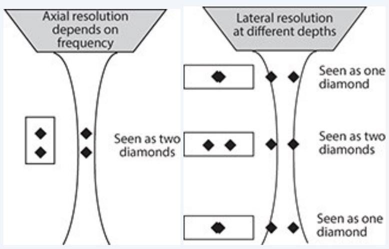
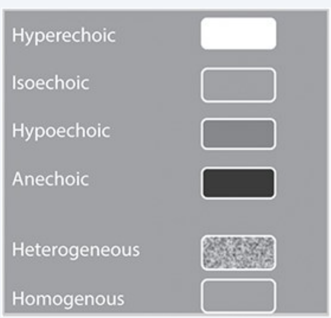
Pocket Guide to POCUS: Point-of-Care Tips for Point-of-Care Ultrasound >

Chapter 2: Physics and Knobology

KEY PHYSICS CONCEPTS—KNOW THE LANGUAGE

Concept	Details	Why It Matters
Frequency	# of cycles/second—measured in Hertz. A megahertz (MHz) = 10^6 Hz. Human hearing is in the range 20-20,000 Hz.	Probe Selection: low frequency/long wavelength, provide better penetration with less resolution, good for deep structures. High frequency/short wavelength, provide better resolution, less penetration.
Resolution	 Schematic showing ultrasound beam edge-on	Lateral resolution is the smallest distance that can be distinguished with a given probe and machine at any given depth. This explains why focal depth and the number of crystals in the transducer are important. Axial resolution allows differentiation parallel to the beam, and is dependent on frequency: higher frequencies give higher axial resolution.
Pulse Echo Principle	Ultrasound waves leave the probe, strike an object, and are reflected back. Depth on the screen is measured by the time for this echo to return to the transducer.	Basics of machine function. Also important to understand several artifacts, including reverberation and shadowing.
Impedance or Density/Stiffness	When ultrasound encounters material of different impedance (from liquid to gas, or a change in tissue stiffness), it reflects.	Explains reflection of ultrasound by gas and solids, and the artifact of posterior acoustic enhancement.
Echogenicity		Hyperechoic: brighter echoes than surrounding structures Isoechoic: equal in echoes to surrounding structures Hypoechoic: darker echoes than surrounding structures Anechoic: completely black Heterogeneous: nonuniform texture Homogeneous: uniform texture

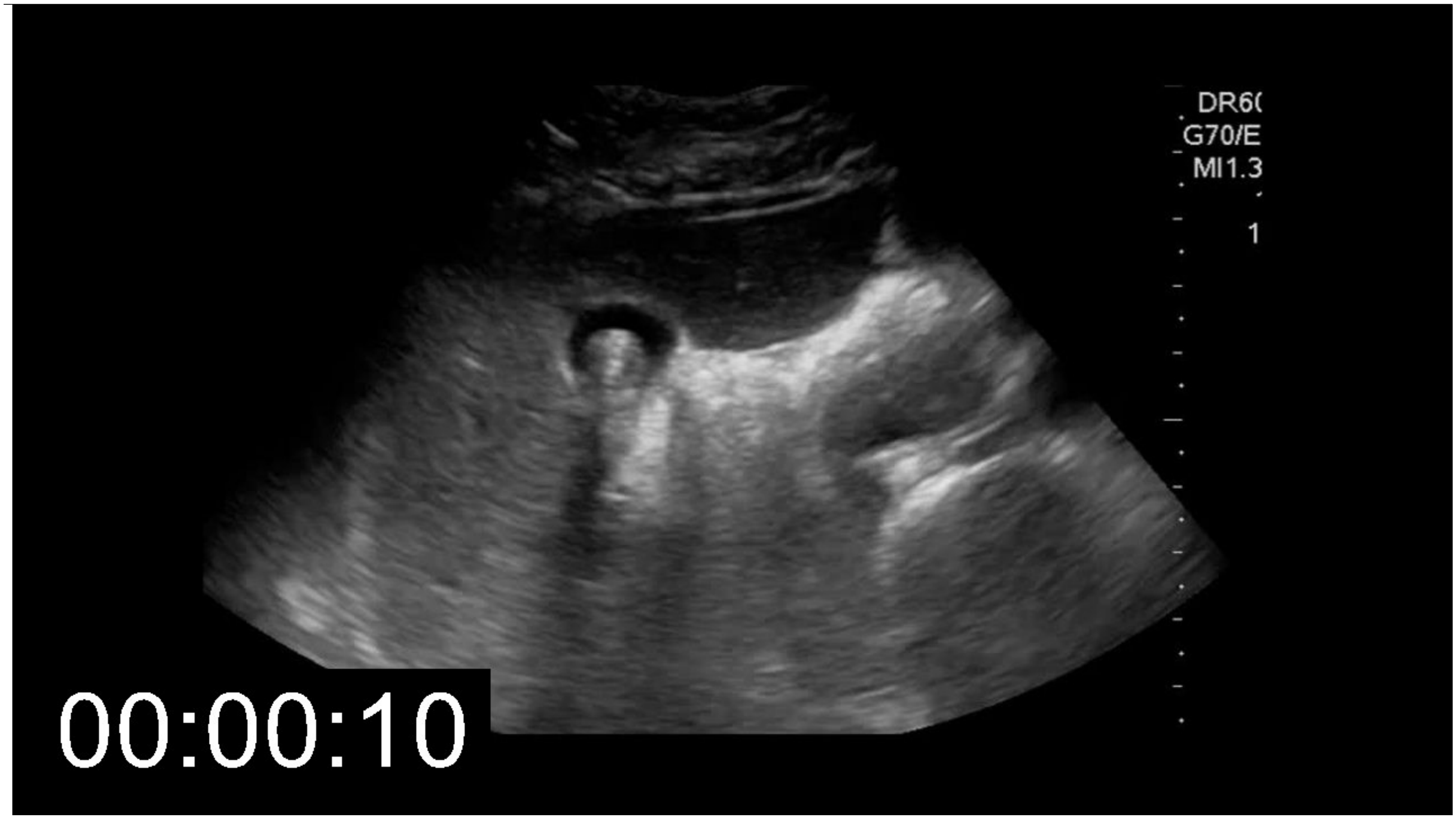
Important Artifacts

Acoustic Shadow

When sound cannot pass through a dense/reflective object and all signal is either returned to the probe or absorbed, the absence of ultrasound posteriorly creates the appearance of a black shadow. This image shows gallstones (arrows) with shadowing (between arrowheads).

Video 02-01: Acoustic Shadowing

Fanning through the gallbladder in the transverse view, several hyperechoic stones can be seen casting dense acoustic shadows.



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Posterior Acoustic Enhancement

Occurs when sound travels through a material with low attenuation (like urine, bile, effusions), resulting in objects behind the material appearing brighter than other tissues of the same echodensity at the same depth. The image shows that tissues between arrowheads are brighter than similar retro-orbital tissue.

Video 02-02: Posterior Acoustic Enhancement

This video quickly fans through the ocular anatomy and demonstrates the soft tissue deep to the globe is notably brighter than that on either side of the eyeball due to posterior acoustic enhancement.

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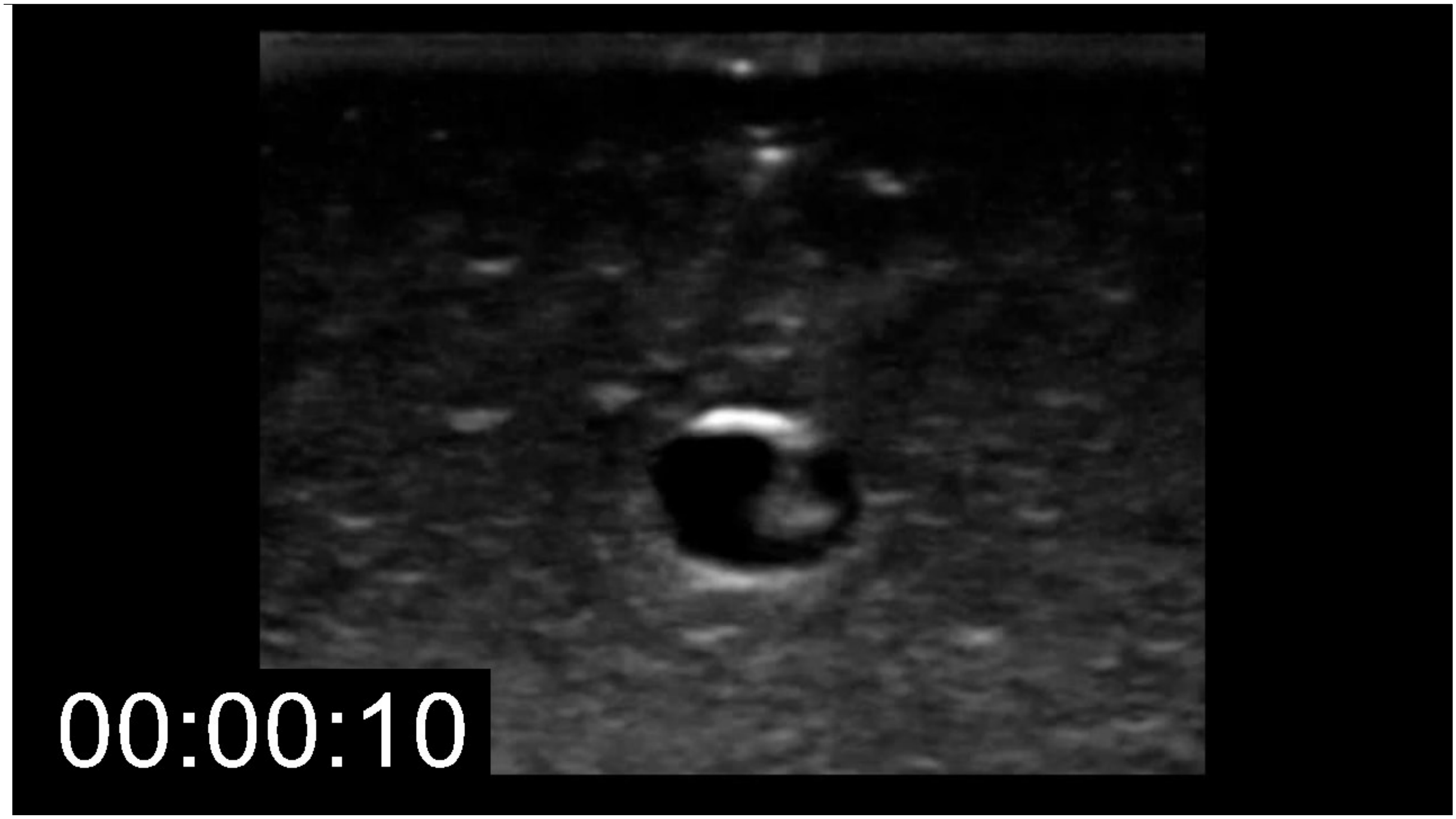
Reverberation

Sound bouncing back and forth between two highly reflective parallel surfaces that are perpendicular to the direction of the ultrasound beam results in the machine displaying multiple versions of the two surfaces at increasing depth, as in the case of the needle and the reverberations (arrowheads in this image).

Video 02-03: Reverberation Artifact

The needle in this video appears to have several "echos" deep to it. These lines run completely parallel to the needle, and are a result of acoustic reverberation in the hollow needle. This can be a distraction in procedural guidance, but is useful in lung ultrasonography.



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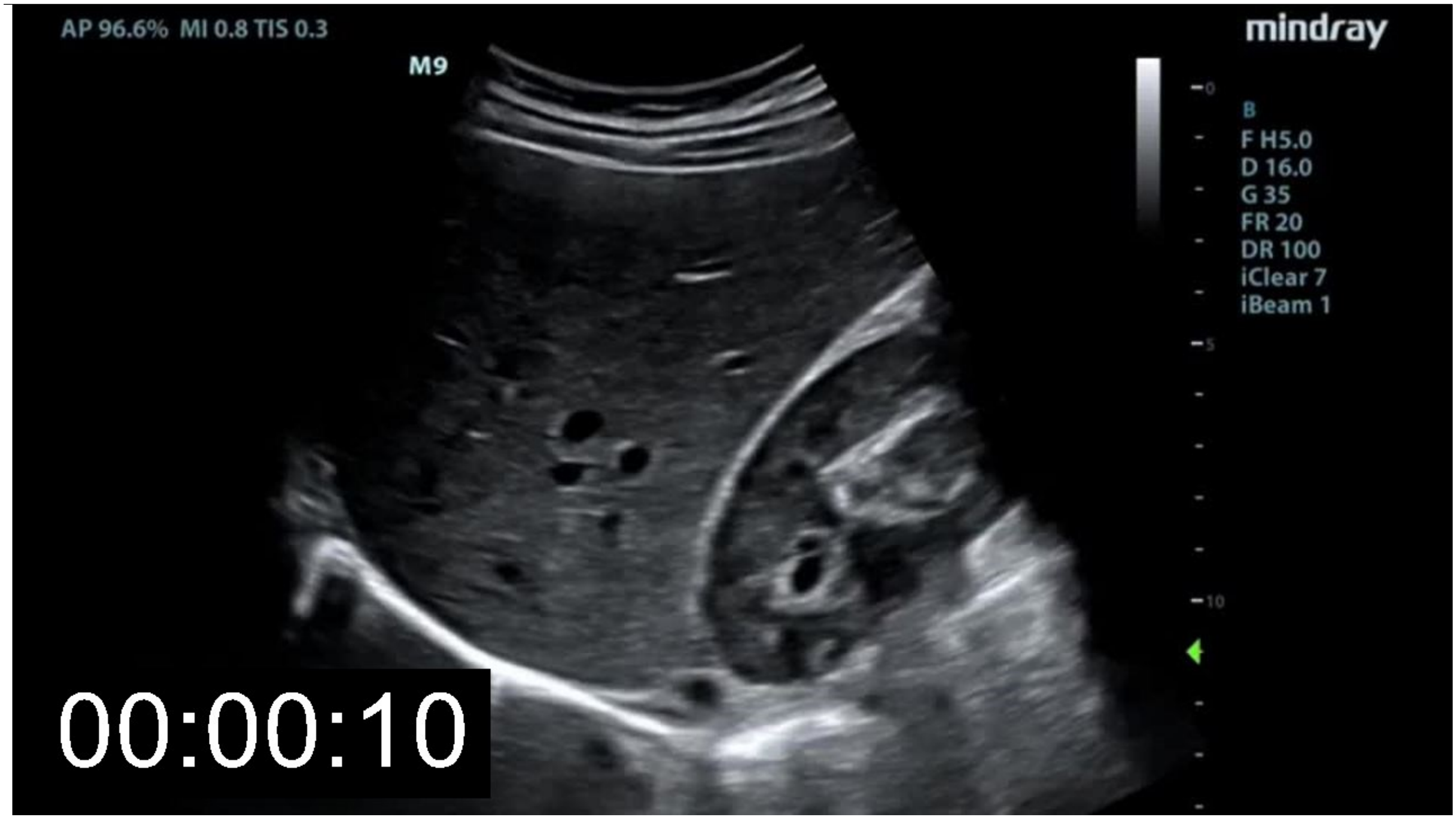
Mirror

When a highly reflective surface causes the machine to display an artefactual image of the reflection of an object, like the second kidney (arrowheads) and the liver (Pleural space) that appear on the far side of the highly reflective visceral pleural surface (often identified as the diaphragm itself) (arrow).

Video 02-04: Mirror Artifact

This view of the right upper quadrant shows the liver, diaphragm, and right kidney. At several points during the respiratory cycle it appears that there is additional liver on the other side of the diaphragm (in the bottom left-hand corner of the video), and a second kidney on the other side of the liver capsule (near the bottom of the screen). Both of these are artifacts from the highly reflective curved mirrors.



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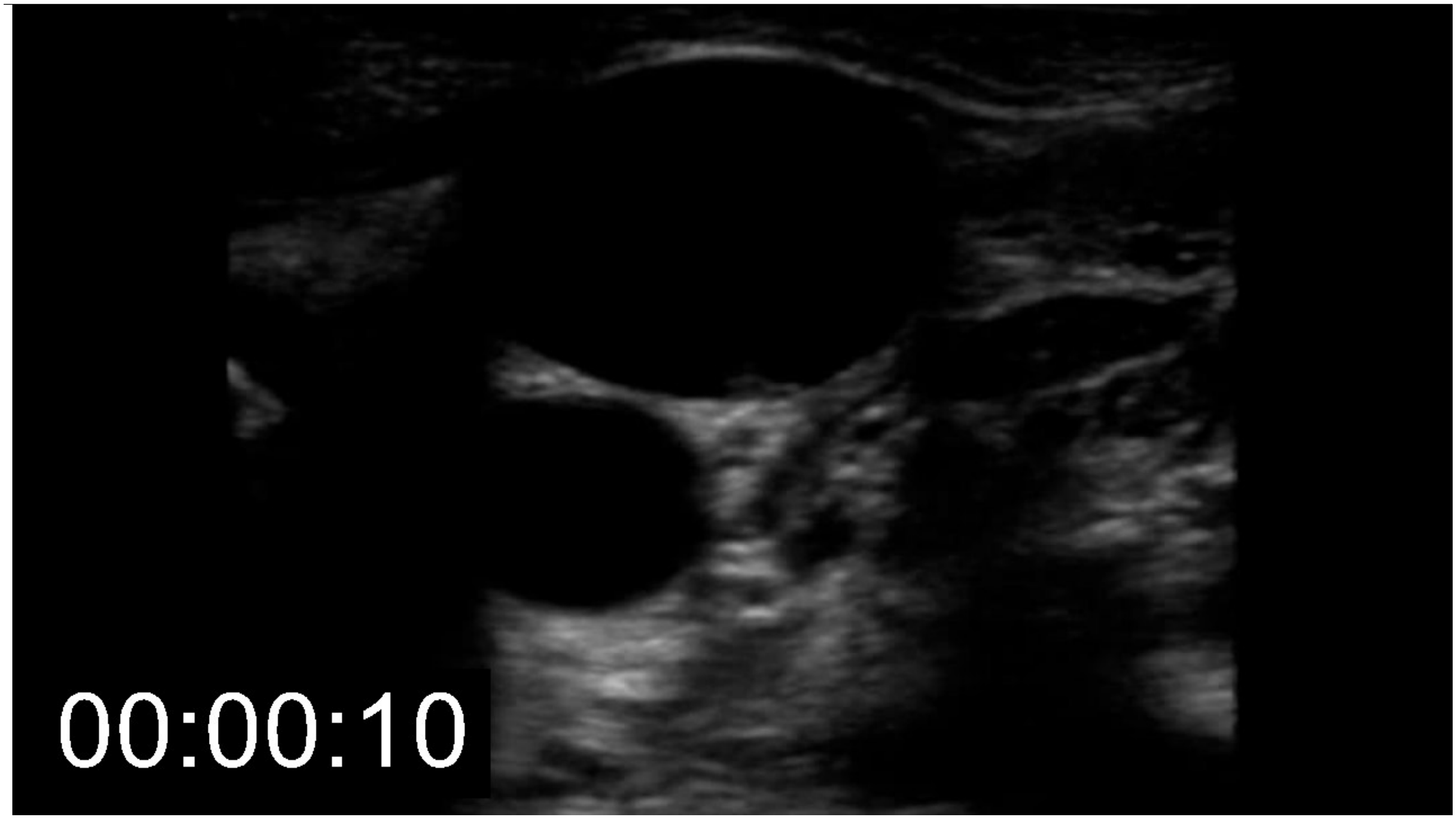
Edge

Sound is refracted by a structure in parallel with the ultrasound beam and does not return to the probe, resulting in the appearance of a shadow behind the surface (arrowheads show edge artifact from the wall of the gallbladder).

Video 02-05: Edge Artifact

This image of the right side of the neck shows the internal jugular vein, carotid artery, and a little bit of the thyroid gland (on the left edge of the screen). The curved walls of the internal jugular vein cause dense wedge-shaped shadows to obscure the imaging of structures deep the vein on either side. These tangent shadows are called edge artifacts.



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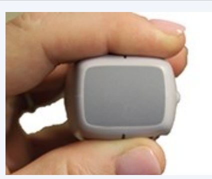
PROBES AND BUTTONS—AKA KNOW YOUR WEAPONS

Probes

There are many different probe types with various shapes, scanning formats, and frequencies. There are new technologies that allow one probe to operate through the frequency range of multiple traditional probes. Currently, the following are the three most common.

Linear (aka "vascular") probe	Sector or phased array (aka "cardiac") probe	Curvilinear (aka "curved array" or "abdominal") probe
• Higher frequencies and resolution • For superficial scanning and procedural guidance • Preserved lateral resolution	• Lower frequencies • Small footprint for intercostal scanning • High frame rates	• Even lower frequencies • Large field of view • Large footprint
		

Orientation

- Probes have an orientation marker—usually a bump on the probe that cannot be moved.
- Every screen has a corresponding orientation marker that can be moved using software.
- By convention (with cardiac being a notable exception) the screen marker is on the left.
    - Longitudinal scanning is with the probe marker toward the head.

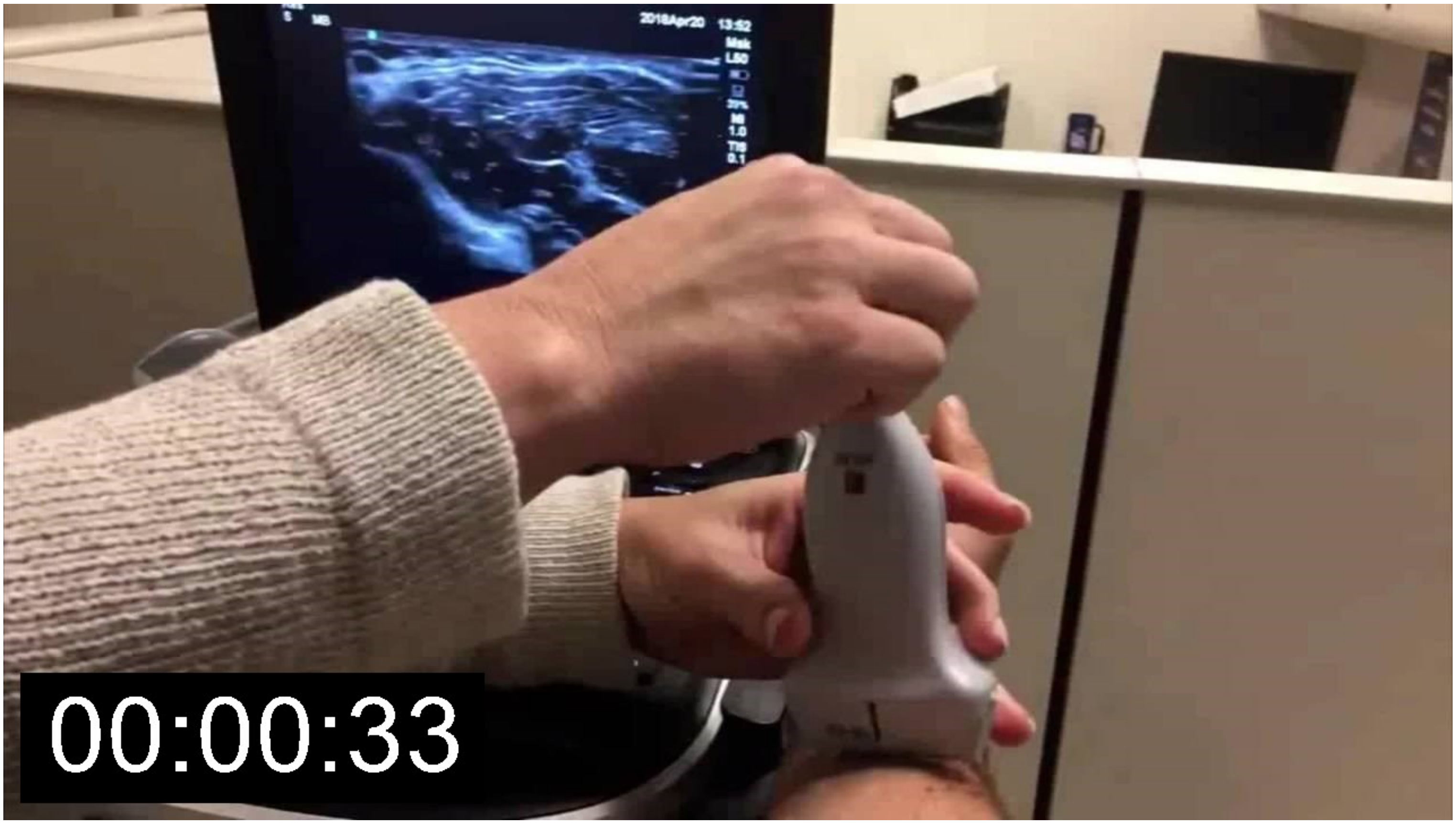
- Transverse scanning is with the probe marker facing the patient's right so that the image will look similar to the orientation of a computed tomographic (CT) scan.

- Flipping the probe will flip the orientation on the screen.
- On many probes the "marker" can be confused with other bumps on the opposite side of the probe, so confirm orientation by lifting up the "marker side" of the probe and ensuring that the air artifact is on the appropriate side of the screen.

Hand position for orientation check

Video 02-06: Orientation Check

It is important to identify which side of the screen corresponds to which side of the transducer. This video demonstrates our preferred technique, of lifting up one side of the probe and ensuring that the corresponding side of the screen demonstrates an air artifact. If there is a mismatch, simply flip the probe.



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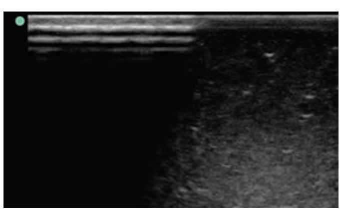
Screen showing air artifact on left



Important Buttons

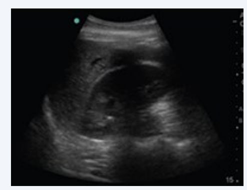
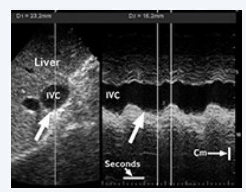
The following will be used in every scan. Check machine manual for details.

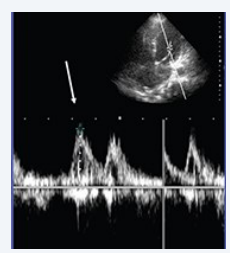
- **Patient information**—Complete this prior to all scans; essential for quality assurance (QA) and documentation.
- **Probe/exam/preset**—Optimizes imaging and selects measurement package.
- **Depth**—Adjusts the depth on the viewing screen. Start deep to search and orient. When objects of interest are identified, adjust depth to fill screen with these structures.
- **Gain**—Adjusts how dark or light the image will look on the screen. Adjust so that objects that are known to be anechoic appear black (i.e., "black should be black").

- **Time Gain Compensation**—Adjusts gain for different depths. Typical time–gain compensation (TGC) controls the sliders from top to bottom on the console correspond to depths from top to bottom on the screen image. For most scans they can be kept in a continuous line in midrange.

- **Frequency**—Can be adjusted for any given probe. Some machines state the frequency choice in MHz, others indicate "Pen"etration (low), "Gen"eral, or "Res"olution (high).
- **Focus**—Narrows the sound beam to improve lateral resolution and image quality at the depth of interest.
- **Dynamic range (DR)**—The number of shades of grey used for the range of echo strength. Low DR yields a picture with more contrast, which is useful for identifying a needle tip or identifying the endocardium in a cardiac echo.
- **Harmonics**—May improve resolution at deeper depths, especially in vicinity of gas-filled structures.
- **Freeze**—Pauses scanning so the still image can be used for measurements or be saved.
- **Cine/clip**—Records a video, either prospectively (future) or retrospectively (past).
- **Zoom**—Magnifies an area on the screen. This does not improve resolution (analogous to enlarging a low-resolution photo).

Modes

B-Mode: Brightness Mode or "Gray-scale" or 2D	• Two-dimensional black-and-white image with shades of gray in between to indicate the strength of the echo. • The default view on most machines. • This is a B-mode image of liver and kidney with overlying rib shadow.	
M (Motion)-Mode	• Draws a line on the screen (adjustable with trackball). • This image shows echo profile of every structure along that line (y-axis) over time (*x*-axis). • Used to demonstrate or measure movement over time in a still image.	

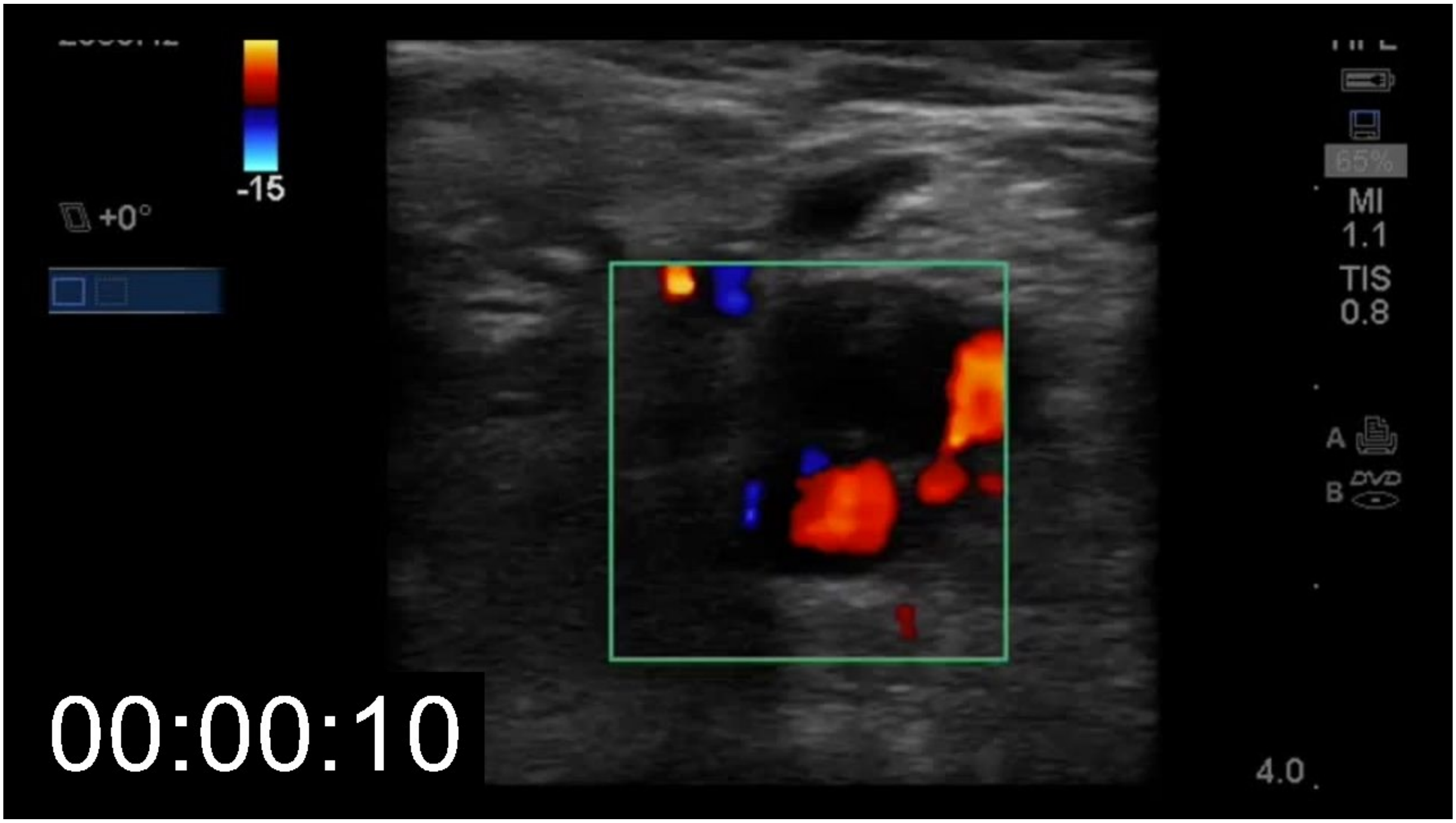
Spectral Doppler (beyond the scope of this book)	• Pulse wave:
	  ◦ Assesses velocity at an adjustable depth (the "gate").
	  ◦ When velocity exceeds the limit, "aliasing" occurs.
	• Continuous wave:
	  ◦ Assesses velocity at all points of a line of interrogation.
	  ◦ Used when velocities are high or when maximum velocity is needed.
		
		Early (E, arrow) and atrial (A) mitral-valve diastolic inflow demonstrated by pulse-wave Doppler

Color Doppler (mostly beyond the scope of this book)

- Color represents velocity and direction of flow.
- Scale and direction shown on screen. Convention: red is toward probe and blue is away from probe.
- For Simpsons fans: BART = blue away red toward.
- The box should be as small as possible around structures of interest.
- Advanced training needed for appropriate use.

Video 02-07: Color Doppler

Color Doppler is a more advanced ultrasound technique. This video of the popliteal vein and artery demonstrates the pulsatile flow of the artery and more continuous flow of the vein. Importantly, you will also notice that the color does not correlate with blood oxygenation, and that halfway through the video the color of flow in the artery changes from blue to red. This is a result of changing the angle of insonation, as blue flow means that fluid is moving away from the transducer, and red means flow is moving toward the transducer. Fanning the probe will thus change the color. If the flow is perfectly perpendicular, then there will be no color on the screen.



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