



**Greater  
Sydney Area HEMS**  
HELICOPTER EMERGENCY MEDICAL SERVICE

excellence in care

# Sonography Training Oriented to RETRIEVAL MEDICINE



**STORM MANUAL**

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## INTRODUCTION

Point of care ultrasound (POCUS) has become an essential adjunct to the care of the critically ill patient in Emergency Departments and Intensive Care Units across the world. It has revolutionised the bedside investigation and management of a number of conditions, particularly with regard to the assessment of shock, breathlessness & fluid status.

POCUS examinations performed by trained clinicians have been shown to improve patient outcomes especially when used to answer specific clinical questions. These benefits can be extended to our patients in the arena of prehospital and retrieval medicine.

Sydney HEMS acknowledges that their clinicians bring with them vast medical experience which often includes regular use of bedside ultrasound and ECHO.

This manual and the following course provides an introduction (and perhaps a refresher) to the field of point of care ultrasound oriented to prehospital and retrieval medicine. It is focussed on the two most commonly used ultrasound modalities in our service; (1) EFAST and (2) Echocardiography in Life Support.

This will be the first step in our formal accreditation program, where we aim to have your skill set recognised by the Australasian College for Emergency Medicine and the Australasian Society for Ultrasound in Medicine.

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## ACCREDITATION

The Sonography Training Oriented to Retrieval Medicine course is recognised by the Australasian College for Emergency Medicine (ACEM) in the modalities of EFAST and Basic Echo in Life Support (BELS). This allows participants to work towards certification in a formal accreditation program.

Subsequent ultrasound use during employment at Sydney HEMS will allow for;

- Image review and critique by credentialed and experienced clinicians
- Recognition by ACEM as a “credentialed practitioner”
- Most importantly; maximally optimised patient care !!

To obtain accreditation the STORM participants must fulfil the following;

- Completion of the STORM workshop + associated prior learning
- Obtain pass mark in the post-course quiz
- Minimum scan requirements met & images reviewed by supervisor
- Complete a final ‘competency’ exam

### Minimum scan requirements for credentialing:

E-FAST	ECHO
<ul style="list-style-type: none"><li>• 25 accurate scans</li></ul>	<ul style="list-style-type: none"><li>• 25 accurate scans<ul style="list-style-type: none"><li>• 5 directly observed scans</li></ul></li></ul>
<ul style="list-style-type: none"><li>• 50% to be <i>clinically indicated</i></li></ul>	<ul style="list-style-type: none"><li>• <math>\geq 5</math> to be positive</li></ul>
<ul style="list-style-type: none"><li>• <math>\geq 5</math> to be positive</li></ul>	<ul style="list-style-type: none"><li>• <i>Additional 25 scans interpreted</i></li></ul>

More details are available at the [STORM Course homepage](#).

Ongoing accreditation is maintained by annual participation including:

- Maintenance of logbook
- 3 hours of teaching
- Additional 25 scans

We will endeavour to enhance your ability to maximise scan numbers through additional ultrasound sessions both on base and at participating hospitals.



This workshop is recognised by the ACEM ED Ultrasound Subcommittee as complying with ACEM ultrasound guidelines and policies for EFAST & Echo in Life Support and is accredited for 6 hours within the continuing professional development program

## THE SEVEN GOLDEN RULES OF CRITICAL CARE ULTRASOUND

- according to Dr Justin Bowra (FACEM, CCPU)

### 1. “Resus only”

The patient must be critically unwell (shocked, breathless, peri-arrest). This is because ultrasound signs of some of these diseases are only reliably present if *severe* (eg. massive PE, severe pneumonia).

### 2. Clinical context is paramount

Make a differential diagnosis list before you switch on the machine. All data must be considered (eg FBC with Hb = 4).

### 3. Only ask questions that you can answer.

Leave the fancy stuff (eg. valve disease) to others.

### 4. Repeat scans are crucial.

Repeat your scan each time the clinical picture changes.

### 5. 90% = 100%

Every test has its limitations. In a peri-arrest patient, no study will be 100% accurate. If this bothers you, don't practice critical care.

### 6. When in doubt, be a doctor!

You were a clinician before you were a sonographer. If the clinical picture and scan findings don't agree, believe the clinical picture.

### 7. A fool with a stethoscope will be a fool with an ultrasound.

## ACKNOWLEDGEMENTS

- Dr Justin Bowra
- Ms Sharon Kay
- Dr Adrian Goudie
- Dr Cliff Reid

**Adapted from:**

- *Emergency Ultrasound Course Manual*, Justin Bowra
- *Critical Care US Manual*, Justin Bowra
- *Basic Echocardiography for Acute Management Course Manual*, Cliff Reid
- *RNSH ECHO Protocol*, Sharon Kay
- *Ultrasound in Emergency Medicine* - Australian Institute of Ultrasound
- Ultrasound Village

## What is ultrasound ?

'Ultrasound' waves are very high frequency, pitched far too high for the human ear. In medicine, we use them in the range of 2-15MHz. A Hertz (Hz) is defined as 1 wave per second, so this means that our US probes send out 2-15 *million* ultrasound waves per second.

## Why is frequency important ?

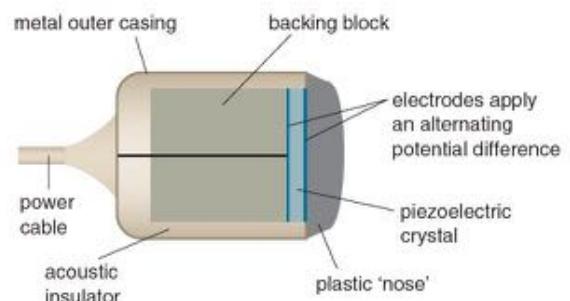
*The lower the frequency, the bigger the actual sound wave.*

This has two practical consequences;

1. **Penetration:** low frequency wave are larger. This means they are harder to deflect & can penetrate further into the body before they are scattered.  
ie. *to 'see' deeper structures, lower the frequency.*
2. **Resolution:** large, low frequency wave aren't deflected by tiny objects. This means that they won't 'see' very small structures in the human body.  
ie. *to 'see' fine detail, increase the frequency.*

## How is a sound wave formed ?

Piezoelectric crystals are found at the end of ultrasound probe that touches the skin. They are safely sheathed in a casing (coupling) material.

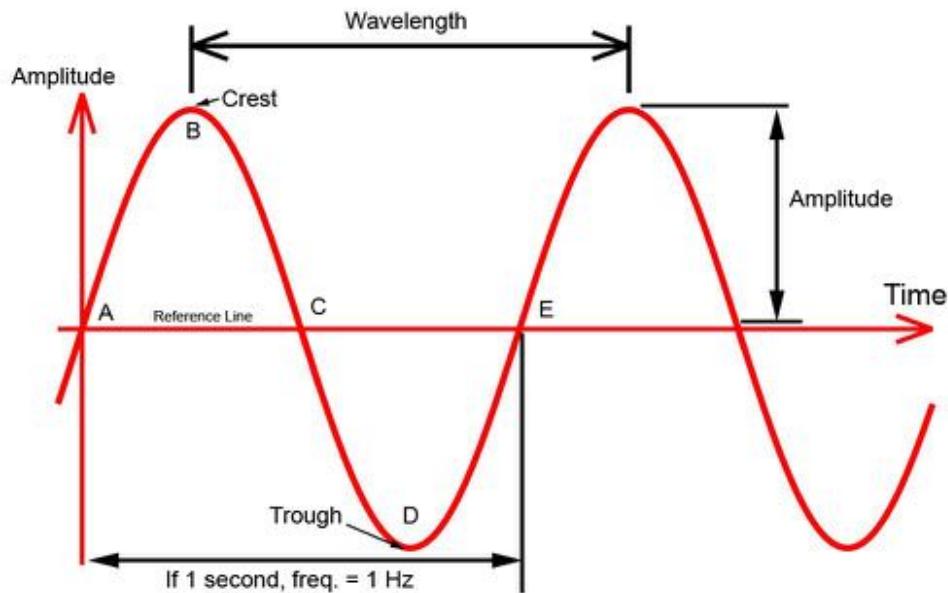


*The piezoelectric effect (PE) refers to the following property of these crystals.*

- If an electromagnetic wave is passed through a PE crystal, it will vibrate. In other words, it has converted the electromagnetic energy into the mechanical energy of a sound wave.
- After sending out the sound wave, the probe switches to receiving mode. It spends about 99% of its time in this mode, 'waiting' for the sound wave to bounce back. When it does, the wave makes the crystal vibrate and the whole process is reversed, converting the wave's energy into an electrical signal.
- This signal is then plotted on the screen attached to the machine, and an image is formed.

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## Characteristics of an ultrasound wave.



A sound wave can be described using the following parameters:

1. **Period ( $T$ )** - the time taken for one complete oscillation to occur (one oscillation is also referred to as a *cycle*) (ie. time taken from point A to point E, above).
2. **Frequency ( $f$ )** - the number of cycles per second (expressed as Hertz). (ie. 4MHz = 4 million cycles per second).
3. **Wavelength ( $\lambda$ )** - the distance between two consecutive, identical positions in a pressure wave (marked above). Determined by frequency of the wave and speed of propagation in the medium it is travelling.
4. **Velocity ( $c$ )** - the speed at which sound propagates through a medium (vector known). Velocity through soft tissue is assumed to be a constant **1540m/sec !!**

The wave equation:

$$c = \lambda f$$

product of wavelength ( $\lambda$ ) & frequency ( $f$ ) represents the velocity ( $c$ ) of the sound wave.

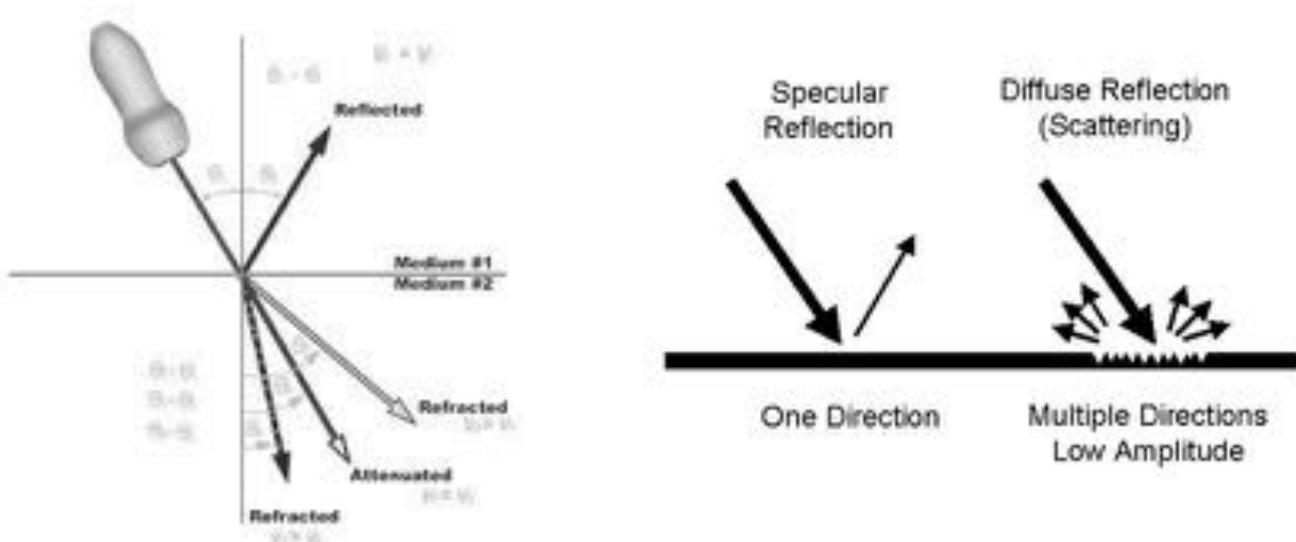
Soft tissue type	Speed of sound (m/sec)
Fat	1450
Liver	1550
Blood	1570
Muscle	1585
Bone	4080

5. **Amplitude ( $A$ )** - the maximum degree of change within a medium when a sound wave pass through it (marked above). It relates to the severity of disturbance.

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## What happens to the sound waves in the human body ?

All sound waves get weaker the further they travel through the human body. Some of them are scattered, some are transmitted, and some are refracted etc. But the general principle is that the further the sound wave goes, the weaker it gets and the less we see on screen. This is less of a problem for larger, low frequency waves, which travel further (see below).



### 1. Attenuation

As a sound beam traverses tissues within the body, various factors cause it to lose energy and therefore undergo a reduction in amplitude and intensity. This loss of energy is called *attenuation*.

### 2. Reflection.

To form an image, sound waves need to bounce back to the probe. This means they need to be *reflected*. Most of the reflection happens at the interface between organs and tissues. This is because each tissue/organ has a different *acoustic impedance* to the sound wave (in other words, each tissue slows down the sound wave to a different degree).

#### *Why is this important?*

It means that the edges of organs, and the fascial planes between structures such as muscles, appear very 'bright' or 'echogenic' on the screen. The denser the structure (eg bone, gallstones, metal), the more sound is reflected and the 'brighter' (echogenic / hyperechoic) it looks. (See note below.)

### 3. Refraction.

Refraction is the deviation in the path of a beam, occurring when the beam passes through interfaces between tissues of differing speeds of sound (ie. when the angle of incidence is not 90°).

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### 4. Transmission.

Fluid filled structures offer very little resistance to the sound waves, which easily pass through the fluid without losing much energy. They send no signals back to the probe, so they are *dark* or *anechoic*. This makes deeper structures look 'brighter' (known as '*posterior acoustic enhancement*').

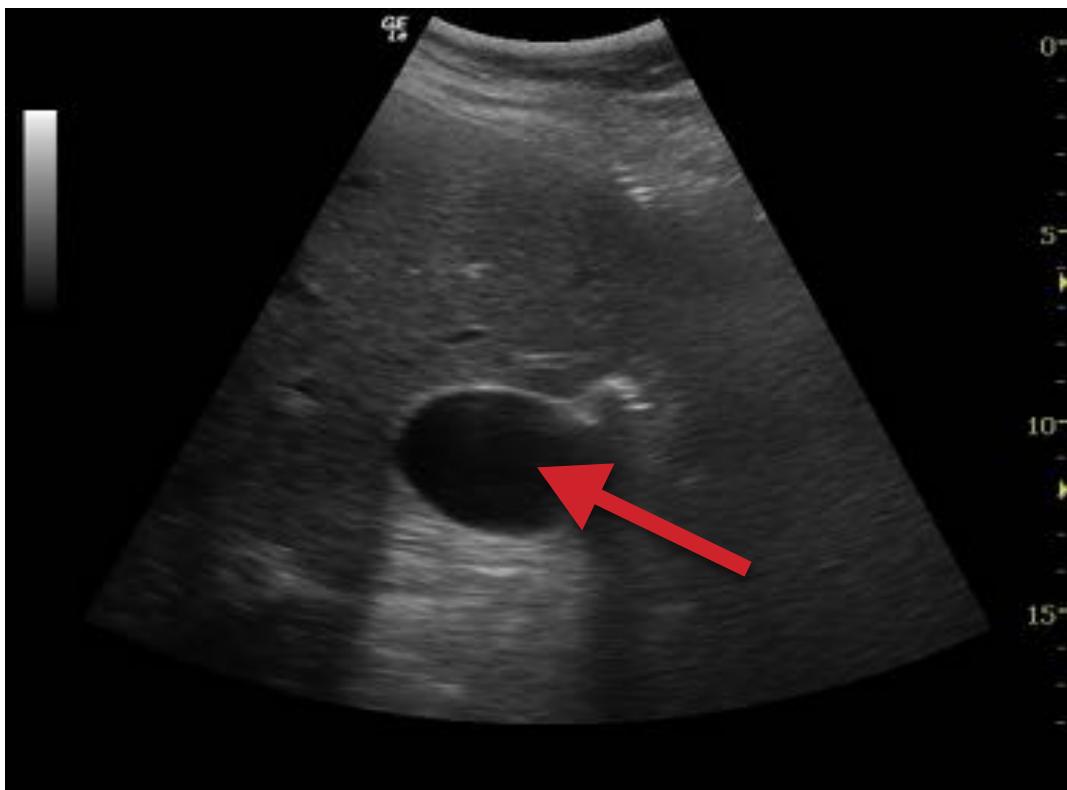
### 5. Scatter.

When the sound wave hits air (eg. in the bowel, or in the lung), most of it is scattered in all directions. Much of it returns to the probe (which is why the air appears bright). Very little, if any, is transmitted to the deeper structures, which remain invisible (which is why bowel air can cause 'dirty shadowing').

### Ultrasound appearances of normal tissue.

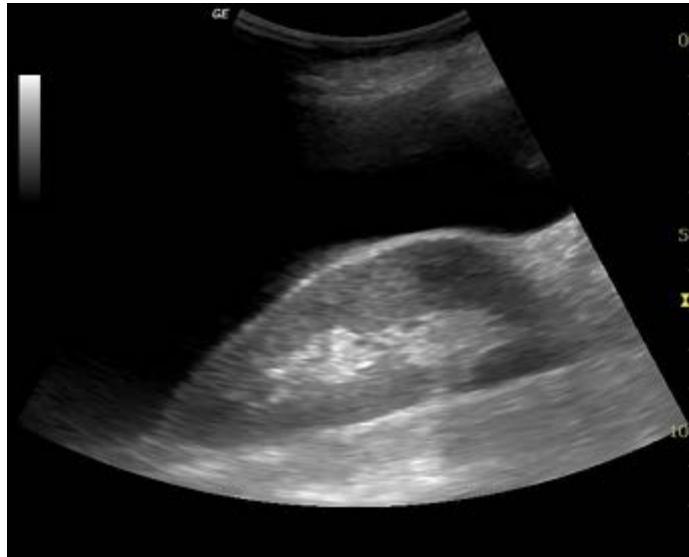
Simple fluid is **BLACK** (ie. 'anechoic' - lacking internal echoes).

Fluids such as blood, urine and bile appear anechoic and exhibit posterior acoustic enhancement (see 'Transmission' above). This helps identify cystic structures (such as cysts, bladder and gallbladder) and tubular structures (ducts and vessels). See examples below including the gallbladder, ascites and inferior vena cava.

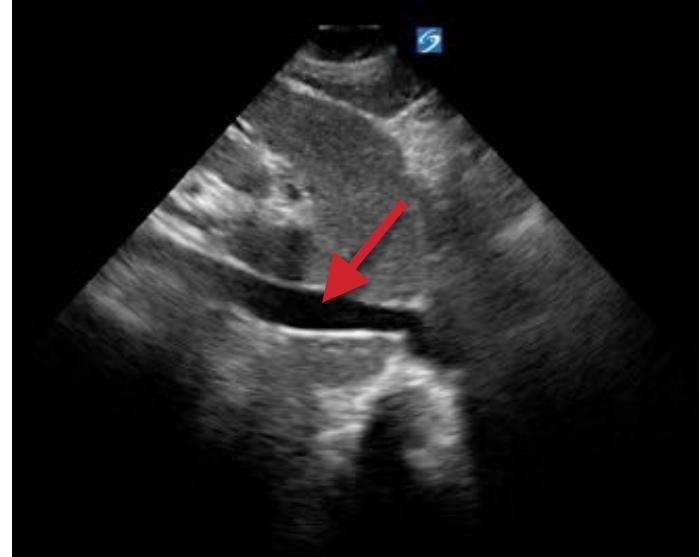


THE BILE IN THIS GALLBLADDER (ARROWED) IS BLACK (ANECHOIC) AND EVERYTHING BELOW IT IS BRIGHTER (POSTERIOR ACOUSTIC ENHANCEMENT)

## STORM MANUAL



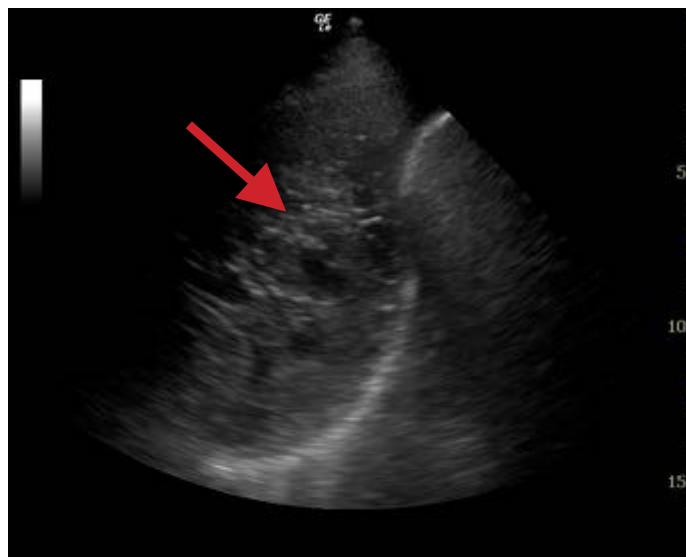
SIMPLE FLUID = ASCITES  
KIDNEY AT BOTTOM OF IMAGE



SIMPLE FLUID: INFERIOR VENA CAVA  
(MARKED BY ARROW)

Complex fluid is HETEROGENOUS on screen.

Examples below include a pleural effusion and subcutaneous abscess.



COMPLEX FLUID: RIGHT SIDED PLEURAL  
EFFUSION IMAGED TRANSVERSELY

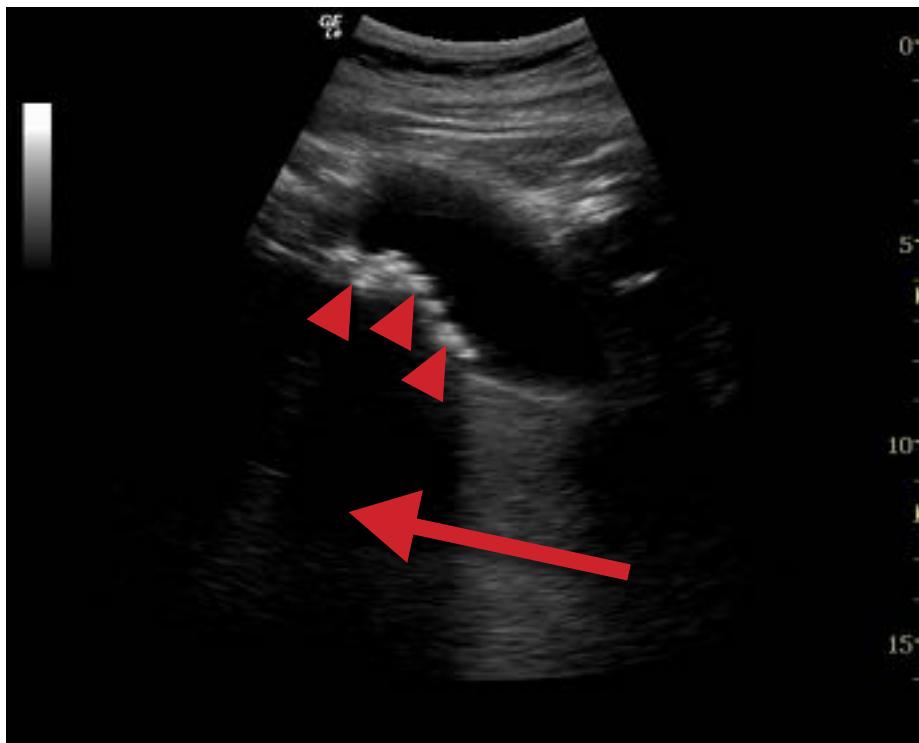


COMPLEX FLUID: SUBCUTANEOUS  
ABSCES

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Dense structures are **BRIGHT** (ie. 'echogenic' or 'hyperechoic' - highly reflective). The more dense the structure (eg bone, gallstones, metal), the more sound is reflected and the 'brighter' it looks on screen. But this also means that the sound doesn't get through to deeper structures, and a 'shadow' appears on screen behind (= deep to) the metal/bone/stone. This is called *posterior acoustic shadowing* and helps identify the dense structure.

See image below: the gallstones (arrowheads) within the gallbladder are bright and cast a shadow.



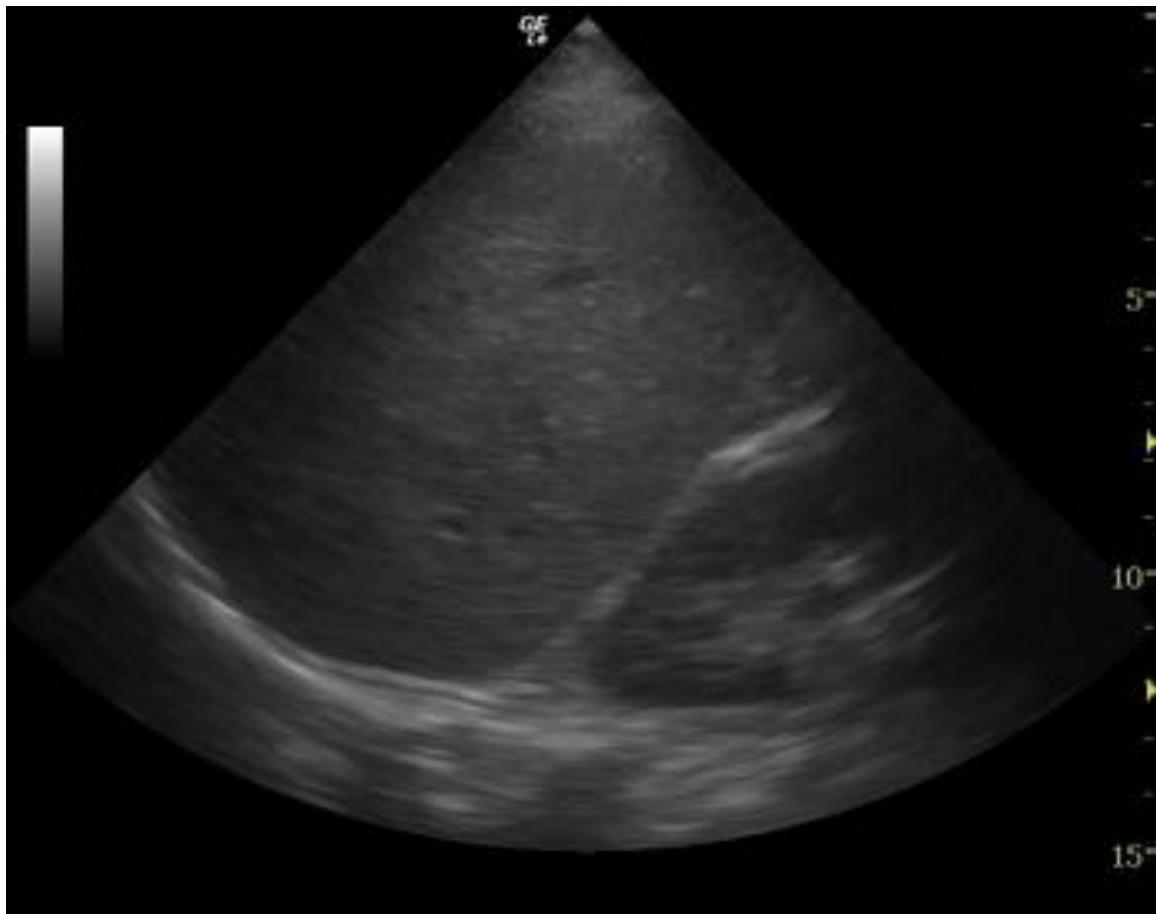
THE STONES IN THIS GALLBLADDER (ARROWHEADS) ARE BRIGHT (HYPERECHOIC) AND CAST A POSTERIOR ACOUSTIC SHADOW (ARROWEDED).

Some structures are **GREY**.

These are typically the *solid organs*: liver, spleen, kidney, uterus and heart. See the relevant images in this section:

In the right upper quadrant image below the normal liver is grey, and the normal kidney cortex is darker grey.

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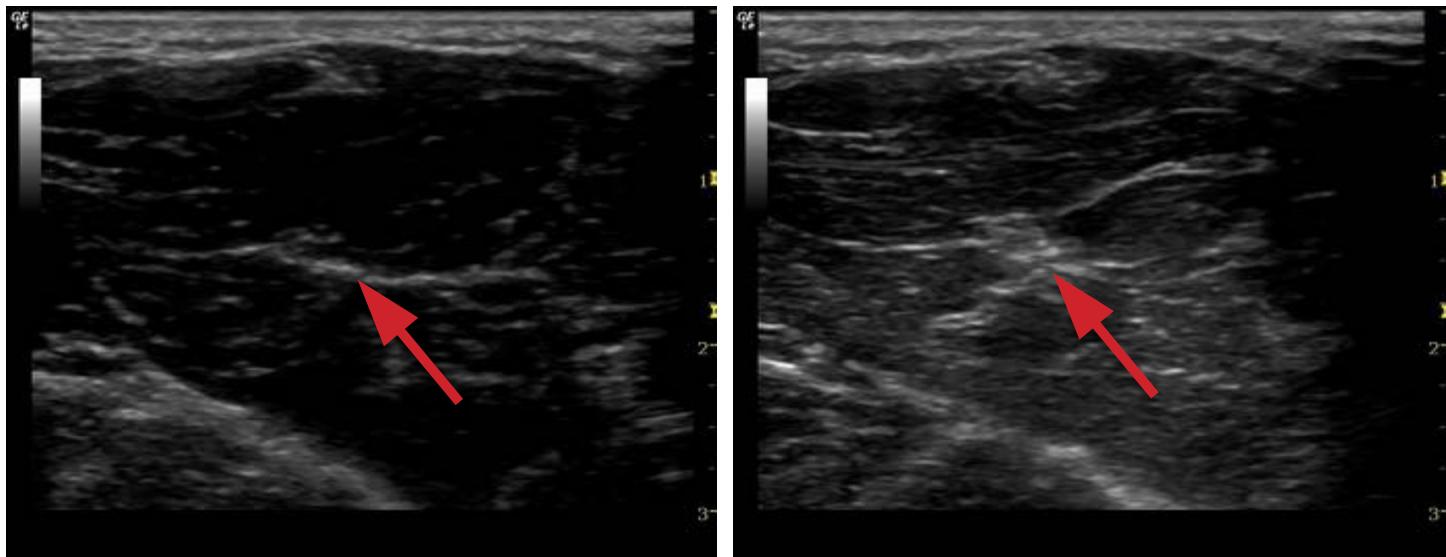
**RUQ VIEW: THE BRIGHT POTENTIAL SPACE OF MORISON'S POUCH SEPARATES TWO ORGANS: THE **LIVER** (LARGER AND ON THE LEFT) AND THE **KIDNEY** (SMALLER WITH A CORTEX THAT IS A DARKER GREY THAN THE LIVER)**

Some structures are **ANISOTROPIC**: their image depends on the angle at which the probe is held.

This means that their appearance depends on the angle of the sound waves. Typically these are fibrous structures such as *nerves, tendons and muscles*. These structures appear 'grainy', and if the probe is perpendicular to the direction of the fibres then they are bright. The closer the probe parallels the fibres, the darker they appear because less sound is reflected.

In the 2 images below, the same median nerve (arrowed) and surrounding forearm flexor muscles are viewed from slightly different probe angles. On the left image, the probe is held at an angle to the muscle and nerve, which appear dark. On the right image, the probe is held perpendicular to the forearm and the structures appear brighter.

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THE MEDIAN NERVE (ARROWED) AND THE SURROUNDING MUSCLE FIBRES ARE DARK IN THE LEFT IMAGE (MADE WITH PROBE AT AN ANGLE TO THE SKIN) AND BRIGHTER IN THE RIGHT IMAGE (MADE WITH THE PROBE AT RIGHT ANGLES TO THE SKIN).

THEY DEMONSTRATE **ANISOTROPY**.

Some structures vary because of their contents.

This is typical of the GI tract:

- If a segment of the GIT (stomach, bowel) is fluid-filled it appears black.
- If it is filled with gas it appears bright white, as the air 'scatters' the sound wave.

### WARNING!

Like dense substances, AIR also appears bright on US. This is because the sound wave is scattered and some returns to the probe. It can also cause a form of acoustic shadowing, which can be confusing (eg it can mimic gallstones).

# STORM MANUAL

## RESOLUTION.

Resolution is defined as the ability to distinguish echoes in terms of space, time or strength. Good resolution is thus critical to the production of high quality images.

### 1. Contrast resolution.

The ability of an ultrasound system to *demonstrate differentiation between tissues* having different characteristics (eg. liver & spleen).

### 2. Temporal resolution.

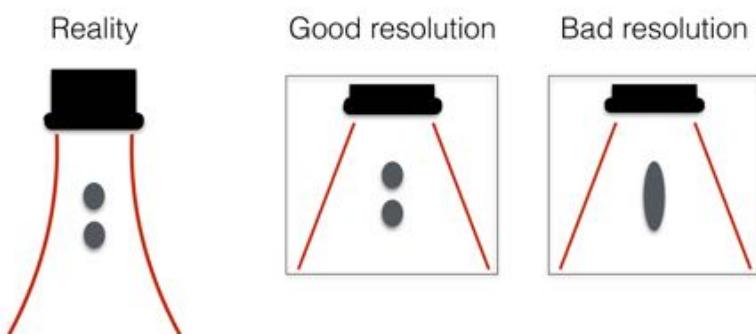
The ability of an ultrasound system to *accurately show changes in the underlying anatomy over time*. This is particularly important in echocardiography.

### 3. Spatial resolution.

The ability of an ultrasound system to *detect and display structures that are close together*. This can be divided into axial & lateral spatial resolution.

#### Axial Resolution.

Differentiation of small targets along the path of the beam as separate entities.



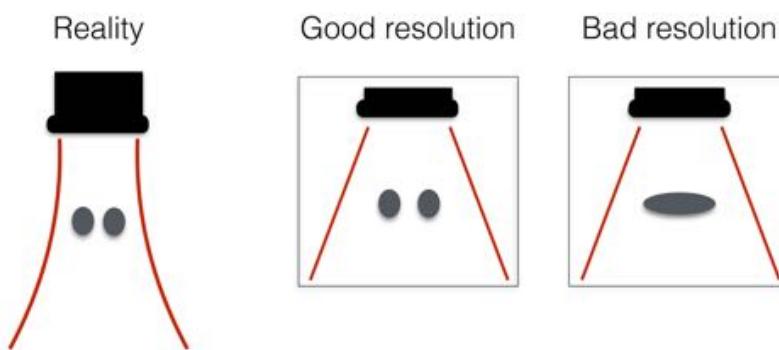
Factors affecting axial resolution include:

- Spatial pulse length: length of the pulse used to form a beam. The shorter the pulse the better the resolution.
- Frequency: Higher frequencies generate shorter wavelengths & therefore shorter pulse lengths.
- Transmit power: The greater the amplitude of voltage striking the crystal, the longer the ringing time & longer the pulse length (reducing resolution).
- Received gain settings: higher gain leads to poorer resolution.
- Field of view settings: a smaller field of view leads to better resolution.

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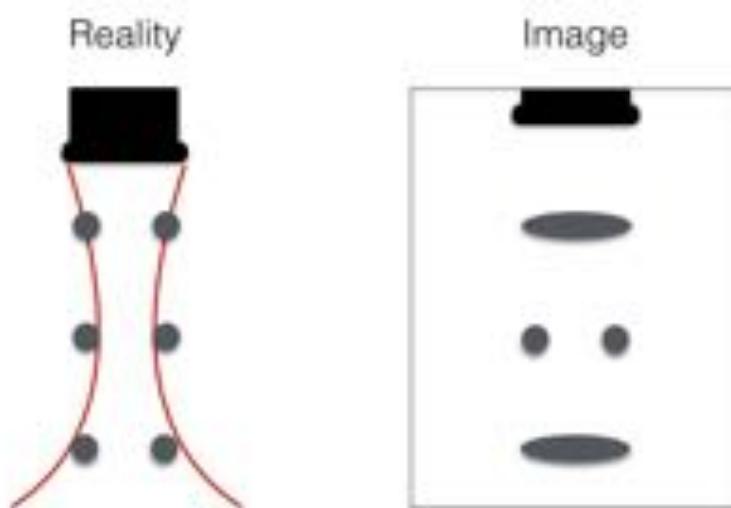
### Lateral Resolution.

The ability to distinguish between two separate targets perpendicular to the path of the ultrasound beam (that are the same distance from the transducer).



Factors affecting lateral resolution include:

- Width of the ultrasound beam: the wider the beam the poorer the lateral resolution. Recall: ultrasound machines assume that all received echoes arise from the central axis of the beam.
- If the beam is narrower than the distance between the two objects, then both objects will be interrogated separately and both will register on the image (see below).
- Focal zone location: narrows the beam for tighter focus, allowing greatest resolution at these points.



# STORM MANUAL

## ARTEFACTS.

An artefact is an image on screen that does not correspond to actual anatomic information: in other words, it is a picture of something that '*isn't there*'. They occur because ultrasound systems operate on the basis of certain assumptions such as:

1. The speed of sound in the body is constant (1540m/sec)
2. All echoes detected by the transducer originate from the central axis of the beam
3. Ultrasound beams travel in straight lines
4. Time taken for an echo to return to the transducer is directly related to the distance from the transducer
5. The rate of beam attenuation is constant with depth throughout field of view.

Artefacts may be:

- **Bad:** artefact may obscure detail or mimic pathology leading to diagnostic uncertainty or error. A classic example is a rib shadow that gets in the way of the structures below... or an edge artefact that mimics free fluid.
- **Good:** artefacts make up the basis of lung US. Also, acoustic shadowing can help identify structures such as gallstones.

### Acoustic Shadowing.

As described above, very dense objects cast 'acoustic shadows'. On the screen one sees the bright object with a black shadow distally. See image of gallstones above.

### Acoustic Enhancement.

This artefact occurs when sound passes through an anechoic structure. No echoes are reflected and so they are all available to pass through. More echoes then return to the probe from deeper structures, making them look 'brighter' on screen. See images of gallbladder above.

### Edge Shadowing.

This is commonly seen deep to the edges of rounded structures (eg. aorta or gallbladder) when the velocity of sound in the rounded structure is different from that of the surrounding tissue. This results in a combination of reflection & refraction occurring at the edge of the rounded structures.

### Reverberation.

It's obvious that the sound waves must 'bounce' off structures in the body to form an image but when they return to the surface of the probe, some of them will 'bounce' back from the probe... back into the body! Although weaker by now, some of these waves will repeat the process and return to the probe once more.

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Every time the waves return to the probe in this manner, they will generate an image on screen. But with each repetition, the image will appear 'deeper'.

- The waves that form the 2<sup>nd</sup> image took twice as long as the first (total travel time), so this image will be twice as deep as the 'real' image.
- The waves that form the 3<sup>rd</sup> image took 3 times as long (total travel time), so this image will be 3x as deep as the 'real' image.

The result is a 'ghost' image (or a series of 'ghost' images) deep to the real image. In the image below (reverberation artefact in normal lung), the yellow arrows represent the path that the sound waves travel to create the bright white line that represents the pleura. Notice the second 'ghost image' below. This is a reverberation artefact.



### Mirror Image.

Certain structures are called '*specular reflectors*'. They act as 'mirrors' and reflect sound waves so perfectly that on the screen two images of the same structures can form: a true image and a 'mirror' image. This can be confusing.

Examples of these reflectors include the diaphragm, bone and the bladder can be found on the following pages.

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- **The diaphragm:**

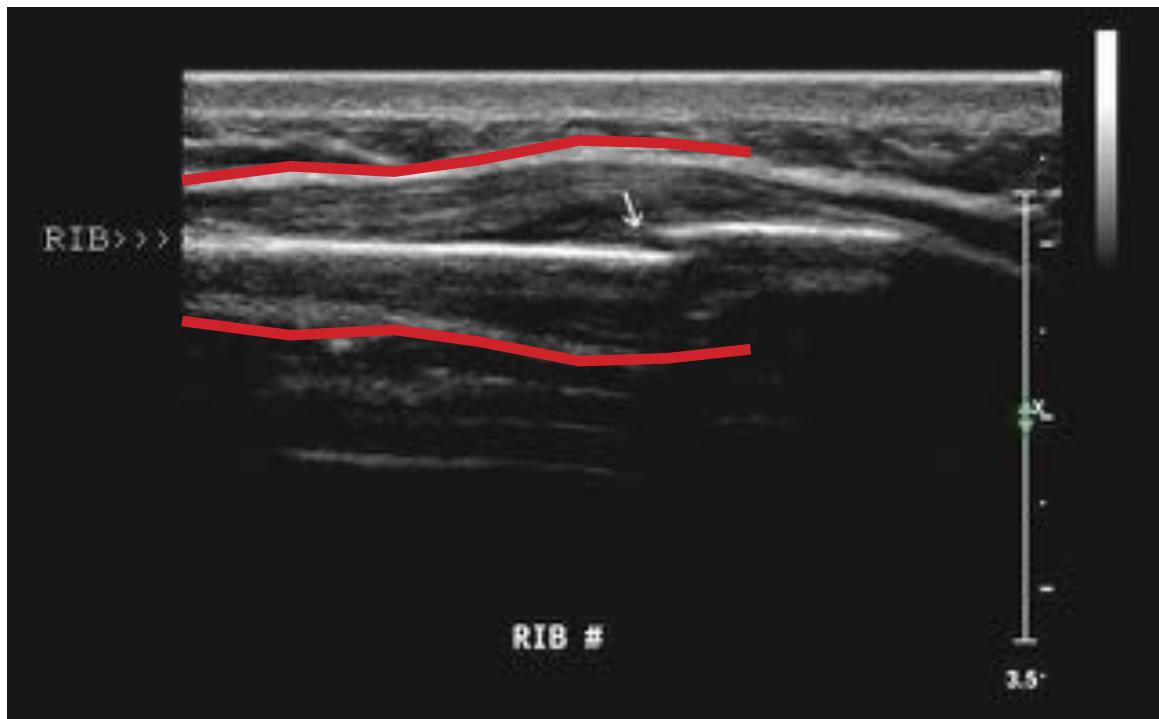
The air above the diaphragm, combined with the smooth curve of the diaphragm itself, can create a 'mirror image' of the liver / spleen. This mirror image is seen above the diaphragm. In the picture below, the arrows represent the path of the sound waves as they bounce off the curve of the echogenic diaphragm, into the liver tissue, then back via diaphragm again to the probe. The machine however cannot tell that this occurred, and plots an image on screen depending on how long it took the waves to return, so it extrapolates the image to the point on screen represented by the dotted line.



- **Bone:**

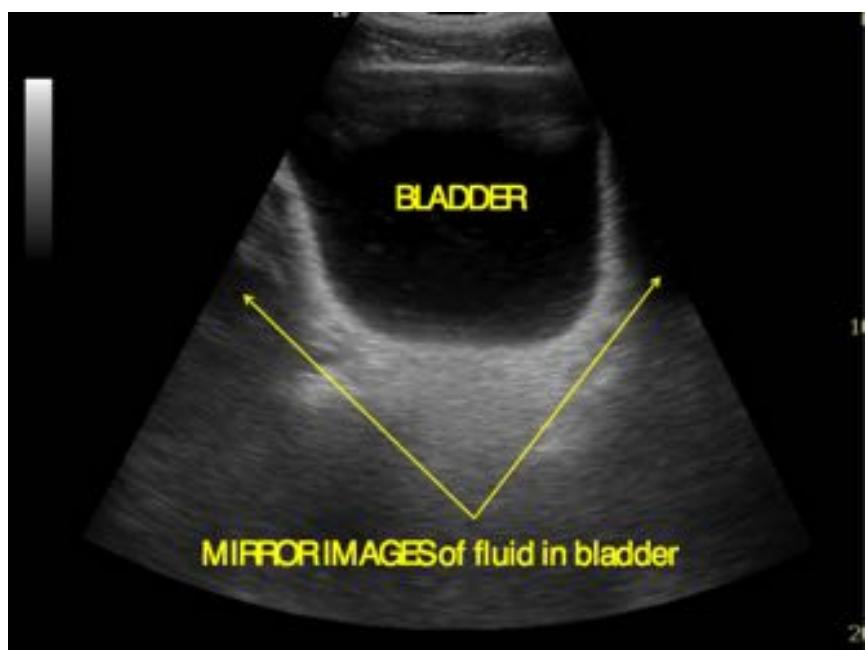
This can generate a mirror image of the muscles and tissues above. In the image below 'ghost' echoes of the muscle fibres & tissue planes can be seen below the surface of the rib (red lines). The white arrow demonstrates a rib fracture.

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- **Bladder:**

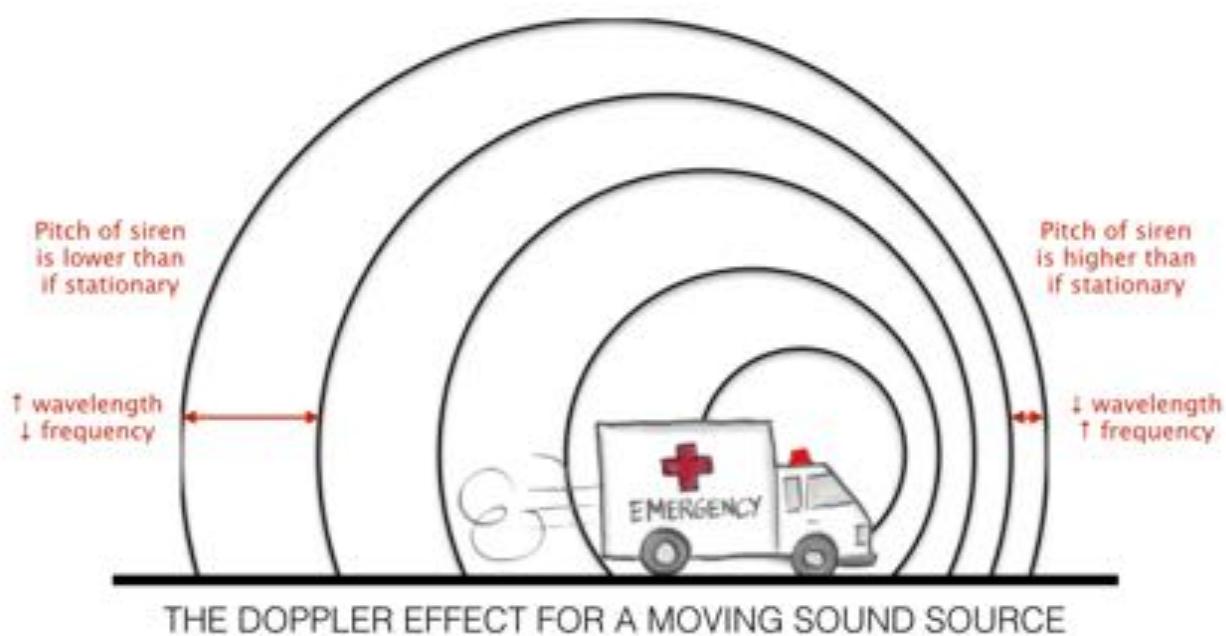
As in the image below, the air in the bowel next to the bladder, combined with the smooth curve of the bladder wall, can create a mirror image of the fluid inside the bladder. This mirror image can resemble free fluid, so be careful! Note the very dark areas to the right and left of the bladder: these are mirror images and not free fluid.



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### THE DOPPLER EFFECT.

The ultrasound probe sends sounds waves at a known frequency. If these hit objects moving *towards* the probe (eg. RBCs in a vessel), the sound waves 'bunch together' and get smaller' therefore reducing the wavelength and thus increasing the sound wave's frequency. If the moving object is moving *away* from the probe, the sound waves 'stretch out' and their wavelength increases, therefore decreasing its frequency. This is classically portrayed with an ambulance siren changing its audible frequency as it approaches and passes on the road.



RECALL:  $c = \lambda f$  or  
velocity (c) = frequency (f) *times* wavelength ( $\lambda$ )

Therefore, Doppler imaging can show you the *direction of flow* in a blood vessel as velocity doesn't change, so as wavelength increases, frequency must decrease (and vice versa).

Furthermore, the *amount* of frequency shift is proportional to the velocity of the moving RBCs. The fast the RBCs are moving, the more the sound wave shifts. As a results Doppler imaging can also estimate the *rate of flow* in a blood vessel.

*BUT; you have to get the angles right !!*

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The Doppler equation (below) basically states that your measurement will be much more accurate the more your probe can parallel the direction of the flow. When you think about it, if your probe is perpendicular to the moving object (eg the RBCs in a vessel) then that object will appear as though it's not moving at all. In the equation below, *the cosine of 90 degrees is zero*.

In practice, if the angle between the probe and the direction of flow is more than 60 degrees, your velocity assessment will be inaccurate. This is one of the reasons that we avoid Doppler in critical care.

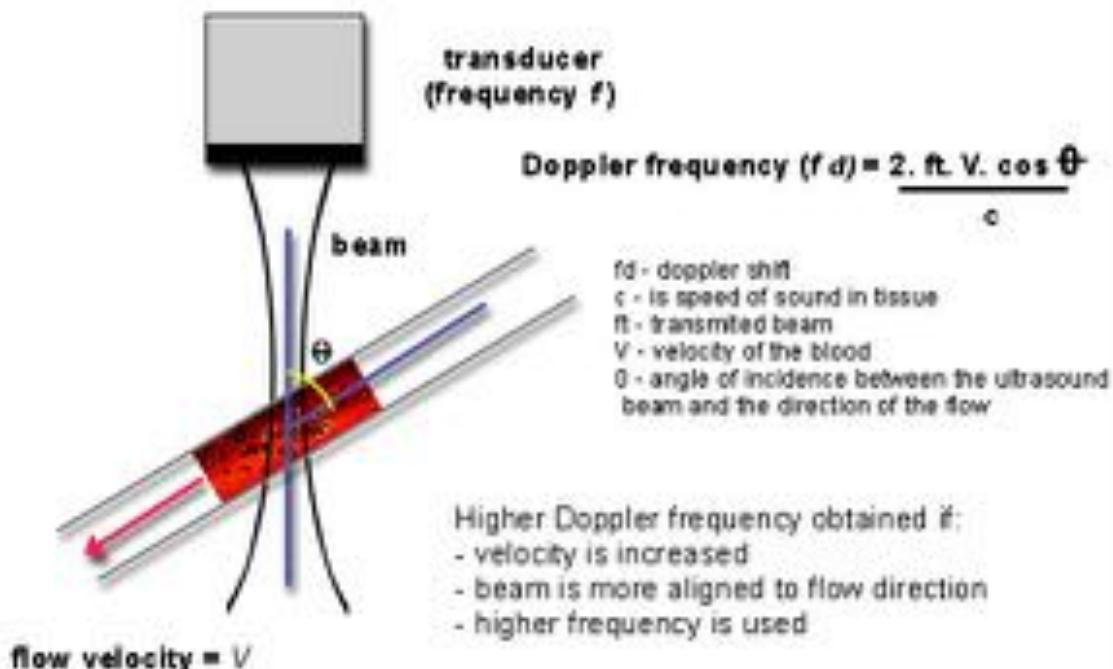


Image courtesy of Colin Deane (sonoworld.com)

## TYPES OF DOPPLER.

### Continuous Wave (CW) Doppler:

Provides continuous wave generation with a receiver that detects the change in frequency (Doppler shift) which result from reflector motion. The information received is presented as an audible signal and a spectral display. There is no depth range gate. It is very sensitive, but won't tell you what point the signal is coming from.

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### Pulse Wave (PW) Doppler:

The transducer functions as both a transmitter and receiver, sending 'packets' of sound waves and then waiting for each 'packet' to return before sending the subsequent packet. Once magnitude and direction of the Doppler shift is derived, it is presented as both audible and spectral displays. It is less sensitive, but locates the site of the signal.

There are three variations;

1. Colour flow (CF); remember the *BART convention* (Blue Away, Red Towards).
2. Spectral
3. Power

### DOPPLER PRACTICALITIES IN CRITICAL CARE.

We should generally avoid using Doppler in critical care for the following reasons;

#### 1. Doppler is usually unnecessary.

Most of the information we need doesn't require Doppler for example we can tell between arteries and veins using B-mode US, and we can tell if a vein is thrombosed by compressing it.

#### 2. Doppler is complicated.

It takes a good working knowledge of Doppler principles to get it right, especially getting the angles correct.

#### 3. Doppler is fiddly.

It depends on operator skill and experience, angle of insonation and pulse repetition frequency (how many 'packets' of sound the probe sends per second).

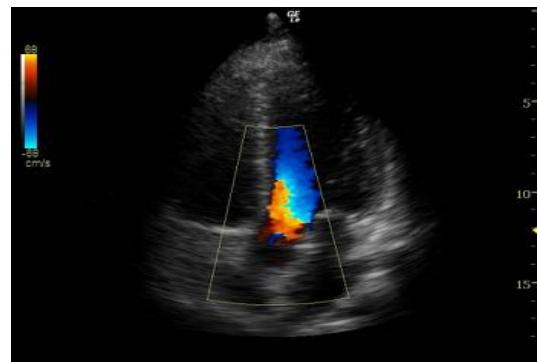
#### 4. The conditions that really benefit from Doppler usually are subtle.

A classic example is mitral regurgitation. If you detect a regurgitant jet across the mitral valve, is it physiological or a high-flow, large volume jet measured at an incorrect angle.

### ALIASING.

As velocity increases the signal alters (eg. in CF Doppler) until aliasing occurs, then colour reversal occurs.

Image (right): Is this turbulent flow from aortic valve disease or aliasing from normal high velocity flow from the LVOT ??



## INSTRUMENTATION

**MACHINE.**

At Sydney HEMS we are currently using the Sonosite M-Turbo. There is also access to the Sonosite Nanomaxx at Orange, Wollongong and Mascot.

For more details please on the M-Turbo visit;  
<http://www.sonosite.com/au/ultrasound-products/m-turbo>

**PROBE TYPES.**

The probes (transducers) that we commonly use are *linear, curved and sector array*.

**A. Linear array probe:**

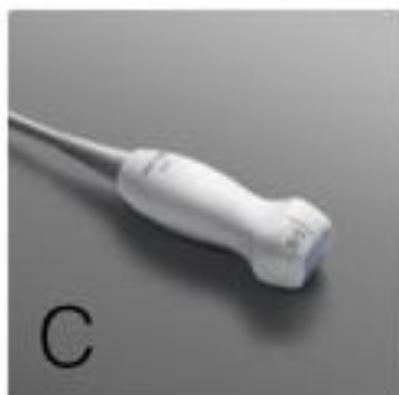
This has a rectangular footprint on the screen. They produce the highest frequency sound waves, which means they are excellent for superficial work (eg. vascular access, DVT studies and soft tissue foreign body identification).

**B. Curved array probe:**

This has a curved footprint and produces lower frequency sound waves which can penetrate further. This is ideally suited to abdominal work (eg. EFAST, AAA studies, early pregnancy, renal and biliary scans).

**C. Sector (phased) array probe:**

This produces a triangular-shaped image on the screen. The small footprint allows for access between the ribs and is preferred for cardiac scanning.



# STORM MANUAL

## PRESETS.

There are a number of ways to modify your on-screen image. Some are touched on here, but only briefly. For those of us who aren't expert sonologists, the machines come equipped with certain '*presets*' that optimise the image for the particular region and purpose. For example, the cardiac preset applies more contrast to the image because the heart is essentially 'black and white' and we don't need to see as many shades of grey (fine detail) as we might when scanning an organ like the liver.

### Changing Presets:

Press the "EXAM" key & then select from menu.

## WHICH PROBE & WHICH PRESET ?

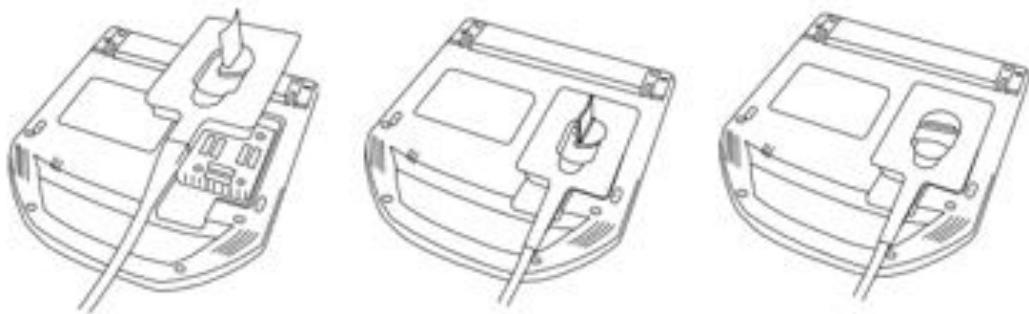
	PROBE	PRESET
VASCULAR ACCESS	Linear array probe	Vascular/venous preset
ABDOMEN - EFAST - RUSH - AAA	Overall, the curved probe is best for abdominal studies.  The sector probe is also good (esp. if answering simple questions ie. is there FF? )	Abdominal preset.  Many machines have dedicated EFAST, AAA or Obstetric presets.
ECHO	Sector probe is best.  Possible to do 'screening' scan with curved probe (eg. subcostal window)	Cardiac present.  Be aware this alters probe marked position (flips image).
IVC	Curved probe is best for image quality and anatomy.  Sector probe is also good.	Generally ok to continue current preset (Abdo, FAST or Cardiac).
LUNG	for EFAST: curved or sector probe is adequate.  for ARTEFACTS: (eg. lung sliding or B-lines) curved or sector probe is best.  for PLEURAL detail: linear probe	Some machines have LUNG preset.  Alternatively; use Abdo/EFAST preset and turn off filters (eg. THI).

## STORM MANUAL

### CHANGING PROBES.

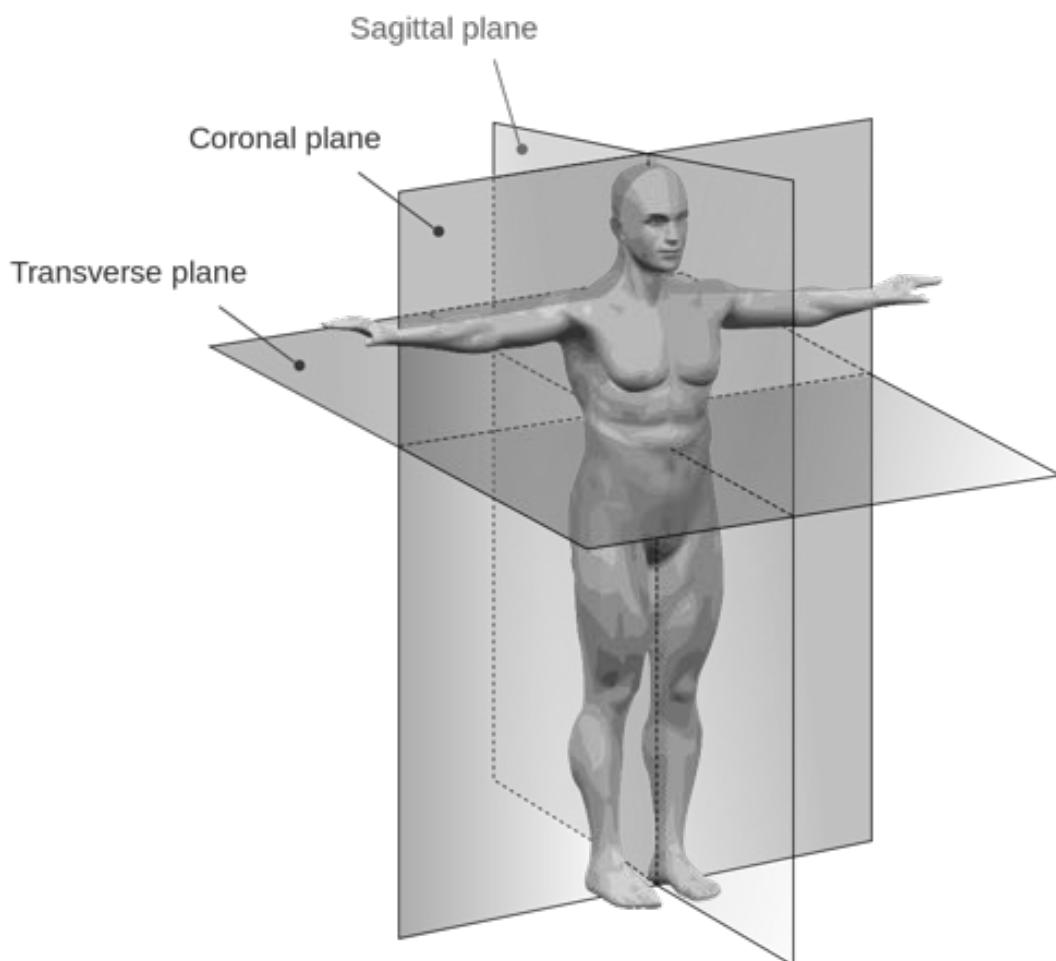
Turn the system upside down. Pull the transducer latch up and rotate it *clockwise*. Remove the transducer and store safely.

Next, align the new transducer's connector with the port. Insert transducer into connector and turn latch *counterclockwise*. Press the latch down & continue scanning.



### SCANNING PLANES.

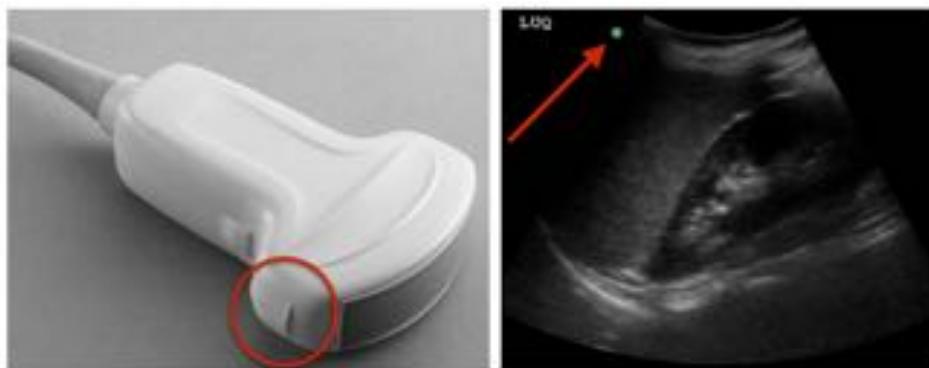
Recall the anatomical planes which are regularly utilised in ultrasound.



# STORM MANUAL

## PROBE ORIENTATION.

To orient yourself to the probe locate the marker on the side of the probe (see below). This correlates with the marker identifier on the screen. Alternatively, touch your finger to one side of the probe and observe which part of the screen records a signal.

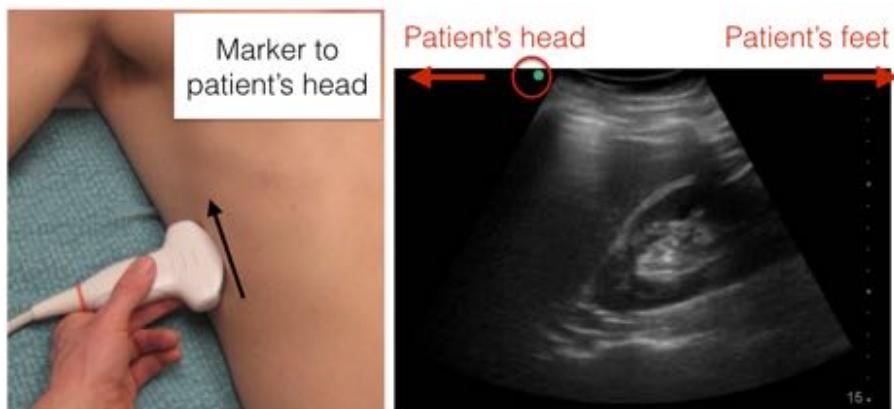


### Probe orientation for imaging the TORSO:

- When the probe is placed *transversely* (transverse plane), the marker is placed to the patient's *right*. Therefore, structures on the right of the body will appear on the left of screen (just like reading an abdominal CT scan) (see image below).



- When the probe is placed *longitudinally* (coronal and sagittal planes), keep the probe marker to the patient's head: cephalad structures (closer to the head) will now appear on the left of the screen, and caudal structures (closer to the feet) will appear on the right of the screen (see following image).



# STORM MANUAL

## Probe orientation for CARDIAC scanning:

- This can be tricky.
- See the 'Echocardiography in Life Support' section for more detail.

## Probe orientation for PROCEDURAL GUIDANCE:

- Be sure to align left of the screen to the left of the probe.

## IMAGE OPTIMISATION.

The following are basic adjustments that can be made to optimise your image once you start scanning.

### DEPTH:

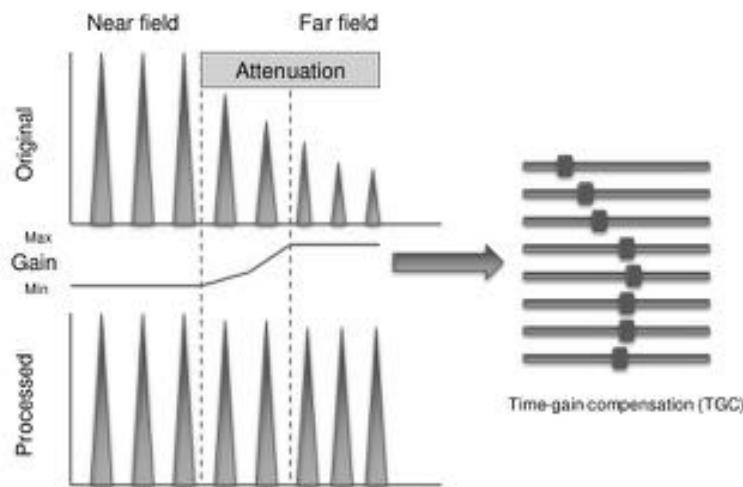
- Alters your depth of the field of view.
- Always set your depth 'just deeper' than the structure you are scanning.
- This can be adjusted using the hard keys located on the left side of the keyboard.

### FOCUS:

- Image quality and beam focus are best at the focal zone.
- Typically the focal zone(s) will be manually placed to optimise the resolution of an area of interest.
- The Sonosite machines used by Sydney HEMS do not have manual focal zone adjustment. Instead they automatically focus on an area approximately half-way to two-thirds along the depth of the screen. Therefore *depth* will provide *focus*.

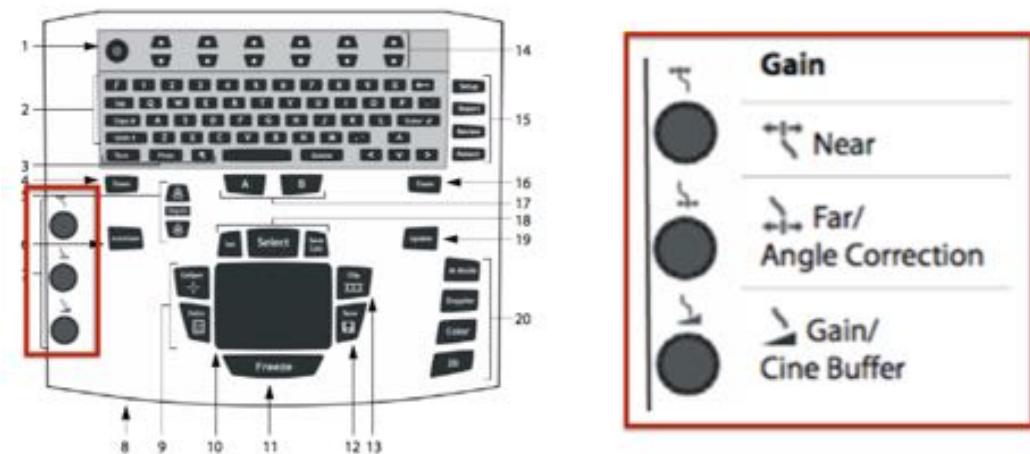
## TIME GAIN COMPENSATION (TGC) & OVERALL GAIN:

- Gain compensates for attenuation and acts by amplifying the signals returning to the receiver. Displayed images will appear brighter and more visible.
- The operator can decide at what rate gain is applied to their signal using TGC controls (see below).



## STORM MANUAL

- On our Sonosite M-Turbo machines; gain can be adjusted near field, far field or overall (see image below).
- In reality, adjust gain so that *fluid just appears black*.
- NB. excessive gain will cause excessive noise in your image.



### REMEMBER THE ULTRASOUND MANTRA

- Patient
- Probe
- Preset
- Depth
- Focus
- TGC

#### Helpful tip

The “2D” button is your ‘get out of jail free’ card.

Use this if others (or yourselves) have played around with M-mode, Gain, Doppler etc and you just want to get back to scanning

**NOW YOU'RE READY TO START SCANNING...**

# STORM MANUAL

## SOME MORE PRACTICAL TIPS & TRICKS.

### LABELLING IMAGES.

The easiest way to label your images is by placing text on the image.

On the Sonosite, simply press the *TEXT* key & a green cursor appears on the screen.

- This cursor can be moved where desired with the *touchpad* or *arrow keys*.
- Pressing *HOME* takes the cursor back to the home position.
- Use the keyboard to type free text.

If desired, pictographs and *arrows* can be placed on your image by pressing the *PICTO* and “*↖*” keys respectively.

### IMAGE MEASUREMENT.

Basic measurements can be performed in 2D imaging including distance (cm), area (cm<sup>2</sup>) and circumference (cm).

On a frozen 2D image, press the *CALIPER* key; a pair of callipers will appear connected by a dotted line.

- Using the touchpad, position the first caliper then press *SELECT*. The other caliper now becomes active.
- Using the touchpad, position the other caliper. Distance will be displayed in *cm*.

### SAVING IMAGES.

When you've acquired an interesting (or diagnostic) image, the easiest and quickest thing to do is save it to the devices internal storage.

- To save an image, simply press the *SAVE* key. This saves the image to internal storage.
- To capture and save a clip, simply press the *CLIP* key. It is recommended to save several loops as some machines will save loops prospectively, others retrospectively.
- Once you have finished scanning your current patient press the *EXAM* key and select “*END EXAM*”.

### EXPORTING IMAGES.

You can export your saved images and loops onto a USB device at a later date.

- Press the *REVIEW* key & select your patient from the patient list.
- Insert your USB device into the machines side port.
- Select *Exp. USB* on screen & select your device.
- Select *Export*.
- A USB animation will commence on the screen. The exporting is finishing approximately 5 seconds after the animation stops.

## INTRODUCTION.

Extended Focused Assessment with Sonography in Trauma (EFAST) has supplanted FAST as the standard of care in bedside imaging of the trauma patient.

It is a means of detecting:

- free intraperitoneal fluid
- free pleural fluid
- free pericardial fluid
- pneumothorax

## Why use ultrasound ?

Traumatic cardiac tamponade, massive HTX and PTX can obviously be rapidly fatal if not detected & treated early. Unfortunately, physical examination is unreliable for the detection of these entities. Number studies have demonstrated that EFAST is both easy to learn as well as capable of producing reliable and repeatable results with as little as 10 proctored scans. It is up to 90% sensitive & 99% specific for traumatic haemoperitoneum and 92-98% sensitive & >99% specific for pneumothorax

## Basic Principles of EFAST:

1. *Pneumothorax (PTX)* collects at the anterior chest in the supine patient
2. *Haemothorax (HTX)* collects at the posterior lung bases in the supine patient
3. The *amount of fluid* is important in the pleural & peritoneal spaces, but less so in the pericardium. This means that:
  - (a) *Pericardial blood* rapidly accumulates in trauma. The pericardium does NOT have time to stretch to accommodate the volume (ie. you don't need much to cause tamponade !!)
  - (b) There is more room to move in the pleural & peritoneal spaces. So if you see a tiny bit of fluid in these spaces in a shocked patient, then look elsewhere for the cause of the shock.
  - (c) In patients who have been sitting up (or standing) there may only be a little free fluid in Morrison's pouch. This may have drained into the pelvis.
  - (d) Free blood is only black (anechoic) if it's fresh. Look carefully if the presentation is slightly delayed as blood may be clotted & therefore missed.

## STORM MANUAL

### WHERE DOES FLUID COLLECT IN THE SUPINE PATIENT ?

Haemothorax collects posteriorly.

Haemopericardium collects first below the left side of the heart.

Haemoperitoneum will first collect in certain potential spaces in the supine patient;

1. **Right upper quadrant (RUQ):** FF will first collect around the liver in either;
  - (a) Morison's pouch (between liver & kidney)
  - (b) The anterior recess (caudal tip of the liver)
  - (c) Between the diaphragm & the liver (subphrenic space)
2. **Left upper quadrant (LUQ):** FF may collect here in the following spaces
  - (a) Between the diaphragm and spleen (subphrenic space)
  - (b) The lienorenal interface (between the spleen & kidney)
3. **Pelvis:** FF will collect in the Pouch of Douglas (rectovesical pouch in the male) deep to the bladder.

### CAUTIONS, CONTRAINDICATIONS AND LIMITATIONS.

Recall that EFAST cannot determine the *source* and *nature* of free fluid (eg. it is unable to differentiate between blood and ascites). It is also not capable to identifying solid organ or hollow viscous injuries and it is unable to identify the presence of retroperitoneal injuries.

Although EFAST is the standard of imaging in trauma, it is indicated only if it will affect patient management. For example, in the *stable* patient with blunt abdominal trauma, a negative FAST gives no information about solid organs or hollow viscous injury. Such patients may require other imaging such as CT at the receiving hospital.

The only *absolute contraindications* to performing an EFAST are;

1. The presence of a more pressing problem or need for resuscitative intervention
2. A clear indication for emergency laparotomy is already present (eg. abdominal stab wound and shock).

A very early EFAST scan may be *falsely negative* as sufficient bleeding may not have occurred to collect in dependent locations. There is benefit in repeating the scan if your index of suspicion is high.

# STORM MANUAL

## PROBE AND SCANNER SETTINGS.

### PROBE.

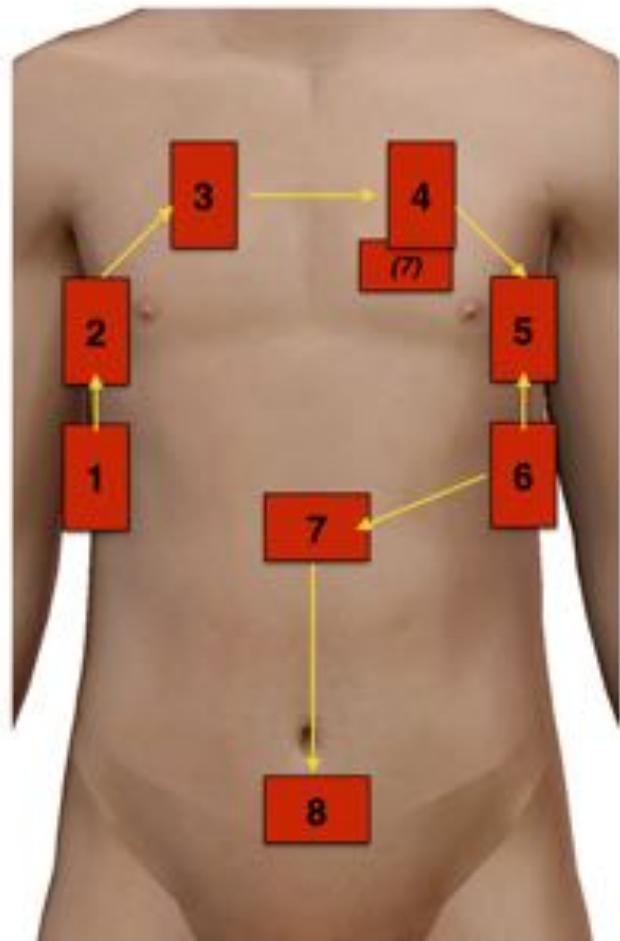
The curvilinear, low-frequency probe should be used & will suffice for all windows. Alternatively the cardiac sector probe allows adequate assessment of all windows also. The high-frequency linear probe allows for accurate assessment for pneumothorax.

### DEPTH.

- 5cm for anterior chest (PTX)
- 15cm for HTX & haemoperitoneum
- 20cm for subcostal cardiac view.

## EFAST - THE WINDOWS:

1. Right upper quadrant
2. R. chest (lower)
3. R. chest (upper)
4. L. chest (upper)
5. L. chest (lower)
6. Left upper quadrant
7. Pericardium
8. Pelvis (two planes)



The order in which you scan will be entirely dependent upon the clinical context & in the retrieval environment, your access to the various body regions.

## STORM MANUAL

### RIGHT UPPER QUADRANT.

Scanning the RUQ.



1. Set depth to 15cm
2. Begin with the probe parallel & between the ribs where the costal margin meets the mid-axillary line on the right of the patient. This window uses the liver as an acoustic window & should demonstrate right kidney, liver, diaphragm (highly echogenic) and right lung base (for PTX/HTX).
3. Scan all the way through the kidney.
4. Scan down to the tip of the liver.
5. Scan as much of the hemidiaphragm as possible. Ask the patient to take a deep breath.

Normal RUQ.

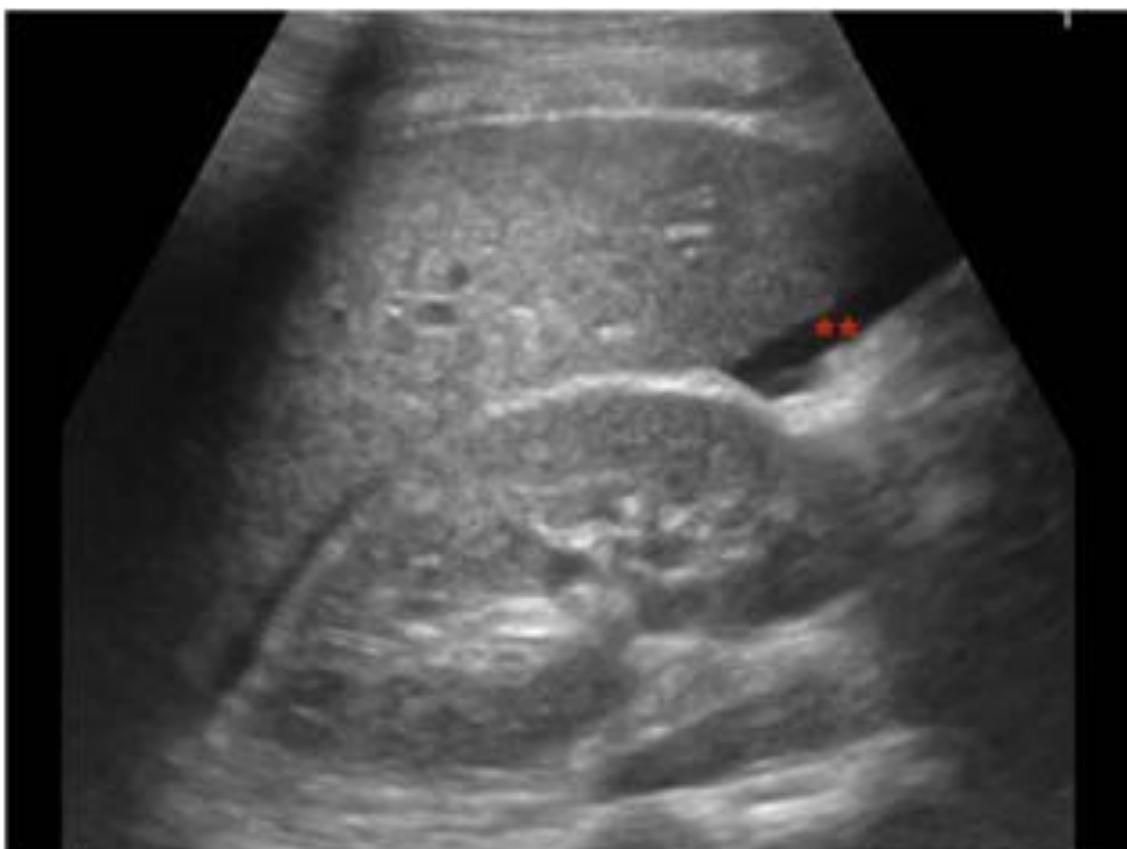


## STORM MANUAL

### Abnormal RUQ.



RUQ VIEW: HYPOECHOIC FREE FLUID (FF) SEEN WITHIN MORISON'S POUCH



RUQ VIEW: FREE FLUID WITHIN MORISON'S POUCH AND ADJACENT TO THE CAUDAL TIP OF THE LIVER.

## STORM MANUAL



RUQ VIEW: FREE FLUID ADJACENT TO THE CAUDAL TIP OF THE LIVER.  
THERE IS RELATIVE PRESERVATION OF MORISON'S POUCH.



RUQ VIEW: MASSIVE HAEMOPERITONEUM WITH CLOTTED (HETEROGENOUS)  
BLOOD SURROUNDING THE LIVER TIP & MORISON'S POUCH

## STORM MANUAL

### LEFT UPPER QUADRANT.

Scanning the LUQ.



1. Set depth to 15cm
2. Begin with probe on left side; as for RUQ except higher (ribs 9-11) and more posteriorly (posterior axillary line). This is the "*knuckles to the bed*" window. The spleen is smaller, more posterior & higher than the liver, so this side is always trickier than the RUQ.
3. Sweep the probe and alter its angle as above until you obtain a clear view of the left kidney, spleen, diaphragm and left lung base.
4. If you still cannot find the spleen, ask the patient to take a deep breath.

Normal LUQ.

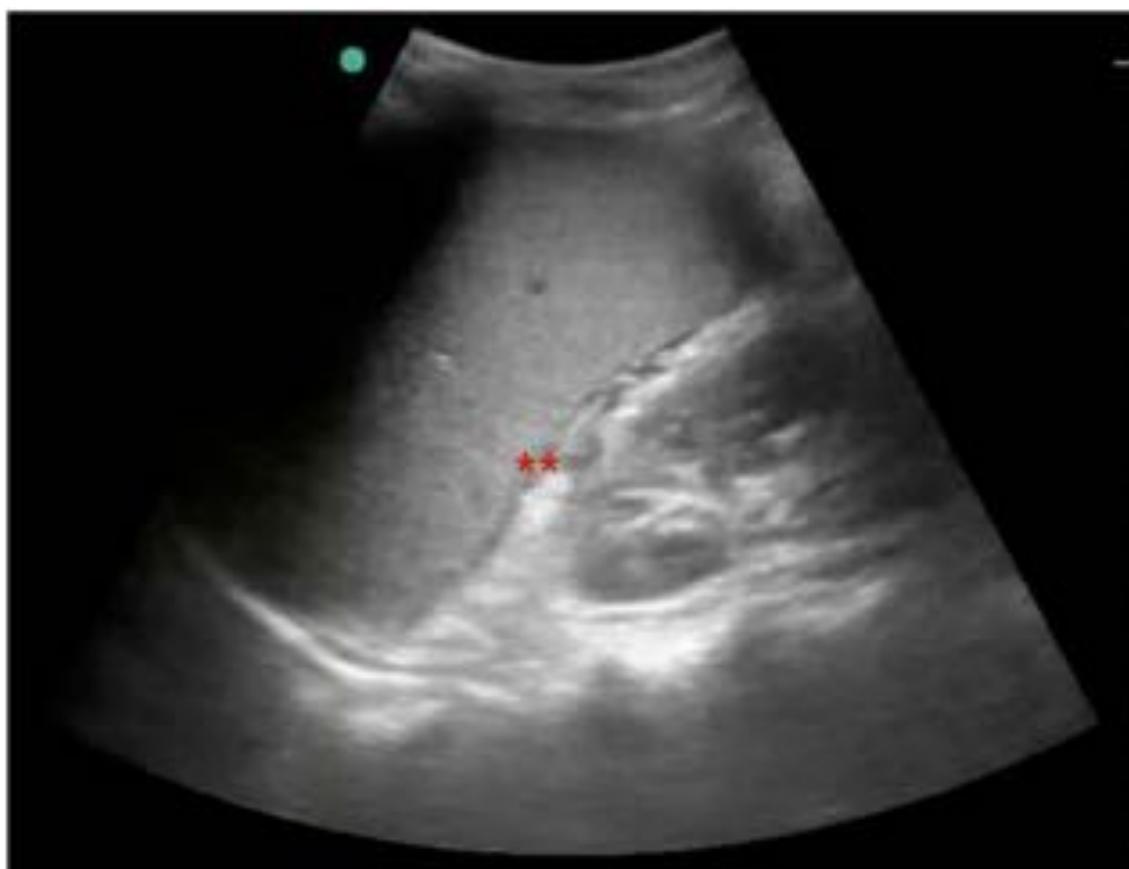


## STORM MANUAL

### Abnormal LUQ.

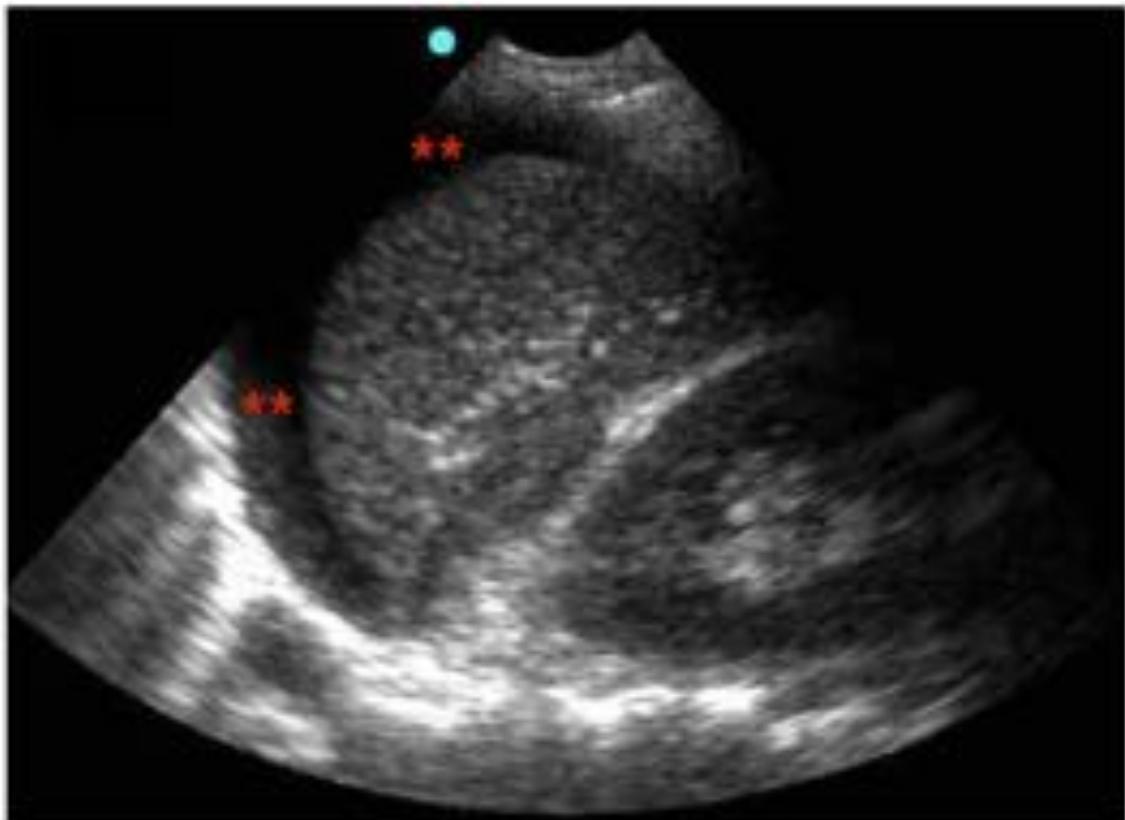


LUQ VIEW: POSITIVE SCAN WITH LARGE VOLUME FF SURROUNDING THE SPLEEN.

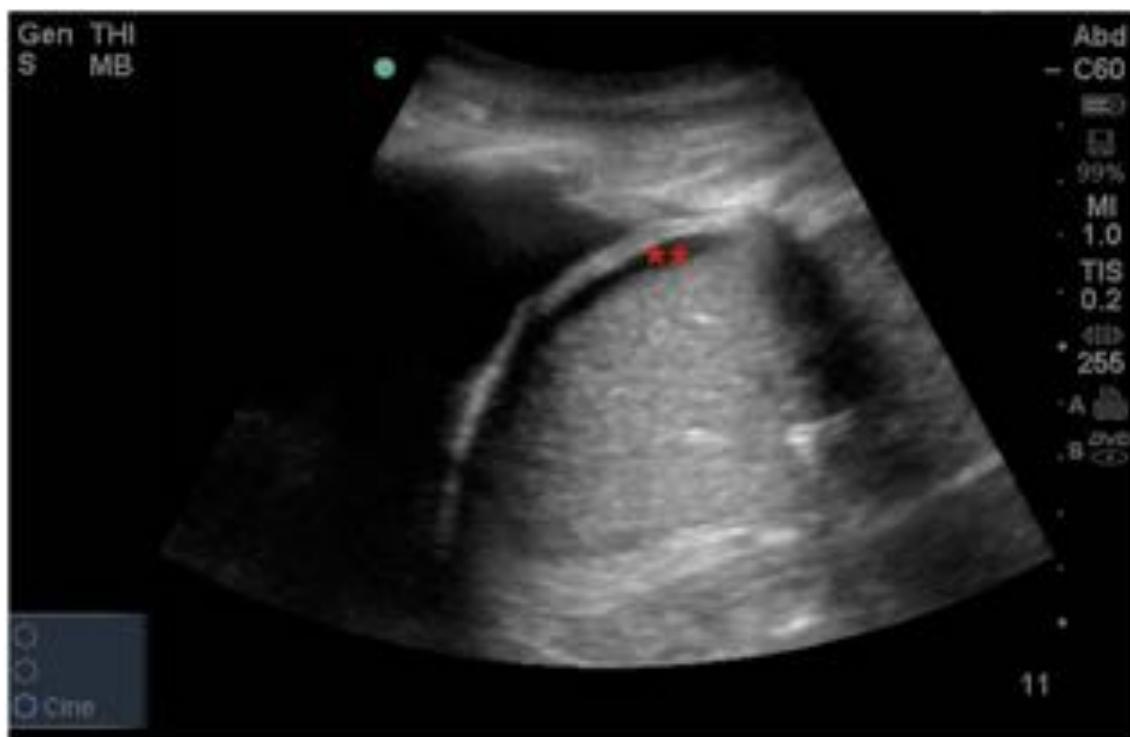


LUQ VIEW: SMALL AMOUNT OF HYPOECHOIC FF AT THE LIENORENAL INTERFACE

## STORM MANUAL



LUQ VIEW: POSITIVE SCAN LARGE VOLUME OF SUBPHRENIC FF.



LUQ VIEW: POSITIVE SCAN WITH SUBPHRENIC FF.  
NB. THE ASSOCIATED LEFT PLEURAL EFFUSION.

## STORM MANUAL

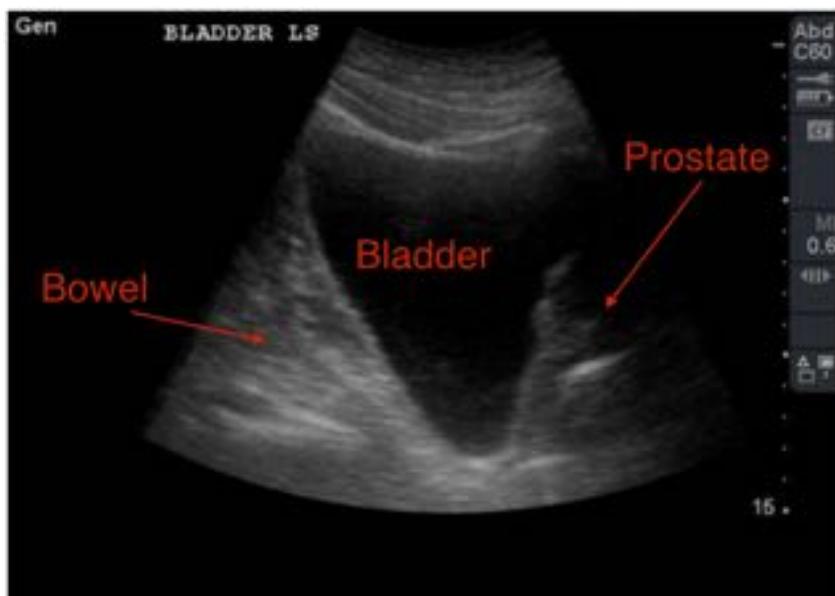
### THE PELVIS.

#### Scanning the PELVIS.



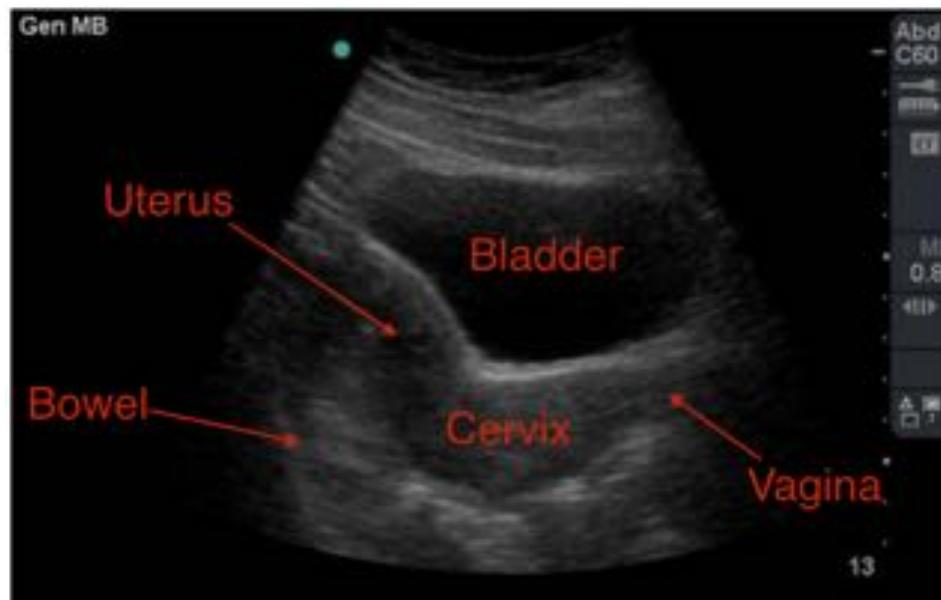
1. Set depth to 15cm
2. Begin with the probe resting just above the pubic symphysis, angling the probe down into the pelvis.
3. Fan the probe back and forth until you see the bladder. The fluid-filled bladder is used as an acoustic window, so if possible scan before catheterising the patient.
4. Increase the depth so that you obtain a good view of the structures deep to the bladder.
5. Scan in *TWO* planes at 90 degrees to each other.
  - Sagittal plane
  - Transverse plane
6. Scan all the way past the bladder to be sure you are not missing anything.
7. Free fluid will be around the bladder, or behind it in the Pouch of Douglas.

#### Normal SAGITTAL PELVIS (male).

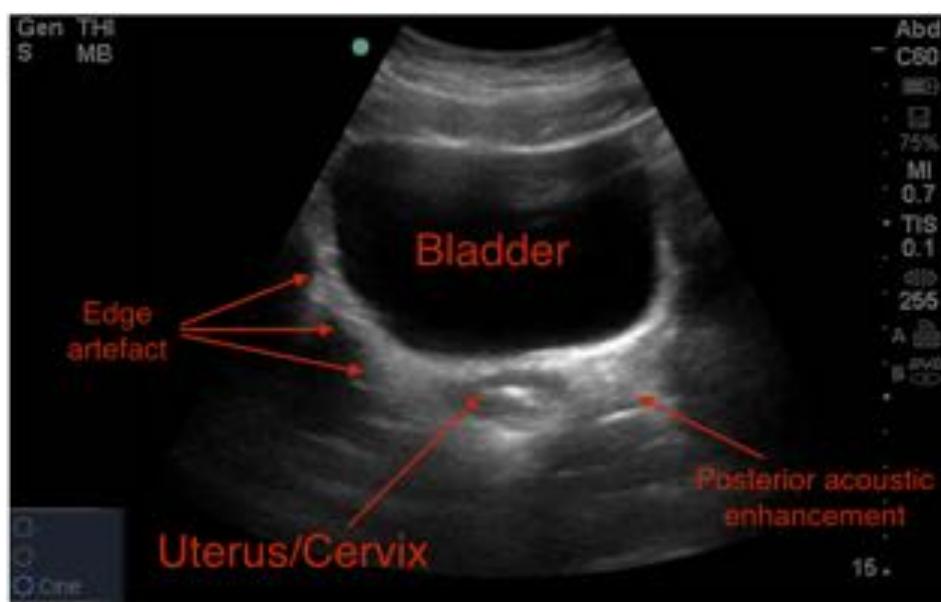


## STORM MANUAL

Normal SAGITTAL PELVIS (female).



Normal TRANSVERSE PELVIS.



TWO ARTEFACTS THAT EXIST AROUND THE BLADDER.

### 1. Mirror artefact:

The presence of a smooth, curved surface (in this case the bladder wall) with air on one side (in this case, in the bowel next to the bladder) creates perfect conditions for a mirror artefact. It is very common to see the FF in the bladder reflected outside it. This can mimic intraperitoneal FF and obscure underlying structures (see page 20).

## STORM MANUAL

### 2. Edge artefact

The lateral edges of any curved structure (such as the bladder) will cause sound waves to reflect off at such an angle that they simply don't return to the probe. This creates 'shadows' and obscures deeper structures.

In order to avoid getting caught out by these artefacts make the effort to scan *through the bladder from left to right* and remember to always scan the bladder in two planes !

Abnormal PELVIS.

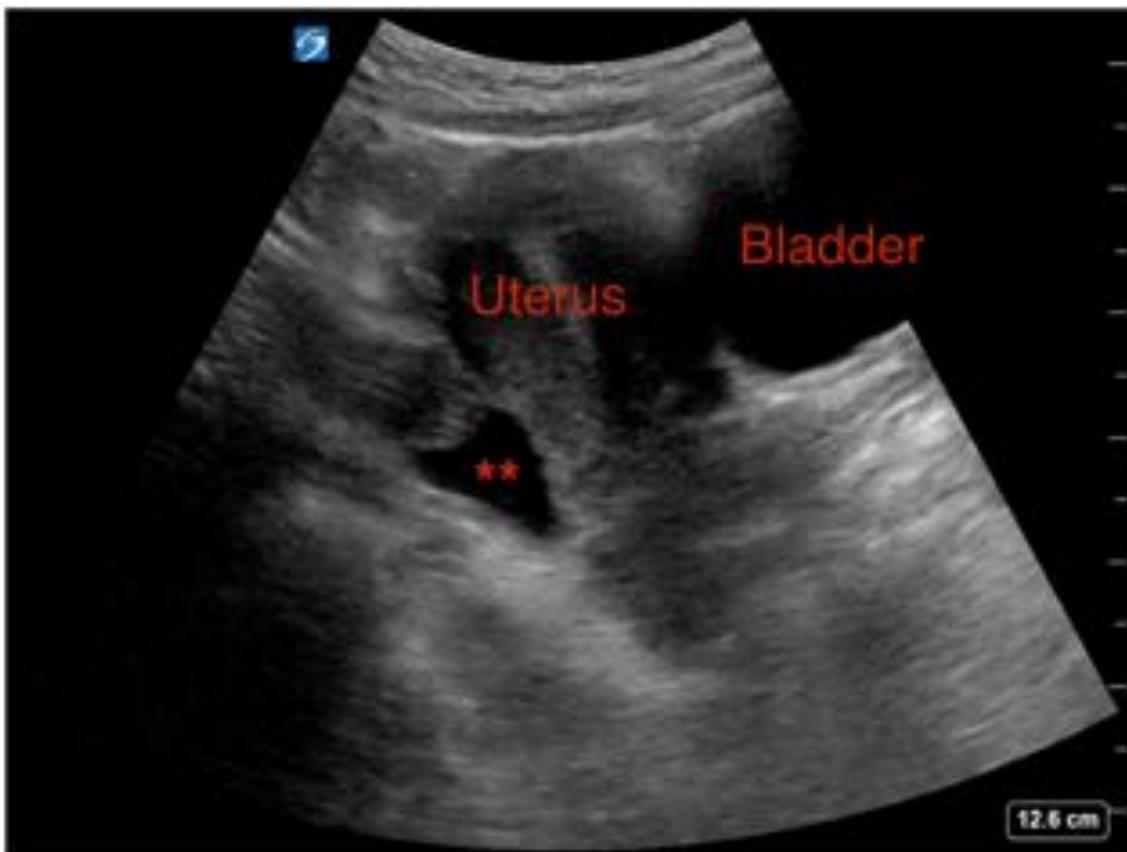


TRANSVERSE VIEW: POSITIVE SCAN WITH FF ADJACENT TO BLADDER

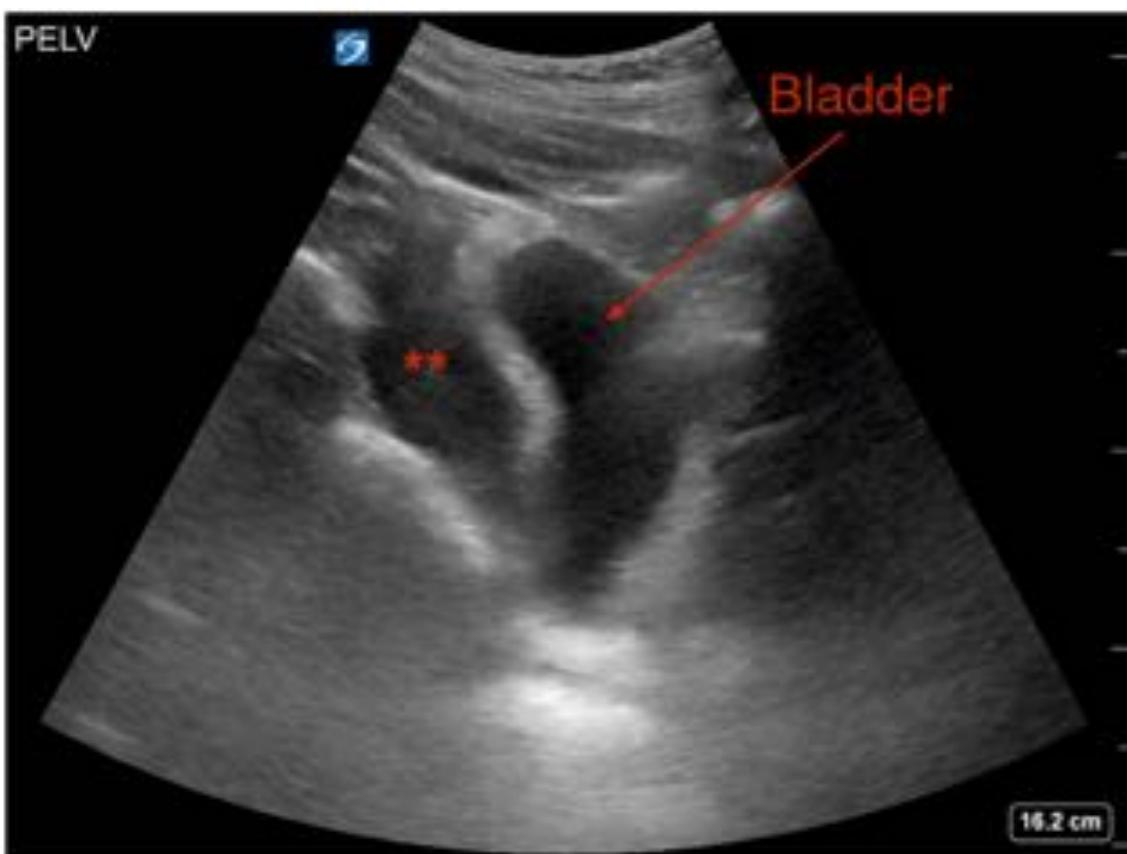


SAGITTAL PELVIS VIEW: LARGE VOLUME FF WITH BOWEL LOOPS CLEARLY DEFINED.

## STORM MANUAL



SAGITTAL PELVIS VIEW: FF WITHIN THE POUCH OF DOUGLAS



SAGITTAL PELVIS VIEW: FF WITH ECHOGENIC CLOT

## STORM MANUAL

### THE PERICARDIUM.

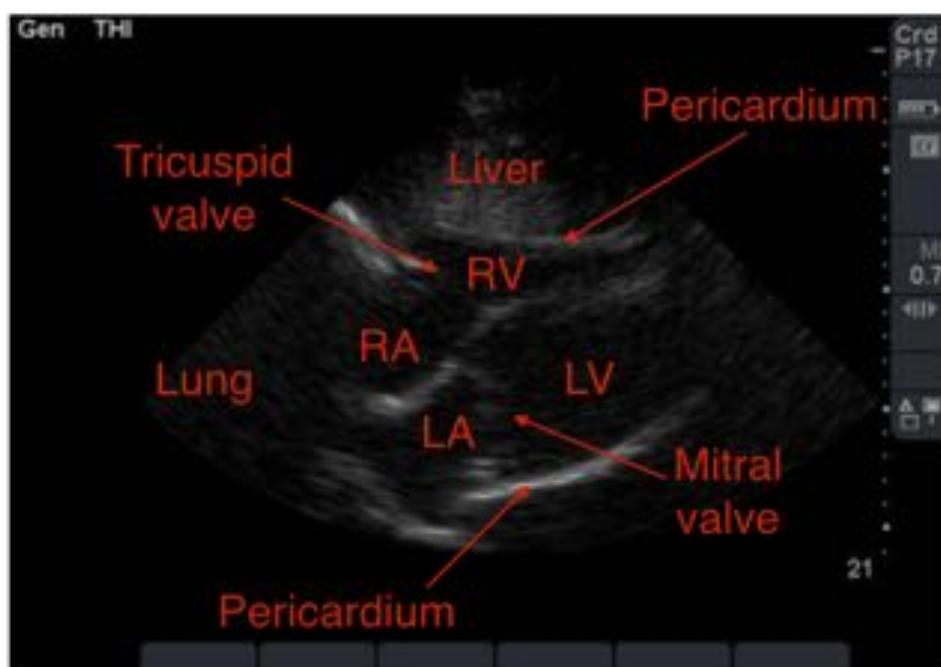
#### Scanning the PERICARDIUM.



The easiest window is the subcostal/subxiphoid view (*left image*). Alternate views include the parasternal (*right image*) or apical windows.  
(see *Echocardiography in Life Support chapter* for more details)

1. Set depth to 20cm
2. Lay probe almost flat on the patient's epigastrium & angle it up towards the head.  
Advance the probe towards the xiphisternum.
3. Find the left lobe of the liver on the screen. The heart will be deep to this.
4. Pericardial fluid appears as a black stripe around the heart if the blood is fresh.
5. If the blood is clotted, it will appear grey or even heterogenous.

#### Normal PERICARDIUM.



## STORM MANUAL

Abnormal PERICARDIUM.



SUBCOSTAL VIEW DEMONSTRATING A LARGE CIRCUMFERENTIAL PERICARDIAL EFFUSION



SUBCOSTAL CARDIAC VIEW DEMONSTRATING PERICARDIAL EFFUSION AND RIGHT VENTRICULAR COLLAPSE SUGGESTIVE OF TAMPOONADE

## STORM MANUAL



SUBCOSTAL CARDIAC WINDOW DEMONSTRATING HETEROGENOUS CLOTTED PERICARDIAL BLOOD

### Cardiac tamponade.

In true cardiac tamponade the IVC distends and the right ventricle will collapse during diastole. This can be difficult to assess for the non-echocardiographer, so *clinical* likelihood of tamponade (shock + chest trauma) must be taken into consideration when acting on a positive scan. For more details on tamponade see *Echocardiography in Life Support* chapter.

### Tips to improve your view:

1. Scan during maximal inspiration. This will push gas-filled bowel out of the way.
2. Bend the patient's knees: this will relax the abdominal wall muscles.

## STORM MANUAL

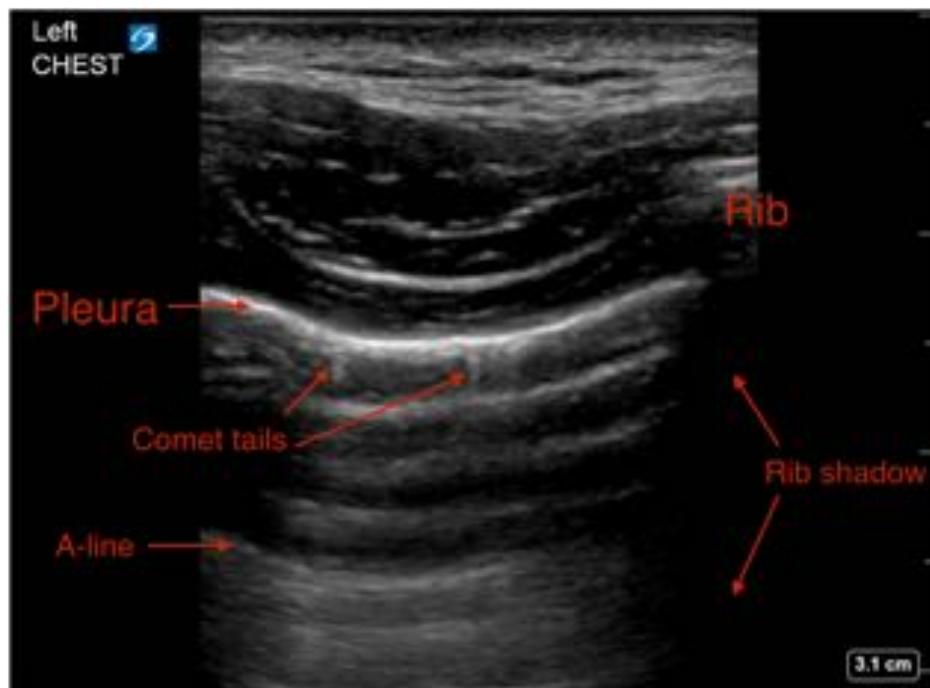
### THE CHEST (PNEUMOTHORAX).

#### Scanning for PNEUMOTHORAX.



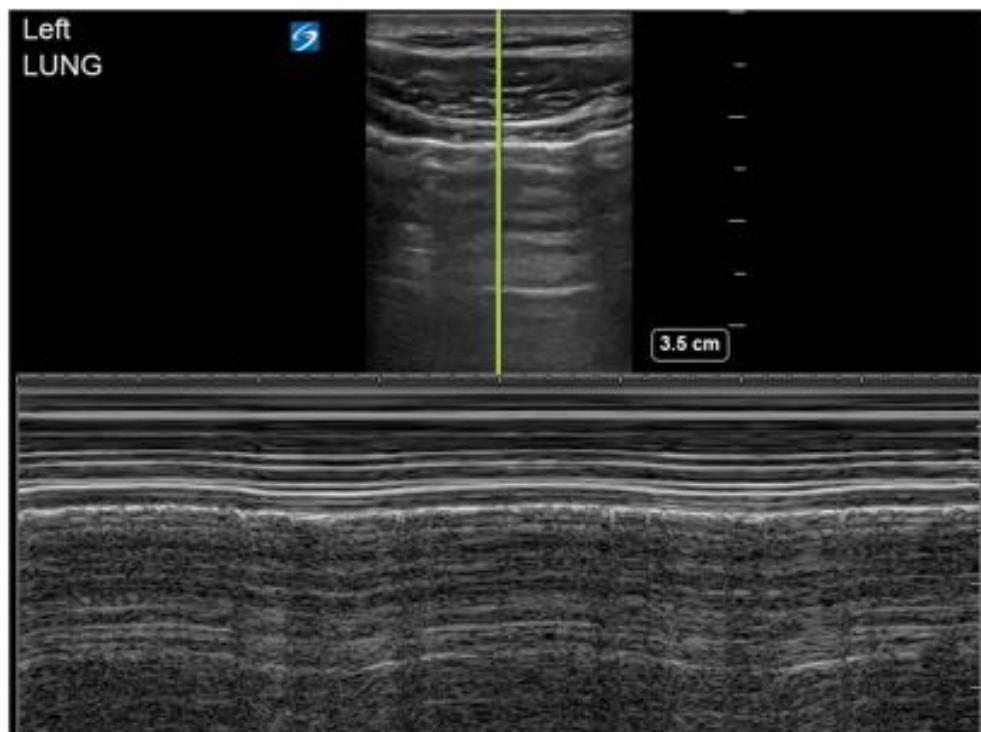
1. The curved, sector or linear probes can all be used for this study (use dedicated *lung* preset, alternatively *FAST* or *Abdo* preset will be ok).
2. Set depth to ~5cm
3. Place the probe on the highest part of the anterior chest with the marker aimed cranially.
4. Examine for lung-sliding at the pleural line as well as the presence of *comet tails* and *A-lines* - these suggest the presence of normal lung (ie. no pneumothorax).
5. Active 'M-mode' and place the sampling line to intersect the pleural line.  
Normal lung will create a *seashore sign*.

#### Normal 2D appearance.



## STORM MANUAL

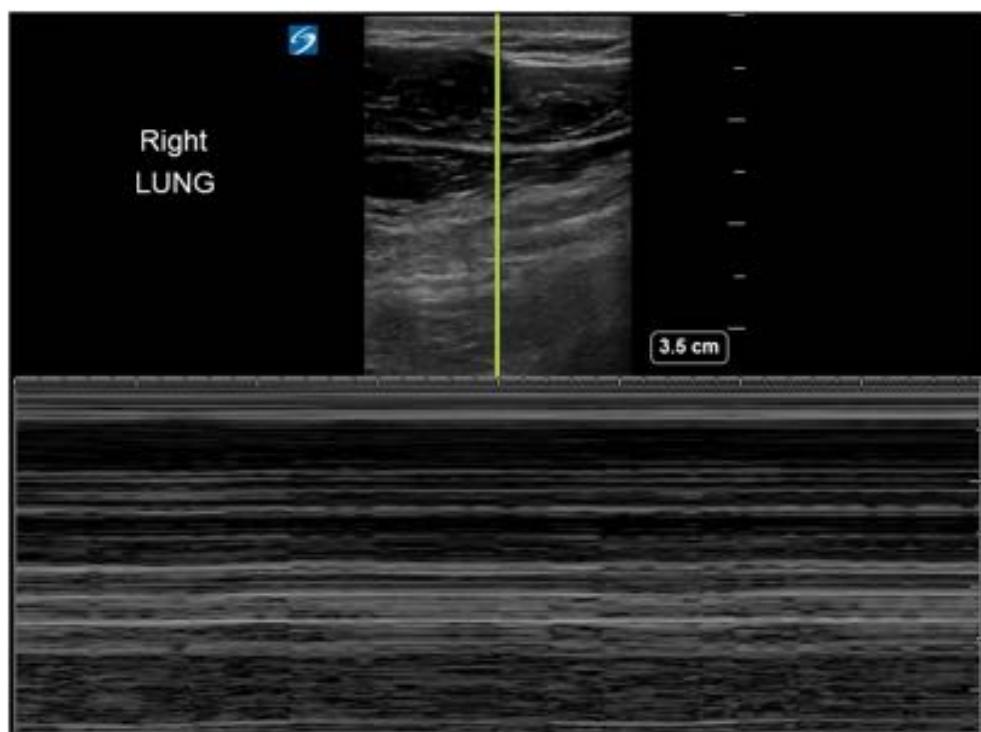
Normal M-mode appearance.



M-MODE IMAGE - SEASHORE SIGN

Pneumothorax is diagnosed by absent lung-sliding and absent comet tails (on 2D imaging) as well as *Stratosphere* or *Bar-code* signs on M-mode images.

Abnormal M-mode appearance.



M-MODE IMAGE - STRATOSPHERE (OR BARCODE) SIGN

## STORM MANUAL

*Lung sliding will be absent in several conditions:*

- Pneumothorax
- Pleurodesis
- Bronchial intubation (non-ventilated lung)
- Malignancy
- Subpleural bullae
- Pneumonia, contusion or ARDS
- Severe fibrosis

### THE CHEST (HAEMOTHORAX).

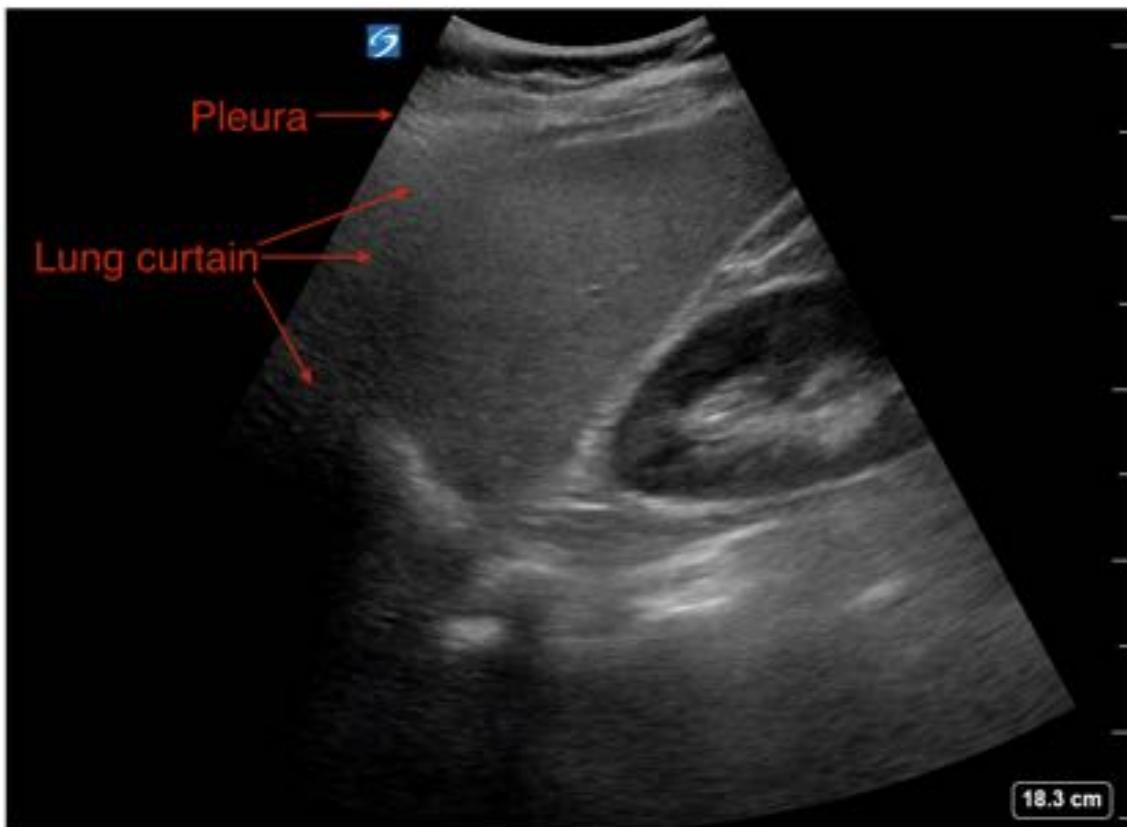
Scanning for HAEMOTHORAX.



1. Set depth to 15cm
2. Slide the probe up 2-3 rib spaces from your RUQ/LUQ position until the diaphragm is in the centre of the screen.
3. As the patient breathes in watch for the bright 'scatter' from air in the lung sweep down and obscure the image. This is called '*the lung curtain*' and its presence means that there is no pleural fluid (such as haemothorax) at that site.
4. Scan as far posteriorly as possible as there may still be a small amounts of pleural fluid. To increase your sensitivity, scan the most inferior part of the thorax.
5. Fluid will appear black, dark or clotted, just above the diaphragm. You may see the lung floating within a large effusion.

## STORM MANUAL

### Normal PLEURA.



RIGHT CHEST IMAGE DEMONSTRATING THE PRESENCE OF A LUNG CURTAIN (NO HAEMOTHORAX)

### Abnormal PLEURA.



RIGHT CHEST IMAGE DEMONSTRATING A LARGE HYPOECHOIC PLEURAL EFFUSION

# STORM MANUAL

ultrasound  
VILLAGE

# E-FAST

E-FAST is a limited trauma ultrasound that only aims to detect:  
 - Free abdominal fluid  
 - Penetrating injuries  
 - Major hematomas  
 - Pneumothorax

Patient details  
 A normal E-FAST does not exclude hemoperitoneum, hemothorax, or pneumothorax

Mechanism of Trauma		Patient details			
Examination findings		Pulse	BP	RR	Sats
Profile Position	Upright	Normal			
1. Head	Right	Normal	Inadequate	Positive	< 20mm maximal depth
Head rotates to a neutral position Head rotates to a lateral position Glasgow score of 10 or more with full					2-5mm maximal depth
2. Neck	Left	Normal	Inadequate	Positive	> 10 mm maximal depth
Left					
3. Subcostal	Subcostal	Normal	Inadequate	Positive	< 20mm maximal depth
Subcostal is a line of attachment In the neck in the posterior axillary line In the neck in the anterior axillary line In the neck in the posterior midline In the neck in the anterior midline In the neck in the posterior axillary line In the neck in the anterior axillary line In the neck in the posterior midline In the neck in the anterior midline					2-5mm maximal depth
4. Middle Posterior L5	Posterior	Normal	Inadequate	Positive	> 10 mm maximal depth
Posterior In the low back region and below the ribcage In the middle back in the posterior axillary line In the middle back in the anterior axillary line In the middle back in the posterior midline In the middle back in the anterior midline					
5. Femoral Pelvis T12	Subcostal	Normal	Inadequate	Positive	
Subcostal					
6. L8-S2 Lumbar	Posterior	Normal	Inadequate	Positive	Maximal depth_____mm
Posterior In the low back region and below the ribcage In the middle back in the posterior axillary line In the middle back in the anterior axillary line In the middle back in the posterior midline In the middle back in the anterior midline					
7. Left Lung Pneumothorax	Normal	Inadequate	Positive	Positive	< 2mm maximal depth
Left Lung Pneumothorax					2-10mm maximal depth
8. Right Lung Pneumothorax	Normal	Inadequate	Positive	Positive	> 10 mm maximal depth
Right Lung Pneumothorax					
9. Left Lung Pneumothorax	Normal	Inadequate	Positive	Positive	Detected airway
Left Lung Pneumothorax					Airway and lungs
10. Right Lung Pneumothorax	Normal	Inadequate	Positive	Positive	Airway and lungs
Right Lung Pneumothorax					
Conclusions (Note: E-FAST findings must be consistent with clinical suspicion, etiologic history, examination, investigations and E-FAST findings to reach a conclusion)					
Examiner	Signature	Date	Time		
EMERGENCY SURGICAL Ultrasound					

## ECHOCARDIOGRAPHY IN LIFE SUPPORT

### INTRODUCTION.

Numerous studies demonstrate that echo can be safely and reliably performed by critical care physicians (and medical students!) after brief training, as long as it is used to answer specific and focused questions produced by the clinical assessment.

In other words, the *right approach* would be: 'This hypotensive patient has not responded to a fluid challenge. I'll perform a focused echo to exclude cardiac tamponade and visually assess his LV systolic function to see whether pump failure could be the cause of his hypotension.'

The *wrong approach* would be: 'I'm not sure what's wrong with this dizzy patient with chest pain. Let's do an echo and see if we find anything'.

It should be obvious that the 'right' approach outlined above requires limited, focused training in specific areas to bring echo into the critical care physician's diagnostic toolbox. The 'wrong' approach could only be of any value if the sonographer had completed in depth echo training that would allow detailed assessment of all measurable aspects of cardiac structure and function.

### The focused questions.

- ***Is the heart beating ?***

In the arrested patient, cardiac standstill carries a significantly worse prognosis and may clinicians would cease resuscitation at this point.

- ***Is there a tamponade ?***

This is a clinical question, ie. the patient is critically shocked. One needs to identify a pericardial effusion (this can occasionally be subtle / localised, but will usually surround the heart & be present throughout the cardiac cycle). The easiest, most reliable US feature of tamponade (versus simple effusion) is the presence of distended veins (IVC & elsewhere). Other features such as right ventricular collapse can be subtle.

- ***Is the IVC/RV/LV small, large or grossly normal ?***

- ***Is RV or LV contraction grossly normal ?***

## STORM MANUAL

### Principles of basic cardiac ECHO.

- **Opportunistic:** You often can't achieve all the views in the critically ill, but you can usually obtain at least one useful view of the heart.
- **Qualitative:** 'Gross visual' assessment (no measurements).
- **Simple:** Limited to 2D 'B' mode scanning.
- **Caricatural:** Life threatening abnormalities are usually obvious on ultrasound (eg PE causing shock will be large enough to distend the IVC and stretch the RV).

### Examples of basic ECHO in critical care ?

A 56 year old breathless hypotensive man is hypoxaemic despite a high fractional inspired oxygen concentration, and the chest x-ray is unremarkable. The patient is too unstable to move to the CT scanner for a CT pulmonary angiogram.

Your basic echo reveals a dilated, poorly contracting right ventricle and abnormal septal motion. These are in keeping with acute cor pulmonale due to pulmonary embolism.

The patient receives fibrinolytic therapy in the resuscitation room and improves.

### ABBREVIATIONS.

A4C	Apical 4 chamber
A5C	Apical 5 chamber
IVC	Inferior vena cava
LA	Left atrium
LV	Left ventricle
LVEF	LV ejection fraction
LVIDd	LV internal diameter in diastole
PE	Pulmonary embolus
PLAX	Parasternal long axis
PSAX	Parasternal short axis
PTX	Pneumothorax
RA	Right atrium
RV	Right ventricle
RVOT	RV outflow tract

## STORM MANUAL

### FINDING THE HEART.

#### PATIENT POSITIONING.

During resuscitation it may not be possible to move the patient from a supine position. This is appropriate for the subcostal view, but if possible for the other views the patient should be positioned on the left side with the left arm above the head. This maximises the rib space and minimises the amount of left lung between the heart and the chest wall.

A good ECHO position if your patient is well enough:

- The left lung drops away from the midline of the chest
- The heart moves away from behind the sternum
- The intercostal spaces are widened



#### PRACTICAL CONSIDERATIONS.

As well as supine positioning, other factors related to resuscitation may impede the acquisition of an optimal view. Hyperinflation of the lungs leads to the presence of air between the heart and the chest wall, which is a poor conductor of ultrasound waves. This is often an issue in patients with chronic obstructive pulmonary disease (COPD) and in intubated patients receiving invasive mechanical ventilation. In patients in cardiac arrest, access to the chest wall may be limited by the need to provide chest compressions. In these situations, the best view may often be the subcostal view, although an attempt to obtain parasternal and apical views often yields useful images.

Despite these limitations in the resuscitation setting, studies show that transthoracic echo provides useful diagnostic information in critically ill patients in a high proportion of patients.

#### PROBE & SCANNER SETTINGS.

Whilst it is possible to get away with a curvilinear probe on abdo/FAST settings, the sector array probe on a cardiac preset will provide better images (especially on fast moving structures like valves). Its smaller footprint allows for better visualisation between the ribs.

## STORM MANUAL

### PROBE POSITIONING.

The probe should be held gently with the operator's arm relaxed. This requires the operator to be close enough to the patient to avoid elbow extension and straining of the shoulder and back muscles.



Correct operator positioning.

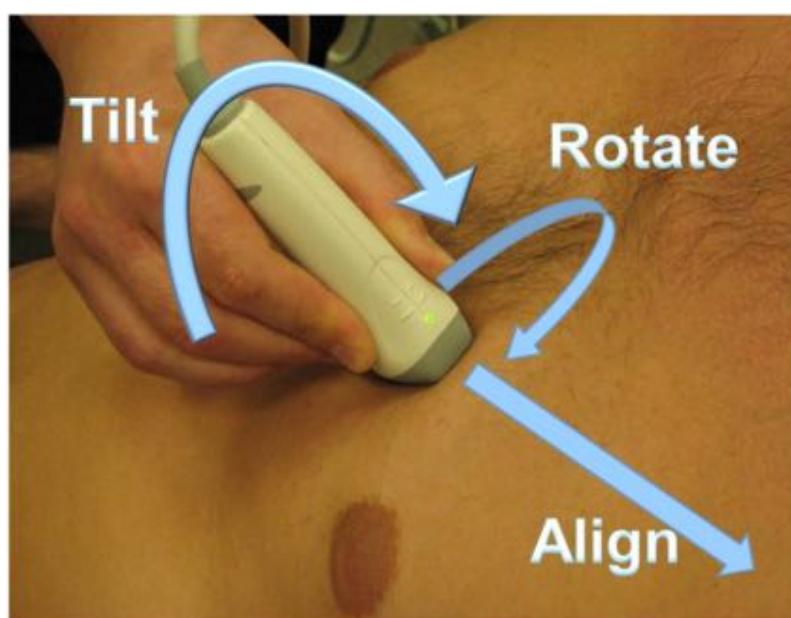
- Trolley height avoids stooping
- Back straight
- Elbow bent
- Shoulder relaxed

Poor operator positioning.

- Back is leaning
- Shoulder is not relaxed
- Elbow extended

Poor transducer control and discomfort will prevent the attainment of optimal images.

Probe positioning may be gently altered to obtain the best image by moving gradually in one plane at a time. The mnemonic 'ART' is useful which stands for 'align, rotate, tilt'.



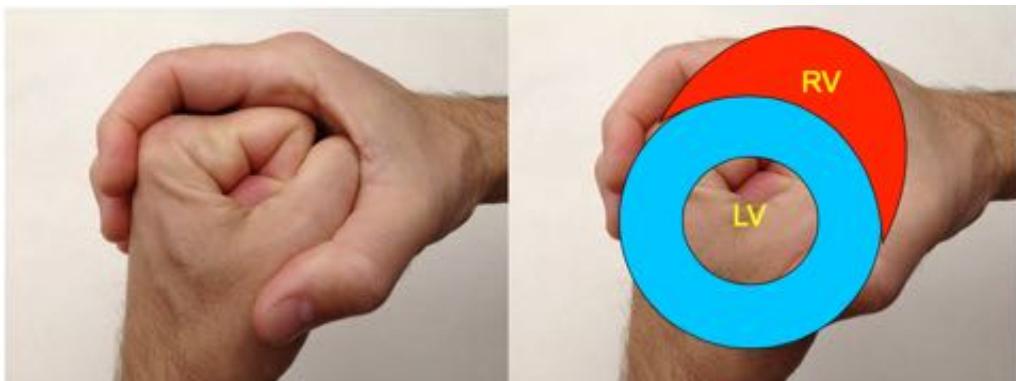
## Helpful tip

The *cardiac preset* flips the image in a right-left direction giving you a mirror image of what you see with an abdominal preset.

As a result, in contrast to the EFAST & abdominal scanning, in ECHO the side marker on the screen is on the right hand side of the image.

## BASIC ANATOMY.

Recall that the right side of the heart lies in front of the left. This means that it is closer to the probe on all views *except the apical*. The image below is a reminder of its complex structure and the relationship between the right and left ventricle.

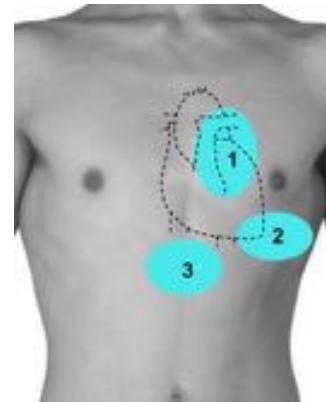


## ECHOCARDIOGRAPHIC WINDOWS.

The recommended sequence in a basic echo study examines four views in a convenient order. The practical considerations listed above along with the urgency of a resuscitation scenario may prevent the acquisition of all four views, but in most cases an attempt should be made to complete the sequence in order to maximise the reliability of the findings.

*These windows include;*

1. Parasternal (long & short) axis
2. Apical 4 chamber (& 2 chamber)
3. Subcostal (subxiphoid)

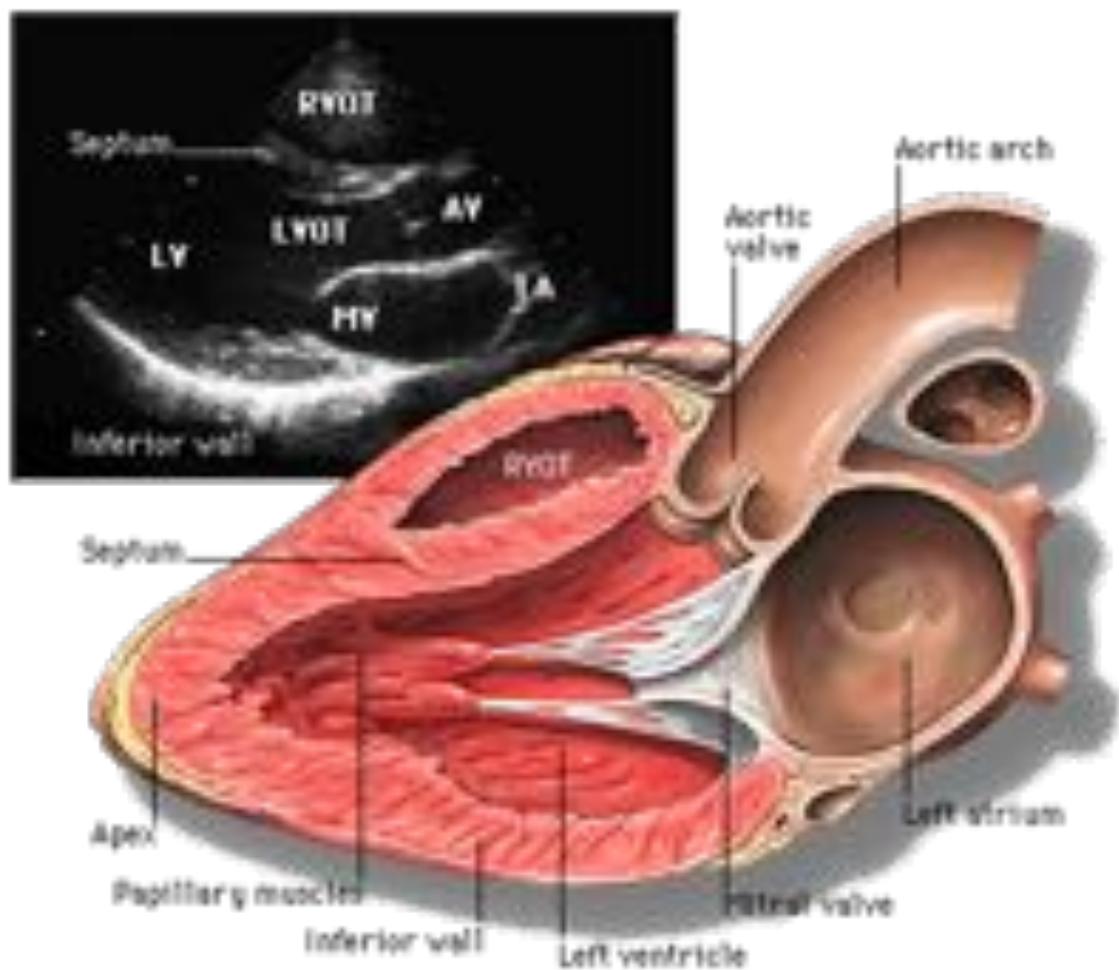
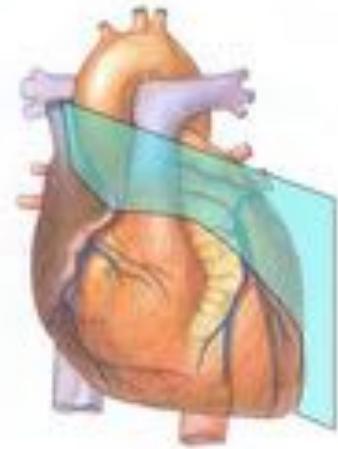


## STORM MANUAL

### PARASTERNAL LONG AXIS VIEW.

The aim is to orientate the beam with the long axis of the left ventricle.

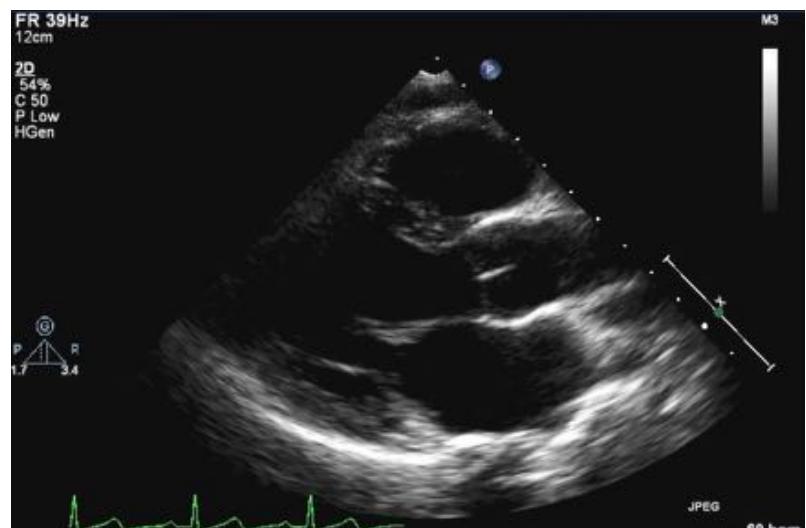
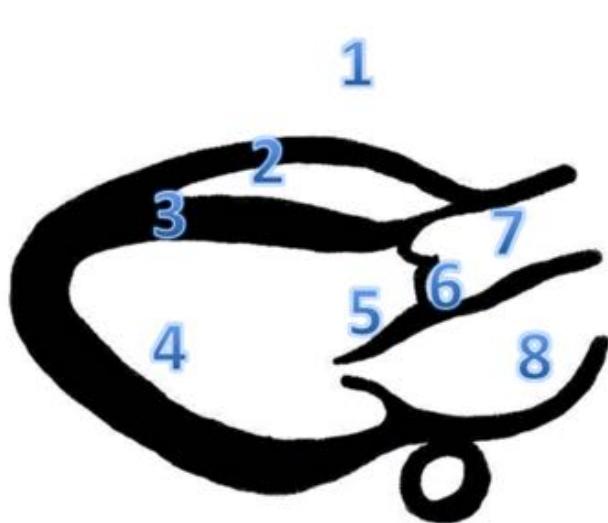
The transducer is placed to left of the sternum in the 3<sup>rd</sup>, 4<sup>th</sup>, or 5<sup>th</sup> intercostal space with the marker orientated towards the right clavicle (approximately 11 o'clock).



## STORM MANUAL

### A structured approach to the PLAX:

1. Examine the pericardial space. Is there fluid, or a fat pad? Is fluid pericardial or pleural? If there is pericardial fluid, can you demonstrate tamponade physiology?
2. Is the RV a normal size and contracting normally?
3. Is the septum a normal size and moving normally?
4. Is the LV a normal size and contracting normally?
5. Is the anterior MV leaflet moving normally?
6. Are the AV cusps thin and mobile?
7. Is the aortic root normal size; is there a dissection flap?
8. Is the LA a normal size?



### Criteria of quality for a good parasternal long axis view.

- the septum must be as horizontal as possible
- you should not visualise the apex of the left ventricle
- the interventricular septum and posterior wall should be parallel
- you should see the aortic and mitral valves but not the tricuspid valve

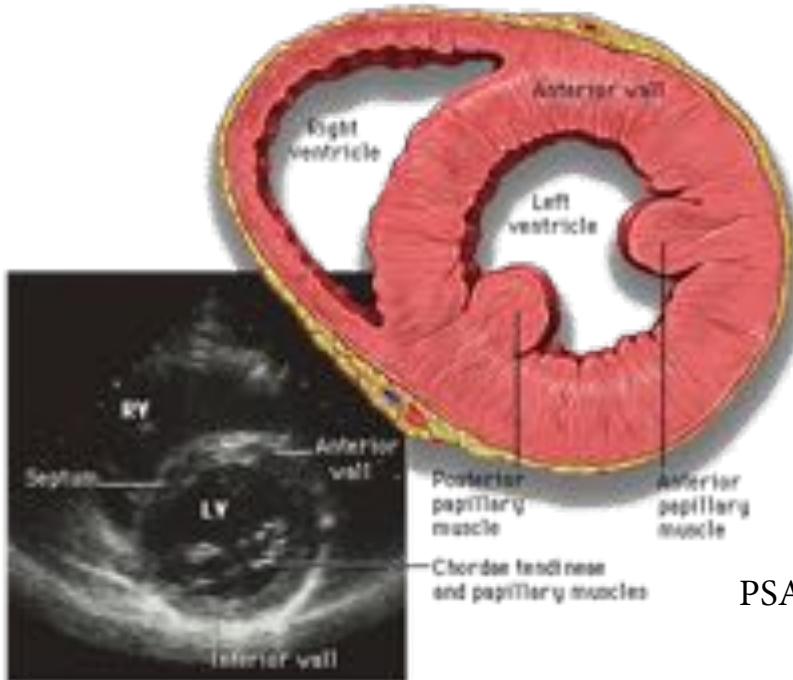
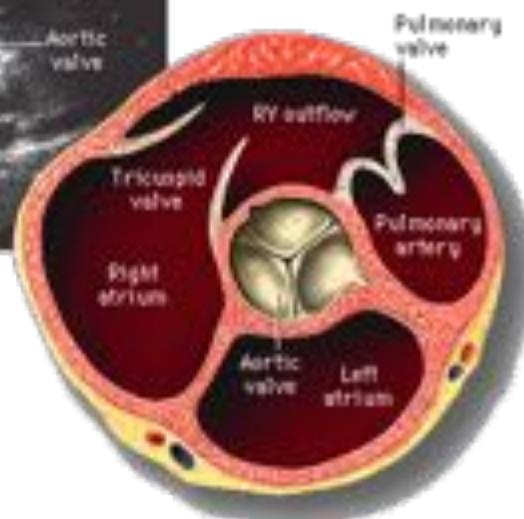
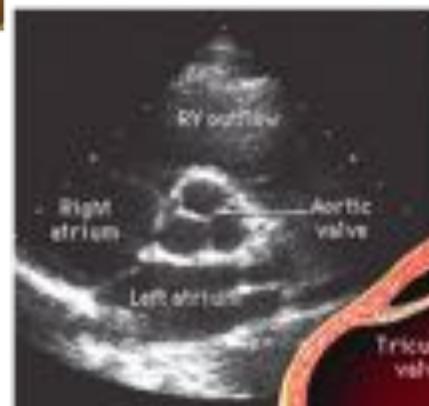
## PARASTERNAL SHORT AXIS VIEW.

The transducer remains in the intercostal space used to obtain the parasternal long axis view and is rotated clockwise 90 degrees so that it is perpendicular to the long axis of the LV. It is then tilted to sweep through from base to apex, obtaining a number of different views (see below).



The principal applications of this view is to assess the relative shapes and sizes of the two ventricles in suspected PE, and to visually assess LV function, both globally and regionally, by looking for abnormal wall motion.

PSAX view at level of aortic valve

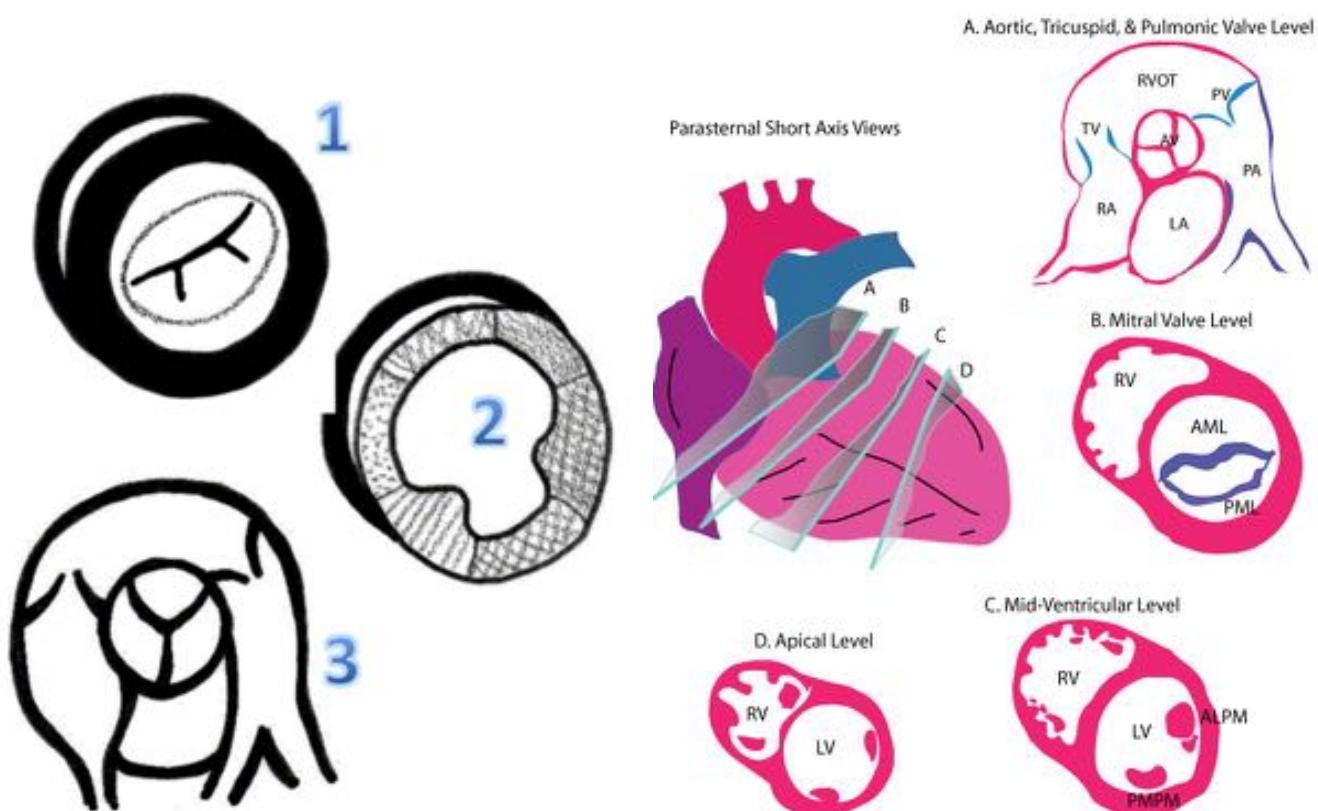


PSAX view at level of papillary muscle

# STORM MANUAL

## A structured approach to the PSAX:

1. Examine the shapes and sizes of the ventricles. The LV should be bigger than the RV. The LV should be round and the RV crescent shaped, like a reverse letter 'D'. This relationship is reversed in acute cor pulmonale due to pulmonary embolism.
2. The LV should appear as a ring which thickens evenly as it contracts inwards. Are there any regional wall motion abnormalities?
3. The aortic valve can be visualised – are there three cusps, which open in systole?

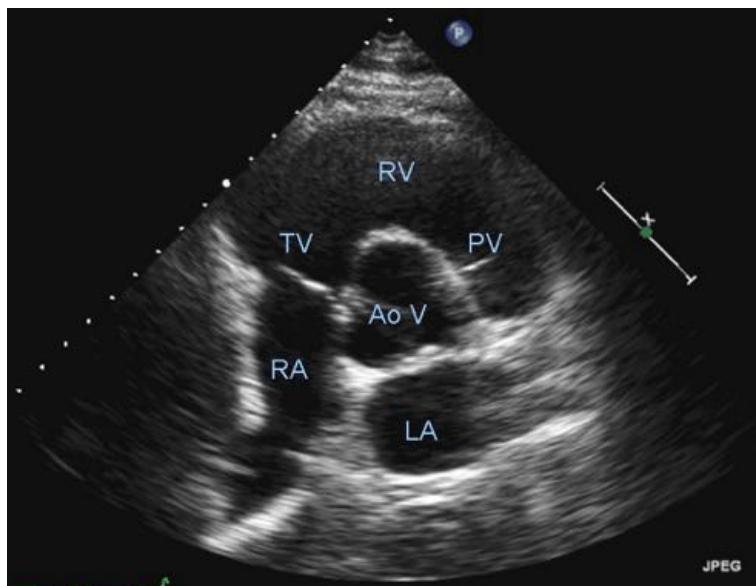


## Criteria of quality for a good parasternal short axis view.

- the left ventricle should be round shaped and symmetric
- the left ventricle should be in the middle of the screen
- Remember that PSAX is not a good view to look at the left ventricle apex but you can get an idea of size

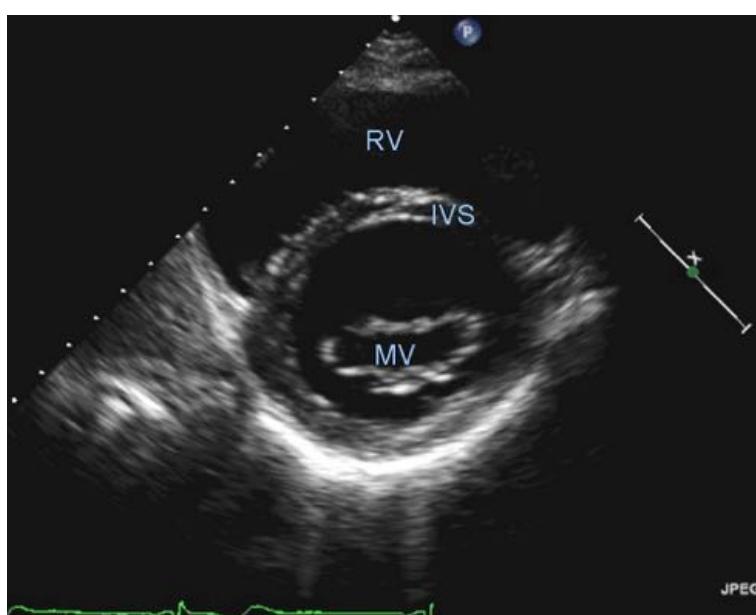
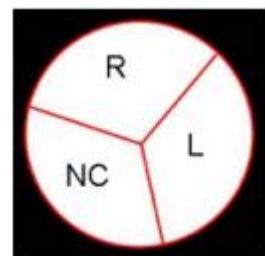
# STORM MANUAL

Examples of PSAX views at various levels of the LV.

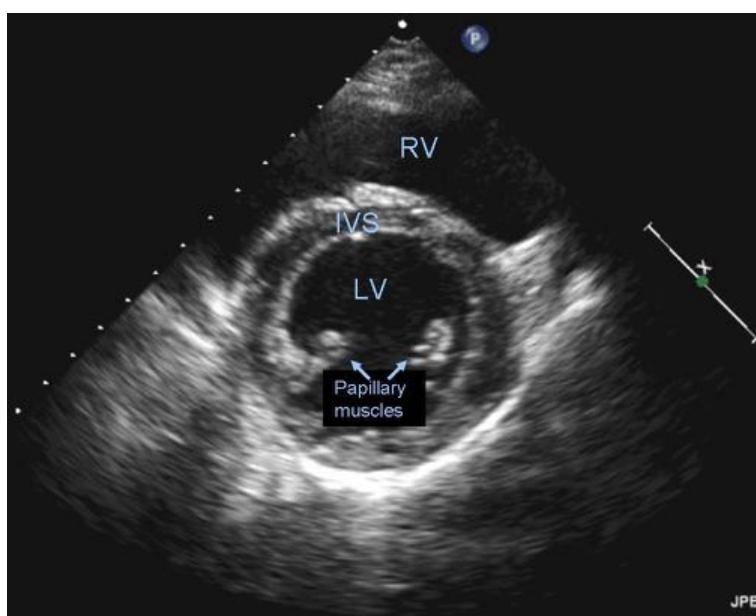


PSAX view at the base of the heart

Aortic cusps labelled below.



PSAX view at the level of the mitral valve.

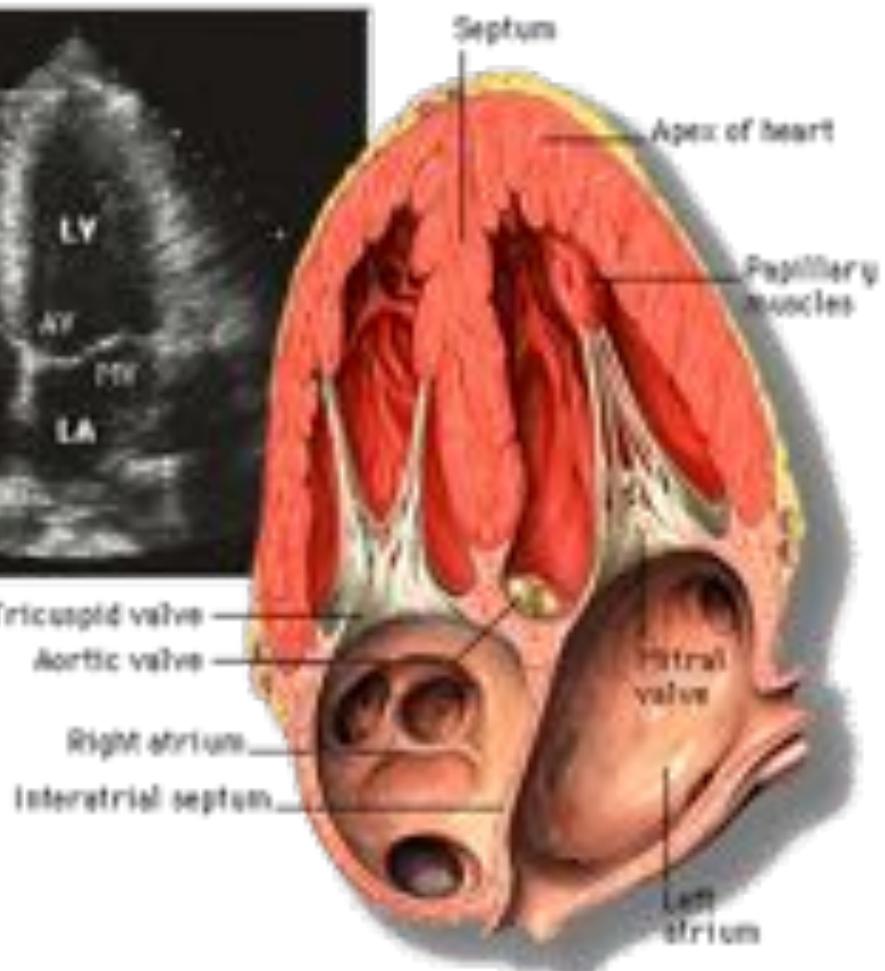
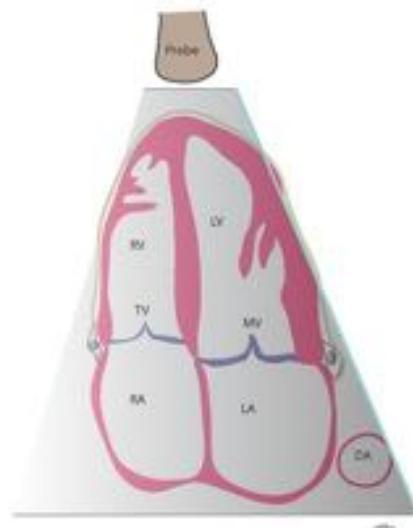


PSAX view at the mid ventricular level.

## STORM MANUAL

### APICAL FOUR CHAMBER VIEW.

The transducer is placed at the point of maximum impulse if the patient has a palpable apical beat; otherwise it is placed in the fifth intercostal space near the anterior axillary line. The beam is directed up towards the patient's head, and the transducer is rotated so the marker is at around 3 o'clock.

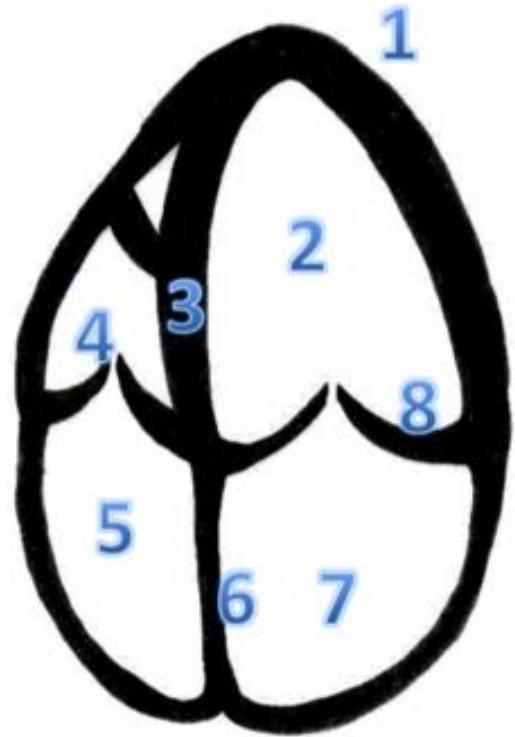


## STORM MANUAL

This view is helpful for the identification of pericardial effusions and demonstrating tamponade physiology (right sided diastolic chamber collapse), as well as RV dilation in massive and submassive pulmonary embolism.

### A structured approach to the A4C:

1. Examine the pericardial space. Is there fluid? If there is pericardial fluid, can you demonstrate tamponade physiology?
2. Is the LV a normal size and contracting normally?
3. Is the septum a normal size and moving normally?
4. Is the RV a normal size and contracting normally?
5. Is the RA a normal size?
6. Is the interatrial septum in a normal position?
7. Is the LA a normal size?
8. Is the MV annulus moving up & down, suggesting good long axis function of the LV?



### Criteria of quality for a good parasternal short axis view.

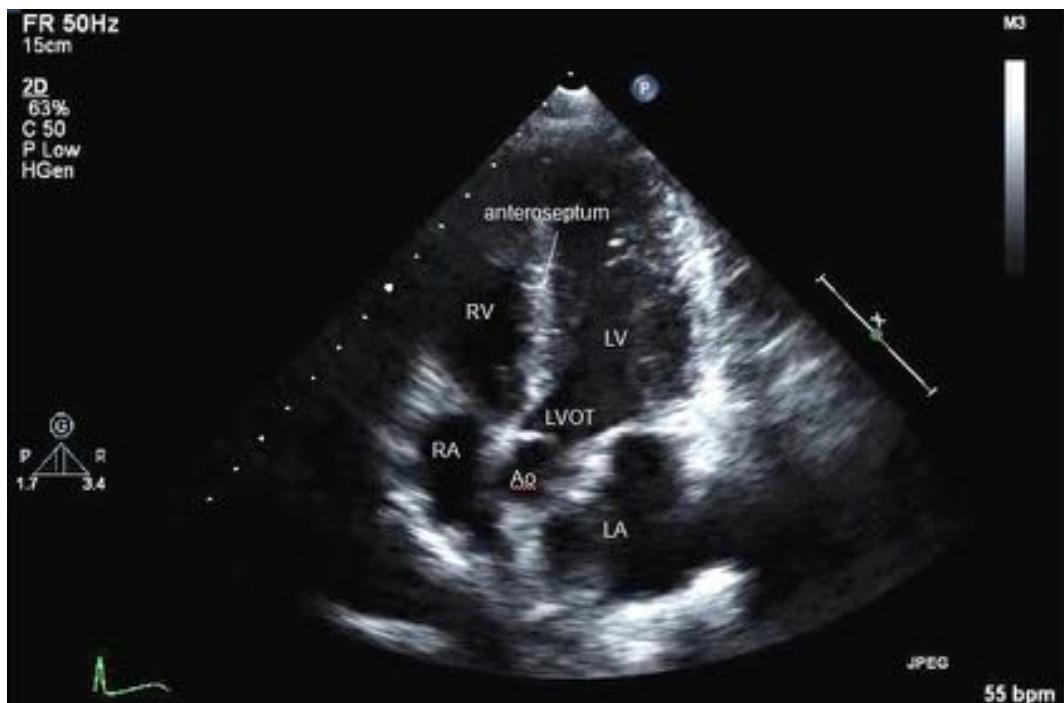
- The apex of the left ventricle should be close to the probe, and the lines of the crux should be vertical and horizontal, the intersection point at the middle of the image.
- You should visualise the atria plus the mitral & tricuspid valves fully opening & closing.
- Be careful not to shorten the apex of the left ventricle, which would appear round-shaped and hyperkinetic.

## APICAL FIVE CHAMBER VIEW.

### How to get an APICAL 5 CHAMBER view.

- Firstly, you need a good A4C view. The objective is to visualise the 5th chamber: the aorta.
- Since the aorta is the most anterior, you will need to tilt your probe upwards (=angle up): the tricuspid valve and RA will go out of the imaging plane, the aorta will appear in the middle of the screen.
- Sometimes you will need to go one intercostal space higher and more lateral to have a better alignment of your ultrasound beam with the LV outflow tract.

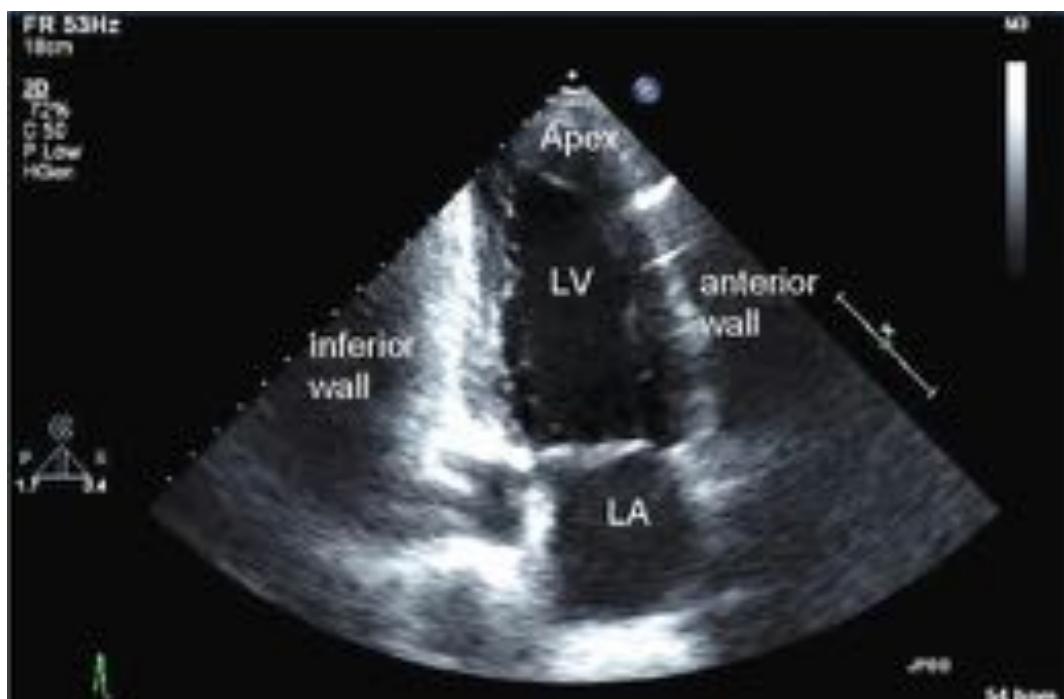
## STORM MANUAL



A5C VIEW WITH LABELLED ANATOMY

### APICAL TWO CHAMBER VIEW.

This is achieved after the apical four chamber view by rotating the transducer approximately 45 to 90 degrees anticlockwise. This visualises the true anterior and true inferior walls of the left ventricle which is important for the assessment of regional wall motion abnormalities.

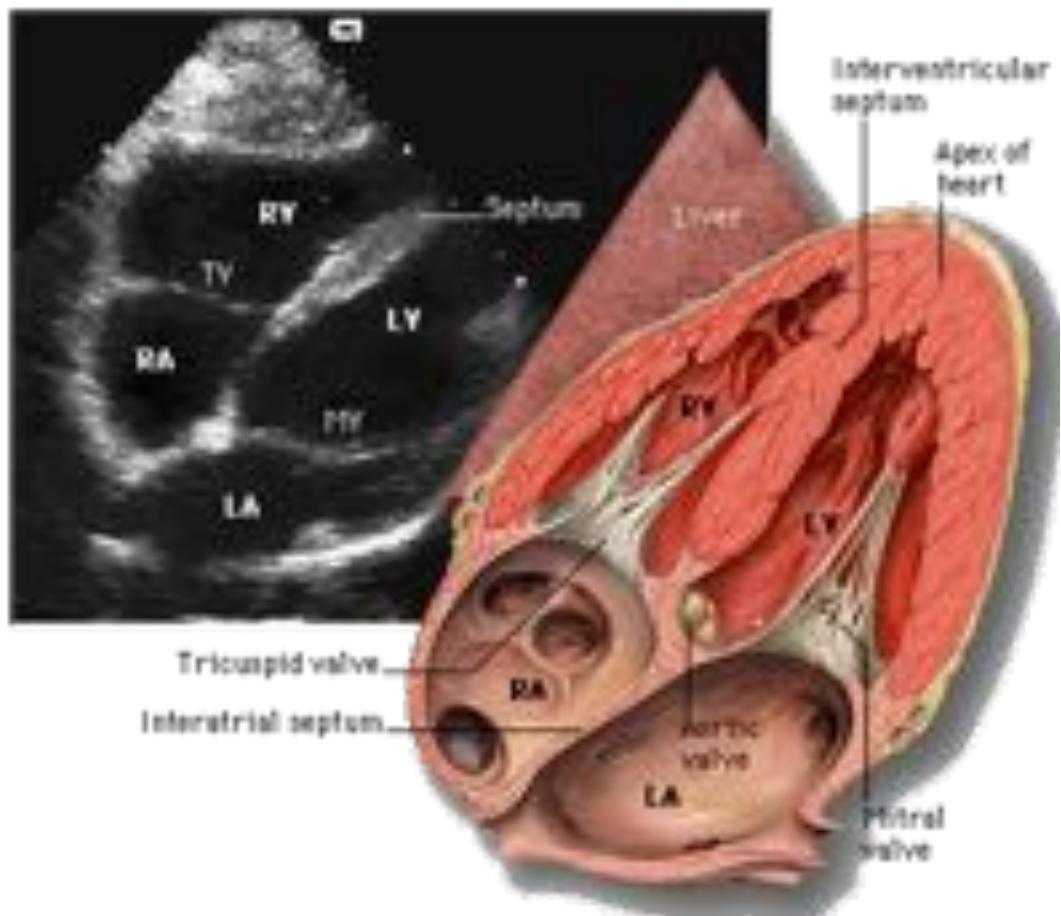


A2C VIEW WITH LABELLED ANATOMY

## STORM MANUAL

### SUBCOSTAL VIEW.

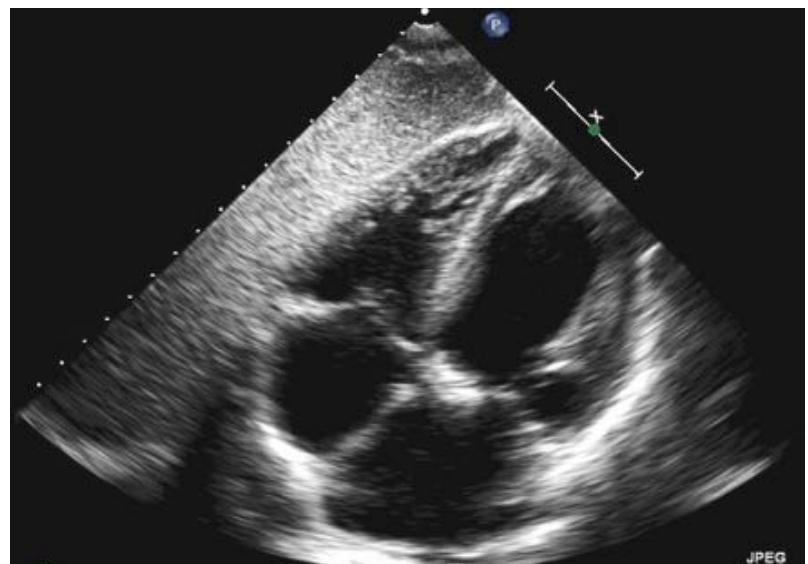
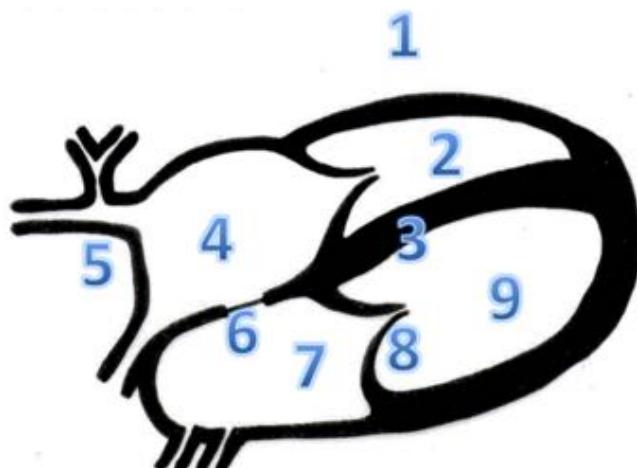
This window may provide the only achievable view in technically difficult patients such as those with chronic obstructive pulmonary disease or who are receiving mechanical ventilation. The patient is supine and if possible the knees are slightly bent to reduce abdominal wall tension. The transducer is placed below and slightly to the right of the xiphisternum. The side marker is in the 3 o'clock position and the transducer is tilted anteriorly. It may be necessary to push slightly downwards into the abdomen in order to achieve this scan plane.



## STORM MANUAL

### A structured approach to the PLAX:

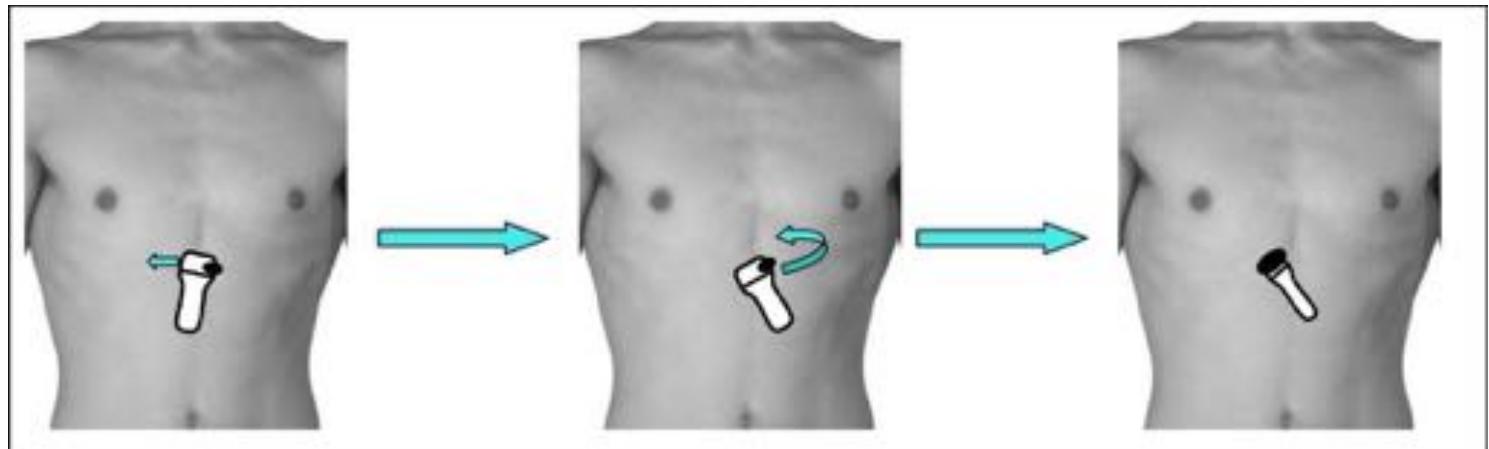
1. Examine the pericardial space. Is there fluid? If there is pericardial fluid, can you demonstrate tamponade physiology?
2. Is the RV a normal size and contracting normally?
3. Is the septum a normal size and moving normally?
4. Is the RA a normal size?
5. Measure the IVC and assess its collapsibility
6. Is the interatrial septum in a normal position?
7. Is the LA a normal size?
8. Is the MV annulus moving up and down, suggesting good long axis function of the LV?
9. Is the LV a normal size and contracting normally?



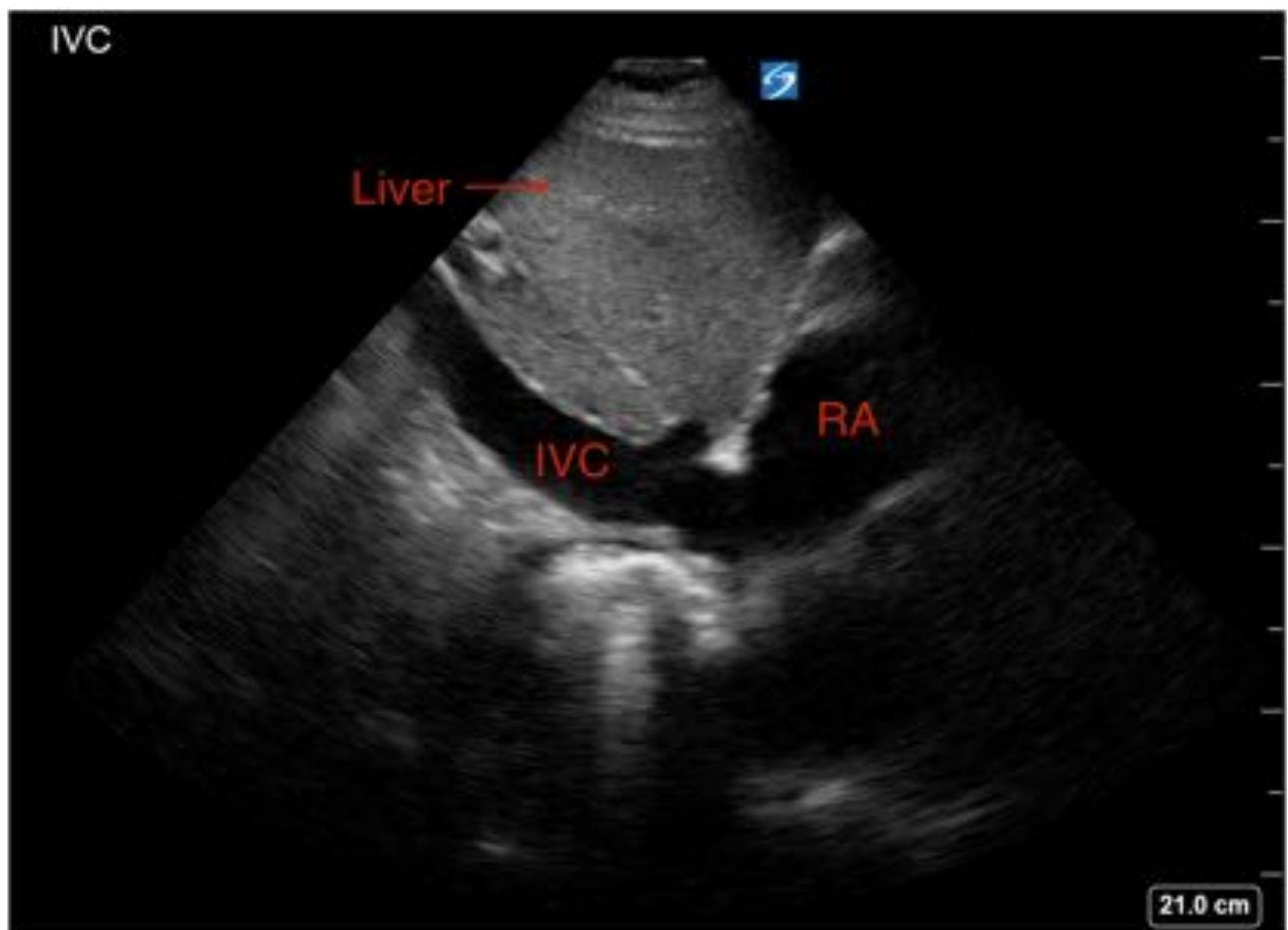
### How to visualise the *Inferior Vena Cava*.

- From subcostal 4 chamber view, translate the probe medially to visualise the right atrium on the right of the screen, and to see a large part of the liver: keep the same depth and direction, translate the tip of the probe toward the right shoulder.
- Then rotate the probe counter-clockwise until you see the long axis of the IVC merging into the right atrium.
- You will see the IVC passing through the liver and merging with the right atrium. Often, you can visualise the sub-hepatic veins merging in the IVC.

## STORM MANUAL



ACQUIRING AN IVC IMAGE FROM A SUBCOSTAL POSITION



SUBCOSTAL IMAGE DEMONSTRATING RELATIONSHIP OF THE IVC  
TO THE LIVER AND RIGHT ATRIUM

## STORM MANUAL

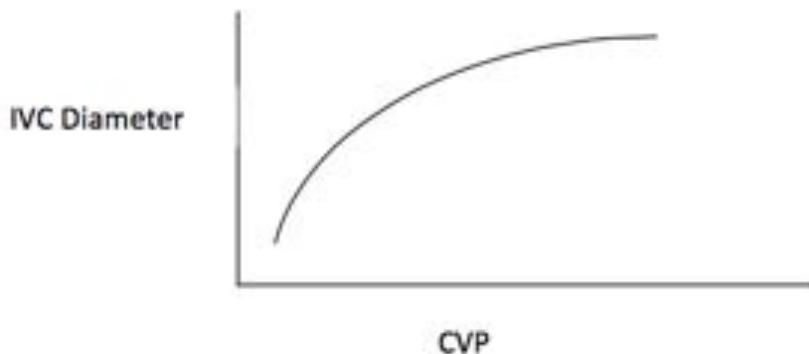
### HYPOVOLAEMIA.

#### NORMAL PHYSIOLOGY.

It is normal for the inferior vena cava (IVC) to partially collapse during inspiration. This is because the negative inspiratory pleural pressure is transmitted to the right atrium, and this negative pressure assists venous return to the heart.

In cases where the right atrial pressure, and therefore the central venous pressure (CVP), is high, there will be an increase in IVC diameter. As the IVC distends, it becomes less compliant (see image below). This means the reduction in CVP associated with inspiration will result in only a small decrease in diameter. Therefore high CVP states are associated with less IVC inspiratory collapse. Conversely, a low CVP state, typically caused by hypovolaemia, will result in an increase in IVC inspiratory collapse as the pressure-diameter relationship is located on the steeper left hand portion of the compliance curve.

Measuring the IVC diameter during inspiration and expiration therefore allows an approximation of CVP, both by the absolute diameter and by the percentage of decrease in diameter during inspiration.

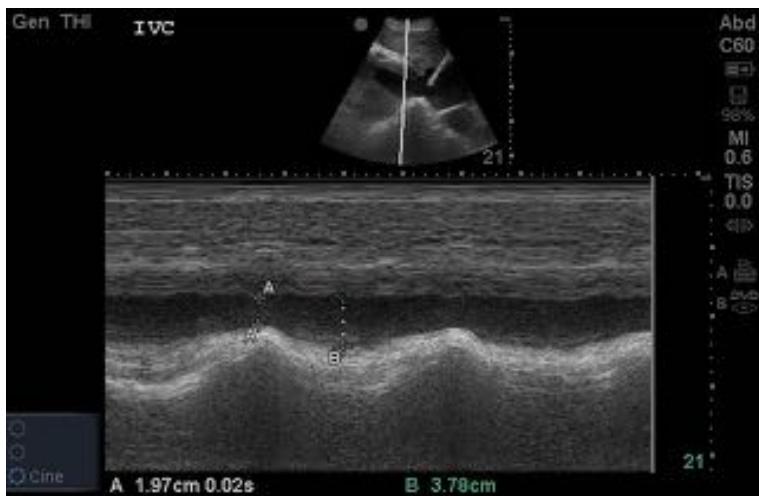


#### HOW TO MEASURE THE INFERIOR VENA CAVA.

A subcostal window is obtained and the IVC imaged in its longitudinal axis as it enters the right atrium (see previous page). The diameter is measured just distal to the junction between IVC and RA, in both inspiration and expiration. The collapse index is the percentage decrease in IVC diameter during inspiration. A normal value is approximately 50%. The patient is asked to take a gentle sniff when the inspiratory measurement is made. M Mode is used to obtain the image and then measurements at the widest and narrowest parts of the IVC are taken.

$$\text{Collapse index (\%)} = \frac{\text{Maximum (expiratory) IVC diameter} - \text{minimum (inspiratory) IVC diameter}}{\text{Maximum (expiratory) IVC diameter}} \times 100$$

## STORM MANUAL



Example of serial IVC measurements taken during volume resuscitation of a patient with septic shock.

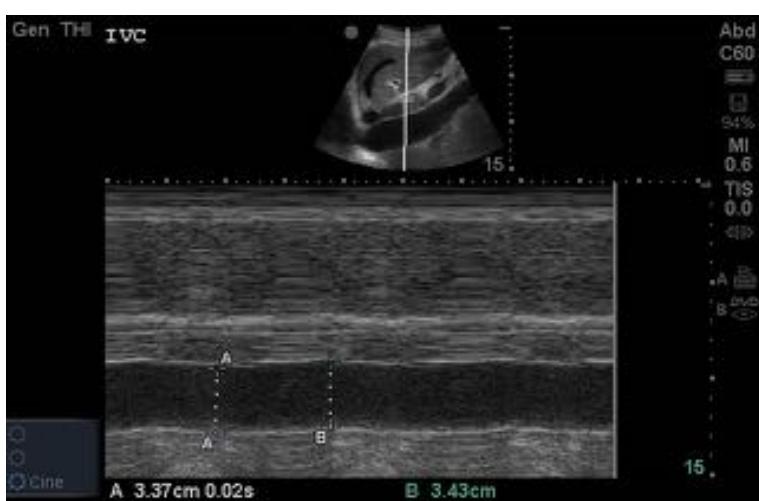


Image 1 shows a collapse idea of 47%

Image 2 shows *no* respiratory variation of IVC diameter.

The box below provides a guide to the interpretation of IVC measurements. However it must be stressed that this method is not infallible and results must be interpreted in the context of other clinical findings. Serial measurements and assessing the response to interventions such as a fluid challenge may be more meaningful.

IVC Size (cm)	Changes with respiration or "sniff"	Estimated mean CVP (mmHg)
Small < 1.5	Collapse	0-5
Normal 1.5 – 2.5	↓ by ≥ 50%	5 – 10
Normal 1.5 – 2.5	↓ by ≤ 50%	10 – 15
Dilated > 2.5	↓ by < 50%	> 15

### LIMITATIONS.

## STORM MANUAL

Pressures are not the same as volumes, and hypovolaemia can occur in the presence of a high CVP, particularly in the context of a poorly compliant right ventricle or obstructive causes of shock such as tamponade or pulmonary embolism. The best estimation of preload would be to measure left ventricular end diastolic volume. This can be estimated echocardiographically by measuring left ventricular end diastolic area using specific software settings, but can be inaccurate when the endocardial border is not clearly defined. Such measurements are outside the scope of this course, but a visual impression of an 'empty ventricle' would support the diagnosis of hypovolaemia. In particular, systolic obliteration of the left ventricle indicates severe hypovolaemia.

In vasodilated states such as sepsis, the decreased afterload assists LV emptying; therefore the appearances of the septic heart can be similar to the hypovolaemic heart.

### MECHANICALLY VENTILATED PATIENTS.

In mechanically ventilated patients, the positive intrathoracic pressure during inspiration is transmitted to the right atrium and IVC, reducing venous return. Therefore the normal cyclic variation in IVC diameter is not seen. However hypovolaemia may still result in a variation in IVC diameter, with a decrease occurring during expiration. Studies in ventilated patients demonstrate that the more the IVC diameter increases during inspiration, the more likely a fluid challenge will result in an increase in cardiac output.

In one of these studies, the IVC diameter variability from the mean diameter was measured approximately 3 cm from the right atrium and an IVC diameter variability >12% predicted fluid responsiveness with 93% positive predictive value and 92% negative predictive value. In another study, the IVC diameter was measured just upstream of the origin of the hepatic vein. The inspiratory increase in IVC diameter relative to the expiratory diameter, expressed as a percentage, predicted a response to volume expansion when a cut off of 18% was selected, with 90% sensitivity and 90% specificity.

IVC diameter may be affected by ventilator settings, patient-ventilator dysynchrony, and conditions associated with elevated intra-abdominal pressure. Caution should therefore be applied when using this method to predict fluid responsiveness.

### SUMMARY.

- An increase in the usual physiological variation in IVC diameter with the respiratory cycle suggests that volume therapy will increase the cardiac output.
- This may also apply in mechanically ventilated patients although other factors may confound this.

## STORM MANUAL

### CARDIAC TAMPONADE.

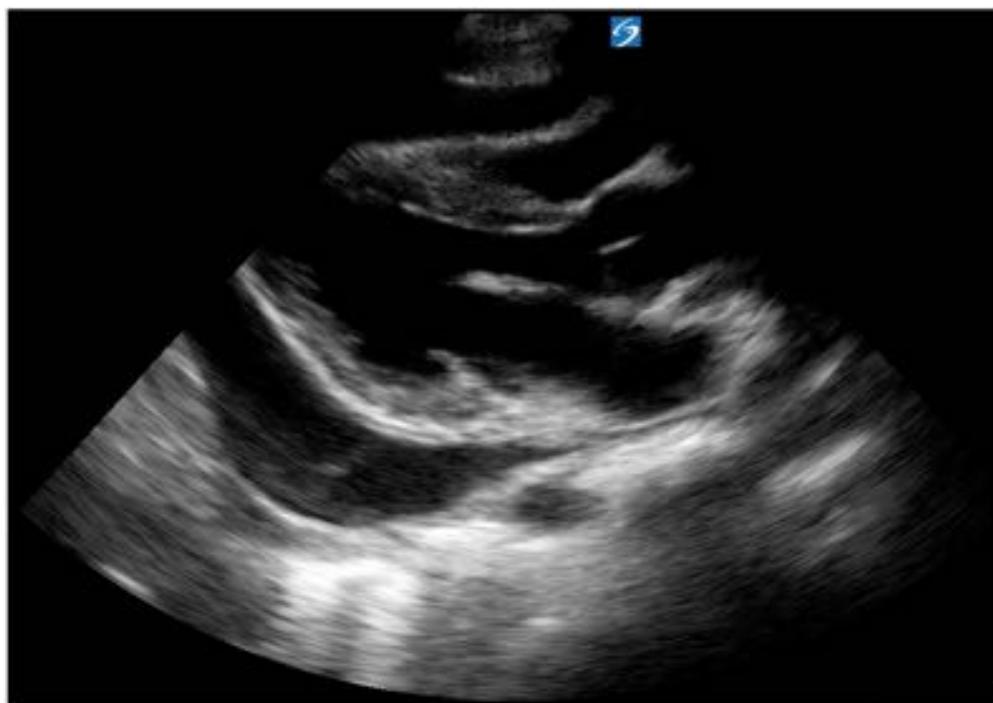
#### WHAT IS CARDIAC TAMPONADE?

Cardiac tamponade occurs when the pericardial space fills with fluid. As the pressure in the pericardial cavity increases, a point is reached when this pressure exceeds the pressure in the right side of the heart during diastole. The resulting diastolic collapse of the right ventricle and/or atrium prevents cardiac filling and shock ensues, ultimately followed by cardiac arrest.

Because the pressure, rather than the volume, of the pericardial fluid is the issue, it is possible to have a large pericardial effusion without tamponade, or a small pericardial effusion with tamponade. The rate of accumulation is highly significant – acute haemopericardium due to traumatic injury often results in tamponade, even when only small volumes of pericardial blood are present.

#### MAKING THE DIAGNOSIS.

Pericardial fluid is easily detected as a hypoechoic appearance in the space around the heart. Visualising this pericardial fluid using ultrasound makes the diagnosis of pericardial effusion. Additional evidence of haemodynamic compromise is necessary to demonstrate that the pericardial effusion is causing cardiac tamponade. This may be a convincing clinical scenario, such as a shocked patient with penetrating thoracic injury in whom pneumothorax has been excluded, or finding ultrasound evidence of tamponade physiology.



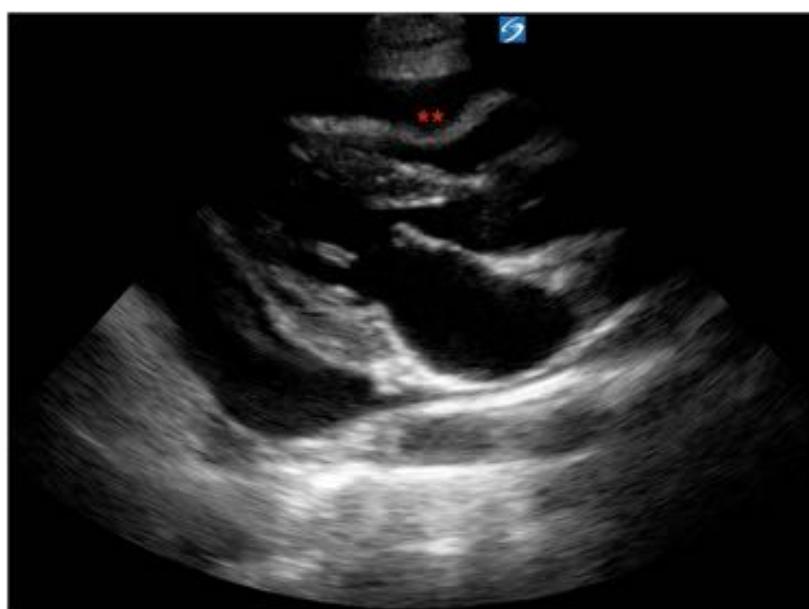
PLAX VIEW DEMONSTRATING A LARGE HYPOECHOIC PERICARDIAL EFFUSION

## STORM MANUAL

### TAMPONADE PHYSIOLOGY.

The two components of tamponade physiology demonstrable on echo are: (1) right-sided cardiac chamber collapse in diastole, and (2) loss of IVC inspiratory collapse.

1. Right ventricular free wall collapse is observed in early diastole and right atrial free wall collapse occurs in late diastole. This sign can be subtle and difficult to observe, especially in a tachycardic patient. The use of ECG monitoring and M mode are helpful adjuncts to the interpretation of the scan.
2. A dilated IVC or reduced IVC collapse index (see Hypovolaemia chapter 5) is invariably seen in cardiac tamponade.



PLAX & A4C VIEWS DEMONSTRATING FEATURES OF TAMPONADE PHYSIOLOGY WITH RIGHT ATRIAL AND VENTRICULAR COLLAPSE

### PERICARDIAL VERSUS PLEURAL EFFUSION.

A left-sided pleural effusion may be confused with a pericardial effusion. Two methods may be used to differentiate one from the other:

1. Identify the descending aorta on the parasternal long axis view, behind the posterior surface of the heart. A pleural effusion lies deep (posterior) to the descending aorta, whereas a pericardial effusion lies between the descending thoracic aorta and the heart.
2. Examine the pleural space elsewhere to demonstrate a pleural effusion. A good place is just above the diaphragm laterally, which is readily identifiable using ultrasonography.

NB. In the image on page 71; the pericardial effusion clearly passes *anteriorly* to the descending thoracic aorta.

## STORM MANUAL

### PITFALLS.

A hypoechoic appearance outside the heart may be due to a pericardial fat pad. The fat pad is usually anterior so an attempt should be made to examine as much of the pericardial space as possible using more than one window.

In some situations, particularly on the intensive care unit after cardiac surgery, a pericardial haematoma may cause tamponade effects through local compression of a cardiac chamber. When this is present posteriorly, there may be no identifiable effusion anteriorly.

### SUMMARY.

- Pericardial effusions must be differentiated from pericardial fat pads and pleural effusions.
- The diagnosis of cardiac tamponade requires the demonstration of tamponade physiology, either clinically or sonographically - such as IVC dilation and diastolic RA or RV collapse.

## POOR LEFT VENTRICULAR FUNCTION.

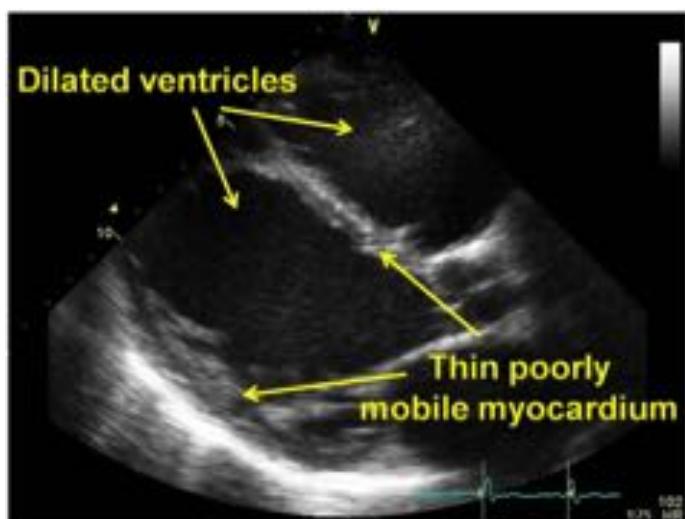
### WHY ASSESS LV FUNCTION?

Hypotension may be due to a failure of the pump function of the heart. Many echocardiographic methods exist to measure LV systolic function, but in the emergency setting a gross visual assessment can yield very useful information.

### QUALITATIVE ASSESSMENT.

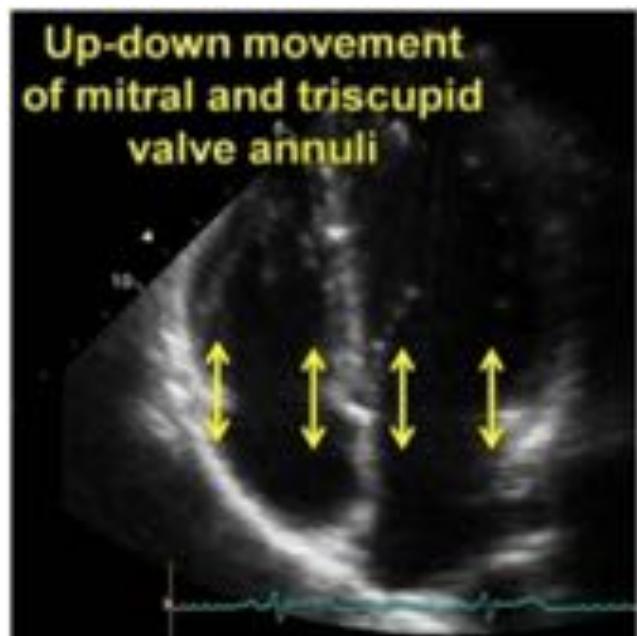
LV systolic function can be approximately described as normal, impaired, or severely impaired. This assessment can be made by examining the following:

**LV wall thickening:** all areas of the myocardium should thicken during systolic contraction. This results in a smaller chamber in systole compared with diastole, meaning a good proportion of the blood in the ventricle has been expelled, ie. a good 'ejection fraction' (the normal range for ejection fraction is 50-85%).



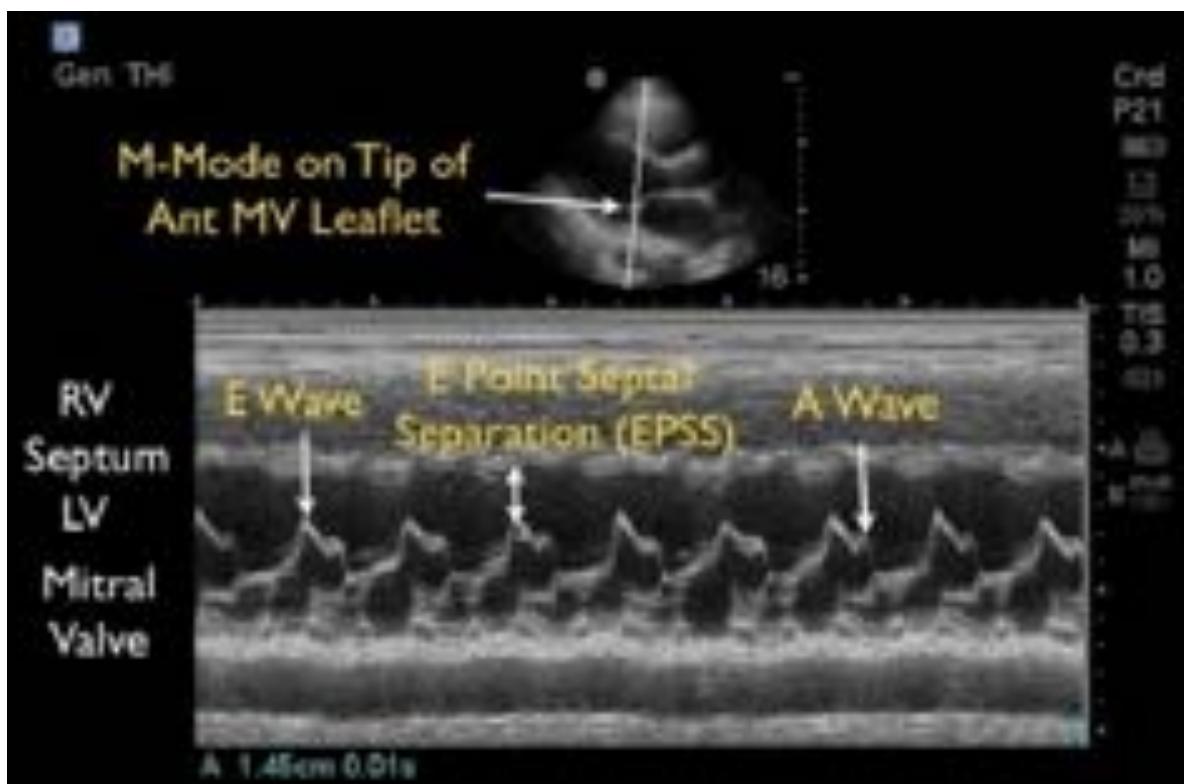
**LV size:** generally 'a big heart is a bad heart', although regional wall motion abnormalities can lead to poor function without changing overall ventricular dimensions.

**Valve movement:** in the normal heart, both the tricuspid and mitral valves move towards the apex in systole, drawing blood into the atria. They move away from the apex in diastole, which allows blood to move from the atria into the ventricles. This 'up-down' movement of the tricuspid and mitral valves on the apical four chamber view is a marker of good 'long axis function' of the heart. Many of the longitudinal muscle fibres that cause this movement are subendocardial, and poor long axis function can be an early sensitive sign of



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ischaemia. In the parasternal long axis view, it is normal for the anterior mitral valve leaflet to appear to touch or closely approximate the interventricular septum in diastole (this distance is known as the *E Point Septal Separation - EPSS*, see image below). A failure of the leaflet to open within 1cm of the septum indicates poor LV function.



### QUANTATIVE ASSESSMENT OF LV FUNCTION.

Most echo machines have software that enables calculation of cardiac output or ejection fraction using various methods. All require certain assumptions to be made about the geometry of the ventricle and therefore can be inaccurate. The qualitative visual assessment described above is usually adequate for emergency management. Beginners are advised to seek further training & supervision for quantitative measurement of LV systolic and diastolic function, which is beyond the scope of this course.

### SUMMARY.

A gross qualitative assessment of LV function can be made by visual inspection of:

- LV wall thickening in systole
- Systolic excursion of the mitral annulus on the four chamber view
- Proximity of the anterior mitral valve leaflet to the interventricular septum in diastole (E-point septal separation).

## AORTIC DISSECTION.

### TRANSTHORACIC ECHO AND AORTIC DISSECTION.

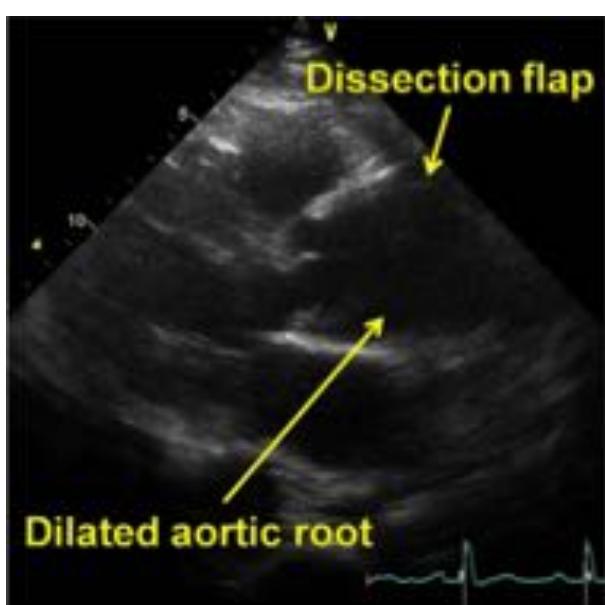
Transthoracic echocardiography (TTE) is effective at evaluating the proximal aorta but not the descending thoracic aorta, which is best visualised with transoesophageal echocardiography. Consequently TTE can not and must not be used to rule out suspected aortic dissection.

However, the focused echocardiographic evaluation of a patient with shock, chest pain, or dyspnoea may reveal signs of a type A (proximal) aortic dissection. If these are present, it is important a practitioner is able to recognise them, particularly as the mortality of untreated aortic dissection increases by 1% per hour for first 48 hours.

### SONOGRAPHIC FEATURES OF AORTIC DISSECTION.

Four sonographic signs may support the diagnosis of aortic dissection:

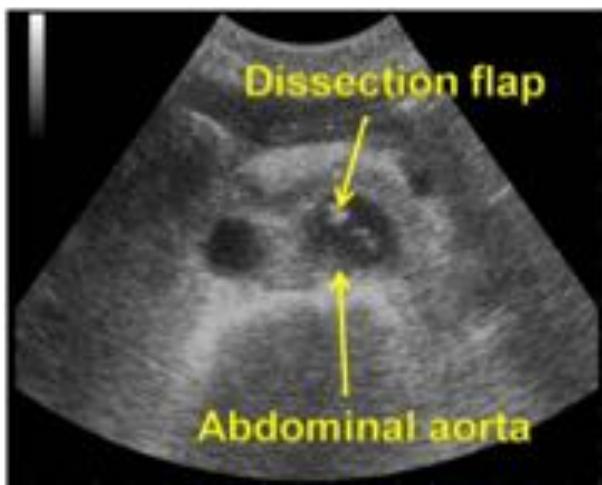
1. Pericardial effusion with or without tamponade. This finding is not specific for aortic dissection as there are many other possible causes of a pericardial effusion. However, the presence of this entity may prompt further evaluation for clinical, sonographic, or radiological signs of aortic dissection.
2. Dilated aortic root. The sinuses of Valsalva bulge outward at the level of the aortic valve, and beyond this the aortic root should then be tube-like and a similar size to the left atrium or only slightly larger. A diameter  $> 3.8$  cm is considered enlarged, although subjective assessment of aortic root enlargement can be made if the aortic root appears significantly bigger than the left atrium.
3. Visible dissection flap. A linear echodensity may be seen in ascending aorta



Parasternal long axis view showing dilated aortic root and linear echodensity suggestive of a dissection flap. This patient had type A aortic dissection.

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4. Abdominal aortic evaluation. Sometimes the suspicion of aortic dissection may be confirmed by demonstrating that the dissection flap extends distally all the way down to the abdominal aorta. An echodense flap may be seen on transverse and longitudinal views of the abdominal aorta, separating the true and false lumens.



Abdominal aorta showing dissection flap in longitudinal (left) and transverse (right) views.

### SUPRASTERNAL ECHO.

The suprasternal notch view may provide additional information in the assessment of thoracic aortic pathology. Its use however is outside the scope of this course.



Suprasternal notch views: Normal (left) & aortic arch dissection flap (right)

### SUMMARY.

- Transthoracic echo cannot rule out aortic dissection.
- Basic ultrasound in patients with shock or chest pain may reveal features of aortic dissection, such as a pericardial effusion, dilated aortic root, a visible dissection flap, or extension of the dissection into the abdominal aorta.

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### PULMONARY EMBOLISM.

#### WHAT DOES ECHO TELL YOU ABOUT PE?

A pulmonary embolus (PE) cannot usually be visualised by transthoracic echo, since standard views do not demonstrate the pulmonary arteries. Echo is however useful in suspected PE because the effects of massive pulmonary embolism on the heart, particularly the right ventricle, may be seen. Furthermore, diagnoses that may mimic PE such as aortic dissection, pericardial tamponade, or acute myocardial infarction may be confirmed or excluded.

#### HOW DOES ECHO HELP THE MANAGEMENT OF PE?

Massive PE occurs when life-threatening haemodynamic instability is present. The treatment of choice is thrombolysis which significantly reduces mortality. However movement of an unstable patient in order to obtain a computed tomographic pulmonary angiogram (CTPA) to confirm the diagnosis is inappropriate. Consequently bedside emergency echo is an excellent tool to guide emergency management of this life-threatening disease.

Criteria for categorising PE as massive include hypotension and cardiogenic shock. Hypotension in this context is defined as a systolic blood pressure  $<90$  mm Hg or a drop in systolic blood pressure of at least 40 mm Hg for at least 15 minutes.

Submassive PE refers to patients with echocardiographic features of right ventricular dysfunction without the clinical features of hypotension or shock. Thrombolysis in this group is more controversial and has not been shown to reduce overall mortality. Echo is however still useful in confirming the diagnosis and therefore the need for immediate systemic anticoagulation.

#### CARDIAC PATHOPHYSIOLOGY IN MASSIVE PE.

In massive PE there is an acute rise in right ventricular afterload which causes failure of the right ventricle, known as acute cor pulmonale. The failure of the right ventricle causes abnormal contraction (hypokinesis) and the pressure overload causes the RV to acutely distend.

The right and left ventricles occupy a fixed pericardial space so acute changes in the size of one ventricle affect the size and function of the other, a phenomenon known as ventricular interdependence. In the normal heart the left ventricle is larger than the right; in acute cor pulmonale this may be reversed.

In the normally functioning heart, the concentric contraction of left ventricular muscle fibres results in movements of all parts of the LV inwards during systole. Therefore the septum and posterior walls move towards each other in systole and

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away from each other in diastole. In acute cor pulmonale, the obstruction to RV outflow causes a prolongation of RV systole, so that LV diastole begins earlier than RV diastole. This results in a pressure difference across the septum that pushes the septum towards the left during diastole. This is opposite to the normal direction of septal movement and is therefore known as 'paradoxical septal motion'.

### OTHER CAUSES OF COR PULMONALE.

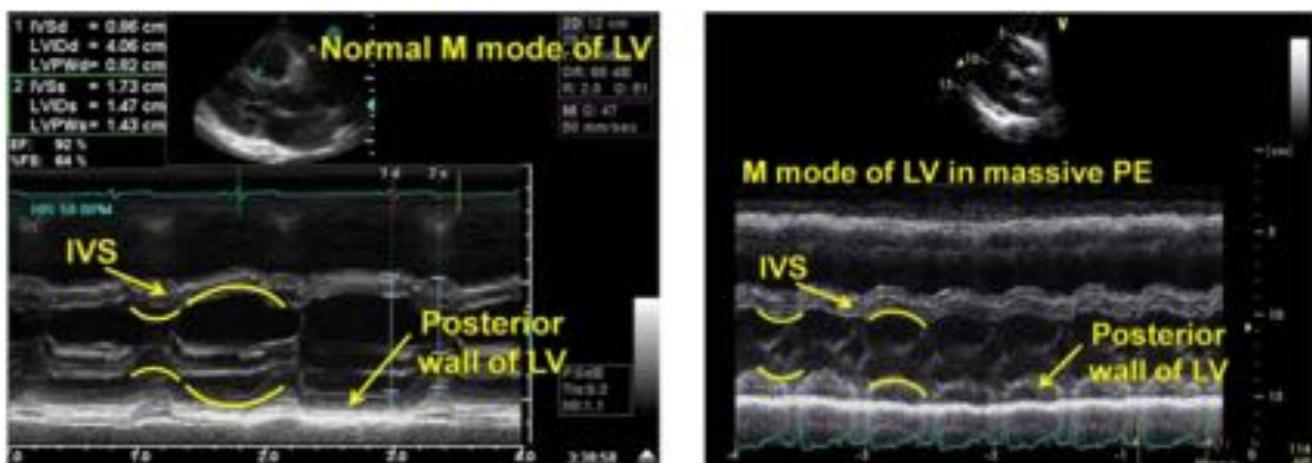
Acute respiratory distress syndrome (ARDS), which may complicate many critically ill patients particularly severe sepsis, is another common cause of acute cor pulmonale. In ARDS, bilateral infiltrates will be evident on the chest radiograph.

Chronic cor pulmonale is most often caused by chronic lung disease such as COPD. The chronically raised RV afterload results in hypertrophy of the RV, which is not present in acute cor pulmonale in a patient who has no prior history of cardiorespiratory disease.

In RV hypokinesis due to massive PE, there is relative sparing of function of the RV near the apex, with reduced or absent contraction of the mid-free wall of the RV. This relative sparing of the apical part of the RV appears to be specific to the RV dysfunction associated with pulmonary embolism.

### WHAT ARE THE ECHO SIGNS OF MASSIVE PE?

In the parasternal long axis view, look for an enlarged RV and paradoxical septal motion. The latter feature may best be demonstrated using M- mode.



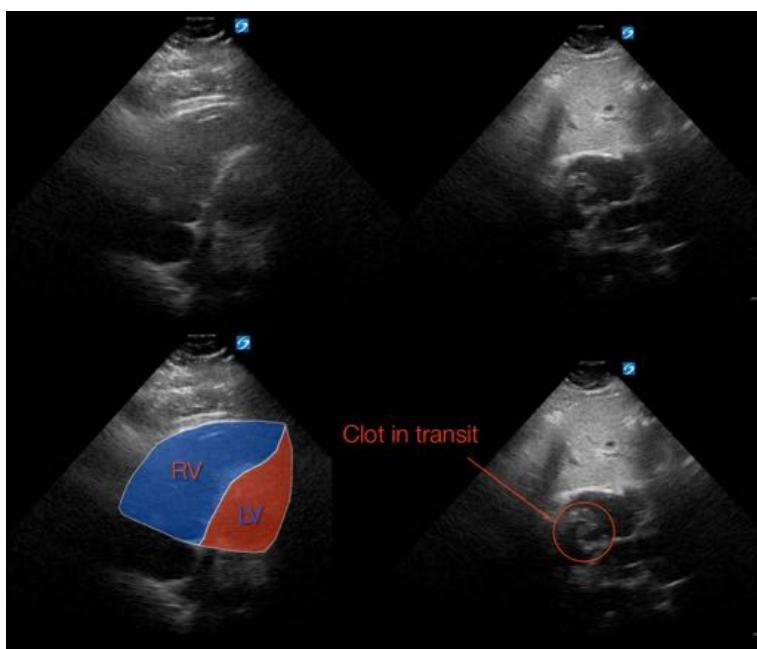
M-mode echo of normal LV (left hand picture) shows that the interventricular septum (IVS) and posterior LV wall move towards each other in systole and away from each other in diastole. In massive pulmonary embolism (right hand picture) the septum moves paradoxically, posteriorly in diastole and anteriorly (into the RV) in systole, which parallels rather than mirrors the posterior wall movement.

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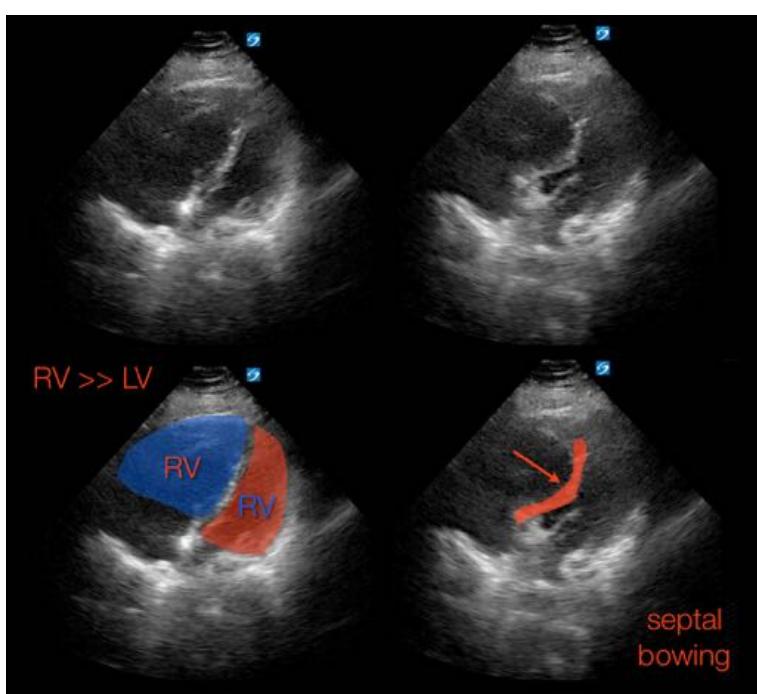
In the parasternal short axis view, observe the relative size and shape of the two ventricles.

Normally, the LV has a round appearance and the RV appears like a reverse 'D', wrapped onto the side of the LV. In acute cor pulmonale this relationship is reversed, with the RV taking on a more round shape and the LV appearing like a 'D'.

In apical and subcostal views, compare the sizes of the right and left ventricles in diastole. If the RV is larger, this supports the diagnosis of cor pulmonale.



Example 1: A case of massive PE. Subcostal view showing a grossly enlarged RV and evidence of clot in transit through the tricuspid valve.



Example 2: A case of significant PE. Subcostal view again showing a grossly enlarged RV ( $RV:LV > 1$ ) and paradoxical septal bowing (from right to left).

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Obtain a visual impression of the contractility of the right ventricle (and compare with the left). Decide whether any impairment is global or localised to the mid-part of the RV, sparing the apex. This is called McConnel's sign and has a specificity of 94% for the diagnosis of acute PE.



McConnel's sign: Poorly contractile right ventricle with preservation of apical function.

Consider the possibility of chronic cor pulmonale (eg. due to COPD). A thickened RV wall ( $> 1$  cm) is usually due to a chronic process rather than acute PE.

Finally, examine the IVC. A distended IVC or reduced IVC collapse index is expected in massive and submassive PE.

### SUMMARY.

- PE cannot be ruled out by echocardiography
- Submassive and massive PE result in acute cor pulmonale
- Fibrinolysis is only indicated when there is clinical, as opposed to echocardiographic, evidence of haemodynamic compromise.
- Basic echo assessment in suspected PE includes assessment of RV size and motion, septal motion, and IVC filling.
- Other causes of acute cor pulmonale should be considered in the differential diagnosis.

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### SEVERE SEPSIS.

#### THE HEART IN SEVERE SEPSIS.

Severe sepsis and septic shock are syndromes of organ dysfunction due to a widespread inflammatory response to infection. The systemic release of inflammatory mediators has varied effects on the heart and vascular system. Vasodilation leads to afterload reduction and increased cardiac emptying, which in association with tachycardia gives rise to a 'hyperdynamic' appearance on echo. However this response is only present in approximately 65% of septic shock patients. Thirty-five per cent of septic shock patients have a markedly hypokinetic left ventricle, which may in part be due to cardiosuppressive effects of some circulating mediators.

RV dysfunction may also be seen in severe sepsis / septic shock. In addition, acute cor pulmonale may result from the acute respiratory distress syndrome (ARDS), when the commencement of positive pressure ventilation may be the precipitant. This can result in an echo appearance similar to that found in pulmonary embolism.

One study showed that a qualitative impression of a hyperdynamic LV when assessed by an emergency physician had a specificity of 96% for sepsis as a cause of undifferentiated hypotension in symptomatic emergency department patients. However this small study may not have included patients with other causes of a hyperdynamic state, such as anaemia or anaphylaxis.

#### ECHOCARDIOGRAPHIC FINDINGS.

- Examine the LV and RV for evidence of a hyper- or hypodynamic state.
- Examine the IVC for evidence of hypovolaemia.
- Exclude cardiac tamponade as a cause of hypotension.

Repeat the echo after interventions such as fluid administration or the commencement of vasoactive infusions to guide therapy in concert with clinical and laboratory findings and other haemodynamic measurements including central venous and arterial pressures.

Some septic patients will have endocarditis, and it is possible that a valvular vegetation will be seen during an echo. Other pathologies may mimic this and a full assessment must include measurement of valve function which requires Doppler measurements. Therefore if endocarditis is suspected a formal echocardiographic study and cardiology opinion should be requested.

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### SUMMARY.

- A hyperdynamic heart in sepsis may be indistinguishable from that seen in hypovolaemia.
- One third of septic shock patients will have a hypokinetic left ventricle.
- ARDS can cause acute cor pulmonale in which the echo appearances resemble those of pulmonary embolism.
- Serial evaluations of the heart and IVC using echo can contribute to goal-directed resuscitation in severe sepsis and septic shock.

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### ECHOCARDIOGRAPHY IN CARDIAC ARREST.

Echo can guide cardiac arrest management both diagnostically and prognostically.

#### PROGNOSIS.

An absence of cardiac activity on ultrasound in a non VT/VF arrest indicates futility and can assist the decision to terminate resuscitation.

#### DIAGNOSIS.

Some of the treatable causes of cardiac arrest, often known of as the “H’s and T’s”, can be directly or indirectly demonstrated on echo. These are cardiac tamponade and pulmonary embolism (see earlier discussion).

Rarely fine ventricular fibrillation may masquerade as asystole on three-lead ECG monitoring and the opportunity to treat a shockable rhythm may be missed. In this situation the fibrillating ventricle can be visualised using echo. The literature describes such a situation in which the echo appearances of VF in an apparently asystolic patient led to the successful defibrillation to a perfusing rhythm, although the patient subsequently died so this approach has not been shown to improve outcome.

Pulseless electrical activity may result from a truly non-beating heart with intact electrical activity detectable on ECG monitoring, or from a beating heart in a patient whose hypotension and shock state is too profound to generate a detectable pulse<sup>17</sup>. The former situation, known as ‘true electromechanical dissociation (EMD)’, carries a hopeless prognosis, whereas the latter, known as ‘pseudo-EMD’ indicates a ‘live’ beating heart which may respond to further resuscitation and treatment of reversible causes of circulatory insufficiency.

In patients receiving artificial pacing (by percussion, transthoracic, or transvenous techniques) electrical capture is demonstrated by ECG monitoring, but mechanical capture needs to be confirmed to demonstrate that the ventricular muscle is able to contract in response to depolarisation. Traditionally this is detected by palpating the pulse, but as described above an absence pulse in the presence of an electrical rhythm, including a paced rhythm, may be due to ‘true-EMD’ or ‘pseudo-EMD’. Echo may therefore be used to determine whether the ventricle is failing to contract in response to the paced rhythm, which indicates further resuscitation is likely to be futile, or whether the pacing is successful but profound hypotension co-exists, encouraging further resuscitation and treatment of reversible causes of circulatory insufficiency.

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### WHEN TO ECHO IN CARDIAC ARREST.

It is the author's practice to echo all cardiac arrest patients, due to the powerful prognostic information it provides as well as the occasional diagnostic surprise, such as unsuspected tamponade.

### HOW TO ECHO IN CARDIAC ARREST.

Because of the supine position of the patient and the presence of positive pressure ventilation, the subcostal approach may obtain the only achievable view of the heart. This position also allows the transducer to be placed on the patient while external cardiac compressions are taking place. The image can then be obtained, assessed and recorded when CPR is interrupted for pulse and rhythm checks. This approach minimises the likelihood that echo will interrupt recommended CPR techniques.

### SUMMARY.

- Cardiac standstill on echo is associated with a poor outcome.
- VF can be demonstrated by echo.
- Pulseless electrical activity may be due to 'true-EMD' or 'pseudo-EMD'
- 'Pseudo-EMD' has a better prognosis if the underlying cause can be treated.
- Echo can provide direct or indirect evidence of cardiac tamponade and massive pulmonary embolism in cardiac arrest.
- Echo can be used to determine whether emergency cardiac pacing is generating mechanical capture.

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### ACUTE CORONARY SYNDROME.

#### RELEVANCE OF ECHOCARDIOGRAPHY IN ACS.

Myocardial infarction may occur in patients with normal or non-specifically abnormal ECGs. In such cases echo may show abnormalities of ventricular wall motion which suggest ischaemia or infarction in the region concerned.

Chest pain may also be caused by non-ischaemic aetiologies such as pulmonary embolism, aortic dissection, aortic stenosis, or hypertrophic cardiomyopathy; occasionally echo done to investigate possible ischaemic chest pain may reveal one of these alternative diagnoses.

The mechanical complications of acute myocardial infarction include ventricular rupture, ventricular septal defect, and acute mitral valve dysfunction due to papillary muscle dysfunction or rupture of the chordae tendineae. With the exception of ventricular rupture with tamponade, these other disorders are best diagnosed with a more sophisticated echo study that includes Doppler measurements.

#### REGIONAL WALL MOTION ABNORMALITY.

The normal appearance of ventricular contraction shows a thickening and inward movement of ventricular muscle in all areas. An isolated area of muscle that moves inadequately or in the wrong direction is called a regional wall motion abnormality (RWMA). By far the most common cause of this is myocardial ischaemia. Decreased movement is called hypokinesia, absent movement is called akinesia, and outward systolic bulging is called dyskinesia.

The parasternal short axis view enables visualisation of a number of segments for assessment of regional wall motion. The apical 2 chamber view demonstrates the free anterior and inferior LV walls.

#### CAN I USE ECHO TO RULE OUT ACS?

On its own, echo has insufficient sensitivity to rule out acute coronary syndrome, as regional wall motion abnormalities may not persist when ischaemia resolves. However, sensitivity of clinical and ECG assessment is enhanced in emergency department patients with the addition of echo.

Specificity of echo is limited by the fact that RWMA may persist after old infarction, and so an observed echo abnormality may not be new. LV dysfunction on echo is however associated with a poorer outcome and therefore echo may be helpful in risk stratification as part of a pathway that also includes clinical and electrocardiographic findings and cardiac biomarkers such as troponin.

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### SUMMARY.

In chest pain, echo may:

- Increase the sensitivity of assessment of acute coronary syndrome by identifying wall motion abnormalities.
- Identify alternative causes of chest pain.
- Diagnose mechanical complications of myocardial infarction.

## RESOURCES & FURTHER LEARNING

### Webpages.

- [Ultrasound Village](#)
- [Sonoworld](#)
- [Mount Sinai Emergency Medicine Ultrasound](#)
- [Virtual Transthoracic Echocardiography](#)
- [Stanford University - Echocardiography in ICU](#)
- [Yale University - Atlas of Echocardiography](#)
- [Echopraxis](#)
- [Echo Basics](#)
- [5 Minute Sono](#)
- [Hennepin Ultrasound](#)

### Podcasts.

- [Ultrasound Podcast](#)

### Courses.

- [Australian Institute of Ultrasound](#)
- [Ultrasound Training Solutions](#)
- [Australian School of Medicine Imaging](#)
- [ECHO ED](#)
- [Rapid Assessment by Cardiac Echo](#)