Point-of-Care Echocardiography

A Primer, 1st edition

Dr. Michael Wong

Editors

Dr. Rajiv Thavanathan
Dr. Michael Woo
Dr. Nathan Hecht
Dr. Brandon Ritcey

Acknowledgements

Thank you

To the countless patients, volunteers, and models who have participated in our education.
To the echocardiographers at The Ottawa Hospital, General Campus.

To the faculty who fostered my interest in ultrasound and paved the way:

Dr. Michael Woo
Dr. Paul Pageau
Dr. Brandon Ritcey
Dr. Nathan Hecht
Dr. Rory Connolly
Dr. James Worrall
Dr. Shuo Peng
Dr. Talia Burwash-Brennan
Dr. Robert Suttie
Dr. Rajiv Thavanathan
Dr. Charisse Kwan
Dr. Rob Chen

Table of Contents:

Common Abbreviations:
Left ventricle (LV)
Right ventricle (RV)
Aorta (Ao)
Left ventricular outflow tract (LVOT)
Inferior vena cava (IVC)
Left atrium (LA)
Right atrium (RA)

Point-of-care ultrasound (POCUS)
Focused cardiac ultrasound (FOCUS)

Subxiphoid (SX)
Parasternal long axis (PSLA)
Parasternal short axis (PSSA)
Apical 4-chamber (A4C)
Apical 5 chamber (A5C)
Apical 3 chamber (A3C)
Tricuspid Annular Plane Systolic Excursion (TAPSE)

Definitions:
Near-field and far-field: refers to whether the structure in question is close to the probe at the top of the screen (near-field) or far from the probe at the bottom of the screen (far-field)

Anechoic, hypoechoic and hyperechoic: put simply, these are terms used to describe the appearance of structures as black, dark, and bright, respectively

Introduction:
Cardiac point-of-care ultrasound (POCUS) is an abbreviated echocardiographic examination of the heart to answer a specific clinical question. It is performed by clinicians at the bedside, distinct from Diagnostic Medical Sonographers. In non-emergency medicine literature, cardiac POCUS is termed “focused cardiac ultrasound” or “FoCUS,” and has been the subject of national cardiology and intensive care guidelines.[1,2] It is used by emergency medicine, trauma, internal medicine, cardiology, and intensive care teams to facilitate early diagnosis, guide management, and safe disposition for patients.

The basic competency of cardiac POCUS involves use of the subxiphoid, parasternal long axis, and parasternal short axis views to assess for pericardial effusions, cardiac activity, and LV function. The addition of apical views is helpful to better assess RV dysfunction, valvular disease, wall motion abnormalities, etc. Multiple views to maximize accuracy are recommended to maximize accuracy.[1,3]

Altogether, a qualitative assessment of the heart with the four core views provides a wealth of information to reliably answer urgent clinical questions. Additional information can be obtained using Doppler measurements and advanced training, but it is important to recognize that POCUS does not supplant a comprehensive echocardiogram, which involves advanced training to generate and interpret approximately 50 clips and measurements.

Probe choice:
The phased array transducer is preferred for its resolution, depth, and small footprint to image between the ribs. In the trauma setting, the curvilinear probe is sometimes used for the subxiphoid view. New technologies, including chip-based transducers and micromachined ultrasound transducers, will likely challenge this paradigm in years to come.

Institutional and Specialty-based Conventions:
The cardiology and radiology convention for the onscreen location of the probe marker (screen left versus right) are often discordant. This varies by institution. If you generate a view that is a mirror image of what you are used to, turning the probe 180^{o} will recreate the familiar view. In the emergency department of The Ottawa Hospital (TOH), the *cardiac settings* of our machines are set using the convention that the probe marker should be on the right side of the screen.

This document is limited by having only still images. The appendix has links to online resources that are very helpful!

In particular, The POCUS Atlas is a free online resource that has example clips of all of these pathologies.

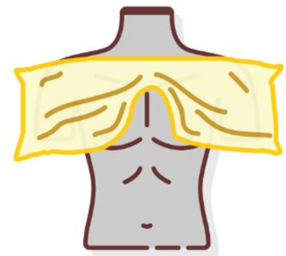
Chapter 1: Producing the Views

Sound waves do not travel well through air (i.e. the lungs) or bone. One must find echocardiographic “windows,” where the lung and ribs are not in the way.

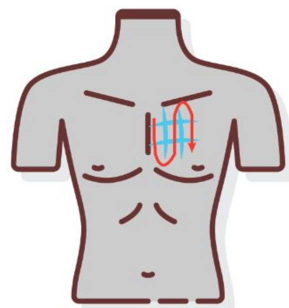
In general, producing each view is an exercise in moving the probe in **one plane at a time**. It’s easy to get lost if you do two probe movements simultaneously.

Stepwise approach to generating an optimal echo image using each of the cardinal motions:

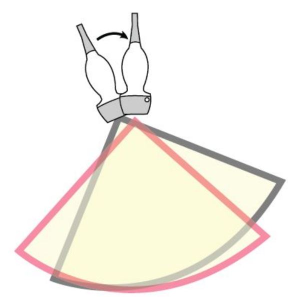
1. Position Like any procedure, half the work is in the preparation – position the patient, raise the bed, etc. Draping the patient is usually easiest with a large towel across the chest, with an “upside-down U” shape to access the 4 echocardiographic windows while keeping the breasts draped.



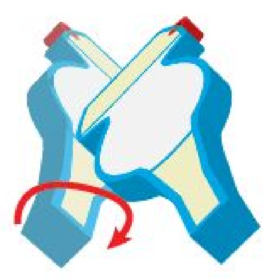
2. Slide (or “translate”) Place the probe on the chest and slide without changing the angle with the skin. For instance, try several rib spaces in a systematic fashion.



3. Heel-toe A heel-toe motion will swing the image left/right on the screen. Put the structure of focus in the middle



4. Rotation All of the views have a “starting point” for rotation (e.g. probe marker to R shoulder for parasternal long axis). Sometimes a slight rotation is necessary to generate the optimal image (e.g. an egg-shaped heart in parasternal short axis needs slight rotation to generate the proper doughnut shaped circle).

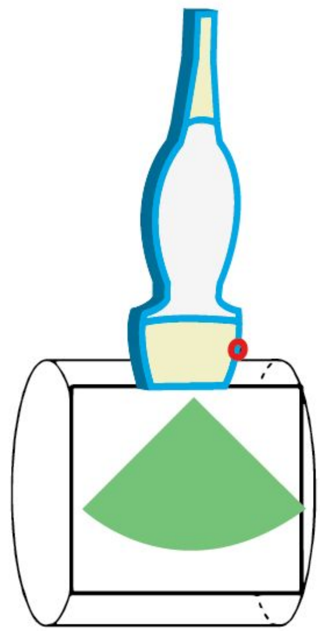


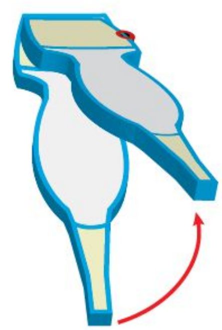
5. Sweep (or "fan")

Fan the probe to ensure you are cutting the structure through its centre such that you are seeing its true diameter.

Imagine putting the probe on the side of a soda can. The can is similar to the heart in that it is easy to slip off the centre and cut the can unevenly (see right, where the probe is not slicing the can in half, generating a smaller rectangle cross-section than if it was at the centre of the can).

Through experience and knowing the ideal target image, you will learn to adjust and compensate for anatomical variation.



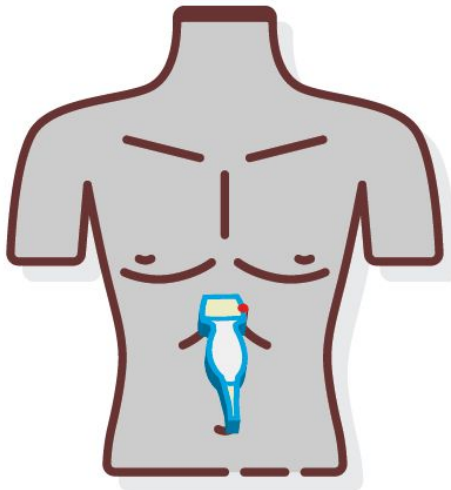


6. Coach breathing

The patient's breathing will move the heart and lung in and out of the way. Asking the patient to breathe slowly and hold at a specific point may help produce the optimal view.

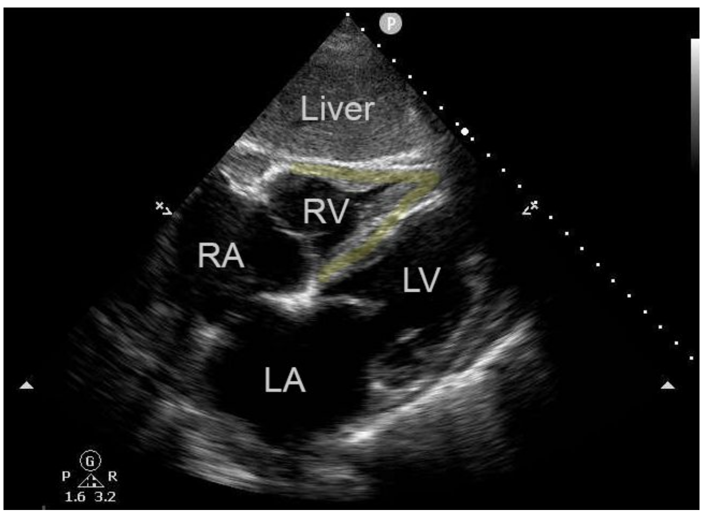
When faced with a partial view, obstructed by lung or bone, use these cardinal motions to move into the window where there is an unobstructed view.

<u>Subxiphoid view (also known as subcostal or SX)</u>



This is the ideal window to examine for a pericardial effusion. It is an underappreciated view. If no other windows are available, an experienced echocardiographer could obtain comprehensive images analogous to the standard slices of the heart from this position. This approach can be very helpful when the lungs are over-inflated (i.e. COPD, intubated, etc.).

With the patient supine, the probe is placed nearly flat on the abdomen, just under the diaphragm, looking at the heart from the bottom up. In cardiac settings (varies by institution), the marker is placed towards the patient's left; in abdominal settings when doing an eFAST with a curvilinear probe, it's to the patient's right. This produces an image where the inferior wall and interventricular septum produce a "7". The depth of the image should be just deep enough to include the entire heart. To adequately assess for pericardial effusion, one must see the entire "7," being careful not to miss the apical region of the septum.



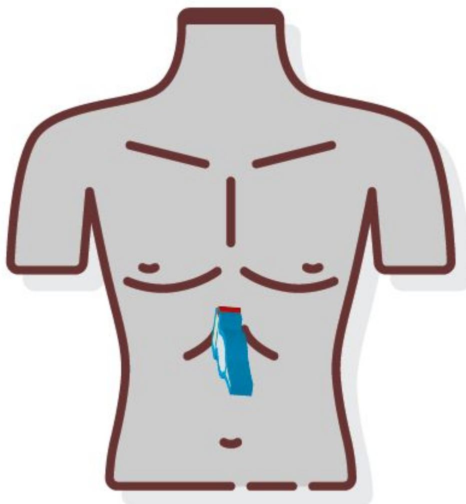
The inferior RV wall and septum form a "7" shape (highlighted in yellow).

Image optimization tips:
- Flexing the hips and knees may minimize abdominal muscle tension
- If bowel gas is in the way,
    - **Use the liver as an acoustic window** - **slide** the probe slightly towards the patient's right, and **heel-toe** towards the patient's left.

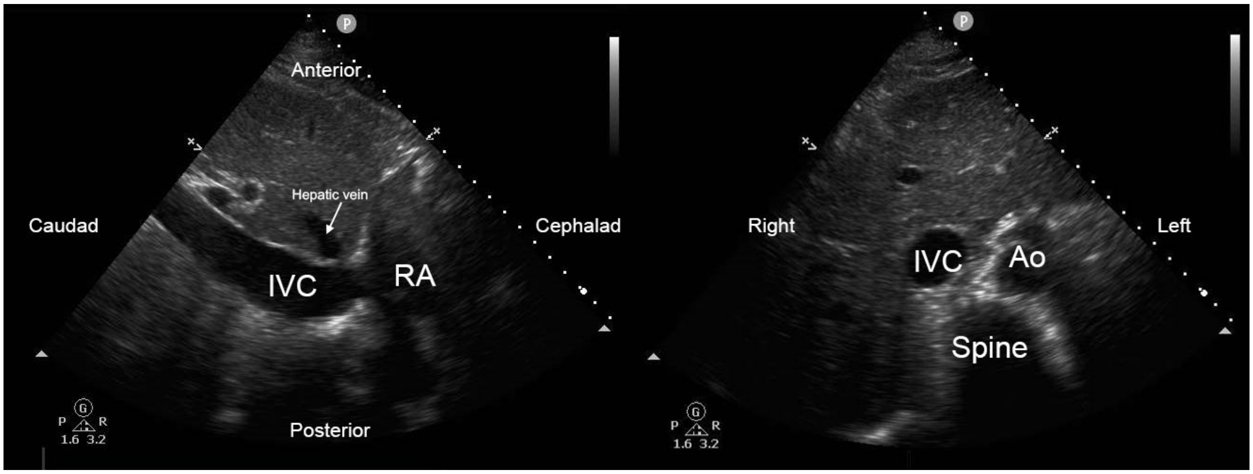
- **Coach breathing -** Ask the patient to take a deep breath and hold. This will bring the heart inferiorly towards the probe.

<u>IVC View</u>

The subcostal view is also the basis from which the inferior vena cava (IVC) can be examined. Angling the probe towards the patient's right to bring the right atrium into the center of the image, and 90^{o} of rotation will produce an image of the liver, IVC in longitudinal, and right atrium.



The IVC can be easily mistaken for the aorta; visualization of the IVC draining directly into the right atrium is necessary to differentiate the two in longitudinal. Both the IVC and aorta may have pulsatile flow and thus it is not reliable as a differentiator. The aorta and IVC can also be imaged in transverse, similar to an abdominal aortic aneurysm scan.



The IVC imaged in longitudinal/sagittal (left) and transverse (right). In longitudinal, ensure the IVC drains directly into the RA. The aorta looks otherwise quite similar.

The IVC alone is not a reliable marker as a sole measure of fluid responsiveness.[4] However, it is still useful information to help narrow the differential, especially at the extremes. Interpret it cautiously in the clinical context:

- A completely full IVC with minimal respiratory variation is valuable information – is there a chronic reason for this (i.e. tricuspid regurgitation, intense athletic training), an obstructive reason (i.e. tamponade, pneumothorax, or positive pressure ventilation), or is the patient hypervolemic?
- A dramatically small "flat" IVC suggests poor venous return along the IVC – is this due to hypovolemia, impaired venous return (e.g. a large IVC clot, increased intra-abdominal pressure), vasodilatory shock, or some other cause?

- In evaluating shock, a normal or small IVC makes obstructive physiology less likely as the cause of hemodynamic instability (i.e. tamponade, tension pneumothorax).

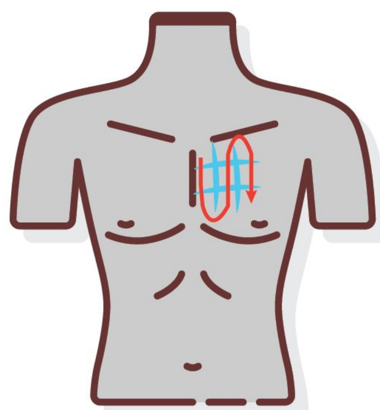
A “normal IVC” is <2.1cm **and** ≥50% collapsible, a “full” IVC is >2.1cm and not 50% collapsible. These are adapted from comprehensive echocardiogram in which right atrial pressure is estimated to be 3, 5, or 8 mm Hg based on if the IVC meets none, one, or both of the “full” criteria.

There is no clear consensus definition of a “flat IVC.”

<u>Parasternal long axis (PSLA)</u>
The parasternal views are optimal for assessing left ventricular (LV) function, the left ventricular outflow tract (LVOT), aortic valve, mitral valve, and proximal aorta. It is also often helpful to assess for pericardial effusion in conjunction with the other views.

The parasternal window is just lateral to the sternum, around the 3rd intercostal space. Place the probe here, angled perpendicular to the patient’s chest, with the probe marker to the right shoulder. The depth of the image should be barely deep enough to see the thoracic aorta in the farfield. Additional depth may be needed to judge if an effusion is pericardial or pleural (see chapter 2).

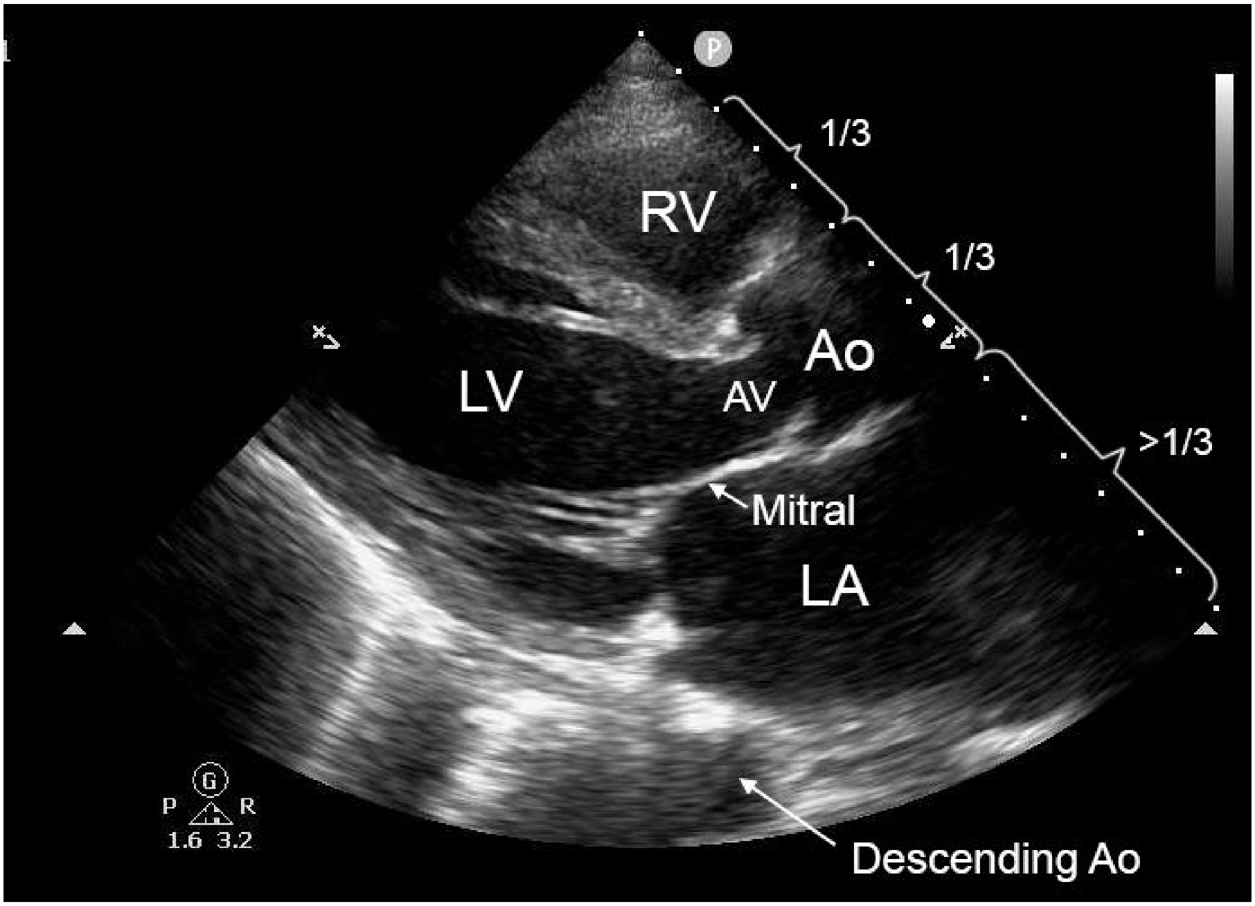
Image optimization tips:



- **Position -** Left lateral decubitus moves the heart towards the chest wall and is the standard position from which echocardiographers do most exams. Rarely is supine better.
- **Slide -** Finding the best window is like going through a tic-tac-toe grid. Systematically check all the squares. The angle of the image and visible structures will change depending on how far away from the sternum you are.
- **Heel-toe** – this motion can be used to center the image on structures at the apex vs the base of the heart.
- **Rotation and Sweep/Fanning –**
    - o Once in the ideal window, you may need to make small rotational or sweeping motions to ensure you are cutting the LV through the centre.
    - o The ideal rotation ensures the LV cavity is visible all the way to the edge of the screen. The ideal sweep will mean the LV cavity appears as large as possible, as if you are slicing the centre of the "pop can" (see page 7).
- **Coach breathing** – Usually, the parasternal is best in full expiration

Other tips
- “Rule-of thirds.” The right ventricle, aortic root, and left atrium should each generally take up 1/3 of the screen unless one is enlarged. Interpret this cautiously if slice is off-axis, as in the soda can analogy described above.

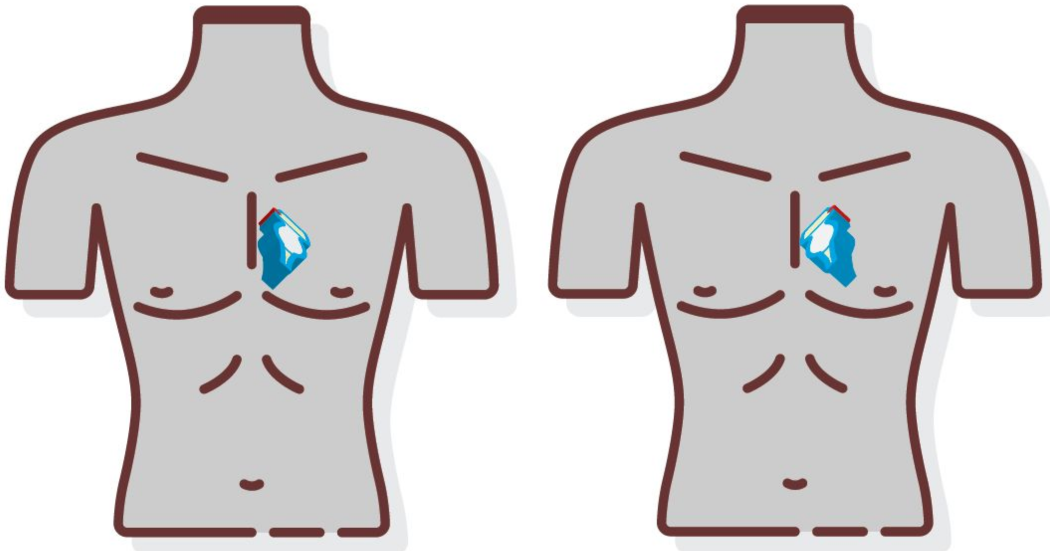
- It is often necessary to make slight adjustments by translating, sweeping, or heel-toe motion to focus on each structure of interest – aortic valve, mitral valve, LV function, aorta, etc.



Parasternal long axis view during systole. Note that both valves are well visualized: the aortic valve (AV) is open and the mitral valve is closed. According to the "rule of thirds," the RV, Ao, and LA on the right of the screen should roughly each take up 1/3 of the screen. In this image, the LA appears larger, suggesting enlargement.

<u>Parasternal short axis (PSSA)</u>

From the long axis view, a clockwise rotation of 90° such that the probe marker moves from the R shoulder to the L shoulder will produce the PSSA view. If you rotated perfectly, whichever structure was in the middle of your screen in the long axis view should still be the focus of your short axis view. If evaluating LV function, one should centre on the papillary muscles when rotating.



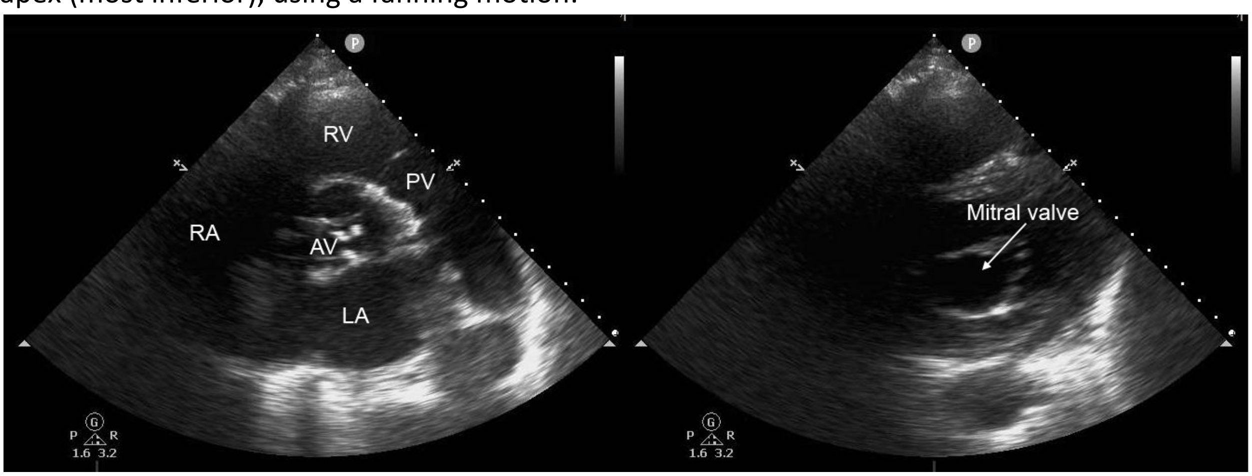
Probe positioning in parasternal long axis (left) versus short axis (right) are 90^o perpendicular. Note the probe marker, visible in red.

You are now cutting the heart in cross-section in a series of doughnut shapes. If you sweep/fan down towards the patient's L foot, you will get apical cross-sections. Sweeping/fanning up towards the patient's head will visualize basal structures such as the aortic valve.

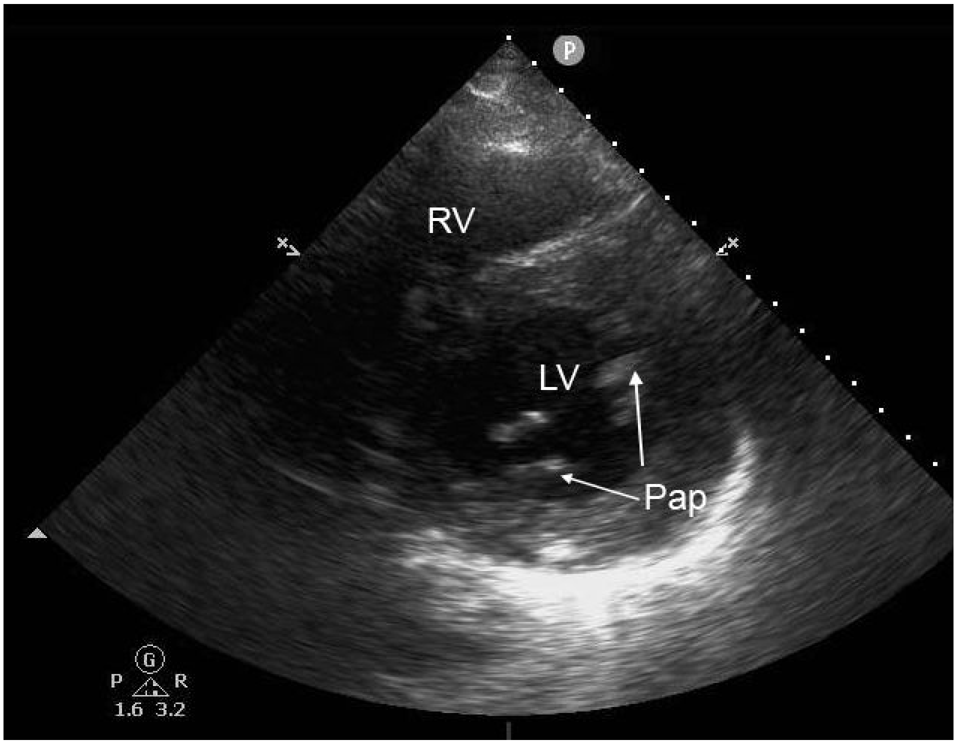
Image Optimization Tips:

- If needed for stability, use two hands to rotate from parasternal long axis
- An egg or oval shaped LV usually indicates over- or under-rotation

The below images are in order from the base of the heart (most superior), down towards the apex (most inferior), using a fanning motion:



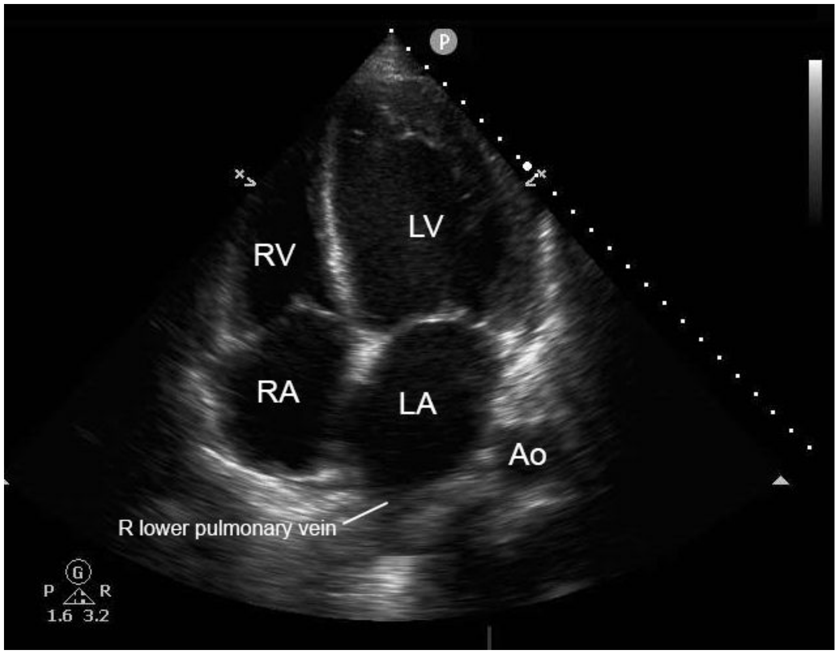
LEFT: *The parasternal short axis view at the level of the aortic valve (AV). Note the classic "Mercedes-Benz sign" of this somewhat sclerosed aortic valve. Also visible is the pulmonic valve (PV).*
RIGHT: *Scanning inferiorly, the "fishmouth" appearance of the mitral valve becomes visible.*



The classic parasternal short axis view of the left ventricle, with the papillary muscles (pap) in cross-section. Fanning superiorly will produce images of the aortic and mitral valve (see above page). Fanning inferiorly will look at the apex of the heart. These papillary muscles are sometimes described as "boxing gloves."

Apical 4-chamber (A4C)

The apical views are core to the RV assessment, but also useful for assessing LV function, valvular pathology, and pericardial effusions. The apical 4-chamber looks at the heart from the tip of the interventricular septum at the apex towards the base.



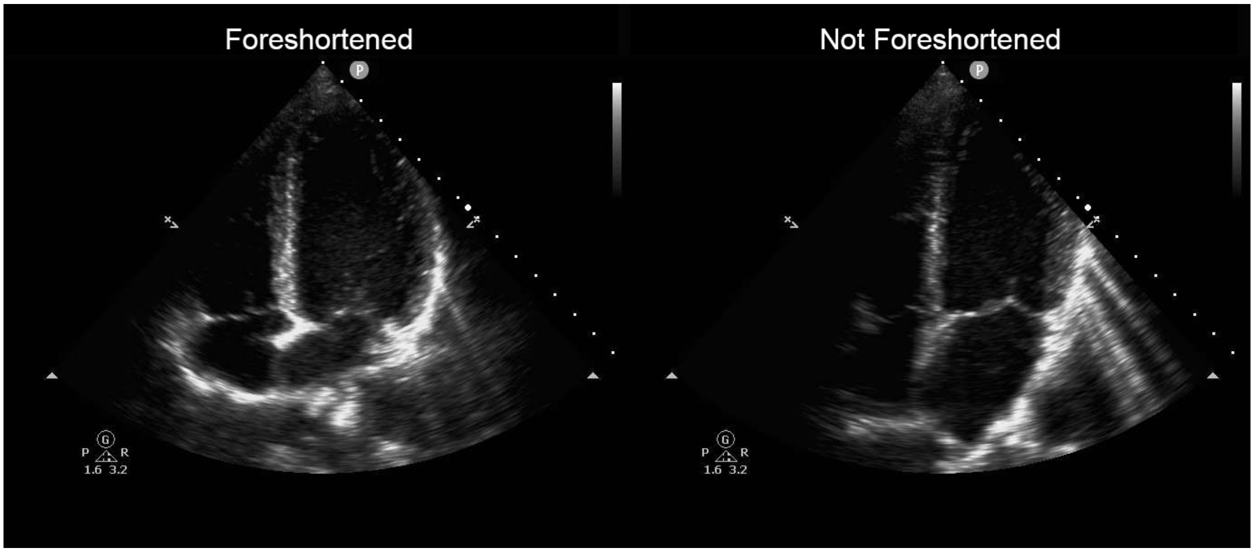
Apical 4-chamber view; to improve this image, one should slide slightly medial, away from the probe marker, to place the tip of the apex in the centre of the screen

Put the probe where you would expect the patient's point of maximal impulse is on clinical exam. A patient with cardiomegaly may have a laterally displaced apex, where a young patient with no cardiac disease should be relatively medial. It tends to be along the inframammary line, under any breast tissue, in the 5^{th} intercostal space.

The probe marker location will be institution dependent. In the cardiac settings, the probe marker is to the patient's left. The probe is angled shallowly and upwards towards the patient's head.

Image optimization tips:

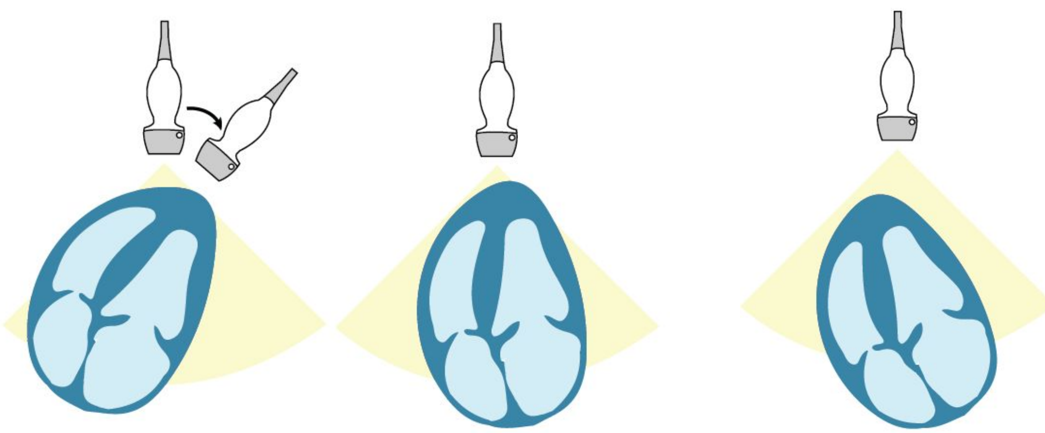
- **Position -** Left lateral decubitus moves the heart towards the chest wall. Only rarely is supine better.
- **Slide –** Place the probe near the point of maximal impulse as discussed above. Finding the best window by translating systematically, trying medial, lateral, down a rib space and up a rib space.
    - o Avoid foreshortening (see image below)



This is the same patient, with the heart viewed from two different rib spaces. The image should look more like a bullet, than a ball. If too round, this is called "foreshortened," and one should attempt more inferior rib spaces. Note how the left atrium becomes much more visible with a non-foreshortened view.

  - o The tip of the apex should be in the centre of the screen – this may require slight medial or lateral translation (see image below)

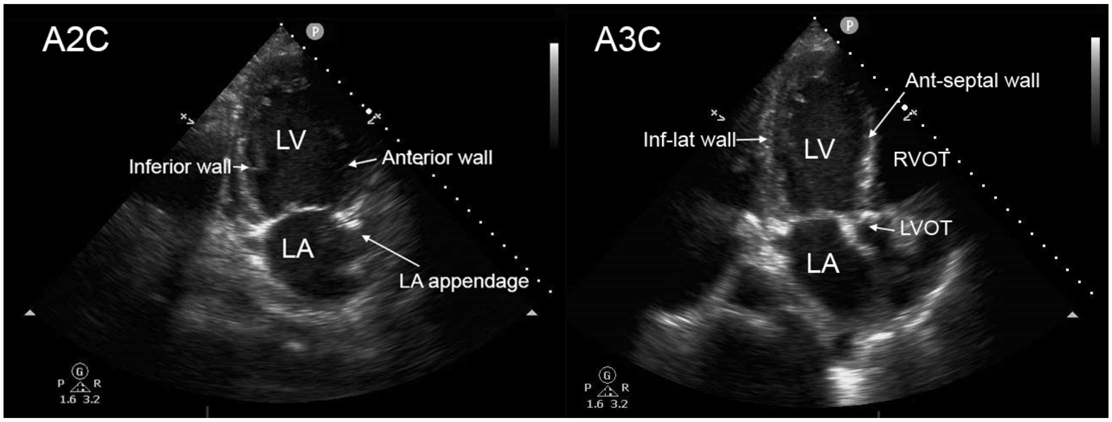
- **Heel-toe** – after sliding to place the tip of the apex in the centre, a heel-toe motion should be used to centre the septum down the centre of the screen.



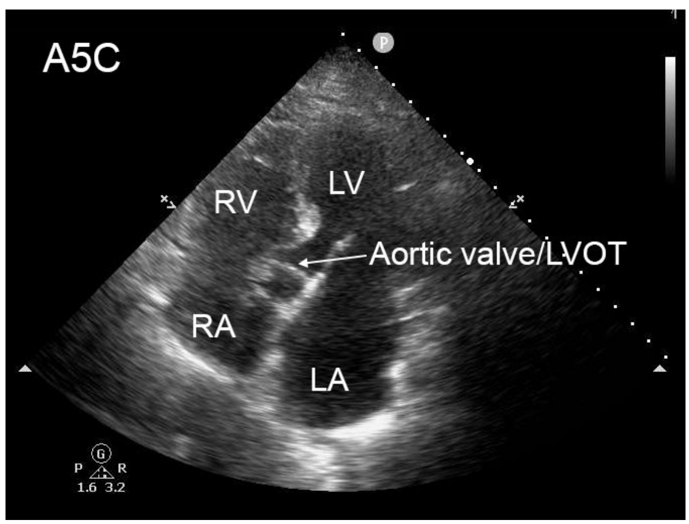
Slide to put the tip of the apex in the centre, then heel-toe such that the septum is down the middle of the screen.

Sometimes using the LV as a blood-filled window will allow better visualization of the RV

- **Rotation -** Once in the ideal window, you may need to make small rotations to maximize width of the ventricles and ensure you see both the tricuspid and mitral valve opening well in the same plane. For advanced indications such as wall motion abnormalities and flow velocity measurements, continued rotation 60^{o} counter clockwise will produce the apical 2-chamber view. Another 60^{o} will produce the apical 3-chamber view.



Fanning/sweeping – Slight fanning may be needed if both the mitral and tricuspid valves appear blurry. If you see the apical 5 chamber view (A5C), which includes the LVOT and aortic valve as the associated "fifth chamber," congratulations you have produced an advanced view! To get back to the A4C view, just fan slightly posteriorly until the aorta disappears.



- **Coach breathing** – The apical view is often best with some inspiration, however, in patients with hyperinflated lungs (i.e. COPD or intubated), this may not be the case. Some trial and error may be needed!

Chapter 2: Clinical Context: Does this patient have…?

Does this patient have **cardiac activity**?

Use of cardiac POCUS during a cardiac arrest requires thoughtful coordination with the rest of the team. For a transthoracic point-of-care assessment, it is often best to start with the probe placed in the subxiphoid region with the image set to an appropriate depth while CPR is still ongoing, *prior* to a pulse-and-rhythm check, and immediately start archiving a clip as the pause begins. Care must be taken to minimize the duration of the echocardiographic assessment to prevent prolonged pauses in CPR. Similarly, avoid distracting the rest of the team with image acquisition and interpretation – if the entire team is looking for cardiac activity, no one is looking at the rhythm, feeling for a pulse, or preparing to resume CPR.

There is no consensus definition of organized cardiac activity during cardiac arrest.[5] However, a reasonable definition is a change in the size of the ventricular cavity and/or synchronized movement of the walls. Slight movements in the valves may not reflect truly organized activity. Providing positive pressure ventilation, or even passive expiration changes the intrathoracic pressure and causes slight movements in the cardiac valves.

CAEP guidelines under review indicate the minimum archiving requirement is the single best possible view.[3]

In the cardiac arrest setting, POCUS is useful:

- to rule out reversible causes of cardiac arrest
    - pericardial effusion suggesting tamponade,
    - pneumothorax
    - signs of pulmonary embolus (beware false positives, see Table p.24)
    - fine ventricular fibrillation mistaken for asystole
- to supplement carotid or femoral pulse checks
- to facilitate invasive femoral arterial blood pressure monitoring or central venous access
- to confirm that the endotracheal tube is not in the esophagus during intubation
- for prognostication (see below)

In the trauma setting, one well-conducted prospective study found that lack of cardiac activity on POCUS predicted death despite resuscitative thoracotomy with 100% sensitivity.[6]

In the medical setting, the absence of cardiac activity with ultrasound does not, by itself, rule out a survivable cardiac arrest. POCUS must be integrated with other prognostic factors including the ECG rhythm, time-to-CPR, duration of CPR, comorbidities, and the reversibility of the suspected etiology. In a 2019 systematic review of non-traumatic, non-shockable cardiac arrest, cardiac activity by itself had a sensitivity of only 60.3% for return of spontaneous circulation.[7] In one retrospective study combining ultrasound with ECG, however, absence of cardiac activity with asystole was 98% sensitive for ruling out ROSC, and 87% with PEA.[8] Incorporating additional prognostic factors may further improve the sensitivity.

Conversely, presence of organized cardiac activity confers a positive prognosis. The aforementioned systematic review of atraumatic PEA/asystole arrest demonstrated a specificity of 91.5% and positive likelihood ratio of 6.9 for return of spontaneous circulation.[7] The odds ratio for ROSC was 16.9, and 8.0 for survival to hospital discharge.

In PEA arrest with organized cardiac activity, framing the patient's condition as severe hypotension and assessing the LV dysfunction may help direct further management. Refer to Dr. Bo Zheng's EMOttawa blog post on PEA arrest on how to consider adjust ACLS if cardiac activity is detected without a palpable pulse.

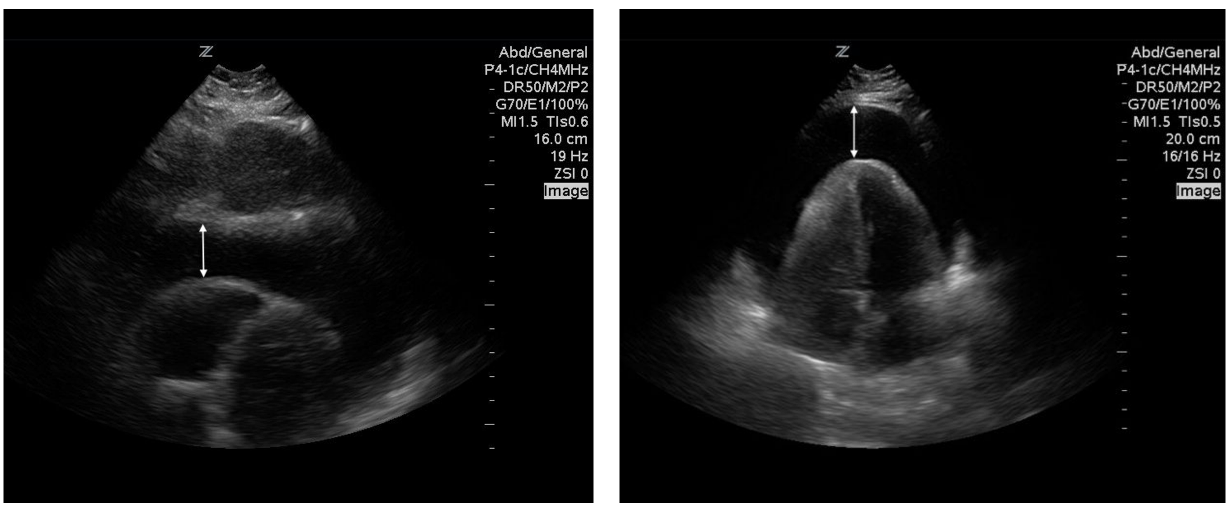
Does this patient have a **pericardial effusion**?

Ultrasound to rule out the presence of a pericardial effusion is part of an eFAST trauma assessment. It should also be considered routinely with unexplained pleuritic chest pain, low voltage ECG, syncope, shock or hypotension, as well as suspected pericarditis, aortic dissection.

A pericardial effusion may be localized or global. Depending on the etiology, it may be free-flowing or localize in one area (e.g. a clot).

Large or free-flowing effusions should be gravity dependent and settle inferiorly. By looking up at the inferior aspect of heart with the subcostal/subxiphoid view, free-flowing pericardial fluid should be most visible just adjacent to the RV in the near-field. A sweep posteriorly, increasing the angle of the probe from shallow to perpendicular will help differentiate a pericardial fat pad from a true effusion.

CAEP Best Practice guidelines under review indicate the minimum archiving requirement is a single view, however, routine correlation with multiple views is recommended if windows are available.[3]

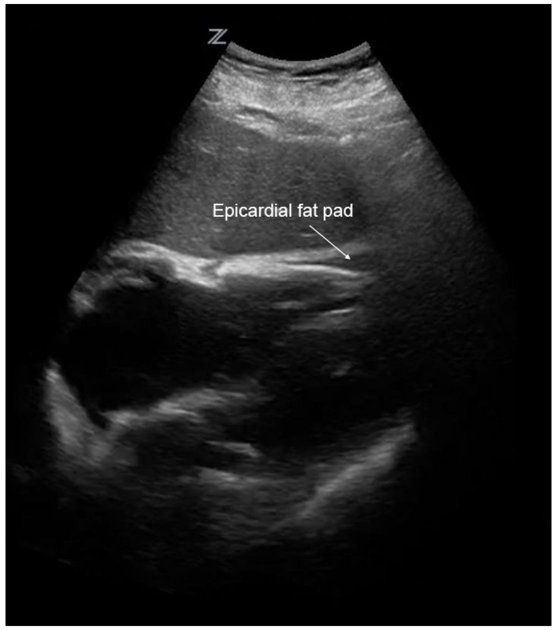


A large pericardial effusion seen in SX and A4C. Size approximately 20mm in diastole.

A pericardial effusion should be characterized:[10]

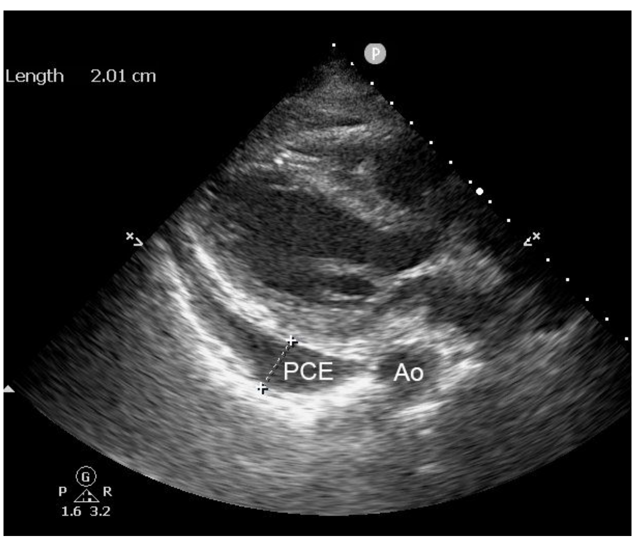
- Measure size in end-diastole: as trivial (seen only in systole), small (<10mm), moderate (10-20mm), large (>20mm), very large (>25mm)
- Fluid appearance (simple, loculated, hypo or hyperechoic, etc.)
- Location (global or localized)

In the subcostal view, the angle between the probe and skin may image the effusion in an oblique fashion, causing over-estimation of the effusion size. Additionally, the pericardial fat pad is a normal anatomic variant and can be seen anterior to the heart as a hypoechoic structure but is lost as one sweeps posteriorly.

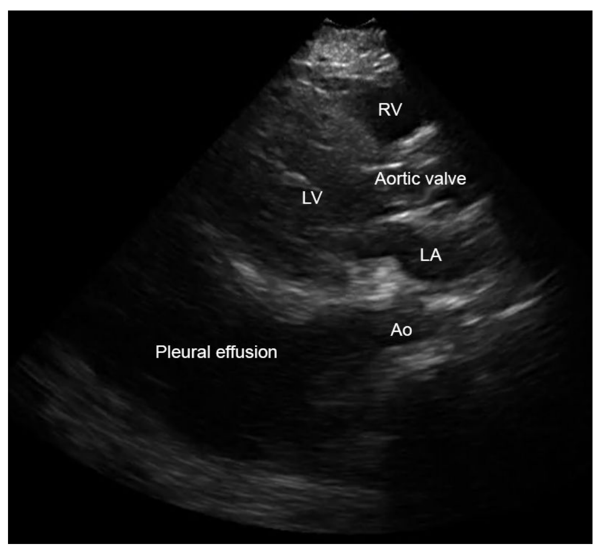


The epicardial fat pad appears similar to a pericardial effusion, but it disappears as one sweeps posteriorly. Additionally, it is usually slightly more hyperechoic (i.e. brighter) than an effusion.

In the parasternal long axis, it is important to distinguish a pericardial effusion from a pleural effusion. A pericardial effusion will track between the heart and the descending thoracic aorta, whereas pleural effusions will track posterior to the descending Ao.



A pericardial effusion (PCE) bound by the layers of the pericardium. The pericardium tracks anterior to the thoracic aorta (Ao).



A pleural effusion continues deep to the thoracic aorta (Ao).

As per usual, interpret the diagnosis a pericardial effusion within the clinical context.

In pericarditis, a pericardial effusion is not required for diagnosis, and echocardiography is often normal. However, it is one of the four possible diagnostic criteria, of which at least two are needed to make a diagnosis.[11] Furthermore, a large pericardial effusion is an indication for admission.[12]

In suspected aortic dissection, a pericardial effusion is a poor prognostic factor and should prompt emergent surgical consultation.

An effusion in the context of penetrating trauma is certainly different than a patient with a slow-growing effusion due to cancer. In the presence of a pericardial effusion, the diagnosis of cardiac tamponade is a clinical one, but may be assisted by a more detailed echocardiographic assessment (see next page).

Does this patient have **cardiac tamponade?**

Cardiac tamponade is a clinical diagnosis, based upon the patient's history, symptoms, vital signs, and physical exam maneuvers such as the presence of a pulsus paradoxus.

POCUS provides a useful adjunct with several sonographic signs that support a diagnosis of tamponade. As the pressure causing tamponade increases, it causes changes initially in the low-pressure systems and progresses to disrupt increasingly higher-pressure systems.

Pericardial effusion with:

- Plethoric, non-collapsable IVC (92-97% Sn)[13,14]
    - IVC <21mm and ≥50% collapse with inspiration is considered normal (defines right atrial pressure = 3 mm Hg)
- Right atrial systolic collapse longer than 1/3 systole (100% Sn and Sp)[13]
    - Intracavitary pressure lowest in early systole; more prolonged with severity
- Right ventricle diastolic collapse[10]
    - Initially only during inspiration, early diastole, and more prolonged with severity
- Inspiratory septal bulge (D-sign during inspiration)[10]
- Additional Doppler signs beyond the scope of this book

Note that RA/RV collapse may be absent with chronically elevated right sided pressure, but absence of collapse of any cardiac chamber has 90% NPV. Elevated R sided pressures (pulmonary hypertension), LBBB, paced rhythm may also cause the inspiratory septal bulge.

With a pericardial effusion, a normal IVC and absence of any chamber collapse is unlikely to represent tamponade, however, clinical and physical exam signs are also key to definitively rule out tamponade.

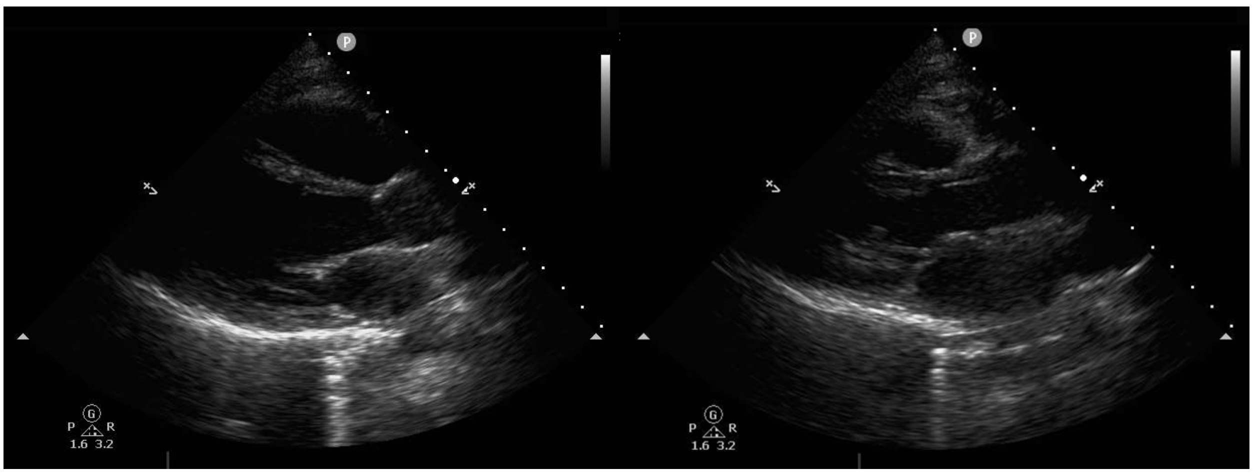
Remember – cardiac tamponade is a clinical diagnosis!

Does this patient have **left ventricular dysfunction?**

Left ventricular function is often expressed as an ejection fraction – what fraction of the blood present in the LV in diastole is ejected? Two methods for estimation of LV systolic function are commonly used in POCUS:

Fractional Shortening (FS)

One can assess the "squeeze" of the left ventricle qualitatively or quantitatively using fractional shortening. It is the change in anterior-posterior measurement of the left ventricle at end systole versus end diastole, expressed as a percentage.



More simply, how much does the ventricle contract between diastole (left) and systole (right)? 10%, 25%, 50%?

An experienced individual looking qualitatively at the ventricle has similar accuracy to quantitative measurements.[15]

Some learners may better understand the concept mathematically:[16]

$$FS = \frac{LV\ \text{end diastolic diameter} - LV\ \text{end systolic diameter}}{LV\ \text{end diastolic diameter}} \times 100$$

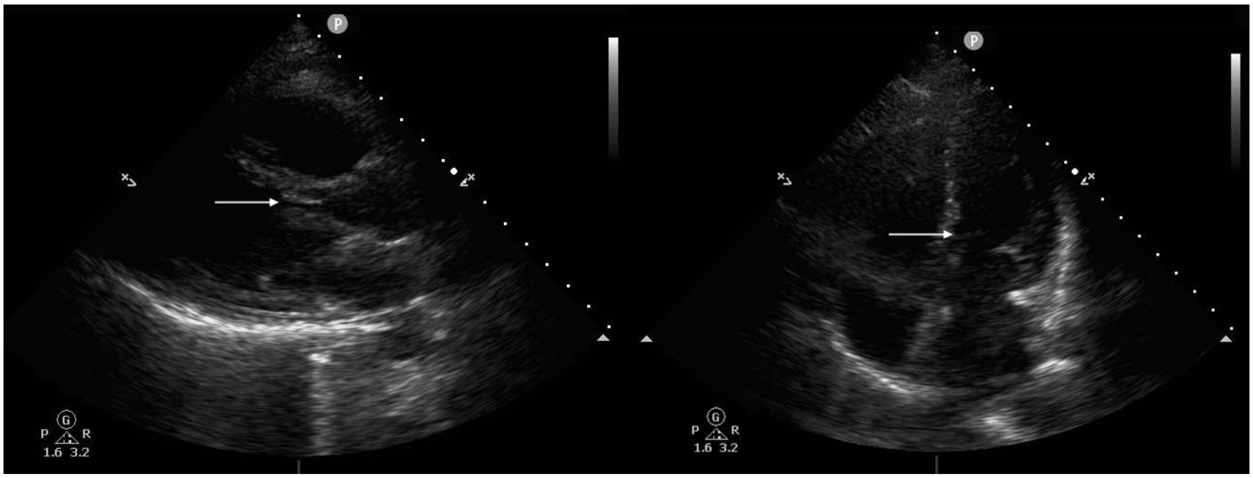
It can be assessed in any of the four main views, but it is most reliable in the parasternal short and long axis. It should be assessed at the level of the chordae tendinae, which lie about 1cm apical from where the septum and aorta join.

It should be noted that this is *not* the same as "ejection fraction" (EF) even though both are expressed as percentages. Fractional shortening is said to be approximately half the ejection fraction, though this is a very rough estimate at best.[17]

Pitfalls: Wall motion abnormalities from scarring or conduction abnormalities may cause specific decrease in movement of septal or lateral wall. If the heart is otherwise globally contracting well, FS will underestimate the LV function. To overcome this, comprehensive echocardiograms use other methods such as Simpsons' method of disks.[16]

<u>E-point septal separation (EPSS)</u>[18,19]

With every diastole, the mitral valve opens and approaches the septum. In the parasternal long axis, the closest distance between the septum and the anterior mitral valve leaflet defines the EPSS. This occurs in early diastole.



EPSS can be evaluated in multiple views. In this case, the mitral valve essentially touches the septum in both the PSLA and A4C views.

The EPSS correlates with ejection fraction in multiple ways. In one MRI study, EPSS can be estimated with the formula:[20]

$$LVEF \ = \ 75.5 - (2.5 \ x \ EPSS)$$

If the EPSS is <7mm, this is likely to be normal. EPSS >7mm is 100% sensitive for predicting severe LV dysfunction.[18]

Pitfalls: EPSS can be falsely elevated if there are other forces pushing the mitral valve away from the septum. This includes any aortic regurgitation, mitral stenosis/restricted movement, or significant LV dilation.

A hyperdynamic left ventricle is defined by an LVEF of 70%, and may qualitatively appear as near-complete collapse of the ventricular cavity during systole. Note that tachycardia with a normal EF may mimic a hyperdynamic heart.

Descriptor	Ejection fraction (LVEF)
Severely depressed	<30%
Mild-moderately depressed	30-55%
Normal	>55%
Hyperdynamic	≥70%

Clinical Integration:

Assessment of the left ventricular function can expedite and increase accuracy of the diagnosis of heart failure, provide information key to guide management of shock, decompensated heart failure, and atrial fibrillation. If LV dysfunction is detected, understanding the cause is key to appropriate disposition.

In one large systematic review (n=17 893), visibly reduced ejection fraction had a sensitivity and specificity of 80.6% for the diagnosis of heart failure.[21] Combined with lung ultrasound, this is a powerful tool. This had the highest positive likelihood ratio compared to any element of the physical exam. It can thus be a powerful tool for differentiating CHF from other causes of dyspnea (i.e. pneumonia or COPDe).

Consider routine use of bedside cardiac ultrasound to assess LV function in the following cases:

- Undifferentiated shock, hypotension, or bradycardia
- Shock or hypotension refractory to initial management
- Undifferentiated dyspnea
- Rapid atrial fibrillation, to rule out severe LV dysfunction before giving rate-control medications that are negative inotropes (beta-blockers or calcium channel blockers)

CAEP Best Practice Guidelines under review indicate that the minimum archiving requirement is a PSLA view.[3] Additional views may be necessary for an adequate assessment.

Does this patient have **acute RV dysfunction (e.g. pulmonary embolism)?**
Diagnosing a pulmonary embolus by ultrasound in a patient too unstable for a CT scan may be a life-saving event made possible by your skills as a clinician-ultrasonographer.

UpToDate (2020) recommends POCUS prior to administration of thrombolysis when CT is unsafe. The 2019 European Society of Cardiology (ESC) guidelines[22] also makes several relevant Class IC recommendations:

- The use of bedside echocardiography for diagnosis of high-risk PE
- Empiric anticoagulation in patients with high or intermediate probability of PE while awaiting definitive imaging

Remember that the accuracy of the exam depends on the pre-test probability. The test characteristics of POCUS significantly improve in the subgroup of patients who are hemodynamically unstable (further discussed below).[23] The ESC guidelines reflect this by stratifying the use of POCUS in the suspected high-risk versus low-risk PE:

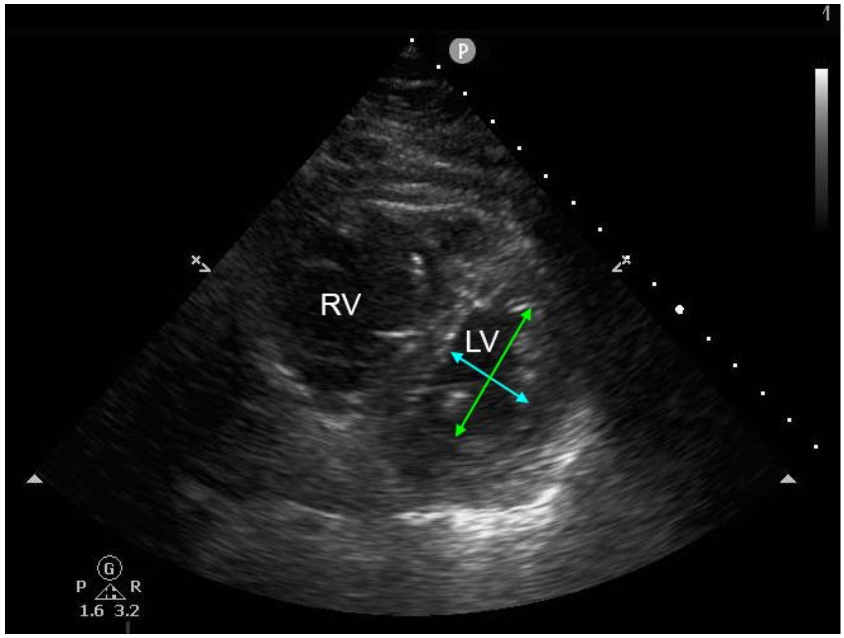
> "Because of the reported NPV of 40-50%, a negative result cannot exclude PE, […] signs of RV overload or dysfunction may also be found in the absence of acute PE. […]
> This is in contrast to suspected high-risk PE, in which the absence of echocardiographic signs of RV overload or dysfunction practically excludes PE as the cause of haemodynamic instability."

Thus, be sure to consider a broad differential diagnosis of RV dysfunction. One important caveat is that in animal studies RV dilation can develop during cardiac arrest irrespective of the etiology of the arrest. The timing and prevalence of this phenomenon is not well studied in humans.[24]

Differential diagnosis of RV dysfunction detected on POCUS
- Pulmonary embolus - Inferior or RV myocardial infarction - Chronic RV disease or pulmonary hypertension - Severe tricuspid regurgitation - Volume overload and left sided heart failure - General low-flow state

Performing the scan:
Diagnosing acute RV dysfunction requires integration of information from multiple views:
On the parasternal short axis view,

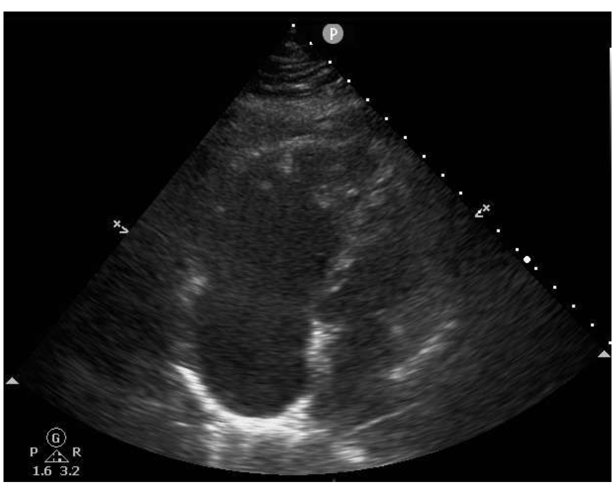
- Evaluate the RV size and presence of D-sign. The D-sign describes the flattening of the interventricular septum, such that the LV is shaped like a D rather than a circle.



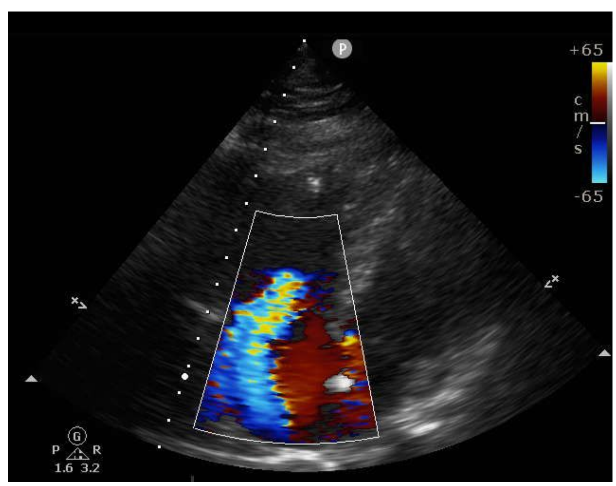
The D-sign. Note the D-shape of the left ventricle with flattening of the septum instead of its usual round shape. The D-sign is technically defined by the anterior-posterior distance (green) being longer than the septal-lateral wall distance (blue).

On the apical 4-chamber view,

- **RV:LV size -** Analogous to the D-sign in the PSSA is the RV: LV ratio in the standard apical 4-chamber view. Normally, RV size is ≤2/3rds that of the LV size. This should be measured at the base of the ventricles in end-diastole. This assessment is limited by how rotation will change the slice of the RV and the relative appearance with the LV. A ratio of RV:LV size ≥ 1 is suggestive of severe RV dilatation.



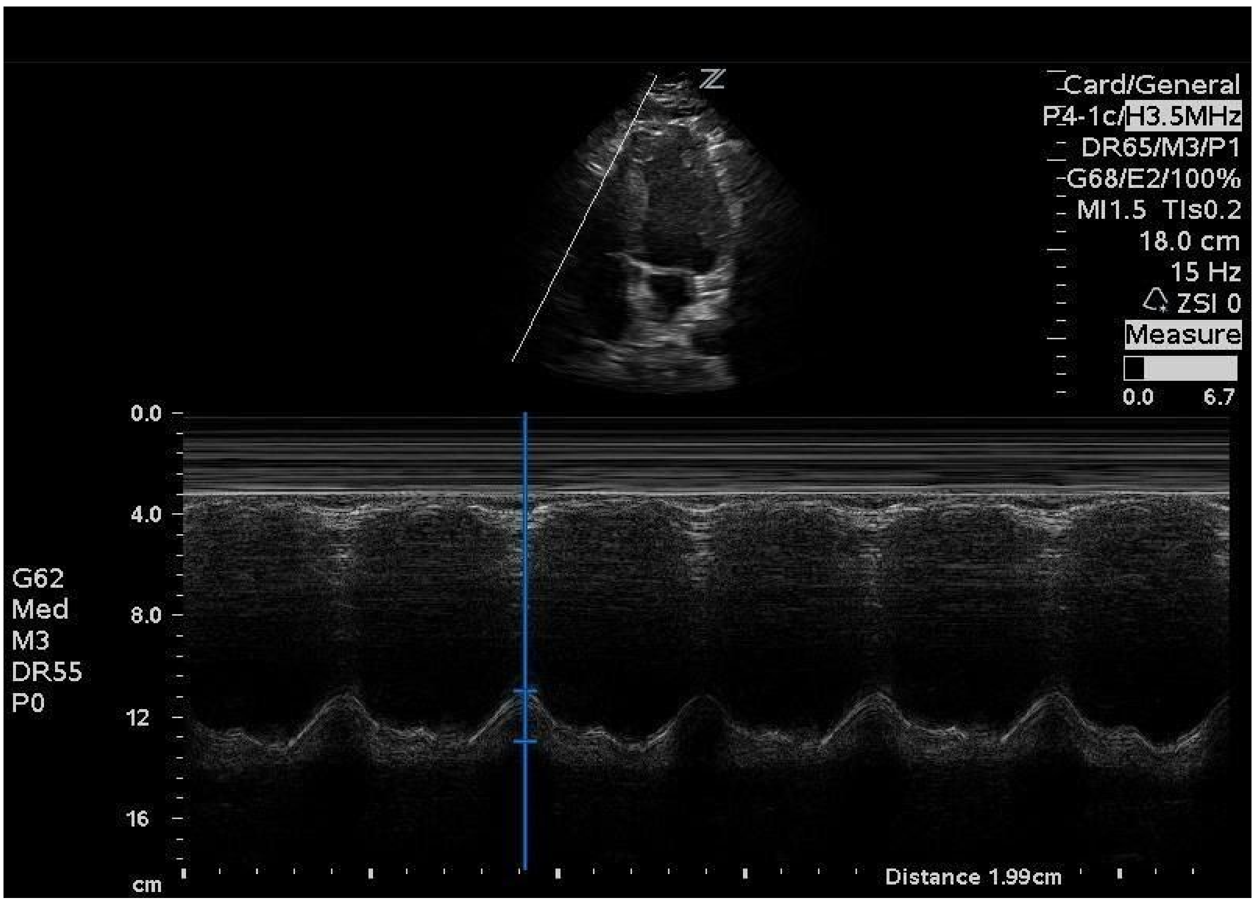
Severe RV dilatation with RV > LV size



Acute tricuspid regurgitation (blue jet) is a non-specific sign of RV dilatation

- **McConnell's sign** is the hypokinesis of the RV free wall with preserved movement of the RV apex. It is hypothesized to be due to tethering of the RV apex to the LV.

- **Tricuspid Annular Plane Systolic Excursion (TAPSE)** may be evaluated qualitatively or quantitatively using M-mode. TAPSE is the distance travelled by the lateral tricuspid annulus towards the apex of the RV during systole. Unlike the LV which contracts concentrically, the RV contracts mostly longitudinally, like a piston. Thus, RV dysfunction can manifest as the tricuspid annulus travelling a shorter distance. Various cutoffs are used but TAPSE <17mm is consistent with severe RV dysfunction; increasing the cutoff to 20mm will increase sensitivity and decrease specificity.[25] It can be quantified by placing the dotted line over the lateral tricuspid annulus and tracing the vertical movement with M-mode. A solid white line will represent the movement of the annulus over time and measuring the distance from peak to trough gives the TAPSE.



TAPSE is measured using M-mode, with the line (see top A4C image) through the lateral aspect of the tricuspid annulus. In this example, the tricuspid annulus is at the depth of approximately 11cm. The user has measured TAPSE at 1.99cm, measuring brightest continuous white line and from peak to trough.

On the subxiphoid or parasternal view,

- In the presence of signs of RV dysfunction, a thick right ventricular wall of at least 5mm suggests the dysfunction may be a chronic process, although this does not necessarily rule out a superimposed acute process. The differential includes pulmonary hypertension, left-sided heart failure, and infiltrative diseases.

On the IVC view,
- A dilated IVC >21mm with <50% inspiratory collapsibility has a differential that includes an obstructive process such as a PE (see IVC discussion above).

The presence of the D-sign/septal flattening throughout the cardiac cycle in end-systole and end-diastole is suggestive of a pressure overload issue. In contrast, the presence of the D-sign/septal flattening only during diastole is more suggestive of a volume overload process.[26]

Differential by presence of septal flattening/D-sign during parts of the cardiac cycle	
Septal flattening in end-systole and end-diastole is **pressure overload**	Septal flattening only in diastole is **volume overload**
- Pulmonary embolism - ARDS - Left sided heart-failure - Pulmonary hypertension - Chronic RV hypertrophy	- Decompensated heart failure - Iatrogenic fluids - Severe tricuspid regurgitation - Developing high-pressure process

<u>Other signs:</u>
Don't forget that POCUS is an excellent test for above knee DVT, which is one of the most specific signs if PE is suspected. Additional signs consistent with pulmonary embolus include seeing a clot in transit, the 60/60 sign and early systolic notching. These are beyond the scope of this book, but if interested, take a look at online resources.

RV strain is one of the components that defines submassive pulmonary embolus and usually managed initially as an inpatient.[27] This can be assessed by ECG, CT, or bedside echocardiography. Compared to comprehensive echocardiography, POCUS by emergency physicians was shown to be 100% sensitive for diagnosing right ventricular strain in patients with known PE, as defined by any of: RV≥LV size, free wall hypokinesis or TAPSE < 10 mm, interventricular septum flattening, or bowing into the LV.[28]

The CAEP Best Practice Guidelines under review indicate that the minimum archiving requirement is an A4C view.[3] Additional views may be necessary for an adequate assessment.

The test characteristics of POCUS for PE in different populations is an area of active research. Briefly, here are key points of three important studies which may inform your practice:

In one sample of patients undergoing POCUS before CT PE, no sign was particularly sensitive, but McConnell's sign and the septal flattening were the most specific tests.[25]

	Sensitivity	Specificity	LR+	LR-
TAPSE 17mm	56%	79%	2.6	0.56
TAPSE 20mm	72%	66%	2.1	0.43
RV ≥ LV size	37%	85%	2.6	0.73
Septal flattening	31%	94% (88-97%)	5.3	0.35
TR (any jet)	43%	80%	2.2	0.71
McConnell's sign	13%	97% (92-99%)	4.8	0.9

In patients with unstable vital signs, the test characteristics of POCUS are much better as a rule out test – just as described above in the European guidelines.[23] A negative test was defined as none of: right ventricular dilation, McConnell's sign, septal flattening, tricuspid regurgitation, and TAPSE <20mm.

	Sensitivity	LR+	LR-
HR ≥ 100 or SBP < 90 mm Hg	92% (78-98)	2.5	0.13
HR ≥ 110 (n = 98)	100% (88-100%)	2.7	0

Combining lung, heart, and DVT scans improve the test characteristics for PE. In one study, among adult patients suspected of PE with a Wells score > 4, finding an alternate diagnosis was an excellent rule out test (100% sensitivity), and finding a DVT was an excellent rule in test (97% specificity).[29]

Chapter 3: Intro to Advanced Cardiac Ultrasound

Doppler

The Doppler Effect refers to the change in frequency of a wave (e.g. the pitch of a sound) as the source moves towards or away from the listener, like the sound of race car passing by. This same principle allows the ultrasound machine to determine if blood or other tissue is moving towards or away from the probe, and how fast.

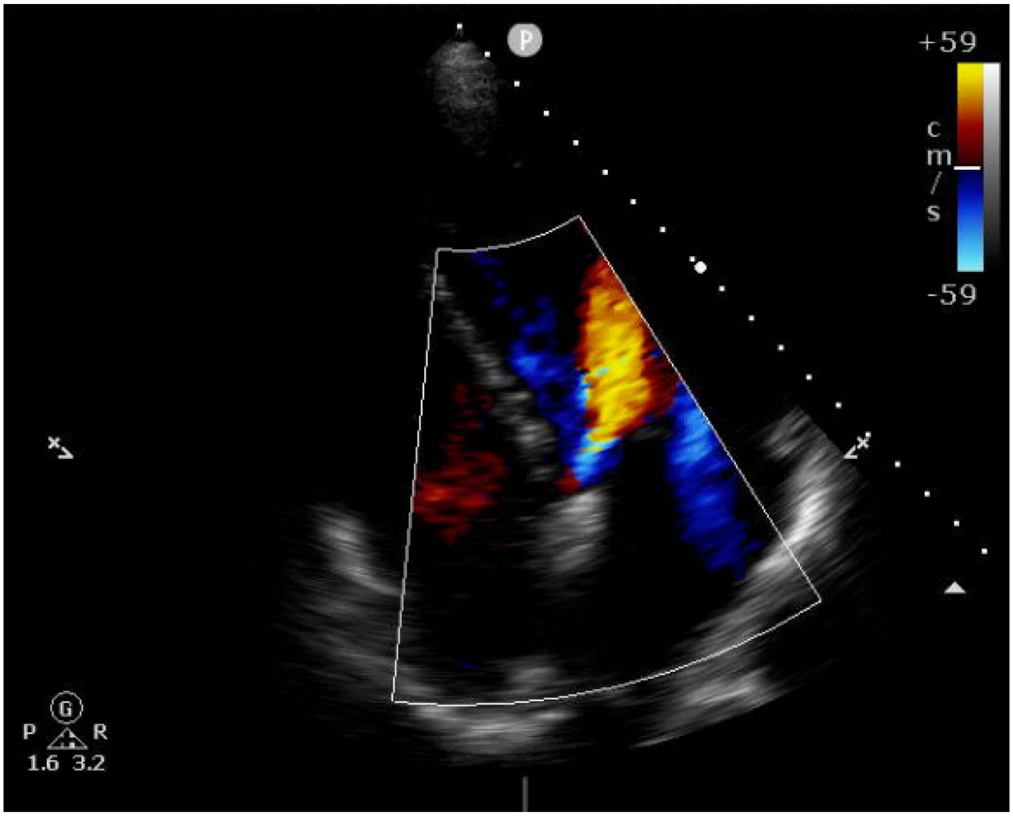
This is most accurate when the object of interest is moving directly towards or away from the ultrasound transducer, in the same path of the ultrasound beam. Conversely, the machine will not detect flow perpendicular to the beam.

The 3 most common uses of Doppler:

- Continuous wave Doppler – the machine emits and samples sound along a straight line, so the machine can pick up the echoes representing the fastest velocity at any point along that line (helpful for high-speed blood flow)
- Pulse wave Doppler – the machine intermittently emits and pauses to "listen". This effectively samples sound at a given distance and can thus measure velocities at that specific point.
- Colour Doppler uses pulse wave Doppler at many points simultaneously to visually show the user flow within the colour box
    - The direction of flow can be remembered by **BART – blue away, red towards**. That is, blue flow is away from the probe and red flow is toward the probe. Despite the use of red and blue colours, please note this does not necessarily correspond to arterial or venous flow.
    - Mixed blue/red/yellow flow indicates the flow is too fast for the machine to determine the direction. This is called aliasing.

Practical points:

- When using colour Doppler, the size of the box should be large enough to encompass the area where flow is expected (e.g. the left atrium and mitral valve when looking for mitral regurgitation) but should also be as small as possible to maximize framerate.
- Remember that structures perpendicular to the beam will not reliably exhibit colour flow.



Blue away, red towards (BART). In this A4C image, there is aortic regurgitation towards the probe, and mitral regurgitation away from the probe. In the top corner, 59cm/s is shown as the maximum speed that the machine can detect. This image could be better optimized by translating so the probe is over the apex, and heel-toe-ing to make it straight. Making the box smaller and evaluating each separately would increase the framerate in a video clip.

Basic approach to valvular abnormalities

Accurately grading valvular abnormalities requires a comprehensive echocardiogram to produce reliable, advanced Doppler measurements. POCUS may not be sufficient to rule out valvular abnormalities in someone with a high pre-test probability. However, the benefit of POCUS is that early detection of severe, clinically significant valvular disease that may prompt appropriate cardiology consultation to determine the need for mechanical interventions. Examples include severe aortic stenosis and chest pain, acute mitral regurgitation with a myocardial infarction, or severe mitral regurgitation with shock.

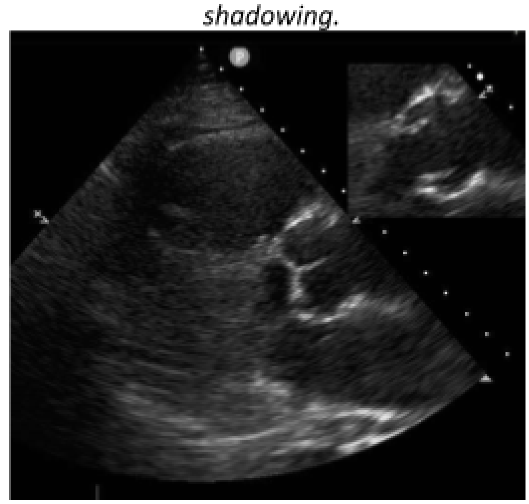
Thickening of aortic valve. More severe calcification often has posterior shadowing.

Adapted approach to valve assessment from the [EMOttawa blog post] by Dr. Darren Wong:

1. Assess the valve form qualitatively
   - Assess the annulus to the leaflet tip
     - Are there areas of calcification or thickening?
   - Is there a mass?
     - Does it move independently of the valve (i.e. suspicious for a vegetation) or is it stuck to the valve?

2. Assess the valve function
   - How does the valve move?
     - Is there normal excursion? (i.e. valve leaflets should open to be fully parallel to the flow)
     - Is there appropriate valve coaptation?

   - Is there severe regurgitation?
     - Add color Doppler, placing the box to include the valve of interest and the chamber in which you are looking regurgitation (e.g. if looking for mitral regurgitation, the box should encompass the mitral valve and the left atrium)
     - If the regurgitant jet fills more than 50% of the area (i.e., LA for MR or Aortic Outflow Tract for AV) then consider the possibility of severe regurgitation.

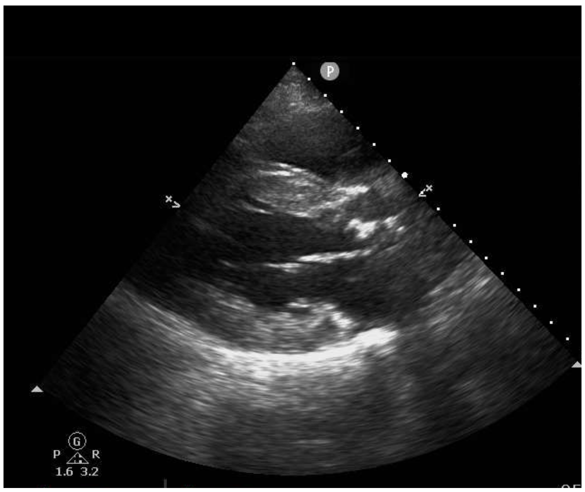


This aortic valve coapts well and opens fully (top right corner) parallel to flow

Aortic stenosis (AS)[30]

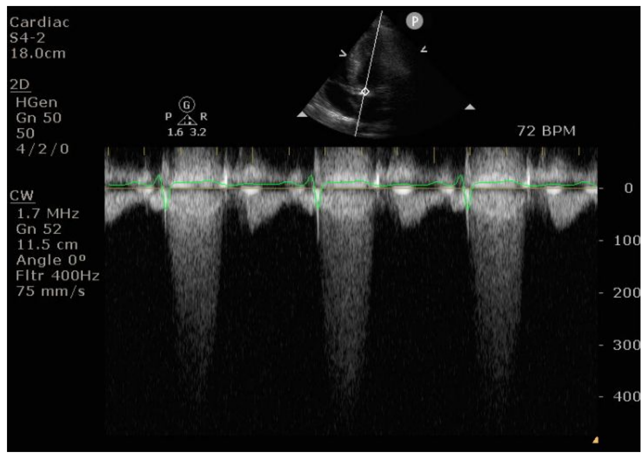
In the context of a murmur, chest pain, or syncope, qualitative assessment alone may increase suspicion of severe aortic stenosis. Grading the stenosis or confirming it to be severe requires continuous wave Doppler measurements from various views.

- AS is unlikely to be severe if at least one cusp, or just the tips of the cusps are opening well.[31,32]
- Features concerning for severe AS:
  - A heavily thickened, calcified, and immobile valve
  - Turbulent flow on colour Doppler
  - Peak velocity of systolic ejection jet ≥4m/s (A5C or A3C view with good alignment of flow directly away from the probe)



Severe AS – note how the calcification of the aortic valve is so severe that there is posterior shadowing

Continuous wave Doppler



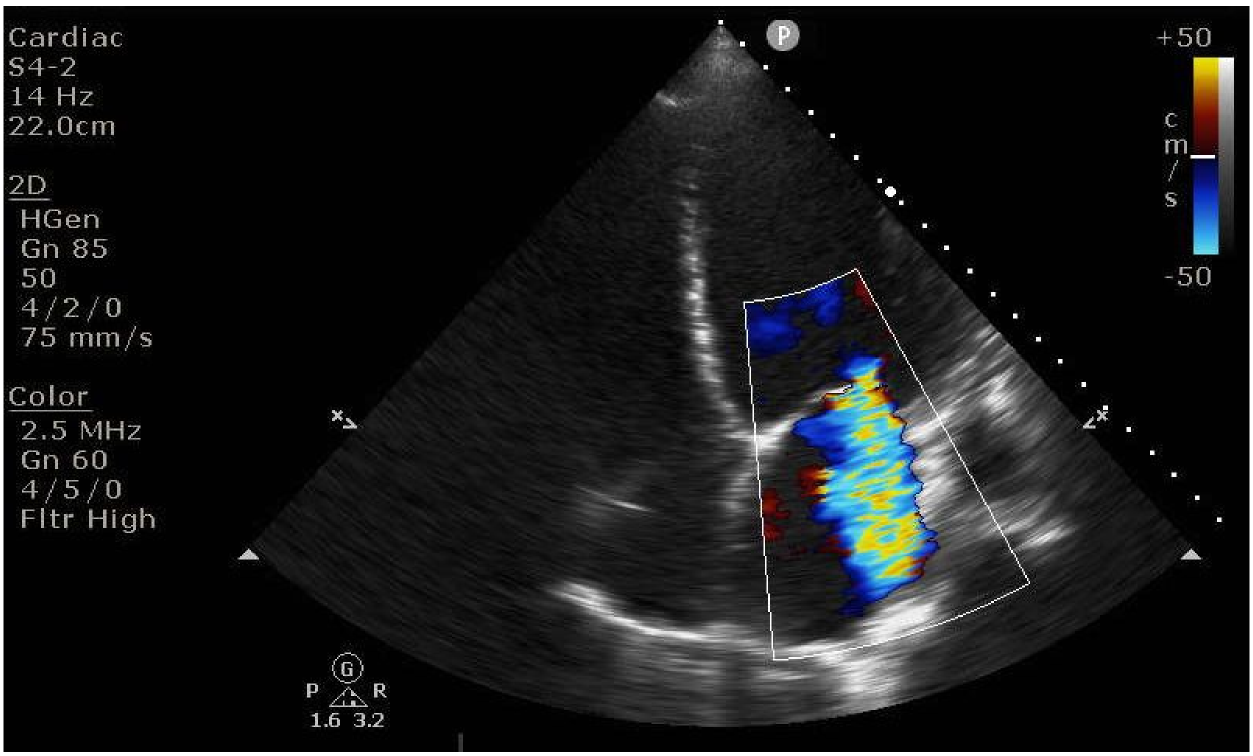
Note how the peak velocity away from the probe (below the baseline) exceeds -400cm/s

Mitral regurgitation[33]

In the context of a myocardial infarction with acute heart failure, cardiogenic shock, or severe heart failure, a diagnosis of severe MR may change management by prompting a mechanical solution. Several POCUS findings are concerning for severe MR:

- Large gap between the mitral valve leaflets during systole
- Ruptured papillary muscle, flail leaflet
- Colour flow jet: LA area >50% or travels to the back wall of the LA (see below)

Beware that the findings may be exaggerated if the LV is over-filled due to hypervolemia or LV dilation. The appearance of functionally severe MR may thus improve with diuresis if there is not an underlying severe structural lesion.

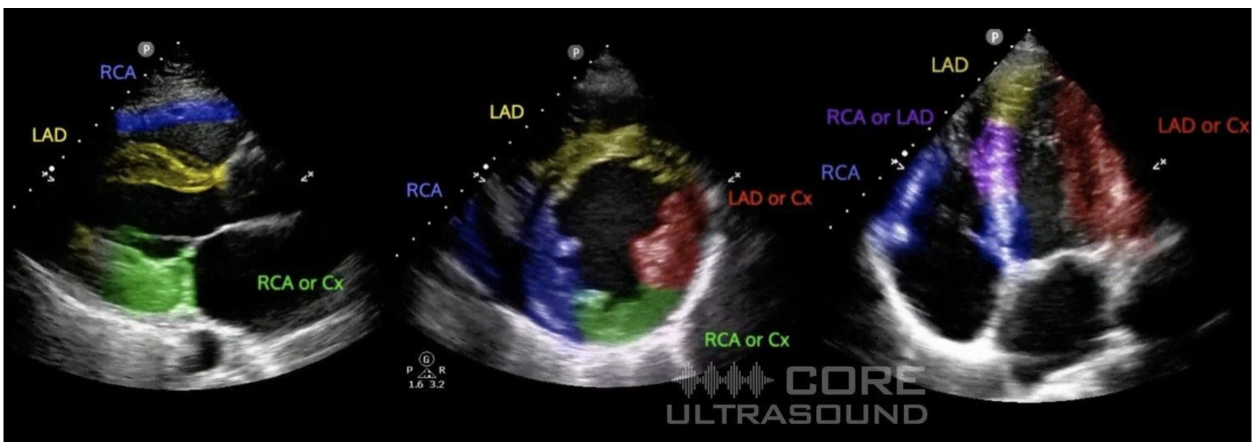


Mitral regurgitation (MR): The size of the jet, with flow reaching the far atrial wall is suspicious for severe MR. Note the aliasing indicating that the flow is faster than 50cm/s. In this case, a comprehensive echo characterized the MR as functional rather than a fixed structural lesion. It may improve with diuresis and medical therapy of the underlying LV dysfunction.

Regional wall motion abnormalities (RWMA)
Regional wall motion abnormalities are potentially useful in the undifferentiated chest pain patient, and to identify high-risk NSTEMI patients that may benefit from early revascularization. The 2014 American Heart Association Unstable Angina/NSTEMI guidelines[34] indicate that echocardiography "may be useful to detect RWMA. [...] Coronary angiography is usually indicated in NSTE-ACS [...] at high risk as categorized by clinical findings [...], non-invasive test findings (significant LV dysfunction with EF <0.40, large anterior or multiple perfusion defects or wall motion abnormalities on echocardiography." Combined with other elements of the clinical picture, it may thus prompt early cath lab activation.

During angioplasty, complete coronary occlusion produces RWMA within seconds, often preceding ECG changes. Reports of the test characteristics in using echocardiography to diagnose myocardial infarction range from sensitivity of 71-100% and a specificity of 53-100%.[35]

There are 17 different muscular segments of the left ventricle. The greatest value for emergency department providers is in assessing segments corresponding to territories of each coronary artery in multiple views.



PSLA, PSSA, A4C views and association with coronary blood supply. As you can see the PSSA view is particularly high-yield.
Reproduced with permission from www.coreultrasound.com/5ms_rwma

The apical 2-chamber view is also particularly helpful to evaluate the anterior and posterior walls.

Each segment is scored using this system:

Category	**Numerical grade**	**Description**
Normal or hyperkinetic	1	Normal thickening and excursion
Hypokinetic	2	Reduced thickening
Akinetic	3	Absent or negligible thickening
Dyskinetic	4	Systolic thinning or bulging away in systole

Beware - assessing RWMA is an advanced skill, and if the angle of insonation is not optimal, it is easy to over-call a wall motion abnormality. They must also be interpreted in the clinical context as the differential is broad.

Differential diagnosis for regional wall motion abnormalities

- Coronary artery disease
    o New/active
    o Old /myocardial scarring
- Myocardial scar from surgery
- Localized myocarditis
- Takotsubo cardiomyopathy
- Electrical abnormality (e.g. pacer, LBBB, accessory pathway, etc.)
- RV pressure/volume overload
- Sarcoidosis
- LV aneurysm

Chapter 4: Quick Reference

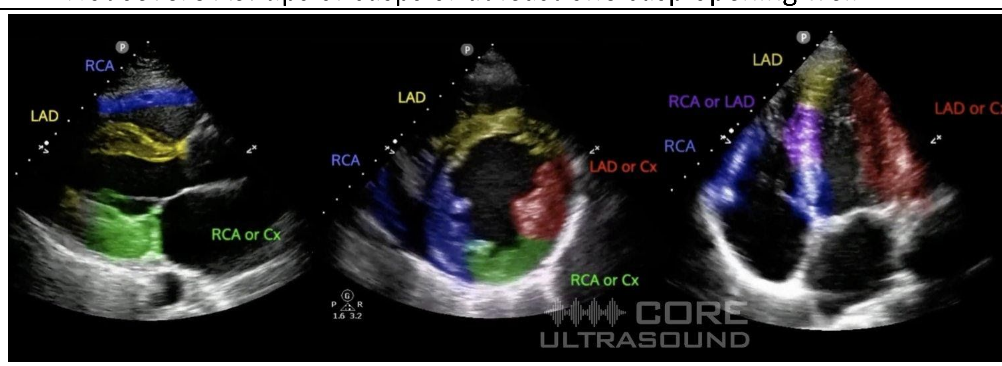
Dr. Rob Chen's 'Dim Sum Rules' of Cardiac Ultrasound – a.k.a. The Rule of Fours
The below is quoted from Dr. Chen's blog:

> Dim sum is usually served with items coming in groups of three or five. To avoid bad luck, garnish is usually added to a four-item dish because four is a homonym for death in Cantonese. Nonetheless, four is a very convenient number for cardiac ultrasound:
>
> LA diameter: 4 cm (bigger = bad)
> RA diameter: a bit more than 4cm
> LV diameter in diastole: at least 4cm (smaller = empty)
> Aortic root size: <4cm (bigger = bad)
> LV fractional shortening: 1/4 (25% = normal)
> AS severe when dimensionless index 1/4 (or Doppler velocity index = 4)

Best Practice: Minimum Archiving Requirements[3]
Additional views should be routinely assessed if windows are available and may be needed for an adequate assessment. This table represents the absolute minimum requirement for archiving, reflecting that if only a single view is available, it should be archived.

Indication	**Minimum Archiving Requirement**
Cardiac arrest	Best possible view
Left ventricular function	Parasternal long axis view
Right ventricular function	Apical 4-chamber view
Pericardial effusion	Best possible view, subxiphoid is the most common

Quick Reference Handout

<u>PCE</u>	
Size	- Trivial (seen only in systole), small (<10mm), moderate (10-20mm), large (>20mm), very large (>25mm)
Tamponade	- Clinical dx - Plethoric, non-collapsible IVC (92-97% Sn) - RA systolic collapse longer than 1/3 systole (100% Sn and Sp) - RV diastolic collapse (initially inspiration, more prolonged w/ severity) - Bulge sign on inspiration
<u>LV function</u>	
EPSS	- EPSS > 7mm associated with LVEF≤30% (Sn 100%, Sp 52%) o Increasing to 10mm increases specificity
Fractional Shortening	- Fractional shortening >25% is normal o *Very* rough estimate, FS = ½ EF
<u>RV function</u>	- PSSA: Anterior-posterior diameter > septal-lateral diameter defines the D-sign (in the literature also known as eccentricity sign >1) - A4C: RV:LV size ratio 0.6:1 is normal, ≥1 is definitely abnormal - TAPSE <17mm suggestive of RV dysfunction, increasing to 20mm will increase sensitivity but decrease specificity - SX or PSLA: Free wall thickness ≥5mm suggests chronic RV dysfunction
<u>IVC</u>	- Size <21mm and ≥50% collapsible on sniff test is normal o >21mm and <50% collapsible is full
<u>Valves</u>	- Severe MR: Colour flow jet: LA area >50% or travels to LA back wall - Severe AR: Width of jet diameter: LVOT diameter ≥0.65 - Severe AS: Calcified and not moving. Peak velocity jet ≥4m/s - Not severe AS: tips of cusps or at least one cusp opening well
<u>Regional Wall Motion</u>	
<u>Size criteria</u>	LA diameter ≤ 4 cm RA diameter ≤ a bit more than 4cm LV diameter in diastole > 4cm (smaller = empty) Aortic root size ≤4cm

Appendix: Resources for Further Learning

I have no financial interests in any of these products, they are simply great books and websites that I have found helpful!

University of Toronto Virtual Transthoracic Echocardiography

- Virtual 3D models to play with to understand the anatomy and the views
- http://pie.med.utoronto.ca/TTE/TTE_content/standardViews.html

Introduction to Bedside Ultrasound Volume 1 and Volume 2 *by Dawson and Mallin*

- Available on Apple Books for small-medium cost
- A simple textbook on emergency department POCUS - the "POCUS fellow textbook"
- Written by the creators of the Ultrasound Podcast
- The cardiac chapters are concise and clear

Put the Probe Here *by Christopher Labos and Chris Lui*

- Available on Apple Books for nominal cost
- Meant for residents doing an echocardiography rotation
- Incredibly brief book that goes through physics, how to use Doppler, how to generate the entire comprehensive echo and interpret it

The POCUS Atlas http://www.thepocusatlas.com/

- Free
- GIF based examples of everything
- The Evidence Atlas (part of the POCUS Atlas) keeps track of the sensitivities and specificities of POCUS for various situations

Ultrasound G.E.L. Podcast

- Free - online POCUS journal club

The Ultrasound Podcast

- Free discussions of POCUS related issues and tips and tricks on scans

EchoCalc

- Free App by the British Society of Echocardiography for reference values and calculators

WesternSono

- Excellent website for list of normal measurements: https://westernsono.ca/advanced-critical-care-ultrasound-quantitative-assessment-resource/

Image Attributions:

- Illustrations are original, by Michael Wong, except the image of the human chest was modified from original icon made by Pixel Perfect from www.flaticon.com
- Image of wall motion coronary artery distribution reproduced with permission from www.coreultrasound.com/5ms_rwma

References

1. Spencer KT, Kimura BJ, Korcarz CE, Pellikka PA, Rahko PS, Siegel RJ. Focused cardiac ultrasound: Recommendations from the american society of echocardiography. *J Am Soc Echocardiogr*. 2013;26(6):567-581. doi:10.1016/j.echo.2013.04.001
2. Levitov A, Frankel HL, Blaivas M, et al. Guidelines for the appropriate use of bedside general and cardiac ultrasonography in the evaluation of critically ill patients - Part II: Cardiac ultrasonography. *Crit Care Med*. 2016;44(6):1206-1227. doi:10.1097/CCM.0000000000001847
3. Wong M, Woo M, Cheung W, Pageau P, Olszynski P, Lewis D. P002: Minimum archiving requirements for emergency medicine point-of-care ultrasound: a modified Delphi-derived national consensus. *CJEM*. 2020;22(S1):S65-S65. doi:10.1017/cem.2020.210
4. Orso D, Paoli I, Piani T, Cilenti FL, Cristiani L, Guglielmo N. Accuracy of Ultrasonographic Measurements of Inferior Vena Cava to Determine Fluid Responsiveness: A Systematic Review and Meta-Analysis. *J Intensive Care Med*. 2020;35(4):354-363. doi:10.1177/0885066617752308
5. Hu K, Gupta N, Teran F, Saul T, Nelson BP, Andrus P. Variability in Interpretation of Cardiac Standstill Among Physician Sonographers. *Ann Emerg Med*. 2018;71(2):193-198. doi:10.1016/j.annemergmed.2017.07.476
6. Inaba K, Chouliaras K, Zakaluzny S, et al. FAST ultrasound examination as a predictor of outcomes after resuscitative thoracotomy a prospective evaluation. *Ann Surg*. 2015;262(3):512-516. doi:10.1097/SLA.0000000000001421
7. Lalande E, Burwash-Brennan T, Burns K, et al. Is point-of-care ultrasound a reliable predictor of outcome during atraumatic, non-shockable cardiac arrest? A systematic review and meta-analysis from the SHoC investigators. *Resuscitation*. 2019;139:159-166. doi:10.1016/j.resuscitation.2019.03.027
8. Beckett N, Atkinson P, Fraser J, et al. Do combined ultrasound and electrocardiogram-rhythm findings predict survival in emergency department cardiac arrest patients? The Second Sonography in Hypotension and Cardiac Arrest in the Emergency Department (SHoC-ED2) study. *Can J Emerg Med*. 2019;21(6):739-743. doi:10.1017/cem.2019.397
9. Gaspari R, Weekes A, Adhikari S, et al. Emergency department point-of-care ultrasound in out-of-hospital and in-ED cardiac arrest. *Resuscitation*. 2016;109:33-39. doi:10.1016/j.resuscitation.2016.09.018
10. Klein AL, Abbara S, Agler DA, et al. American society of echocardiography clinical recommendations for multimodality cardiovascular imaging of patients with pericardial disease: Endorsed by the society for cardiovascular magnetic resonance and society of cardiovascular computed tomography. *J Am Soc Echocardiogr*. 2013;26(9):965-1012.e15. doi:10.1016/j.echo.2013.06.023
11. Chiabrando JG, Bonaventura A, Vecchié A, et al. Management of Acute and Recurrent Pericarditis: JACC State-of-the-Art Review. *J Am Coll Cardiol*. 2020;75(1):76-92. doi:10.1016/j.jacc.2019.11.021
12. Imazio M, Demichelis B, Parrini I, et al. Day-hospital treatment of acute pericarditis: a management program for outpatient therapy. *J Am Coll Cardiol*. 2004;43(6):1042-1046. doi:10.1016/j.jacc.2003.09.055
13. Klein AL, Abbara S, Agler DA, et al. American society of echocardiography clinical recommendations for multimodality cardiovascular imaging of patients with pericardial disease: Endorsed by the society for cardiovascular magnetic resonance and society of cardiovascular computed tomography. *J Am Soc Echocardiogr*. 2013;26(9):965-1012.e15. doi:10.1016/j.echo.2013.06.023
14. Alerhand S, Carter JM. What echocardiographic findings suggest a pericardial effusion is causing tamponade? *Am J Emerg Med*. 2019;37(2):321-326. doi:10.1016/j.ajem.2018.11.004
15. Weekes AJ, Tassone HM, Babcock A, et al. Comparison of serial qualitative and quantitative assessments of caval index and left ventricular systolic function during early fluid resuscitation of hypotensive emergency department patients. *Acad Emerg Med Off J Soc Acad Emerg Med*. 2011;18(9):912-921. doi:10.1111/j.1553-2712.2011.01157.x
16. Lang RM, Badano LP, Victor MA, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr*. 2015;28(1):1-39.e14. doi:10.1016/j.echo.2014.10.003
17. Mallin M, Dawson M. *Introduction to Bedside Ultrasound: Volume 2*. Apple Books; 2013.
18. Mckaigney CJ, Krantz MJ, La Rocque CL, Hurst ND, Buchanan MS, Kendall JL. E-point septal separation: A bedside tool for emergency physician assessment of left ventricular ejection fraction. *Am J Emerg Med*. 2014;32(6):493-497. doi:10.1016/j.ajem.2014.01.045
19. Secko MA, Lazar JM, Salciccioli LA, Stone MB. Can junior emergency physicians use E-point septal separation to accurately estimate left ventricular function in acutely dyspneic patients? *Acad Emerg Med Off J Soc Acad Emerg Med*. 2011;18(11):1223-1226. doi:10.1111/j.1553-2712.2011.01196.x
20. Silverstein JR, Laffely NH, Rifkin RD. Quantitative estimation of left ventricular ejection fraction from mitral valve E-point to septal separation and comparison to magnetic resonance imaging. *Am J Cardiol*. 2006;97(1):137-140. doi:10.1016/j.amjcard.2005.07.118
21. Martindale JL, Wakai A, Collins SP, et al. Diagnosing Acute Heart Failure in the Emergency Department: A Systematic Review and Meta-analysis. *Acad Emerg Med*. 2016;23(3):223-242. doi:10.1111/acem.12878
22. Konstantinides S V., Meyer G, Bueno H, et al. 2019 ESC Guidelines for the diagnosis and management of acute pulmonary embolism developed in collaboration with the European respiratory society (ERS). *Eur Heart J*. 2020;41(4):543-603. doi:10.1093/eurheartj/ehz405
23. Daley JI, Dwyer KH, Grunwald Z, et al. Increased Sensitivity of Focused Cardiac Ultrasound for Pulmonary Embolism in Emergency Department Patients With Abnormal Vital Signs. *Acad Emerg Med Off J Soc Acad Emerg Med*. 2019;26(11):1211-1220. doi:10.1111/acem.13774
24. Aagaard R, Granfeldt A, Bøtker MT, Mygind-Klausen T, Kirkegaard H, Løfgren B. The Right Ventricle Is Dilated During Resuscitation From Cardiac Arrest Caused by Hypovolemia: A Porcine Ultrasound Study. *Crit Care Med*. 2017;45(9):e963-e970. doi:10.1097/CCM.0000000000002464
25. Daley J, Grotberg J, Pare J, et al. Emergency physician performed tricuspid annular plane systolic excursion in the evaluation of suspected pulmonary embolism. *Am J Emerg Med*. 2017;35(1):106-111. doi:10.1016/j.ajem.2016.10.018
26. Ryan T, Petrovic O, Dillon JC, Feigenbaum H, Conley MJ, Armstrong WF. An echocardiographic index for separation of right ventricular volume and pressure overload. *J Am Coll Cardiol*. 1985;5(4):918-924. doi:10.1016/S0735-1097(85)80433-2
27. Jaff MR, McMurtry MS, Archer SL, et al. Management of massive and submassive pulmonary embolism, iliofemoral deep vein thrombosis, and chronic thromboembolic pulmonary hypertension: A scientific statement from the american heart association. *Circulation*. 2011;123(16):1788-1830. doi:10.1161/CIR.0b013e318214914f
28. Weekes AJ, Thacker G, Troha D, et al. Diagnostic Accuracy of Right Ventricular Dysfunction Markers in Normotensive Emergency Department Patients With Acute Pulmonary Embolism. *Ann Emerg Med*. 2016;68(3):277-291. doi:10.1016/j.annemergmed.2016.01.027
29. Nazerian P, Vanni S, Volpicelli G, et al. Accuracy of point-of-care multiorgan ultrasonography for the diagnosis of pulmonary embolism. *Chest*. 2014;145(5):950-957. doi:10.1378/chest.13-1087
30. Baumgartner H, Hung J, Bermejo J, et al. Recommendations on the Echocardiographic Assessment of Aortic Valve Stenosis: A Focused Update from the European Association of Cardiovascular Imaging and the American Society of Echocardiography. *J Am Soc Echocardiogr*. 2017;30(4):372-392. doi:10.1016/j.echo.2017.02.009

31. Chambers JB. Aortic stenosis. *Eur J Echocardiogr*. 2009;10(1):11-19. doi:10.1093/ejechocard/jen240
32. Alzahrani H, Woo MY, Johnson C, Pageau P, Millington S, Thiruganasambandamoorthy V. Can severe aortic stenosis be identified by emergency physicians when interpreting a simplified two-view echocardiogram obtained by trained echocardiographers? *Crit Ultrasound J*. 2015;7(1):1-4. doi:10.1186/s13089-015-0022-8
33. Zoghbi WA, Adams D, Bonow RO, et al. Recommendations for Noninvasive Evaluation of Native Valvular Regurgitation: A Report from the American Society of Echocardiography Developed in Collaboration with the Society for Cardiovascular Magnetic Resonance. *J Am Soc Echocardiogr*. 2017;30(4):303-371. doi:10.1016/j.echo.2017.01.007
34. Ea A, Amsterdam EA, Wenger NK, et al. *2014 AHA / ACC Guideline for the Management of Patients With Non – ST-Elevation Acute Coronary Syndromes A Report of the American College of Cardiology / American Heart Association Task Force on Practice Guidelines Endorsed by the American Association For*.; 2014. doi:10.1161/CIR.0000000000000134
35. Kontos MC. Role of echocardiography in the emergency department for identifying patients with myocardial infarction and ischemia. *Echocardiography*. 1999;16(2):193-205. doi:10.1111/j.1540-8175.1999.tb00804.x