Chapter 9: Ultrasound-Guided Volume Assessment

KEY IMAGES

IVC, transverse

Video 09-01: Transverse view of a normal inferior vena cava

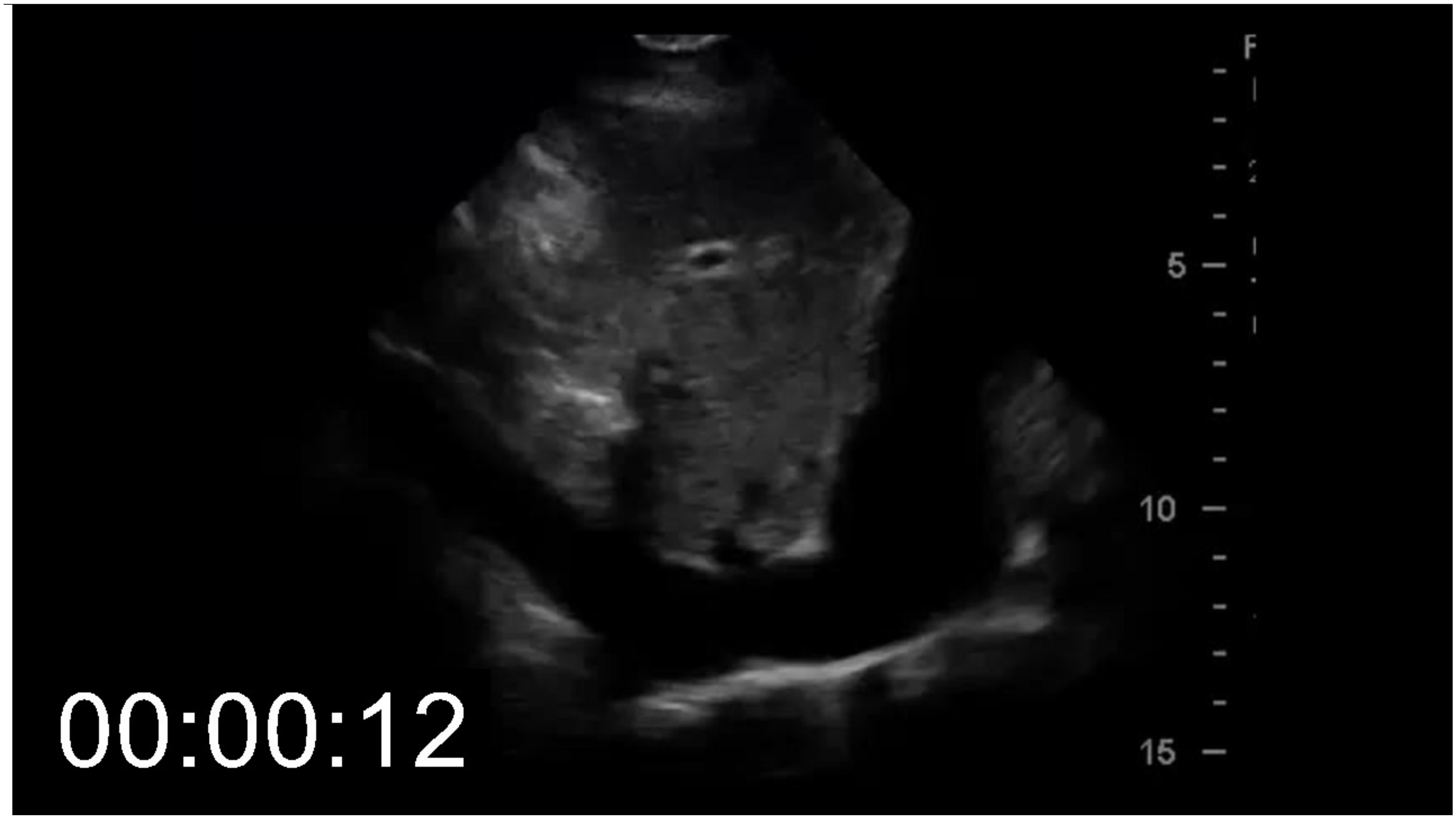
In the transverse view the IVC can be seen to collapse during the respiratory cycle in this patient with normal volume status. The hepatic veins can be seen to converge on the IVC at the beginning of the clip. The aorta can be seen to the right, running in front of the spine. Of note is the impressive pulsatility of the IVC, a reminder not to use that to distinguish it from the aorta.

Play Video

IVC, longitudinal

Video 09-02: Longitudinal view of a normal IVC

In the longitudinal view, the IVC can be seen changing from 2 centimeters to an almost complete collapse. The collapsibility should be measured approximately 1 cm distal to the confluence of the hepatic veins, and normal respirations should be used. In this video of the author's IVC, he may have sniffed to exaggerate the effect.



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Lung ultrasound, apex—A-lines

Video 09-03: A lines at the apex of normal lungs

At the apex of the lung in a patient without any pulmonary edema, the horizontal artifact known as A lines are easily seen repeating 3 times below the bright pleural line.

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Internal jugular vein (IJ) assessment

Video 09-04: Longitudinal view of the internal jugular vein

In the longitudinal view, the internal jugular takes on a paintbrush (or wine bottle) appearance. The point where the walls come together corresponds to the externally measured jugular venous distension or the invasively measured central venous pressure. The movement is driven by the pressure changes during respiration.

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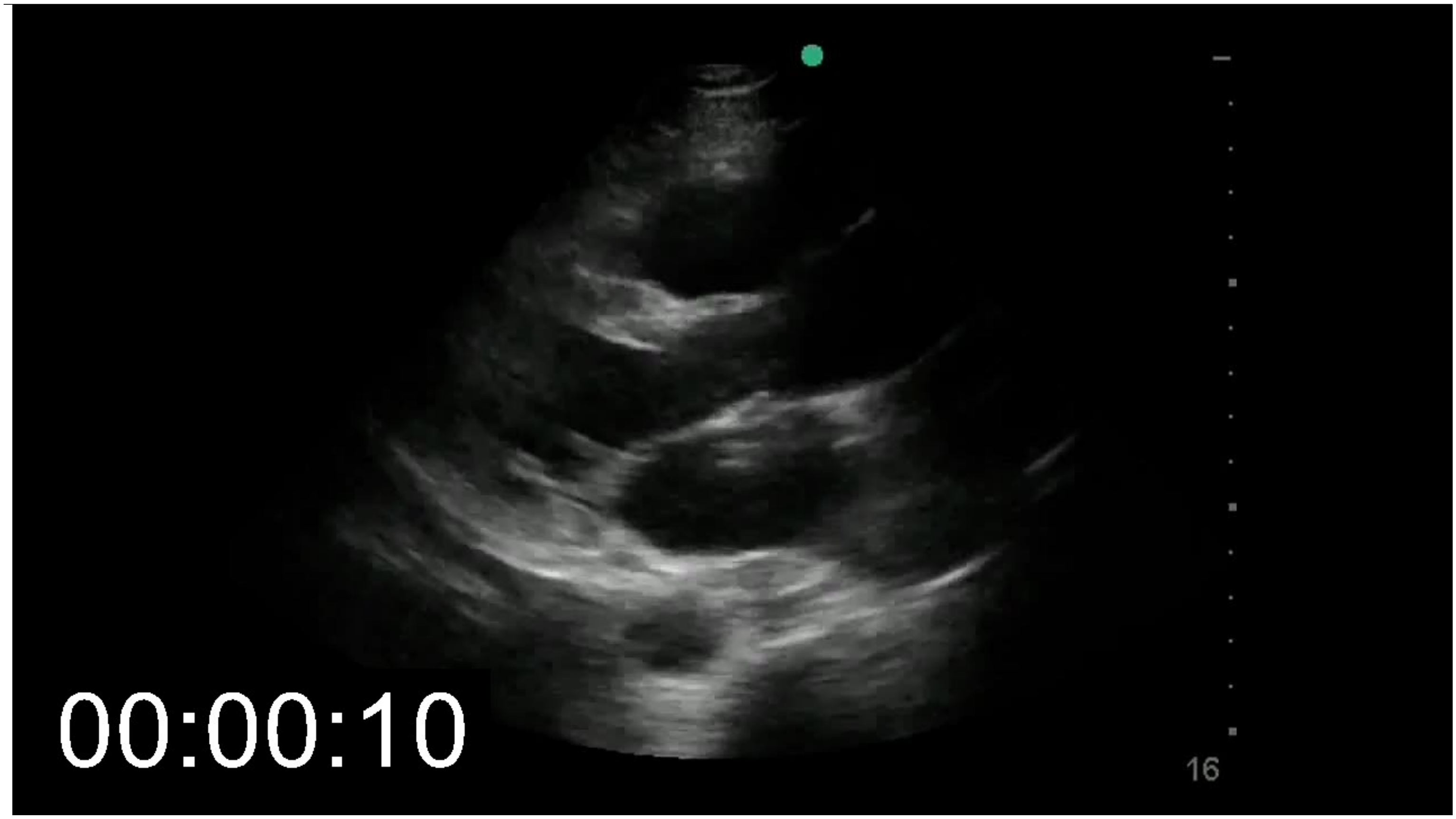
Cardiac ultrasound, parasternal long axis (PLAX)

Video 09-05: Normal parasternal long axis view

This patient with pneumonia and mild tachycardia demonstrates a normally sized left atrium, left ventricle, and right ventricular outflow track. The ejection fraction can also be seen to be normal. The observant user will notice the subtle left sided pleural effusion with some atelectatic lung seen in the bottom left corner of the screen.



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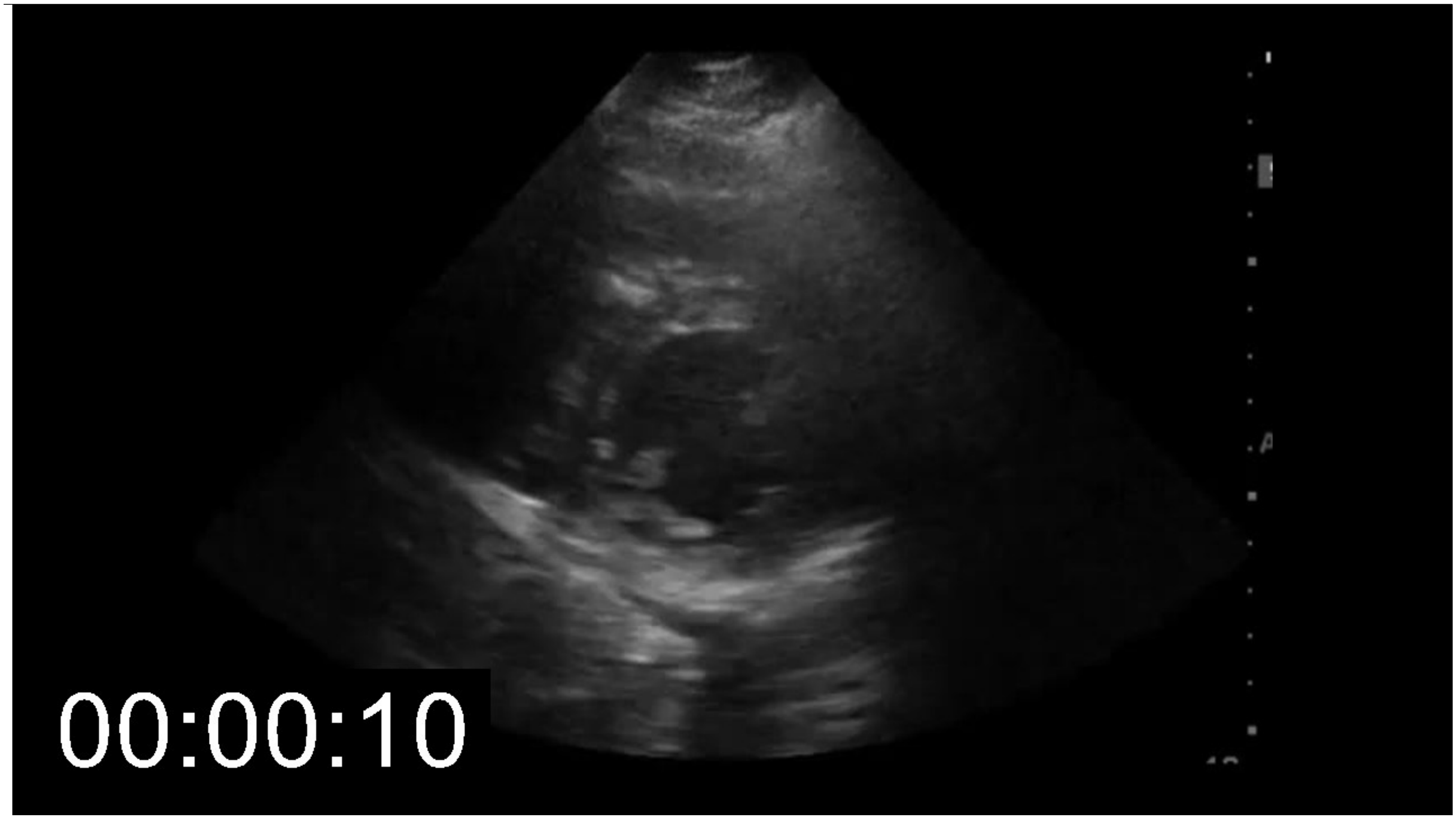
Cardiac ultrasound, parasternal short axis (PSSA)

Video 09-06: Normal parasternal short axis

This video of the heart via the parasternal short axis view at the level of the papillary muscles demonstrates normal ejection fraction anda normal left ventricular end diastolic dimensions.



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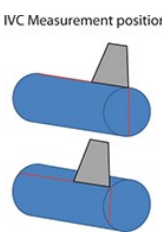
ACQUISITION TIPS

- Indications: When history and physical exam do not provide a clear answer to the volume status of the patient. Especially useful in undifferentiated shock or to assess response to therapy.
- This exam is usually combined with a cardiac and lung assessment, making it most convenient to use the sector/cardiac probe; however, a curved-array probe is equally effective. For assessment of the IJ, a linear probe is preferable.

Inferior Vena Cava (IVC)

- Acquire both transverse and longitudinal views.
- More details, including common acquisition pitfalls are in Chapter 8.
- M-mode of the IVC can be useful to allow for quantitative measurements of diameter change over the respiratory cycle.
    - First, make a visual assessment of the collapse of the vessel.
    - Place the M-mode sampling line through an appropriate location in the vessel.
    - *In the transverse plane*, assess the side-to-side motion of the vessel throughout the respiratory cycle, as a pronounced side-to-side motion is likely to undermine accurate M-mode measurements *in the longitudinal plane*.



    - Set the sweep speed (*x*-axis) of the M-mode to a low speed to assess more than one respiratory cycle.

- In the transverse view, identify the hepatic veins and visualize immediately inferior to that plane.
- The cylinder tangent effect: if a longitudinal ultrasound imaging plane is not precisely in the center of the vessel, it will appear smaller than its true size. This can occur if the vessel moves from side to side during the respiratory cycle.

Lung

- Assess at the midclavicular line in the anterior lung zones bilaterally for the presence of B-lines and lung sliding (see Chapter 6 for details).
- Assess at the lung bases bilaterally for the presence of pleural effusions.

IJ Assessment

- Useful in a situation where JVD would be helpful, but physical habitus or facial hair prevents an evaluation, or when it is impossible to obtain adequate IVC views. In our practice, it has mostly been replaced by IVC imaging.
- Sit patient upright, or correct measurement for the angle of patient incline.
- With a very light touch, visualize the IJ in the longitudinal plane. This is often done by starting in the transverse plane, centering the IJ on the screen, and rotating the probe so the indicator is cranial.
- The goal is to acquire a clip in which the IJ narrows with a "paintbrush" or "German wine bottle" appearance. The height at which the vessel is collapsed has been shown to correlate tightly with jugular venous distention (JVD).
- Excessive hand pressure or misalignment can cause result in the artifactual appearance of a smaller or more collapsed IJ, as with longitudinal scanning of the IVC, as noted above.

Cardiac Ultrasound (see Chapter 8 for details)

- Evaluation of the heart is necessary for accurate interpretation of IVC findings, especially with a plethoric IVC, which can due to heart failure (left, right, or both), valvular failure (especially tricuspid insufficiency), pulmonary embolus, tamponade, among others.
- Parasternal views can be useful to assess for the size and dynamics of the left ventricle (LV).
- The PLAX can also give information about the size of the left atrium (LA).
- From the apical four-chamber view, fan anteriorly to visualize the aortic valve.
- If the machine has the capacity, spectral Doppler can be used to measure the velocity–time integral of the cardiac outflow either at the left parasternal border using the pulmonary trunk or at the apical window using the aortic outflow tract. From this, cardiac output can be measured, which can be used to assess volume responsiveness. Details of this technique are beyond the scope of this text.

INTERPRETATION AND PITFALLS

- Sonographic assessment of volume status includes the capacitance vessels (IVC and IJ), the heart, and the lungs.
- Advanced techniques mentioned in passing but beyond the scope of this text include Doppler assessment of stroke distance, stroke volume, and cardiac output.
- Ultrasonography can provide evolving hemodynamic information when used repeatedly on a single patient. This makes it especially useful in treating critically ill patients and assessing the effect of therapeutic interventions.
- There are multiple protocols for undifferentiated shock, but our preference is to integrate sonographic information with relevant history, physical, and lab findings in all clinical decision making.

IVC Interpretation

- Remember that the IVC is a *pulsatile vessel*—frequently more pulsatile than the aorta.
- While one of the easiest views to acquire, the IVC is challenging to interpret, and the ability of the IVC to predict volume responsiveness is limited except at the extremes.
- The most common serious error in IVC assessment is failure to identify (usually due to failure to see) a slit-like IVC and assuming that it is the aorta. If only one vessel is seen in the transverse plane, it is the aorta, and the IVC is probably critically underfilled.
- While there are many causes of a plethoric IVC, an empty vena cava is almost always due to volume depletion.
- In *spontaneously breathing patients,* the IVC will collapse with inhalation and is effectively a visual representation of the central venous pressure (CVP). The diagnostic performance is very controversial, and it depends on tidal volume, respiratory effort, and abdominal pressure.
- To assess the inferior vena cava collapsibility index (IVCCI), the maximum diameter in expiration ($IVCD_{max}$) and the minimum diameter in inspiration ($IVCD_{min}$) are used, regardless of the cardiac cycle. The IVCCI score is calculated as: IVCCI (%) = $[(IVCD_{max} - IVCD_{min})/IVCD_{max}] \times 100$.

- Attempts have been made to establish a decision point for the IVCCI, but normal values range from less than 25% to more than 75%. At the extremes, this can be valuable, but in the middle ranges, interventions should make use of other tests for volume responsiveness.
- One approach to interpretation is shown in the following table.

IVC_{Max} Diameter	% Collapse	IVC shape	Intravascular volume status
<10 mm	>75	Slit-like, flat football	Very likely depleted
10–25 mm	0–100	Football to rugby ball	Indeterminate. Manage clinically
> 25 mm	<25	Basketball/plethoric	Replete, possibly overloaded, or other (pericardial tamponade, pulmonary hypertension [PHTN], valvular path, etc.)

- In *patients undergoing positive-pressure ventilation*, the IVC will distend with inhalation, as a representation of venous capacitance. The same caveats regarding diagnostic performance apply. We use the broad parameters shown in the following table.

IVC Diameter	% Distention	IVC shape	Intravascular volume status
<15 mm	>20	Varied	Very probably depleted
15–25 mm	0–100	Football to rugby ball	Indeterminate. Manage clinically.
> 25 mm	<3	Basketball/plethoric	Likely replete, possibly overloaded, or other (pericardial effusion, PHTN, valve path, etc.)

Lung Ultrasound Interpretation (see Chapter 6 for more details)

- In the absence of lung disease, diffuse B-lines almost invariably signal the presence of excessive extravascular lung water (pulmonary edema). This does not necessarily indicate a cardiac cause, but it is clinically useful.
- The number of B-lines correlates with wedge pressure. The B-line count has also been shown to change dynamically with volume removal from both hemodialysis and diuresis.
- Algorithms using B-lines as an end point for volume resuscitation in sepsis or as a guide for diuresis have been proposed but have yet to be validated.

IJ Interpretation

- The height of the IJ meniscus (the point at which the IJ turns from a tube into a "paintbrush" shape) correlates with expert evaluation of the JVD and measurement of CVP.
- The diagnostic accuracy of CVP and JVD to answer the clinical question depends on the clinical scenario.
- Common pitfalls include falling off axis, compression of the vein, and measurement of the carotid.

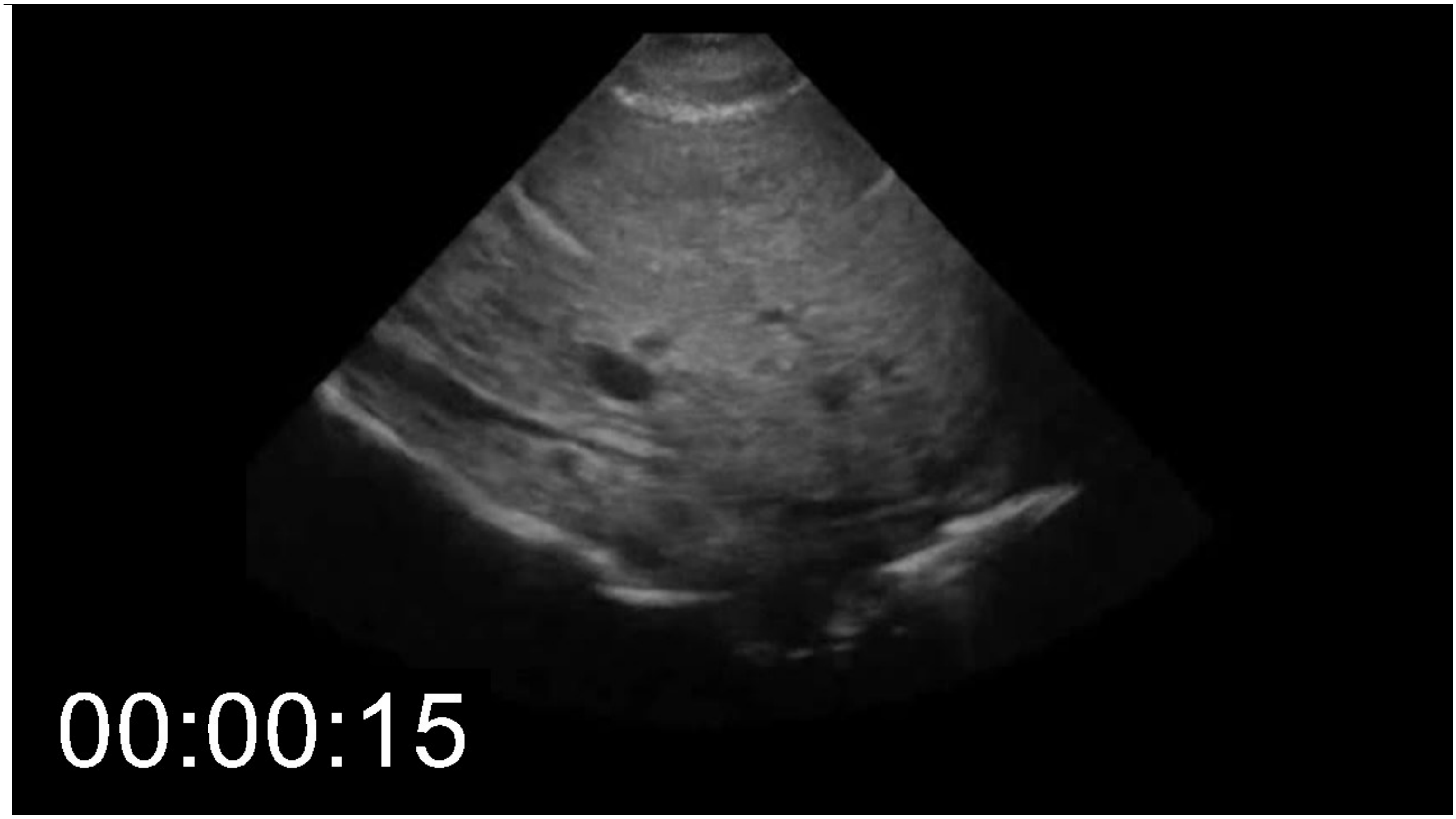
Cardiac Ultrasound Interpretation for Volume Status (see Chapter 8 for more details)

- A small LV end diastolic diameter (LVEDD) may indicate an "underfilled" LV, suggesting volume depletion. However, this should be indexed to height and in general does not predict volume responsiveness. Still, the normal range of LVEDD is 40 to 60 mm. Barring heart disease, values less than this range likely reflect an underfilled ventricle, and values above it likely represent dilatation. The further that a patient is found to be from this range, the more likely it is to be of clinical significance.
- LA size has been used as an indicator of volume status, with a diameter >4 cm correlating with increased pulmonary capillary wedge pressure (PCWP). This does not apply in atrial fibrillation or with mitral valve pathology.

EXAMPLES OF PATHOLOGY

Video 09-07: Longitudinal view of a flat inferior vena cava

This patient with hypovolemic shock demonstrates a nearly flat (<1 cm) IVC with complete collapse during inspiration. The liver occupies much of the screen, and the thin stripe of the IVC can be seen draining into the heart on the right side of the screen.



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Video 09-08: Transverse view of a flat inferior vena cava

In the transverse view, the IVC appears to completely disappear in this patient with hypovolemic shock. The aorta is visible, reminding the scanner that if only one abdominal great vessel can be seen it must be the aorta and the IVC is completely flat, a strong indicator of intravascular volume depletion.

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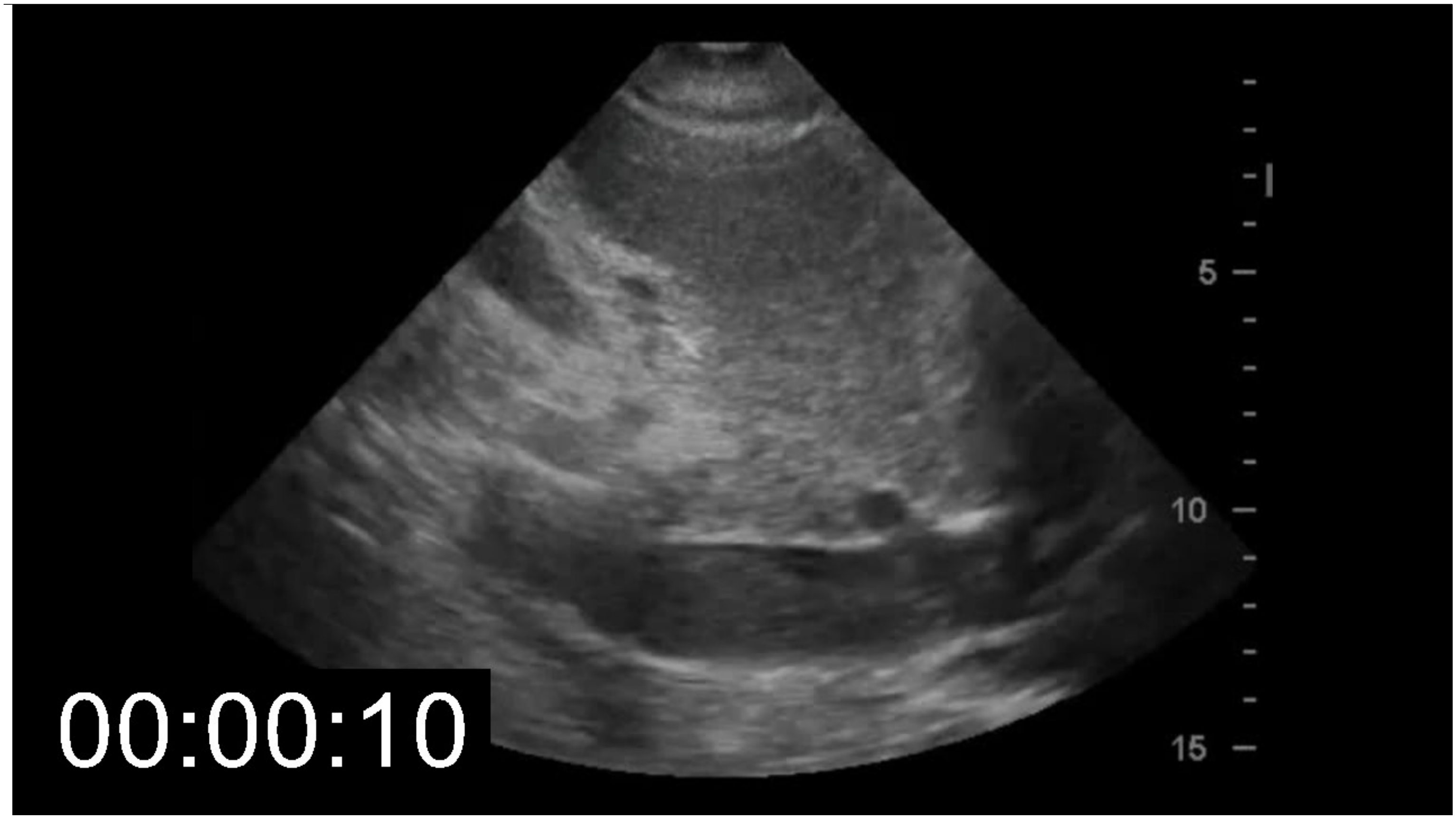
Video 09-09: Longitudinal view of a plethoric IVC

This video demonstrates a large (>2.5cm) and unchanging IVC. The hepatic vein can be seen joining the IVC just before the IVC drains into the heart. The grey smoke that can be seen in the vessel is an artifact frequently seen in low flow states.



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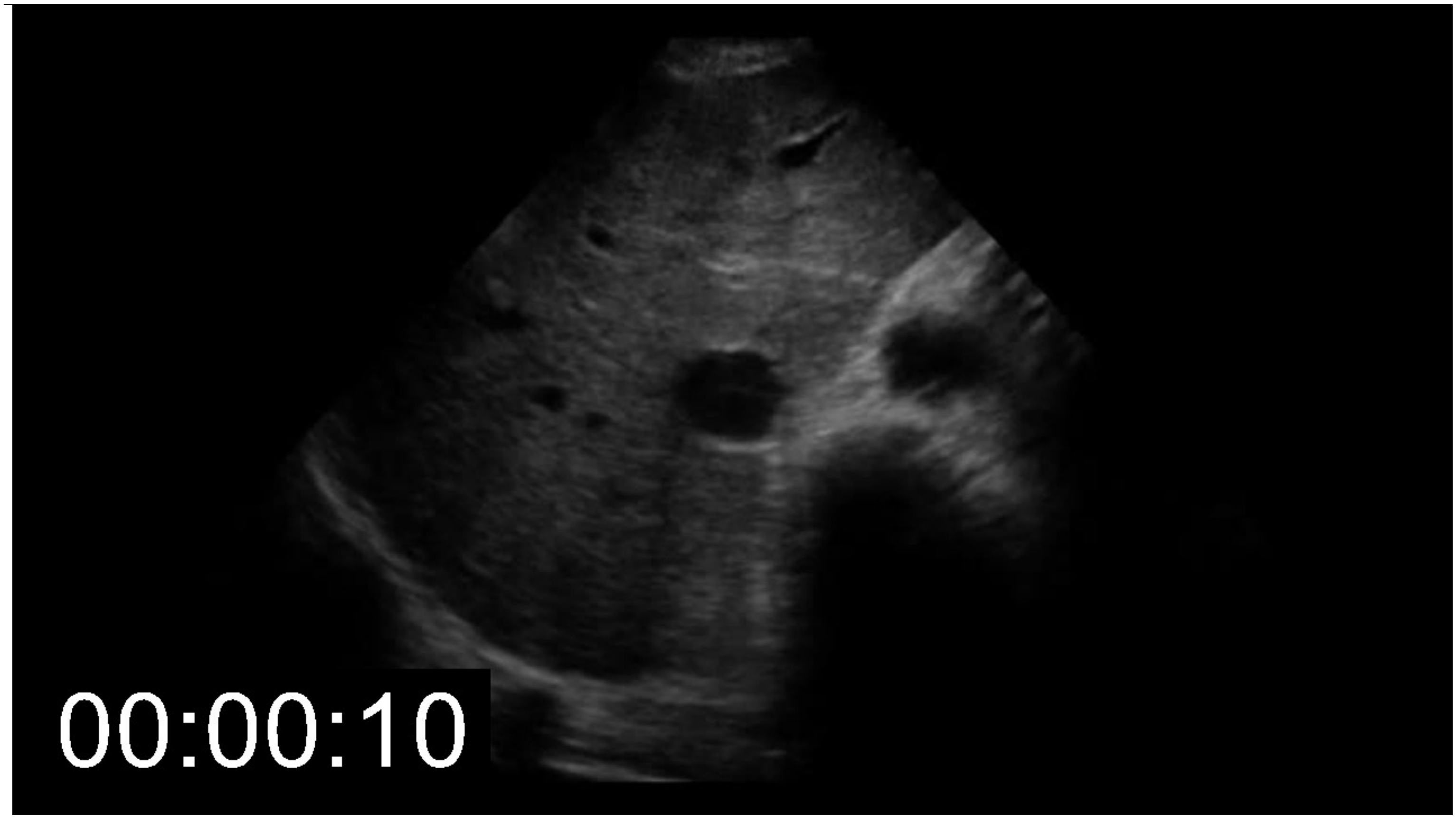
Video 09-10: Transverse view of a plethoric IVC

In the short axis view, the IVC can be seen to be larger than the aorta and unchanging with respiration in this patient with systolic heart failure and volume overload. When the hepatic veins are visualized later in the clip they can be seen to be notably distended as well.



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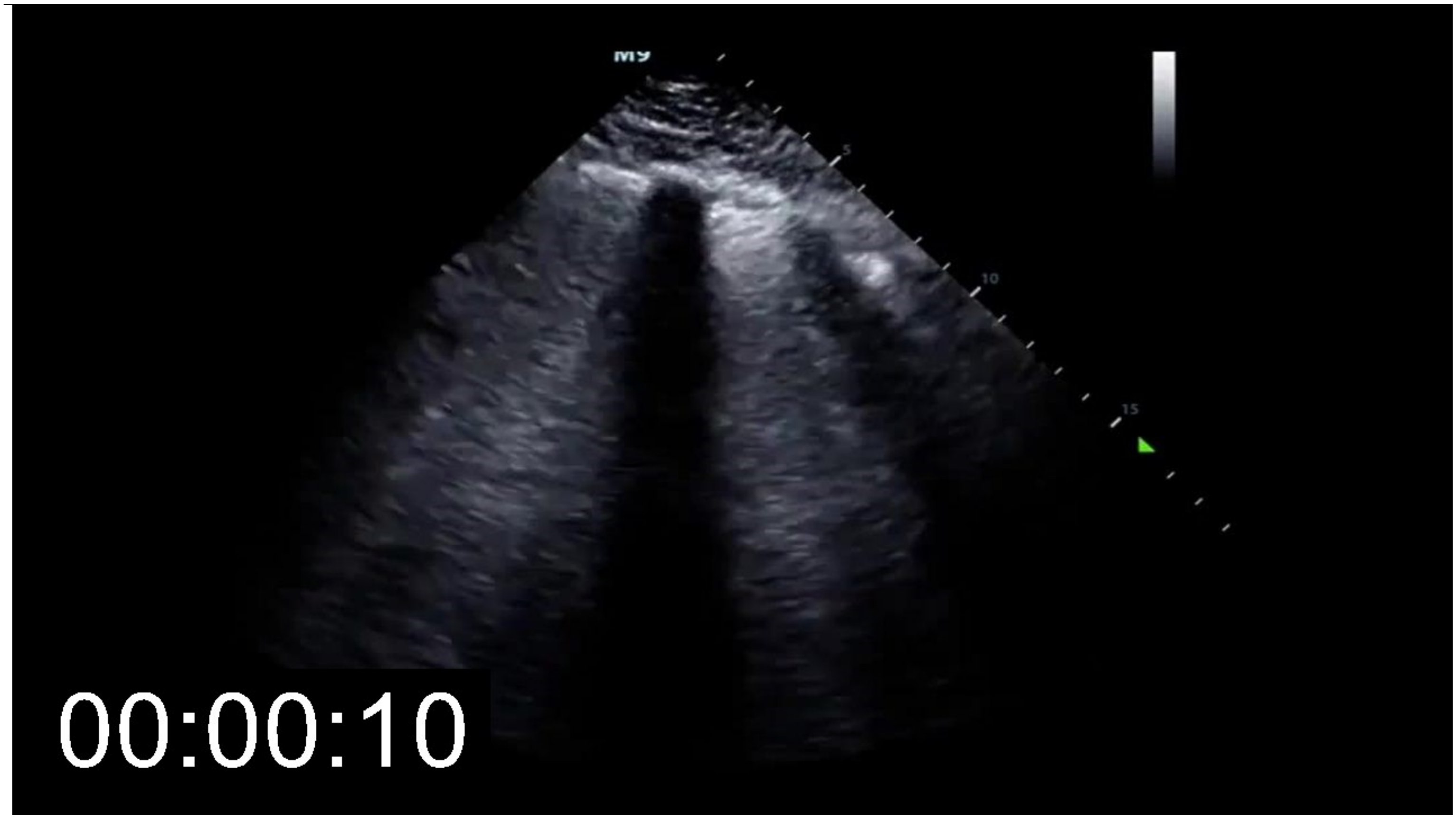
Video 09-11: Discrete B lines in a patient with early pulmonary edema

In this video of a patient with hypoxemia, individual laser-like artifacts can be seen going from the pleura to the bottom of the screen, moving with respiration. These are called B lines and are a marker of extravascular lung water in the appropriate patient population.



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Video 09-12: Coalescent B lines in a patient with severe pulmonary edema

This video can be confusing to the new ultrasonographer, as neither A nor B lines are immediately apparent. In this, case, however, this is due to the B lines becoming so dense that the coalesce into a single "whiteout" of each rib space. This correlates with areas of ground glass on CT scan and is seen in areas with large amounts of extravascular lung water.

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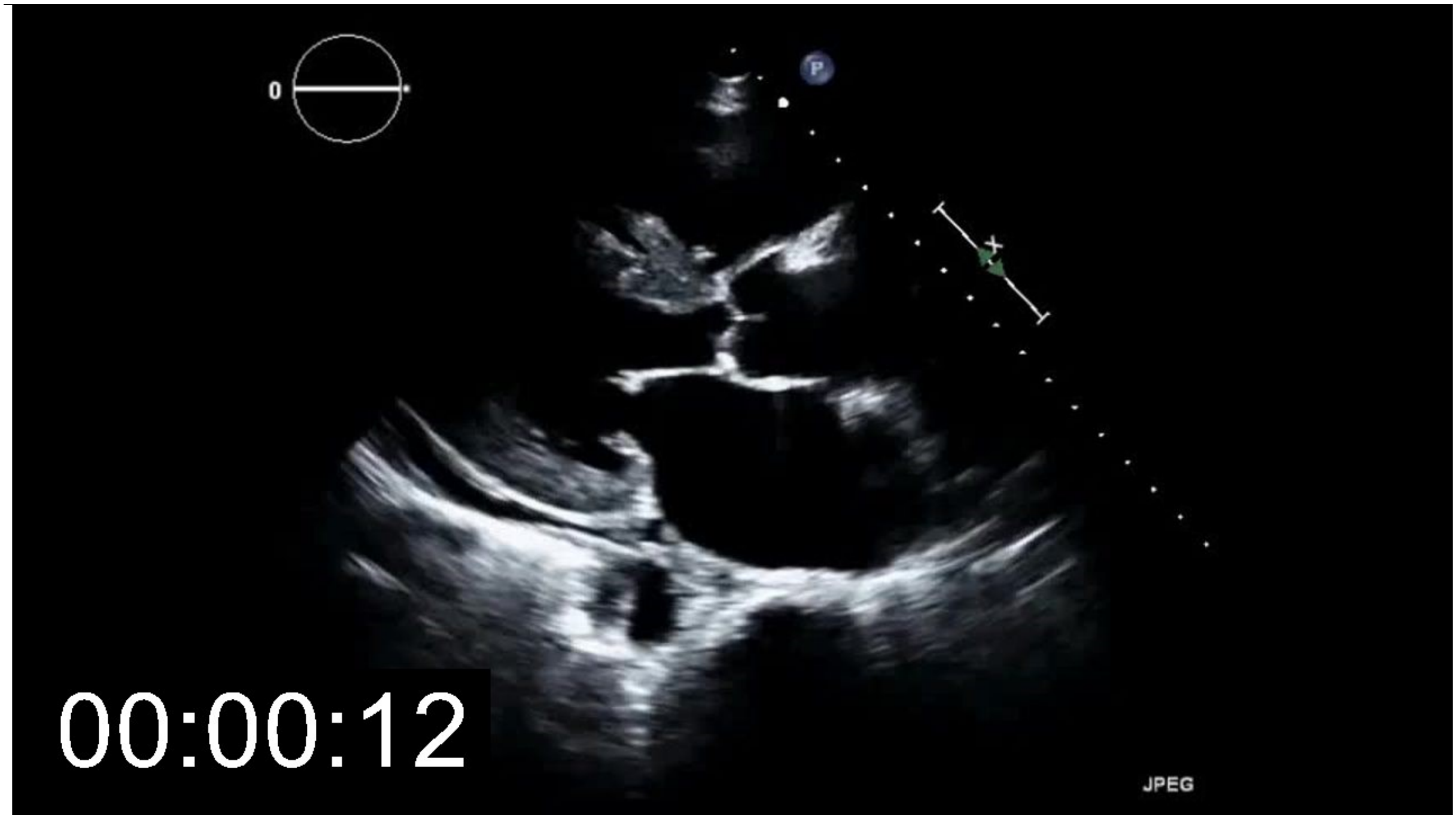
Video 09-13: Enlarged left atrium in a parasternal view

This patient with severe volume overload can be seen to have a small pericardial effusion and a remarkably dilated left atrium. The diameter of the LA is more than twice that of the aorta or the right ventricular outflow track. The left ventricle can be seen to have mildly impaired systolic function, but the volume overload in this case was multifactorial.



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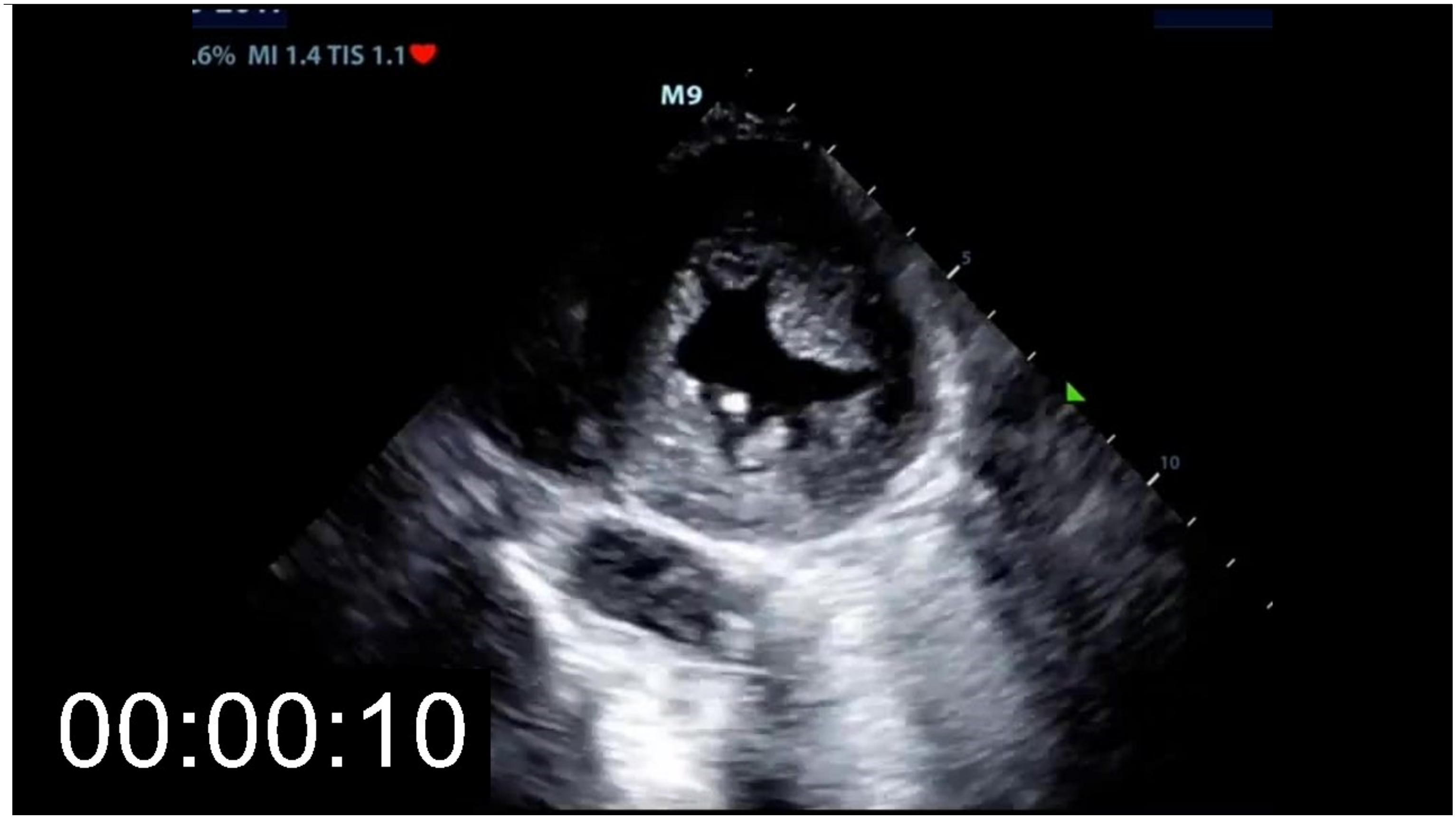
Video 09-14: Decreased left ventricular end diastolic diameter in the parasternal short view

This patient with severe diastolic dysfunction has almost complete obliteration of the LV cavity in the parasternal short axis view. During diastole, however, the LV barely opens, demonstrating that the impressive left ventricular hypertrophy has cause the LV to become too stiff to fill.



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