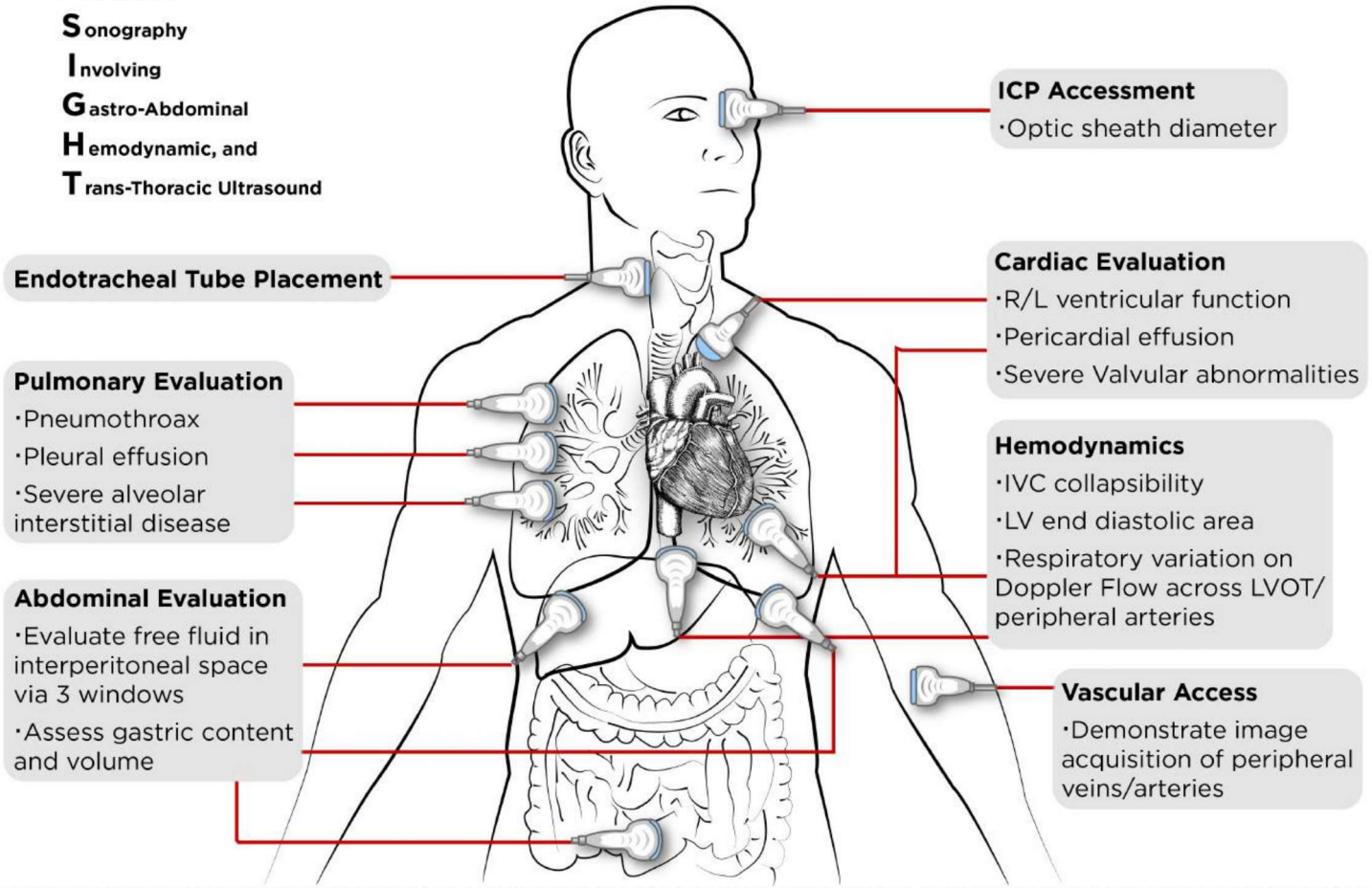
Perioperative Point of Care Ultrasound Educational Manual

F.O.R.E.S.I.G.H.T Ultrasound Examination

Helping Bring the Perioperative Physician out of the Guessing Game

F.O.R.E.S.I.G.H.T. Comprehensive Perioperative Ultrasound Examination

Focused
Peri**O**perative
Risk
Evaluation
Sonography
Involving
Gastro-Abdominal
Hemodynamic, and
Trans-Thoracic Ultrasound



Curriculum and Text Formulated by

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It is my goal for this book to be continuously revised and edited as our speciality embraces point of care ultrasound. This version is the initial starting point to provide free education on this topic and I encourage those who have an interest in this area to look at www.foresightultrasound.com for more content. Ultimately we hope this text can help as an initial starting point to learn more about perioperative point of care ultrasound.

-Davinder Ramsingh, MD

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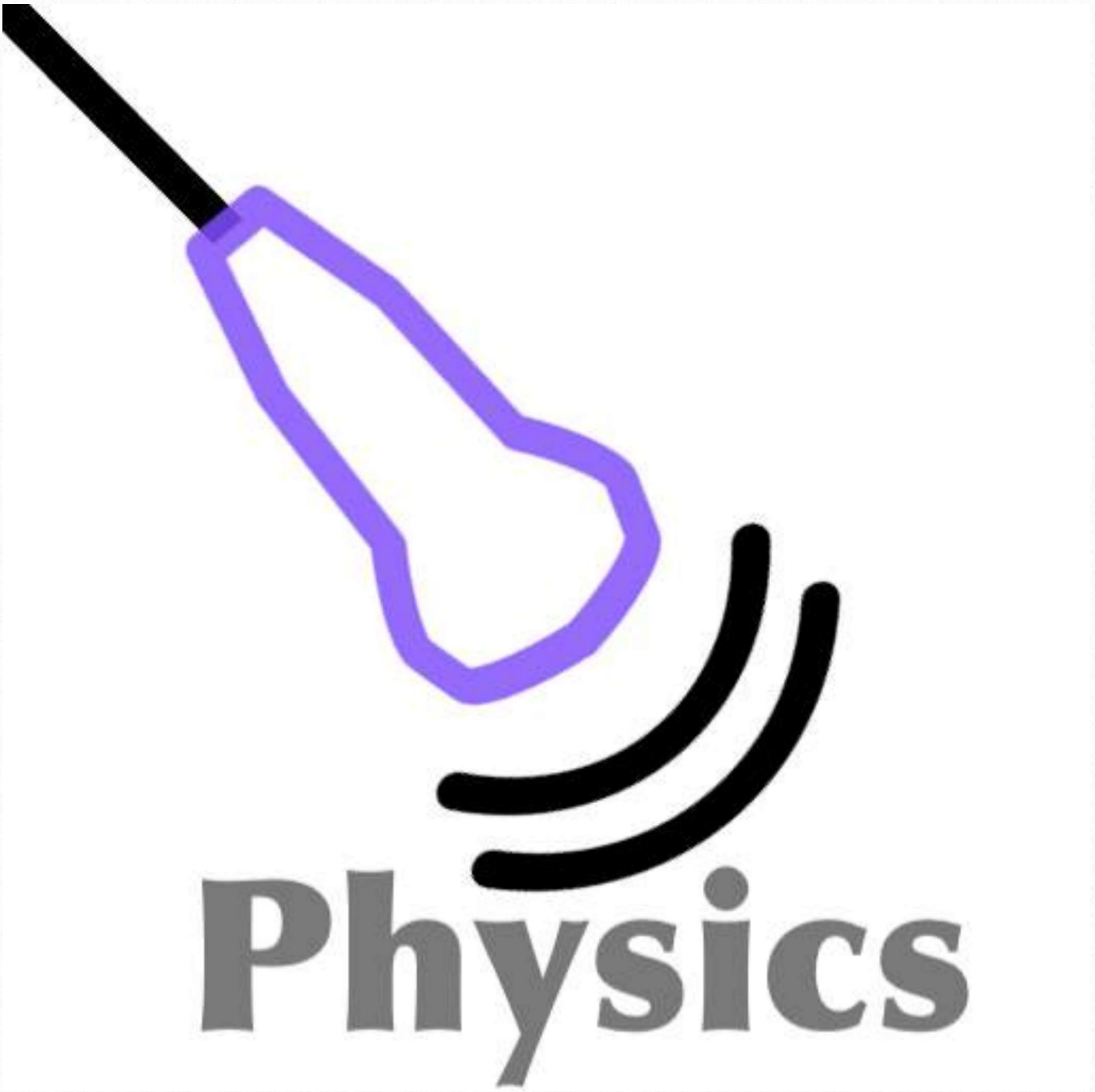
Ultrasound Physics



Ultrasound Physics Overview

BASIC PRINCIPLES OF ULTRASOUND

Sound Waves:
Audible sound waves lie within the range of 20 to 20,000 Hz. Clinical ultrasound systems use transducers between 2 and 27 MHz. Ultrasound wavelengths are produced by passing an electrical current through piezoelectrical crystal elements. These elements convert electrical energy into a mechanical ultrasound wave and not only produce but can receive ultrasound wavelengths. Ultrasound images are produced from collection of emitted and received ultrasound wavelengths. Sound waves are described in terms of **frequency, velocity, wavelength, and amplitude**.

Amplitude: Height of the ultrasound waves, or "loudness" as measure in decibels (dB).

Wavelength: the distance traveled between two consecutive peaks or troughs of a wave.

Frequency: Number of wavelengths per unit time is
1 cycle/ sec = 1 Hz. Frequency is inversely related to wavelength.

Velocity: The speed at which waves propagate through a medium.

Velocity = Frequency x Wavelength

It is important to note that the velocity is dependent on physical properties of the medium through which it travels. Ultrasound image productions relies on the assumption that the velocity in tissue is assumed constant at 1540m/sec.

Image Formation:
The returning electric signals produced represent "dots" on the screen. The *brightness* of the dots is proportional to the strength of the returning echoes. The location of the dots is determined by travel time and the assumption that velocity in tissue is constant. Using the below equation each returned ultrasound wavelength is accumulated to produce an image.

Distance = Velocity x Time

Since the speed in tissue is assumed to be constant and the machine sets the frequency, that is how it identifies the location of each reflected ultrasound wave. on the display

The image is formed from compiling these reflected scan lines. One image frame consists of many individual scan lines. One alters the image mostly by adjusting the frequency.

The frequency affects the image in the following manner:

The HIGHER the frequency, the BETTER the resolution (shorter wavelength), but the WORSE the depth of penetration (too many cycles of attenuation).

The LOWER the frequency, the LESS the resolution (longer wavelength), but the BETTER depth of penetration (fewer cycles of attenuation)

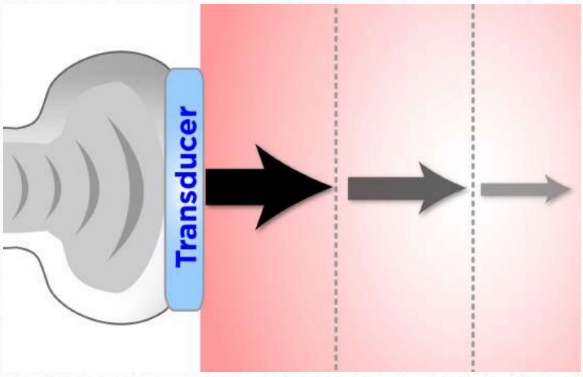
To explain this further, one can think of the ultrasound wavelength as a ruler. If one is using a ruler that has only whole inch markings, then they will be *less* precise in their measurement than if they used a ruler that had quarter-inch markers as well. Thus the shorter the wavelength allows for a more precise or higher quality image.

Along with this principle is the fact that the longer the wavelength the more the depth of penetration. This is secondary to the fact that wavelengths will only penetrate a certain number of cycles before they are not enough in quantity to produce an image (see next Figure). Therefore the longer a given wavelength the further it can penetrate before the "signal" is lost. While this is not a complete explanation, the key-point is to realize the following:

The **HIGHER the frequency, the BETTER the resolution** (shorter wavelength), but this is at the cost of LESS depth of penetration.

The **LOWER the frequency, the WORSE the resolution** (longer wavelength), but the **BETTER depth of penetration**.

The next figure illustrates the loss of ultrasound signal the further it proceeds from the probe.



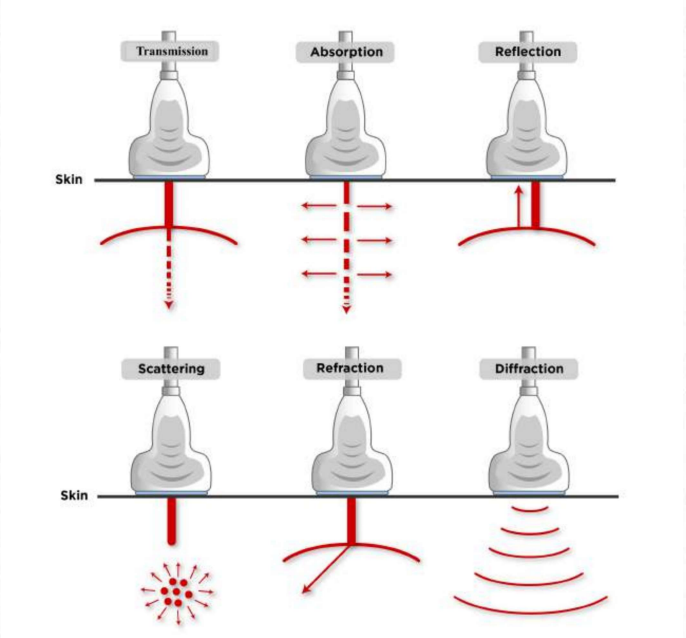
INTERACTIONS OF ULTRASOUND WITH TISSUE

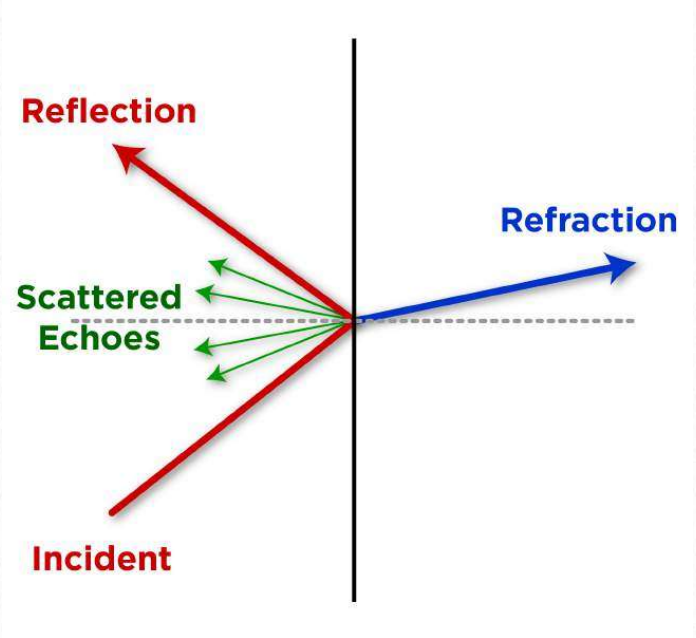
The final fundamental concept when it comes to ultrasound image production is to understand how/why ultrasound devices receive returned ultrasound waves at different times, which as we stated above represents different depths. An ultrasound wave is "affected" every time it interacts with tissues of different density. In fact, this is what produces the ultrasound image. The term **attenuation** is used to describe what happens with the ultrasound wave as it interacts with the tissues. *Its important to realize that you will have more attenuation per depth with higher frequency probes vs lower frequency probes*. As ultrasound penetrates tissue planes it is attenuated. Attenuation is the concept that the deeper the ultrasound waves travel in the body, the weaker it becomes. This is secondary to 4 *main* processes: reflection, absorption, refraction, and transmission. The additional process of scattering and diffraction are also demonstrated in the next figure.

Reflection: This is a mirror-like return of the ultrasound wave to the transducer. Reflections occur at the interface of different densities or acoustic impedances of the tissues. The greater the difference in the density of tissue the greater the amount of tissue reflection. This is why one does not see lung tissue well with ultrasound; the majority of the ultrasound waves are reflected at the plane between the pleura and the lung. Also, it is important to note that the more perpendicular the structure is to the ultrasound wave the more echogenic (or bright) the image will appear since more ultrasound waves are returned back to the probe. Similarly, the more parallel the structure is to the ultrasound probe, the more hypo-echoic (dark) the structures will appear since less ultrasound waves are reflected back to the probe. **Remember, for 2-D images you want to the ultrasound wave to be as perpendicular as possible and for flow assessment you want to be as parallel as possible.**

Absorption: At each tissue plane some of the ultrasound waves are absorbed by the tissues and produce heat.

Refraction: This is a change in the direction of the ultrasound wave secondary to a change in density of one me-



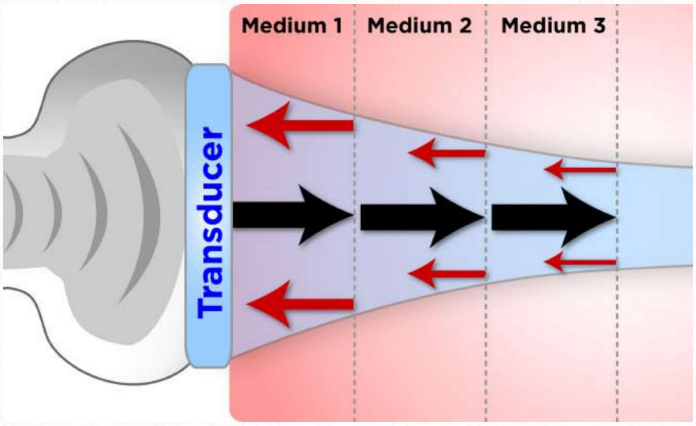


dium to another. This phenomena creates artifacts in the ultrasound image.

Transmission: This is necessary for one to see various tissues at various depths.

It is important to remember that one can counteract the loss of signal during the assessment of deeper structures by altering the power/gain/TGC.

In addition, it is also important to highlight that ultrasound gel is used between the skin of the subject and the transducer face, otherwise the sound would not be transmitted across the air-filled gap.



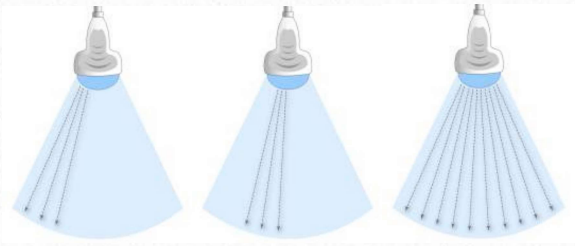
***Interactions of Ultrasound with Tissue**: at each tissue medium the ultrasound is attenuated (waves are reflected, transmitted, refracted, absorbed, etc.)*

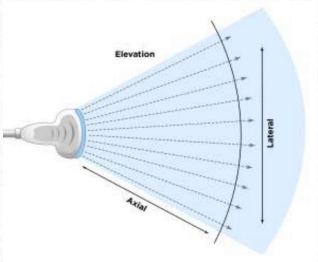
TRANSDUCERS

Transducers have three characteristics that help determine if it is the desired probe for image acquisition. These characteristics are: frequency, insonation footprint, and probe design. Most often, the choice of transducer is based on the depth of the structure being imaged since that will dictate the frequency that will be used to insonate. The higher the frequency of the transducer crystal, the less penetration it has, but the better the resolution. So if more penetration is required you need to use a lower frequency transducer while sacrificing some resolution. The footprint of the ultrasound probe is important since you have to be able to place the probe over the desired area such that the ultrasound wavelengths can penetrate. This is particularly relevant when it comes to the cardiac exam since the probe has to have a small footprint to allow the probe to be placed in between the ribs (since bone is highly echo-reflective). Finally, the shape of the probe and its beam is varied and is different for each transducer frequency.

GENERAL PROBE TYPES

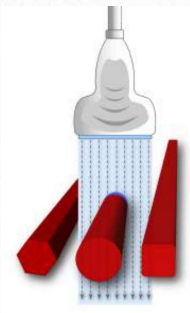
Phased Array:
This probe allows for a significantly larger width of image acquisition than compared to the footprint. This is done by sending directional "phases" of ultrasound wavelengths that are rapidly pulsated and composited together to produce an image. How rapidly the phases are emitted is related to the *frame rate.*





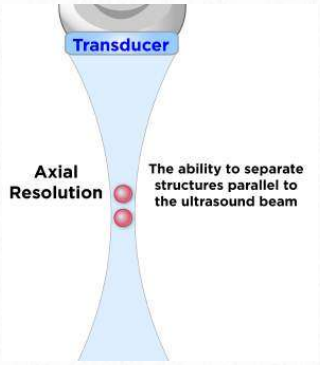
Curved Linear:
4 to 7 MHz, has a large footprint, ideal for abdominal exam, and a wide image is produced because of how US waves are emitted (curved).

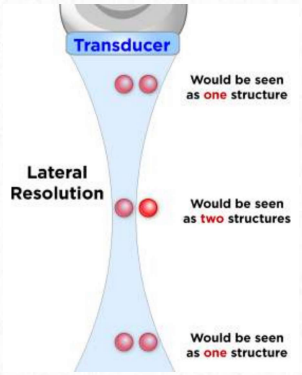
Linear:
10 to 27 MHz, used for superficial structures, and provides the best image resolution.



RESOLUTION

Image resolution is defined as the ability to distinguish two points in space and consists of two components: **spatial and temporal.**





Enhancement	Increase in reflection amplitude from reflectors that lie behind a weakly attenuating structure. This is secondary to the large difference in acoustic impedance and examples include cysts and solid masses.
Reverberation	An artifact that results from a strong echo returning from a large acoustic interface to the transducer. This echo returns to the tissues again, causing additional echoes parallel and equidistant to the first echo.
Shadowing	Created by strong reflectors or attenuating structures (i.e. bone, gas, calcifications, and air).
Speckle	The granular appearance of images and spectral displays that is caused by the interference of echoes from the distribution of scatterers in tissue.

Spatial resolution is the smallest distance that two targets can be separated for the system to distinguish between them. Spatial resolution consists of two parts – *Axial and Lateral. Axial resolution* is the minimum separation between structures that are parallel to the ultrasound beam path. Axial resolution is directly related to frequency, pulse length (period of wavelengths), and inversely related to wavelength. *Lateral resolution* is the minimum separation between structures that are perpendicular to the ultrasound beam path. Lateral resolutions is impacted by the ultrasound wave amplitude, the image depth, and the gain intensity,

Temporal Resolution is the ability of system to accurately track moving targets over time. Anything that requires more time will decrease temporal resolution and includes: 1) Depth, 2) Sweep angle, 3) Line density, and 4) lower frequency or pulse repetition frequency (PRF)

COMMONLY USED METHODS OF IMPROVING ULTRASOUND IMAGE

Depth: Represents the number of pixels per centimeter and directly affects the spatial resolution. One should always adjust the depth to the minimum appropriate level in which all relevant structures are visualized since this will result in the highest frequency and thus image resolution.

Gain: Adjusts the overall brightness of the ultrasound image. It is important to note that this is a post-processing adjustment so it does not improve differentiation of echogenicity (resolution is the same just brighter or darker). One can improve the image differentiation of echogenicity by adjusting the power.

Power: This relates to the strength of the voltage spike applied to the crystal for each pulse. Increasing power output increases the intensity of the beam and therefore the strength of echo returned to the transducer.

Focus: There is a fixed, focused region of the ultrasound beam which is indicated on the system with a small triangle or line to the right of the image. This indicates the focal zone of that transducer and is where the best resolution can be achieved with that particular transducer. Effort should be taken to position the object of interest in the subject to within that focused area to obtain the best detail.

Time Gain Compensation (TGC): Equalizes differences in received reflection amplitudes because of the reflector depth. TGC allow you to adjust the amplitude to compensate for the path length differences (it counteracts the fact that fewer wavelengths penetrate to deeper structures that results in a less echogenic image). One can simply look at TGC as bands of *horizontal gain*.

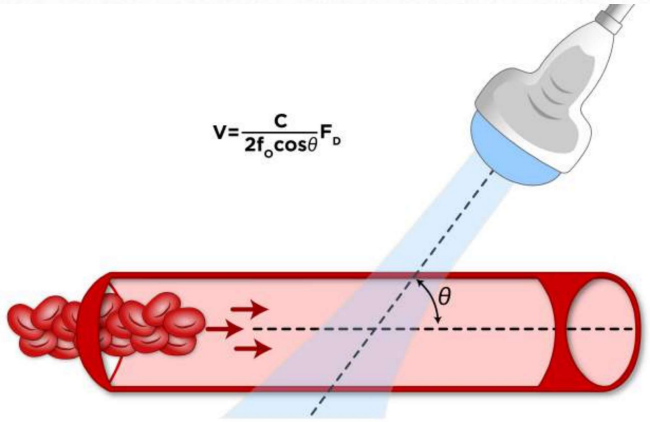
ULTRASOUND MODES

B-MODE (brightness mode):
This is the mode used for standard 2-D image creation. There is a change in spot brightness for each echo signal that is received by the transducer. The returning echoes are displayed on a television monitor as shades of gray. Typically the brighter gray shades represent echoes with greater intensity levels. This mode allows you to scan. Since 2-D images are generated from reflection the best 2-D or B images occur when the ultrasound plan is *perpendicular* to the structure.

M-MODE (motion mode):
A graphic B-mode pattern that is a **single line time** display that represents the motion of structures along the ultrasound beam, 1000fps. In this mode the line of ultrasound reflection or returning echos are shown in the y axis and its change over time is shown in the x - axis. This mode allows you to trace motion (i.e. heart wall motion, and vessel wall motion).

PW MODE (pulsed-wave mode):
Frequency change of reflected sound waves as a result of reflection motion relative to the transducer used to detect the velocity and direction of blood flow. This reflection shift can be displayed graphically, as well as audibly. During Doppler operation the reflected sound has the same frequency as the transmitted sound if the blood is stationary (we know that blood is not stationary, it moves), therefore if the blood is moving away from the transducer, a lower frequency is detected (negative shift), and the spectrum appears below the baseline. If the blood is moving toward the transducer, a higher frequency (positive shift) is detected and the spectral displays above the baseline

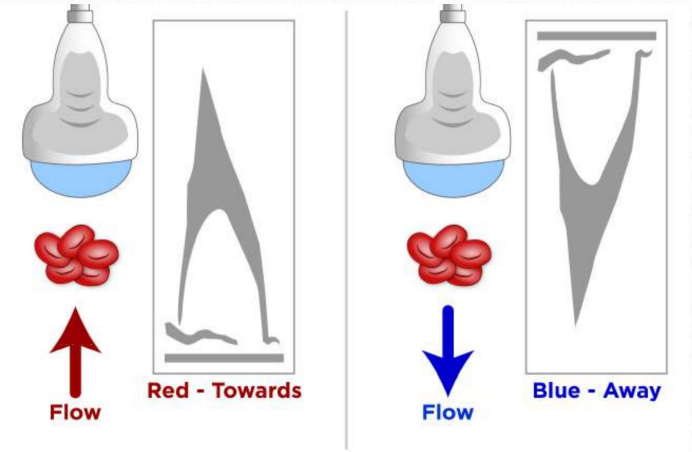
Doppler shift:
Dependent on the insonating frequency, the velocity of moving blood and the angle between the sound beam and direction of the moving blood. THE MOST IMPORTANT THING WITH THIS CONCEPT IS TO REALIZE THAT if the sound beam is **perpendicular** to the **direction of blood** flow, there will **be no doppler shift,** therefore there would be **no display of flow in the vessel**. The angle of the sound beam should be less than 60 degrees at all times.



Aliasing:
The production of false doppler shift and blood velocity information when the Doppler shift exceeds a threshold. It appears as if the spectral display is cut off, wraps around, and reappears in the opposite region of the display.

Color Doppler:
Ultrasound images are usually displayed with gray scale brightness corresponding to their intensities. In color doppler, echoes are displayed with colors corresponding to the **direction of flow** that their positive or negative doppler shifts represent (toward or away from the transducer). This is usually overlaid on a B or 2-D image. The color doppler window can be adjusted and it represents a window of pulsed wave doppler signals that have been assigned a color representation for its direction and velocity of flow. The brightness of the color represents the intensity of the echoes, and sometimes other colors are added to indicate the extent of spectral broadening. A good general rule is the following: BLUE COLOR=BLOOD FLOW MOVING AWAY FROM THE TRANSDUCER / RED COLOR=BLOOD FLOW MOVING TOWARDS THE TRANSDUCER - THINK B.A.R.T (Blue-Away/Red-Towards). The color range in the color doppler setting represents the range of the velocities. Brighter equals a higher/faster velocity and darker is a slower velocity. The range of the velocities is shown above the color range legend on the top left of the screen. This range of ve-

locities is called the **Nyquist limit**. It is important to always look at the range of velocities (Nyquist limit) when using the color doppler modality. This is because the representation of the color doppler window can be greatly altered by changing the range of the velocities. For example, one can make the degree of regurgitation across a cardiac valve appear to be worse by *lowering* the Nyquist limit. Important references include 60 cm/sec to evaluate cardiac valves and 20cm/sec to evaluate atrial or venous flow. Finally its important to realize that the use of color doppler will negatively impact the resolution of the 2-D image directly with the size of color doppler window.



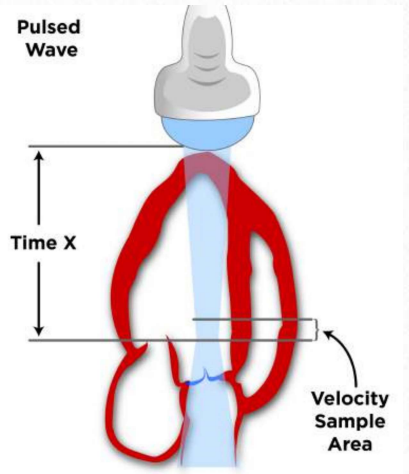
DOPPLER PRINCIPLES

Doppler:
Displays the change in frequency of a wave resulting in the motion of the wave source or reflector. In ultrasound the reflector is the moving red blood cell. The Doppler shift is dependent on the insonating frequency (transducer frequency), the velocity of the moving red blood cells, the angle of the sound beam, and direction of the moving red blood cells.

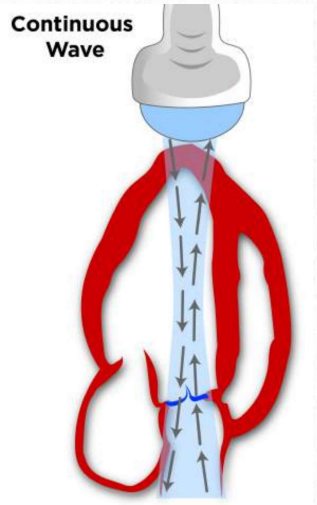
Remember, if the ultrasound beam is perpendicular to the direction of the blood flow, a Doppler shift and potentially incorrect impression of the blood flow velocities may be observed. Therefore, careful consideration should be taken to obtain an angle of less than 60 degrees to the direction of the blood flow to obtain reliable and accurate results in quantifying the velocity in a certain blood vessel.

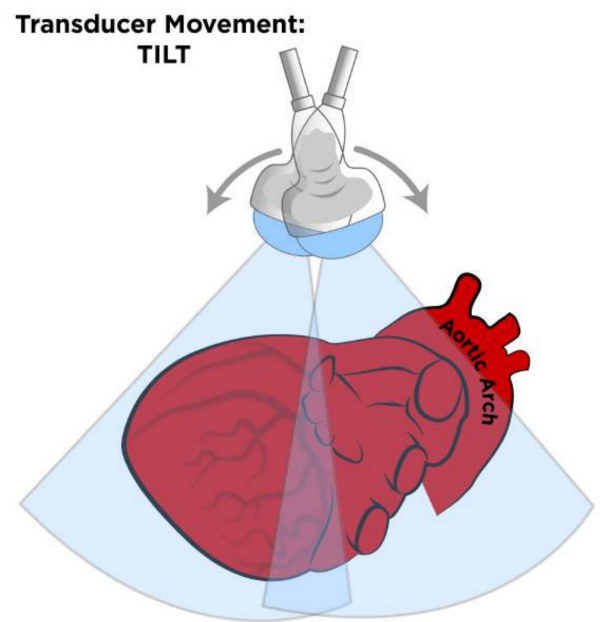
Power Doppler:
Depicts amplitude or power of the Doppler signal rather than the frequency shift. Therefore, there is less angle dependence and visualization of smaller vessels with a Doppler shift; however, velocity and directional information are sacrificed.

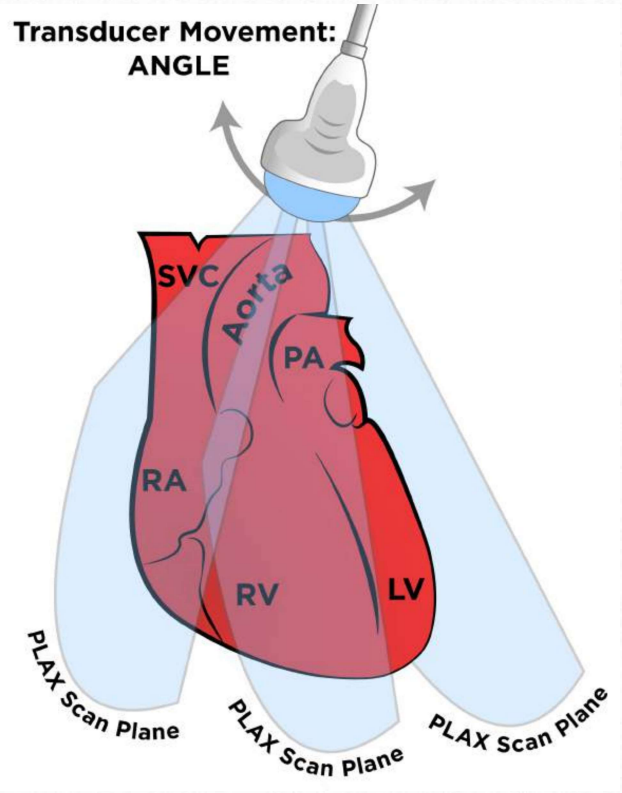
Pulsed Wave Doppler:
This is used with a sample gate or volume, and gives a graphical display of all the velocities within the area sampled. The amplitude of the signal is proportional to the number of blood cells and is indicated as a shade of gray. Pulse wave doppler offers the benefit of providing depth discrimination however because one is identifying a velocity sample area one will have a limitation on the ranges that can be assessed with this technique. This range decreases as you move further from the probe (time increases).

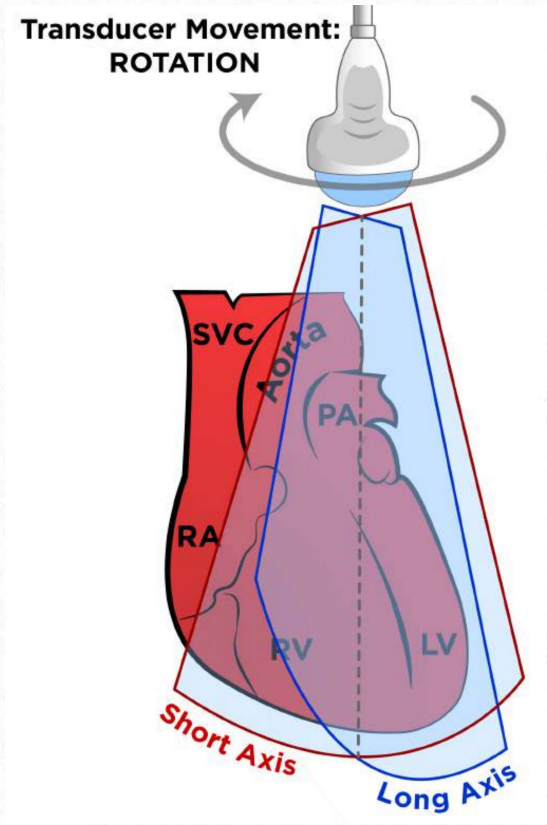


Continuous Wave Doppler:
In this modality there is a constant ultrasound signal being sent and there is a constant part of the piezoelectric crystal that is able to receive the ultrasound signal. The benefit of this is that there are no limitations to velocity measurements. However, this is at a trade-off with losing the ability for depth (or location) identification. In other words, a continuous wave Doppler will show the highest velocities **anywhere** along the continuous wave ultrasound plane.









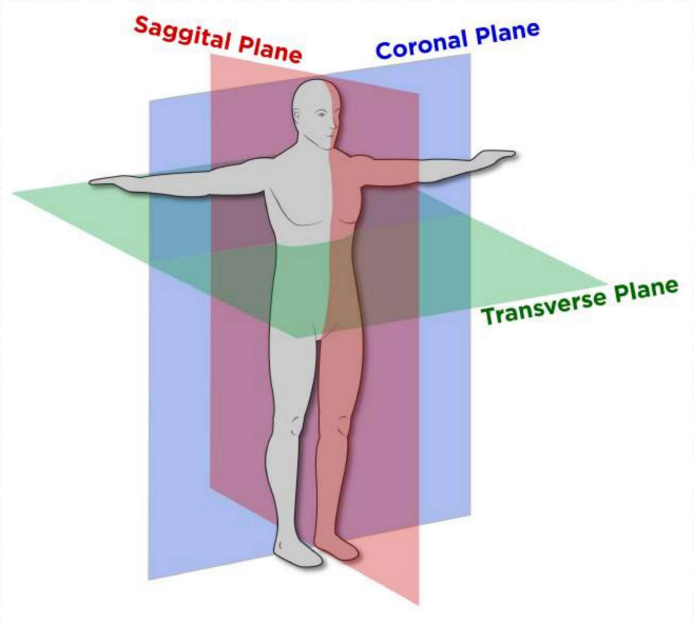
TERMS FOR LABELING AND SCAN ORIENTATION

From each transducer position the target structure is focused by three major movements shown below.

Angle: Scanning in the anterior – inferior direction

Tilt: Scanning in the left – right direction (used to position structures in the middle of the screen)

Rotation: Clockwise, counterclockwise

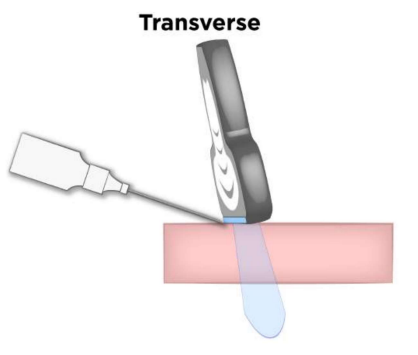


Coronal	The long axis of a scan performed from the subject's side where the slice divides the anterior from the posterior or the dorsal from the ventral in the long axis
Transverse (short axis)	A cross-sectional view
Sagittal (Longitudinal)	The long axis plane
Superior, Cranial, Cephalad, Rostral	Interchangeable terms indicating the direction towards the head
Inferior or Caudal	Indicating the direction towards the feet
Anterior or Ventral	A structure lying towards the front of the subject
Posterior or Dorsal	A structure lying towards the back of the subject

ULTRASOUND PROBE INDICATOR MARKER

Another important point to become familiar with as one learns about point of care ultrasound is the location of the indicator on the probe. All probes will have an indicator mark that can be used to relate the footprint of the probe to the screen (left and right of the probe to the left and right of the screen). The indicator is marked by a line, bump, or with an LED light. One should always identify the indicator of the probe to the marker of the indicator location on the screen. The default location of the indicator for non-cardiac probes and non-cardiac presets is for the indicator to be on the left side of the ultrasound screen. For cardiac presets and the use of the phased array probe, the default for most ultrasound machines is to place the indicator on the right of the screen. To summarize this concept, when doing an ultrasound exam, one should always consider two key issues regarding the orientation of anatomic structures as they are viewed on the screen: 1) relationship of the probe indicator to the image on the screen (indicator-to-screen) and 2) relationship of the probe indicator to the patient (indicator-to-patient). This eBook will describe probe position based on the usual defaults for the probe and presets used to perform the ultrasound exam.

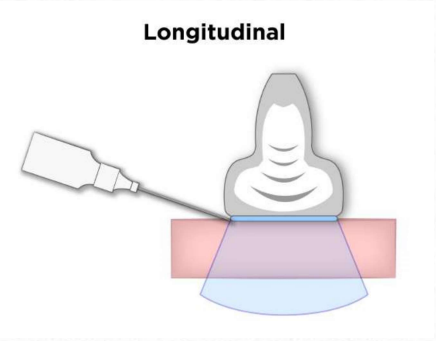
Transverse (Short Axis) Approach



Important Points to the Short Axis Approach

- it provides a cross-sectional view of the needle
- it is known as the out-of-plane technique.
- this technique results in the needle being imaged on cross-section that appears as a small dot, which can be difficult to see in real time.
- the needle will cross the ultrasound beam only once.
- requires frequent probe adjustment (fanning) to maintain continuous visualization of the desired structure (needle) as in penetrates tissue

Long Axis Approach



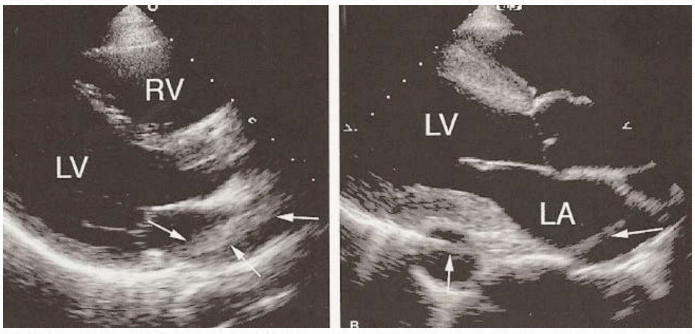
- it provides a view of the entire needle if the ultrasound plan is in the path of the needle.
- the operator loses the lateral-medial perspective.
- the operator loses the ability to assess surrounding anatomy
- probe is more often fixed in position during a procedure

	Basic Physics Terms
Absorption:	The loss of ultrasound energy by converting to another form of energy (heat or mechanical vibration)
Acoustic Impedance:	The resistance to sound transmission through a medium. IT IS THE DIFFERENCE IN ACOUSTIC IMPEDANCES OF DIFFERENT TISSUES THAT RESULTS IN REFLECTION AND IMAGE FORMATION
Amplitude:	The strength of a sound signal
Artifacts:	Alterations to the display that can adversely affect ultrasound image acquisition or interpretation
Attenuation:	The loss of ultrasound energy DUE TO ABSORPTION, REFLECTION, and SCATTERING of sound energy
Axial Resolution:	The ability to distinguish two structures as separate when the structures are close to each other along the same axis as the ultrasound plane. Good axial resolution is achieved with short spatial pulse lengths. Short spatial pulse lengths are a result of higher frequency and higher damped transducers. Therefore the higher the frequency the better the resolution.

Anechoic:	A structure that does not produce any internal echoes
Aliasing	Aliasing occurs with any pulsed ultrasound doppler modality (color doppler and pulse wave). All pulsed ultrasound doppler techniques requiring the machine to have time delays to asses for changes in direction and frequency. This time delay creates a limit or range of velocities that can be assessed. When a velocity is evaluated above this range (Nyquist limit) the phenomena of aliasing occurs in which the flow pattern is reset to the opposite direction. Aliasing can be prevented by using a lower frequency probe, imagining at a shallower depth, and adjusting the pulse repetition velocity scale.
B-Mode:	A two-dimensional display of ultrasound. The A- mode spikes are electronically converted into dots and displayed at the correct depth from the transducer
Complex:	Refers to a mass that has both fluid-filed and solid areas within it
Cystic:	This term is used to describe any fluid-filled structure, for example, the urinary bladder
Enhancement (acoustic):	Sound is not weakened (attenuated) as it passes through a fluid-filled structure and therefore the structure behind appears to have more echoes than the same tissue beside it
Gain:	Refers to the amount of amplification of the returning echoes
Gel Couplant:	A trans-sonic material which eliminates the air interface between the transducer and the animal's skin
Homogenous:	Of uniform appearance and texture
Interface:	Strong echoes that delineate the boundary of organs, caused by the difference between the acoustic impedance of the two adjacent structures; an interface that is usually more pronounced when the transducer is perpendicular to it

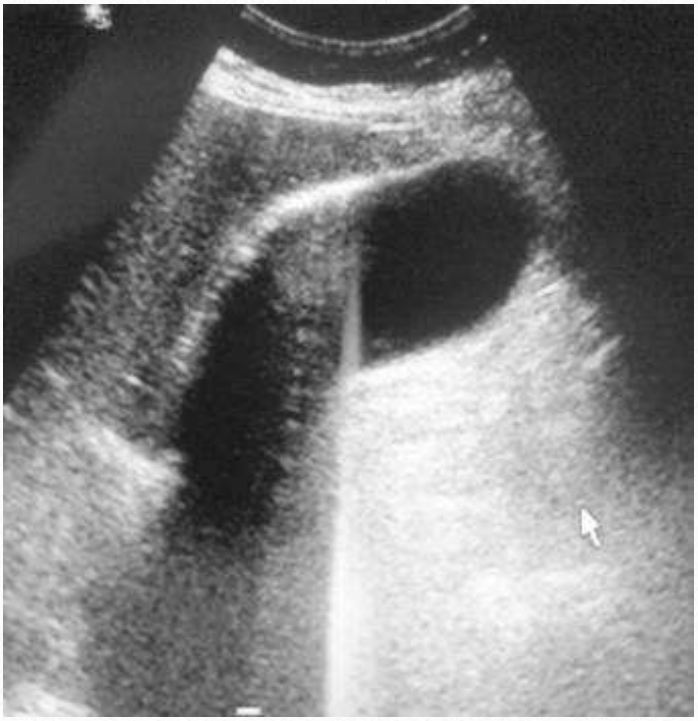
Shadowing:	Created by strong reflectors, or attenuating structures, i.e. bone, gas, calcifications and air (see example below)
Enhancement:	Increase in reflection amplitude from reflectors that lie behind a weakly attenuating structure, i.e. cysts, solid masses
Side Lobe Artifact	During the production of ultrasound beams undesired radial beams are emitted. These beams are called side lobes. Because the ultrasound machine interprets the returning ultrasound beams that were produced from side lobes as actually being from the intended main ultrasound beam the location of the reflected ultrasound beams are no placed in the appropriate position on the screen (side lobe artifact). Side lobe artifacts usually represent very echogeneic structures as they are able to produce enough beam reflection from the weaker side lobe transmissions. (see example below)
Speckle:	The granular appearance of images and spectral displays that is caused by the interference of echoes from the distribution of scatterers in tissue

Reverberation:	An artifact that results from a strong echo reflection from a large acoustic impedance difference t(tissue density difference). This echo returns to the tissues again, causing additional echoes parallel and equidistant to the first echo (see example below)

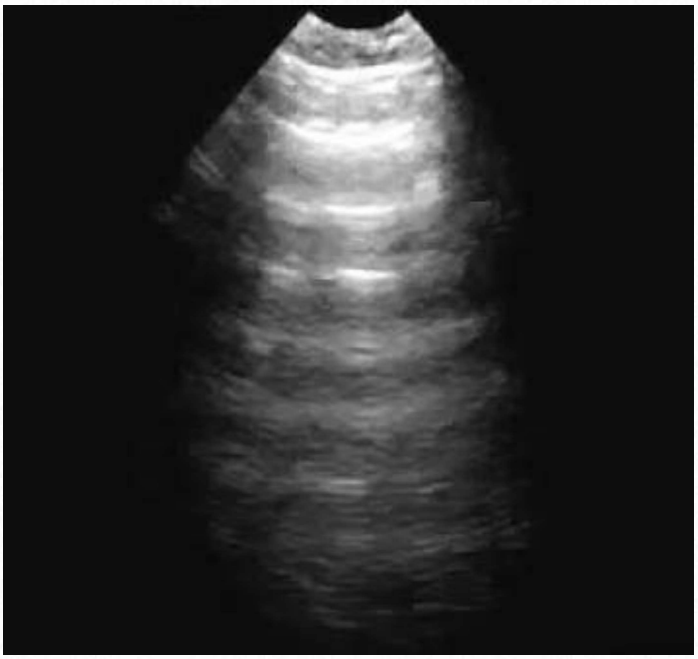


Side Lobe Artifact

Shadowing:

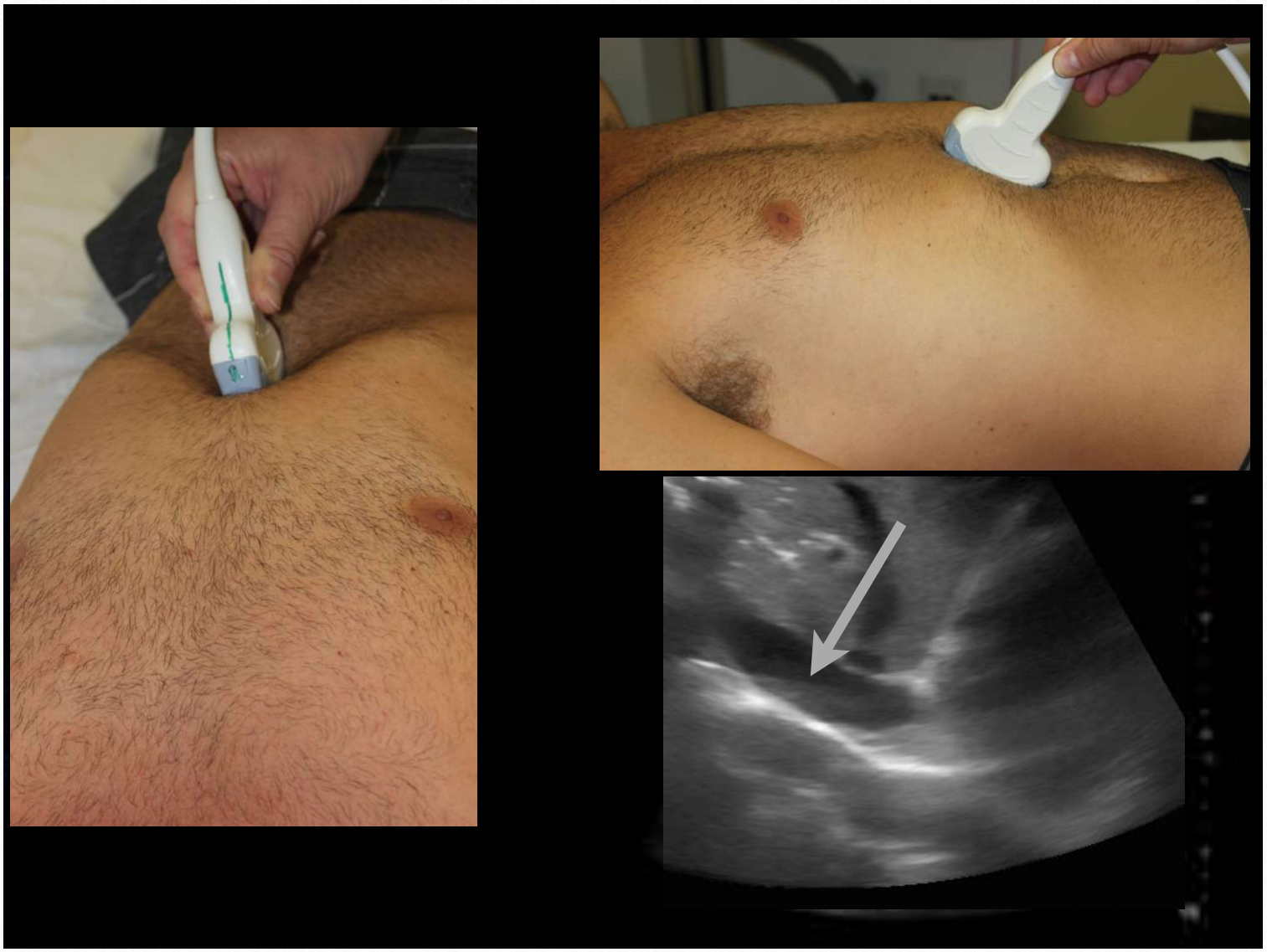


Reverberation:



2

IVC Diameter and Collapsibility



I. Volume Status: Ultrasound provides a variety of techniques to assess the patient's volume status, and, often more importantly, whether or not the patient is fluid responsive. Each subsection (below is part 1 of 4) will cover one ultrasound technique used to answer these questions.

A. IVC DIAMETER & COLLAPSIBILITY

IVC Diameter:

The diameter of the IVC has been shown to accurately predict the pressure in the main vessels emptying to the heart and correlates well with CVP. Using the measure or caliber feature one can assess the diameter of the IVC in either a standard 2–D image or an M-mode image. IT IS IMPORTANT TO REALIZE THAT EVEN THOUGH THIS MODALITY CAN HELP PREDICT CENTRAL VENOUS PRESSURE IT DOES NOT INDICATE VOLUME RESPONSIVENESS. Please see the below table for the relationship between IVC diameter and its collapsibility to the patients CVP.

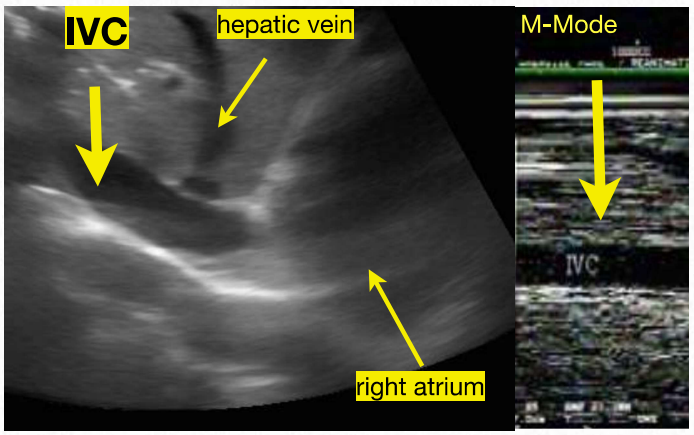
IVC Collapsibility:

Measuring the change in the IVC diameter during different phases of respiration differentiates normal subjects from patients with elevated right atrial pressure. In other words, it is normal for one's IVC to change secondary to changes in the pleural pressure from respiration. If this does not occur, it suggests that the pressure in the venous system (CVP) is abnormally high. In spontaneous breathing, where one generates negative pleural pressure, the cyclic variations in pleural pressure are transmitted to the right atrium and produce cyclic variations in venous return. Specifically, with a ***negative inspiratory breath,*** RA filling is improved and the IVC diameter will ***decrease*** (since it gets unloaded). A reduction of greater than 50% equals a CVP of less than 5 mmHg. Please see the table below for the relationship between IVC diameter and its collapsibility related to the patient's CVP. Please note that when measuring the IVC diameter one uses the **maximum diameter size** achieved during expiration in a spontaneously breathing patient and during inspiration in a mechanically ventilated patient.

In a patient requiring ***ventilatory support***, the inspiratory phase induces an increase in pleural pressure which is transmitted to the right atrium, thus reducing venous return into atrium and increasing the volume in the venous system. The result is an inversion of the cyclic changes in IVC diameter, leading to ***increases*** in the ***inspiratory phase*** and ***decreases*** in the ***expiratory phase***. The same 50% rule and diameter changes apply.

Please note that in a patient presenting with signs of circulatory insufficiency, a 50% change in IVC diameter to respiration may indicate hypovolemia.

IVC Size (cm)	Changes with respiration or "sniff"	Estimated mean CVP (mmHg)
Small (< 0.5)	Collapse	0-5
Normal (1.5-2.5)	↓ by ≥ 50%	5-10
Normal (1.5-2.5)	↓ by ≤ 50%	10-15
Dilated (> 2.5)	↓ < 50%	> 15

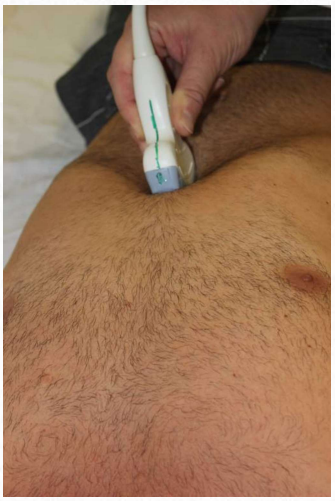


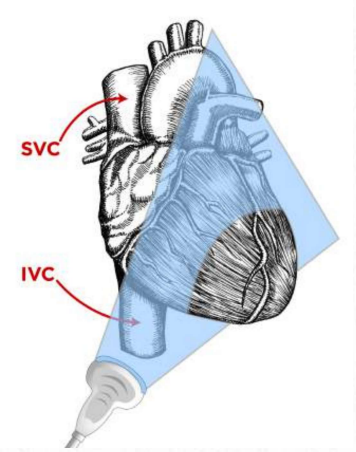
PROBES

Curved Linear

Phased Array

Probe position: To obtain this image, one should place the curved linear or phased array transthoracic probe in the subxiphoid space with the probe indicator in the 12 o'clock position. Ideal measurement of the IVC diameter should be just distal to where it merges with the hepatic vein, which is usually **2 cm to 3 cm from the IVC entry into the right atrium** (see picture below). Sometimes the IVC is completely collapsed and may be difficult to visualize (virtual IVC). Such a situation in a mechanically ventilated or spontaneously breathing patient always indicates severe hypovolemia in the absence of raised intra-abdominal pressure. **2-D imaging** using the caliber/measure feature or **M-Mode** can be used to measure IVC diameter/ collapsibility.

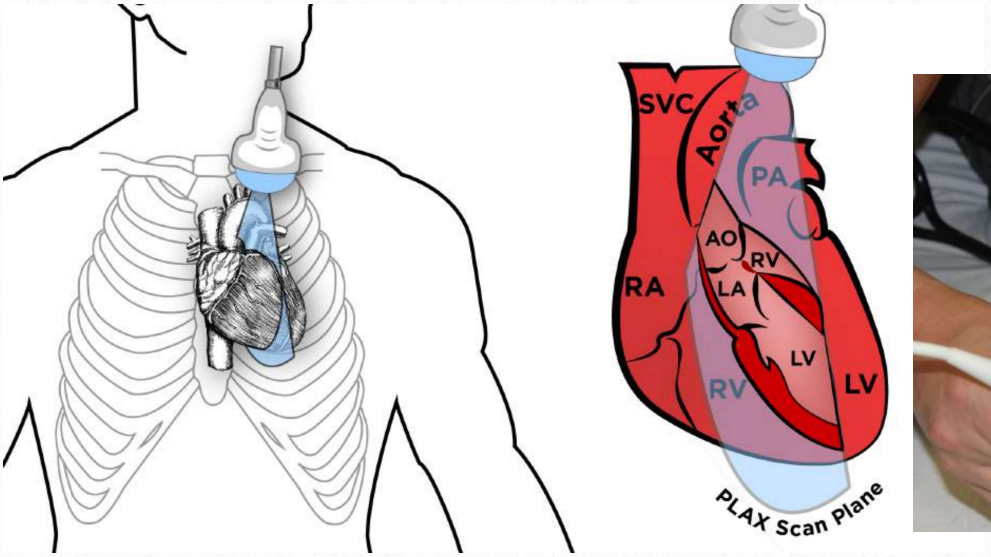


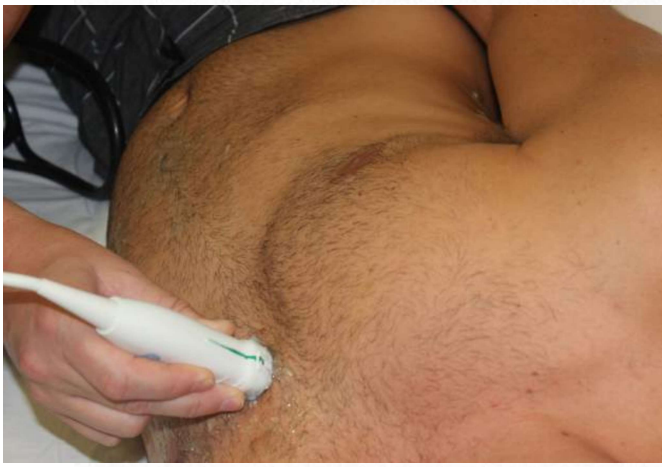


3

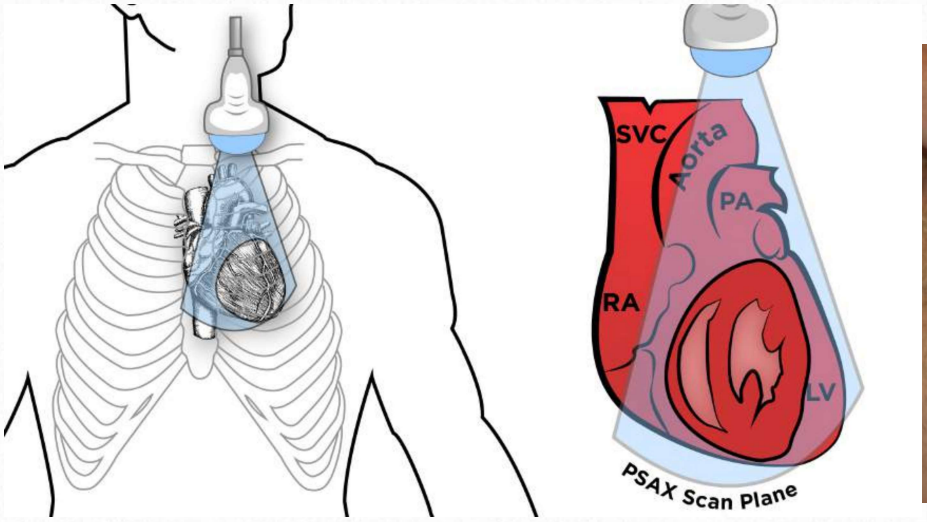
Left Ventricle End-Diastolic Area

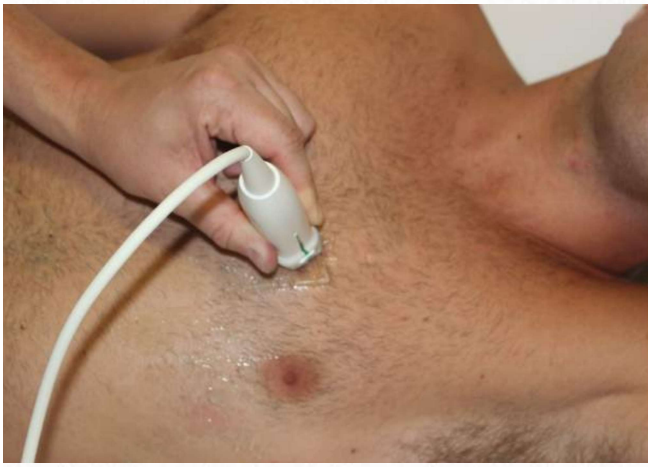
Parasternal Long Axis View (indicator at 10 o'clock position "right shoulder")





Parasternal Short Axis View (indicator at 2 o'clock position "left shoulder")





I. Volume Status: Ultrasound provides a variety of techniques to assess the patient's volume status, and, often more importantly, whether or not the patient is fluid responsive. Each subsection (below is part 2 of 4) will cover one ultrasound technique used to answer these questions.

B. LEFT VENTRICLE END DIASTOLIC DIAMETER/AREA

The diameter and/or the area of the left ventricle at the end of diastole represents the filling of the left heart and can indicate the patient's filling status. Using the measure or caliber feature, one can assess the diameter of the IVC in either a standard 2-D image or an M-mode image. The views used to obtain these measurements are the same views that will be used for further evaluation of cardiac function. Similar to IVC collapsibility, *IT IS IMPORTANT TO REALIZE THAT EVEN THOUGH THIS MODALITY CAN HELP PREDICT LEFT VENTRICLE VOLUME, IT DOES NOT INDICATE VOLUME RESPONSIVENESS.* Please see the table at the end of this chapter for the relationship between LV diameter and LV area. In addition to measuring LV diastolic diameter or area to determine LV volume, these views can also be used to assess cardiac contractility by measuring the change in the diameter of the LV from diastole to systole. A left ventricular end diastolic diameter of less than 3.5 cm is a crude marker of a severely hypovolemic state. This change in area is called fractional area change (FAC) and indicates myocardial contractility (see table below). Additionally, these views are useful in identifying the **mechanism of shock**:

1. Cardiogenic shock: Increased LV area/diameter and a decreased FAC (from decreased contractility).

2. Hypovolemic shock: Decreased LV area/diameter (from decreased preload) and an increased or normal FAC.

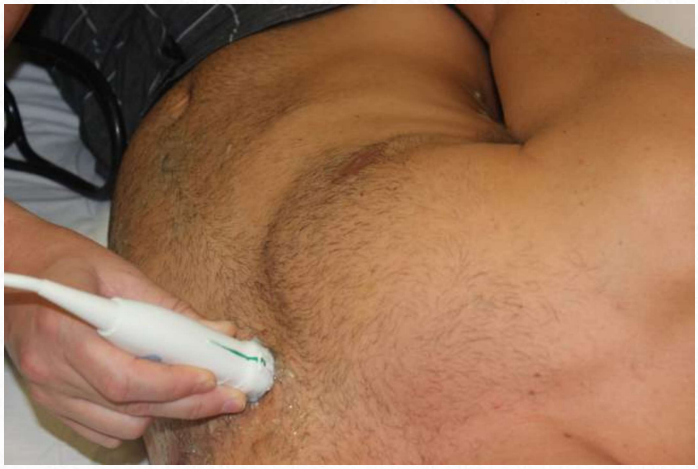
3. Vasogenic shock: Normal LV area/diameter and an increased or normal FAC (from low SVR state).

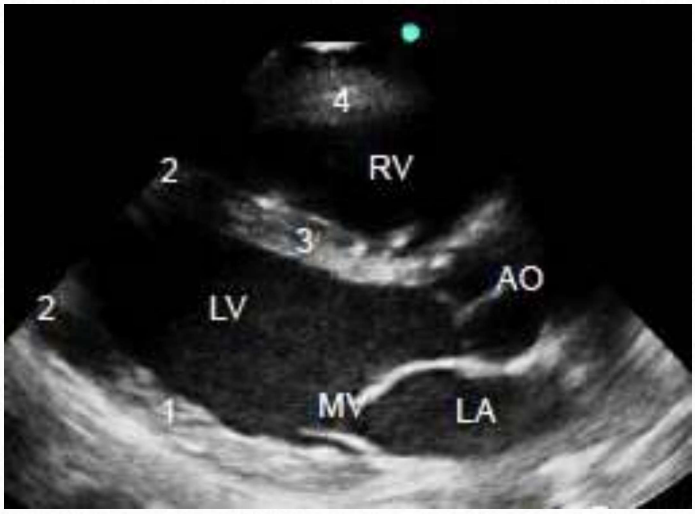
Patient Position: Left-Lateral with L arm extended.

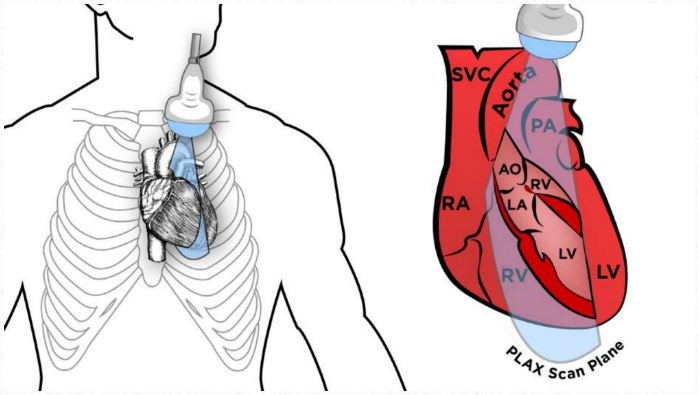
Probe Type: phased array cardiac probe (small footprint/low frequency).

Probe Position: 10 o'clock or towards right shoulder.

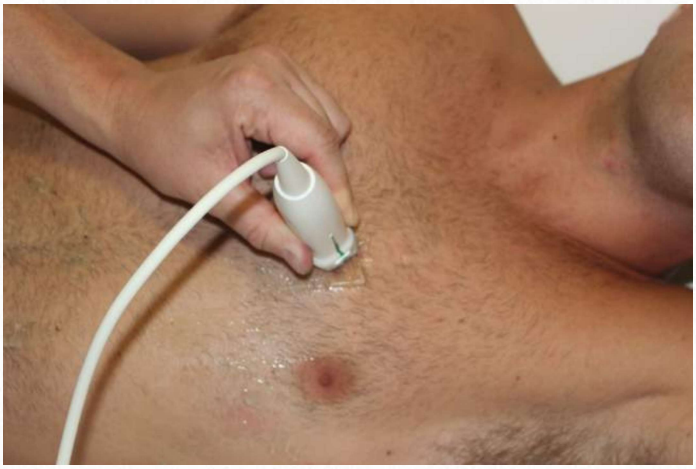
Position 1. ***Left parasternal long axis view:*** 3rd-4th interspace just lateral to the left of the patient's sternum with the index roughly at the *10 o'clock position,* or aiming at the *right shoulder (indicator shown in green).*

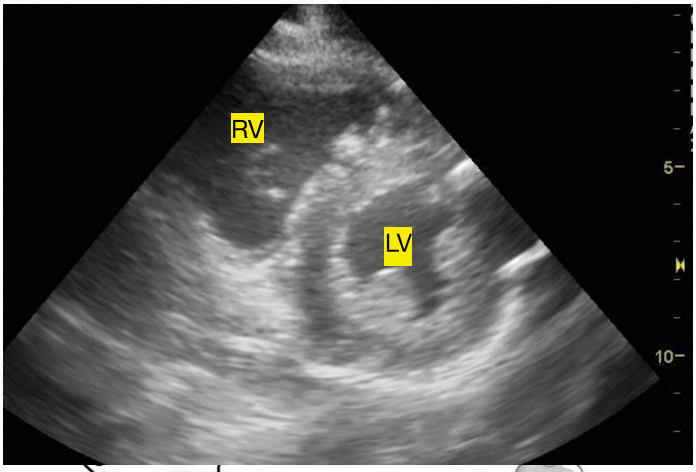


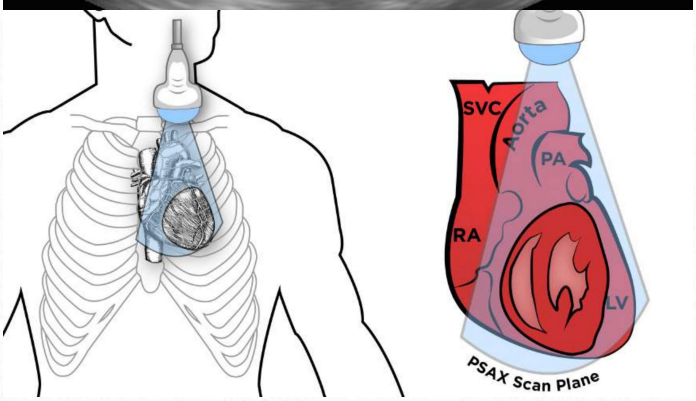




Position 2. ***Left parasternal short axis view:*** 3rd-4th interspace just lateral to the left of the patient's sternum with the index marker approximately at *the 2 o'clock position* or aiming towards the *patients left shoulder* (90 degrees to LAX view). Also, remember that you must adjust the **angle** to get a good view of the midpapillary level of the ventricle. Aiming towards the head will show the mitral valve followed by the aortic valve, and towards the feet will show the LV apex. Finally, one knows that a good cross section is obtained by making sure the two papillary muscles are equal in size.



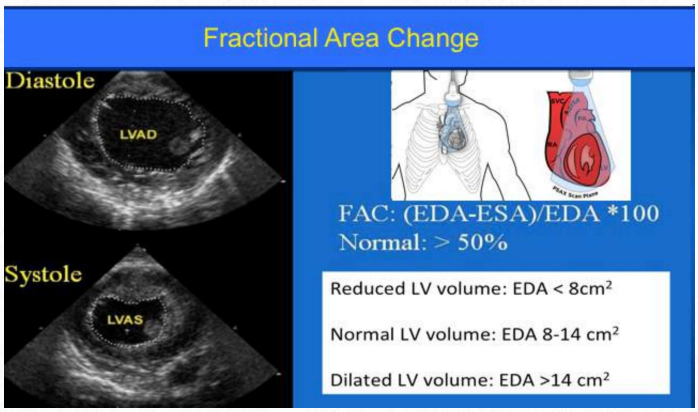




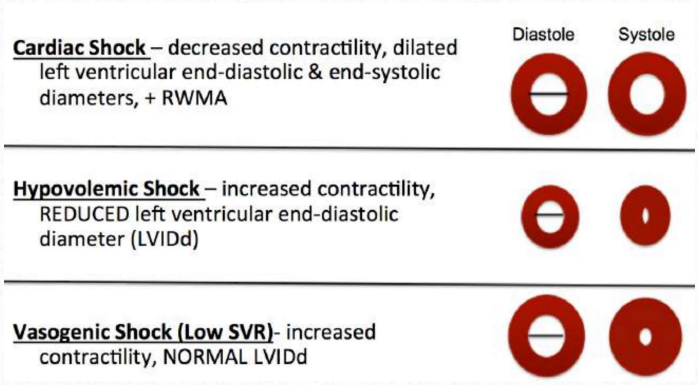
The diameter/area of the LV in end diastole relates to the filling of the left ventricle

Using the measure or caliber feature one can assess the diameter and area of the LV in end diastole in either a standard 2 –D image or an M-mode image.

LV End Diastolic Diameters under 4cm suggest reduced stroke volume



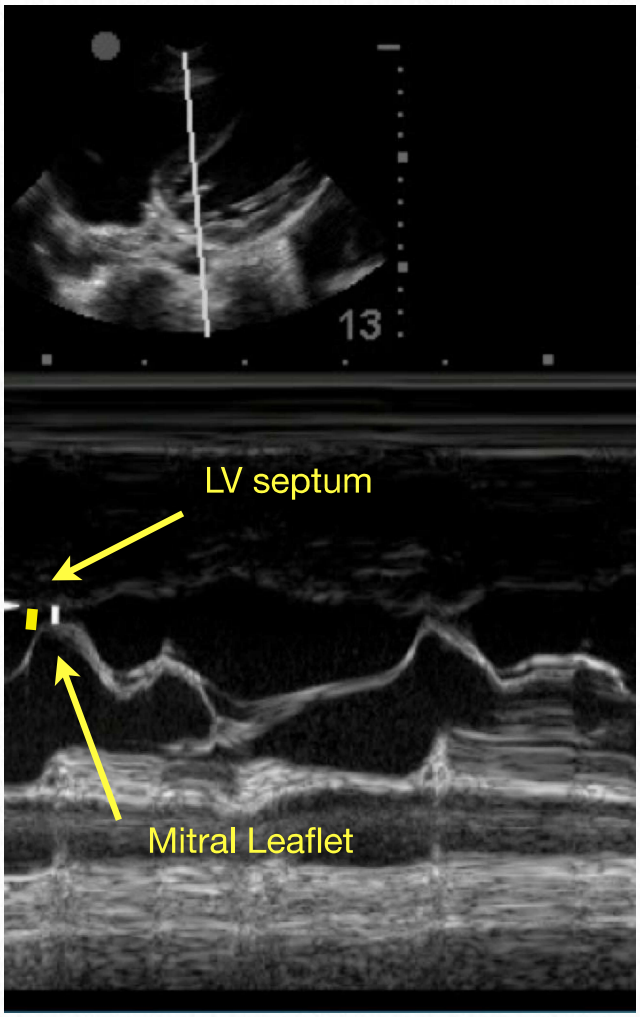
IT IS IMPORTANT TO REALIZE THAT EVEN THOUGH THIS MODALITY CAN HELP PREDICT LEFT VENTRICLE VOLUME IT DOES NOT INDICATE VOLUME RESPONSIVENESS.



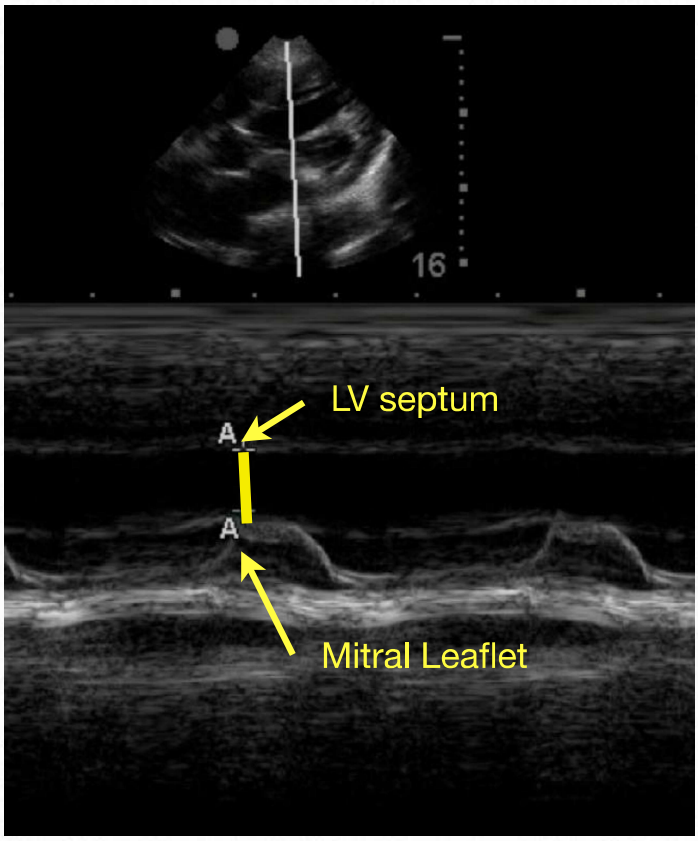
	Women				Men			
	Reference range	Mildly abnormal	Moderately abnormal	Severely abnormal	Reference range	Mildly abnormal	Moderately abnormal	Severely abnormal
LV dimension								
LV diastolic diameter	3.9–5.3	5.4–5.7	5.8–6.1	≥6.2	4.2–5.9	6.0–6.3	6.4–6.8	≥6.9
LV diastolic diameter/BSA, cm/m²	2.4–3.2	3.3–3.4	3.5–3.7	≥3.8	2.2–3.1	3.2–3.4	3.5–3.6	≥3.7
LV diastolic diameter/height, cm/m	2.5–3.2	3.3–3.4	3.5–3.6	≥3.7	2.4–3.3	3.4–3.5	3.6–3.7	≥3.8
LV volume								
LV diastolic volume, mL	56–104	105–117	118–130	≥131	67–155	156–178	179–201	≥201

E–POINT SEPTAL SEPARATION (EPSS)

EPSS is a measurement obtained using M-mode echocardiography of the heart in the parasternal long-axis (PSLA) view through the LV septum and anterior mitral valve leaflet.



Normal EPSS



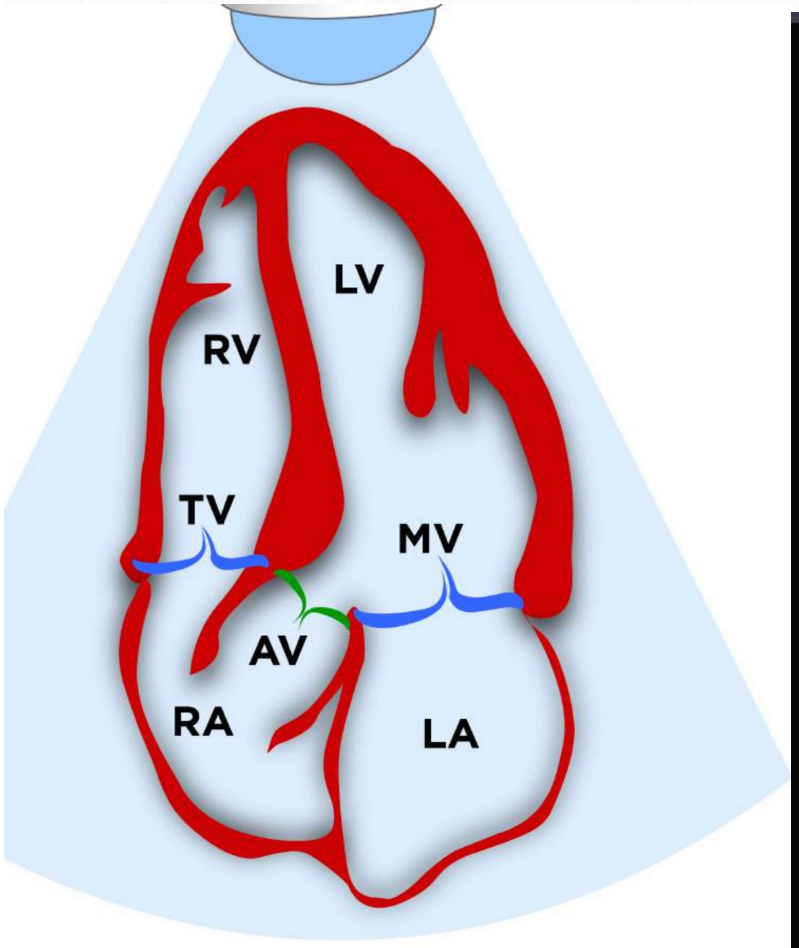
Abnormal EPSS

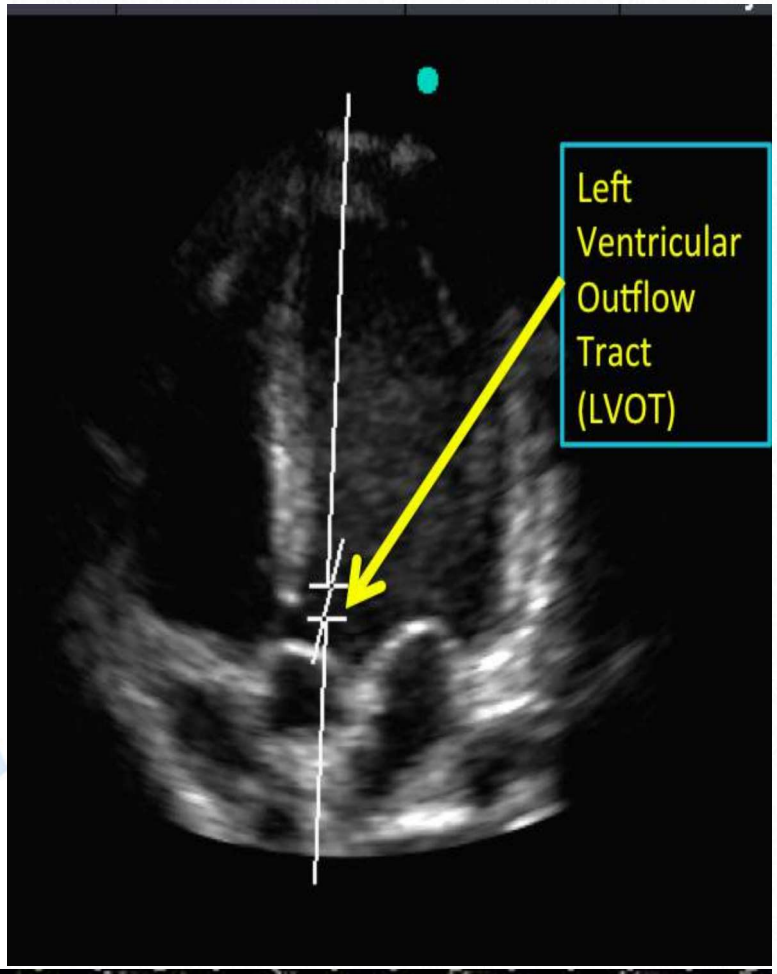
This measurement (in mm) represents the distance from the anterior septal endocardium to the maximum early opening point of the anterior mitral leaflet during early diastole and correlates with ejection fraction.

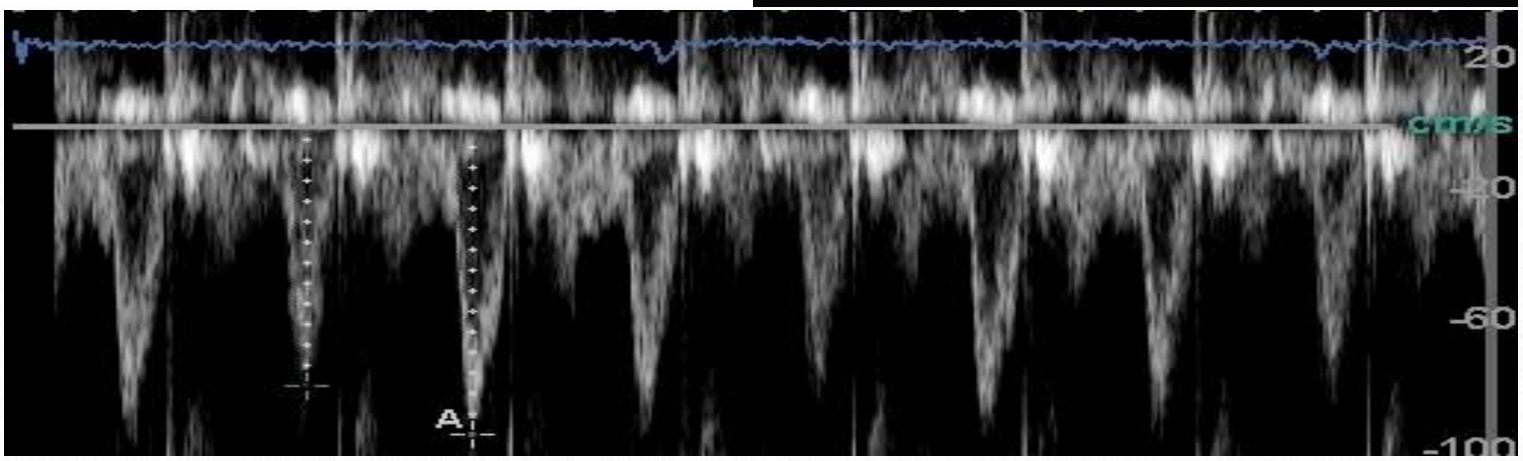
An increased EPSS is specific for decreased ejection fraction. A normal EPSS is 6 mm or less which correlates with a normal EF, between 6 mm and 12 mm correlates with a low-normal EF, and any measurement above 12 mm correlates with a low EF.

4

Volume Responsiveness via Assessment of Velocity Time Integral Variation







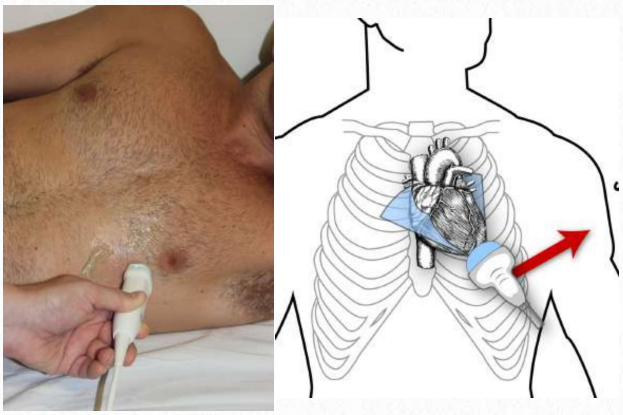
I. Volume Status: Ultrasound provides a variety of techniques to assess the patient's volume status, and, often more importantly, whether or not the patient is fluid responsive. Each subsection (below is part 3 of 4) will cover one ultrasound technique used to answer these questions.

C. RESPIRATORY VARIATION ON VELOCITY TIME INTEGRAL (VTI) OF THE LEFT VENTRICULAR OUTFLOW TRACT

Pulsatile blood flow across a cardiac valve or artery can be measured by a Doppler waveform that quantifies the velocities for each pulse. This waveform (shown below), generated by pulse waveform (PW) or continuous waveform (CW) Doppler ultrasound, is called the **velocity time integral (VTI).** In other words, VTI is the collection of velocities from red blood cells as they get ejected with each cardiac cycle, therefore representing the stroke volume generated with each cardiac cycle. Since VTI represents stroke volume one can monitor the effects of the respiratory cycle on the generation of stroke volume. This change, or *variation,* in the VTI can be used to predict volume responsiveness. Briefly, a patient who is fluid responsive will have a significant (>15%) increase in stroke volume in response to a fluid challenge. This indicates that the heart is on the steep portion of the Frank-Starling Curve. Positive Pressure Ventilation (PPV) causes negative changes in venous return, which is accentuated in hypovolemic patients. By monitoring the variation in VTI secondary to this effect of positive pressure ventilation, one can determine which patients are fluid responsive. Specifically, a variation of VTI ***greater than 12%*** suggests that one is fluid responsive.

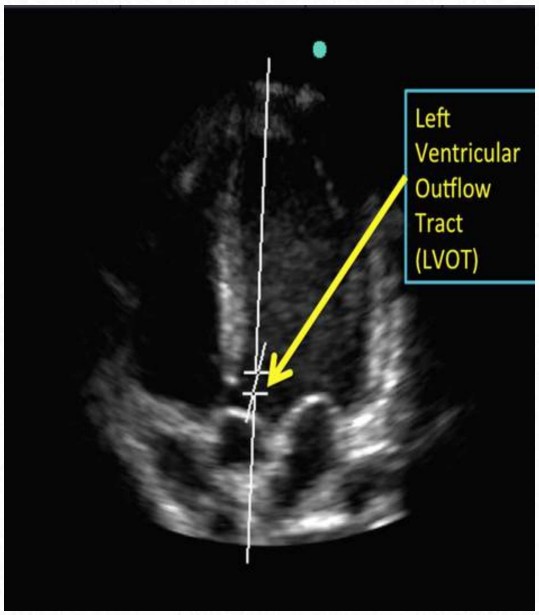
There are many locations that one can sample a VTI waveform to assess for this variation. The most validated is across the left ventricular outflow tract (LVOT). This location is relatively easy to identify and is less predisposed to pathologic diseases than other cardiac valves or locations. However, new literature also shows that one may obtain VTI waveforms with Doppler ultrasound imaging of the radial, brachial, and femoral arteries as well. The benefit of these locations is that they are technically easier to obtain.

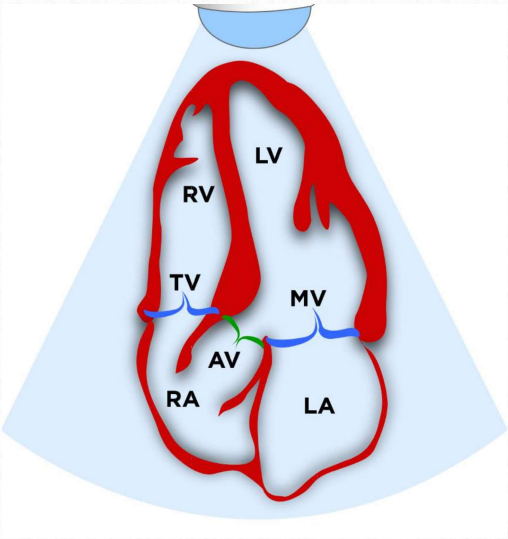
Patient Position: VTI of LVOT: Left-Lateral with L arm Extended.

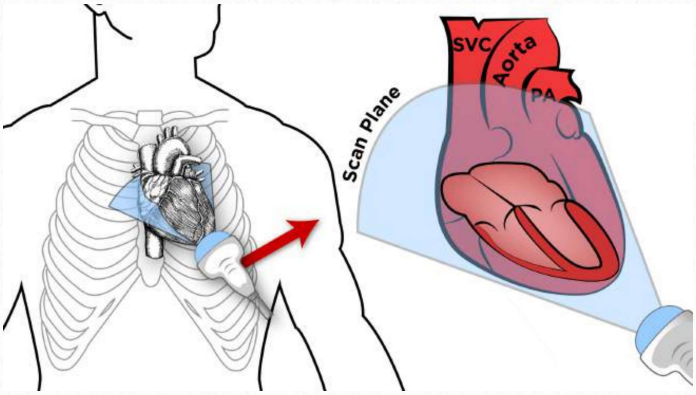


Probe Type: Phased array cardiac probe (small footprint/low frequency).

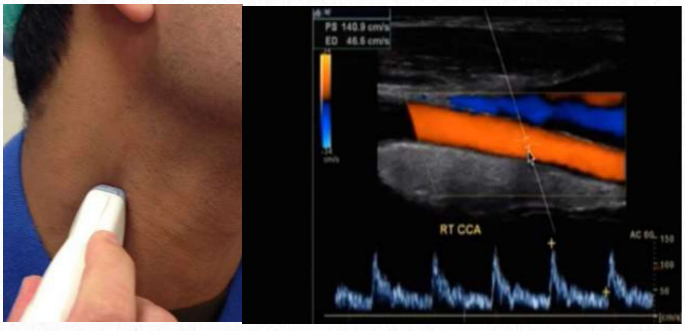
Probe Position: VTI of LVOT: Left lateral point of maximal impulse (one or two ribs spaces below the nipple), the probe is placed approximately at the 2-3 o'clock position. In the apical 5-chamber view, place a PW or CW sample volume in the middle of the LVOT just adjacent to the aortic valve. The sample cursor should not overlie the valve if one is using PW Doppler. PW Doppler provides a more precise measurement and should be used when possible. Make sure there is no valve opening artifact in front of the systolic flow waveform that is shown on PW waveform. This means that the cursor is placed over the aortic valve and needs to be moved into the LVOT by a few millimeters.







Probe Position: Arterial VTI: Ultrasound probe is placed over a major artery such that blood flow is the most **parallel** to the ultrasound plane as possible.



VTI Waveform

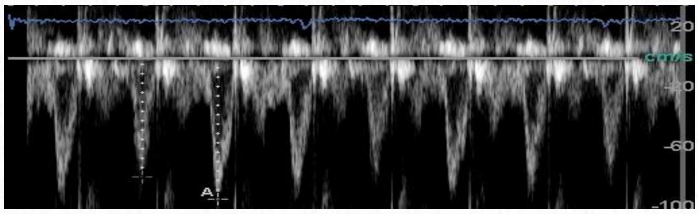


Image Quality Criteria

The apex of the left ventricle should be close to the probe with the LVOT being as close to parallel to the ultrasound plane as possible.

You should visualize the mitral and tricuspid valves fully opening and closing, as well as the atria.

Be careful not to shorten the apex of the left ventricle, which would appear round-shaped and hyperkinetic.

Troubleshooting

If the apex of the heart is tilted toward the right of the screen, you are too medial and should move or tilt your probe laterally.

If the apex of the heart is tilted toward the left of the screen, you are too lateral, and you should move or tilt your probe medially.

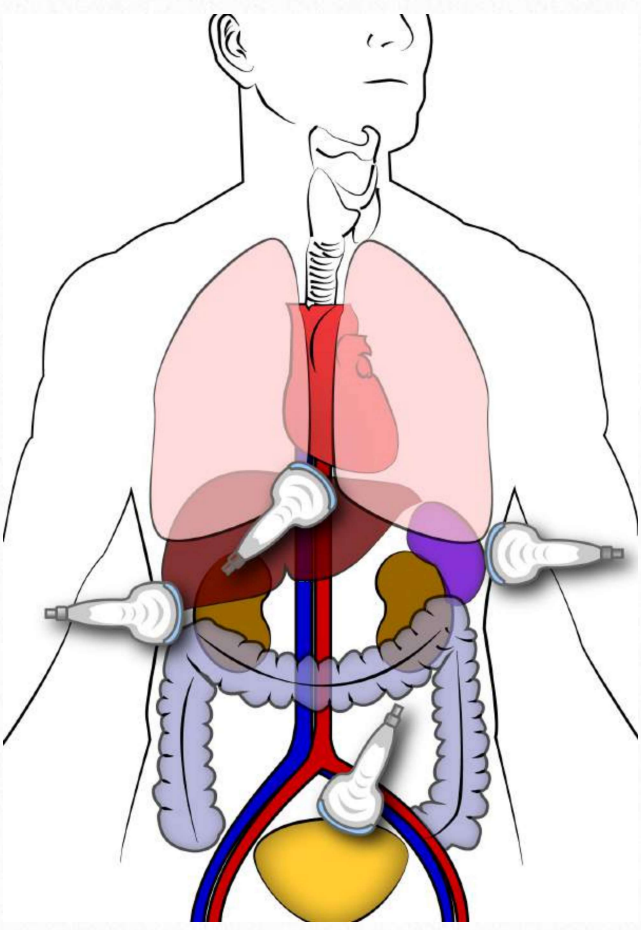
If you don't see the mitral and tricuspid valves of the atria, your probe is aimed too deep. To fix this, angle the probe more anteriorly by decreasing the angle between the probe and the skin to visualize the atria.

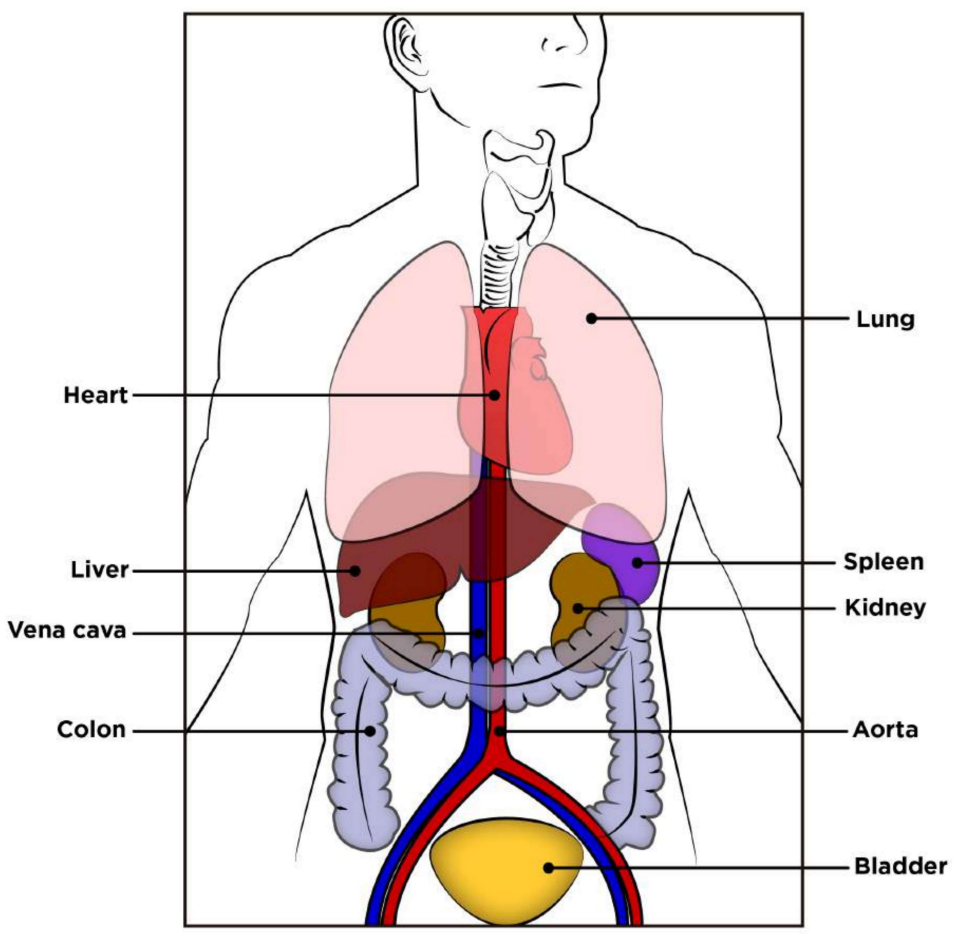
If you don't see the LV apex or if the apex is foreshortened, you are not at the apical window. Try scanning one or two intercostal spaces lower for a better view.

If you see a big and round-shaped right ventricle, you are probably too medial and too high.

5

FAST (Focused Assessment with Sonography for Trauma) Exam





I. Volume Status: Ultrasound provides a variety of techniques to assess the patient's volume status, and, often more importantly, whether or not the patient is fluid responsive. Each subsection (below is part 4 of 4) will cover one ultrasound technique used to answer these questions. This topic will address how one can assess for free fluid in the abdomen to help explain a mechanism for a patient's hypovolemia. This is the FAST (Focused Assessment with Sonography for Trauma) exam.

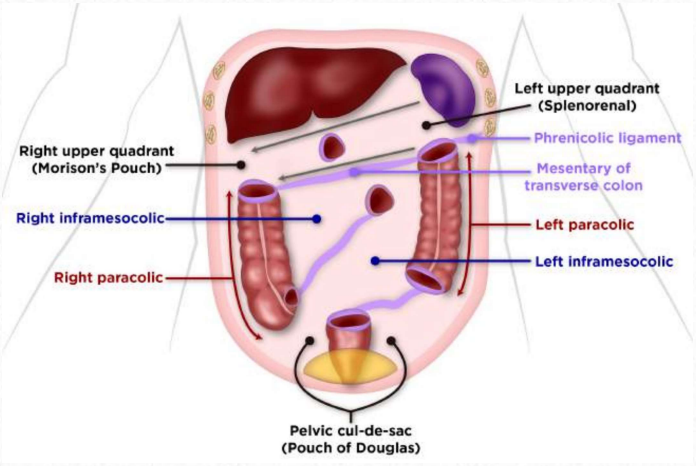
D. FAST (FOCUSED ASSESSMENT WITH SONOGRAPHY FOR TRAUMA) EXAM

Many trauma patients have injuries that are not apparent on the initial physical exam. Studies have shown that 20-40% of patients with significant abdominal injuries may initially have a normal physical examination of the abdomen. The purpose of bedside ultrasound in trauma is to rapidly identify free fluid (usually blood) in the peritoneal, retroperitoneal, pericardial, or pleural spaces. To review, the peritoneum is the serous membrane that forms the lining of the abdominal cavity and overlies most of the intra-abdominal organs. Because of this peritoneal layer, one is able to appreciate the collection of fluid between organs within the peritoneum, behind (retro-peritoneal), and below it (infra or sub-peritoneal). Peritoneal organs include: stomach, spleen, liver, pancreas (only the tail), parts of the colon, uterus, fallopian tubes, and ovaries. Retroperitoneal structures include: kidneys, IVC, aorta, and part of the colon. Infraperitoneal structures include: bladder and distal rectum.

The FAST exam has been shown to be able to very reliably detect >200ml of fluid in body cavities. Indications for the FAST exam include acute blunt or penetrating torso trauma, trauma in pregnancy, pediatric trauma (details below), and subacute torso trauma. To successfully perform the FAST exam one must have a basic understanding of hemorrhage and ultrasound. The sonographic evolvement of hemorrhage depends on time of insult. Initially, the free fluid is sonolucent (black). Clot forms in 2 to 4 hours and becomes more echogenic (more gray), and it returns to being more sonolucent (black) with fibrinolysis over 12-24 hours. On ultrasound, free fluid appears as "pointy," not circular as if it was contained in a walled organ or structure, and forms around bowel and viscera.

OF KEY IMPORTANCE is to understand that free intraperitoneal fluid tends to collect in areas formed by peritoneal reflections and mesenteric attachments (paracolic gutters). Specifically, for the upper abdomen this dependent area is called Morison's pouch. This is the collection site for abdominal injury since the paracolic gutters empty here (see picture below). This area corresponds to the interface of the liver and the R kidney. Here, blood initially develops at the tip of the liver and then progresses to separate the liver and the R kidney. Regarding LUQ injuries, free intraperitoneal fluid will tend to accumulate in the left subphrenic space first (not the splenorenal recess) due to the phrenicocolic ligaments; only on rare occasions, when large amounts of fluid are present, will free fluid occur between the spleen and the kidney. However, because of the paracolic gutters LUQ injuries will still produce a free fluid collection in R Kidney/Liver Interface (Morison's pouch). *Again, the phrenicocolic ligament restricts the flow of free fluid between the left paracolic gutter to the (LUQ, so fluid actually spreads across the midline into the RUQ.* This is why the RUQ view is the most important in the assessment of upper abdominal injuries.

For *lower abdominal* injuries the pelvic (suprapubic) view is the most useful. With this view, you are trying to exam the most dependent area of the lower abdomen in the supine patient, which is in the pelvic cul-de-sac (Pouch of Douglas). **A good rule of thumb volume of free fluid is 1 cm of hypoehoic space = 150ml**



Each of the four views will be discussed specifically below.

Probes Used for FAST Exam:

Curved Linear 

Phased Array 

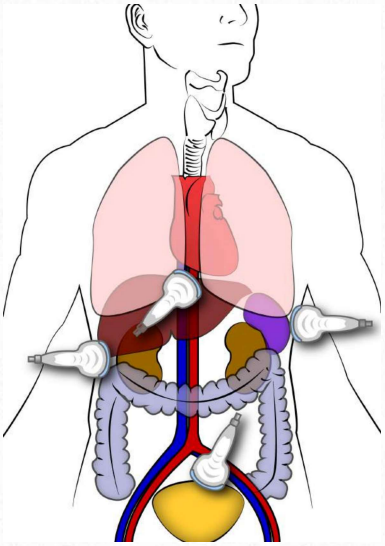
Standard FAST EXAM Views:

Pericardial

Perihepatic (RUQ)

Perisplenic (LUQ)

Pelvic (Suprapubic)

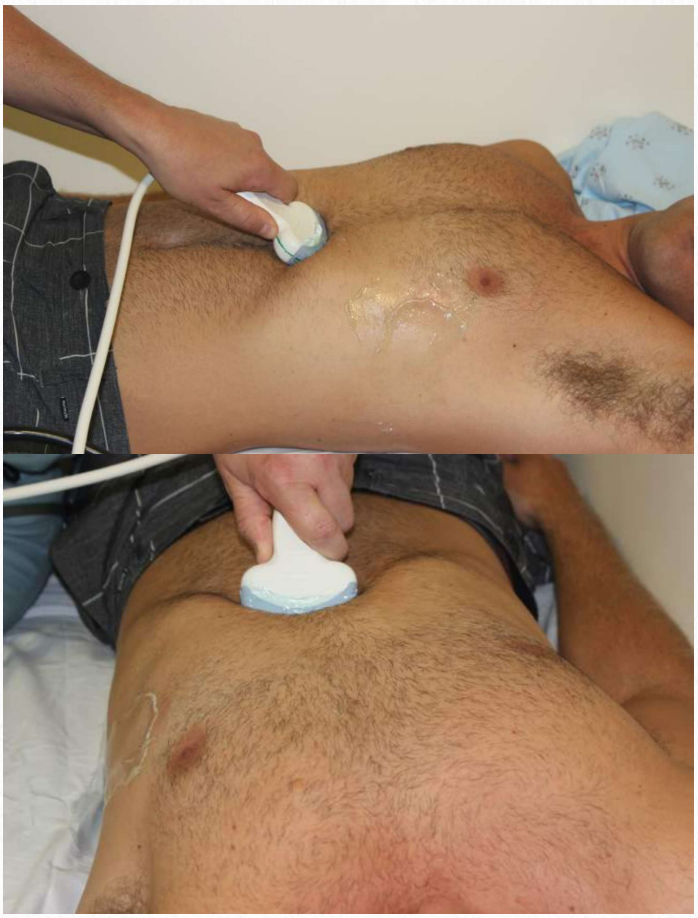


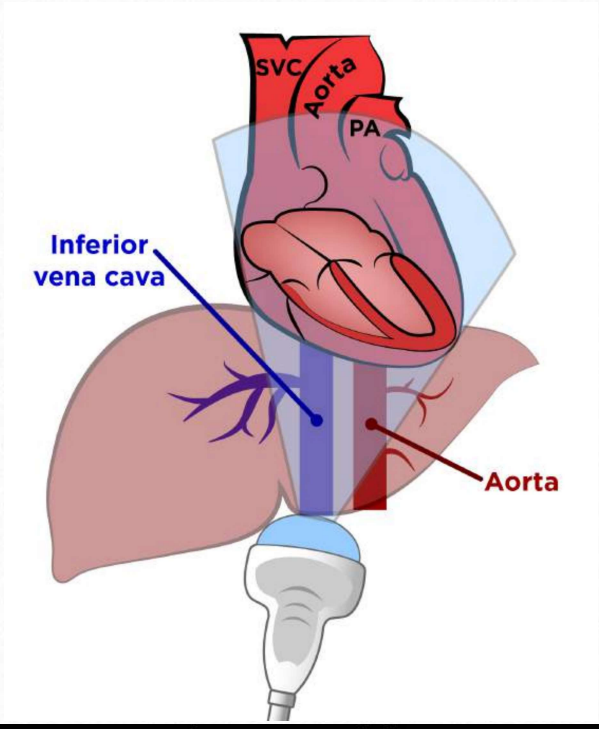
FAST EXAM VIEWS

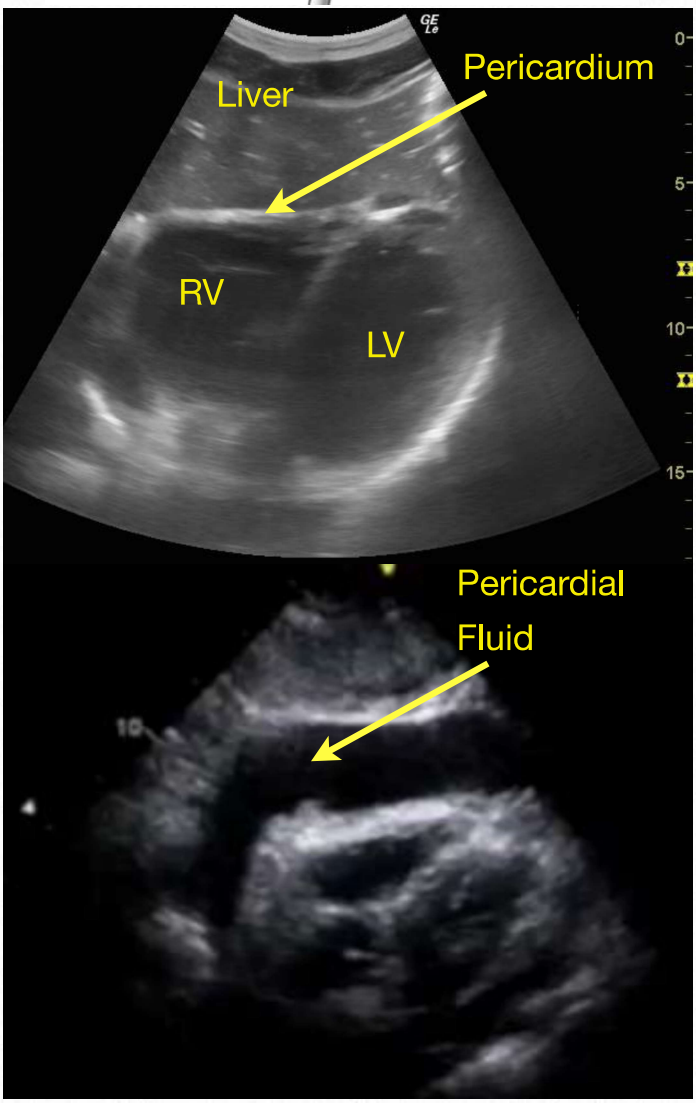
1. Pericardial View: This view is used to look at the interface between the right ventricle and the liver to identify pericardial fluid; the goal for this portion of the FAST exam is the identification of cardiac tamponade. Please note that a small (less than 0.3 cm) collection of fluid may be normal. Normal pericardium is seen as a hyperechoic (white) line surrounding the heart. Also, please note that if a pericardial or subxiphoid view is not obtainable one can assess for tamponade in the parasternal long axis and short axis views (to be discussed in the cardiac section). Scans may be limited secondary to obesity, protuberant abdomen, abdominal tenderness, gas, as well as pneumoperitoneum/pneumothoraces.

Patient Position: Supine with knees/hips flexed in to decrease tension on the subxiphoid space.

Probe Position: Probe (either phased array or curved linear) in the subxiphoid area and angled toward the patient's left shoulder, with the pointer at 3 o'clock position. To visualize the heart, the transducer should be almost parallel to the skin of the torso. Also, to view the heart you may need to press firmly just inferior to the xiphoid. You may need to move the transducer further to the patient's right in order to use the liver as an acoustic window. The image may be optimized by asking the patient to take a breath in and "hold it". This causes the diaphragm to flatten and decreases the depth of penetration required to produce the image.



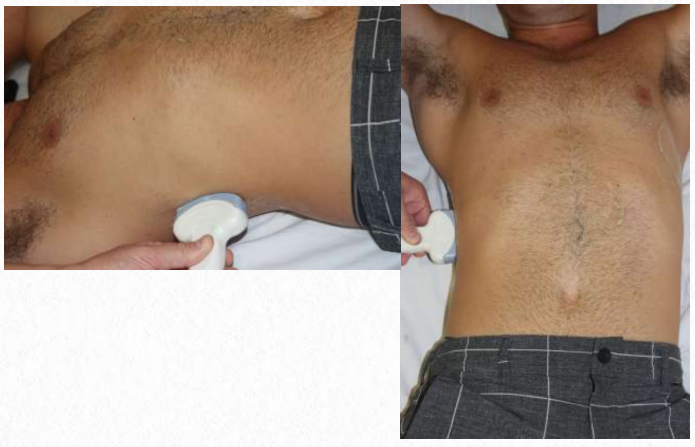


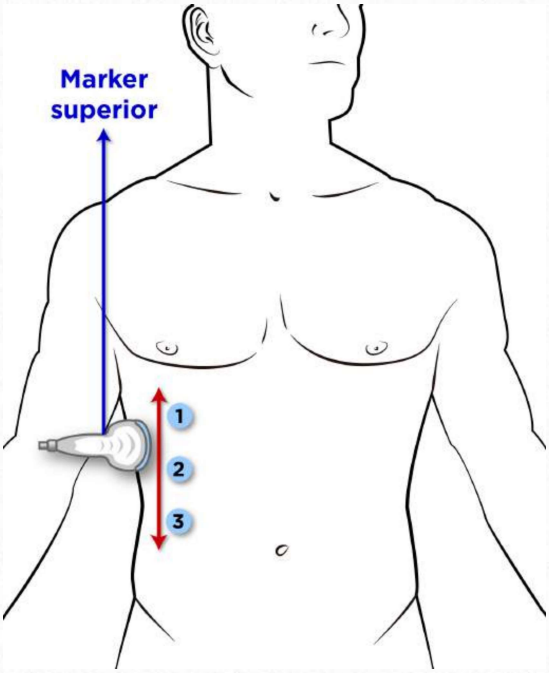


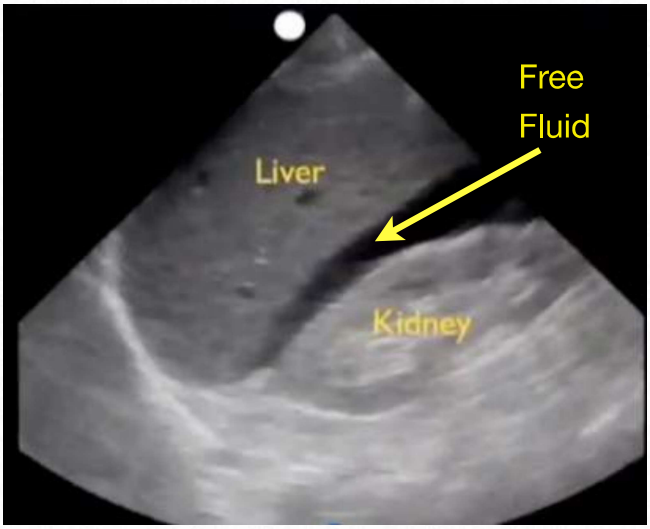
2. Perihepatic (RUQ) View: As stated above, this view is the most important view of the FAST exam pertaining to the assessment of abdominal injury secondary to the way free fluid drains in the abdomen. Here, we are evaluating Morison's pouch, which is the *potential space* between the liver and the right kidney. In this location there are 4 areas that you want to evaluate for "free fluid": 1) Pleural Space, 2) Infradiaphragmatic space, 3) Hepatorenal Interface (Morison's Pouch), and 4) Caudal Liver Tip.

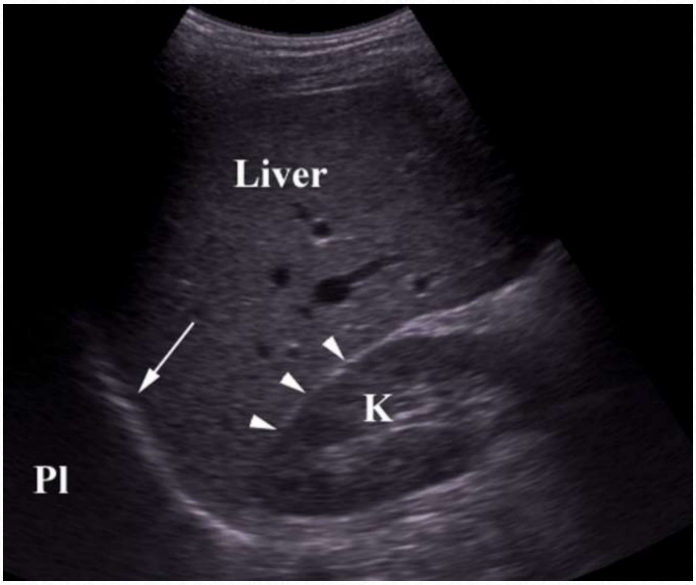
Patient Position: Supine, if possible, tilting the patient slightly toward their left side may make sonography easier.

Probe Position: Probe (either phased array or curved linear) should be placed with the indicator pointing around the 10 to 12 o'clock position perpendicular to last true rib (right costal margin) at the right midclavicular line, then sliding down to the midaxillary line. **Final probe position should be mix-axillary line - 10th rib space.** One should then move the probe inferiorly to the to liver/kidney interface (Morison's pouch). Following this movement pattern one rib space above and below will allow you to see the infra-diaphragmatic space and caudal liver tip, respectively. The liver appears homogenous, with medium-level echogenicity, and the kidneys have a brightly echogenic surface with hypoechoic core.

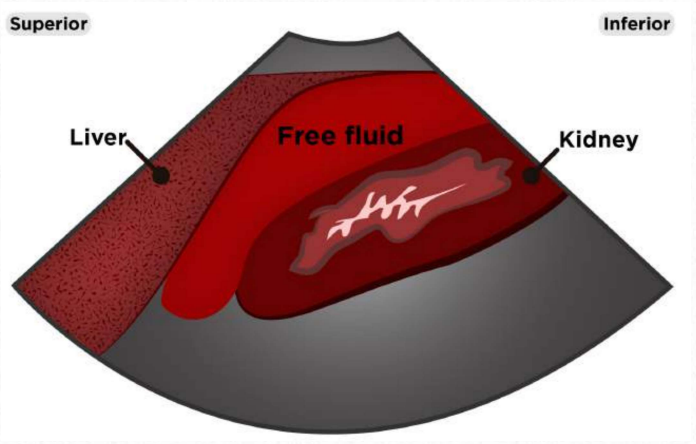






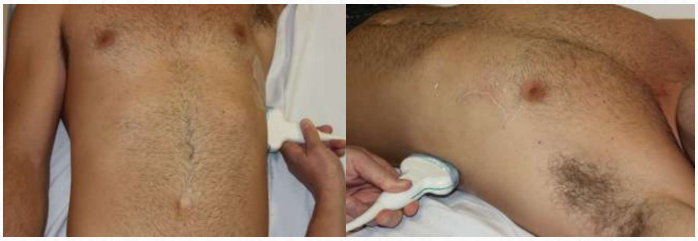


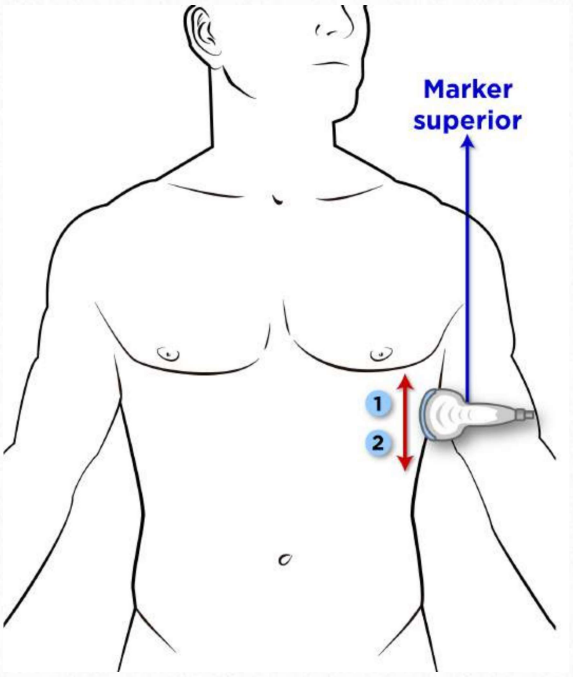
3. Perisplenic (LUQ) View: This view can be the most challenging to obtain in the FAST exam. As stated. with LUQ injuries free intraperitoneal fluid will tend to accumulate in the **left subphrenic space first (not the splenorenal recess)** due to the phrenicocolic ligaments; only on rare occasions, when large amounts of fluid are present, will free fluid occur between the spleen and the kidney. Also, the phrenicocolic ligament restricts the flow of free fluid from the left paracolic gutter to the LUQ, so fluid actually spreads across the midline into the RUQ. This is why the RUQ view is the most important in the assessment of upper abdominal injuries. Regarding LUQ ,there are 4 areas that you want to evaluate for "free fluid": 1) Pleural Space, 2) Infra-diaphragmatic space, 3) Splenorenal recess, and
4) Inferior pole of the kidney/paracolic gutter.

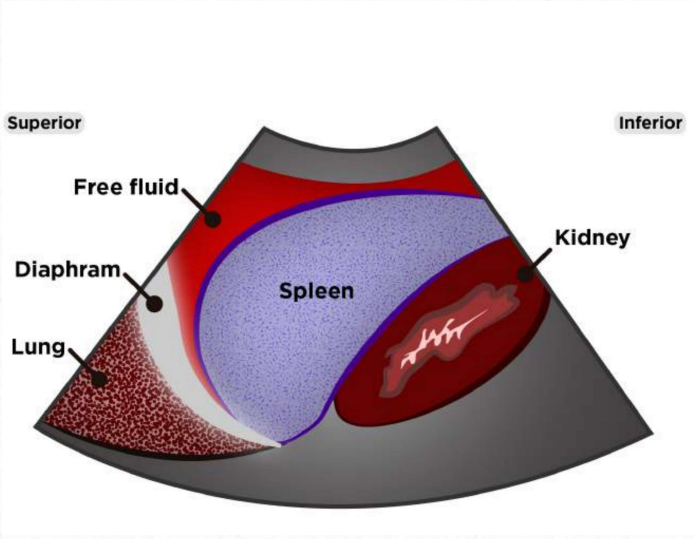


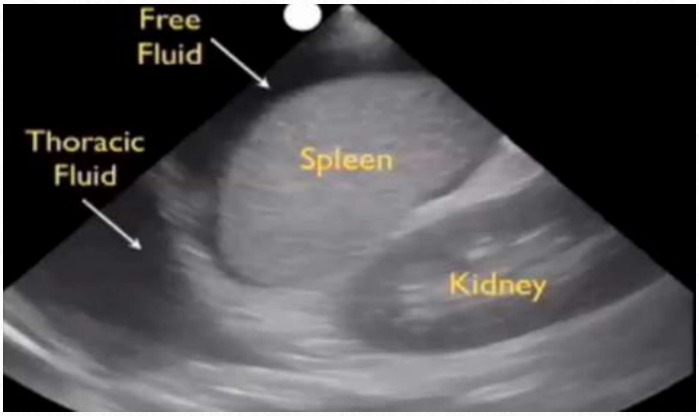
Patient Position: Supine, if possible, tilting the patient slightly to their right side may make sonography easier.

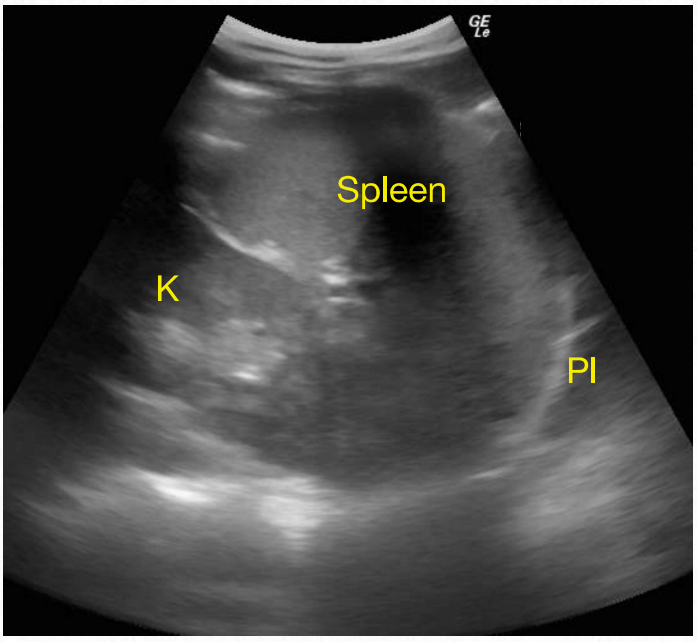
Probe Position: Probe (either phased array or curved linear) should be placed with the indicator pointing around the 12 to 2 o'clock position perpendicular to ribs at the **posterior axillary line - 8th rib space** (always angle probe *with the ribs)*. One should then move the probe posteriorly to the spleen/kidney interface at the posterior axillary line. Once the interface is obtained scan one rib space above and below; **remember that the spleen sits a little more posterior and superior than the liver.** If unable to visualize spleen/kidney one usually needs to aim the probe more posterior (your hand should be on the bed). The spleen is much more homogenous on US then the kidney and it contains a echogenic (bright) capsule.











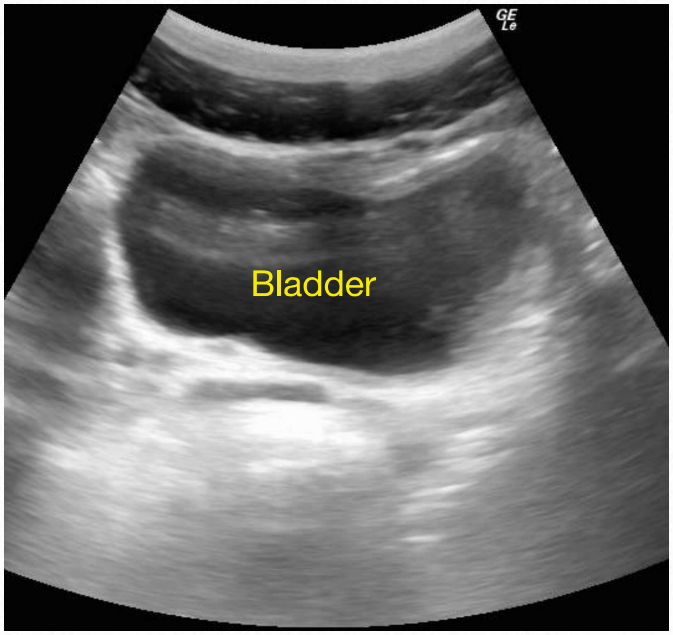
4. Pelvic (Suprapubic) View: This view is used to assess for free fluid in lower abdomen by scanning the most dependent area of the abdomen, which is the area around the bladder (Pouch of Douglas). Because this is the most dependent area, this view can detect the least amount of fluid. However, note that RUQ is still the most sensitive given the system of paracolic gutters and the ease of identification. It is very important to scan this view in both the long and short axis (see below) to assess the entire Pouch of Douglas. In addition to the assessment of free fluid, one can use these views to determine bladder volume by the following equation: 0.7 x (supero-inferior diameter) x TS (maximum transverse diameter) x AP (maximum anteroposterior diameter).

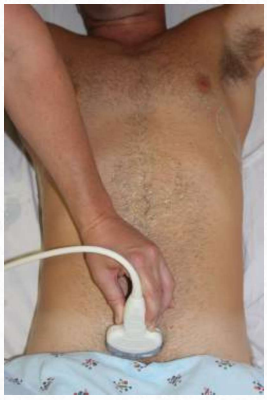
There are many findings that can cause one to inaccurately diagnose free pelvic fluid, making this view difficult. For example, fluid within a collapsed empty bladder or an ovarian cyst may look like free fluid. Also, premenopausal females **may normally** have a small amount of free fluid in this area. To best identify free fluid, one needs a full bladder (which may be difficult with a trauma patient). Regarding free fluid

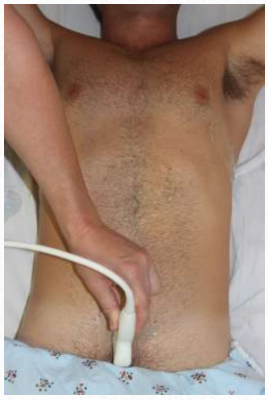
development, the first sign of blood is often two small black triangles on either side of the rectum, the “bow tie sign,” which then connect below the bladder.

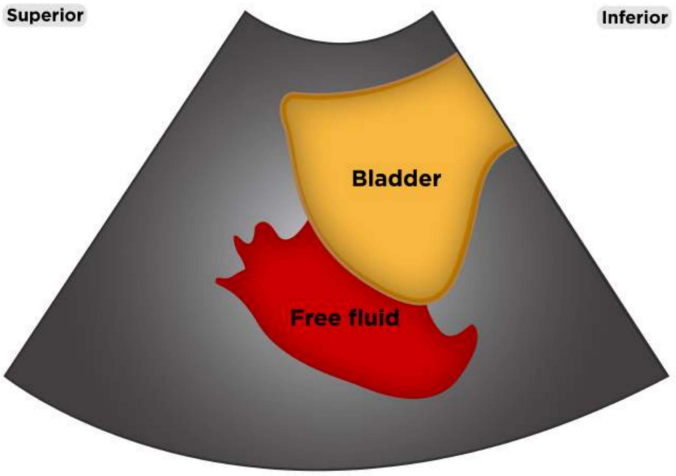
Patient Position: Supine

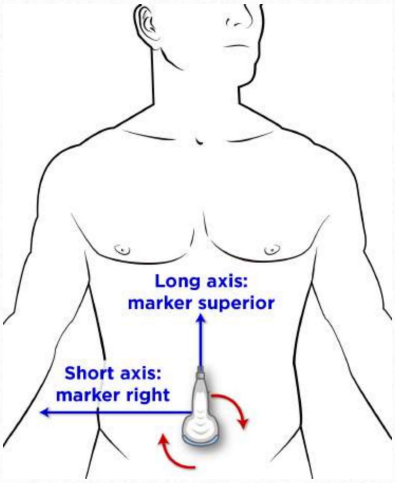
Probe Position: Probe (either phased array or curved linear) should be placed 2cm superior to the symphysis pubis along the midline of the abdomen. At this position one should sweep the bladder by obtaining both short and long axis views (see below). In the longitudinal plane, one should scan side to side to identify pockets of free fluid between bowel loops.

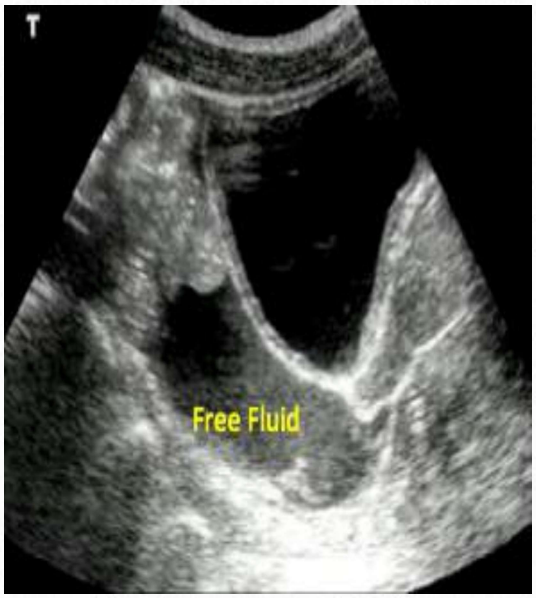


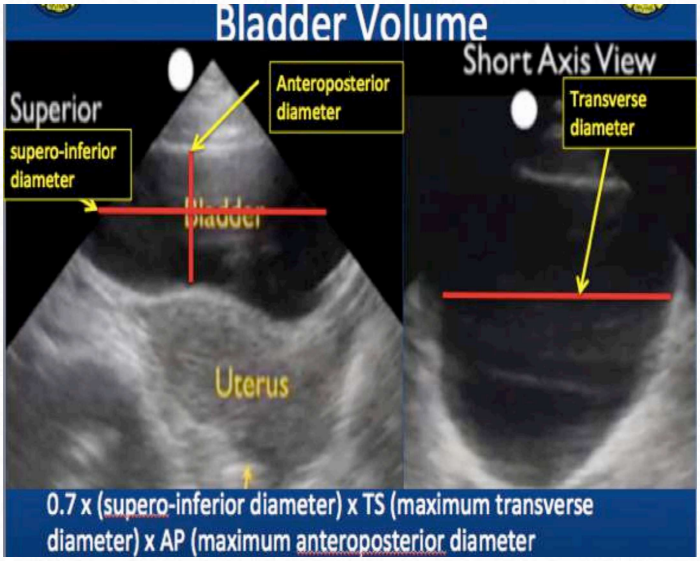






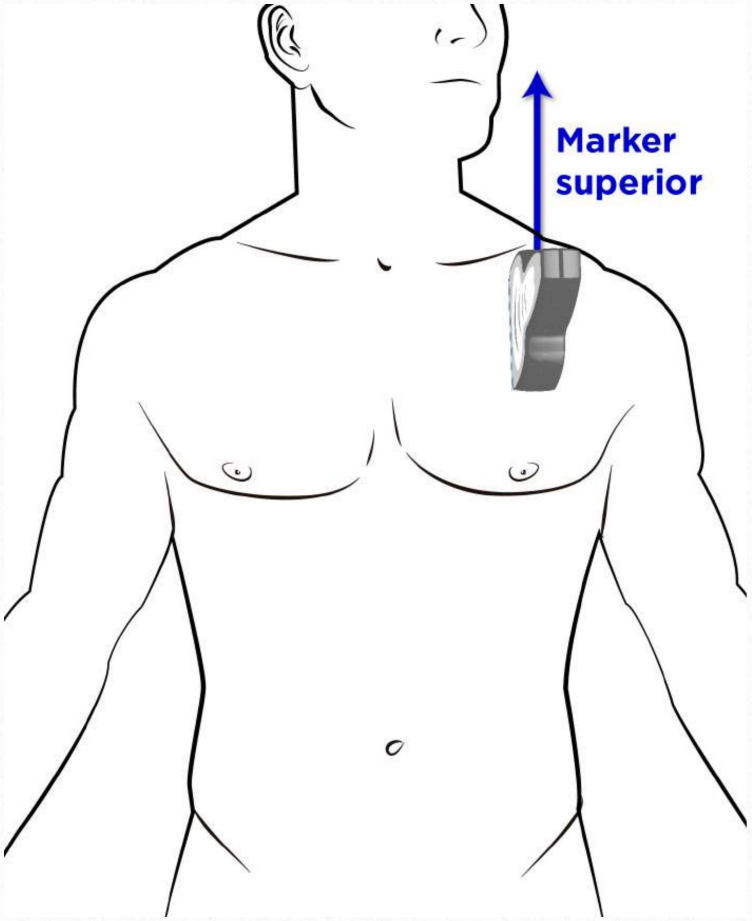


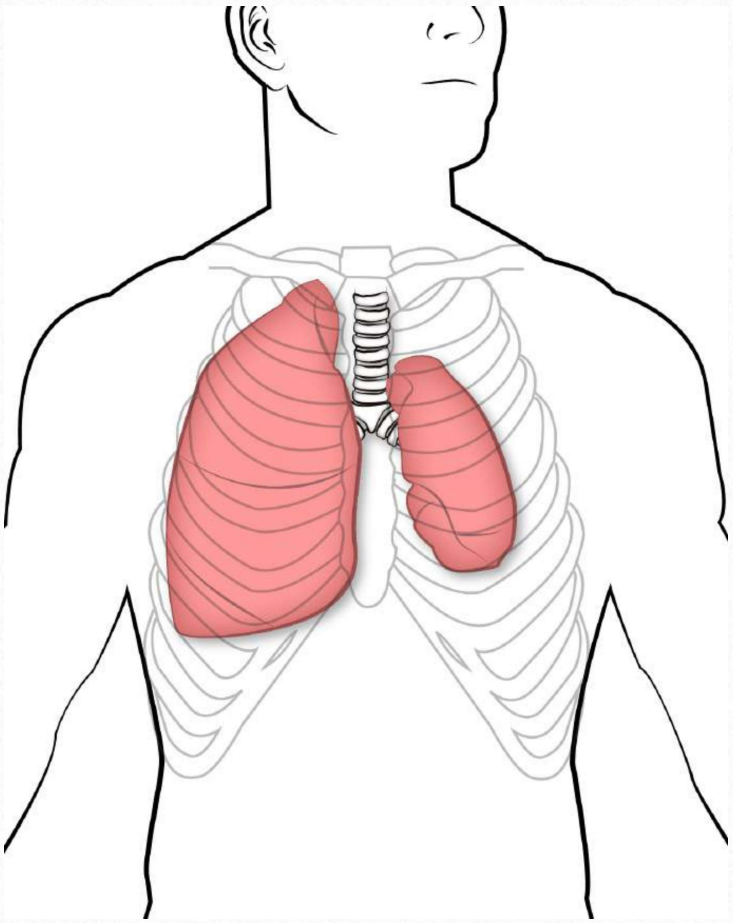



Bladder Volume
Short Axis View
Superior
Anteroposterior diameter
supero-inferior diameter
Transverse diameter
Uterus
0.7 x (supero-inferior diameter) x TS (maximum transverse diameter) x AP (maximum anteroposterior diameter

6

Pulmonary Ultrasound for Pneumothorax Evaluation

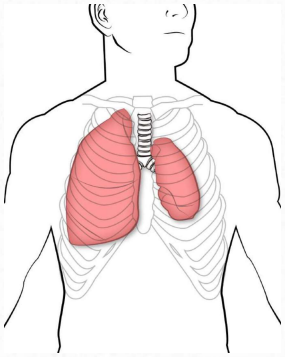




II. Pulmonary US: Ultrasound provides a rapid method of assessing patient's pulmonary status. Ultrasonography has been shown to be more accurate than auscultation or chest radiography for the detection of pleural effusion, consolidation, and pneumothorax in the critical care setting. The indications for lung ultrasound include: 1) detection of a pneumothorax, 2) detection of pleural fluid, and 3) detection of pulmonary parenchymal disease (PN, pulmonary edema, atelectasis, ARDS).

ULTRASOUND FOR EVALUATION OF PNEUMOTHORAX

Assessment of pneumothorax via ultrasound is essentially done by observing the normal motion of the visceral pleura (over the lungs) interfacing or "sliding" with the parietal pleura (see picture below). When a pneumothorax occurs, the air between the visceral and parietal pleura will scatter the transmitted sound, thus disrupting its return to the transducer. This results in a fixed, "motionless" parietal pleura on the ultrasound screen. Realize that this occurs because of the air, so the lung may be still be ventilatable, but the air will prevent one from seeing the "sliding" of the lung being ventilated. This is why ultrasound is more sensitive than a chest x-ray. Also, because the pleural line is usually centimeters below the chest wall, a high-frequency (5.0–10.0 MHz) linear probe provides the most detailed image of the pleural line. However, any transducer can be used, realizing that with the lower frequency probes your image quality will be poorer.



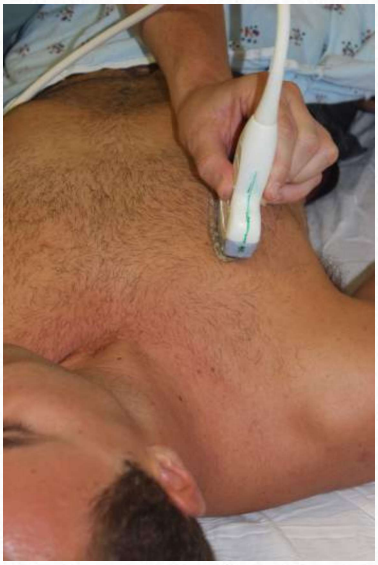
Once the pleural line is identified, there are two critical findings, **lung sliding** and **comet tail artifacts**, that essentially guarantee that the visceral and parietal pleura are opposed, thus ruling out pneumothorax in that space. **Comet tails** are linear reverberation artifacts that originate at the pleural line and are caused by the bouncing back and forth of sound between the dense fibrous tissue of the visceral and parietal pleura "together". This "comet tail" reverberation artifact is only possible if the pleural layers are in opposition and there is no air between them (ie. pneumothorax) scattering the sound and preventing this phenomenon. Therefore, the *presence of* B lines suggested *against* the possibility of a pneumothorax. *It is important to note that the comet tails also represent a differentiation of density of the lung parenchyma and this fact is used to identify and quanitfy air-space disease.* This is discussed further in the next chapter. **Lung sliding** is the visualization of the shimmering, sliding motion of the visceral and parietal pleura with respiration. This is caused by the expansion and contraction of the chest wall with breathing. Again, this motion alteration of the pleural line and sliding can only be visualized when the two pleural layers are in opposition. Air between the visceral and parietal pleura will scatter the transmitted sound, thus disrupting its return to the transducer and ensuring only the fixed parietal pleura will be seen.

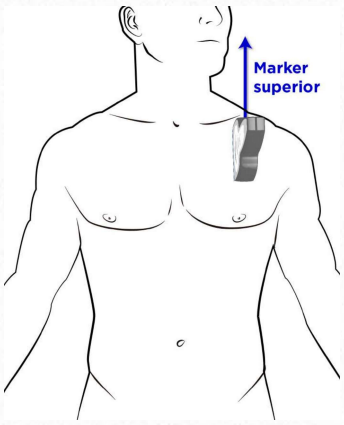
M-mode is the motion mode displaying moving structures along a single line in the ultrasound beam. M-mode imaging can show diagnostic findings for PTX in a still image representation. The "barcode" sign is seen with a lack of lung sliding and indicates air in the pleural space so the fixed chest wall musculature *looks similar* to the lung pleura (they are *both static*). Whereas, the "seashore" sign depicts normal pleural sliding by showing the closely opposed visceral and parietal motion with respiration (static chest wall with distorted or sanding picture of lung pleura motion).

One finding on pulmonary ultrasound that is thought to be almost universally specific for pneumothorax is called the **"lung point sign."** This sign occurs at the point where the partial PTX has started to separate the pleura and reattachment or detachment of the pleura is visible. This results in the screen showing half of the image having lung sliding and comet tails, while the other half of the image shows lack of lung sliding or a fixed parietal pleura with no comet tails. This lung point can be followed around the chest wall to get a sense of how large the pneumothorax is. Finally, the **"lung pulse"**, or visualization of the pleural line "beating" with the underlying heart rate, is a marker of opposed visceral and parietal pleura, because transmitted heart pulsations can only be seen if there is no pneumothorax or air separating the pleural layers.

It is important to note that patients with absence of lung sliding secondary to a pneumothorax should also not demonstrate findings of the ultrasound wavelength penetrating into

the lung parenchyma (because the air interface should cause reflection). Therefore signs of the ultrasound penetrating into the lung tissue, such as the presence of B lines (see next chapter), suggest that there is NOT pneumothorax. To summarize, absence of lung sliding with B lines suggests against a pneumothorax. It is important to note that the lack of sliding alone is not sufficient to make a diagnosis of pneumothorax. This can be secondary to: apnea, bronchial intubation/obstruction, pleural adhesion, and large infiltrates.

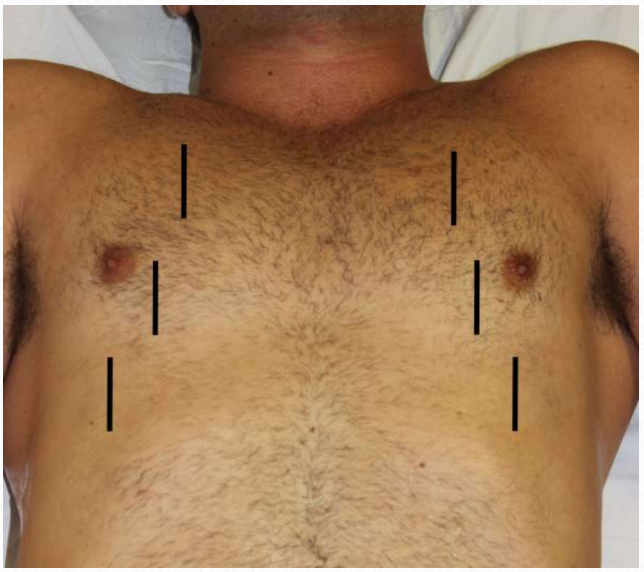




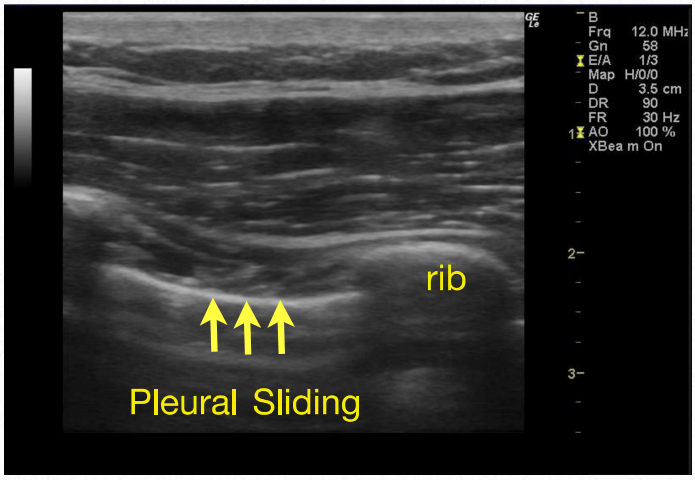
Patient Position: Supine usually and then one would scan the most anterior segments of the chest. If the patient is in another position, realize that one should scan the most the most anterior areas (where one would think air would go). The transducer is placed on the chest wall, starting in the third or fourth intercostal space in the midclavicular line in a supine patient or the second intercostal space in an upright patient (see below), and the rib shadows are visualized with the pleural line identified just deep to the rib shadow. It is important to identify the rib in cross section initially, because patients with deep chest walls can have intercostal fat or pectoralis muscle fascia that can mimic the pleural line. Once the pleural line is identified, there are two critical findings, lung sliding and comet tail artifacts (discussed above), that essentially guarantee that the visceral and parietal pleura are opposed just underneath the probe footprint, thus ruling out pneumothorax in that space.

Probe Position: Probe (linear is best) is placed on the anterior chest wall along the midclavicular line and then followed along the pleural line (see below). The indicator should be at the 12 o'clock position, perpendicular to the ribs. The transducer is oriented to scan between the ribs, as ribs block the transmission of ultrasound. Ideally one should have two ribs in view, one on each of the lateral sides of the ultrasound image. One should move the transducer longitudinally along the pleural line scanning the anterior segments in 3 sections for both sides (total of 6 locations, see picture below). These six regions, delineated by the anterior and posterior axillary lines, should be systematically examined: upper and lower parts of the anterior, lateral, and posterior chest wall.

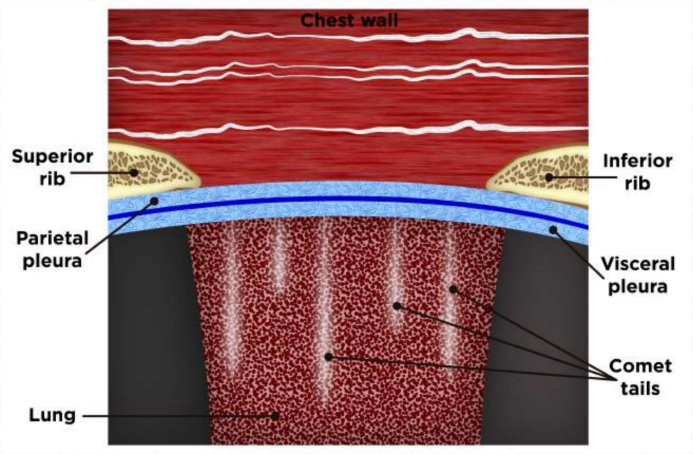
Lung Pleura Examination Windows: Always remember PTX will form at the highest (most anterior) point in the chest.

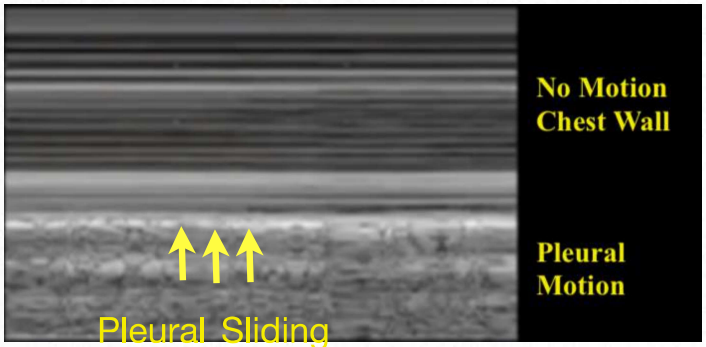


Normal Exam

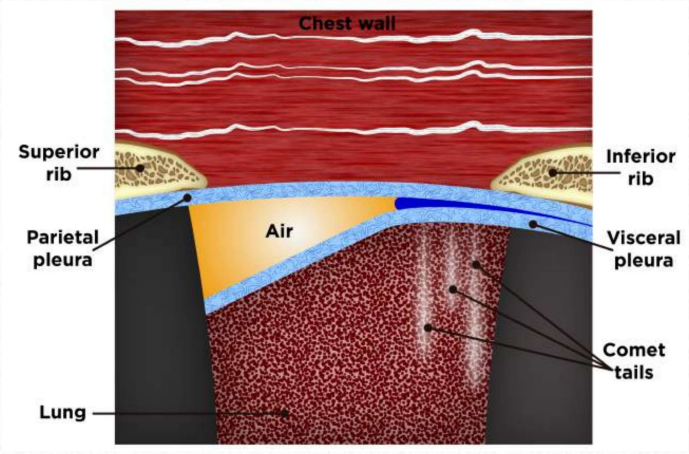


Normal PI

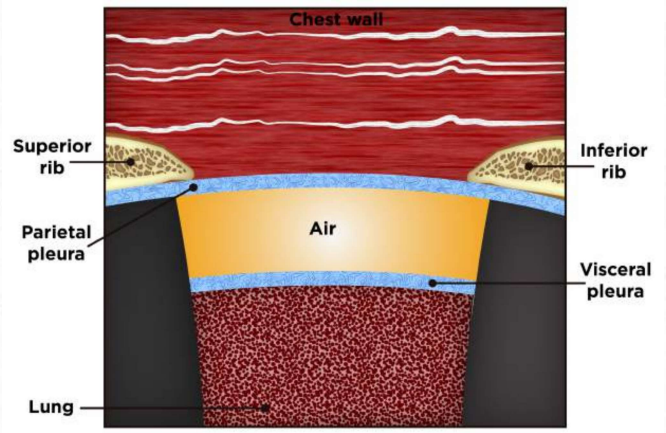


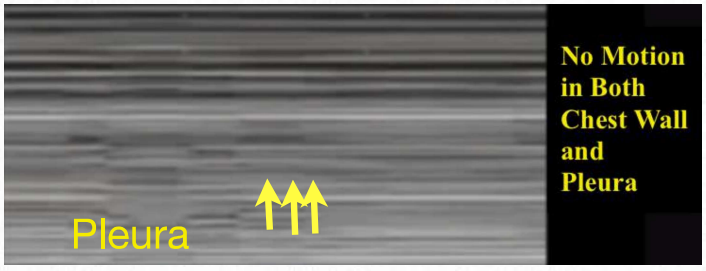


Lung Point



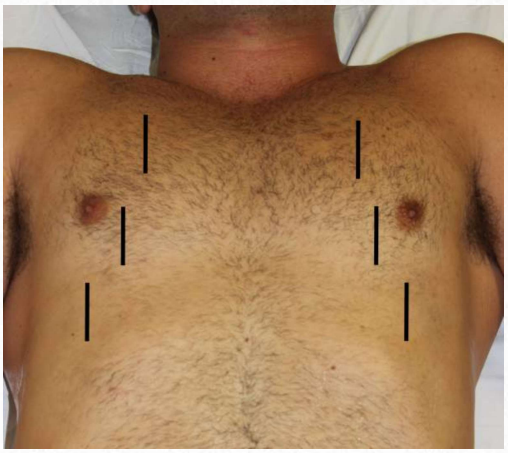
Findings of a Pneumothorax

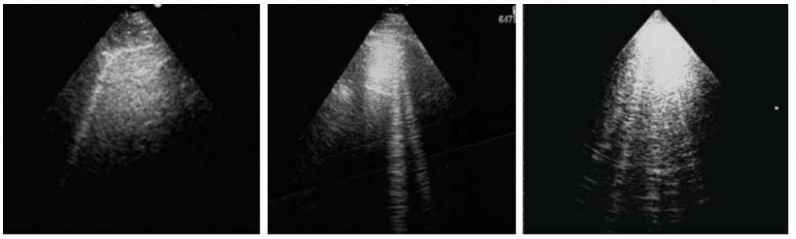


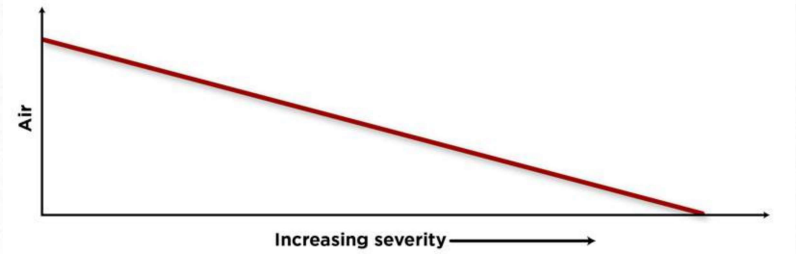


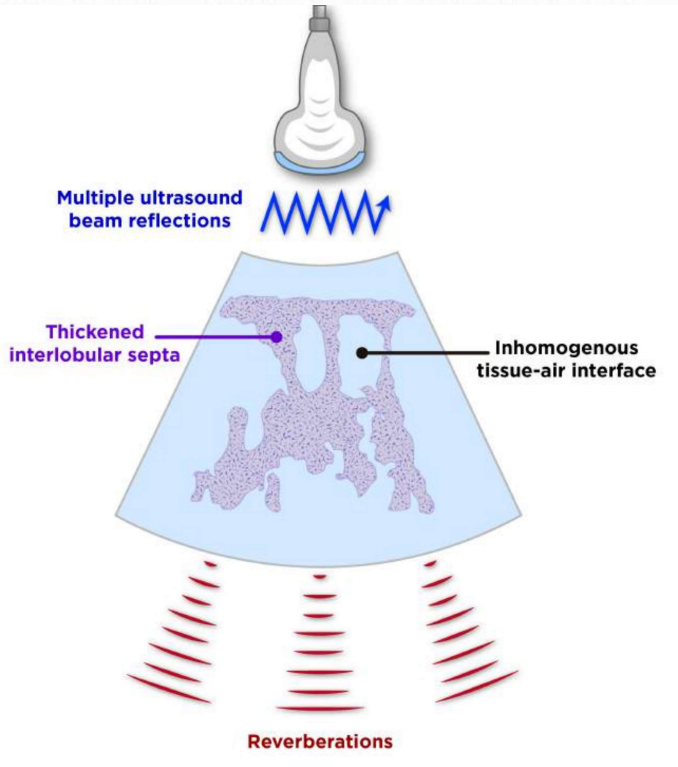
7

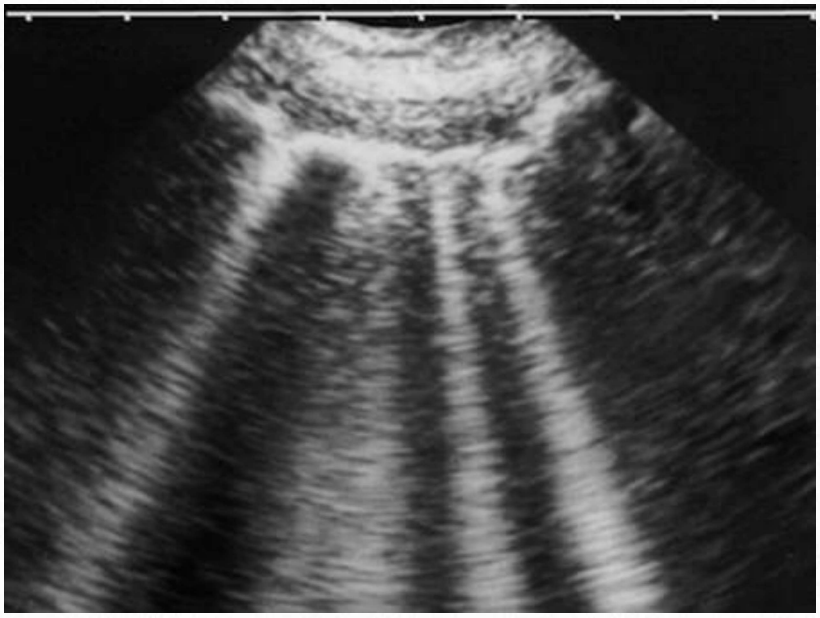
Pulmonary Ultrasound of Lung Parenchyma











II. Pulmonary US: Ultrasound provides a rapid method of assessing a patient's pulmonary status. Ultrasonography has been shown to be more accurate than auscultation or chest radiography for the detection of pleural effusion, consolidation, and pneumothorax in the critical care setting. The indications for lung ultrasound include: 1) detection of a pneumothorax, 2) detection of pleural fluid, and 3) detection of pulmonary parenchymal disease (PN, pulmonary edema, atelectasis, ARDS).

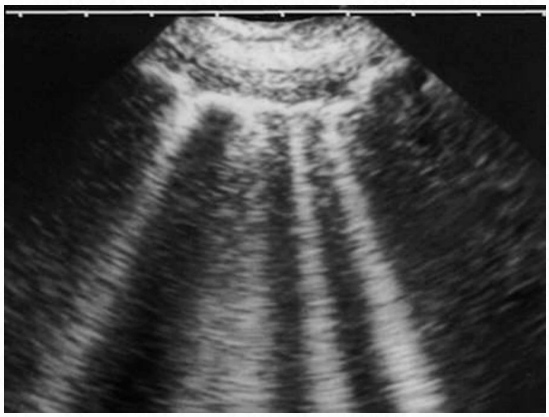
ULTRASOUND FOR EVALUATION OF LUNG PARENCHYMA DISEASE

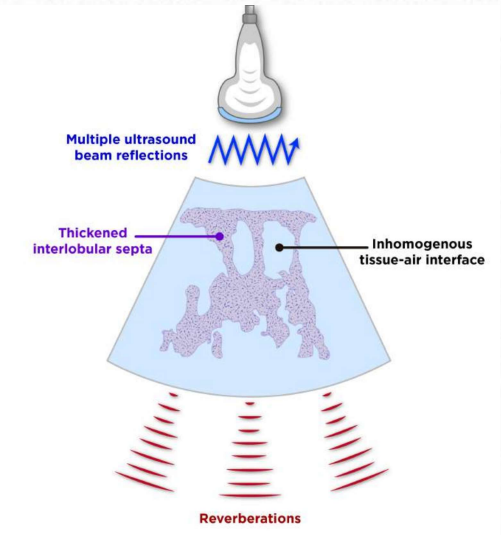
Until recently, it was thought that ultrasound of the lung tissue would be ineffective because the air in the lung parenchyma would cause too much acoustic impedance difference, resulting in essentially a black ultrasound image. However, this has been shown to not be the case; lung tissue has shown to produce distinct ultrasound image signatures for normal and abnormal aeration. Specifically, when the air content decreases (as in pulmonary edema or any interstitial lung disease) an acoustic mismatch needed to reflect the ultrasound beam is created, and a signature ultrasound finding appears (B lines). This reflection of the beam creates some comet-tail reverberation artifacts, called B-lines or ultrasound lung comets. A B-line is a discrete, laser-like, *vertical*, hyperechoic image that arises from the pleural line, extending to the bottom of the screen without fading, and moves synchronously with respiration. Multiple B-lines (>2) are the sonographic sign of lung interstitial syndrome, and their number increases along with decreasing air content. When the air content is further decreased, such as in lung consolidations, the acoustic window on the lung becomes completely open and the lung may be directly visualized as a solid parenchyma, as the liver or the spleen.

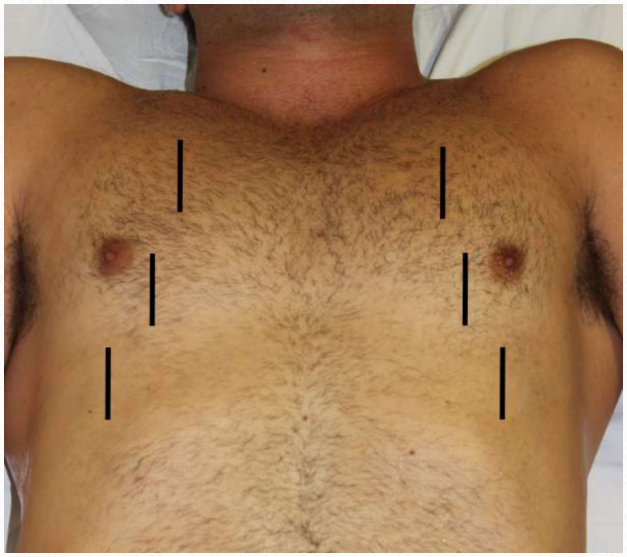
It has been reported that one can assess the space between B lines to help determine further detail about the pathology of the air-space disease. Specifically, multiple B-lines that are 7mm apart are likely to represent interstitial edema vs B-lines 3mm or less apart are caused by ground glass areas characterizing alveolar edema. In either case, the number and intensity of B-lines increases with the degree of loss of aeration.

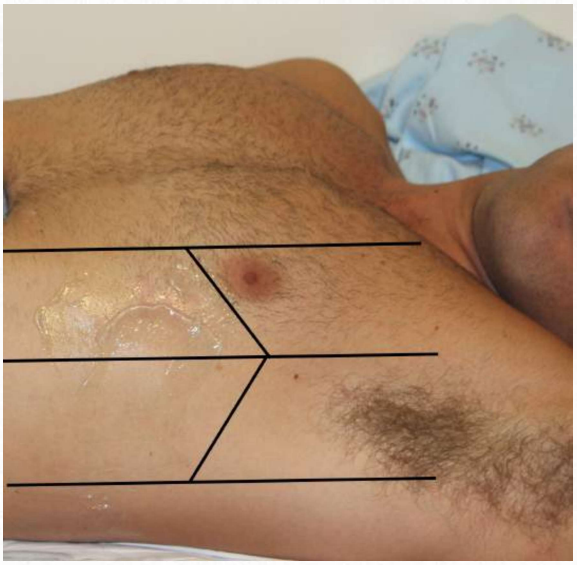
It is important to realize that absence of normal artifacts may also provide useful information. One such artifact is what are termed **A-lines**, which represent the reverberation artifact of lung pleura. This artifact is a hyper echoic horizontal line that is parallel to the pleural line. The distance from A-line to pleural line is equal to the distance between skin and pleural line, and this may repeat further down the ultrasound image. The presence of A lines is a sign of normal aeration but may also occur in the setting of pneumothorax. One must always assess for pleural sliding when A lines are visualized. Also, since the presence of A lines is a sign of normal aeration (assuming normal pleural sliding) one should not often see A lines and B lines in the same image.

It is important to realize that sometimes pleural sliding can cause small vertical called **Z lines**. These only extend 2 to 3 cm and do not represent air-space disease. One can differentiate them from B lines because they are much shorter and can also have A lines in the same image.









Right	Mid-Axillary	Anterior Axillary	Mid-Clavicular	Para-sternal	Intercostal Space	Left	Mid-Axillary	Anterior Axillary	Mid-Clavicular	Para-sternal
					II					
					III					
					IV					
					V					

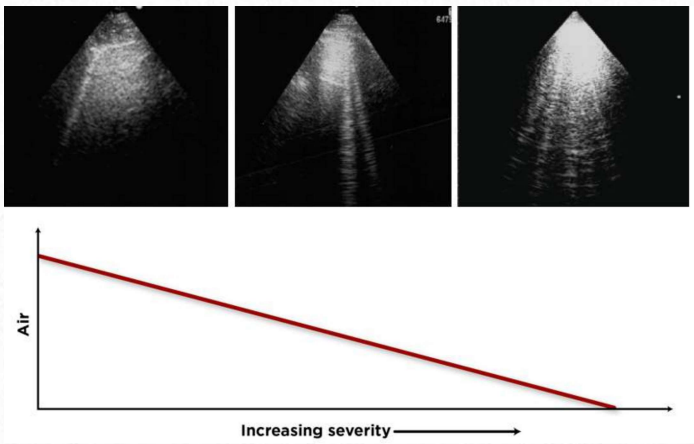
Basic Lung Exam

Patient Position: The supine position usually allows for the majority of lung tissue examination. The full lung parenchyma exam can be very involved (see table/picture below), but a basic six point exam that is used to assess the lung pleura for PTX can provide the majority of information (also shown below).

Probe Position: Either the curved linear or phased array probe can be used. The curved linear, being a higher frequency, will provide an improved image quality (higher frequency) while still providing enough depth of penetration, however the phased array probe can also be used. The indicator should be at the 12 o'clock position, perpendicular to the ribs (similar to the lung pleura exam). The transducer is oriented to scan between the ribs, as ribs block the transmission of ultrasound. Ideally, two ribs should be in view, one on each of the lateral sides of the ultrasound image. Please see the pictures below for further information on the lung parenchyma exam.

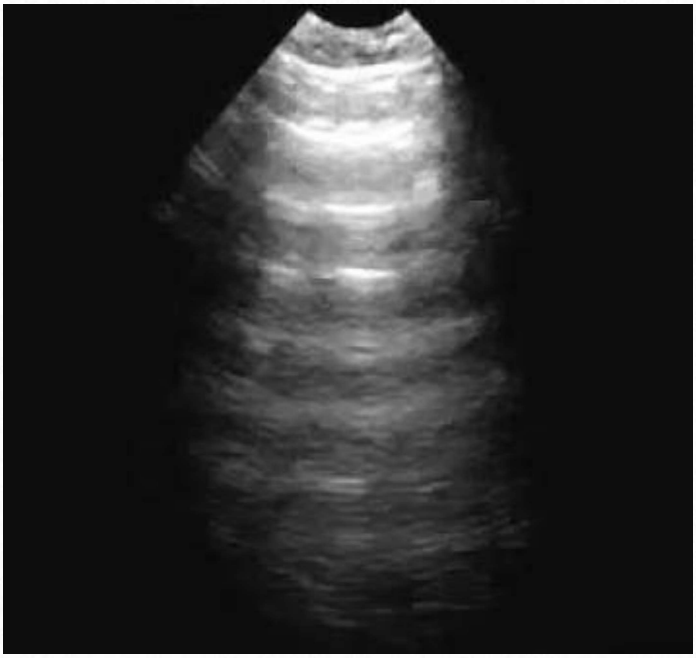
Probes to Use:

Extensive Lung Parenchyma Exam



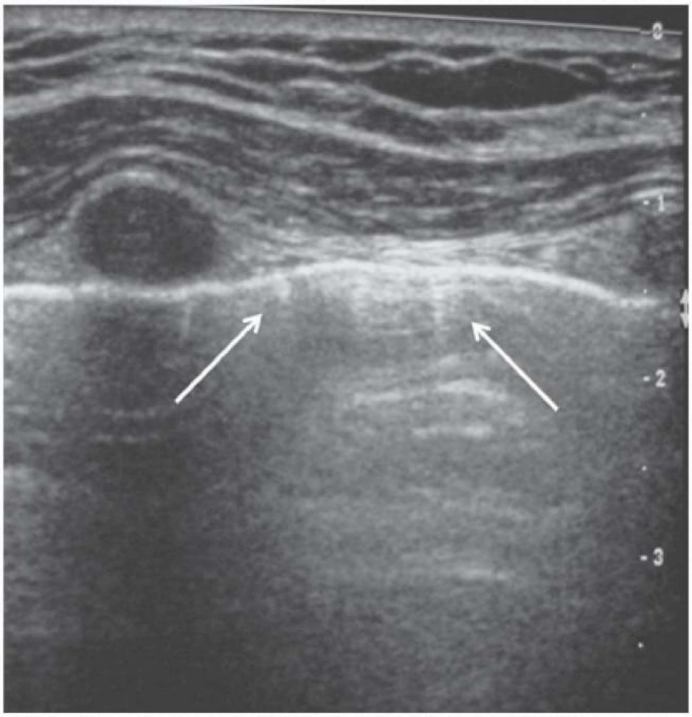
Lung US Artifacts

A lines - Defined as horizontal, regularly spaced hyperechogenic lines representing reverberations of the pleural line.



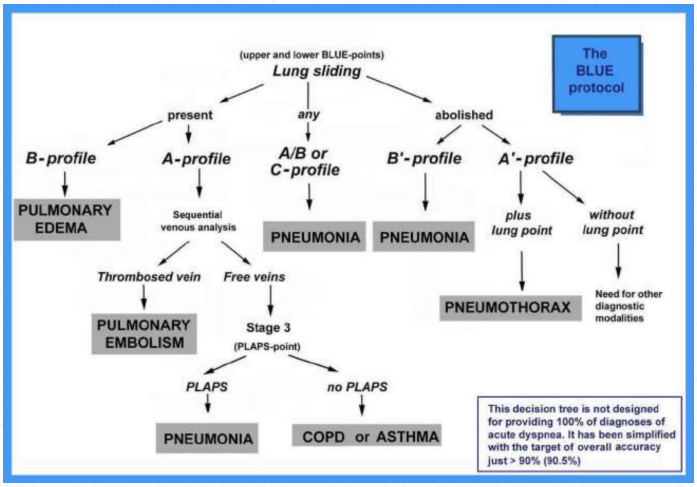
A lines

Z lines – Short, vertical comet tail artifacts arising from the pleural line but NOT reaching (usually only extends 2 to 3cm) the distal edge of the screen (THESE are NOT B lines).



Z lines

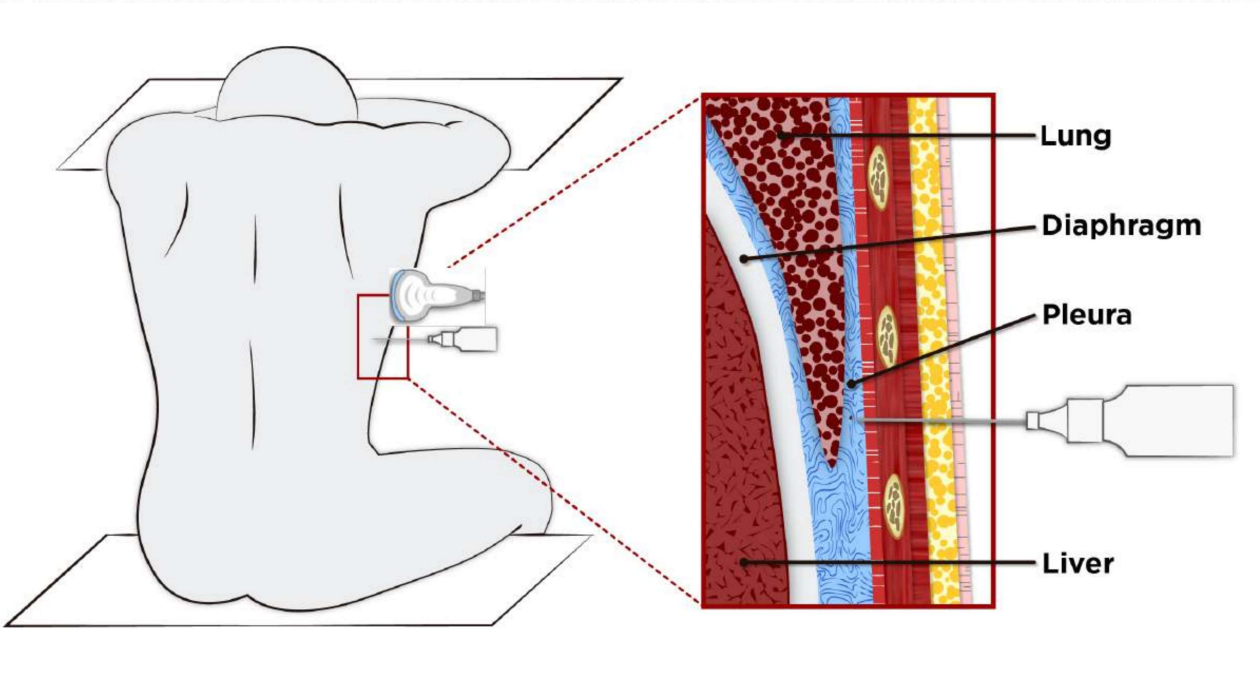
Lung Exam Protocol: search BLUE pulmonary ultrasound protocol

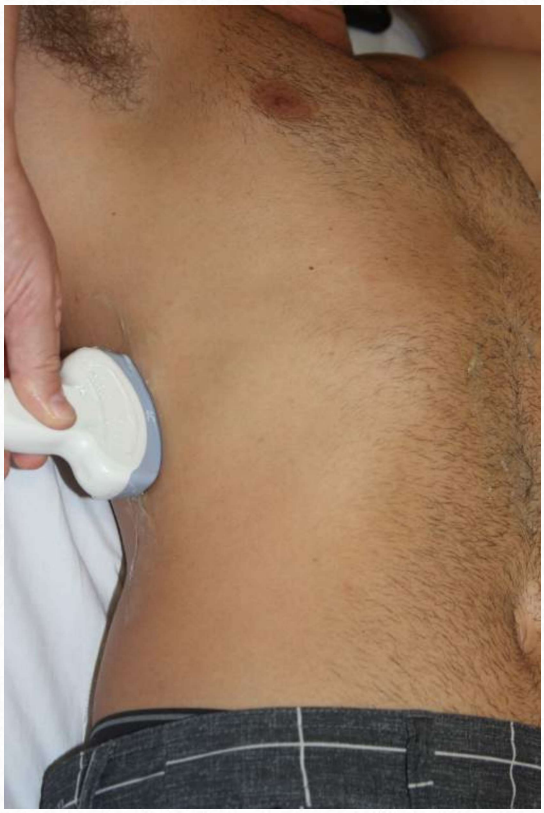


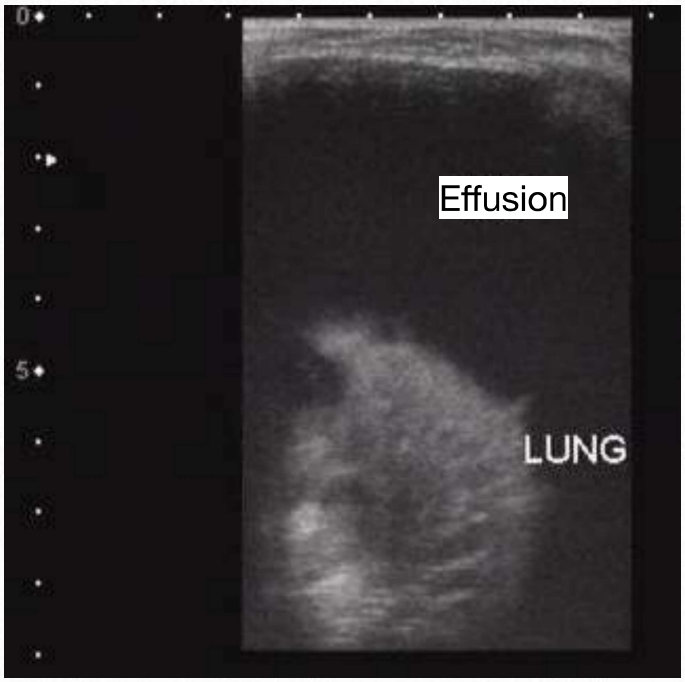
REFERENCE:Lichtenstein, D. "Lung ultrasound in acute respiratory failure an introduction to the BLUE-protocol." Minerva anestesiologica 75.5 (2009): 313.

8

Ultrasound Evaluation for Pleural Fluid







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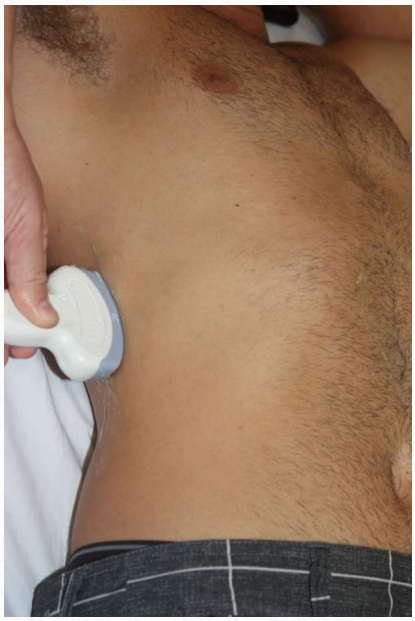
ULTRASOUND FOR EVALUATION OF PLEURAL EFFUSION

Ultrasound examination of the normal pleura is easy to perform. When the probe is applied to an interspace such that the probe is between adjacent ribs, the normal pleura appears as a bright, highly echogenic line interposed between the chest wall and the air artifact of the lung. With small movements of the transducer, the examiner may orientate the rib shadows such that the pleural line is centrally located on the screen. The marker on the probe should be pointed toward the head of the patient so that the cephalad direction is projected to the left of the screen. Approximately 70% of the pleural surface is accessible to ultrasound examination via techniques discussed in the prior lung exam tutorials. The normal pleura is 0.2 to 0.4 mm thick. Using the curved linear (best) or phased array probe to scan the dependent areas of lungs is the best method to assess for pleural effusion (see below).

There are four main considerations when performing a chest needle or chest tube insertion: 1) symptoms and size of the effusion or air, 2) site integrity, 3) coagulation status, and 4) presence of positive pressure mechanical ventilation. *If the distance between the lung and posterior chest wall at the lung base is greater than 5 cm, one can predict that at least 500ml of pleural fluid can be drained safely.* Therefore, 5 cm is a good cutoff point for when patients may have significant pulmonary improvement after thoracentesis. Also, a good equation to estimate ***effusion volume*** is: ***Vol (ml) = 16 X Diameter (mm).*** This diameter is measured from the pleura to the lung tissue (see picture).

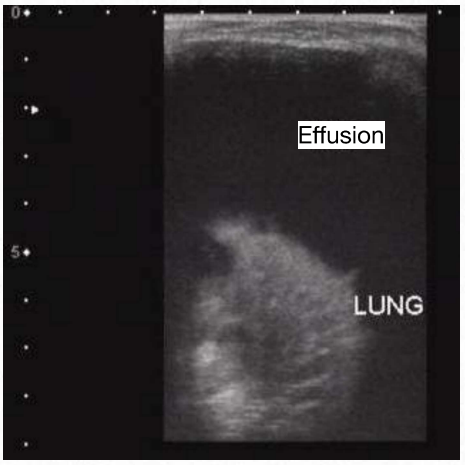
Patient Position: There are two potential positions for pleural effusion evaluation: 1) recumbent, which will usually allow for the majority of lung tissue examination. The full lung parenchyma exam can be very involved (see picture below), but a basic six-point exam that is used to assess the lung pleura for PTX can provide the majority of the information. 2)upright sitting position, this will allow one to easily quantify the severity of the fluid space by evaluating the distance from the diaphragm and lung parenchyma.

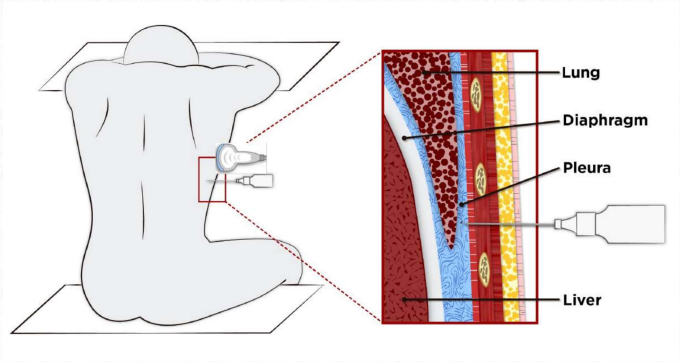


Probe Position: Either the curved linear or phased array probe can be used. Both probes offer a lower frequency that will allow adequate depth of penetration. The curved linear, being of a higher frequency, will provide an improved image quality while still providing enough deep penetration; the phased array probe may also be used. The indicator should be at the 12 o'clock position, perpendicular to the ribs (similar to the lung pleura exam). The transducer is oriented to scan between the ribs, as ribs block the transmission of ultrasound. In the supine position, one should place the ultrasound probe in the posterior axillary line at the 9 th rib space to identify the diaphragm and scan the base of the lung fields for effusion. Please see the pictures for further information on the lung parenchyma exam.

Probes to Use

Ultrasound image of Pleural Effusion



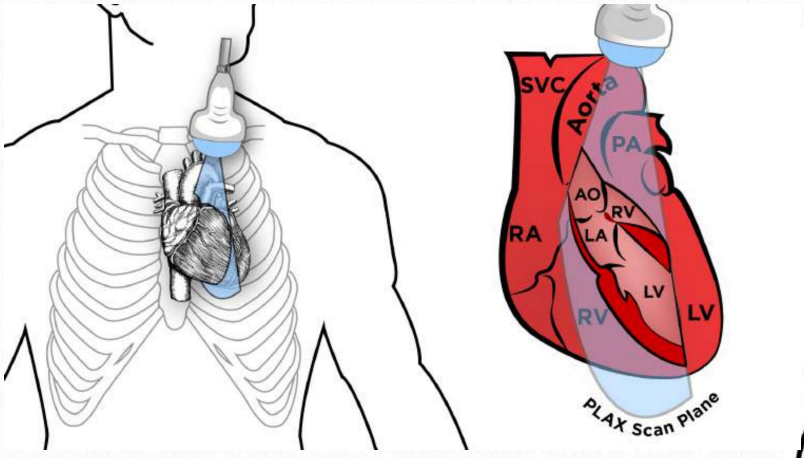


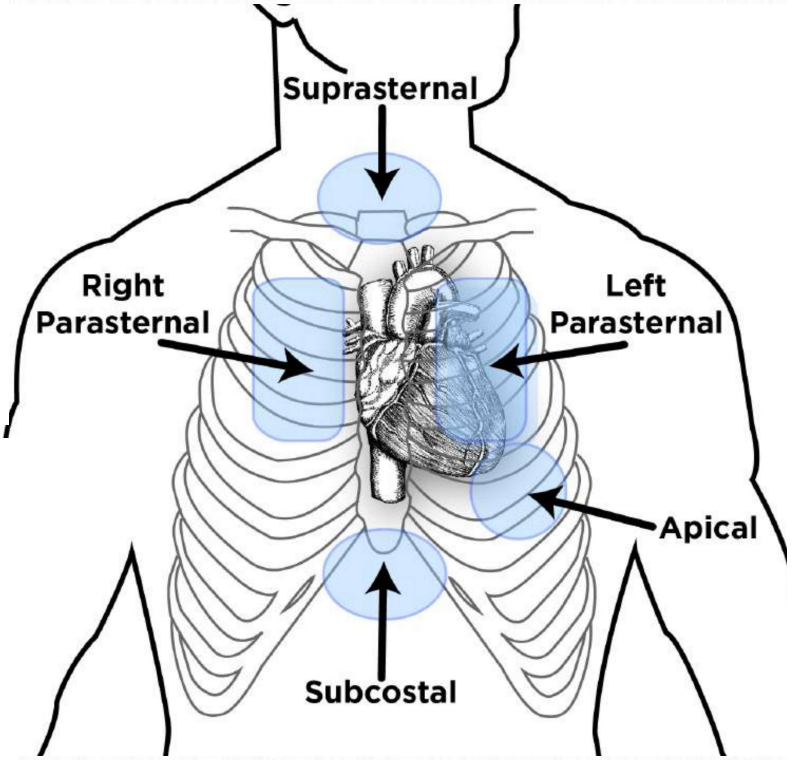
Thoracentesis Procedure

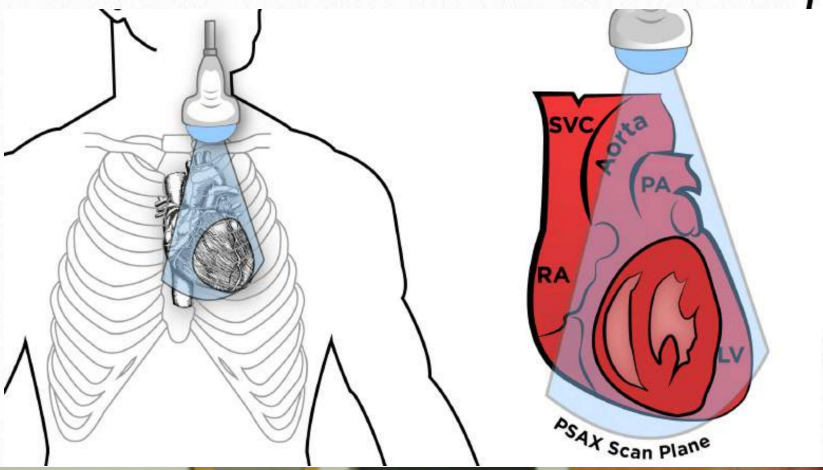
Placement of the needle above the rib at the level of the pleural fluid.

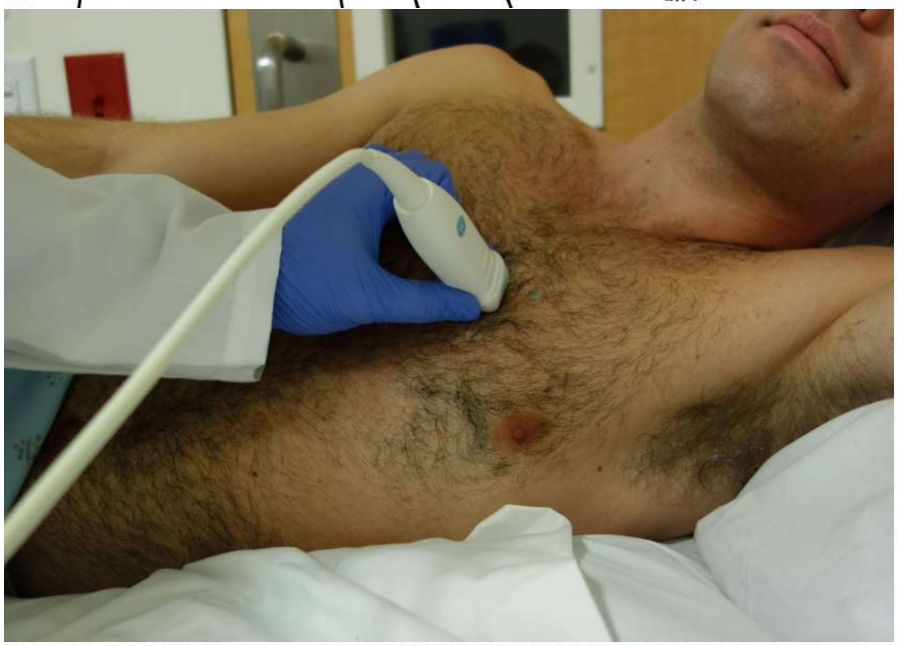
9

Cardiac Ultrasound: Parasternal Views and Methods of Assessing Contractility









III. CARDIAC: Ultrasound is an excellent modality to assess cardiac function/abnormalities. Surface ultrasound can provide an excellent minimally invasive tool to determine the mechanisms of the patient's current hemodynamic status. Each subsection will cover a cardiac ultrasound technique used to answer these questions.

A. PARASTERNAL VIEWS AND CARDIAC CONTRACTILITY

The parasternal window allows one to see the many cardiac structures with great resolution because these structures are perpendicular to the ultrasound plane and the probe is closest to the heart in this window. Because of this, one often will start with this window when performing a cardiac ultrasound examination. However, this window is NOT good to assess for blood flow directionality and therefore is a poor window to assess for valve regurgitation since the flow is perpendicular to the ultrasound image. This window has two major views: the parasternal left ventricle (LV) long axis view and the parasternal LV short axis view.

Parasternal Left Ventricle (LV) Long Axis View (LAX):
The parasternal LV long axis view allows one to assess the following: 1) left atrium size, structure of the mitral valve (NOT FLOW), 2) size/shape/contraction of the left ventricle, 3) structures of the aortic valve (NOT FLOW) and ascending aorta, and 4) RV size/shape/contraction. Of these items, one of the most important is **left atrial (LA) size.** The LA is a storage vessel for volume to the LV. In diastole the LV pressure reduces such that flow can move forward from the atrium. However, in any situation when the LV end diastolic pressure is elevated (diastolic dysfunction, severe aortic regurgitation, frequent episodes of tachycardia, severe systolic dysfunction, etc.) that pressure will get relayed to the LA. The way the LA handles this increased pressure is by dilating so it can hold more volume and therefore generate the necessary pressure to fill the left ventricle. **Because of this, the LA size is regarded as the HgA1c of the heart, since it is a marker for elevated left ventricular end diastolic pressures**. From the parasternal LV long axis view one can measure the diameter of the LA and determine if it is dilated (see table below). One can also get the LA area from the apical window, which will be discussed later. In this view, the RV should be seen as a very small structure. **If the RV diameter is larger than 3.3cm**, then concern for a dilated RV is raised. This view also allows an assessment of the ascending aorta, and we can see if the aortic and mitral valves appear to open and close normally. This view also allows the assessment of LV contractility by a method called fractional shortening. **Fractional Shortening** is determined by taking an M-Mode picture across the LV at the papillary level and comparing the LV internal diameter in end diastole (LVIDd) minus the LV internal diameter in end systole (LVIDs). The equation is ((LVIDd – LVIDs) / LVIDd), see picture below. **IT IS IMPORTANT TO REALIZE, HOWEVER,** that this method of assessing contractility only takes into account one level of myocardium (of three) and only two wall segments (out of six), so it is the least accurate when compared to other methods of assessing contractility. This is further discussed below.

Parasternal Left Ventricle (LV) Short Axis View (SAX):
The parasternal SAX view allows one to assess the contractility of both the LV and RV, diameters of the LV/RV, and detection of regional wall motion abnormalities. The left ventricle can be cross-sectioned into three levels: 1) closest to the atrium is the basal level, 2) mid-papillary level, and 3) the apical level, which is the most distal from the atria at the apex (see picture below). The walls of the left ventricle are divided into six sections (shown below) for the first two levels: 1) anterior, 2) lateral, 3) infero-lateral (posterior), 4) inferior, 5) infero-septal, and 6) antero-septal. The last apical level is divided into four sections: 1) anterior, 2) lateral, 3) inferior, and 4) septal.

The coronary distribution (shown below) is as follows:
LAD - anterior and antero-septal segments.

RCA - right ventricle, the infero-septal segments, most of the inferior segments, and depending on what supplies the PDA the infero-lateral segments (only 20% of the time does the PDA come from the RCA).

Circumflex - lateral segments, and in 80% of the population it supplies the PDA for the infero-lateral segments and part of the inferior segments.

The diameter and/or area of the left ventricle in end diastole represents the filling of the left heart and can indicate the patient's filling status. Using the measure or caliber feature, one can assess the diameter of the left ventricle in either a standard 2–D image or an M-mode image. *IT IS IMPORTANT TO*

REALIZE THAT EVEN THOUGH THIS MODALITY CAN HELP PREDICT LEFT VENTRICULAR VOLUME, IT DOES NOT INDICATE VOLUME RESPONSIVENESS. In addition to measuring the diameter or area of the LV in diastole to determine LV volume, these views can also be used to assess cardiac contractility by measuring the change in the diameter of the LV in diastole to systole. Measuring this change in area is called **fractional area change (FAC)** and indicates myocardial contractility (see figure below). FAC is more accurate then fractional shortening because you are able to look at one level (same as fractional shortening) and all six wall segments as well (compared to two). REMEMBER THAT FAC AND LV DIAMETERS ARE MEASURED AT THE MID-PAPILLARY LEVEL. Also you can assure the LV is sectioned appropriately by comparing the size of the papillary muscles. If they are equal in size then you can reliably calculate the FAC and obtain accurate measurements.

It is important to remember that markers for LV systolic function, such as ejection fraction and fractional area change are significantly affected by preload, afterload, and ventricular contractility. Remember diastolic dysfunction is an issue with ventricular relaxation and often these patients have normal systolic ventricular contractility.

Finally, with these views one is able to help identify the **mechanism of shock**:

1. **Cardiogenic shock**: increased LV area/diameter and a decreased FAC (from decreased contractility)

2. **Hypovolemic shock**: decreased LV area/diameter (from decreased preload) and a increased or normal FAC

3. **Vasogenic shock:** normal LV area/diameter and a increased or normal FAC (from low SVR state)

Patient Position: Left-Lateral with L arm Extended

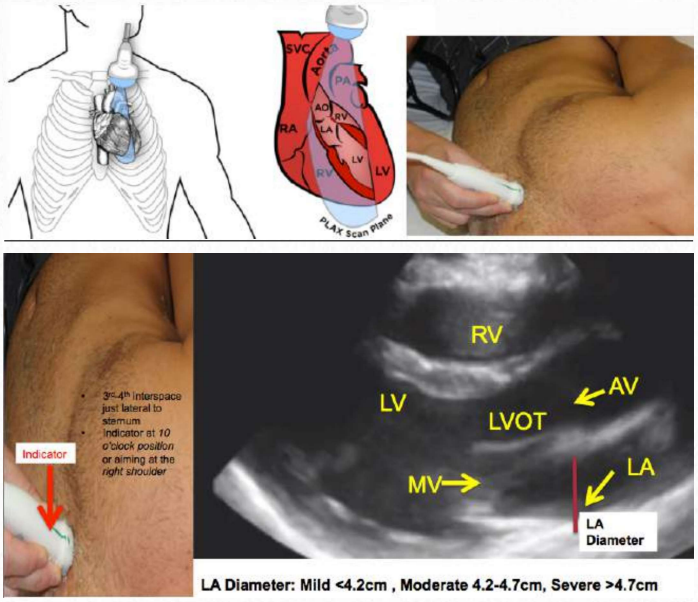
Probe type: phased array cardiac probe

Probe Position:

Position 1. ***Left parasternal long axis view:*** 3rd-4th interspace just lateral to the patient's left side of their sternum, with the index approximately at the *10 o'clock position* or aiming at the *right shoulder (REMEMBER WHEN ROTATING TO SAX VIEW KEEP THE DESIRED STRUCTURE IN THE MIDDLE OF THE SCREEN).*

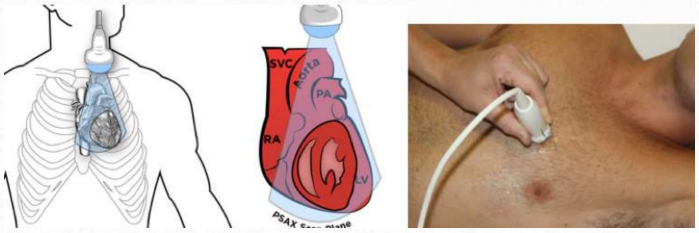
Position 2. *Left parasternal short axis view:* 3rd-4th interspace just lateral to the patient's left side of their sternum, with the index marker approximately at *the 2 o'clock position* or aiming towards the *patient's left shoulder* (90 degrees to LAX view).

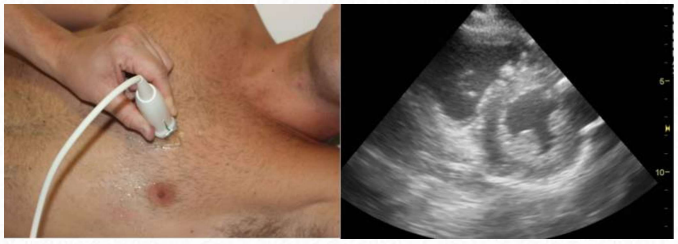
LV Parasternal LAX view Anatomy



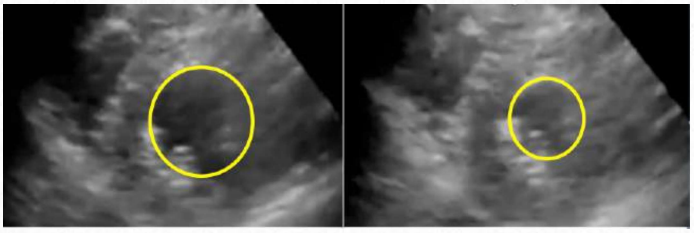
Parasternal Long Axis View (indicator at 10 o'clock position "right shoulder") (LV= left ventricle, MV = mitral valve, LVOT = left ventricular outflow tract, LA = left atrium, AV = aortic valve, RV = right ventricle)

LV Parasternal SAX view Anatomy





Position: 3rd-4th interspace with index approximately at the 2 o'clock position (90 degrees to LAX view).



FAC: (End Diastolic Area - End Systolic Area) / End Diastolic Area X100

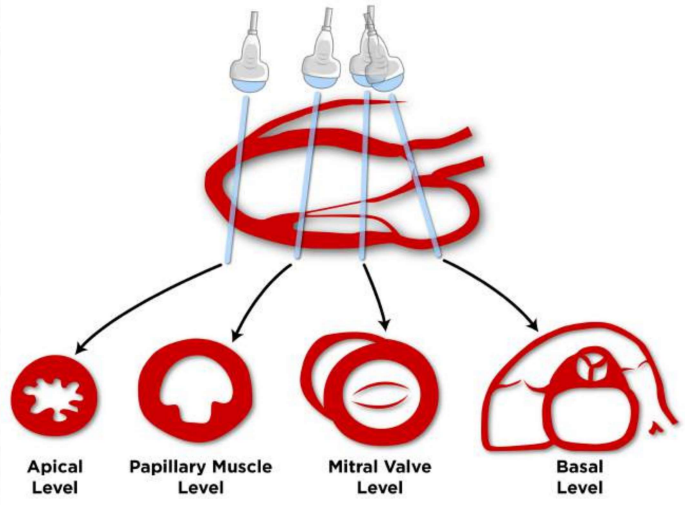
Normal > 50%

Reduced LV volume: EDA < 8 cm^2

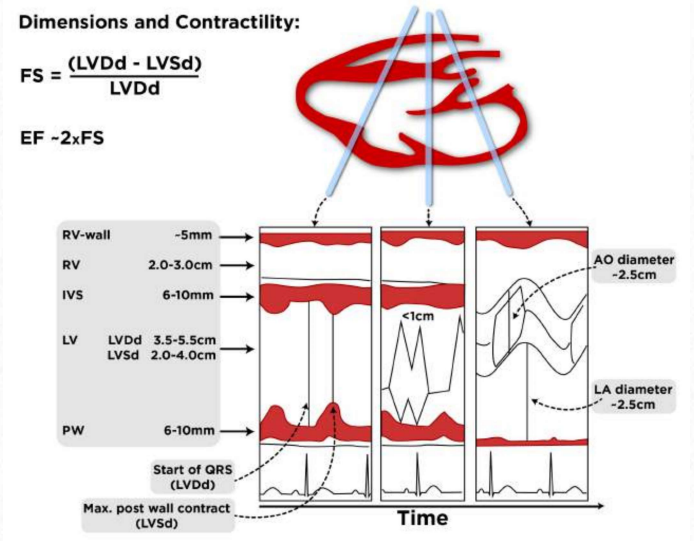
Normal LV volume: EDA 8-14 cm^2

Dilated LV volume : EDA > 14 cm^2

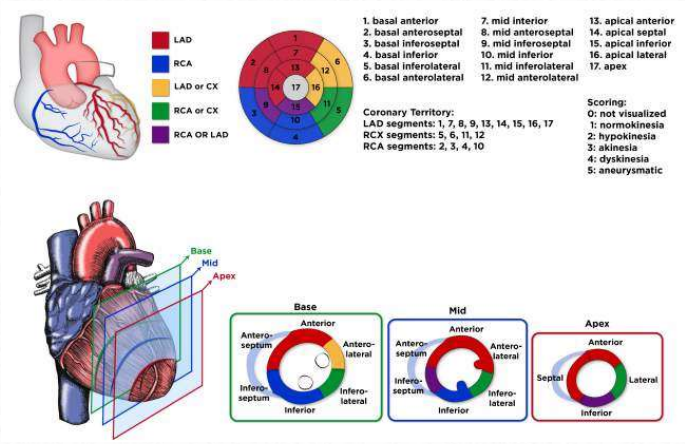
Coronary Distribution



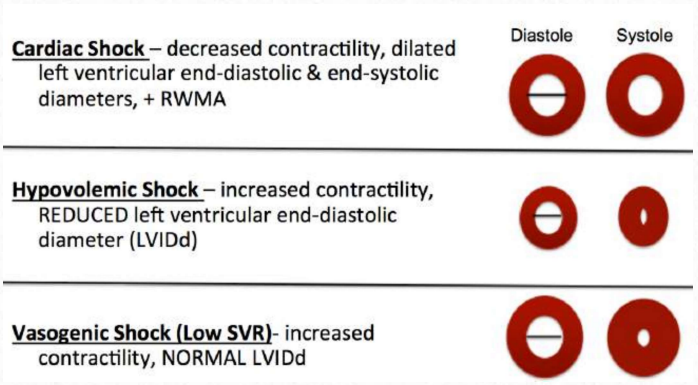
Fractional Shortening:



Fractional Area Change (FAC)



Evaluation of Shock with POC US



Using Parasternal SAX view to Determine Mechanism of Shock

1. **Cardiogenic shock**: increased LV area/diameter and a decreased FAC (from decreased contractility)

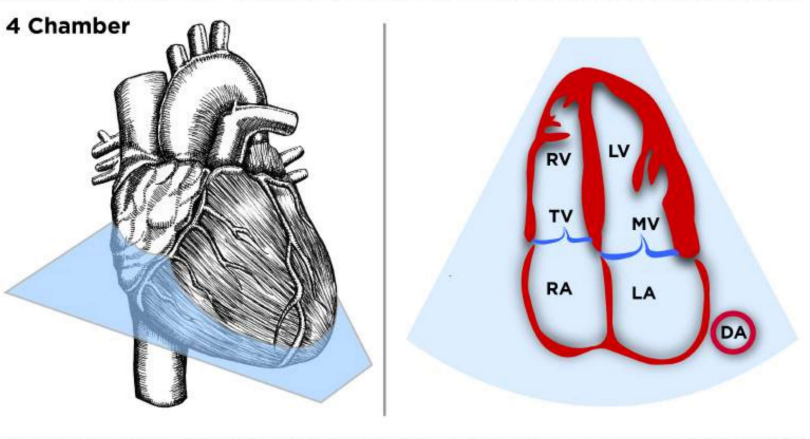
2. **Hypovolemic shock**: decreased LV area/diameter (< 8cm2 area or 3.5cm diameter) from decreased preload) and a increased or normal FAC

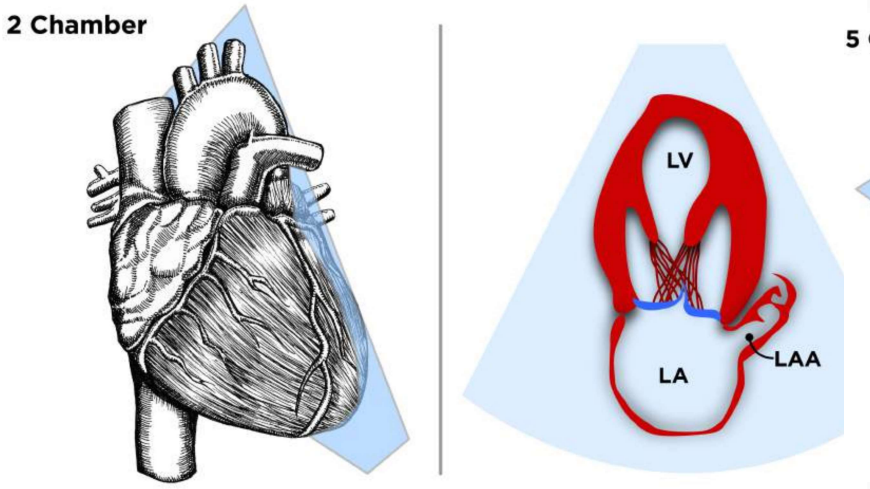
3. **Vasogenic shock:** normal LV area/diameter and a increased or normal FAC (from low SVR state)

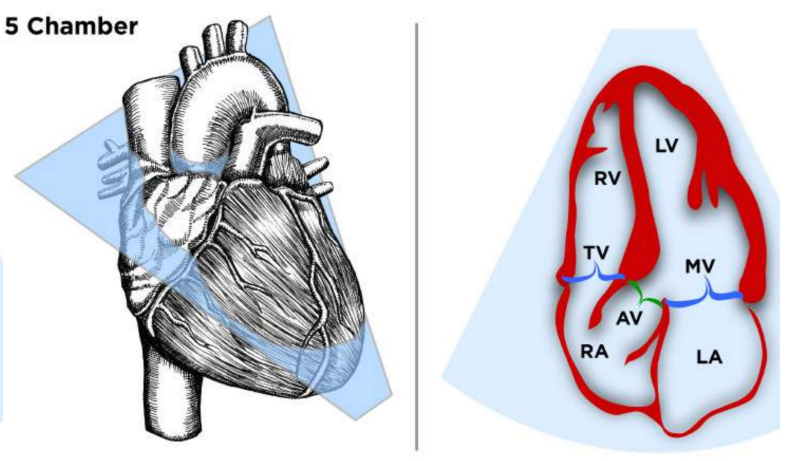
10

Cardiac Ultrasound: Apical Views

Apical Windows







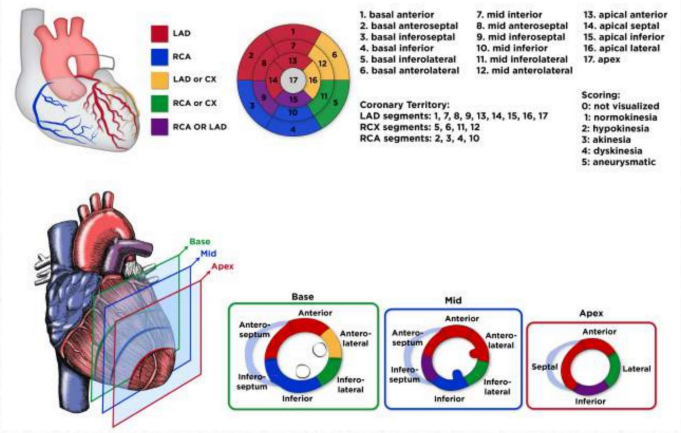
III. CARDIAC: Ultrasound is an excellent modality to assess cardiac function/abnormalities. Surface ultrasound can provide an excellent minimally invasive tool to determine the mechanisms of the patient's current hemodynamic status. Each subsection will cover a cardiac ultrasound technique used to answer these questions.

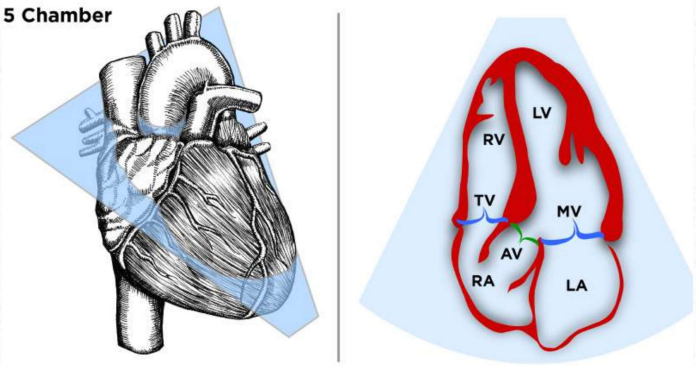
B. APICAL VIEWS

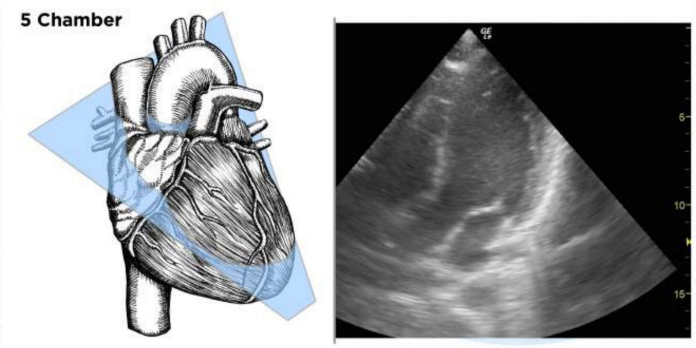
The apical window is used for routine Doppler examination of patients to evaluate for valvular heart disease. This is because, in this view, the Doppler beam is as parallel as possible to the direction of assumed blood flow through the mitral, tricuspid, and aortic valves. By being parallel, it also allows the largest Doppler shift to be recorded and the strongest signals to be reflected back to the Doppler transducer. Continued practice repositioning the probe in the various portions of the cardiac chambers accessible from the apical four chamber view will eventually provide the novice operator with an appreciation of the spatial locations and directions of normal and abnormal flows. Always remember that the heart chambers are actually three dimensional structures, and an abnormal flow jet may be directed anywhere within the three dimensions. An experienced operator will be able to track an abnormal jet, even if it is directed out of a standard two-dimensional plane, by changing the angle, rotation, and tilt of the transducer.

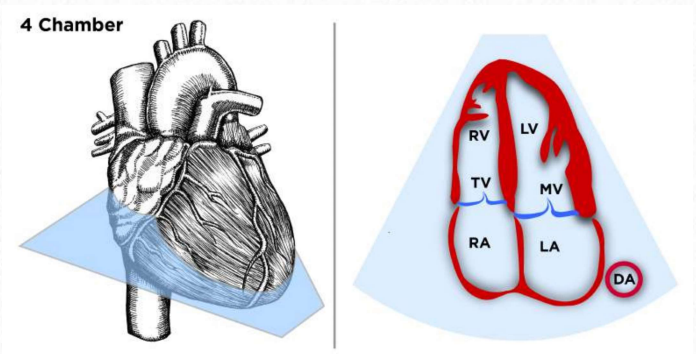
Besides the assessment of the cardiac valves, the apical views allow for: 1) Assessment of diastolic function (to be discussed later), 2) assessment of RV size and function (to be discussed later also), 3) evaluation of LV segmental wall motion, 4) evaluation for LV thrombus, and 5) evaluation of left and right atrial size. There are three views from the apical window that are performed to obtain all information possible from this window. These views are: 1) Four-Chamber, 2) Five-Chamber, and 3) Two-Chamber views. The specifics of each of these views are detailed below.

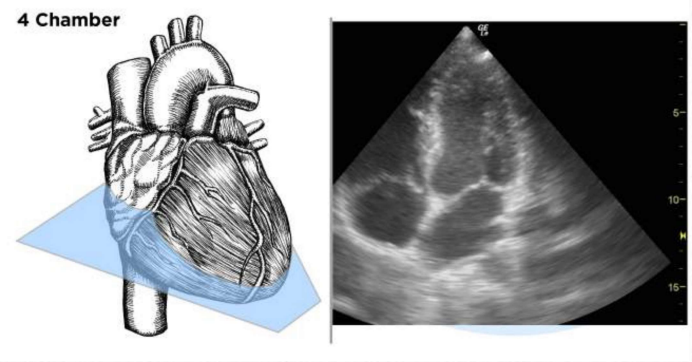
Regarding evaluation of LV segmental wall motion, the diagram below shows the walls of the LV (as well their coronary supply) that are visualized with each of the three views from the apical window.

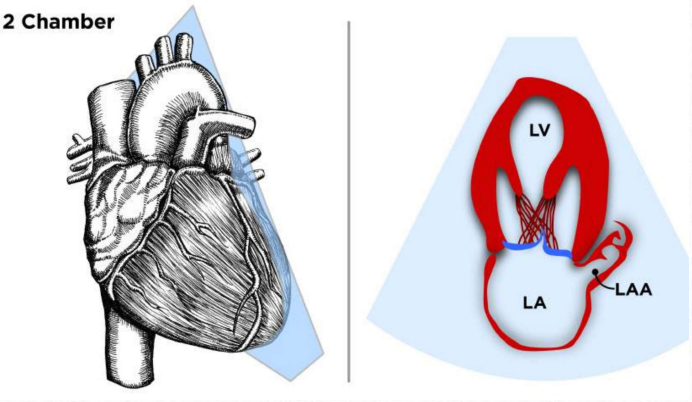


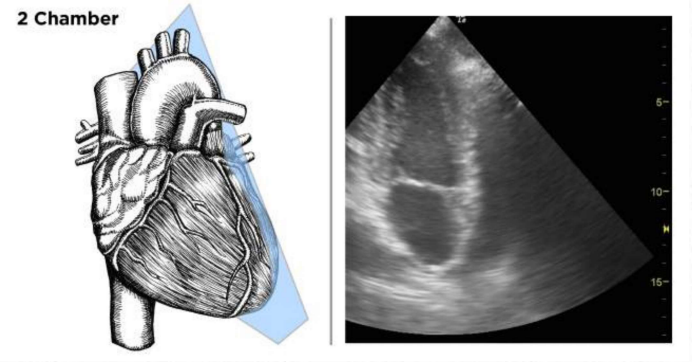


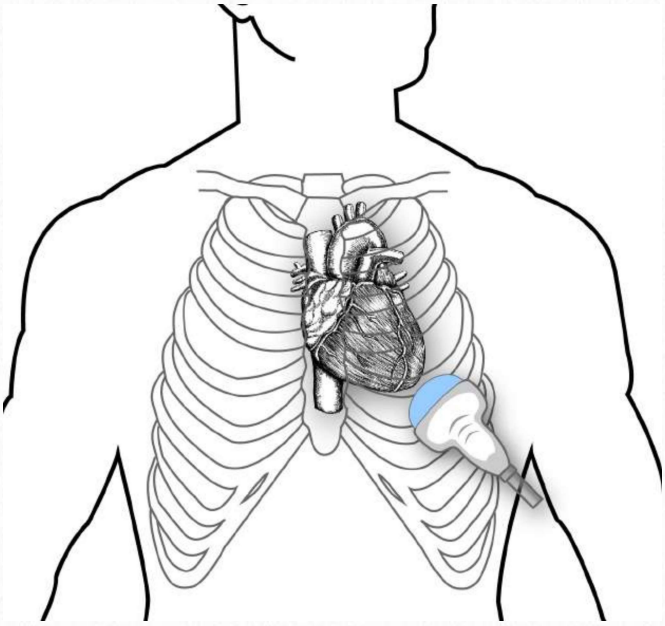












One of the most important measurements that can be obtained from this window is **left atrial (LA) size** (also discussed in left parasternal LAX view chapter). As previously discussed, the LA is a storage vessel for volume to the LV. In diastole the LV pressure reduces such that flow can move forward from the atrium. However, in any situation when the LV end diastolic pressure is elevated (diastolic dysfunction, severe aortic regurgitation, frequent episodes of tachycardia, severe systolic dysfunction, etc.), that pressure is relayed to the LA. The LA handles this increased pressure is by dilating so it can hold more volume, and therefore generate the necessary pressure to fill the left ventricle. Because of this, the LA size is regarded as the HgA1c of the heart since it is a marker for elevated left ventricular end diastolic pressures. From the apical four chamber view, one may obtain the diameter of the LA and determine if it is dilated (see table below).

Patient Position Apical Window Views: Left-Lateral with L arm extended.

Probe Type: Phased array cardiac probe.

Probe Position: The apical window is usually found in the left lateral portion of the chest at the apex of the heart. This can sometimes be located by placing your hand lightly in area of the apex and feeling for the point of maximal intensity (PMI). The PMI will serve as your starting point; however, small adjustments will need to be made to the transducer

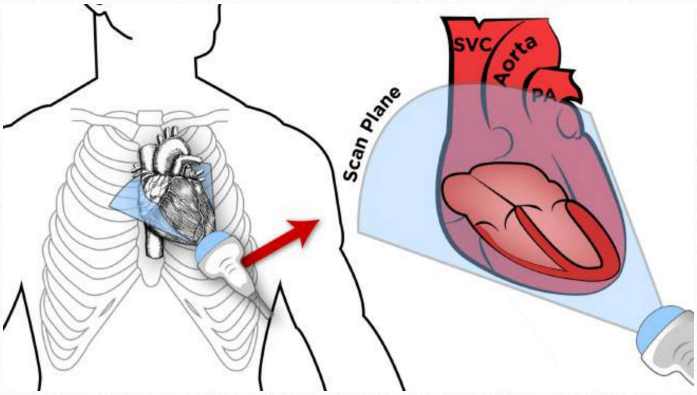
location to optimize your image. Another good starting point is to go one to two rib spaces below, but in the same plane as the nipple.

4-Chamber (4C) View: The transducer is placed at the cardiac apex with the marker dot pointing down to the 3 o'clock position. This gives the typical 'heart-shaped' 4-chamber view (see image on the right). All four cardiac chambers are visualized in the 4C view along with the mitral and tricuspid valves. Ventricular and atrial size can be assessed using 2D echo. Color flow and spectral Doppler can be used to assess for valvular regurgitation and stenosis (discussed in another chapter). Left ventricular diastolic function can be assessed by applying pulsed wave Doppler to the mitral valve and pulmonary veins (discussed in separate chapter). In this view, the right ventricular free wall, inter-ventricular septum, and left lateral wall can be assessed for systolic motion.

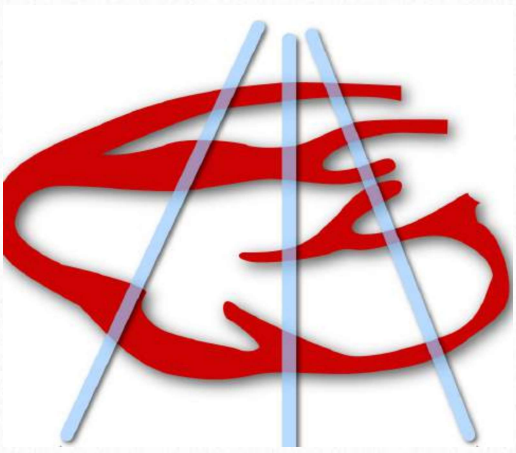
This view allows one to evaluate **RV function** as it provides a good view of the RV chamber. One can assess RV function using this view in 3 ways. One is by looking at the fractional area change of the RV chamber from diastole to systole (normal change is > 30%). It is important to note that normal RV diameter is less than 4.2 cm at the base and less than 3.5 cm at the mid level. The second method is by looking at the movement of tricuspid annulus in systole -TAPSE (tricuspid annular plane systolic excursion). This is done by measuring the distance of the tricupsid annulus to the right ventricular outflow tract in diastole compared to systole. Normal function is a distance change of more than 1.6cm. Finally, one can use pulse wave doppler to assess the velocity of motion of the tricuspid annulus in systole. The PW signal is placed directly on the lateral portion of the tricuspid annulus and the velocity of the tissue motion toward the probe during systole is measured. Normal velocity is > 15cm/sec.

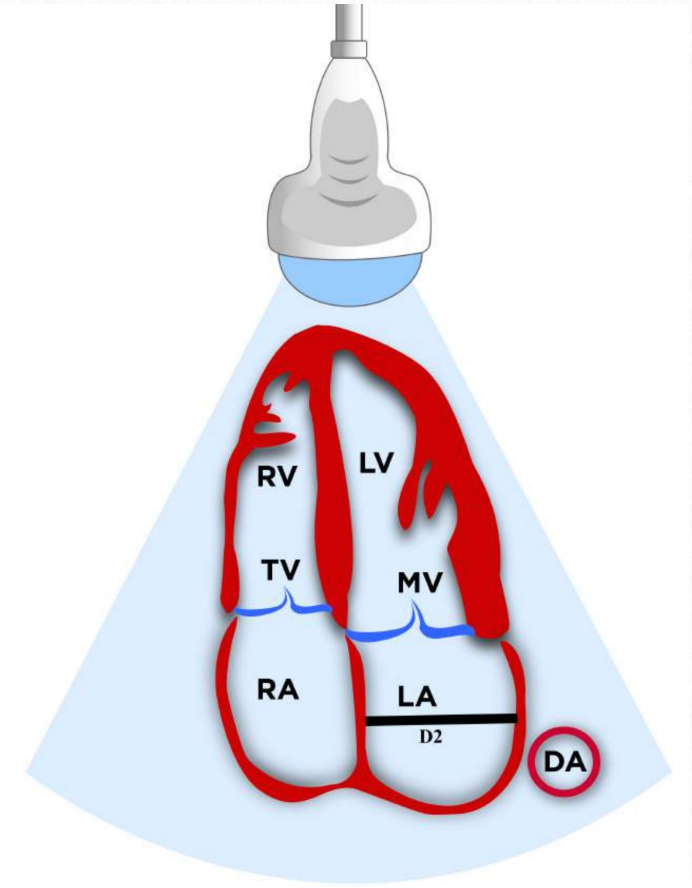
5-Chamber (5C) View: By altering the angulation of the transducer so the ultrasound beam is angled more anteriorly toward the chest wall, a '5-chamber' view is obtained. Specifically, this is done by decreasing the angle between the probe and the skin. The 5th 'chamber' is not a chamber at all, but rather is the conglomerate image of the left ventricular outflow tract (LVOT), aortic valve, and ascending aorta. This view is useful in assessing aortic stenosis (AS) and aortic insufficiency (AI).

2-Chamber (2C) View: By rotating the transducer counter-clockwise 90 degrees on the cardiac apex **(from 3 o'clock to 12 o'clock)** it is possible to obtain the 2-chamber view which shows different segments of the left ventricle (LV) (see diagram above for LV wall segments for each view). In the 2C view, the left ventricle, mitral valve, and left atrium are seen. The inferior and anterior walls of the left ventricle can be assessed for systolic function. Using color flow and spectral Doppler, the mitral valve can be assessed for regurgitation and stenosis. PLEASE NOTE that this view may be difficult secondary to the size of the footprint of the probe and the ribs.



Left Atrial Size:





	Normal	Mild	Moderate	Severe
LA diamter (cm)	2.7-4	4.1-4.6	4.7-5.2	> 5.2
LA area (cm2)	<20	20-30	30-40	>40

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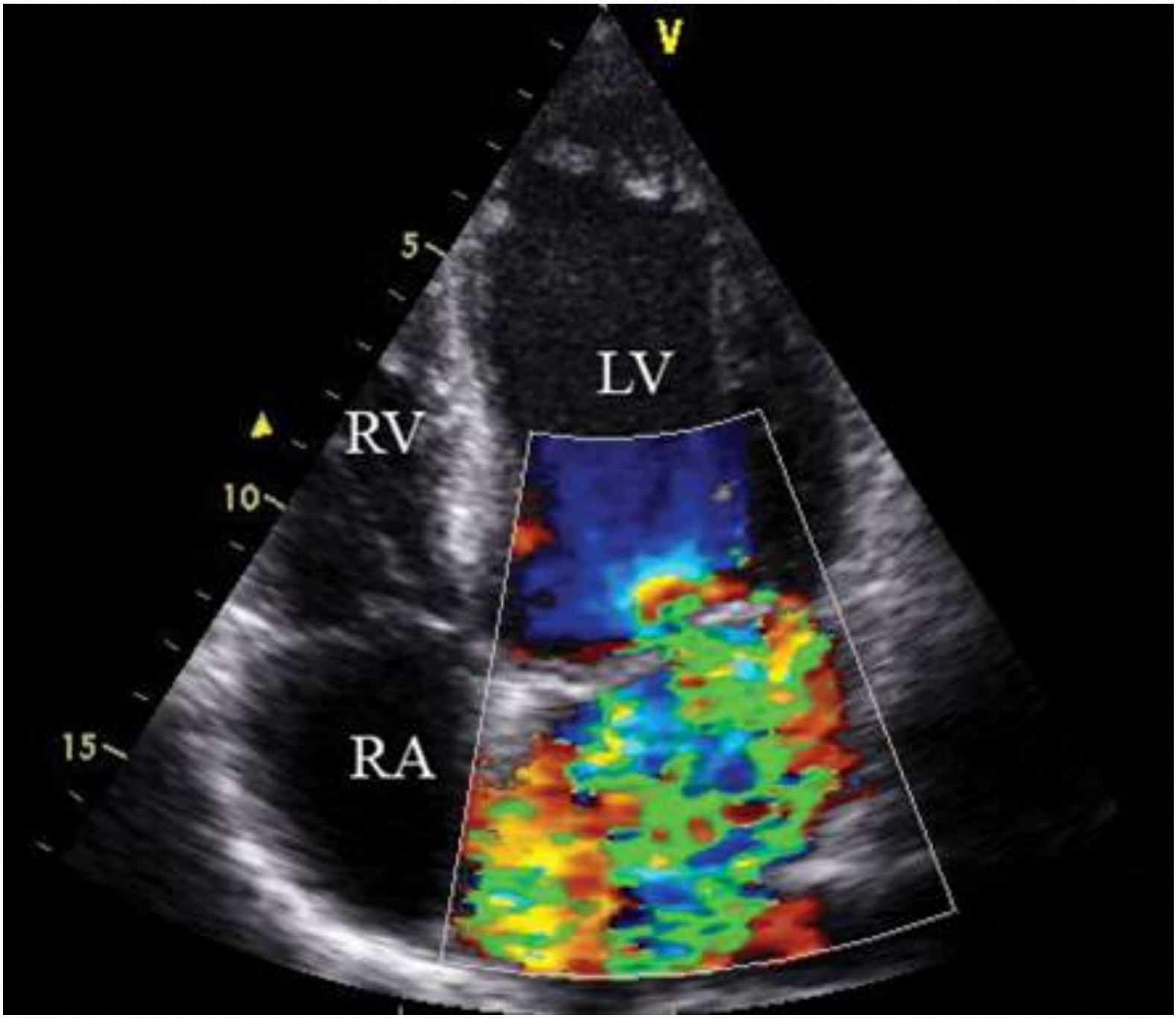
Cardiac Ultrasound: Evaluation of Cardiac Valves



III. CARDIAC: Ultrasound is an excellent modality to assess cardiac function/abnormalities. Surface ultrasound can provide an excellent minimally invasive tool to determine the mechanisms of the patient's current hemodynamic status. Each subsection will cover a cardiac ultrasound technique used to answer these questions.

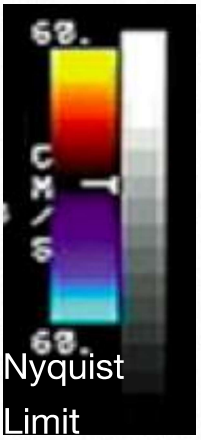
C. DOPPLER EVALUATION OF CARDIAC VALVES

The apical window is used for routine doppler examination of patients for evaluation of valvular heart disease. This is because, in this view, the Doppler beam is as parallel as possible to the direction of assumed blood flow through the mitral, tricuspid, and aortic valves. Let's remind ourselves of the different doppler modes used to assess the cardiac valves in this window.

Continuous Wave Doppler is a doppler modality in which there is a *constant* ultrasound signal being sent, and there is a constant part of the piezoelectric crystal that is able to receive the ultrasound signal. The benefit is that there is no limitation to velocity measurement. However, the trade off is that we lose the ability to obtain depth (or location) identification. A continuous wave doppler will show the highest velocities **anywhere** along the continuous wave ultrasound plane. As it pertains to assessment of cardiac valves, continuous wave doppler **is used to assess for stenosis of the cardiac valves.** This is because, as stated above, it is the only modality that allows one to detect the high velocity blood flow across the valve with stenosis.

Pulsed Wave Doppler is a Doppler modality in which the transducer *alternates* transmission and reception of ultrasound. The benefit is that the user can identify a location in the US plane to sample the velocities and the direction generated in that precise location. However, while defining a specific location, the range of velocities measured (**called the Nyquist limit)** is limited. The closer the sample volume is located to the transducer, the higher the maximum velocity that can be detected, or in other words, the wider the range of the Nyquist limit. For our purposes, we will **use pulsed wave Doppler to assess for DIASTOLIC DYSFUNCTION** (discussed in another chapter).

Color 2-D Doppler is really a modified version of pulse wave doppler in which multiple lines of pulse wave Doppler are used to produce a color *doppler* pattern over the 2 D ultrasound image, allowing one to assess the degree of regurgitation across the cardiac valves. The colors displayed correspond to the *direction of flow,* depending if the returning signals cause either a positive or negative doppler shift (toward or away from the transducer). The brightness of the color represents the intensity of the echoes, and sometimes other colors are added to indicate the range of doppler velocities. One can adjust this range, or Nyquist Limit, to detect velocities in a certain range. Remember: BLUE COLOR = BLOOD FLOW MOVING AWAY FROM THE TRANSDUCER, AND RED COLOR = BLOOD FLOW MOVING TOWARDS THE TRANSDUCER. (B.A.R.T - Blue-Away/ Red-Towards). When using color Doppler you will see the color profile on the top right of the screen and the range of velocities that they represent. Again, this range is the **Nyquist limit. A good rule of thumb is to keep the Nyquist limit at 60cm/sec when evaluating for valve regurgitation.** Another important point regarding color doppler on a 2-D ultrasound image is that the size of your doppler window will directly affect the ultrasound image. By increasing the window size, the frame rate is decreased which will result in a poorer quality window.



Vena Contracta is an important concept to understand in order to help quantify the severity of regurgitation. Vena contracta is the narrowest region of a jet that occurs just below the orifice of a regurgitant valve as assessed by color flow mapping during echocardiography. Vena contracta is smaller than the regurgitant orifice and is characterized by high velocity, laminar flow (color change in color doppler). Even though the measurement of the vena contracta is less dependent on technical factors, small errors in measurement can be multiplied due to the relatively small values of the vena contracta width. Measurement of vena contracta is useful in assessing the severity of mitral, tricuspid, and aortic regurgitation.

Evaluation of Valve Function

Step 1: Evaluate 2-D image of valve structure and motion (movement, calcification, etc.).

Step 2: Apply Color Doppler Window over the desired area to include the entire valve and the area of comparison (*area of backflow*) to assess regurgitation.

Mitral Valve = Left Atrium

Aortic Valve = Left Ventricular Outflow Tract

Tricuspid Valve = Right Atrium

Step 3: Compare the area of the regurgitant jet to the area of comparison (see above).

Step 4: Use Doppler to Assess for Stenosis.

Step 5: If possible, take measurements of vena contracta.

PLEASE SEE CHAPTER 10 FOR INFORMATION ON: Patient Position, Probe Type, and Probe Position

Colour Doppler Indicators of Mitral Regurgitation Severity

	Mild	Moderate	Severe
Colour Doppler Jet area (cm^2) (Nyquist 50-60cm/s)	<4		>10
Ratio of jet area to left atrial area (%)	<20		>40
Vena contracta width (cm)	<0.3		>0.7

Assessment of Tricuspid Regurgitation

	Mild	Moderate	Severe
Colour Doppler Jet area (cm^2) Nyquist 50-60cm/s	<4		>10
Ratio of jet area to left atrial area (%)	<20		>40
Vena contracta width (cm)	<0.3		>0.7

Assessment of Aortic Regurgitation

Mild	Moderate	Severe
Central Jet, width < 25% of LVOT		Central Jet, width ≥ 65% of LVOT
Vena contracta < 0.3 cm		Vena contracta > 0.6cm

Estimation of valve area

As discussed in chapter 4, the doppler flow pattern across cardiac structures can be traced, and this tracing results in the velocity time integral or VTI. Remember that one can view VTI as a summation of all the reflected velocities of blood flow during that cardiac cycle. In chapter 4 we discussed how this parameter represents the patient's stroke volume, assuming that the doppler flow pattern is obtained from an *area without pathology*. This relationship is from the following equation: Stroke Volume = VTI x (area of flow measurement). To go one step further, one can estimate the outflow area of one cardiac valve by knowing the VTI of the flow across the unknown area, the value of a known area, and the VTI of a known area. To put this in an equation: Area 1 x VTI 1 = Area 2 x VTI 2. Thus, by knowing the VTI at two different areas, and the area of one of them, you can calculate for the area of pathology. This is most commonly done to determine the valve area of the pathologic aortic valve (Aortic stenosis). Specifically for this scenario one would get a VTI signal across the LVOT (using PW) and then across the aorta (using CW). Then one would measure the diameter of the

LVOT and determine its area. Finally, one would plug these three variables in to the above equation to solve for the aortic valve area.

Estimation of Pulmonary Artery Systolic Pressure (PASP): Doppler ultrasound can also be used to estimate PASP. To do this, your patient has to have some degree of tricuspid regurgitation (TR). This is because the assessment of the velocity of TR relates to the PASP. One can think of this in the following way: From the right ventricle, blood will flow with the same velocity across the pulmonic valve (forward flow) as it will across the tricuspid valve (TR). From a velocity sample the ultrasound machine can identify a pressure (Bernoulli's principle: Pressure = 4 x velocity^2). So from these points this is how one can calculate an estimate of PASP:

Step 1: Identify a tricuspid regurgitation jet (from the apical 4 chamber view).

Step 2: Use continuous wave doppler across the TR jet and capture the doppler waveform.

Step 3: Measure the peak systolic velocity of the waveform. The machine will automatically calculate the pressure of this velocity using Bernoulli's principle.

Step 4: Add this pressure value to the estimate of right atrial pressure (done from examining the IVC diameter).

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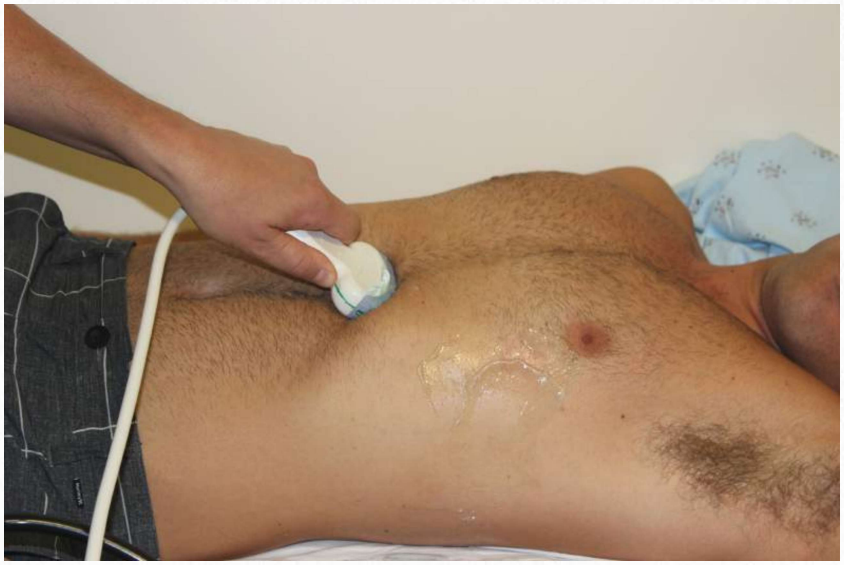
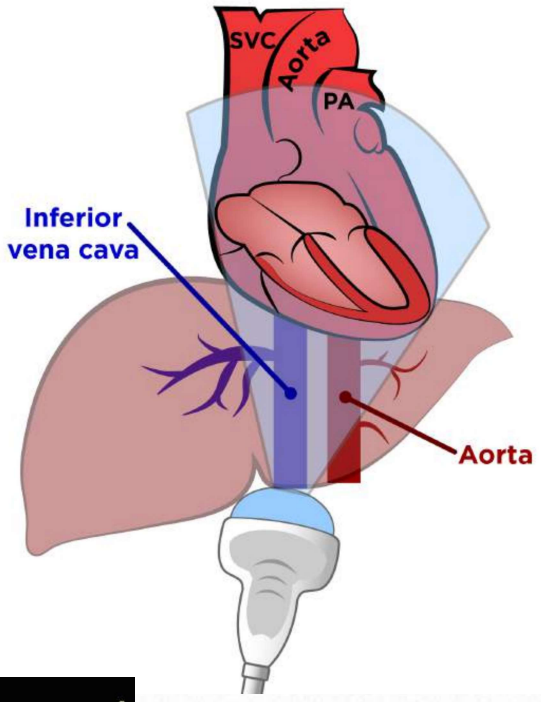
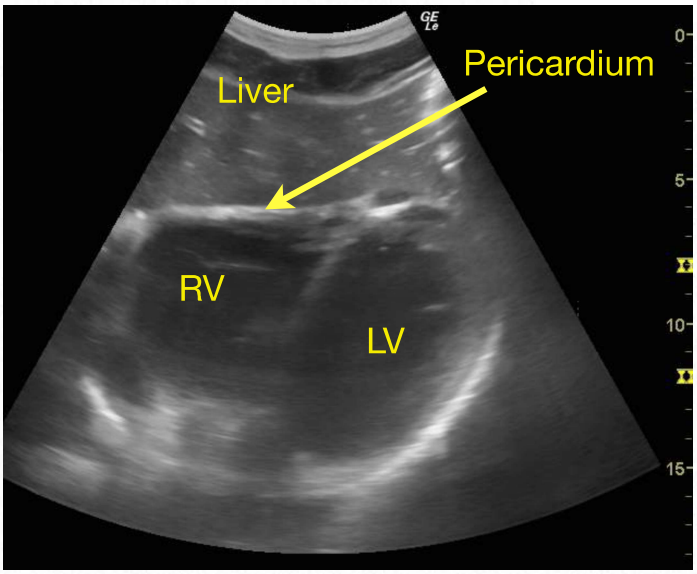
Cardiac – How to Get Some Information Out of a Difficult Patient (Subxiphoid View)







VIEWS DISCUSSED SO FAR

- Subxiphoid View to exam IVC collapsibility
- Doppler of Carotid Artery VTI (velocity time integral) for Assessment of Volume Responsiveness
- Parasternal Long Axis View (Left Ventricular End Diastolic Diameter, Atrial Size, E – Point Septal Separation)
- Parasternal Short Axis View (Left Ventricular End Diastolic Area, Fractional Area change)
- Apical Four Chamber (LA size, Mitral and Tricuspid Valve Evaluation)
- Apical Five Chamber (Aortic Valve Evaluation, LVOT VTI for Volume Responsiveness)

Review of Subxiphoid Pericardial View

- Probe (phased array or curved linear) placed under xiphoid, almost parallel with skin surface, indicator directed to the 3 o'clock position.
- Flexion of hips and knees reduces abdominal tension and aids in image acquisition.
- Image obtained via 90 degree clockwise rotation of the transducer from IVC view.
- Provides ideal view of anterior pericardium, which is the location of most pericardial effusions.
- Consider pneumothorax when unable to obtain images of heart for no apparent reason.

Tips for Subxiphoid View

- Use your liver as an acoustic window (without it you will get gas scatter).
- Have the patient take a deep breath and hold it.

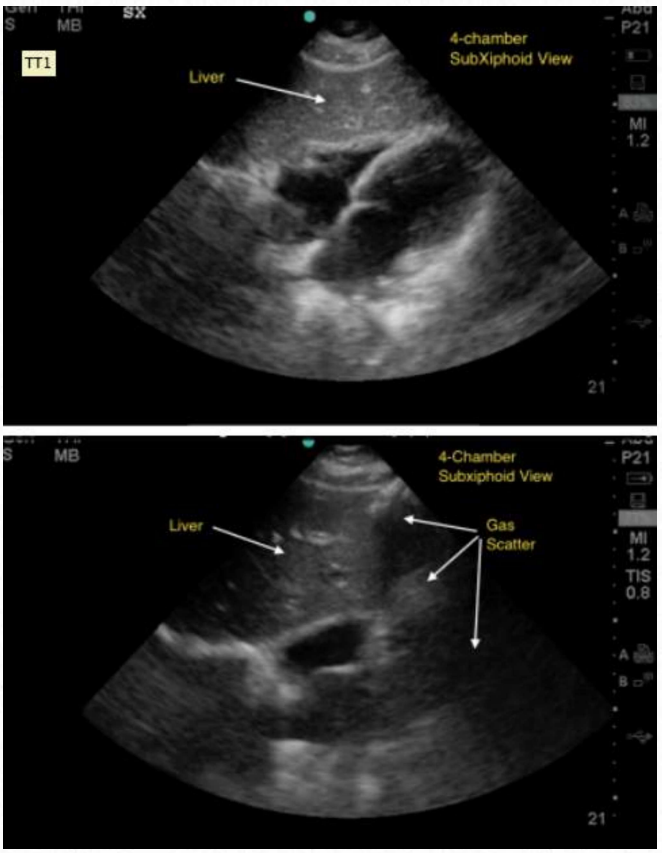
Adjustment from center subxiphoid space to the right (to have ultrasound transmit across the liver versus being reflected by gastric air).

How to Get Some Information from a BAD TTE Image

Image Optimization

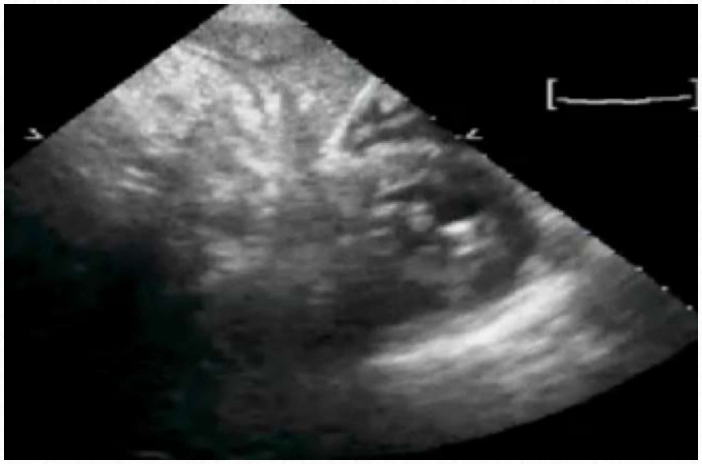
- Make sure you have the best window possible by moving the probe one rib space below and above the standard probe position. When manipulating the probe, it is often best to work in circles around the target area to identify the best acoustic window.
- Remember to always optimize the patient's position.
- If possible hold ventilation.
- Apply more pressure and use adequate amount of ultrasound gel.
- DO MORE EXAMS!

Evaluate for markers of cardiac failure



When one cannot see the entire cardiac anatomy clearly, try to glean information regarding cardiac function from structures that you are able to see.

- Left Atrial Size (> 5cm = Heart Failure)
- E point Septal Separation (1.2cm = Systolic Failure)
- Use non-standard view
- Subxiphoid window altered to get parasternal SAX "like view"



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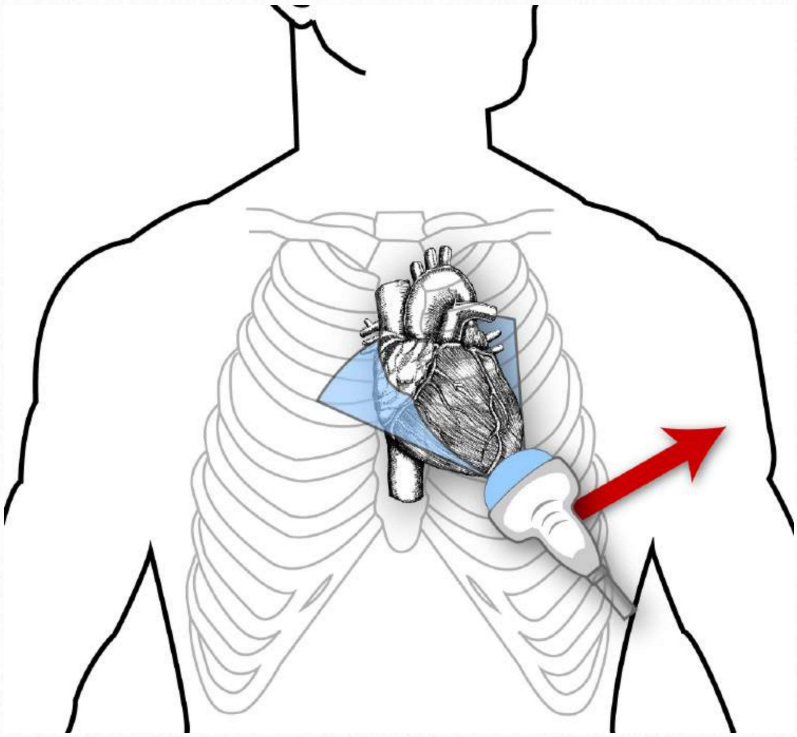
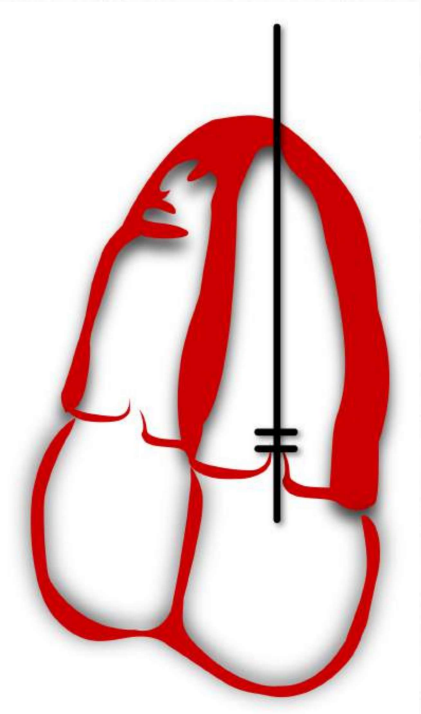
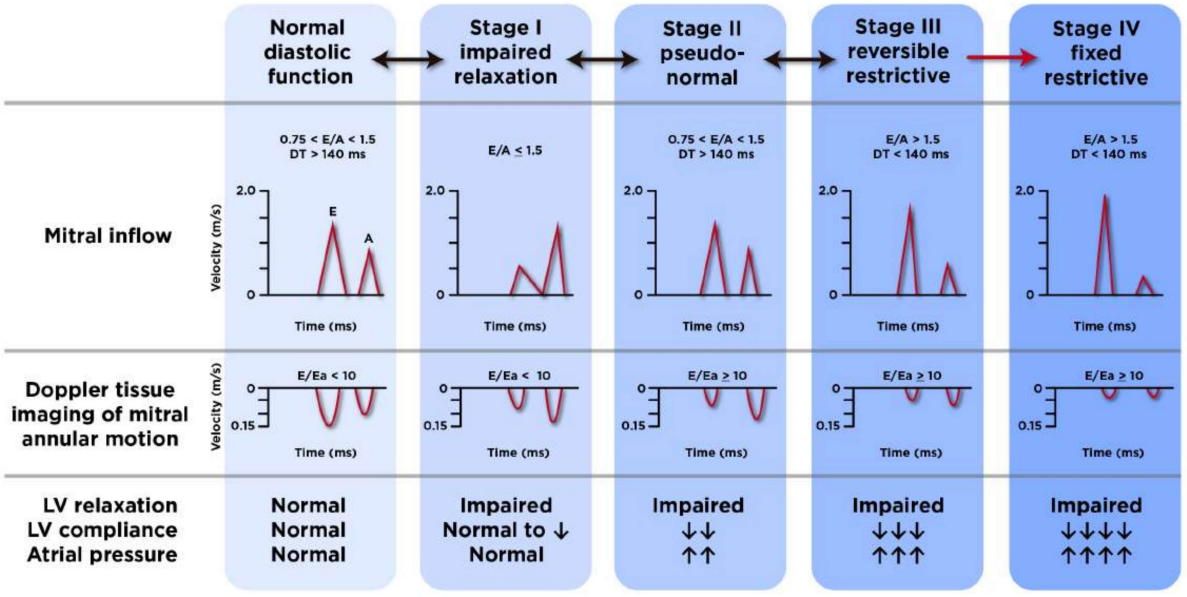
Cardiac Ultrasound: Diastolic Dysfunction





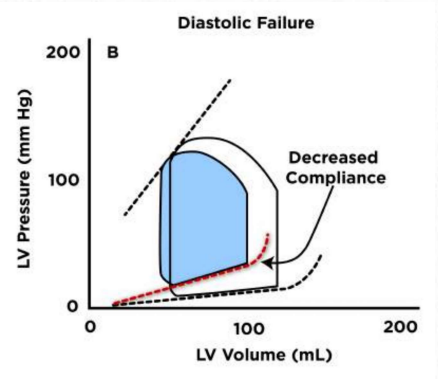
Echocardiographic Classification of Diastolic Dysfunction

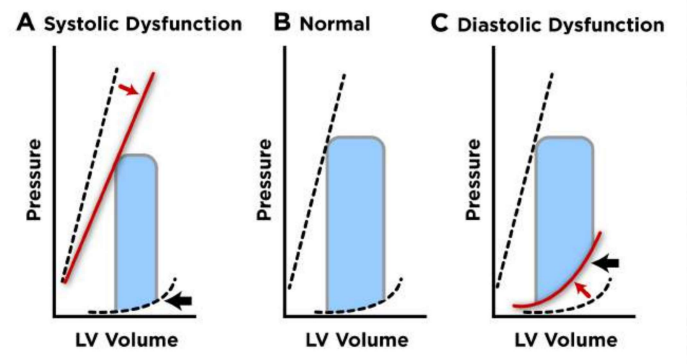


III. CARDIAC: Ultrasound is an excellent modality to assess cardiac function/abnormalities. Surface ultrasound can provide an excellent minimally invasive tool to determine the mechanisms of the patient's current hemodynamic status. Each subsection will cover a cardiac ultrasound technique used to answer these questions.

D. DIASTOLIC DYSFUNCTION

Diastolic Dysfunction is defined as an abnormality of diastolic distensibility, filling, or relaxation of the left ventricle. Normally, diastole occupies about 2/3 of the cardiac cycle. Diastolic relaxation, like systolic contraction, is an active process that requires energy, which is why moments of decreased oxygen delivery will worsen diastolic function. It is important to remember that this abnormality occurs in diastole and therefore is irrespective of systolic ejection fraction (these pathologies can coexist, but one does not require the other). Diastolic heart failure occurs when one's diastolic dysfunction is severe enough to cause dyspnea and decreased functional status. Remember that findings of dyspnea are secondary to venous congestion from elevated pulmonary *venous* pressure and pulmonary edema. Again, diastolic function results in a reduced cardiac output despite a normal ejection fraction. Also, the limited exercise tolerance is a result of elevated left ventricular diastolic and pulmonary venous pressure -> reduction in lung compliance -> increase in the work of breathing.



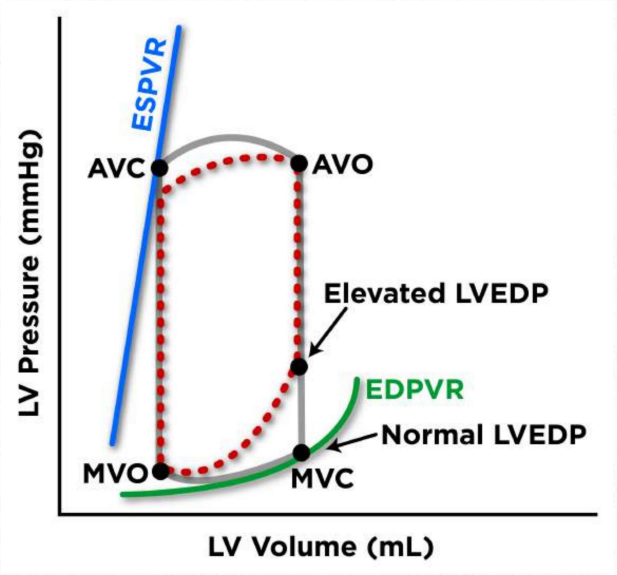


About one third of all patients with congestive heart failure have diastolic heart failure. Prevalence is highest in patients older than 75 years old. The mortality rate is about 5-8% annually as compared to 10-15% among patients with systolic heart failure, and is directly related to age and the presence/absence of coronary disease. Factors that exacerbate diastolic heart failure include uncontrolled hypertension, atrial fibrillation, non-compliance with or inappropriate discontinuation of medications for heart failure, myocardial ischemia, anemia, renal insufficiency, use of NSAIDS or thiazolidinediones, and overindulgence in salty foods.

The pathophysiological features of diastolic dysfunction include 1) abnormal passive elastic properties of the left ventricle, 2) increased myocardial mass, 3) alterations in the extra myocardial collagen network, and 4) increased stiffness of the left ventricle. If you were to look at the pressure-volume curve in a patient with diastolic dysfunction, you would see

Characteristics of Diastolic Heart Failure Compared with Those of Systolic Heart Failure

Characteristic	Diastolic	Systolic
Clinicial Symptoms (dyspnea)	Yes	Yes
LV Ejection Fraction	Normal	Decreased
Left Ventricular Mass	Increased	Increased
Wall Thickness	Increased	Decreased
End Diastolic Volume	Normal	Increased
Left Atrial Size	Increased	Increased
Exercse Capacity	Decreased	Decreased



the curve shift upward and to the left (see picture below). This is because the chamber's diastolic compliance is reduced. This decreased compliance causes the time course of left ventricular filling to be altered. Specifically, the amount of blood and its velocity of flow are altered in early diastole and become more dependent on atrial kick.

Acute management of diastolic dysfunction is to prevent tachycardia and/or slow the heart rate. This will increase the diastolic time and therefore allow for the lowering of pressures to occur by giving more time for them to equalize. Since heart rate determines the length of coronary perfusion time, tachycardia causes a decrease in coronary perfusion time and increases the myocardial oxygen demand. This can be prevented by the use of beta-blockers and non-dihydropyridine calcium channel blockers. For long-term management please see the following:

- To treat hypertension: ACE-Inhibitors or Angiotensin Receptor Blocker
- To promote regression of left ventricular hypertrophy: ACE-Inhibitors
- To prevent fibrosis: Spironolactone
- Control of ventricular rate: Calcium channel blockers
- Control of pulmonary congestion and peripheral edema: Diuretics and nitrates

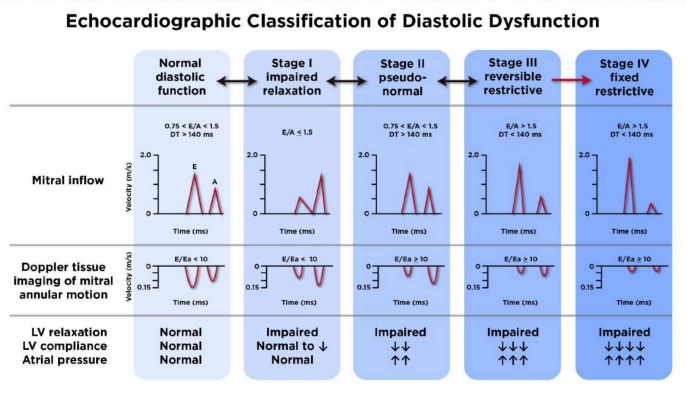
Coronary revascularization in patients with CHD in whom ischemia is judged to have an adverse effect on diastolic function.

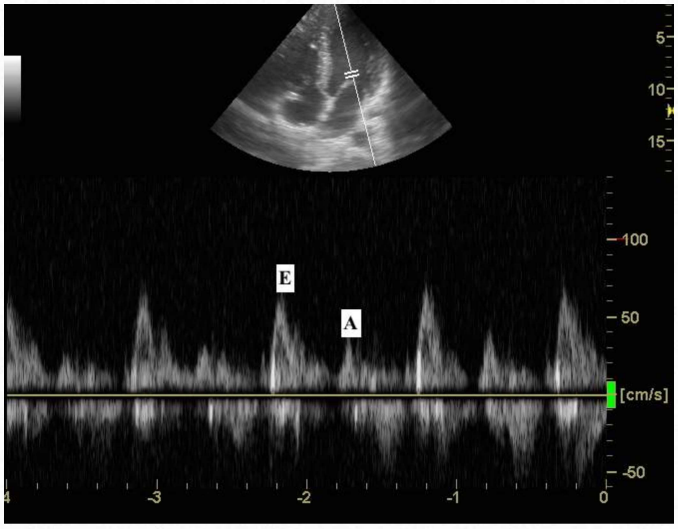
ULTRASOUND ASSESSMENT OF DIASTOLIC DYSFUNCTION

This modality is used to assess diastolic function is pulse wave doppler echocardiography. Remember that pulse wave doppler allows one to assess the velocity in a specific area of the ultrasound image (provides depth and location). The drawback of pulse wave doppler is that there is a limited range of velocities that it can assess (range=Nyquist limit), so it cannot be used to quantify high velocity lesions (such as aortic stenosis). Please review the physics and color doppler chapters for further details on pulse wave doppler. Specifically, for diastolic function we will use PW doppler to assess the mitral inflow of blood from the LA to the LV.

To understand ultrasound assessment of diastolic function, let's first talk about the normal process that occurs in diastole. Diastole consists of 4 phases: 1) isovolumic relaxation, 2) early rapid diastolic filling, 3) diastasis (period of no flow), and 4) late diastolic filling due to atrial contraction. In diastole, isovolumic relaxation (1) is the period during which the LV pressure becomes less than LA pressure and the MV opens. Once the MV opens, rapid early diastolic filling begins (2). The driving forces are predominantly elastic recoil and relaxation of LV muscle. 80% of LV filling normally occurs during this phase. The ultrasound doppler waveform that this phase represents is called the **E wave**. It is important to realize that when both LA and LV pressures at the end of diastole (LVEDP) are normal (low), the **deceleration time** of the E wave, which is the time it takes for the E wave to go back to zero from its peak velocity (see images below), is offset a certain time period **(150-220ms).** When the LVEDP and thus LA pressures are elevated, the peak velocity of the E wave will be higher (since it has a higher forward pressure) and will cause the deceleration time to be faster (<140ms). There is normally a period of no flow, called diastasis (3). This is followed with late diastolic filling which results from atrial contraction, creating the **A wave** (4). This normally accounts for <20% of LV filling, but as the early filling phase (2) is more and more impaired, the atrial kick takes on a greater role of importance.

The normal E, A, and deceleration time patterns are shown below





When it comes to diastolic dysfunction, its severity is graded in **four stages:**

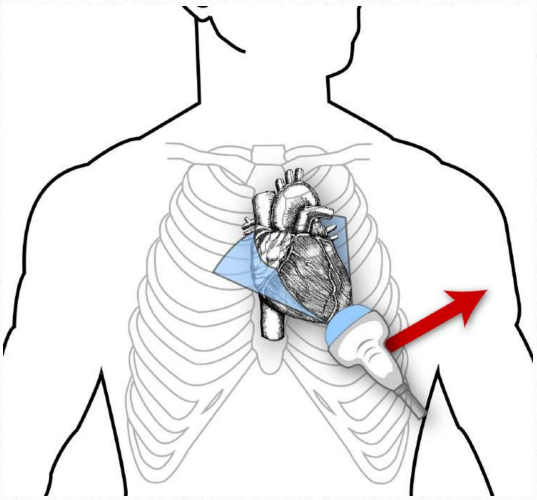
Grade I: First, in the impaired relaxation state (grade I), there is **no elevation of LA pressure**, but rather the LV simply takes more time to fully relax such that there is no diastasis stage. Because the E wave is stretched out over a longer period of time, the peak E velocity is reduced and is actually less than the A velocity. Also, because the E wave takes longer to return to zero from its peak, the deceleration time is increased (defined as being greater than 220ms).

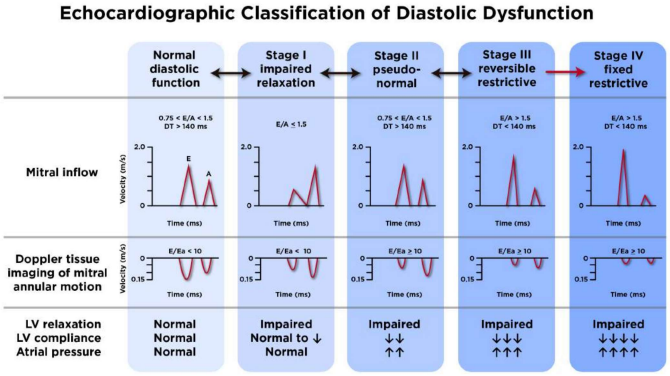
Grade II: In this stage the LV does not relax fully, and therefore **there is an elevation in LVEDP and secondarily in LA pressures.** This increase in pressure causes what is termed *pseudonormalization* of the E and A waves. This is because the now elevated LVEDP (that occurs from incomplete ventricular relaxation) causes the LA pressure to increase. This elevated pressure now causes the early filling stage of diastole (E wave) to shoot into the LV since it has higher LA pressure to drive it. **The way to tell the difference from normal and pseudonormalization is the deceleration time.** With pseudonormalization, the deceleration time will be less than normal (140 ms), because the elevated pressure from the LA and the elevated pressure in LVEDP cause a more rapid time of pressure equalization.

Grade III: This stage is simply a worsening of the phenomena described in Grade II. Now the LA and LVED pressures are even higher. One defines this “worsening” by looking at the E/A ratio. If this ratio is > 2, it has reached grade III diastolic dysfunction.

Grade IV: This stage is the same as grade III, the only difference is that in grade IV there is no change in severity by alerting the patient’s preload, while in grade III there is.

One may assess diastolic function by placing the pulse wave doppler signal just distal to the mitral valve. Looking at the resulting waveform, if one sees E<A then it is mild diastolic dysfunction. If one sees E/A > 2 with a deceleration time <140 ms, it is severe diastolic function. Also, one should examine the left atrium for enlargement to help with the diagnosis as well, since a large atrium may be secondary to an elevated left ventricular end diastolic pressure from diastolic dysfunction. Please see the table below for further details.



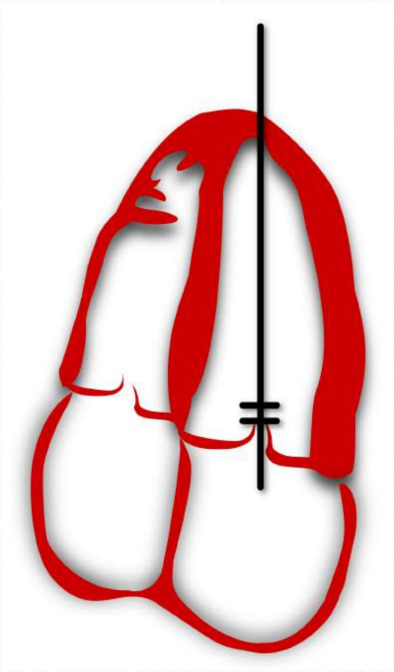


Patient Position Apical Window Views: Left-Lateral with L arm extended.

Probe Type: Phased array cardiac probe (small footprint / low frequency).

Probe Position: The apical window is usually found in the left lateral portion of the chest at the apex of the heart. This can sometimes be located by placing your hand lightly in area of the apex and feeling for the point of maximal intensity (PMI). The PMI will serve as your starting point; however, small adjustments will need to be made to the transducer location to optimize the image. Another good starting point is to go one to two rib spaces below, but in the same plane as the nipple. Also, please see the diagram below for the location of PW doppler signal.

Location of PW Doppler Signal



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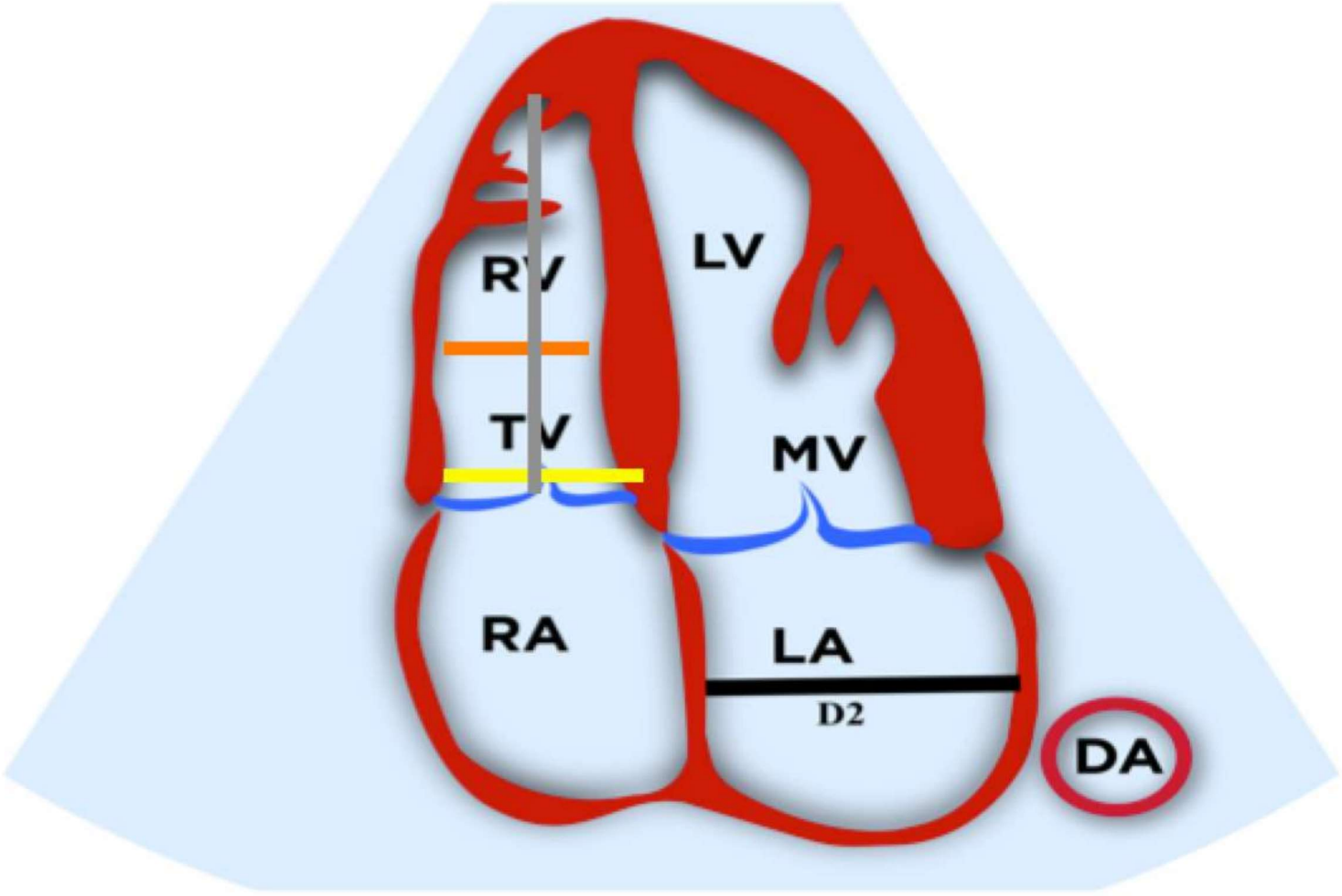
Cardiac Ultrasound:Assessment of Right Ventricular Function

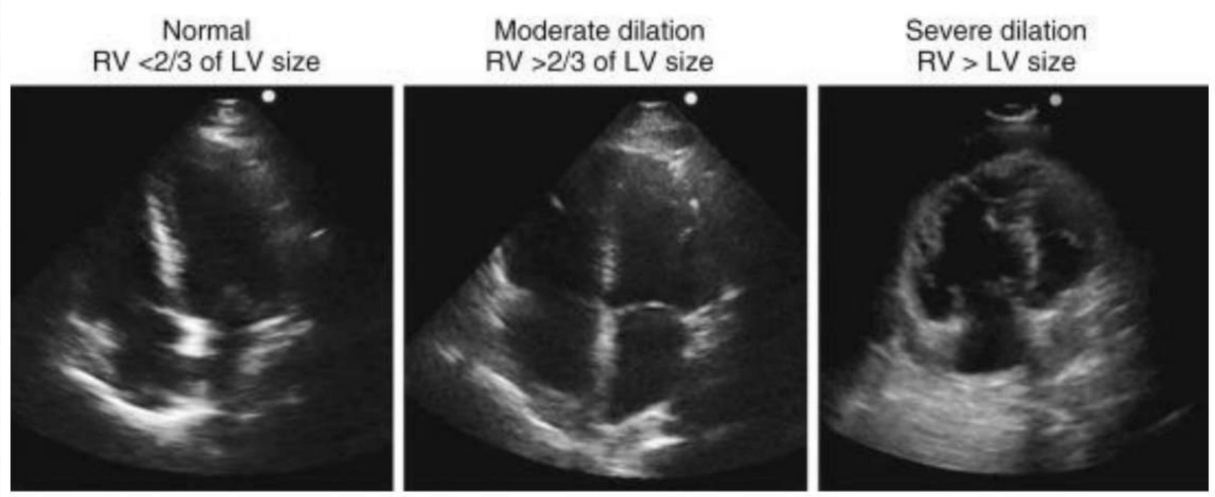


Right Ventricular Dimensions

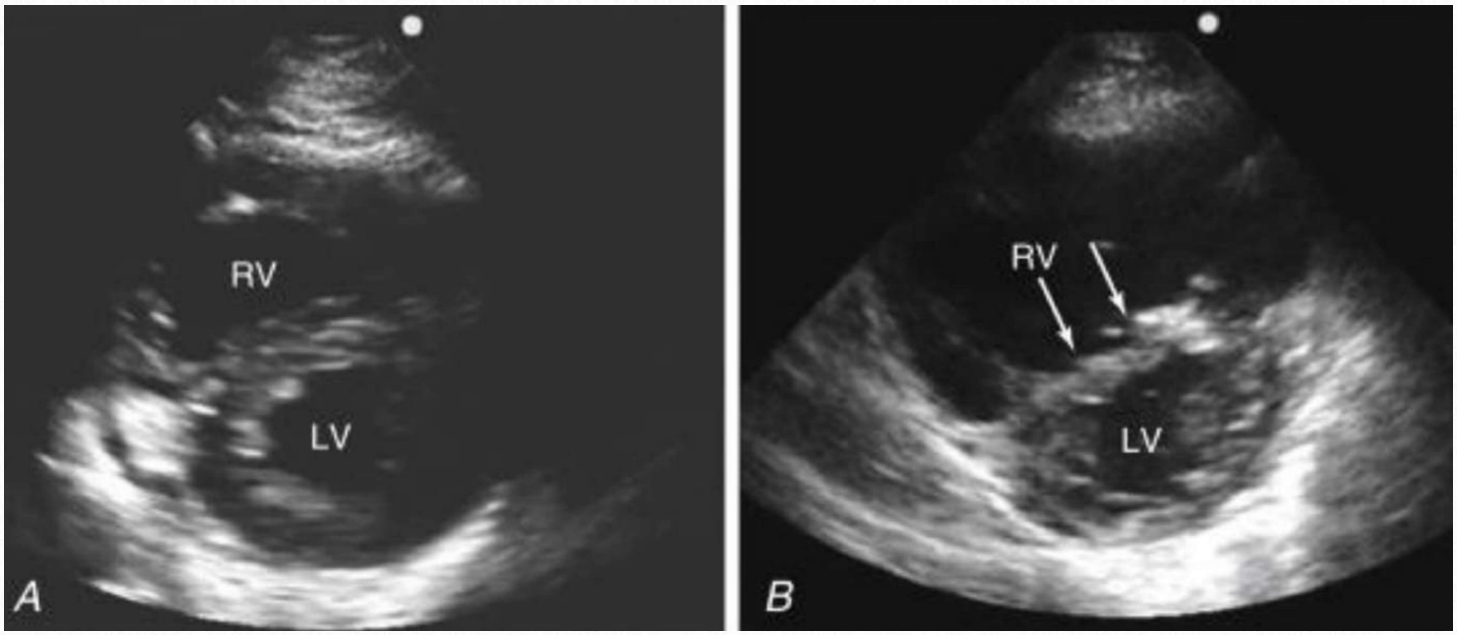
Comparison of right ventricular dimensions to the left ventricle is an important technique to assess function.

Ideal views include Apical 4-Chamber and Subcostal 4- Chamber views

The RV internal diameter should not be more than 2/3 the size of the LV and it should not extend more than 2/3 to the apex of the LV.



Examination of Inter-ventricular septum forming a flattened or "D shaped" LV should be concerning for RV failure



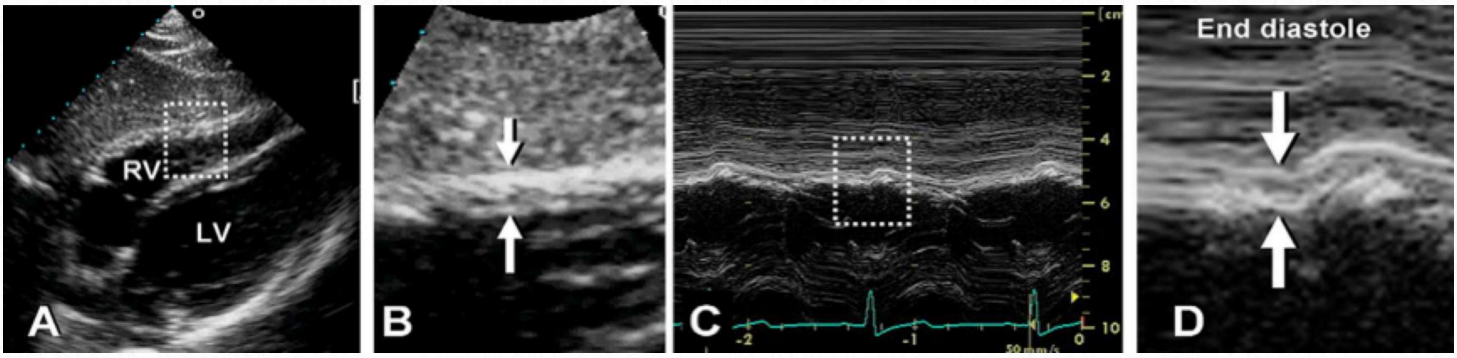
RV Wall Thickness

From the subcostal view, align the u/s beam perpendicular to the RV free wall

Exclude RV trabeculations and papillary muscle from endocardial border

M-Mode Can be helpful

Normal < 0.5 cm



Measurements of RV Systolic Function

The RV is a thin walled and its systolic function is based on longitudinal shortening.

The key assessment relies on seeing a significant change in the “length of the RV” from diastole to systole.

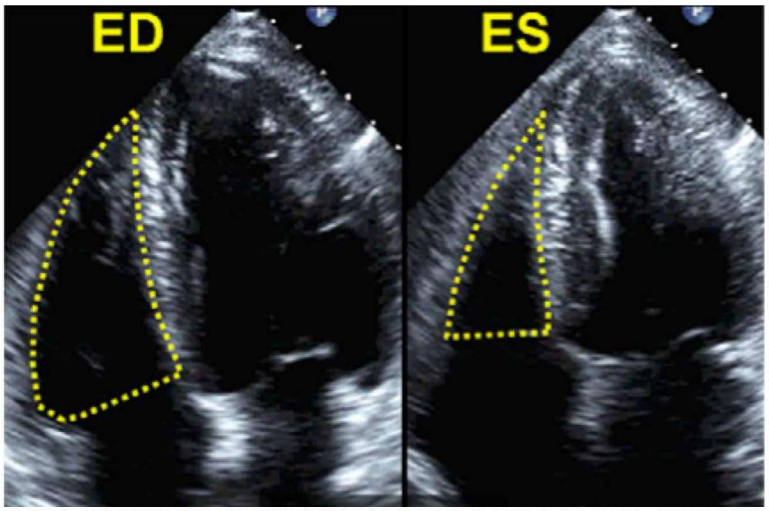
Fractional area change (FAC)

Tricuspid annular plane systolic excursion (TAPSE)

Right Ventricular Fractional Area Change

Obtained by tracing RV endocardium both in systole and diastole from the annulus, along the free wall to the apex, and then back to the annulus, along the interventricular septum

Avoid trabeculations



Normal > 30 %

$$\frac{\text{End diastolic area} - \text{End systolic area}}{\text{End-diastolic area}} \times 100$$

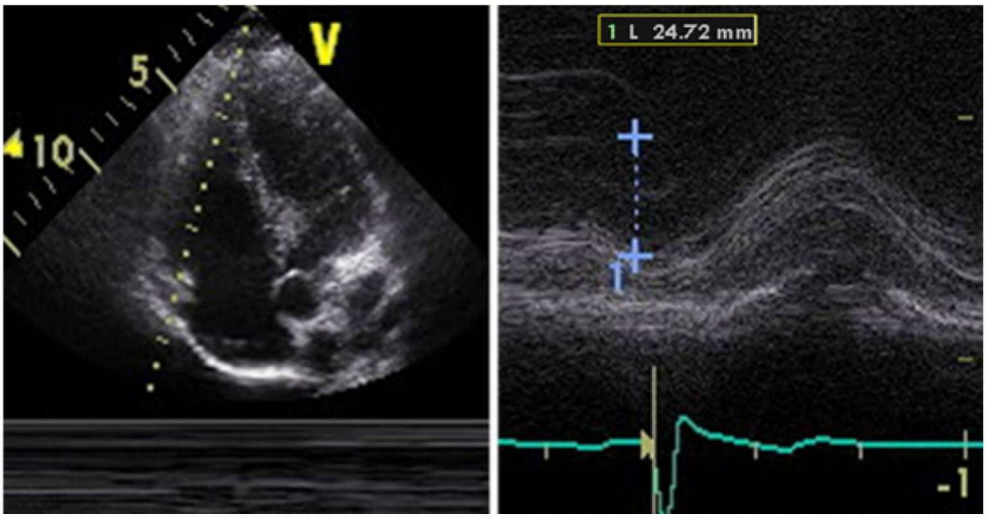
RV FAC correlates well with RV EF by MRI

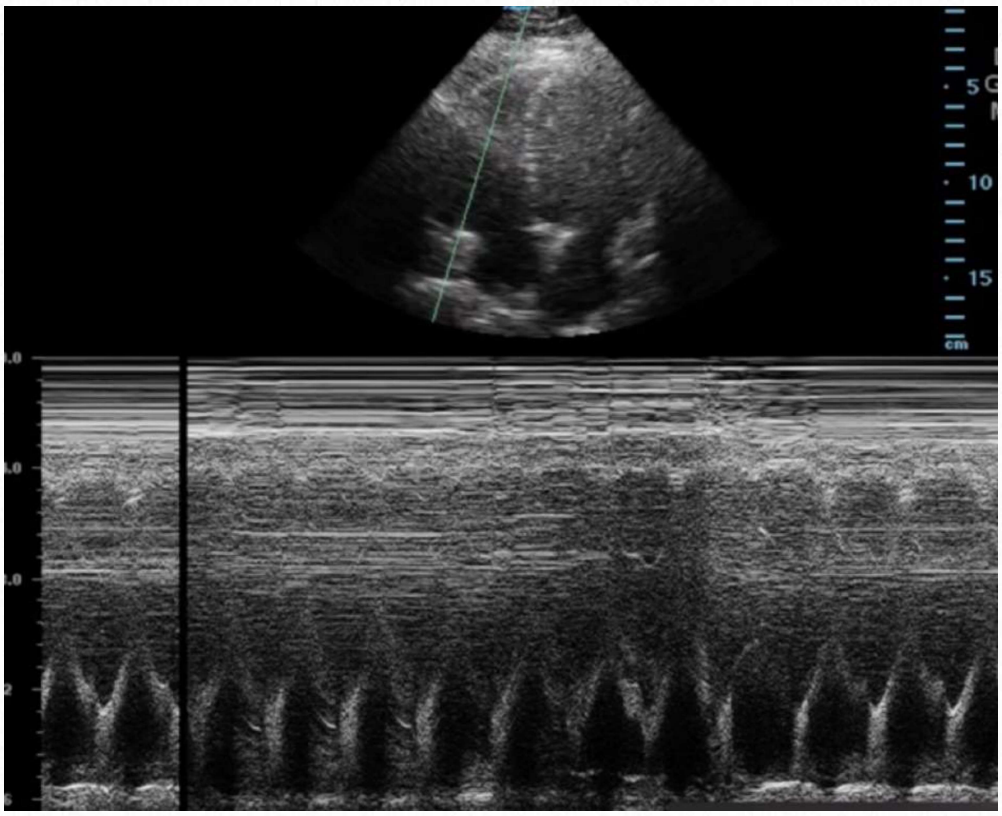
RV FAC found to be independent predictor of heart failure, sudden death, stroke, and/or mortality in studies of patients after pulmonary embolism

Tricuspid annular plane systolic excursion (TAPSE)

Acquired by placing an M-mode cursor through the tricuspid annulus and measuring the amount of longitudinal motion of the annulus at peak systole

Normal > 16 mm





TAPSE

Advantages

TAPSE is simple

Less dependent on optimal image quality

Reproducible

Does not require sophisticated equipment or prolonged image analysis

Disadvantages

TAPSE assumes that the displacement of a single segment represents the function of a complex 3D structure

It is angle dependent

There are no large scale validation studies

TAPSE maybe load dependent

Right atrial assessment

Apical 4-chamber view

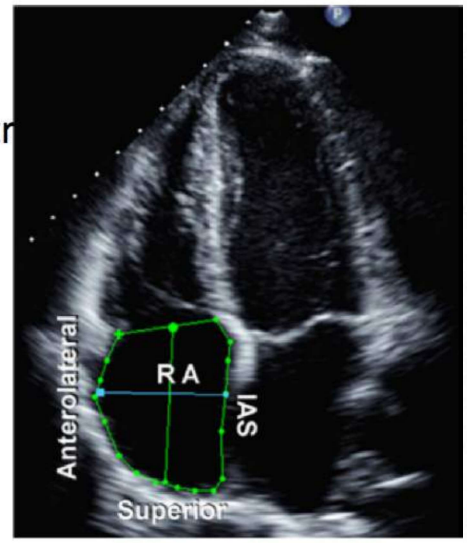
Estimation of right atrial area by planimetr

The maximum long distance of the RAis from the center of the tricuspid annulus to the superior RA wall, parallel to the interatrial septum

A mid RA minor distancve is defined from the mid level of the RA free wall to the interatrial septum perpendicular to the long axis

RA area is traced at the end of ventricular systole, excluding the IVC, SVC, and RAA

Normal area < 18 cm²



Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, Solomon SD, Louie EK, Schiller NB. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of

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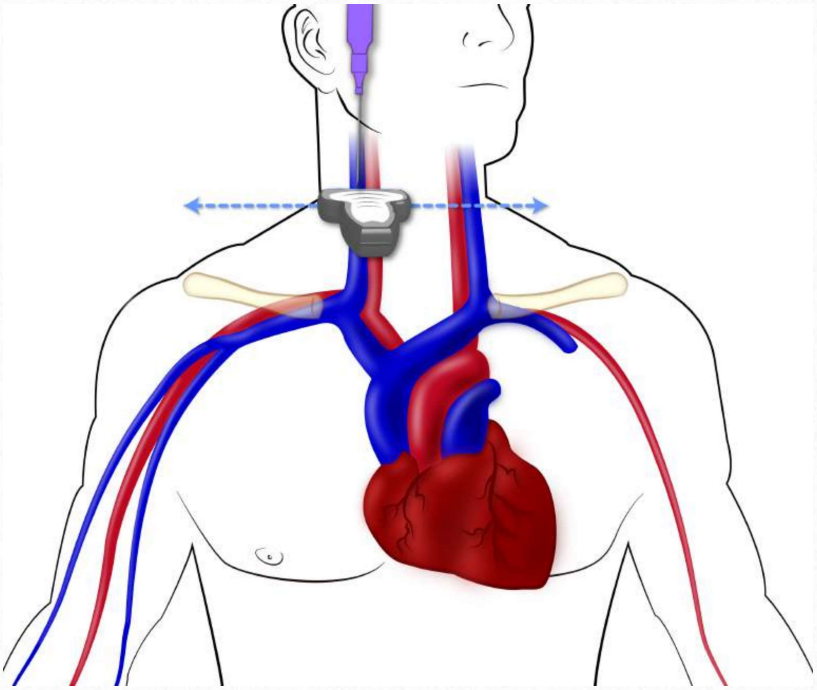
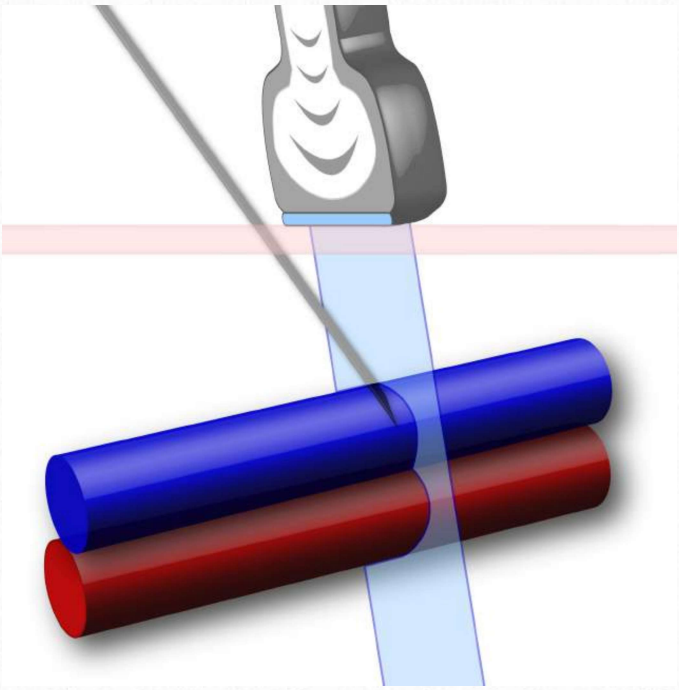
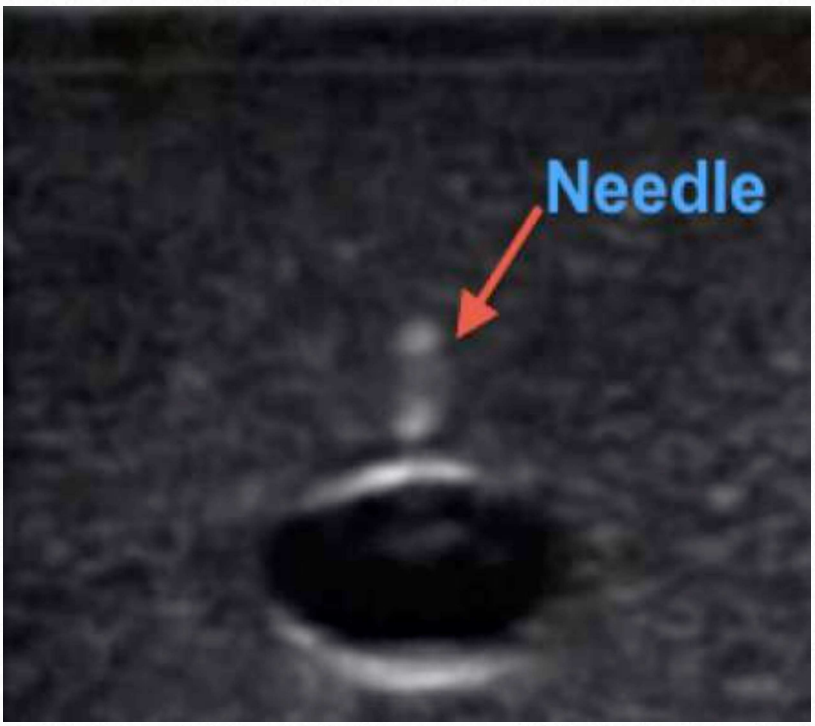
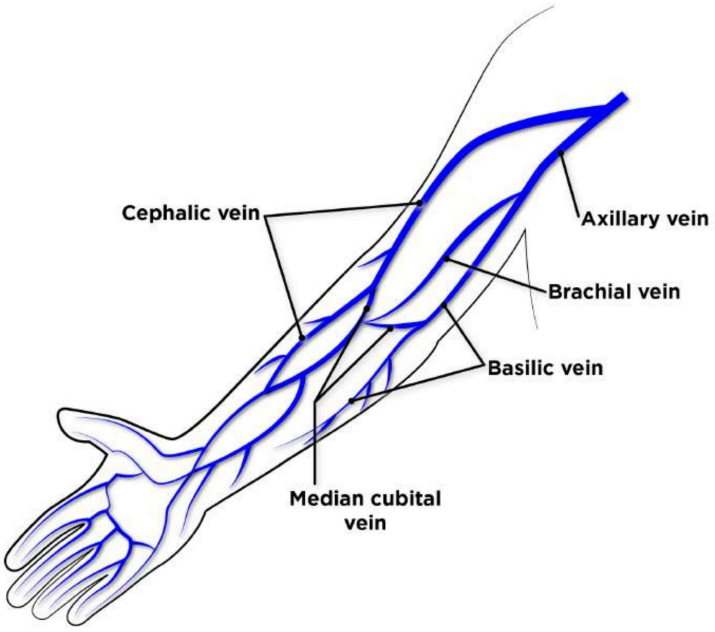
Ultrasound Guided Vascular Access









IV. VASCULAR ACCESS

Obtaining vascular access is a vital procedure for clinicians. Previously, one had to rely on external landmarks to guide placement. However, this can be challenging in chronic medical conditions, intravenous drug use, and obesity. In addition, the proximity of such structures as the large arteries of the chest and neck as well as the apex of the lung results in a 6.2-11.3% rate of immediate mechanical complications when performing subclavian or internal jugular catheterization. With the advancement of ultrasound technology we have been able to reduce this complication rate. Multiple studies have shown the benefit of ultrasound guidance in central venous catheter placement by multiple specialties, and the same technique has been extended to the placement of peripheral intravenous catheters. Ultrasound adds to vascular access in may ways. It provides knowledge of exact vessel location, it allows detection of anatomic variations, helps avoid veins with pre-existing thrombosis, helps identify occluded vessels (one study noted this to occur in the internal jugular 18% of time in patients on hemodialysis), helps guidance of both guide wire and catheter placement after initial needle insertion, reduces venipuncture attempts, and finally reduces overall complications.

Probe Type: High frequency (5-12 MHz) linear probe

Remember that for ultrasound imagery of superficial areas use of a flat linear probe with a small footprint which will be best for image quality and ease of use during vascular access. Image orientation is also key. Make sure to identify the indicator marker on the probe and relate it to the indicator marker or the screen. The goal is to keep the indicator on the side of the probe oriented in the same direction as the orientation mark side of the screen. If there is any confusion about the orientation, one should place a finger on one side of the transducer surface after gel application to produce an image on the screen.

IMAGE OPTIMIZATION

Adjustment of the previously discussed ultrasound settings is crucial to optimize the image. Realize that most ultrasound machines have a pre-programmed vascular setting that may help. Additionally, one must always minimize the depth such that the vessel of interest is in the middle of the screen. Having extra depth essentially wastes ultrasound waveforms and will result in poorer image quality. Also, one should adjust the gain such that blood appears black on the ultrasound screen. Finally, one should always adjust the focus at the level of the target vessel.

DIFFERENTIATING ARTERY AND VEIN

It is essential to be able to differentiate between arterial and venous structures, which does get more difficult when trying to identify deep peripheral veins. One key difference is that the vein should be more compressible, requiring only minimal pressure from the probe, while arteries retain much of their original shape and appearance. Also, remember that Valsalva maneuvers and Trendelenberg positioning make the vein larger, but will have minimal affect on the carotid artery. The application of color Doppler is also very useful in differentiating artery from vein. Arteries have pulsatile flow visualized on color Doppler, while the vein has minimal flow more continuous flow. Finally, when it comes to peripheral vascular access, one should see the vein enlarge after the tourniquet is placed, while the size of the artery should not change.

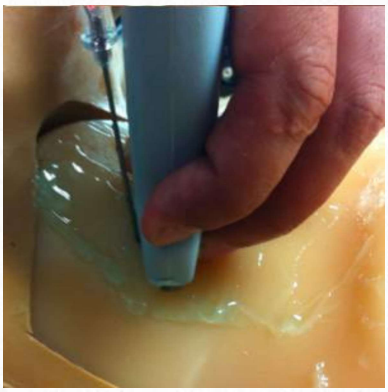
IMAGE VIEWS

There are two planes of ultrasound that are used for vascular access: transverse and longitudinal views (see below). In the transverse view, the transducer plane is in cross section of the target vessel and the vessel is displayed on the screen as a circle. The transverse view gives the advantage of seeing surrounding structures, but one can't see the entire needle. In longitudinal view, the transducer plane and vessel plane are parallel and the vessel is displayed as a long tube running across the screen. A longitudinal view allows visualization of the entire vessel of interest, but it does not show surrounding structures.

ULTRASOUND FOR CENTRAL VENOUS ACCESS

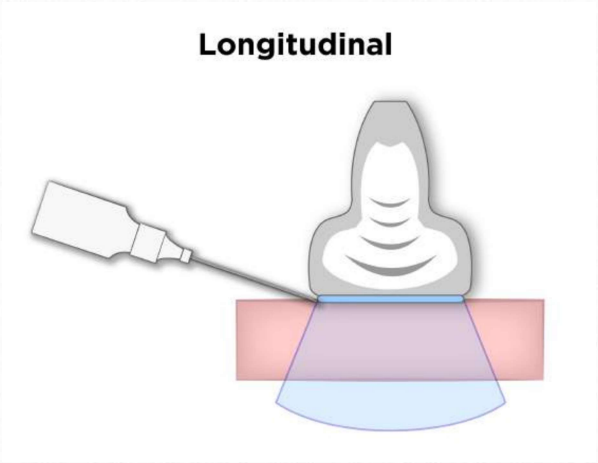
A. Internal Jugular Vein:
The internal jugular vein is typically located anterior and lateral to the carotid artery; however, there is a significant anatomic variation where the vein can overly the artery, and can even be medial to the artery. Please note that in the longitudinal view, the IJ vein can be followed inferiorly, down to the

level of the sternoclavicular joint where it joins the subclavian vein on each side and drains into the superior vena cava.

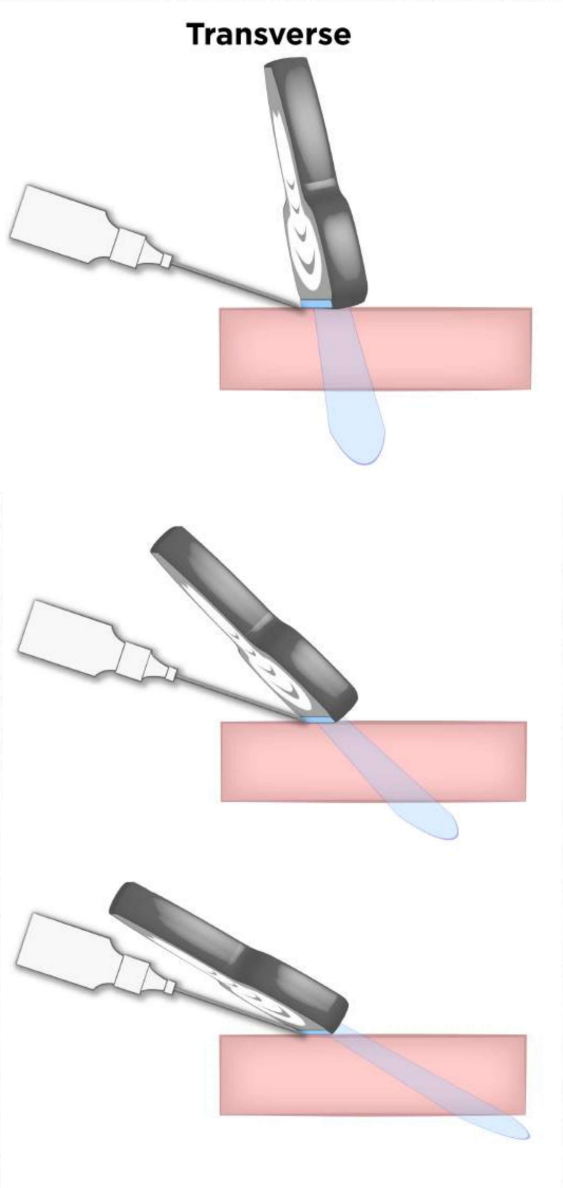


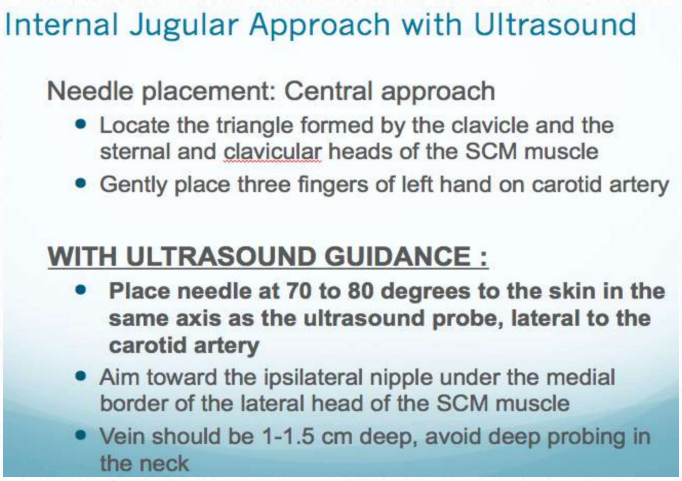
Positioning and preparation: It is important to have proper positioning of the patient. For the IJ cannulation, the patient's head should be rotated slightly contralaterally with the neck extended. Please note that extreme rotation of the neck may increase the amount of overlap of the carotid artery and IJ vein. The patient should be placed in the Trendelenberg position in order to maximally distend the IJ vein. The ultrasound machine should be placed by the same side of the bed and directly in front of the provider to provide a direct line of vision.

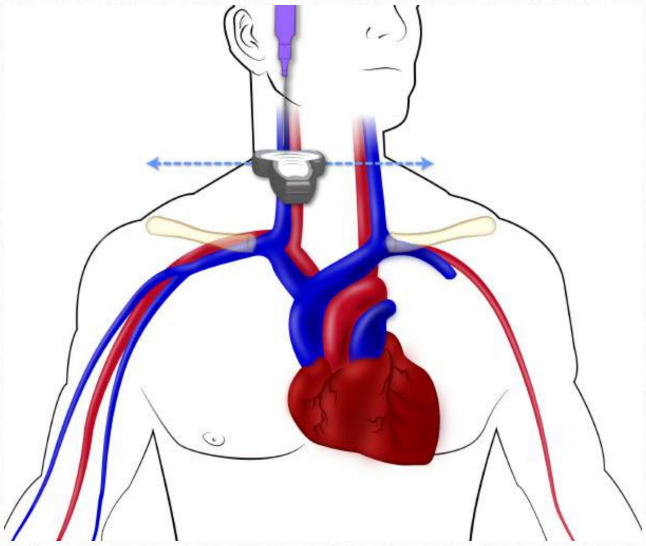
Ultrasound guided catheter insertion: One should start in the transverse view with the dominant hand controlling the needle and the non-dominant hand holding the transducer. One should place the vessel in the middle of the transducer and then place the catheter in the same plane of the ultrasound image (see diagram). Please note that this will result in a much steeper angle than would be used if one were performing a blind insertion. In this approach, the needle tip and the shaft are visualized as a hyperechoic dot. If the needle tip cannot be visualized, indenting the tissue overlying the vein or moving the transducer along the axis of the vein while "agitating" the needle may enhance the image of the needle and tip. As the needle progresses one should "fan" the ultrasound probe to maintain a view of the needle (see diagram). If considering longitudinal plane, the needle is placed inline with and parallel to the transducer, in which the entire length of the needle and the tip are visualized as the vein is punctured. Once the vessel has been successfully punctured, the transducer can be set aside and the procedure can proceed normally with wire and catheter placement.



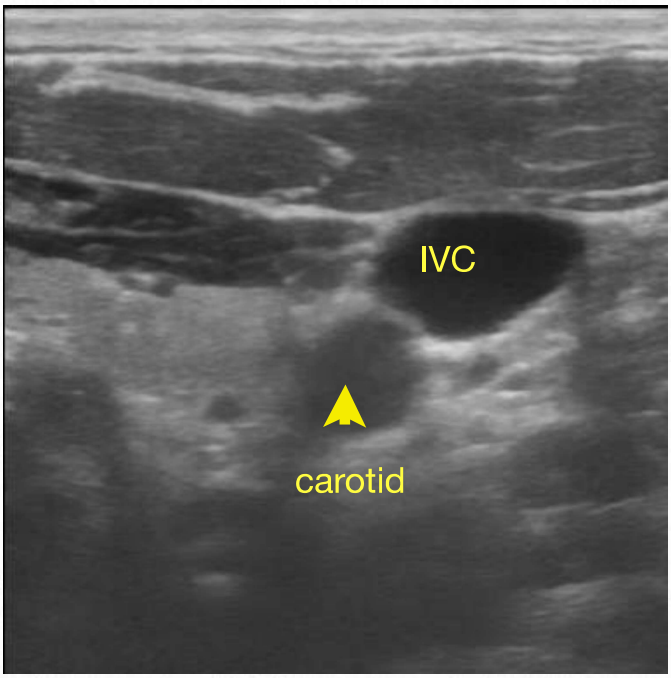
Transverse: Fanning Approach to follow Needle Tip







Internal Jugular Anatomy

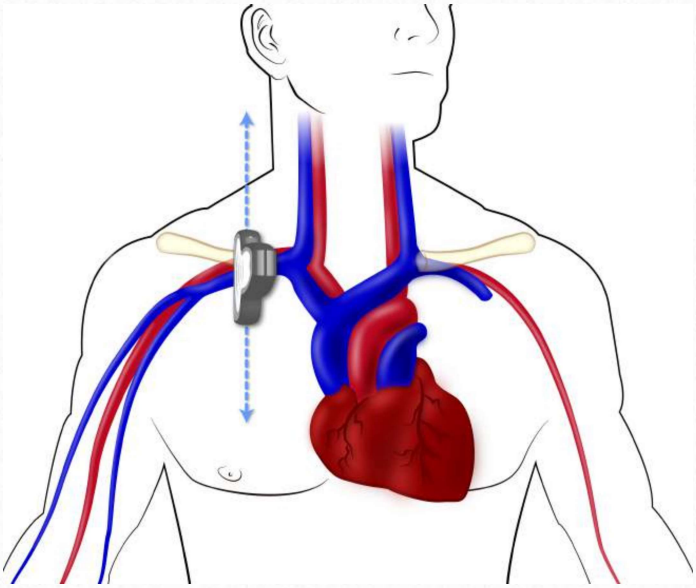


B. SUBCLAVIAN VEIN

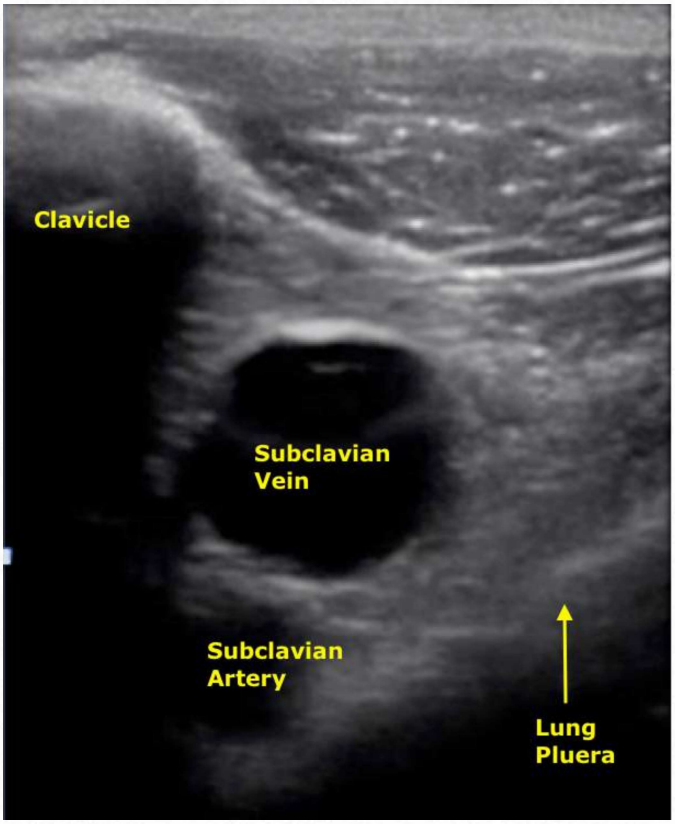
The subclavian vein is a continuation of the axillary vein at the lateral border of the first rib. It crosses over the first rib, and passes in front of the anterior scalene muscle, which separates the vein from the subclavian artery. The subclavian vein (SC) continues behind the medial third of clavicle. At the junction of sternoclavicular joint on each side, SC veins join to the IJ veins and form the innominate vein to the left and brachiocephalic vein to the right side. Also, please note that the RUL is lower than the LUL, so first subclavian vein target should be the right when possible.

Positioning and Preparation: Positioning is key for subclavian vein access. One should again place the patient in Trendelenberg if possible. Also, a roll under the scapula may help make the outline of the clavicle more obvious. Finally, traction on the ipsilateral arm may flatten the clavicle and allow a more direct alignment for access of the subclavian vein. If possible, one should ultrasound the vein prior to sterile prep to get an idea of the anatomy and to see if these maneuvers listed help or hurt.

Ultrasound Guided Catheter Insertion: The subclavian vein can be visualized at the infraclavicular region by placing the transducer at the mid to lateral 2/3 of the clavicle, with half of the footprint covering the cross section of the clavicle and the lower half investigating the infraclavicular region (see picture below). With the probe in this position (using the non-dominant hand), one should have the needle at the junction of the middle and medial thirds of the clavicle, aiming to make contact with the clavicle with the angle of the needle being parallel to the skin. Once this is obtained, one should walk off the clavicle by slightly increasing the degree of steepness of the needle. This should be visualized with the ultrasound image. Once the needle is off the clavicle, one should aim for the subclavian vein, directing towards the supraclavicular notch using the ultrasound image to make sure not to violate the lung pleura. The approach should not be steeper than 45 degrees (see below).



Subclavian Vein Anatomy

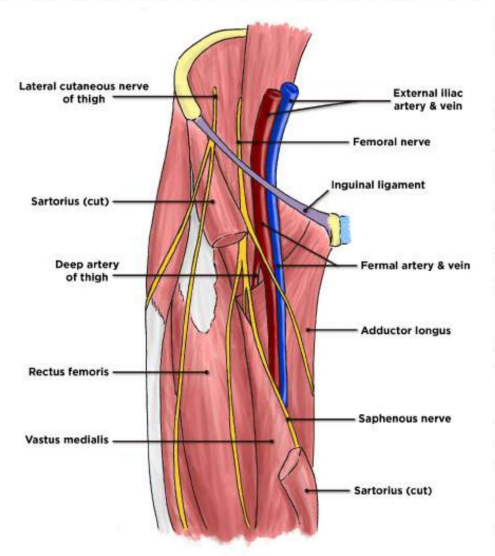


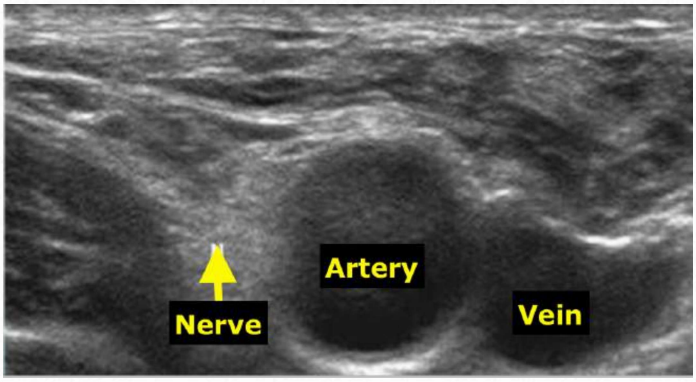
C. FEMORAL VEIN

The proximal femoral vein is medial to the femoral artery/nerve, deep to the fascia iliaca, and superficial to the iliopsoas muscle (see picture below). At the lower level the vein gradually descends posterior to the femoral artery, which would be deeper in ultrasound scanning. Usually, for central catheter placement, one should consider more proximal placement where the vein is medial to the artery. Confirmation of the vein vs. the artery should be obtained using the techniques described above. Also note that minimal pressure on the vein can totally compress the vein, confirming the lack of thrombosis.

Positioning and Preparation: One should externally rotate the hip (frog leg) to optimize exposure to the femoral vein.

Ultrasound Guided Catheter Insertion: Similar to ultrasound of the SVC, one should have the transducer in the transverse position along the inguinal crease. If the femoral artery and nerve are too deep, the machine imaging capability should be adjusted appropriately by increasing the depth and adjusting the gain. Starting with a short axis view will provide a sufficient image of adjacent structures and facilitate a proper needle insertion. Again, the needle should be in line with the ultrasound probe (similar as described for the SVC). Also, as with the SVC, the transducer can be rotated 90 degrees while the femoral vein image is kept in the center of the screen, providing a longitudinal view of the vein. Generally, the needle insertion should be around 2 cm below the inguinal ligament and the needle should be directed to the umbilicus.



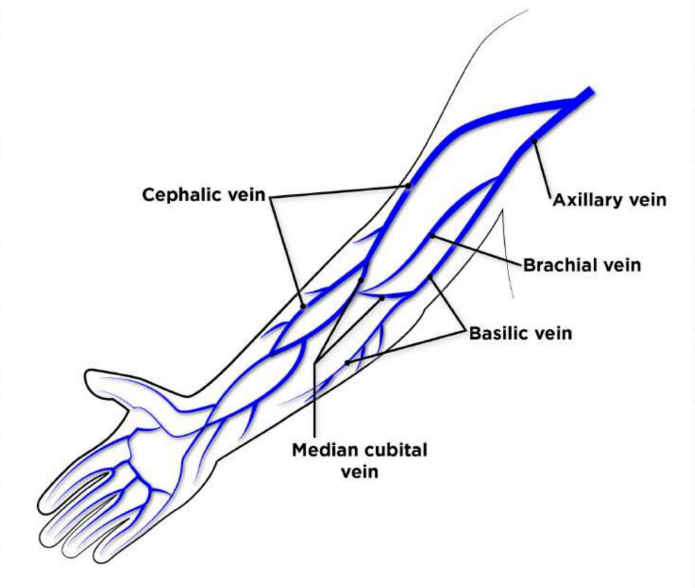


Location	Advantage	Disadvantage
Internal Jugular	• Bleeding can be recognized and controlled • Malposition is rare • Less risk of pneumothorax	• Risk of carotid artery puncture • PTX possible
Femoral	• Easy to find vein • No risk of pneumothorax • Preferred site for emergencies and CPR	• Highest risk of infection • Risk of DVT • Not good for ambulatory patients
Subclavian	• Most comfortable for conscious patients • Lowest infection rates	• Highest risk of PTX,

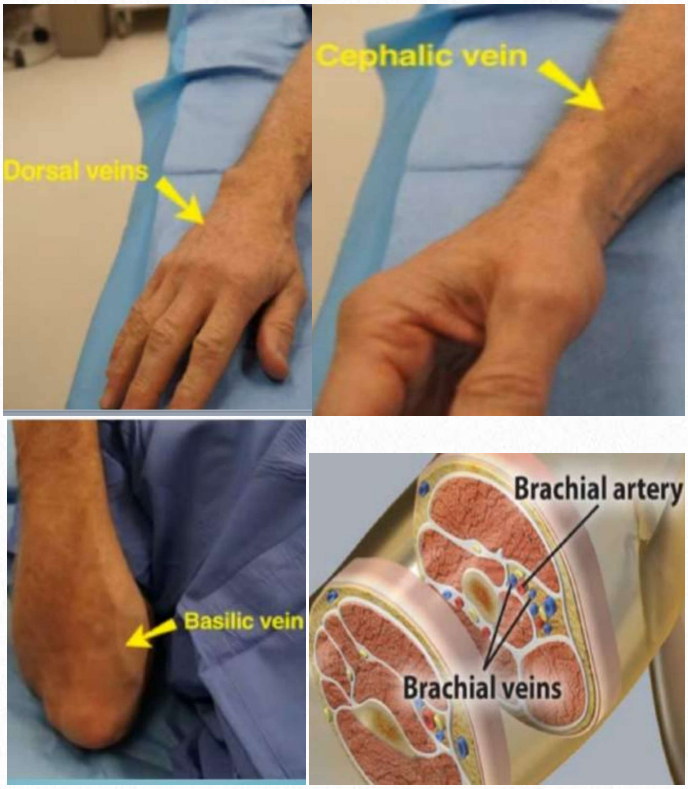
ULTRASOUND FOR PERIPHERAL VENOUS ACCESS:

Intravenous (IV) access is a basic, yet critical procedure. While this procedure is usually performed by medical technicians or nurses, sometimes they are unable to obtain access, and the physician should be knowledgeable in the use of ultrasound to establish IV access. This knowledge can help obtain an IV quicker, with fewer complications, and may prevent the unnecessary placement of central venous catheters.

Here's a brief review of anatomy (see pictures). The upper extremity consists of two types of veins: superficial and deep. The deep veins accompany the arteries, and they are connected to the superficial system by perforating veins. The superficial veins start on the back of the hand and are called the dorsal veins. Note that for pediatrics and obese adults one can reliably "predict" that a dorsal vein lies between the third and fourth digits. Dorsal veins of the hand empty into the cephalic vein on the lateral aspect and into the basilic vein on the medial aspect of the forearm. The cephalic vein ascends in the lateral aspect of wrist and courses laterally upward around the anterior surface of the forearm. Under the front of the elbow it divides into some branches, receives a communicating branch from the deep veins of the forearm (median cubital vein), and passes across to join the basilic vein. In the upper arm, the cephalic vein terminates in the infraclavicular fossa, and empties into the axillary vein. This vein can be quite superficial compared to the basilic. The basilic vein runs medially along the ulnar part of the forearm, and penetrates the deep fascia as it courses past the elbow in the upper arm. It then joins with the deep brachial veins to

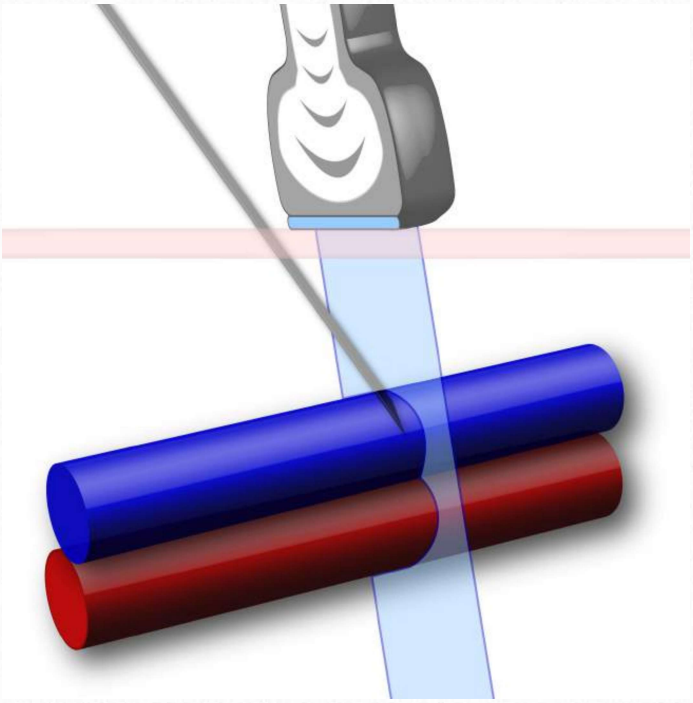


become the axillary vein. The basilic vein is the first choice for PICC line insertion. The median cubital vein joins the cephalic and the basilic veins on the ventral surface of the elbow. The axillary vein becomes the subclavian vein at the lateral border of the first rib as described above.

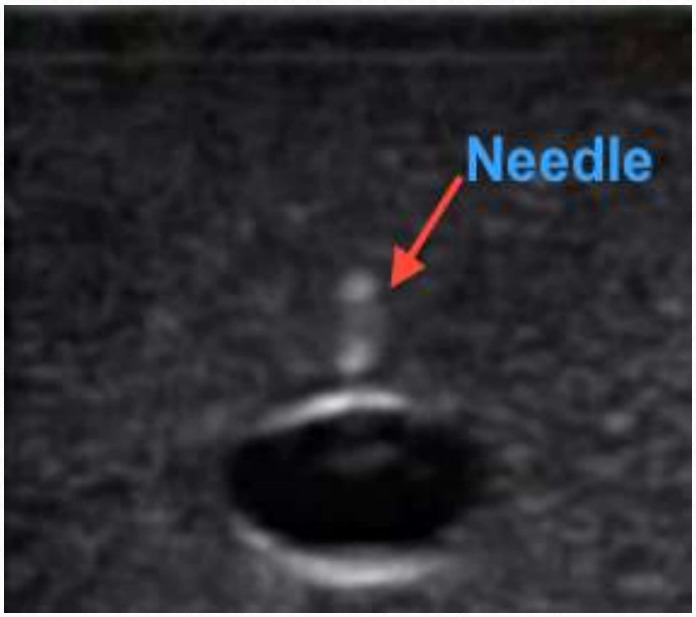


Positioning and Preparation: Please review the criteria to differentiate between veins and arteries. The depth key should be adjusted to make sure veins are in an approachable depth.

Ultrasound Guided Catheter Insertion: The high frequency, linear probe is appropriate for peripheral IV access. Please review the above section on the differentiation between veins and arteries. One should have the ultrasound probe in the transverse view, making sure to be aware of the orientation marker and its relationship to the indicator of the US monitor. Remember, the depth key should be adjusted to make sure veins are in an approachable depth. Using the transverse axis approach, the vein should be positioned in the middle of screen. In this situation, the middle of the transducer is compatible with the middle of the US screen. Appropriate angiocatheter size should be used. Introduce the angiocatheter at a 45 degree angle to the probe with a 3-5 mm distance between the catheter and the US probe (see picture below). THIS APPROACH IS DIFFERENT THAN THE US TECHNIQUE FOR LARGER/DEEPER STRUCTURES. This technique is used for all superficial structures, because with this approach the needle tip should be visualized by the US probe, the same point that it is about to cannulate the vein. THIS IS A VERY IMPORTANT CONCEPT. WHEN TRYING TO USE ULTRASOUND TO CANNULATE SUPERFICIAL STRUCTURES, IT IS BETTER TO TRACE OUT A TRIANGLE SUCH THAT THE CATHETER TIP WILL INTERSECT THE ULTRASOUND PLANE RIGHT AT THE ENTRY POINT OF THE VESSEL (see pictures below). You should see the tip of the needle as a hyperechoic structure as you approach the vein. You should stop advancing your needle as soon as you get

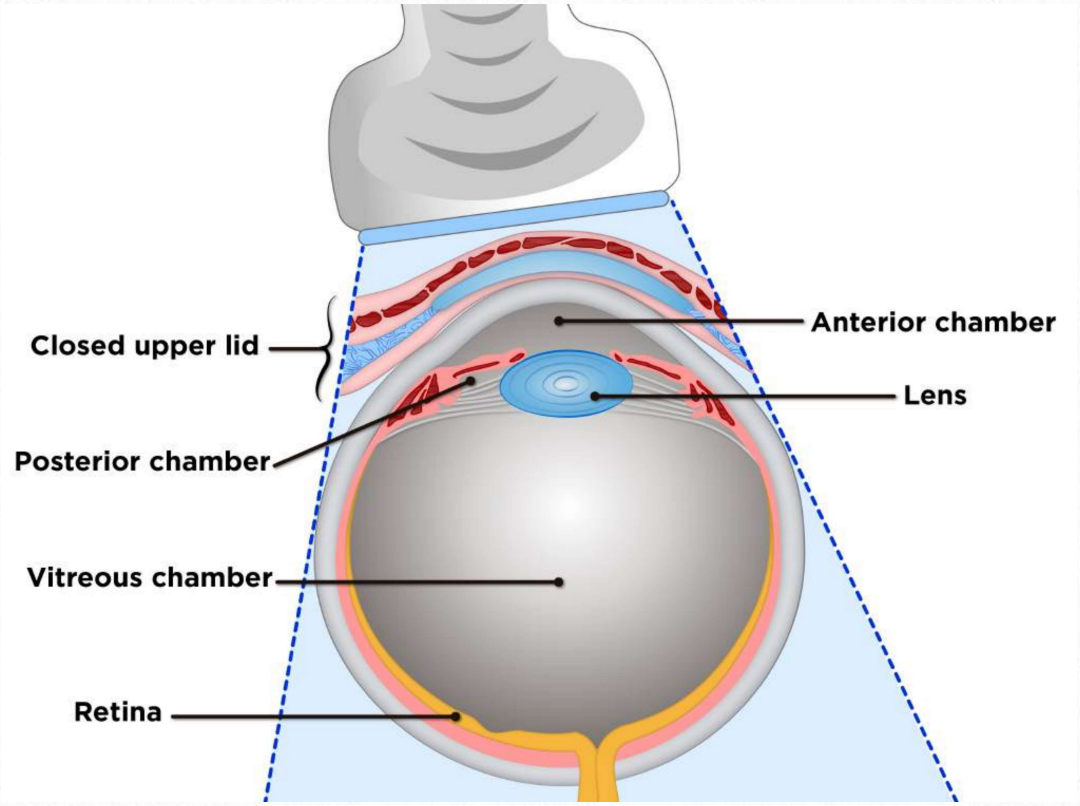


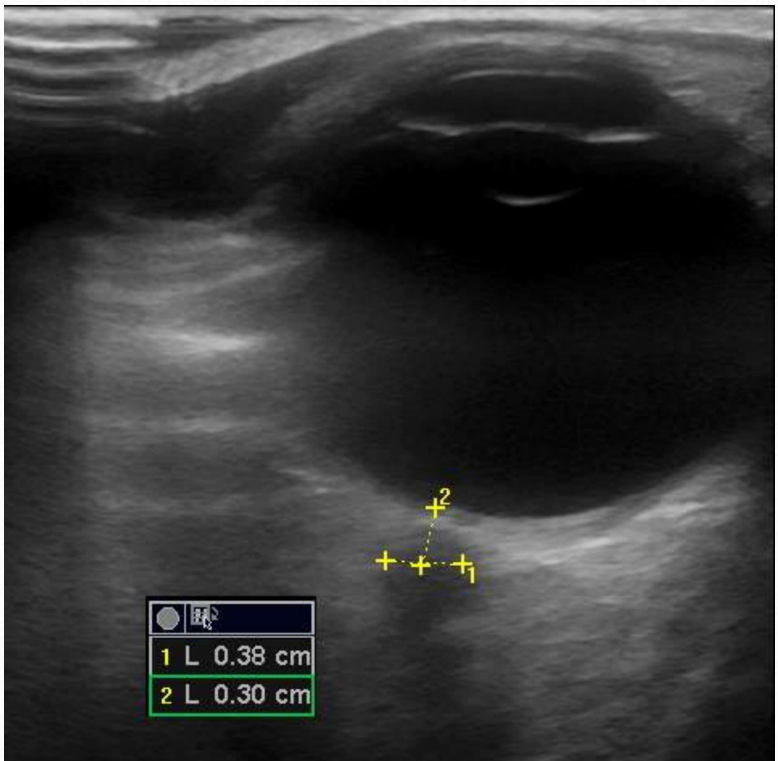
blood flush back. Now, remove the introducer and advance the plastic angiocatheter all the way in, reducing your angle prior to catheter advancement.

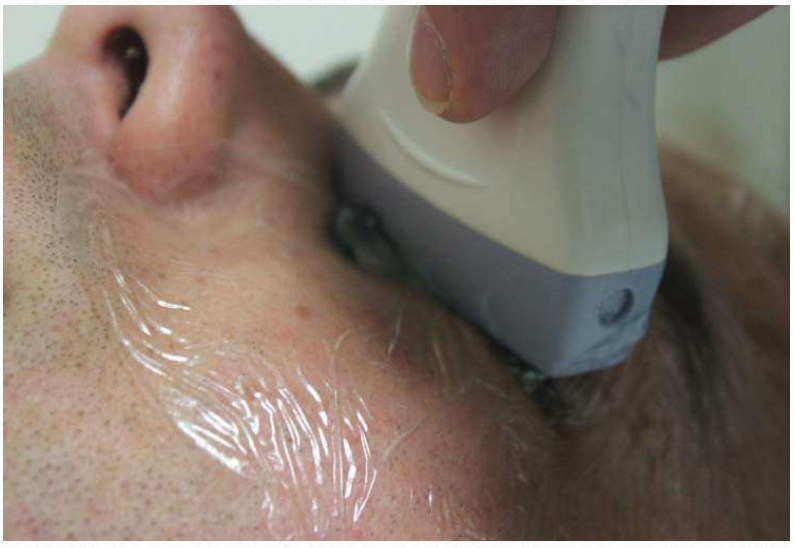

Needle

16

Ultrasound of Optic Nerve Diameter for Intracranial Pressure



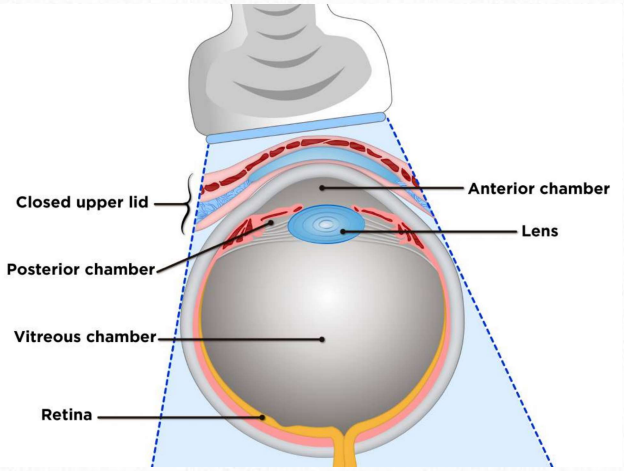




V. ADDITIONAL TOPICS - OPTIC NERVE DIAMETER

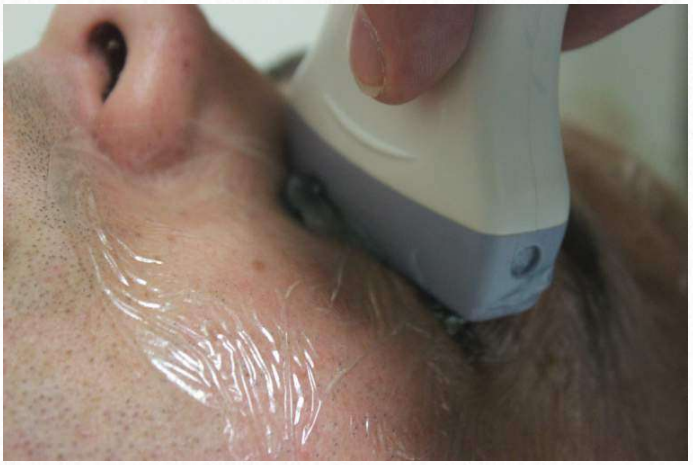
A. Optic Nerve Diameter: Elevated intracranial pressure (ICP) is a challenging and potentially fatal complication of acute head trauma. Early intervention in the form of either surgical evacuation of the space-occupying hematoma or medical management of the raised ICP is vital to improve outcome. Unfortunately, the ability to detect elevated intracranial pressure by physical examination alone is difficult. Diagnosis is often made by cranial CT. However, CT has some disadvantages: 1) it involves transporting the critically ill patient, 2) the scanner is often situated away from the resuscitation room, and 3) transport to CT is not feasible during acute hemodynamic instability.

Recently, point of care (POC) ultrasound (US) of the optic nerve sheath diameter (ONSD) has been suggested as a possible indicator of elevated ICP. Studies have shown that the measurement of the optic nerve sheath diameter has a sensitivity of 98.6% and specificity of 92.8%. The following CT findings in clinically significant elevated ICP normally include (used traditionally to identify elevated ICP): significant edema, midline shift, mass effect, effacement of sulci, collapse of ventricles, or compression of cisterns. The ability to correlate the ONSD with ICP is possible because the optic nerve sheath includes the subarachnoid space around the optic nerve, which enlarges in situations of elevated ICP (see picture below). Therefore, POC US of ONSD provides a reliable, rapid, bedside, non-invasive test for raised ICP. **The upper limit of normal ONSD is 5 mm for adults, 4.5 mm for children aged 1—15 years, and 4.0 mm for infants up to 1 year of age.**

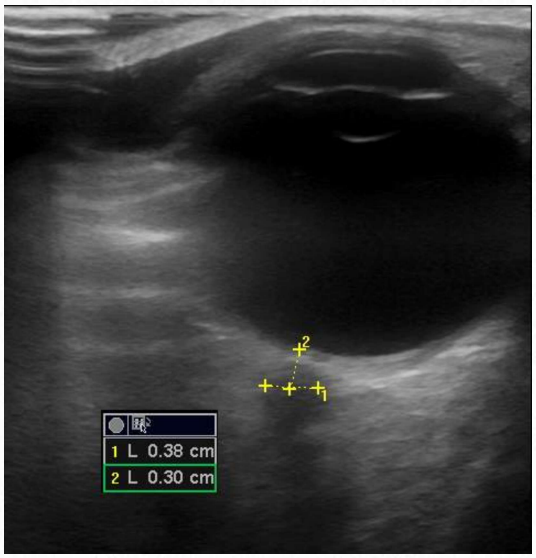


Probe Type: High frequency linear probe only

Image Acquisition: Place the high frequency probe transversely (indicator at the 9 o'clock position) to the patient's eyelid. Keep the probe over the top part of the eyelid and aim the probe in a slightly caudad direction, such that the probe makes a 60 to 70 degree angle with the eyelid. Remember, the optic nerve exits the eye posteriorly approximately at the middle of the eyeball. One should keep increasing and decreasing the axis angel of the probe to the eyelid to **MAXIMIZE** the diameter of the optic nerve sheath (=ONSD). **Measurements of the ONSD should be done approximately 3 mm behind the optic disc (see below).**

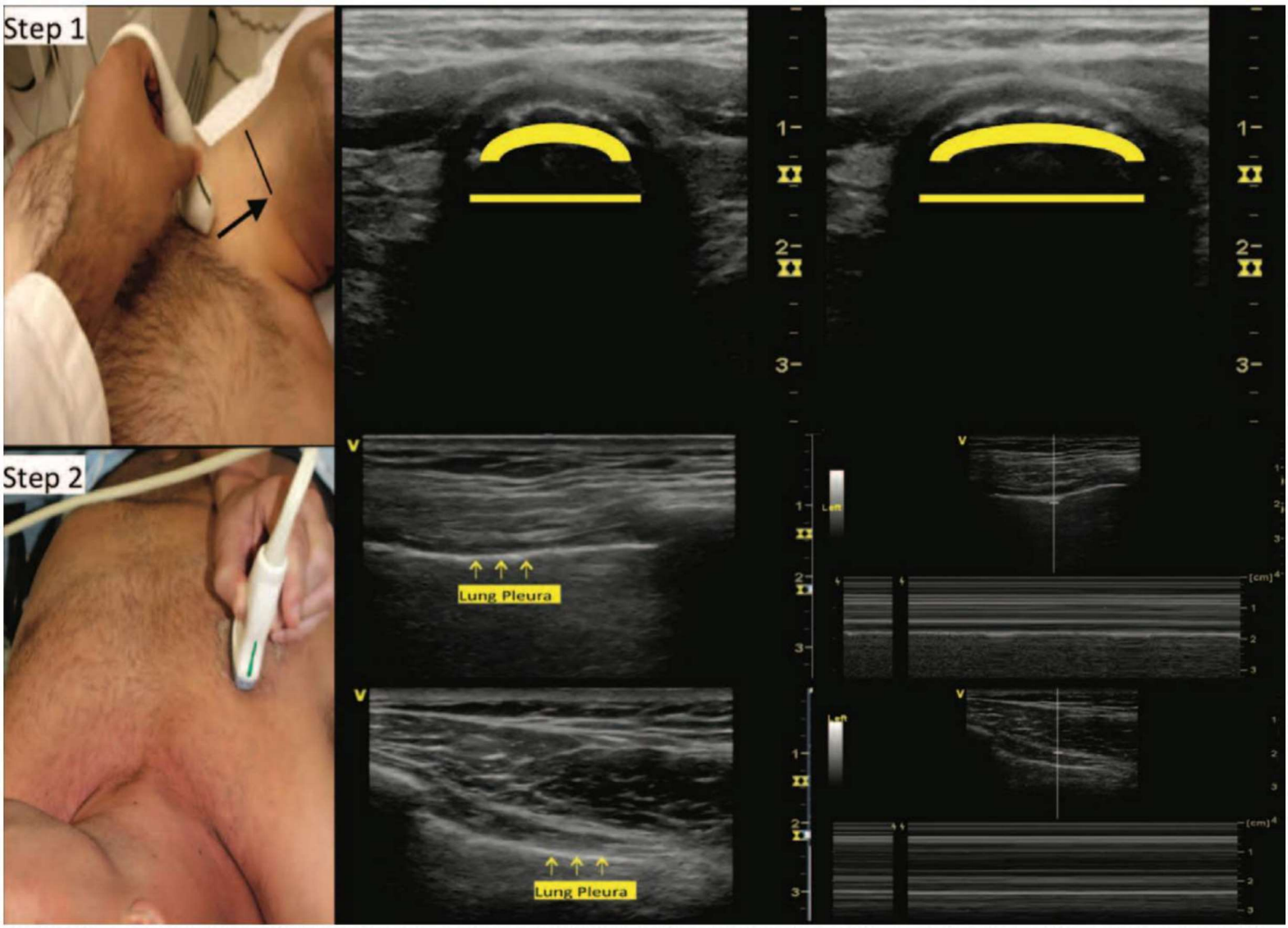


Place high frequency probe transversely over upper part of eyelid. Measure the optic nerve 3 mm behind the optic disc.



17

Ultrasound for Identification of Successful Endotracheal Tube Placement & Position



V. ADDITIONAL TOPICS - IDENTIFICATION OF SUCCESSFUL ET PLACEMENT AND CUFF LOCATION

Ultrasound for Identification of Successful ET Placement: Esophageal intubation is one of the main causes of accidents leading to death or neurologic damage. Direct visualization of the tracheal tube passing through the glottis is often applied in practice, but it is not always possible to see the glottis, especially if intubation is difficult. Recently, POC US has been proven to reliably detect successful trachea intubation as well as identify unwanted esophageal intubation with 100% sensitivity and specificity.

Probe Type: High frequency linear probe only.

Image Acquisition: Place the ultrasound probe transversely on the anterior neck, just superior to the suprasternal notch, **BEFORE** tracheal intubation (see picture below). When the tracheal tube passes through the trachea, a hyperechoic shadow, or comet sign, is shown in the trachea. Esophageal intubation is much more striking because one sees it being opened by the tracheal tube.

ETT Location Within the Trachea: One can identify the location of the ETT by placing the ultrasound probe transversely on the anterior neck approximately 2 cm superior to the suprasternal notch and scanning (cranially / caudally) to the cricothyroid membrane. During this exam one will deflate and inflate ETT to examine for tracheal dilation. Then, one can examine the lung pleura to also assess for bilateral equal pleural lung sliding. In this examination, it is the **absence** of tracheal dilation with cuff inflation that is concerning for deep ETT position (at risk for main stem intubation), and one can examine for pleural sliding to see if the ETT is likely mainstemed (lack of lung sliding would indicate main-stem on the opposite side).

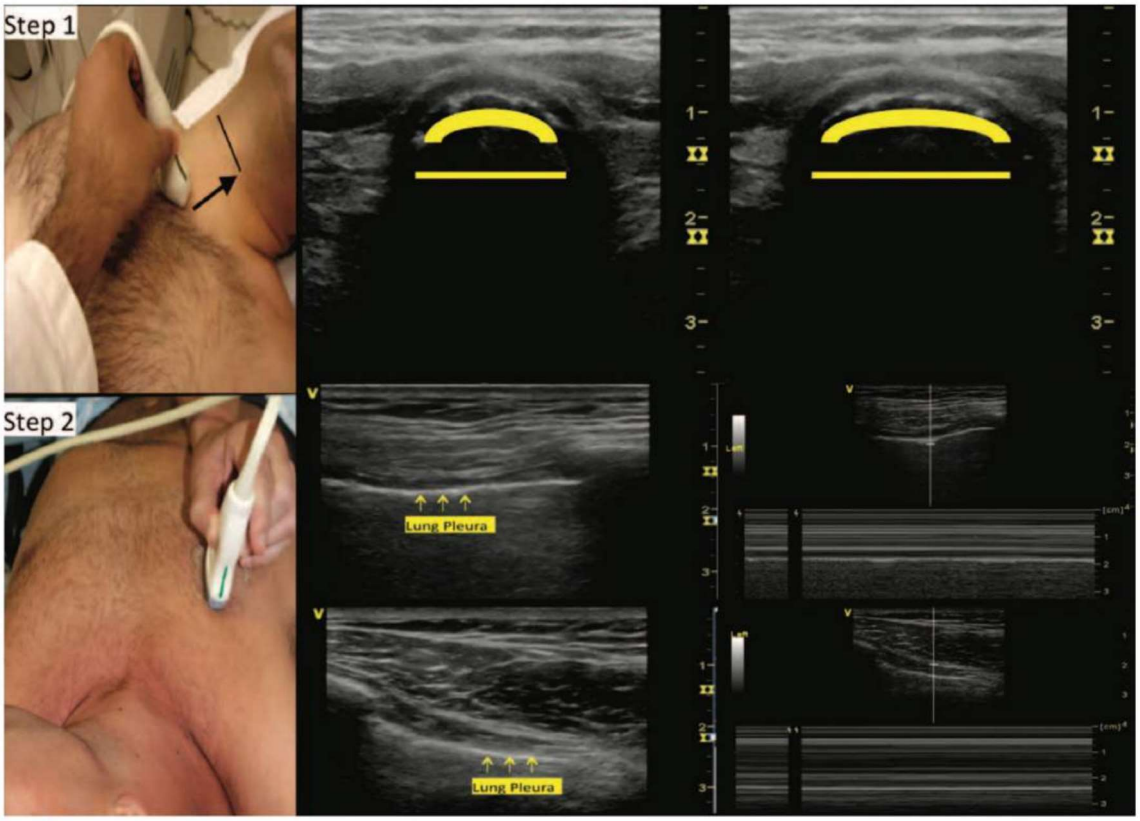


Fig. 1. Pulmonary tree and Lung expansion Ultrasound Study examination. Step 1: tracheal dilation assessment—ultrasound probe placed transversely on the anterior neck approximately 2 cm superior to the suprasternal notch and scanned cranially to the cricothyroid membrane. The marker for endotracheal cuff is tracheal dilation with balloon inflation. The image on the *left* in step 1 shows a nondilated trachea, and the one on the *right* shows a dilated trachea secondary to balloon inflation. Absence of tracheal dilation suggests that the endotracheal cuff is not in the area examined. Step 2: pleural sliding assessment—ultrasound placed vertically on the anterior chest at the third rib space midclavicular line bilaterally. Assessment of lung expansion evaluated by the detection of the horizontal movement of the two pleural linings with respiration. Use of M-mode facilitates pleural sliding assessment. The *top* image for step 2 examination shows normal pleural sliding verified with M-mode identification of pleural motion. The *bottom* image for step 2 examination shows absence of pleural sliding verified with no motion identified with M-mode.

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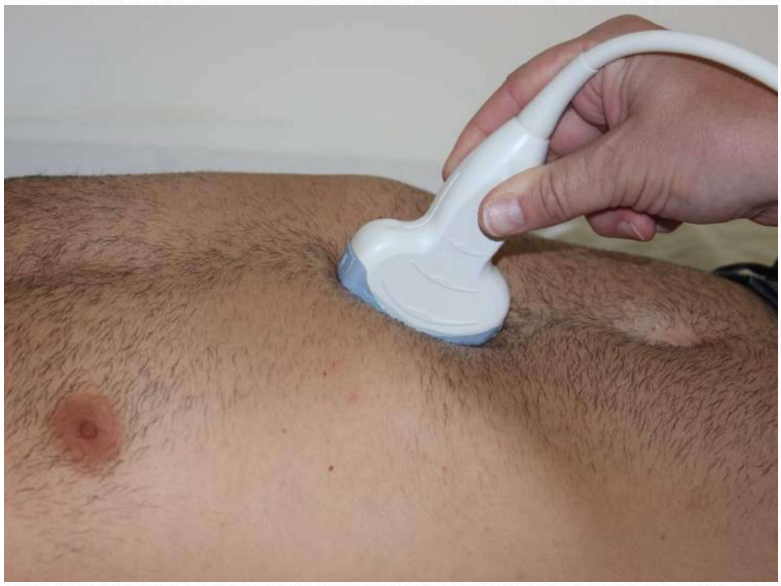
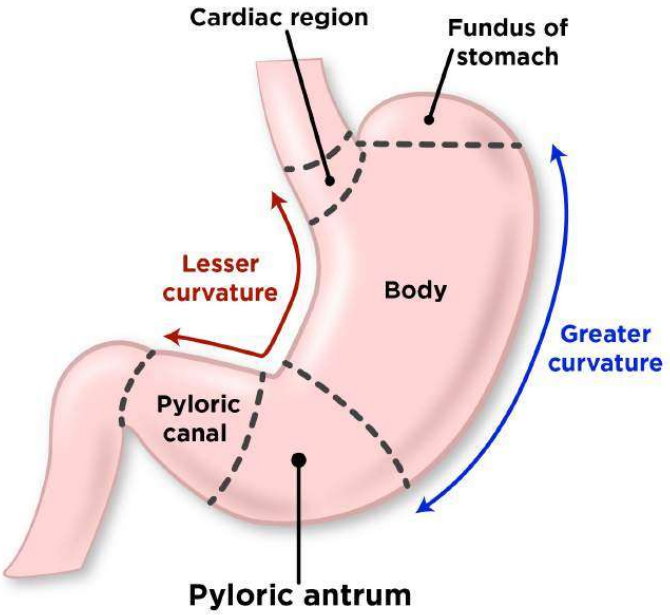
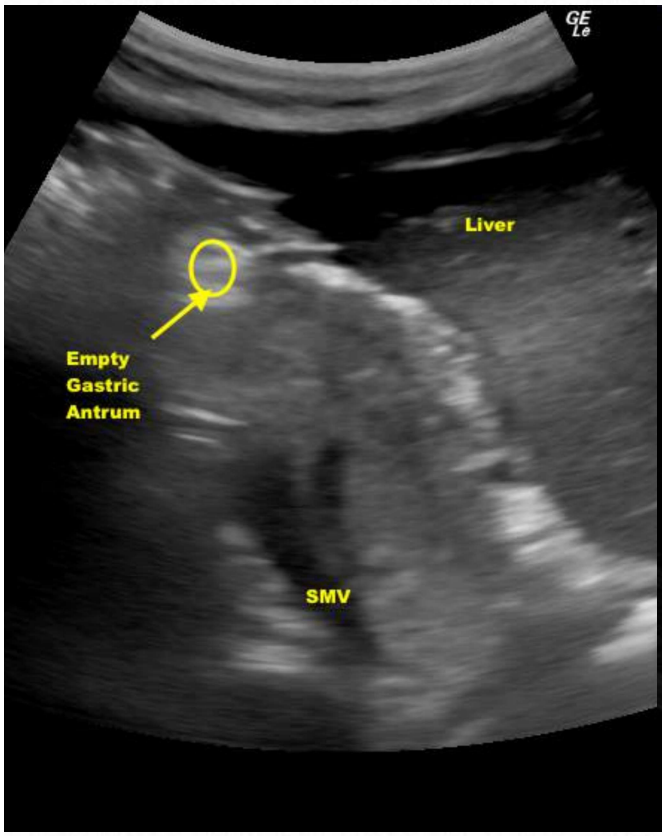
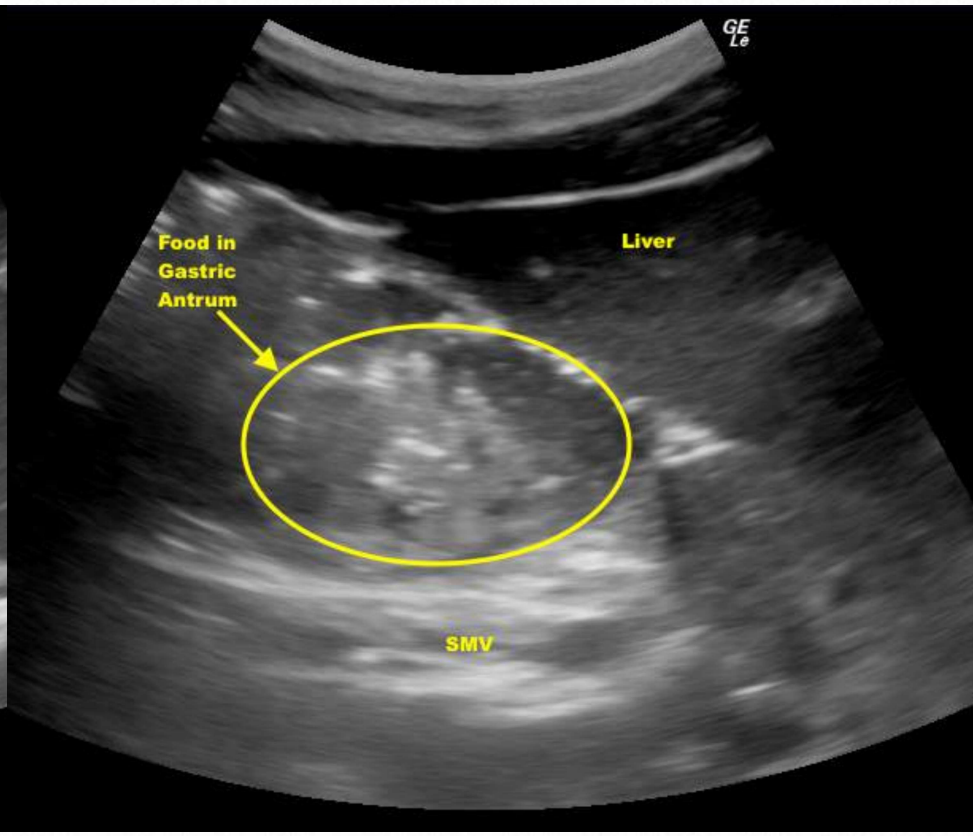
Ultrasound for Gastric Antrum Diameter



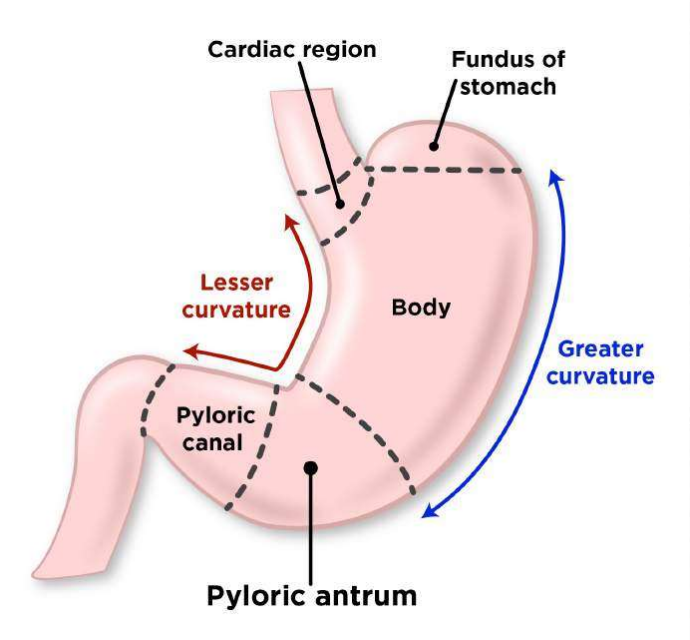






V. ADDITIONAL TOPICS - ULTRASOUND OF GASTRIC ANTRUM AREA

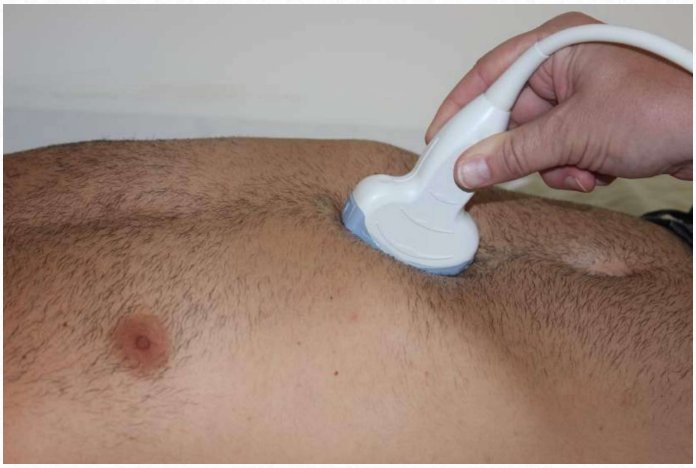
Ultrasound of Gastric Antrum Area: Aspiration of gastric contents can be a serious perioperative complication, associated with significant morbidity and mortality**.**

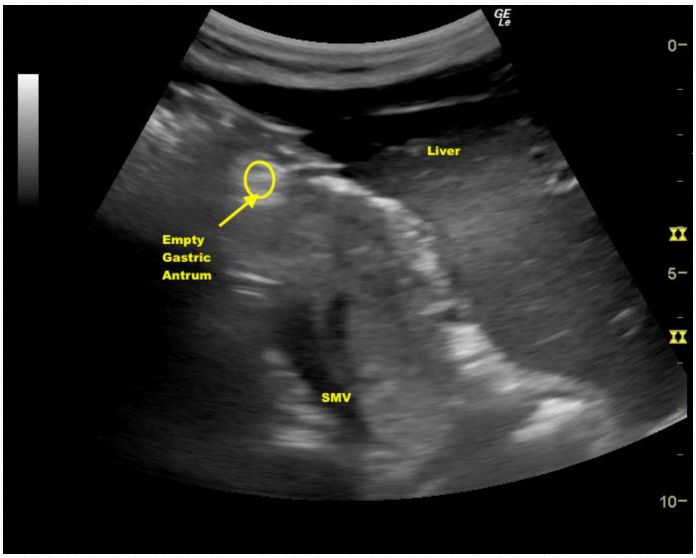


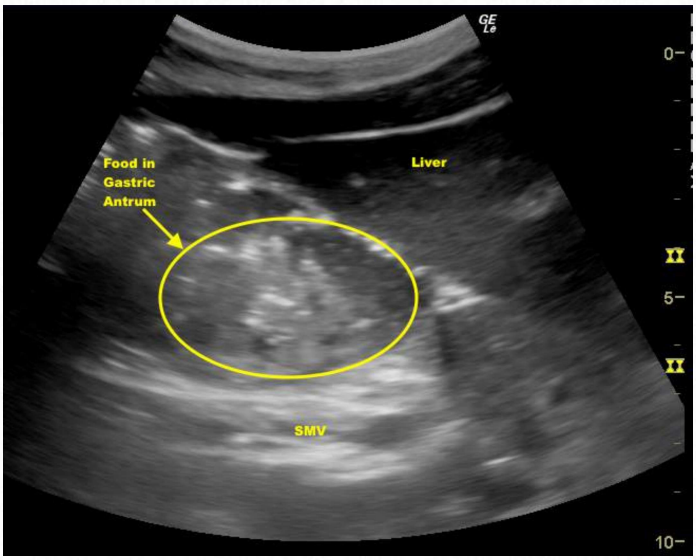
In particular, aspiration of solid particulate matter, large volumes (>0.8 ml/kg or 50 ml), or fluid with a low PH (< 2.5) carries high morbidity. Mortality after aspiration pneumonia can be as high as 5% and it accounts for up to 9% of all anesthesia-related deaths. In addition, it occurs quite frequently in certain populations. For example, it is believed that 38% of all trauma patients have aspirated. Also, several clinical studies have shown that healthy fasting patients frequently have residual gastric volumes larger than previously thought, up to 1.6 mL/kg (well above the volume needed to cause significant complications). In addition, there is some debate that fasting guidelines are not applicable in the urgent or emergent surgical patient, and certain physiologic states (e.g. pregnancy) and medical conditions (e.g. diabetes, trauma, renal, or liver dysfunction) may result in delayed gastric emptying and significant residual gastric volume, despite recommended fasting times. Finally, the utility of cricoid pressure has also been debated. This is because studies have shown that **in 50% of the population, the esophagus is not behind the trachea,** but rather lateral (90% of the time to the left), therefore making the cricoid pressure ineffective for these patients.

Because of significant complications that can occur from aspiration, as well as the fact not all of the patients we take care of have fasted, there are many issues that limit the utility of the fasting guidelines. A tool to quickly determine the patient's gastric volume would be extremely useful for anesthesiologists. Fortunately, point of care (POC) ultrasound provides such a modality via the assessment of *gastric antrum area*. Several studies have proven that gastric antrum area, measured by POC US, can easily detect patients with the critical volume of 0.8 ml/kg. For our purposes we will use POC to measure the gastric antrum only and not other areas of the stomach; this is because the gastric antrum is the easiest to ultrasound. Additionally, the gastric antrum expands from a baseline empty state as fluid enters the stomach, with gastric volume in a close-to-linear manner up to 300 ml. Volumes in excess of 300 ml result in only modest further increases in antral size, with excess volumes being accommodated by more proximal areas of the stomach.

Ultrasound Probe and Position: One should use the **Curved Linear Probe ONLY.** This is because it provides the right combination of frequency, footprint, and depth of penetration. The patient should be slightly head up (25 - 45 degrees) and positioned in **right lateral decubitus position,** which makes measurements more sensitive. The gastric antrum is imaged in a parasagittal plane (indicator somewhere between 11 and 1 o'clock position) in the epigastric area, using the left lobe of the liver, the inferior vena cava, and the superior mesenteric vein as internal landmarks. The two vessels are usually visualized slightly to the right of the abdominal midline. Once these vessels are identified, the transducer should be rotated slightly clockwise or counterclockwise to best obtain a true cross-sectional view of the antrum **(the SMALLEST possible cross-sectional view).** The **antero-posterior** and **craniocaudal diameters** are measured in this view.







MEASUREMENTS AND ABNORMAL IMAGE APPEARANCE

The gastric antrum area is calculated by first obtaining the **SMALLEST possible cross-sectional view.** The **anteroposterior** and **craniocaudal diameters** are measured as shown in the picture to the left. One uses the diameter measurements to calculate the cross sectional area (CSA) using the following equation:

$$CSA=(AP \times CC \times \pi)/4$$

- A **CSA of 4 cm^2 or less** equals an empty stomach.
- A **CSA of 10 cm^2** corresponds to a gastric volume of between **100 and 240 ml.**
- A **CSA greater than 10 cm^2** equals a volume over **300 ml.**

Clear fluids appear hypoechoic (see picture to the left) and particulate material (food) appears as a "frosted-glass appearance" (see picture to the left). This frosted-glass appearance is likely related to air mixed with solid food during the swallowing process. Also, remember that placement of the patient in the right lateral decubitus position makes measurements more sensitive.

Volume Calculation:

Volume (mL) = 1199.99 + 483.09*log (CSA supine) - 5.84*age - 9.94*height

Volume (mL) = -372.54 + 282.49*log (CSA lateral) - 1.68*weight

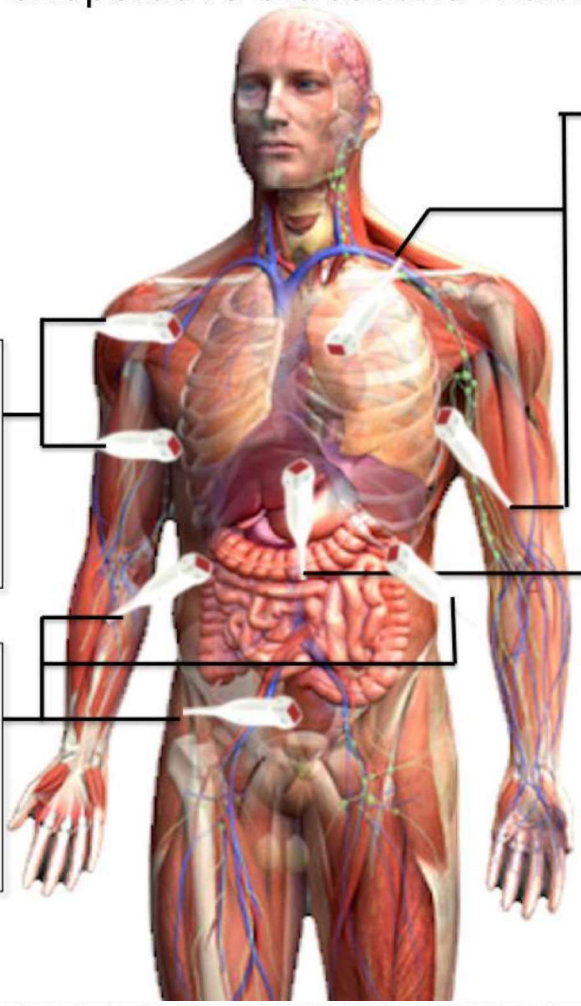
19 12 VIEW FOCUSED PERIOPERATIVE ULTRASOUND EXAM and FORESIGHT EXAM REVIEW SHEETS

Perioperative Ultrasound Examination

To optimize image:
- Make good probe contact
- Ensure proper pt position
- Parallel to US plane ideal to measure blood flow
- Perpendicular to US plane ideal to show best picture

Pulmonary Evaluation:
- Pneumothorax
- Pleural Effusion
- Severe Alveolar Interstitial Disease
- Position: supine

Abdominal Evaluation:
- Evaluate free fluid in intraperitoneal space via 3 windows
- Views: RUQ, LUQ, Suprapubic
- Position: supine



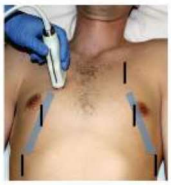
Cardiac Evaluation:
- R/L ventricular function
- Pericardial Effusion
- Severe Valvular abnormalities
- Views: Parasternal Long Axis/ Short Axis, Apical 4 Chamber, Subxiphoid Pericardial
- Position: Left side down with L arm stretched out

Hemodynamics:
- IVC Collapsibility
- Left Ventricular End Diastolic Diameter
- VTI across aortic valve
- VTI across radial/brachial artery
- Views: Subxiphoid IVC, Parasternal Short Axis. Pulse Wave Doppler across radial/ brachial artery

12 View Focused Perioperative US Exam

LUNG: (probe indicator perpendicular to ribs scanning along pleural line)

1. RUQ
2. RLQ
3. LUQ
4. LLQ



CARDIAC:

1. L PARASTERNAL LONG AXIS :(probe indicator 3 to 4th rib space directed to 10 o'clock position)
2. L PARASTERNAL SHORT AXIS: (probe indicator 3 to 4th rib space directed to 2 o'clock position)
3. APICAL 4-CHAMBER VIEW: (probe indicator at 6th rib space midclavicular line directed to 3o'clock position)
   * adjust image to a 5-chamber view by decreasing probe angle with the chest (to see more anterior structures)
4. SUBXIPHOID 90 DEGREE IVC VIEW: (probe indicator at subxiphoid space with indicator directed to 12 o'clock position)

Abdominal:

1. RUQ (probe indicator perpendicular to 10th rib space and move caudal): looking for free fluid at the hepato-renal interface (Morrisions pouch)
2. SUBXIPHOID PERICARDIAL VIEW (probe indicator directed to 3 o'clock position with sig reduced angle of insonation): looking for pericardial tamponade
3. LUQ (probe indicator perpendicular to 10th rib space and move caudal with probe pointing more *inferiorly* than RUQ)
4. SUPRAPUBIC (probe indicator directed to 3 o'clock position with sig steep angle of insonation)

- Free fluid appears as poorly defined irregularly shaped hypoechoic (black) regions

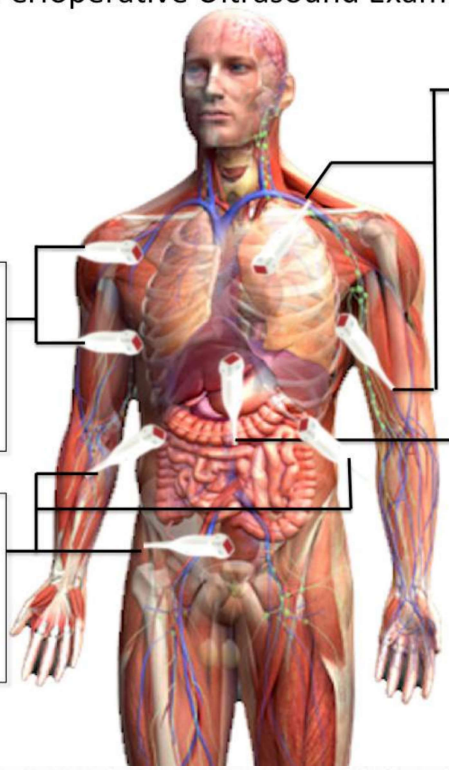
IVC	% Collapse	Estimated CVP
<20	>50	5
<20	<50	10
>20	<50	15
>20	0	20

Data References:

- Diaphragm – 9th rib space
- Lung Sliding- motion of parietal pleura along visceral pleura during respiration
- B Lines- increased echo reflective bands from the pleura line throughout the lung parenchyma, suggests decreased area of lung aeration. (> 2 B lines suggests significant disease)
- Pleural effusion-hypoechocic (blank) areas above the lung hyperechoic diaphragm
- Velocity Time Integral is a measure using continuous wave or pulse wave Doppler to assess flow proximal to a cardiac valve (usually aortic) or across an artery and is related to stroke volume and can be used for fluid responsiveness (greater than 15% variability =fluid responsiveness)
- Velocity Time Integral traces also provide estimated pressures when the waveform are traced (how one sees gradients across valves)
- PA systolic pressure estimated by using continuous wave Doppler across tricuspid valve in the apical view to get peak regurgitate pressure and this valve is added to the estimated CVP.
- Normal LVIDd: > 3.5cm
- RWMA: assessed in parasternal SAX
- Fractional Area Change quantifies LV and RV contractility (similar to EF) and is quantified by measuring the following in the parasternal SAX views (Area of Chamber (RV or LV) in Diastole – Area of Chamber (RV or LV) in Systole / Area of Chamber (RV or LV) in Diastole) x 100
- Valve function: assessed in apical view using color Doppler
- Severe Regurgitation is estimated by tracing the regurgitate jet area in the apical view, area (> 10cm is severe) or measuring the vena contracta (the point in a regurgitate jet that originates from the fluid stream where the diameter of the stream is the least, > 7mm =severe)
- Tamponade: assessed in parasternal LAX and subxiphoid pericardial views
- Abdominal Free Fluid appears as "black" non-echogenic spaces between organs and will accumulate in RUQ if there is a upper abdominal injury and in suprapubic if lower abdominal injury
- Combined FAST exam can reliably detect > 200ml
- 0.7 x (supero-inferior diameter) x TS (maximum transverse diameter) x AP (maximum anteroposterior diameter
- IVC diameter measured on end expiration (spont breathing patient) and 1cm distal to the IVC-hepatic

Perioperative Ultrasound Examination

To optimize image:
- Make good probe contact
- Ensure proper pt position
- Parallel to US plane ideal to measure blood flow
- Perpendicular to US plane ideal to show best picture



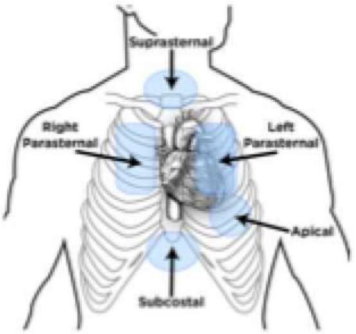
Cardiac Evaluation:
- R/L ventricular function
- Pericardial Effusion
- Severe Valvular abnormalities
- Views: Parasternal Long Axis/ Short Axis, Apical 4 Chamber, Subxiphoid Pericardial
- Position: Left side down with L arm stretched out

Pulmonary Evaluation:
- Pneumothorax
- Pleural Effusion
- Severe Alveolar Interstitial Disease
- Position: supine

Hemodynamics:
- IVC Collapsibility
- Left Ventricular End Diastolic Diameter
- VTI across aortic valve
- VTI across radial/brachial artery
- Views: Subxiphoid IVC, Parasternal Short Axis. Pulse Wave Doppler across radial/ brachial artery

Abdominal Evaluation:
- Evaluate free fluid in intraperitoneal space via 3 windows
- Views: RUQ, LUQ, Suprapubic
- Position: supine

FORESIGHT EXAMINATION:



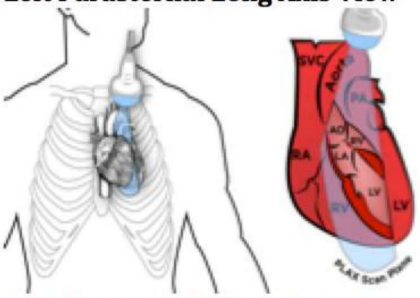
CARDIAC

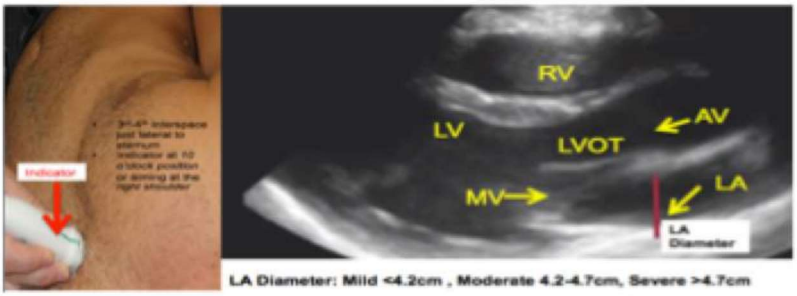
Overview:

Views:

1. Left Parasternal Long Axis
2. Left Parasternal Short Axis
3. Apical 4 Chamber View
4. Apical Two Chamber View
5. Apical 5 Chamber View
6. Subxiphoid View

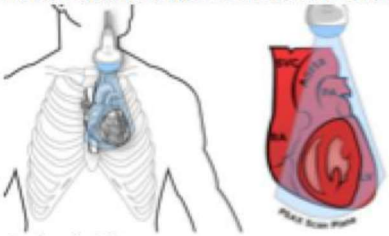
Left Parasternal Long Axis View

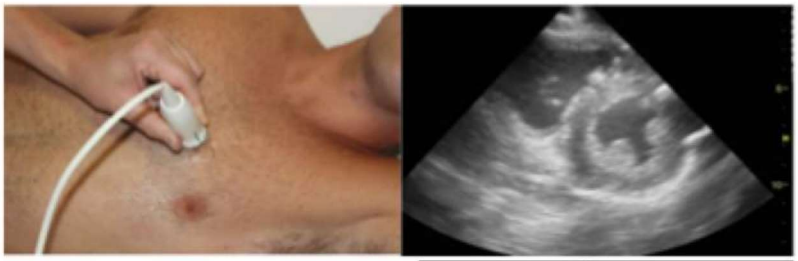




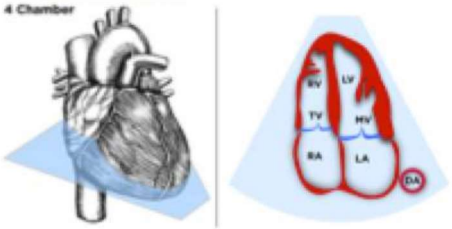
LA Diameter: Mild <4.2cm , Moderate 4.2-4.7cm, Severe >4.7cm

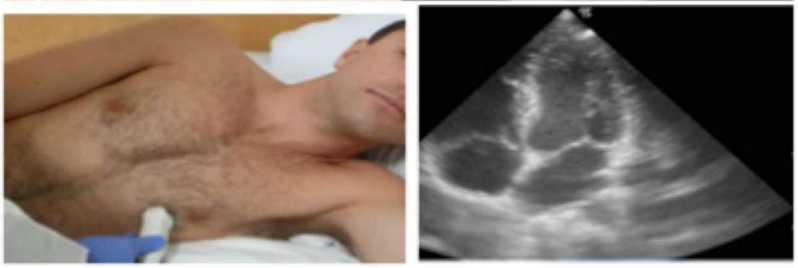
Left Parasternal Short Axis View

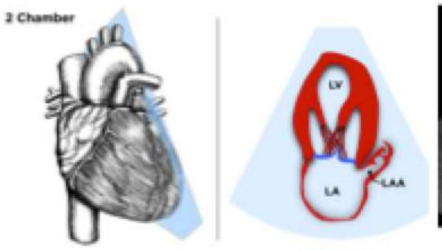


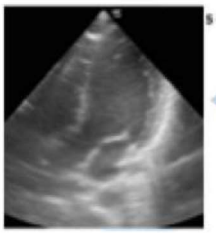


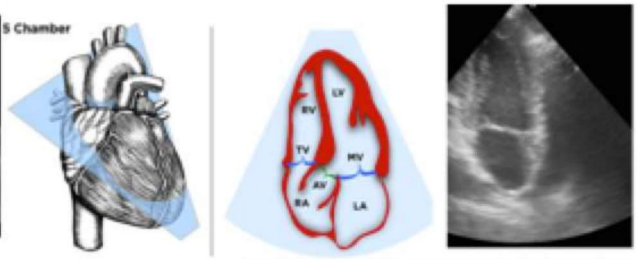
Apical Views



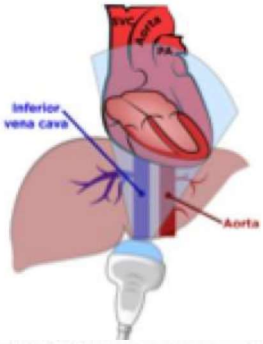


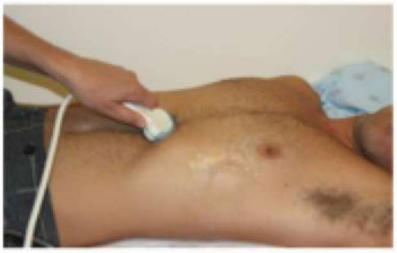


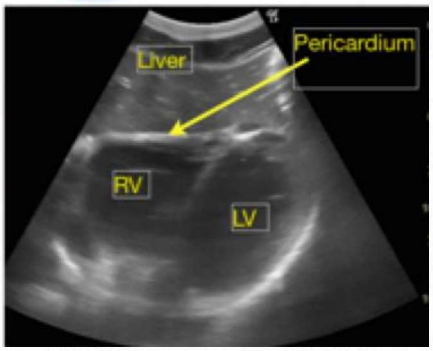




Subxiphoid







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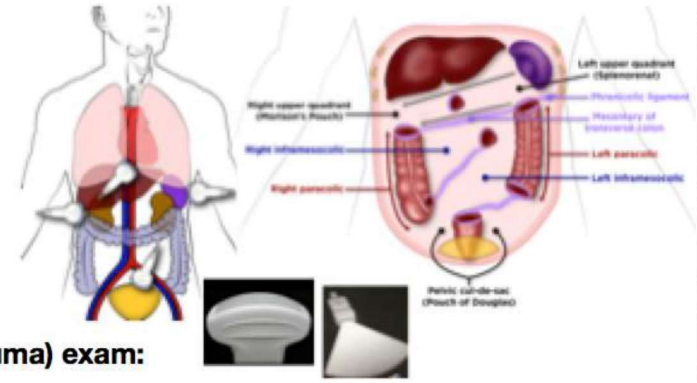


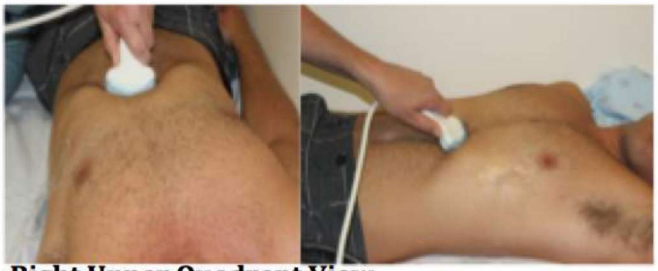
Abdominal

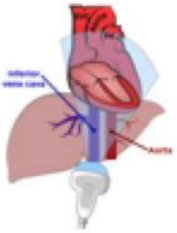
Assessment Categories

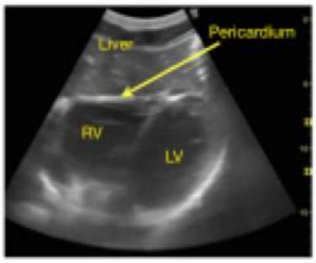
1. FAST (Focused Assessment with Sonography for Trauma) exam:

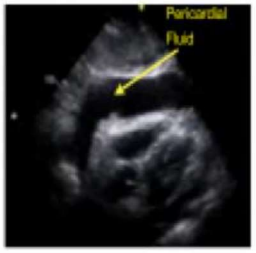
FAST (Focused Assessment with Sonography for Trauma) exam:

Sub-xiphoid

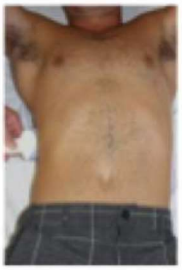


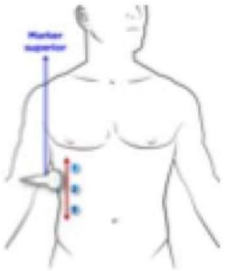


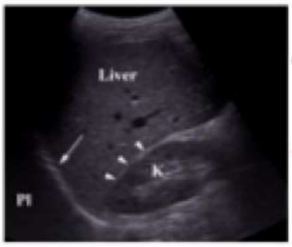


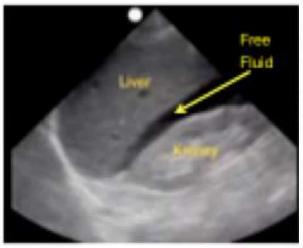


Right Upper Quadrant View

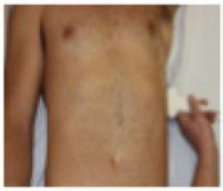


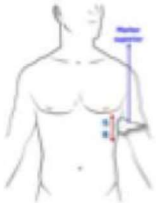


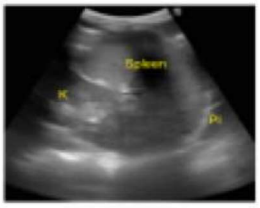


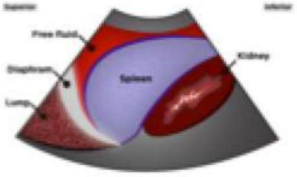


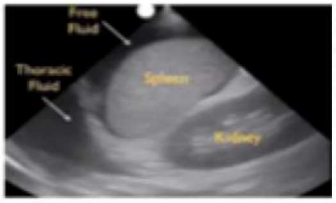
Left Upper Quadrant View



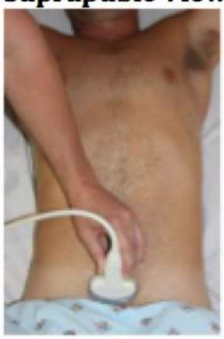


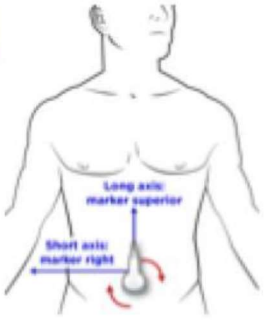


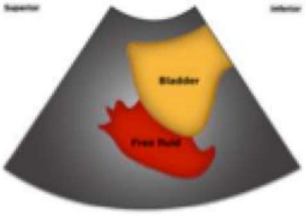


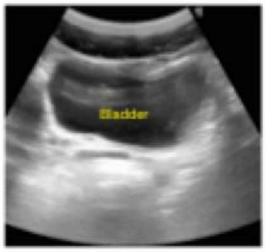


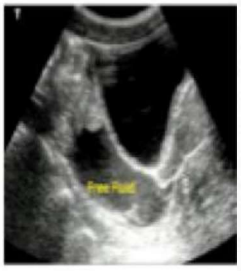
Suprapubic View







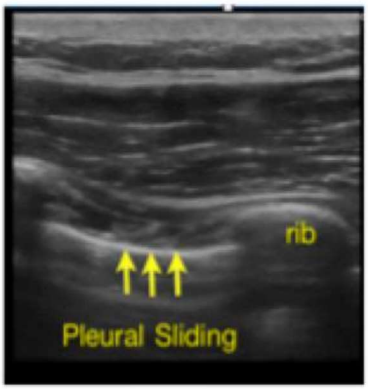


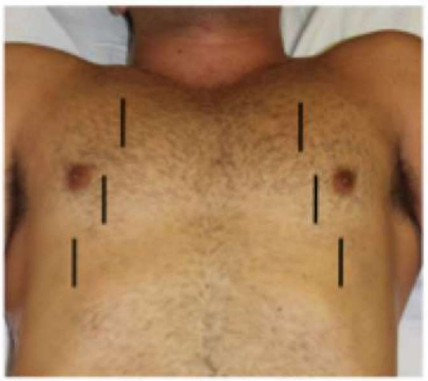


FORESIGHT EXAMINATION:

Pulmonary
Assessment Categories

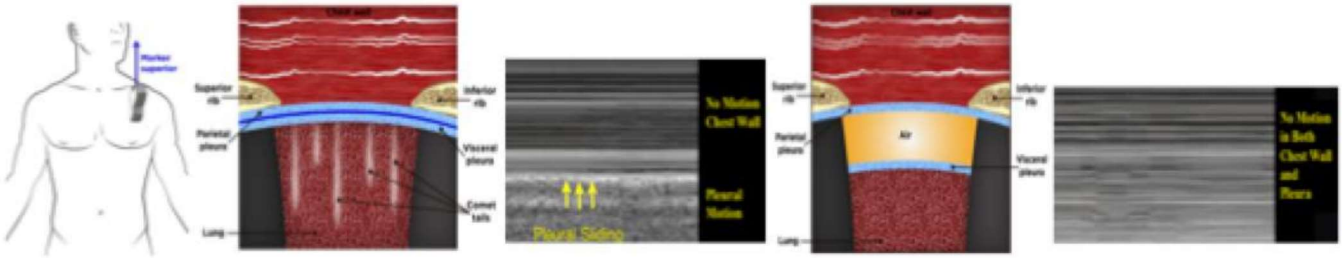
1. Pneumothorax
2. Pleural Effusions
3. Air Space Disease



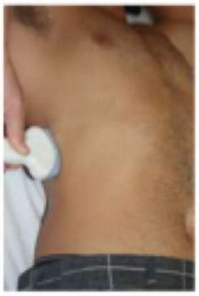


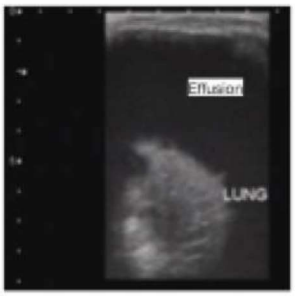
Pulmonary Examination Views

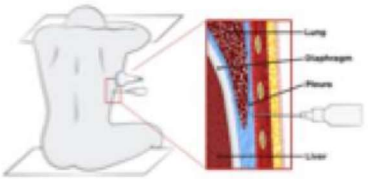
Pneumothorax Evaluation via Pleural Lung Sliding



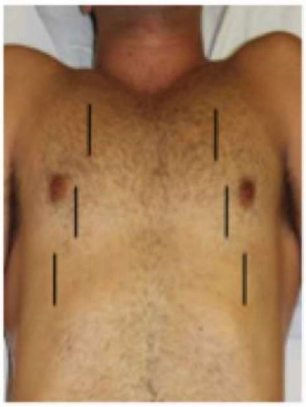
Pleural Effusion Evaluation

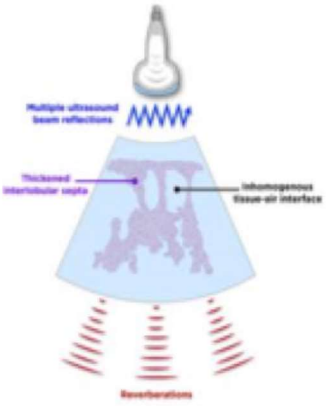


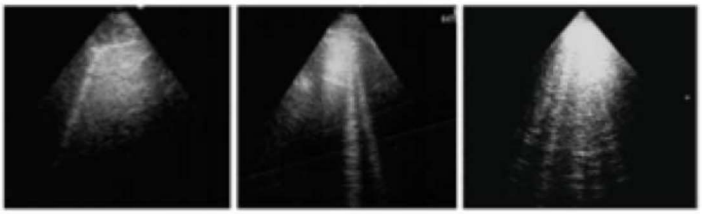


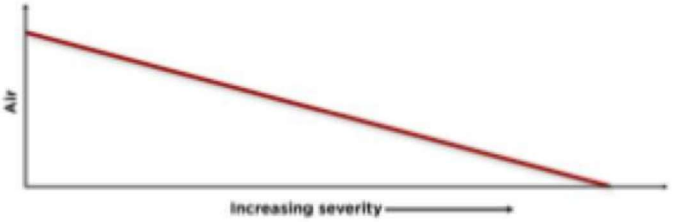


Air Space Evaluation









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