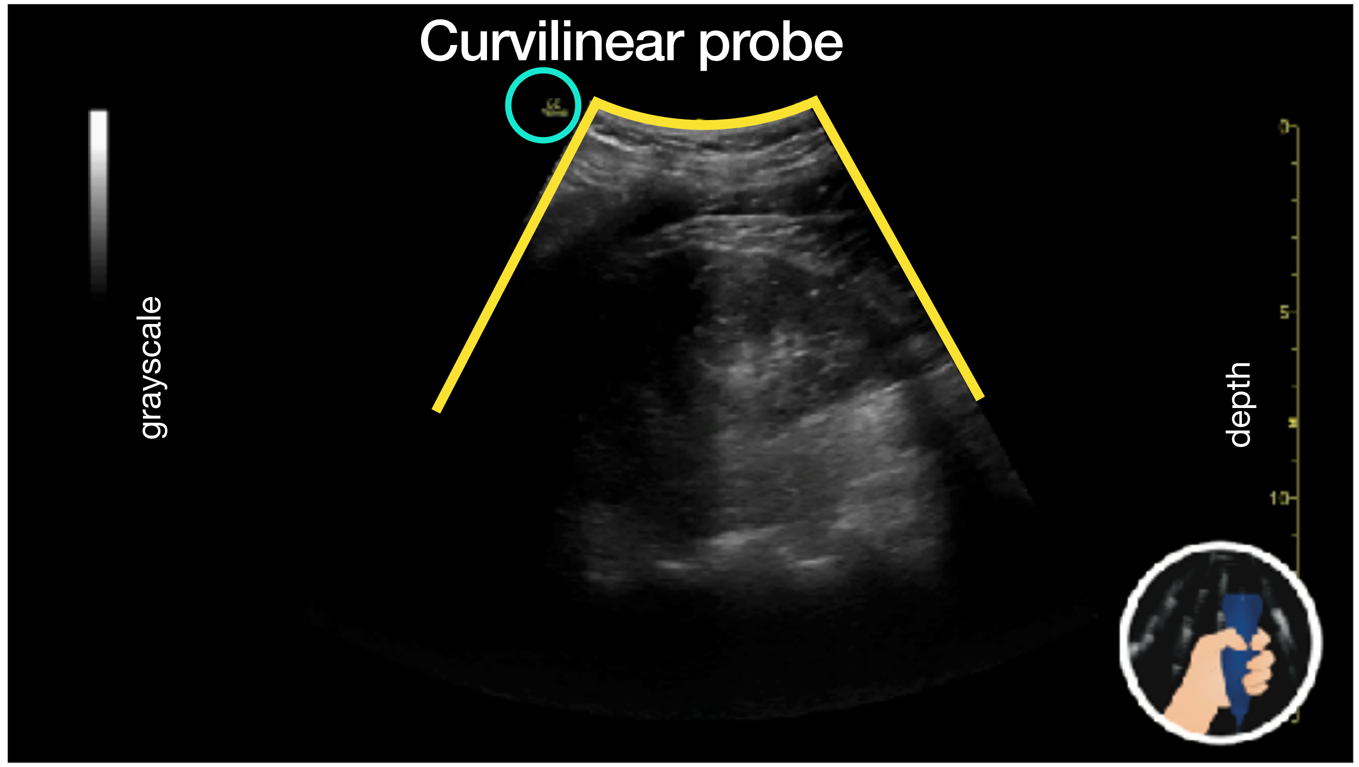
This probe is also used in obstetrics.

General internal medicine: Ascites detection, pleural fluid, and deep organ pathology. FAST exam, trauma scans, and abdominal aortic aneurysm screening.

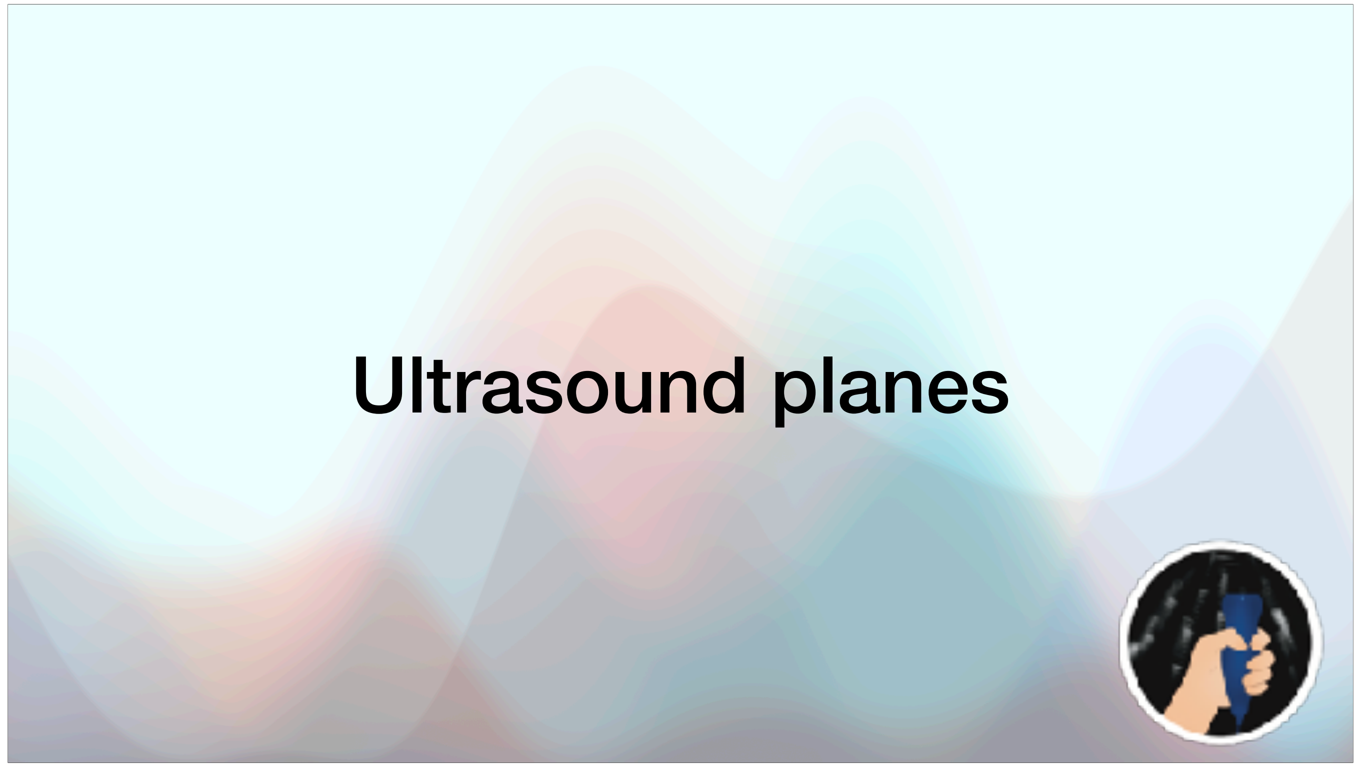
Frequency Range

Typically 1–5 MHz

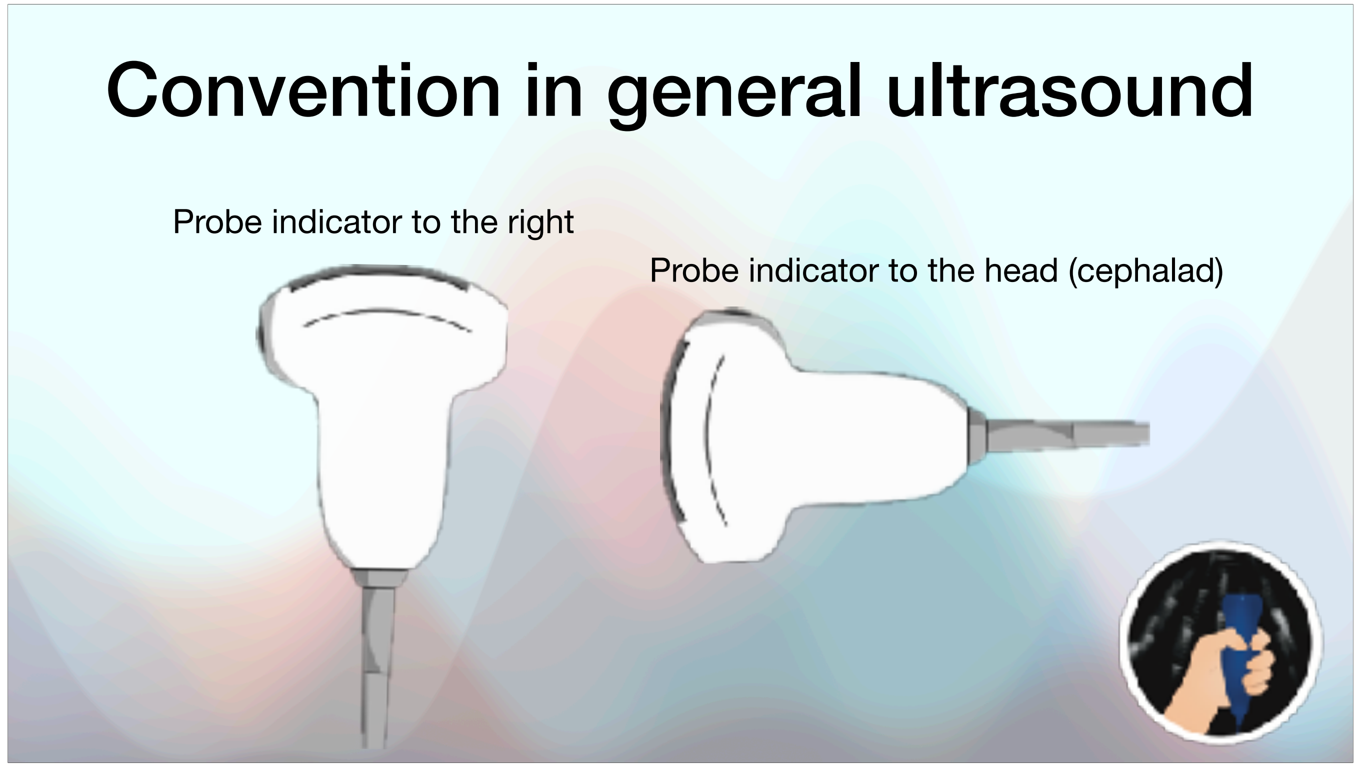
Some probes have wider ranges (e.g., 1–8 MHz) for flexibility between penetration and resolution.



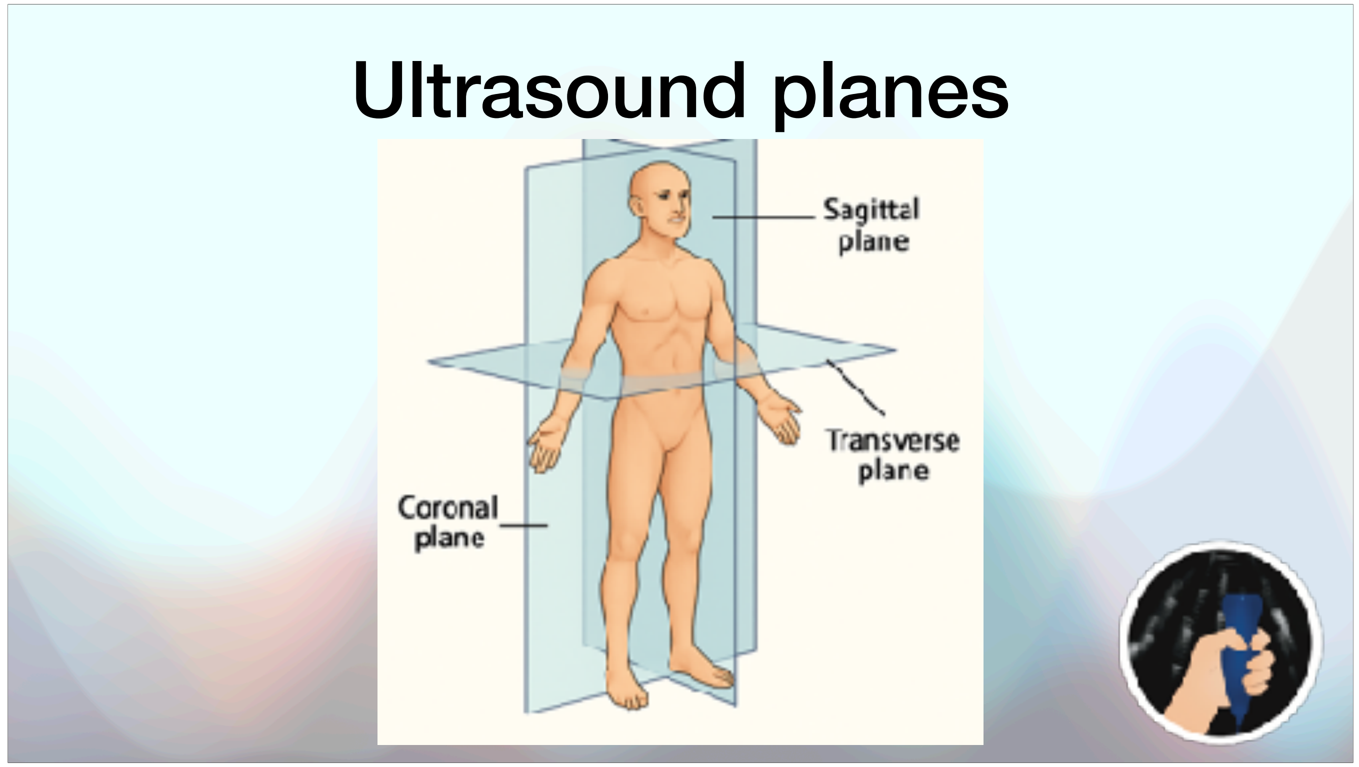

In this video, we see a kidney, thanks to the wider field of view of this probe. We are able to evaluate the whole organ. To your right, you can see the depth to your left, a grayscale display, and the probe side indicator.  You can see how the surface of contact of the probe is curved, and the shape of the image is sector-shaped



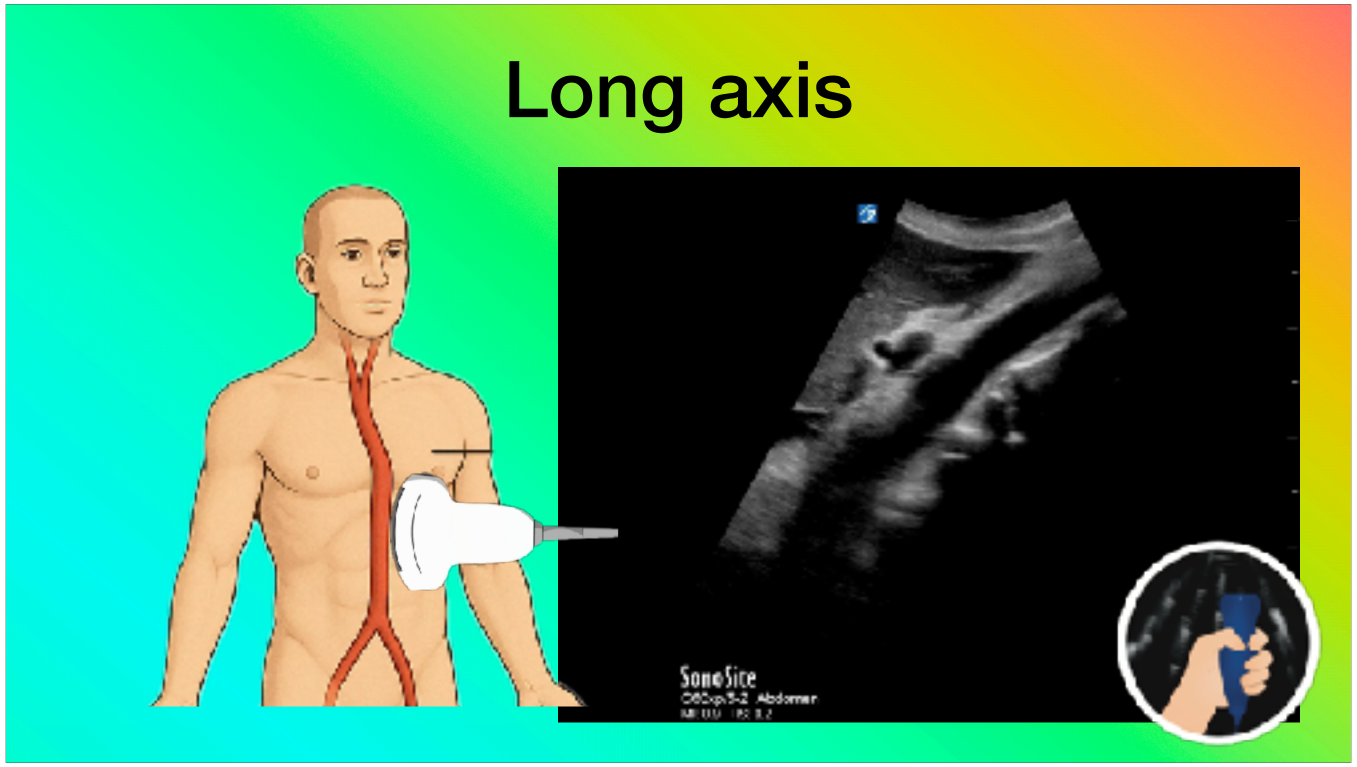

In imaging, we use different planes to evaluate different organs. It is crucial to evaluate an organ or structure through different planes, as we are dealing with 3D objects through a 2D video or imaging.




General convention dictates that the indicator of the probe should always point to the right of the patient or to the head of the patient. We call that cephalad. These are to ensure. The structures are always oriented in the same way for correct interpretation. Cardiac evaluation uses its own convention. Sometimes specially, during procedures we can use a special conventions.

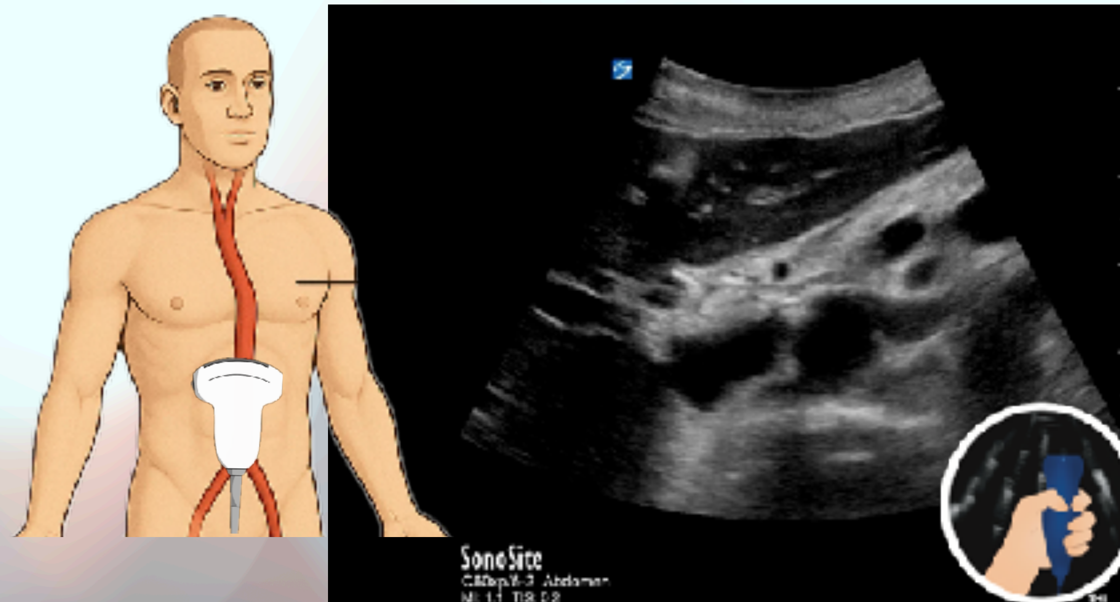



Here we see the different ultrasound planes. These are only the most common and related to the whole body. The transverse plane is the horizontal plane or axial plane of the body. In this plane, we will see the right side of the body on the left side of the screen and vice versa. The sagittal plane is a vertical plane extending anteriorly. "Cutting the body in half from front to back. On the left side of the screen, we will see structures that are “cephalad”, and on the right side of the screen, we will see structures that are caudal.  The coronal plane scans the body in a vertical plane from side to side. Again in the left of the screen, you'll see structures that are “cephalad” and on the right of the screen, you will see structures that are caudal.




Almost every organ will have a long axis and a short axis. In this video, we see the superior part of the abdominal aorta in the long axis using a curvilinear probe. This is a normal aorta. Note how the liver is used as an acoustic window.

# Short axis

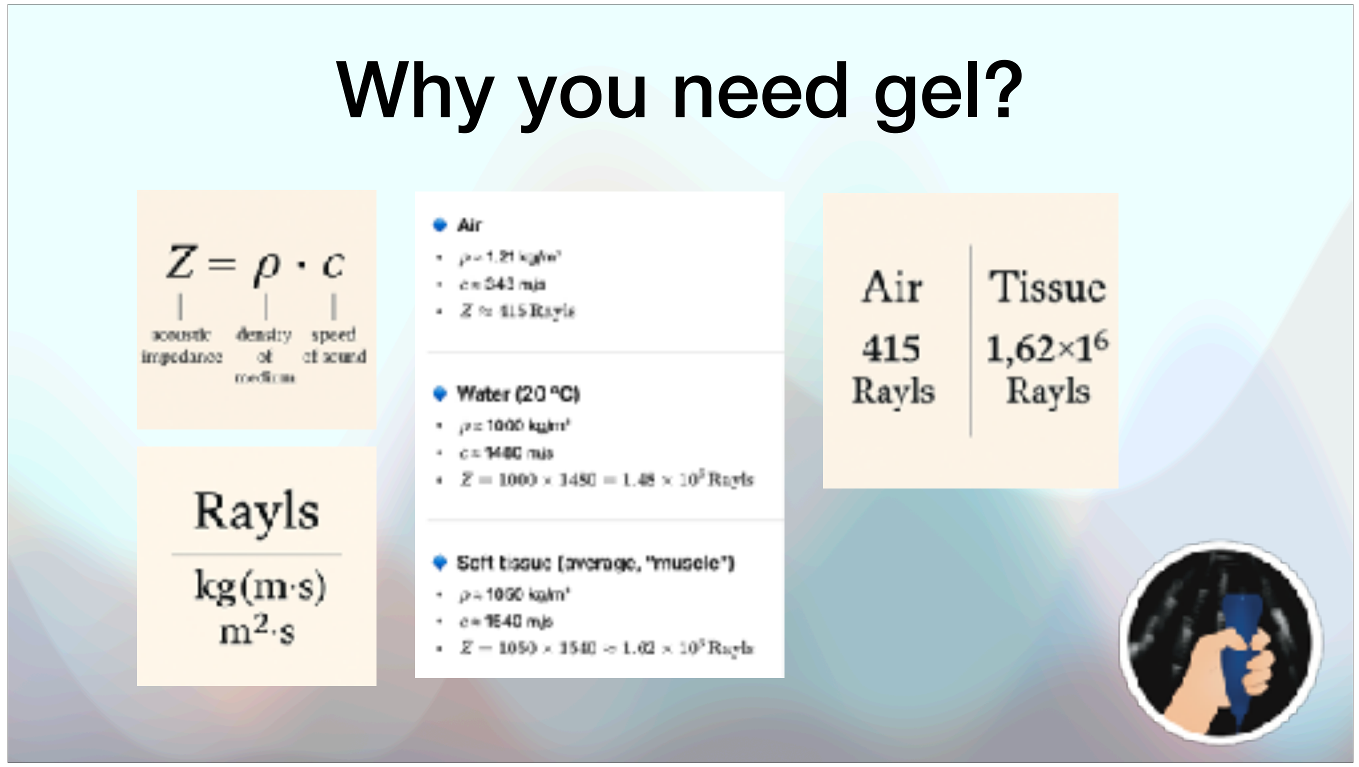



This is the same patient as before, we are seeing the short asses of the aorta. Again, this is a normal aorta, and we are using the liver as acoustic window. We have also adjusted the depth to optimize the images.
It is possible to get a coronal view of the aorta using kidneys and other organs as acoustic windows.

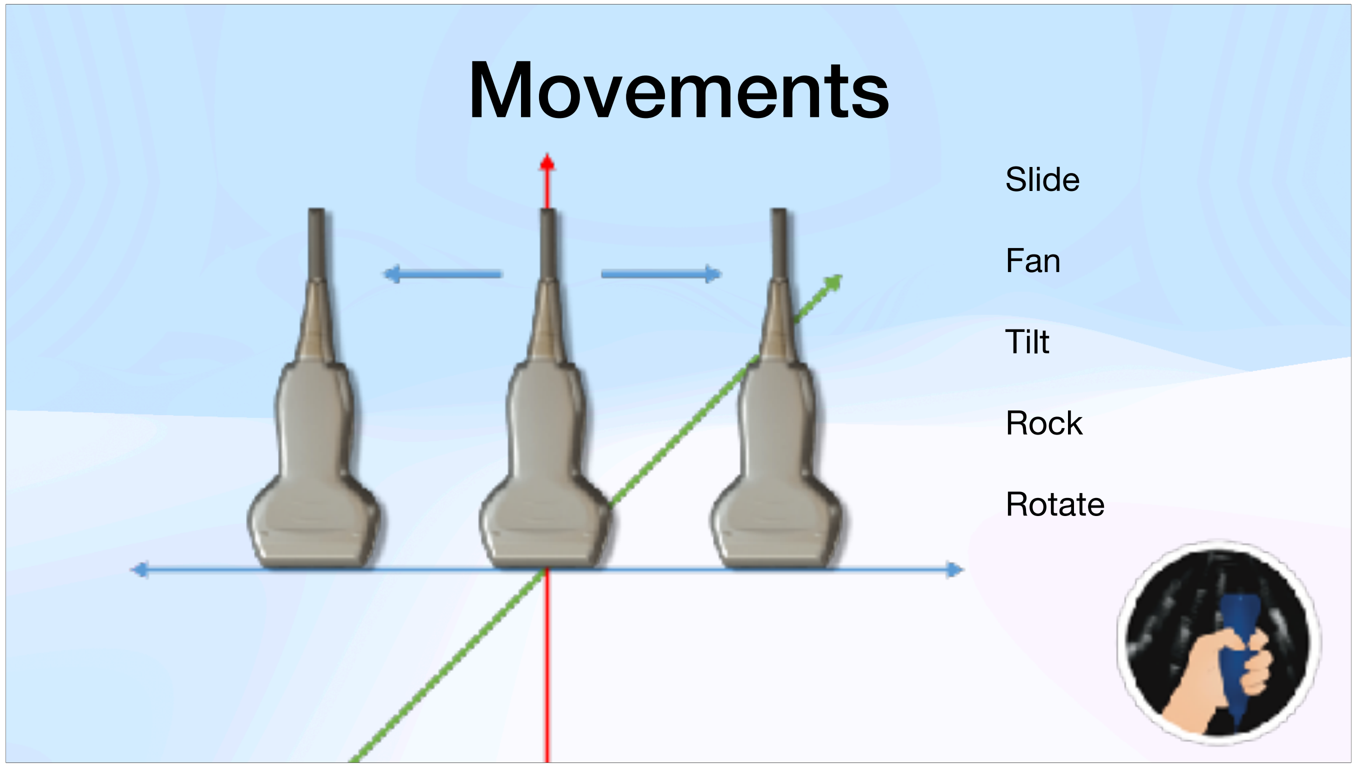
# Positioning the probe for general ultrasound

$$\underbrace{Z}_{\text{acoustic impedance}} = \underbrace{\rho}_{\text{density of medium}} \cdot \underbrace{c}_{\text{speed of sound}}$$

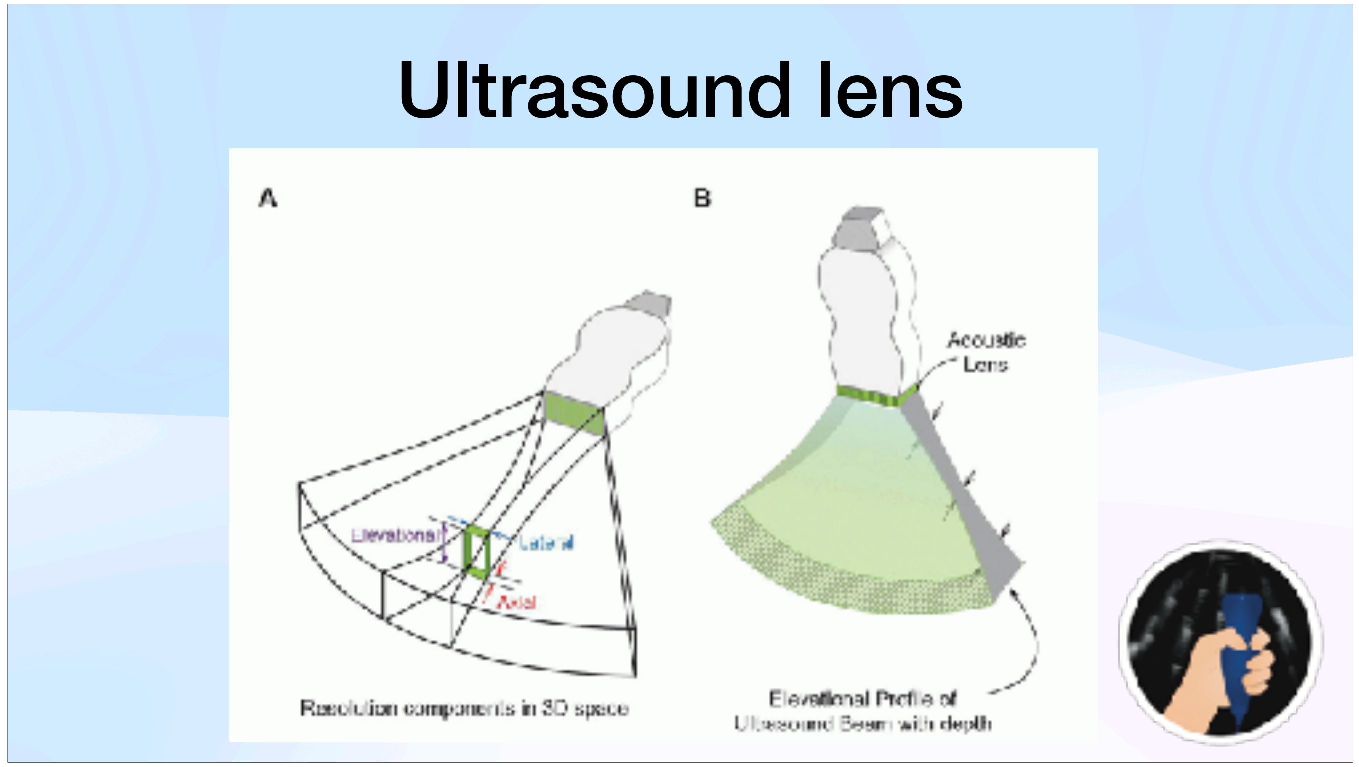
| Air | Tissue |
|---|---|
| 415 Rayls | 1,62×1⁵ Rayls |


The use of ultrasound gel in avoiding air:
The difference in impedance between air and tissue is about 3900 times. This is due to the velocity of ultrasound in air and also to the density of air. This difference in impedance prevents the ultrasound from being transmitted from the lens to the body. To avoid this, we need to use ultrasound gel, which avoids these differences, making the use of ultrasound and medicine feasible. It is also important to remember this concept later during this talk, as it is the main reason we see A lines in lung ultrasound.

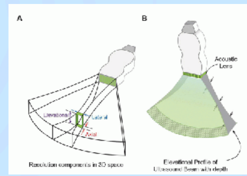


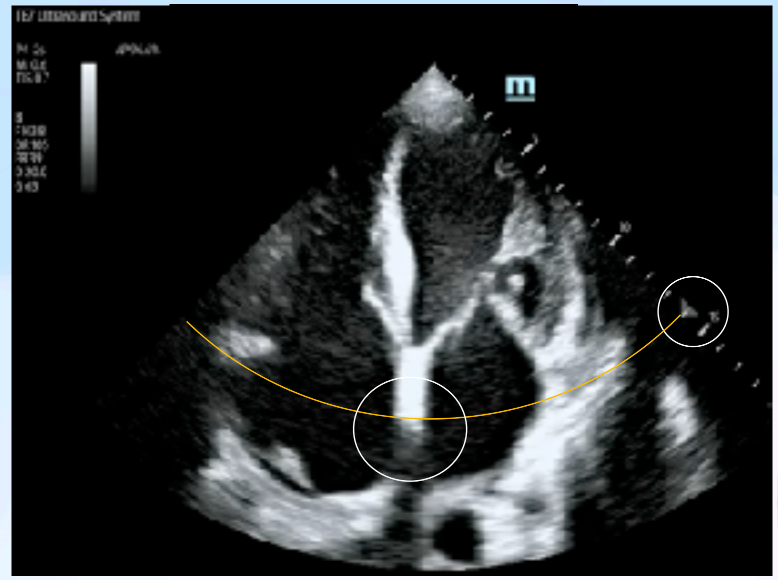

The cardinal movements of the ultrasound probe are: sliding in any direction, tilting, rotating, and rocking. Another concept is fanning, which was applied when the probe was tilted on the major axis of the ultrasound. However, this term is less used today.




This is a phased array, ultrasound beam. We can see the different parts of it. The ultrasound, however, is only 1 mm thick.  The areas in the center of the ultrasound beam are more accurately represented than those in the periphery.  The periphery may exhibit some distortion due to the sector beam.

# Ultrasound lens





Here we have a sector image of a heart with heart failure, and a vegetation of the mitral valve.  The structure at the center of this sector image will be better represented and with less distortion than the areas at the periphery of this sector image.

# Ultrasound artifacts

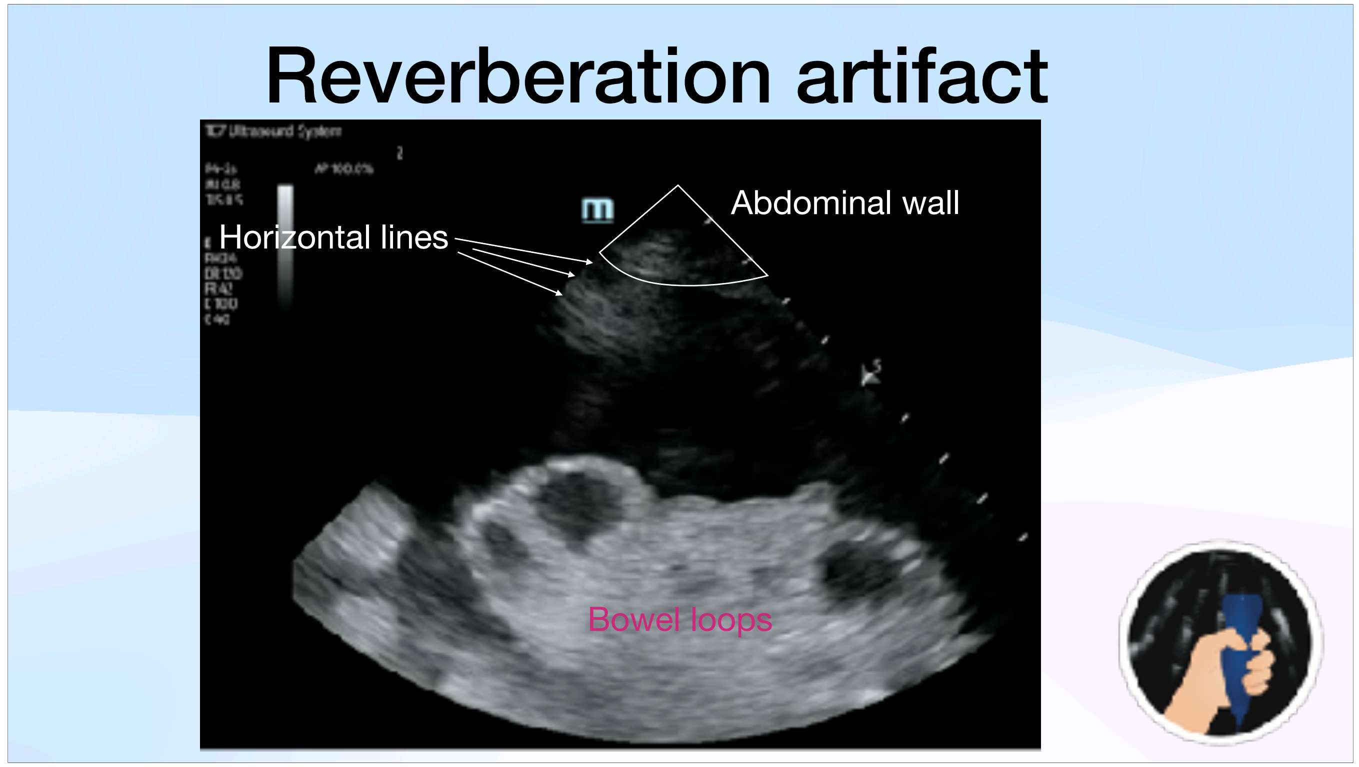
- Half of what we think we see is an artifact.

An imaging artifact is a term used to describe any part of an image that does not accurately represent anatomy or physiology within the subject being imaged.
In this section we will talk about the artifacts related to the use of gray scale or B-mode.

# Artifacts related to structure

- Reverberation artifact

A reverberation artifact is caused by significant differences in the acoustic impedance of two adjacent tissues are their interface. For a perpendicular beam, the amount reflected at an interface is related to the acoustic impedance difference between adjacent media.  With a large impedance, the portion reflected is maximized. The reflected beam strikes the transducer and returns to the subject tissue.  This process can be repeated several times to create multiple echoes.




In this case, we see an abdominal ultrasound obtained over the left lower quadrant. In the near field, we can see the abdominal wall; after that, we have fluid. The fluid should appear dark; however, the difference in impedance between the abdominal wall, fluid, and bowel loops creates a state of reverberation, resulting in the numerous horizontal lines noted in the midfield, where we should have only black signals. These horizontal Lines are the result of reverberation.  If the operator is not aware of the possibility of reverberation, this could be easily confounded as structures.

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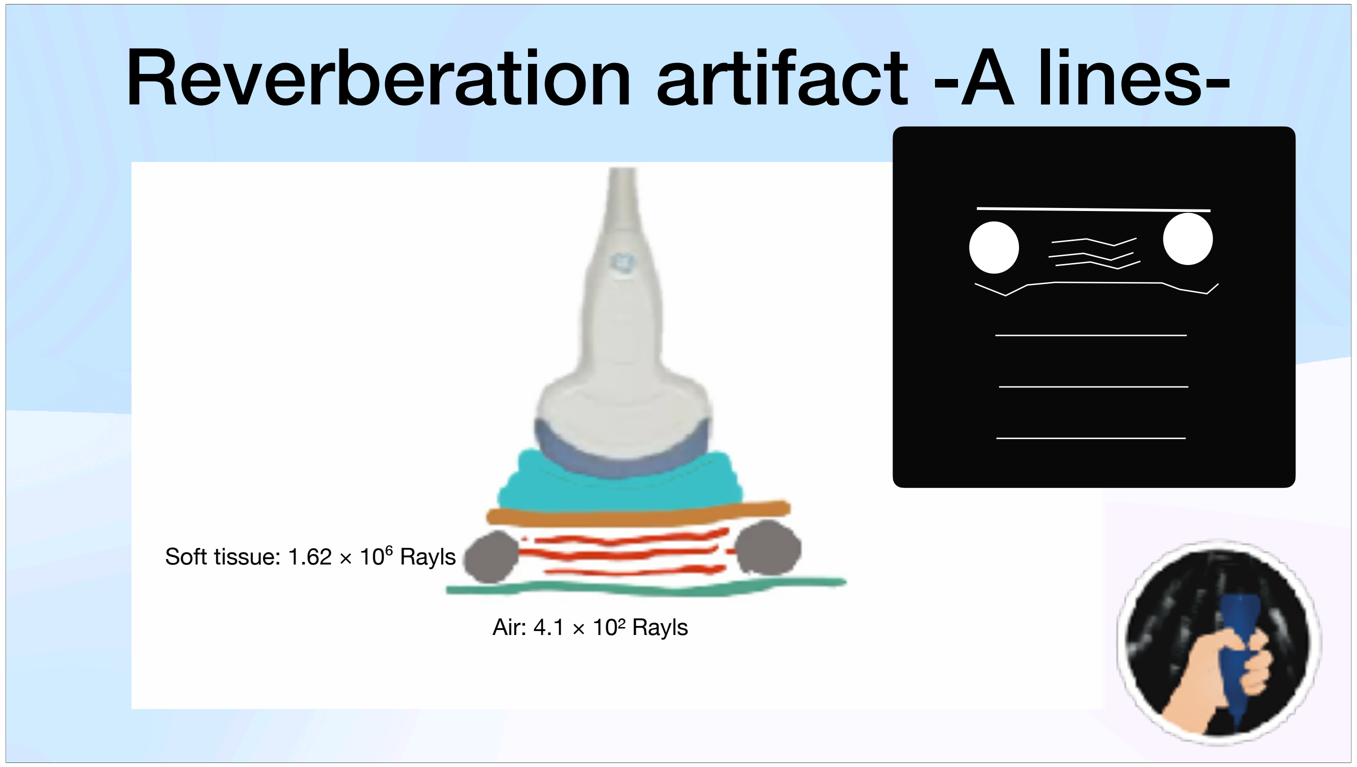



As we stated before, there is a large difference in impedance between tissue and air. The lungs are mainly composed by air. This creates an area where ultrasound cannot be transmitted at the pleura.  The pleura then acts as a mirror, creating reverberation. This reverberation creates the illusion of multiple pleuras that are equidistant. This phenomenon is called A lines and is correlated to normal lungs.

3900-fold difference in impedance

🔷 Air

$\rho \approx 1.21\ kg/m^3$

$c \approx 343\ m/s$

≈415 Rayls

Z≈415Rayls

🔷 Water (20 °C)

$\rho \approx 1000\ kg/m^3$

$c \approx 1480\ m/s$

1000

1480

1.48×10 6

Rayls

Z=1000×1480=1.48×10 6

Rayls

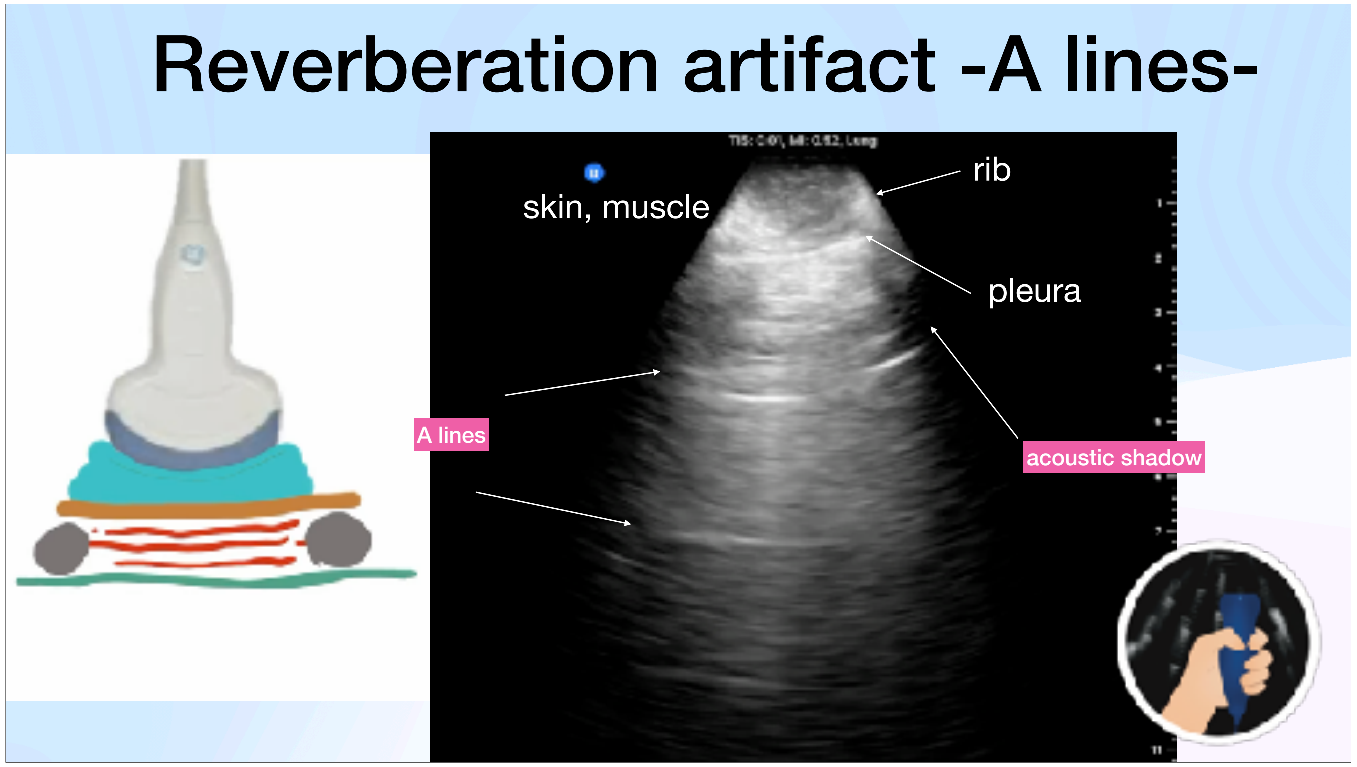
🔷 Soft tissue (average, "muscle")

$\rho \approx 1050$ kg/m³
$c \approx 1540$ m/s
Z 1050
1540≈1.62×106

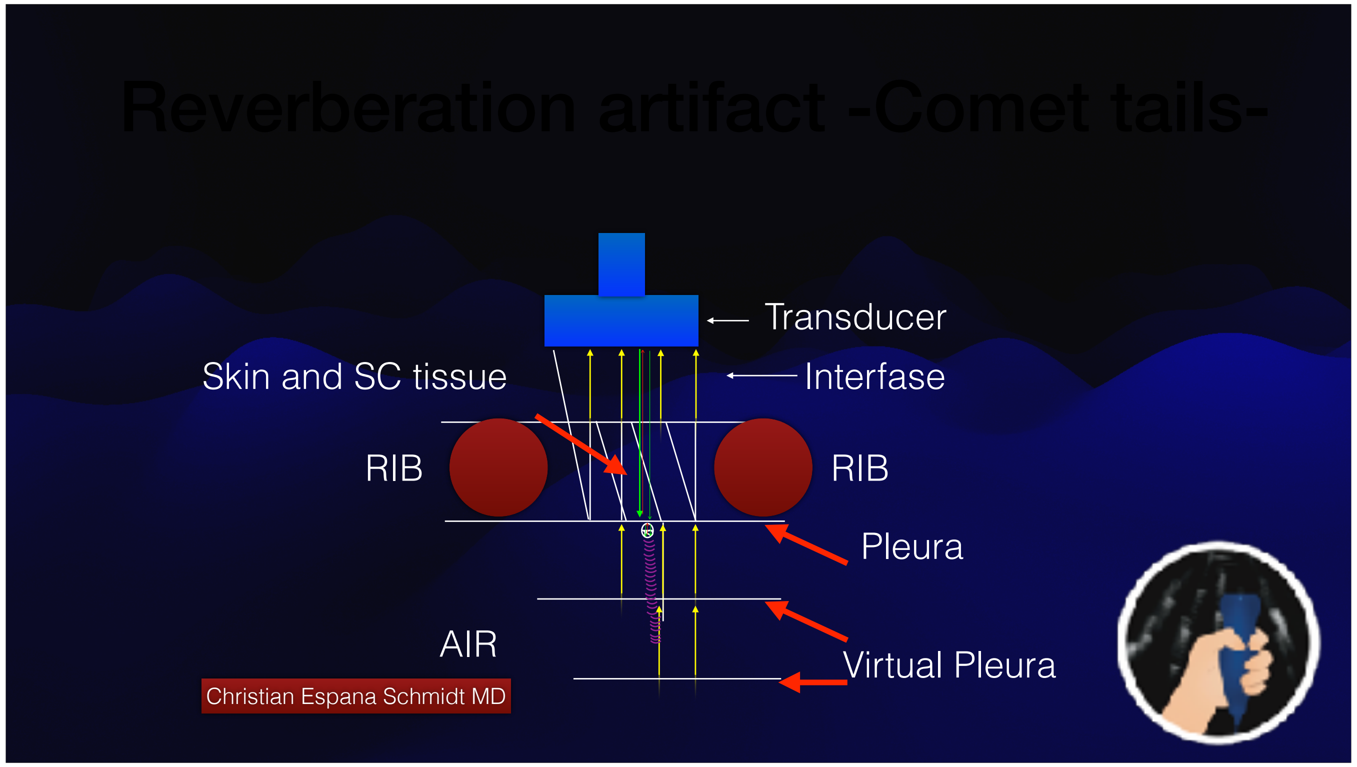
Rayls
$Z=1050\times1540\approx1.62\times10$
6
Rails

🔷 Comparison

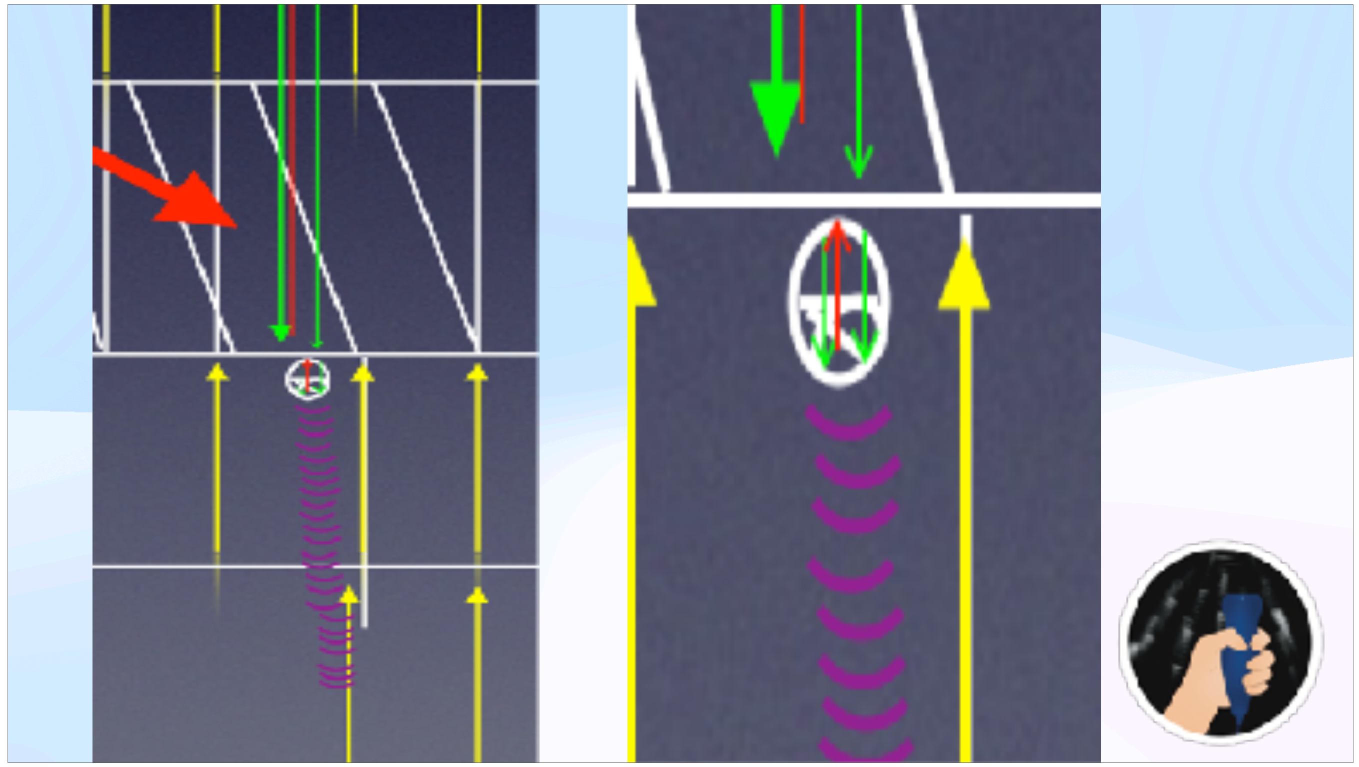
Air: $4.1 \times 10^2$ Rayls
Water: $1.48 \times 10^6$ Rayls
Soft tissue: $1.62 \times 10^6$ Rayls
That's about a 3,900-fold jump in impedance from air to tissue!



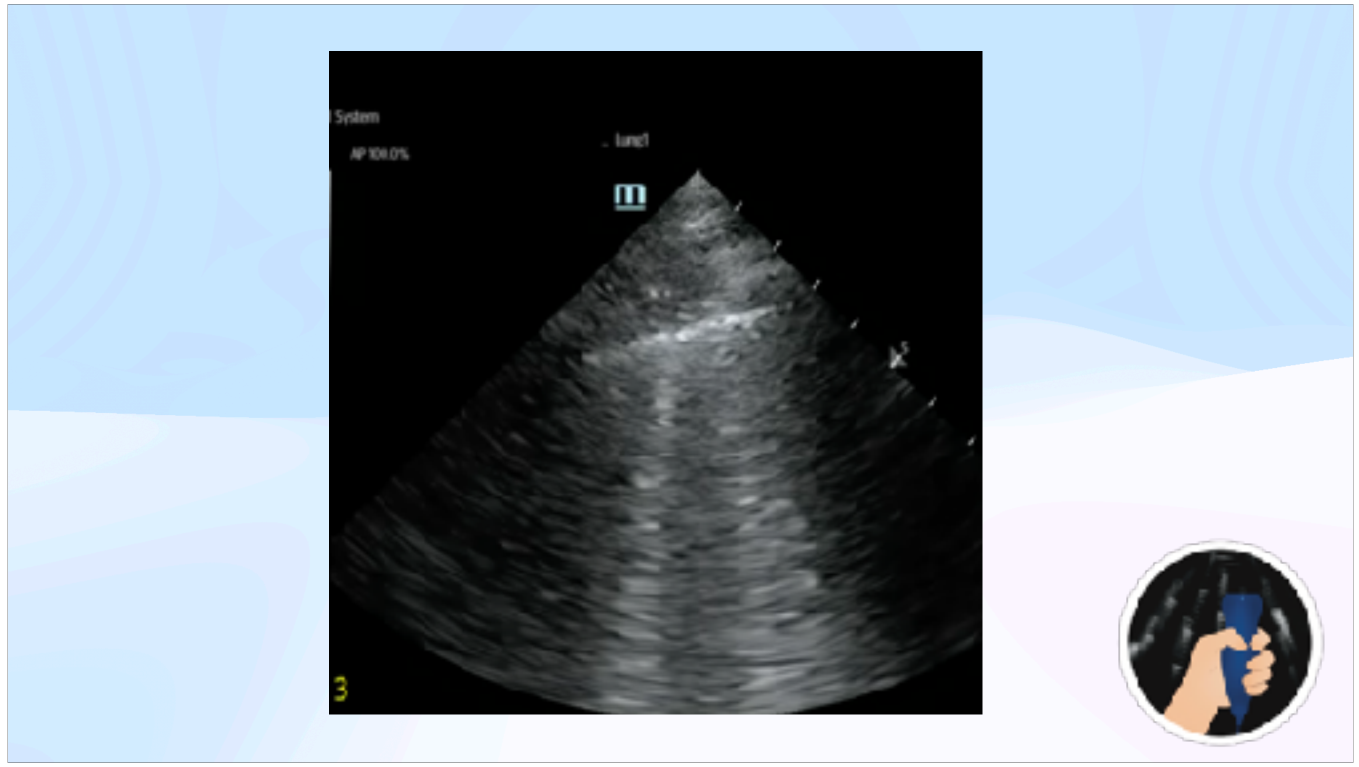

In this slide, we can see the different A lines created by the reverberation of the sound waves at the pleura.



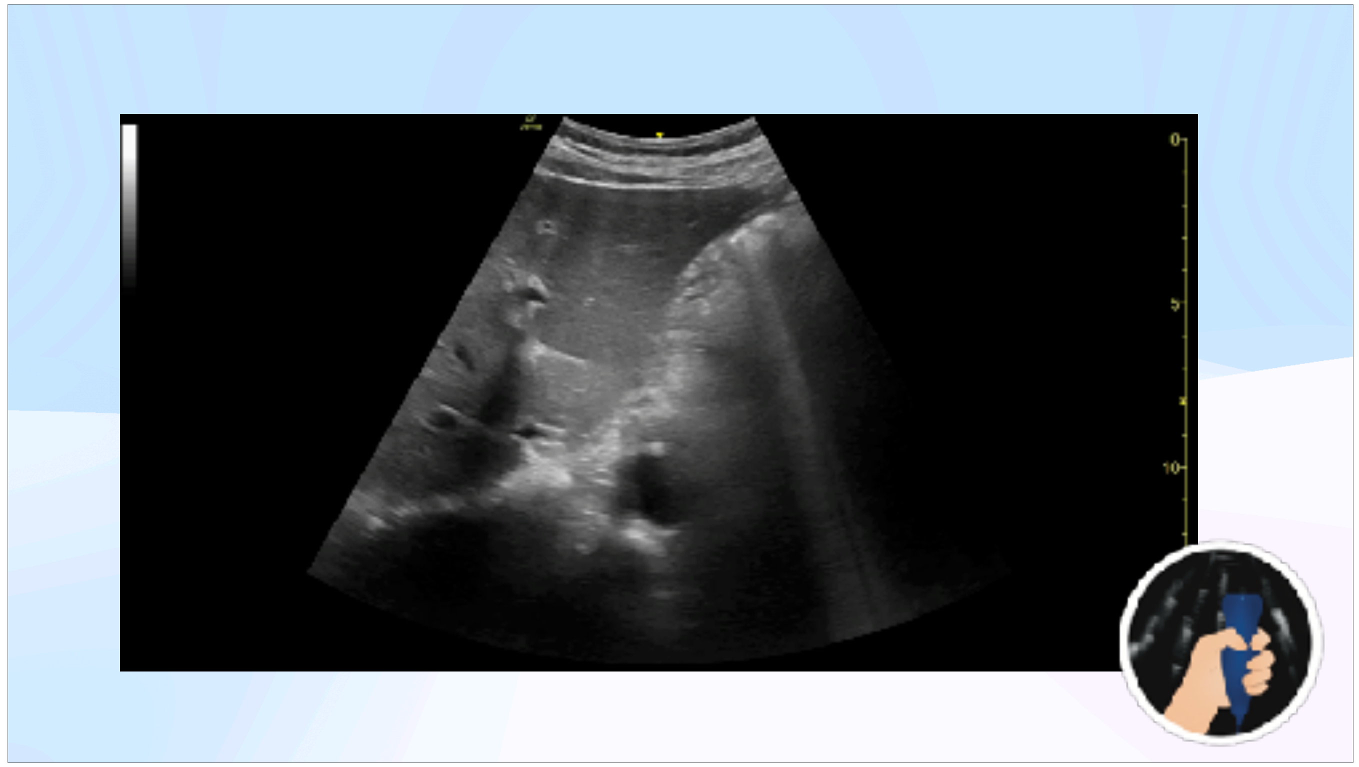

A similar case happens with B lines or comment tails. In this diagram, you see a small bubble of fluid and gas that creates what we call a comet tail.



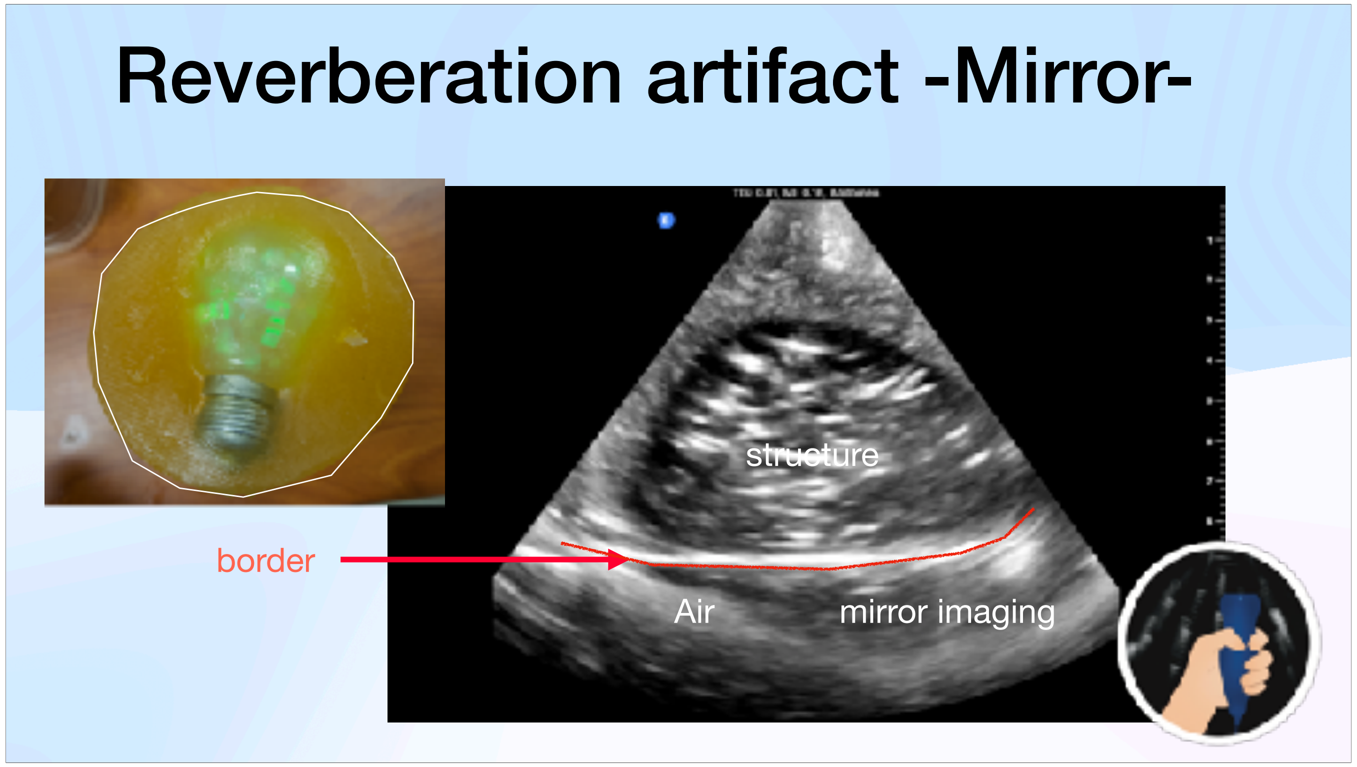
The comet tail is a reverberation within a space that contains materials with very different impedances; the comet tail artifact will appear throughout the entire image.



In this slide, we see a picture of a lung with comet tail artifacts. We called this artifact in the lung “B” lines.  As you can see, the B line extends from the pleura to the end of the image or the bottom of the image, erasing the A lines.  This is a case of ARDS where areas of fluid and gas are causing reverberation.



In this video, we see a comet tail emerging from the patient's intestine, right at the border of the liver. The artifact erases everything from its origin. In this case, it is caused by a reverberation with the gut and its contents, as well as the surrounding tissue.

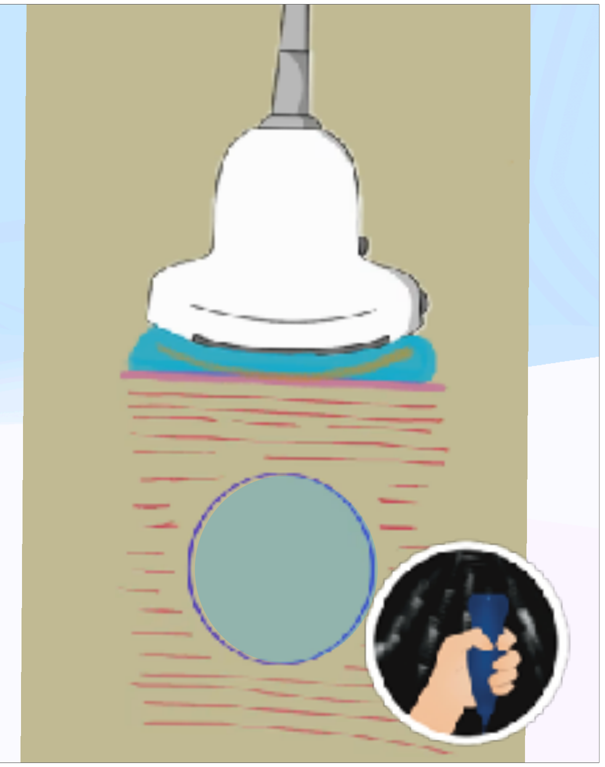



A mirror artifact occurs in a similar manner to A lines.  In this case, we have a structure, and after that, we have Air just like in the diaphragm. The most common place for mirroring is the liver, which appears mirrored at the level of the diaphragm due to intense reverberation. The diaphragm acts as a mirror. I do not have an example; however, in this case, we can see a structure inside a phantom from my lab. The structure is mirrored or reflected at the border of the Phantom that is in contact with the Air, creating the reverberation.

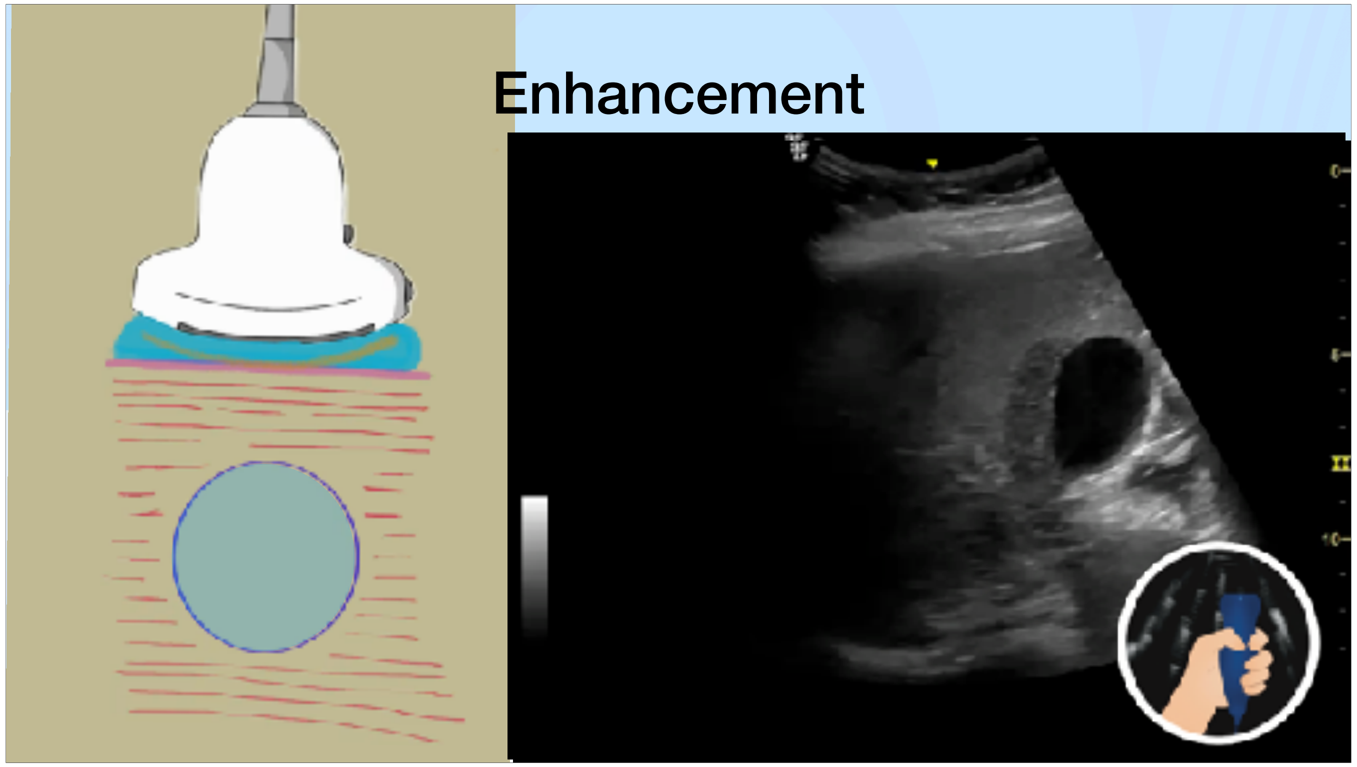
Soft tissue: $1.62 \times 10^6$ Rayls
Air: $4.1 \times 10^2$ Rayls

## Enhancement

The far field is enhanced because of little absorption of ultrasound waves in a fluid-filled area

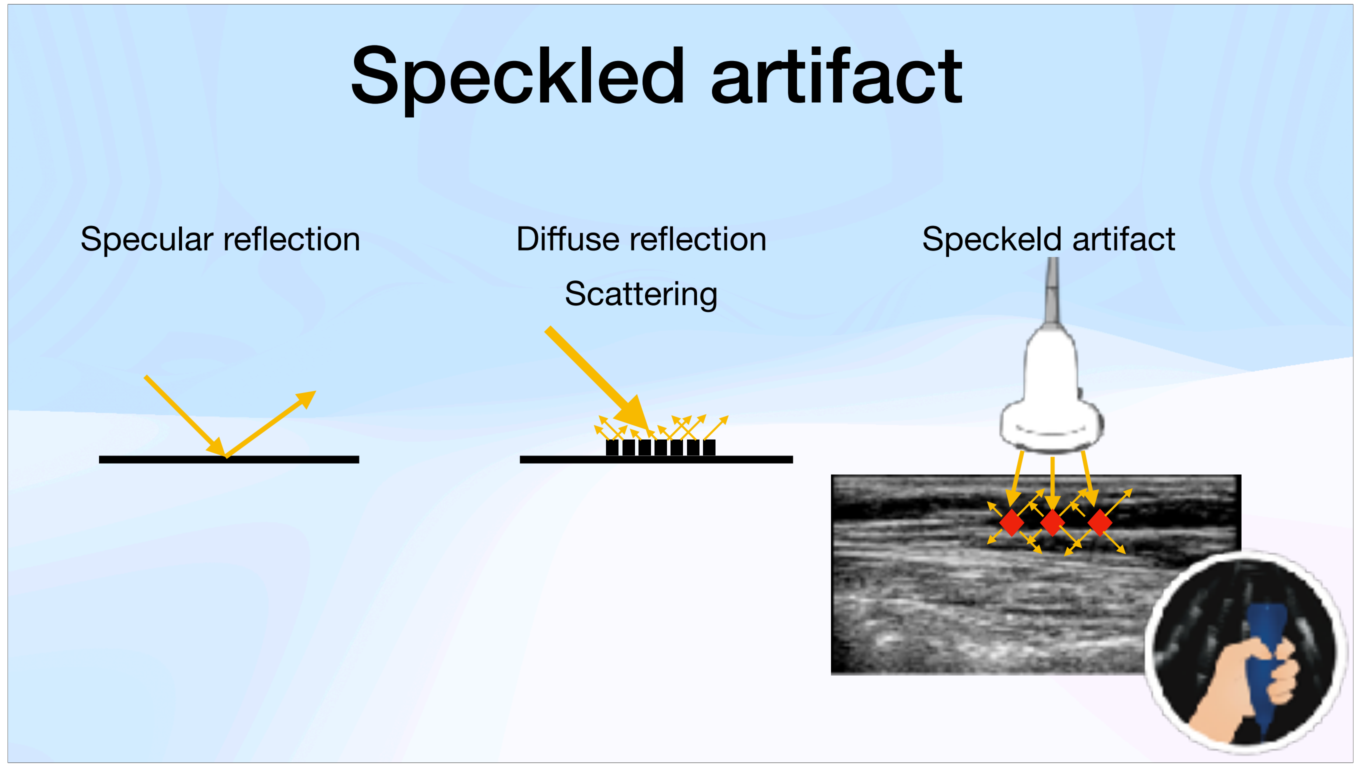


Acoustic enhancement: This artifact is produced due to the decreased attenuation of the ultrasound beam as it crosses tissue that is less dense than the surrounding tissue. In this case, we see a vessel or a bladder full of fluid attenuating the beam less than the surrounding tissue, creating a far field that is brighter or more echogenic than the rest of the tissue.




This is a sonogram of the gallbladder, and you can see enhancement in the far field of the gallbladder because the bile attenuates the ultrasound beam less than the surrounding tissue.

In this ultrasound of the heart, taken in a parasternal short access view at the level of the mitral apparatus, it is evident that the far field is brighter and more echogenic because the blood inside the left ventricular cavity has less attenuation of the ultrasound beam.



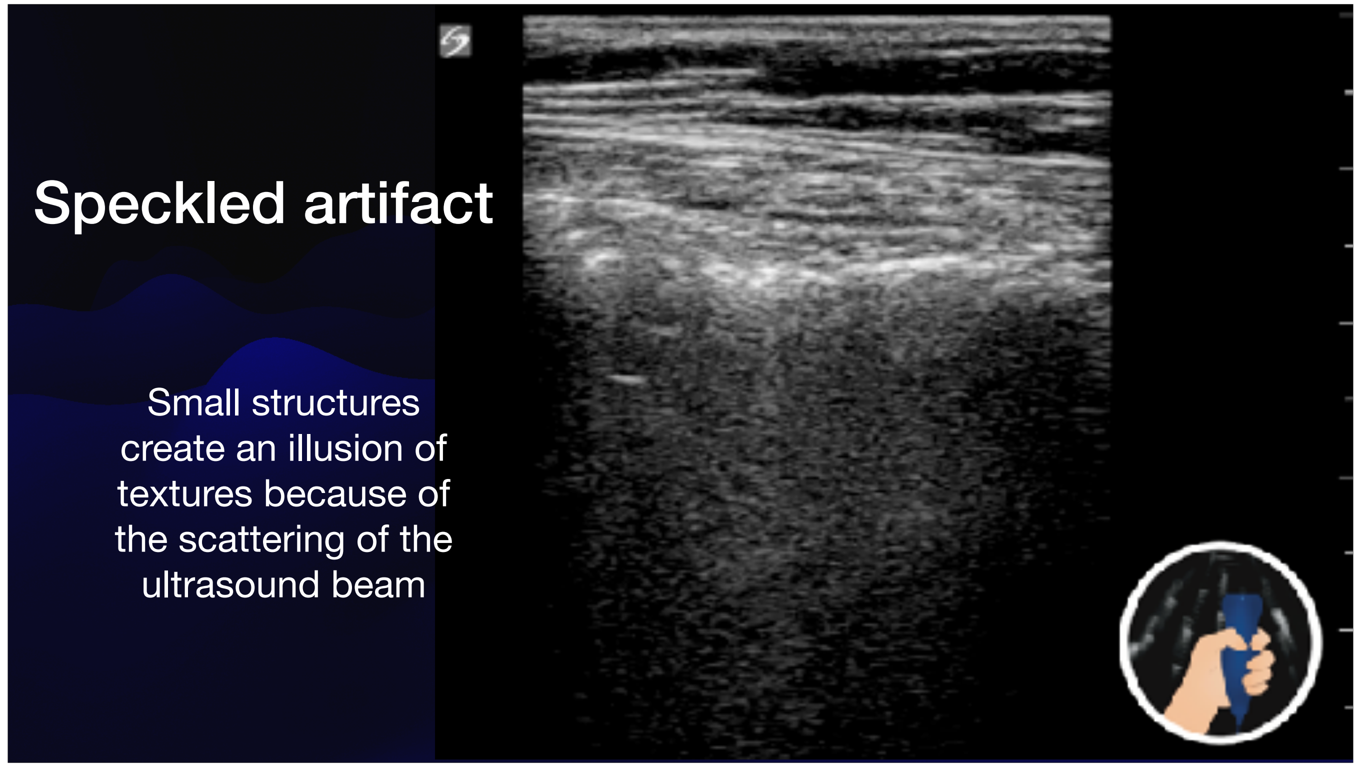

Speckle is an interference pattern caused when ultrasound waves scatter off many small reflectors (like tissue microstructures) and then overlap. Depending on whether the overlapping echoes combine in phase (constructive interference) or out of phase (destructive interference), some pixels appear brighter or darker. This creates the mottled, spotty grayscale texture known as the speckle artifact.

🔷 Key Characteristics

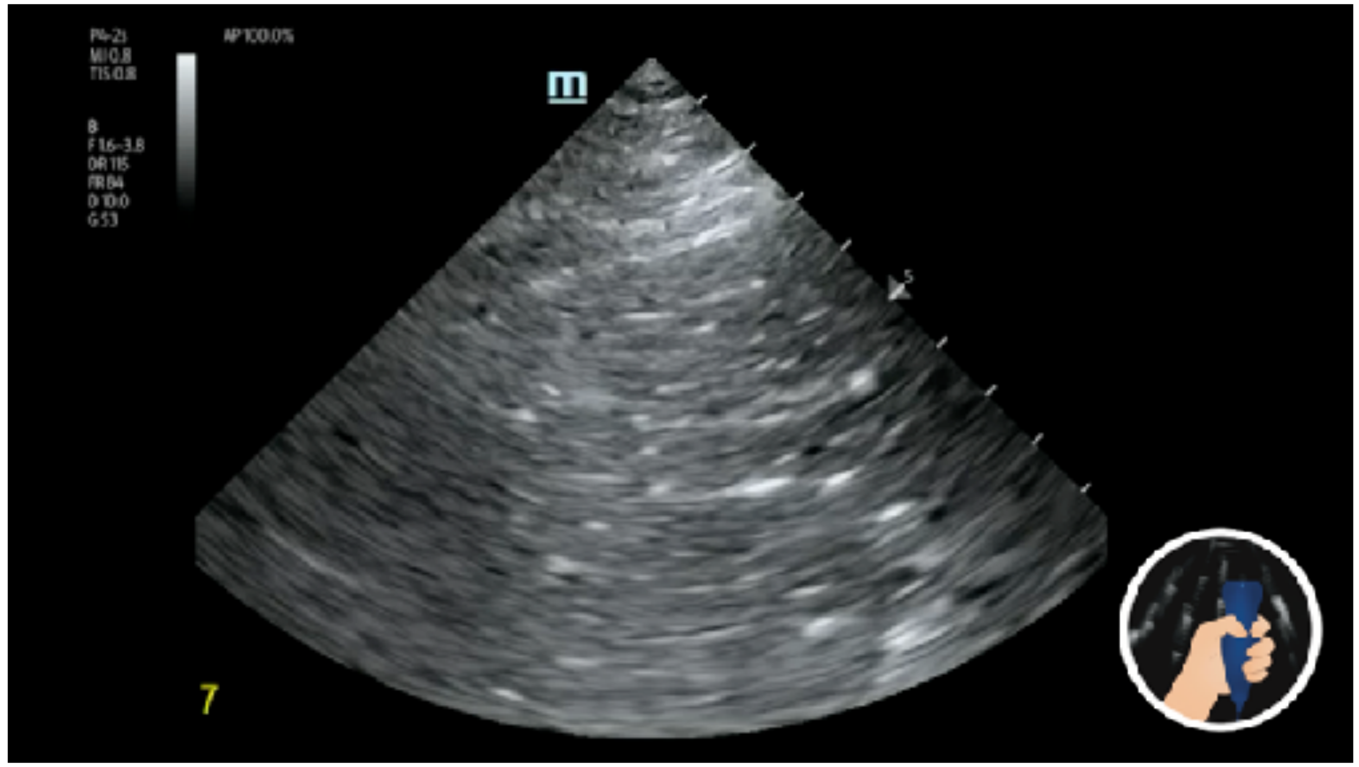
Appears as random bright and dark dots across otherwise uniform tissue.
Caused by constructive and destructive interference of scattered echoes.
Not a true anatomical finding (i.e., it doesn't correspond to an actual tissue pattern).
It can sometimes reduce image quality and diagnostic clarity.

🔷 Clinical Relevance

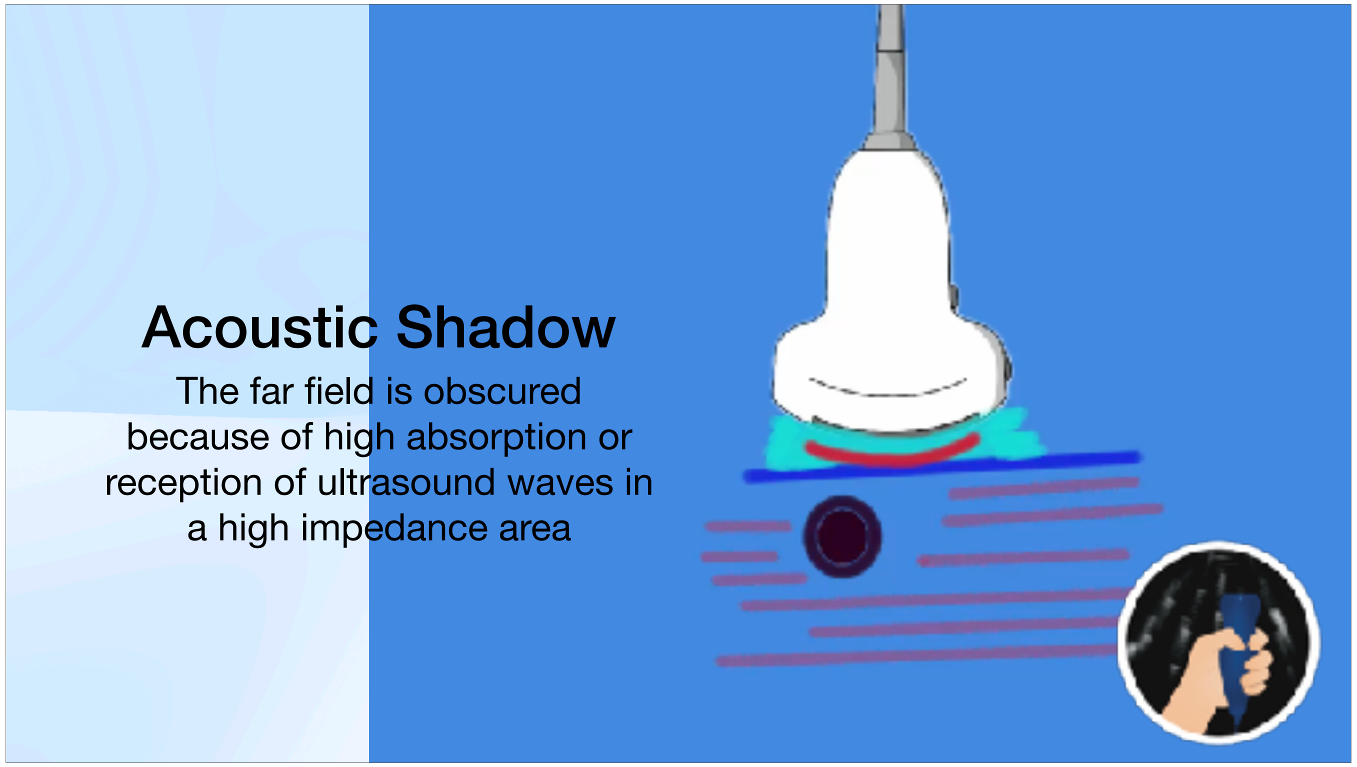
Seen in virtually all ultrasound images to some degree.
Sometimes useful (provides tissue texture impression), but often considered undesirable “noise”.
Techniques such as spatial compounding, harmonic imaging, or post-processing filters can reduce speckle to enhance clarity.




This is a video from a patient who has subcutaneous emphysema. This secondary to traumatic pneumothorax. This is a classic example of speckled artifact. There is gas inside the tissue, creating scattering both constructive and destructive. Exaggerating the normal echo texture of the tissue. The scattering is so intense that we cannot see clearly the ribs below, and we cannot see the pleural line. When found, this image is diagnostic of pneumothorax and subcutaneous emphysema.  We can find similar cases when there is gas in the tissue, such as necrotizing fasciitis.

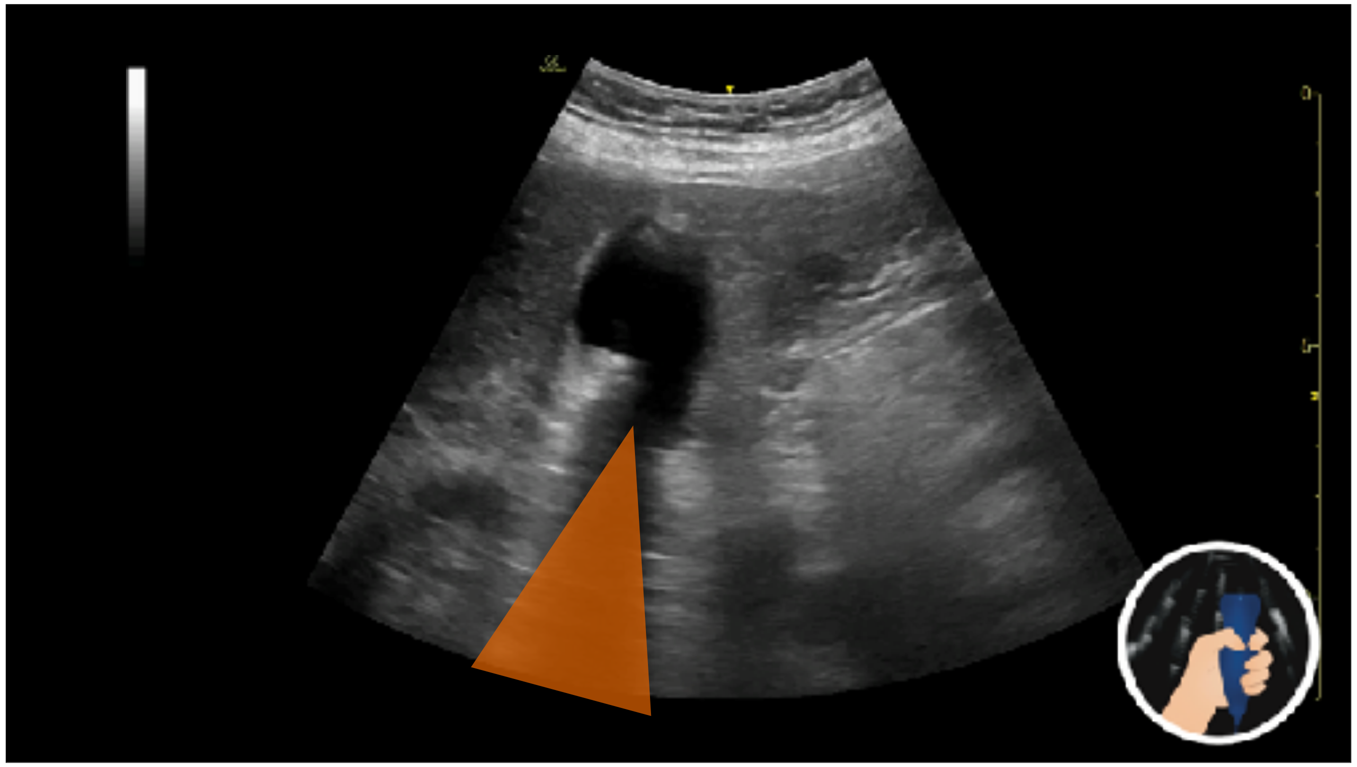



In this video, we see scattering again. This is a consolidated lung with an air bronchogram.  In this case, we do not see any more A lines but a lung full of fluid or pus with gas in the bronchi. Again, this is characteristic of consolidation.

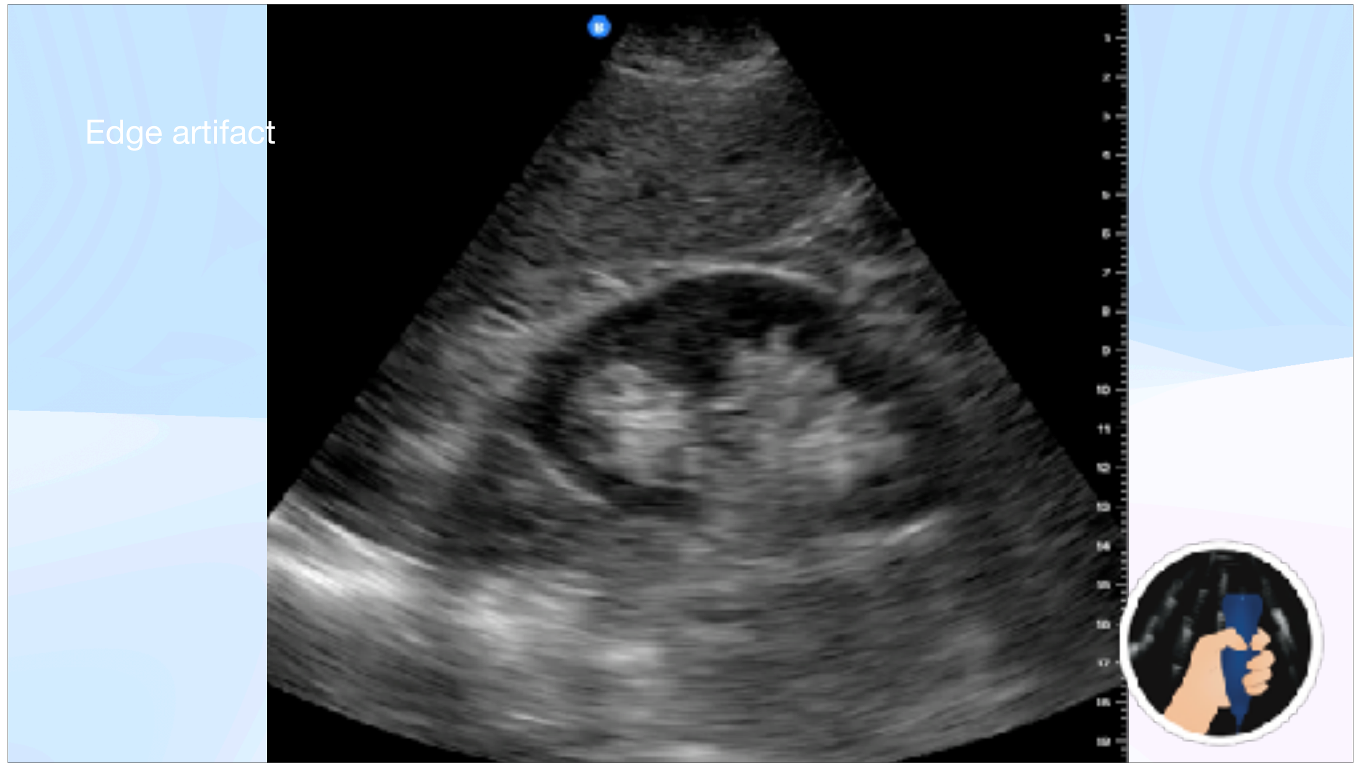



Acoustic shadowing is an artifact that occurs when a structure prevents the ultrasound beam from passing through and reflects or absorbs the ultrasound. Structures like bone absorb the ultrasound, creating an acoustic shadow. Other structures, such as calcium-rich stones, can also produce the same artifact.

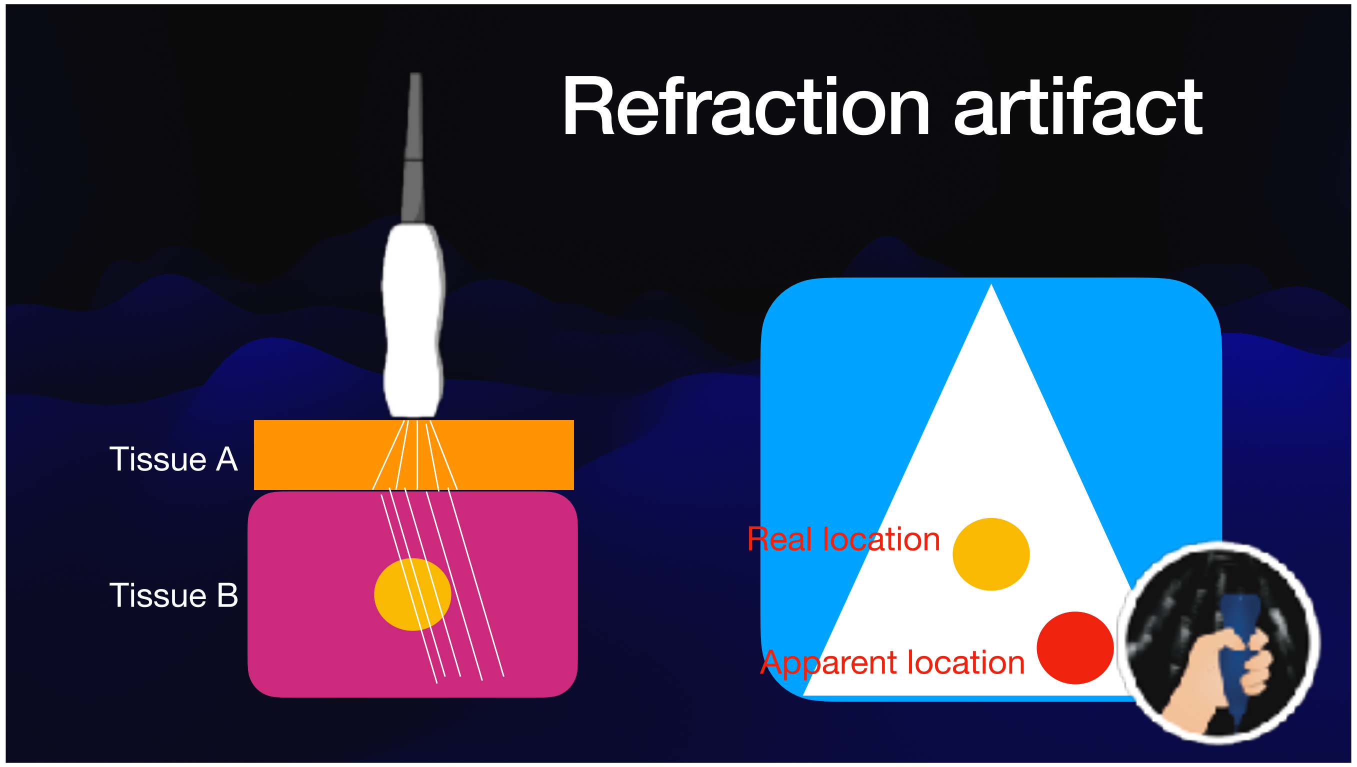
This artifact is particularly useful in cases where we encounter bone or stones.  In this video, we see acoustic shadowing secondary to gallstones.  Acoustic shadowing reveals the presence of a stone. You can see that a shadow appears intermittently in the video.



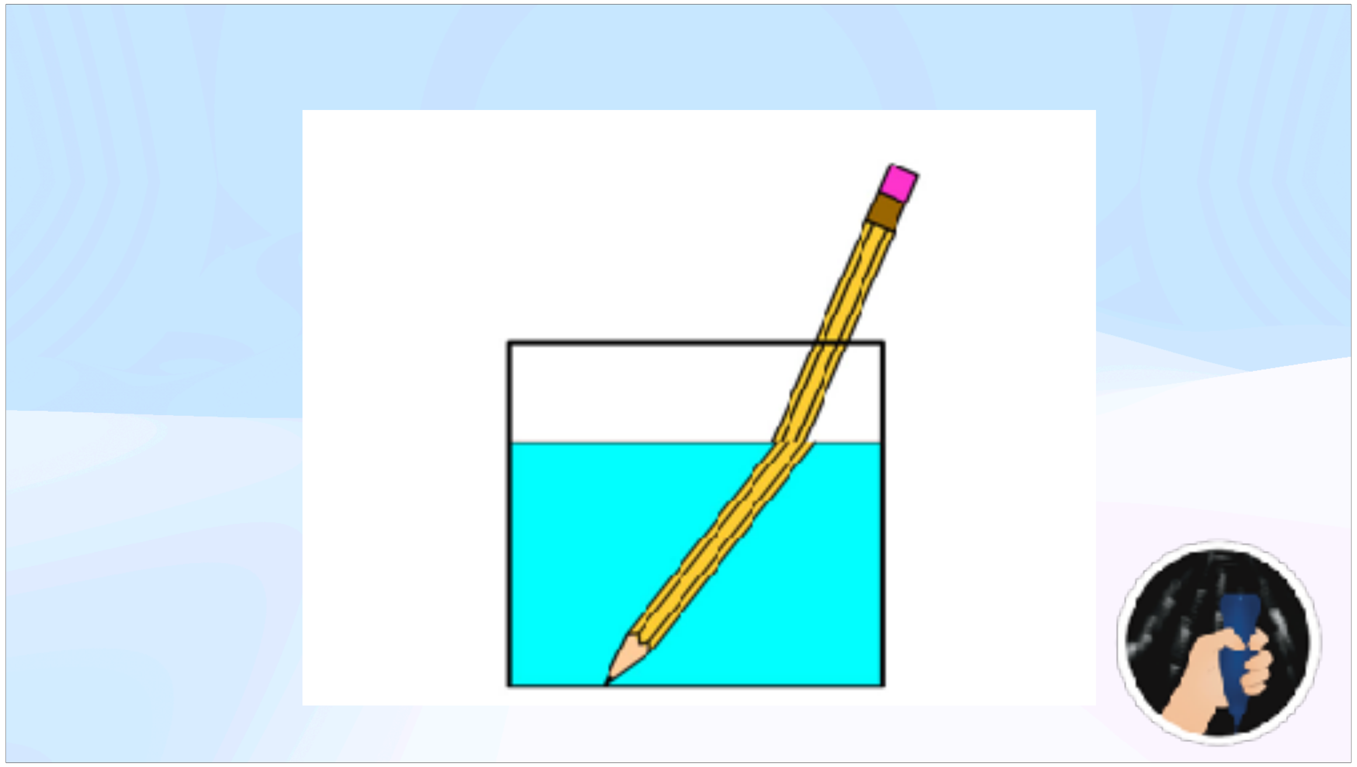
In this picture, we can see the path of the acoustic shadow in a very reflective stone in the neck of the gallbladder.



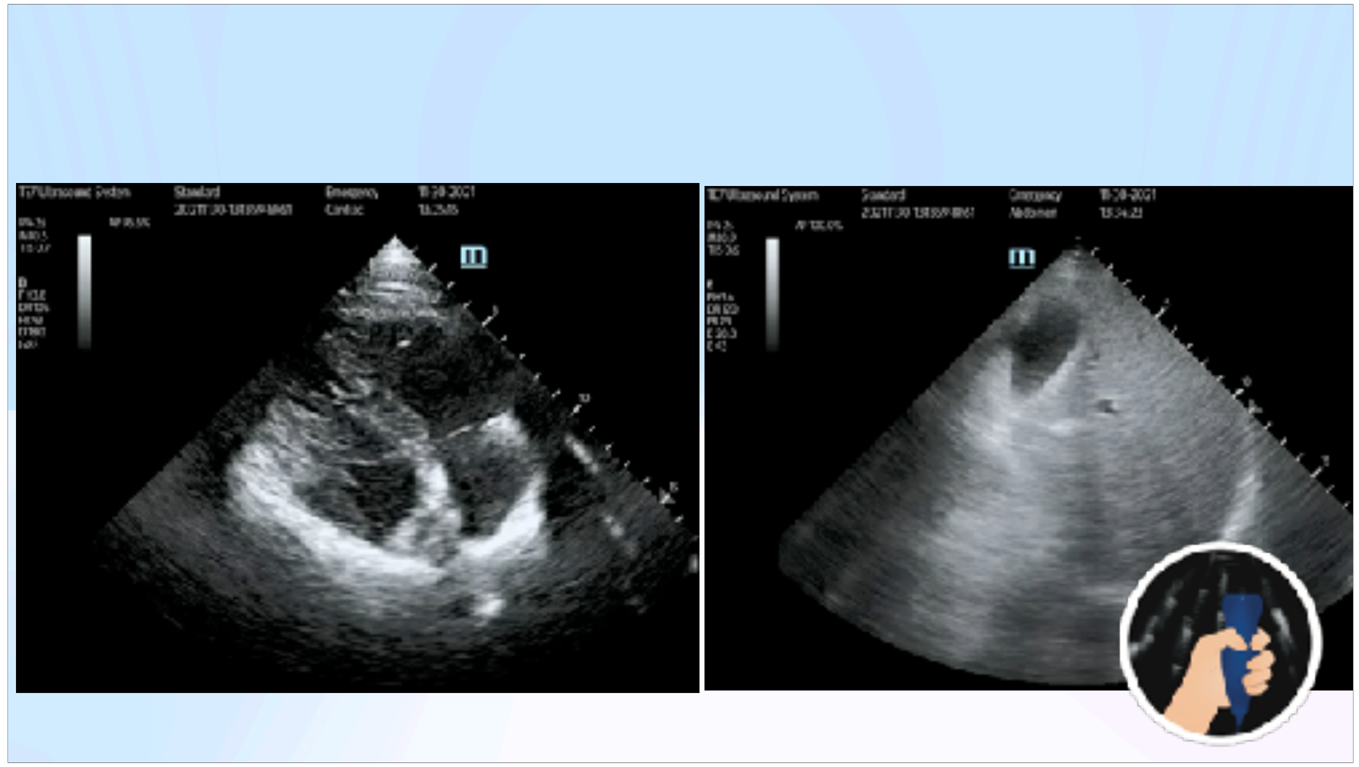

Edge artifact.  It is a hypoechoic area that forms at the edge of the curved edges of structures. Likely secondary to refraction and beam divergence. In this case, we see a right kidney projecting edge artifact.  It is essential to recognize this to avoid confusion with genuine hypoechoic areas.




Refraction artifact occurs because of the difference in the velocity of ultrasound within different tissues. This can create the illusion of a structure being in a different plane or position than what is shown on the screen.



It is not different from the reflection of light showing us a bent pencil in the water.



Last in our grayscale artifacts, we can see the effects of two ultrasound beams in the same frequency while scanning an organ. The lines are visible due to constructive interference between the ultrasound beams from different probes. This may be more common now because clinician teams might inadvertently use two probes while performing a clinical ultrasound. I first observed this during ultrasound rounds, while one of my residents was using a butterfly probe that I was not aware was in the room.

medpocus.com by Christian Espana Schmidt MD