Acute Care and Perioperative Point-of-Care Ultrasound

Edited by
Davinder Ramsingh

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

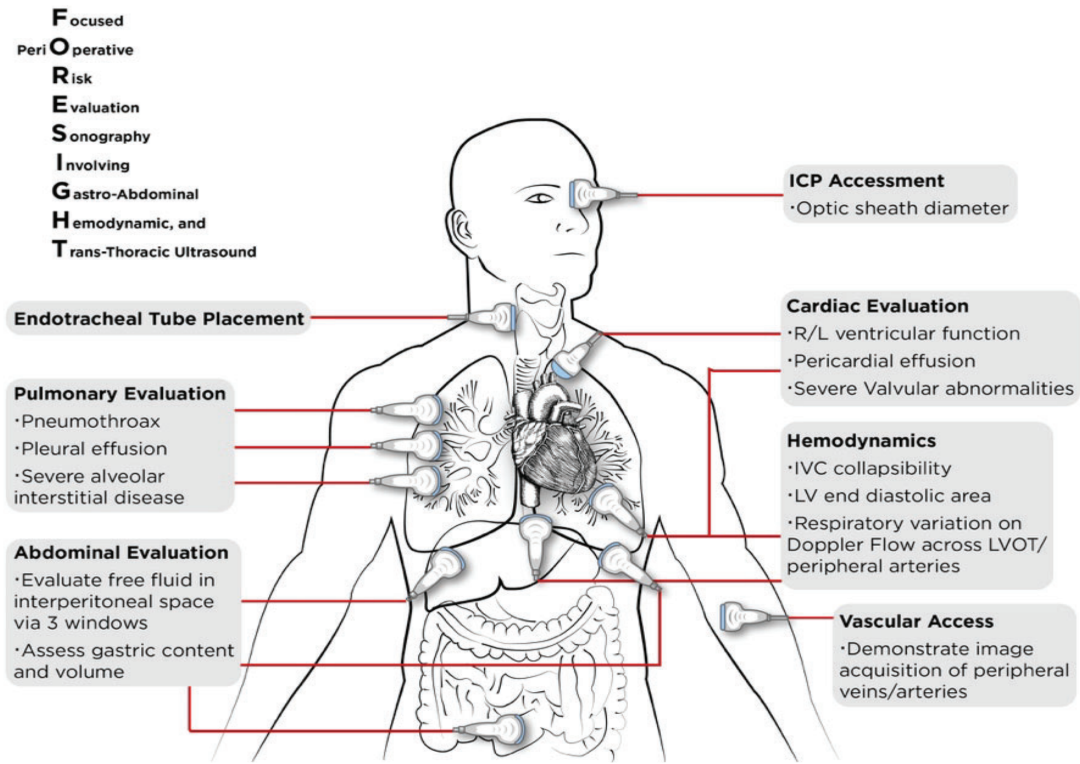

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TABLE OF CONTENTS

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EBSCOhost - printed on 2/10/2023 5:48 PM via . All use subject to https://www.ebsco.com/terms-of-use

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Preface

This book is designed to serve as an introduction to the topic of point of care ultrasound and highlight how it can be applied to improve care in acute care and perioperative settings. Each section is designed to be succinct and provide the following: a brief background on the topic, a description/illustration of image acquisition, and a discussion of essential pathology identification.

Thanks to all of those that have offered their time, advice, expertise, and support for developing this book. Also, many thanks to those that have helped review/edit/design this book, including Drs. Andy Trang, and Ceci Canales. Special thanks to my mentors Drs. Maxime Cannesson, Zeev Kain, Aman Mahajan, and Robert Martin.

Finally, words cannot express my eternal gratitude to my loving wife Sefali, and my wonderful kids Nikhil and Ishani. May life always allow us to endorse the importance of kindness and hard work.

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TABLE OF ABBREVIATIONS

ACLS	
AI	Aortic insufficiency
AO	Aortic outflow
AP	Antero-posterior
AS	Aortic stenosis
BMJ	British Medical Journal
CSA	Cross-sectional area
CVP	Central venous pressure
CW	Continuous wave
DVT	Deep vein thrombosis
EF	Ejection fraction
ETT	Endotracheal tube
EVD	External ventricular drains
FAC	Fractional area change
FAST	Focused assessment with sonography for trauma
FS	Fractional shortening
HF	Heart failure
HFpEF	Heart failure with preserved ejection fraction
HFrEF	Heart failure with reduced ejection fraction

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ICP	Elevated intracranial pressure
IJ	Internal jugular
IVC	Inferior vena cava
LA	Left atrial
LAX	Long axis
LUQ	Left upper quadrant
LV	Left ventricle
LVEDD	Left ventricle end diastolic diameter
LVEDP	Left ventricle end diastolic pressure
LVOT	Left ventricular outflow tract
MV	Mitral valve
ONSD	Optic nerve sheath diameter
PAP	Pulmonary artery pressure
PE	Pulmonary embolus
PG	Pressure gradients
PICC	Peripherally inserted central catheter
PLAX	Parasternal long axis
PLUS	Pulmonary tree and Lung expansion Ultrasound Study
PMI	Point of maximal impulse
POCUS	Point of care ultrasound
PRF	Pulse repetition frequency
PSAX	Parasternal short axis

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PW	Pulse wave
RA	Right arteriole
RAP	Right arteriole pressure
RBC	Red blood cell
RUQ	Right upper quadrant
RV	Right ventricle
RVSP	Right ventricular systolic pressure
SAX	Short axis
SCV	Subclavian vein
SVR	Systemic Vascular Resistance
TDI	Tissue Doppler imaging
TGC	Time gain compensation
TS	Transverse
VTI	Velocity time integral

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I

ULTRASOUND PHYSICS

DAVINDER RAMSINGH, MICHAEL MA
AND JARED STAAB

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Principles of Ultrasound Physics

Sound Waves

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

Frequency (*f*): The number of wavelengths per unit of time: 1 cycle / sec = 1 Hz. Frequency is inversely related to wavelength.

Velocity (v): The speed at which waves propagate through a medium (meters per second, m/s).

Wavelength (λ): The distance traveled between two consecutive peaks or troughs of a wave (m).

Amplitude (A): Height of the ultrasound waves, or “loudness” as measured in decibels (dB).

Velocity = Frequency × Wavelength

It is important to note that the velocity of sound waves is dependent on the physical properties of the medium through which they travel. Ultrasound image production relies on the assumption that the velocity within the tissue is a constant, specifically 1540 m/s.

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. Using the equation below, each returning ultrasound signal is accumulated to produce an image.

Distance = Velocity × Time

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Given the constant tissue velocity assumption and preset frequency, the ultrasound machine depicts the location of each reflected ultrasound wave on the display. One can alter the image mostly by adjusting the frequency, which is inversely related to the ultrasound wavelength.

Think of the ultrasound wavelength as a ruler: if one is using a ruler that has only whole inch markings, then measurements will be *less* precise compared to using a ruler with quarter-inch markings. Thus, a longer wavelength provides less detail for an ultrasound image, and a shorter wavelength allows for a more precise or higher quality image.

Along with this principle is the fact that the longer the wavelength, the greater the depth of penetration. This is due to the fact that wavelengths will only penetrate a certain number of cycles to produce an image before they diminish in quantity. This phenomenon is termed attenuation (Figure 1.1).

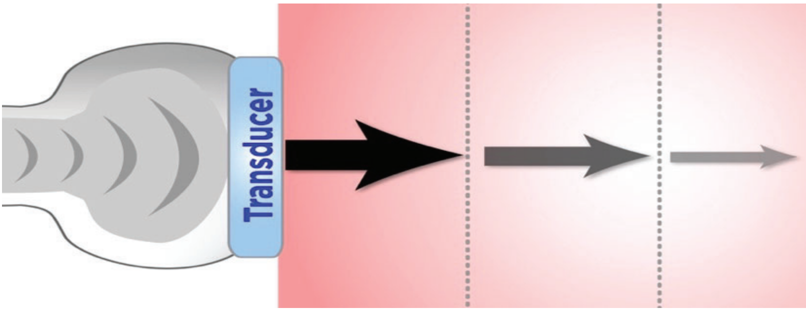

Figure 1.1 Attenuation of ultrasound across tissue planes.
The figure shows the transducer emitting signals across different tissue layers. As the signal penetrates deeper into the tissue, it becomes weaker.

Therefore, an ultrasound probe emitting a longer wavelength (lower frequency) will penetrate the body further and thus produce a better image for deeper structures in comparison to a shorter wavelength probe (Figure 1.2). While this is not a complete explanation, these are the key points to understand:

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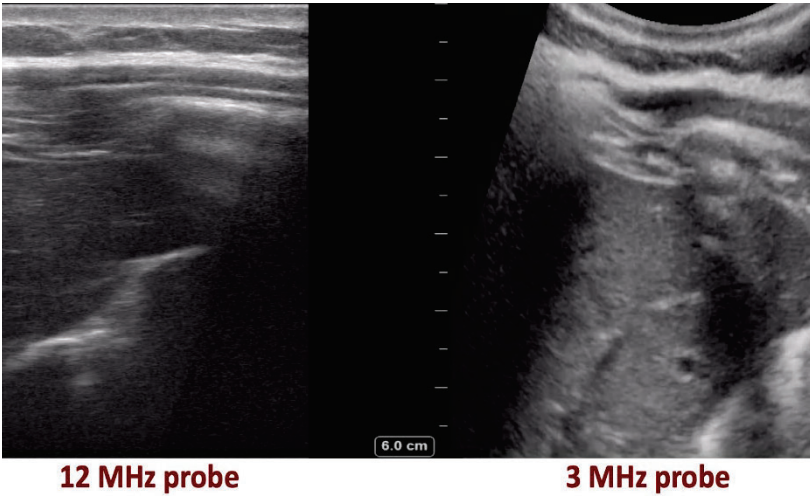

Figure 1.2 Comparison of liver ultrasound with high frequency probe (12 MHz) vs. low frequency (3 MHz).

- 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 *GREATER depth of penetration.*

In effect, lower frequency probes provide better scanning for deeper structures.

Ultrasound Interactions with Tissue

The term attenuation is used to describe what happens to the ultrasound wave as it interacts with the tissue planes. Because of attenuation, the deeper the ultrasound waves travel into the body, the weaker they become. Equally important is to understand that the greater the frequency of the ultrasound wave, the more attenuation occurs at a given depth. Thus, a lower frequency transmission will have less attenuation at a given depth compared to a higher frequency transmission.

Attenuation can be divided into four main processes: reflection, absorption, refraction, and transmission. The additional processes of scattering and diffraction are also demonstrated in Figure 1.3.

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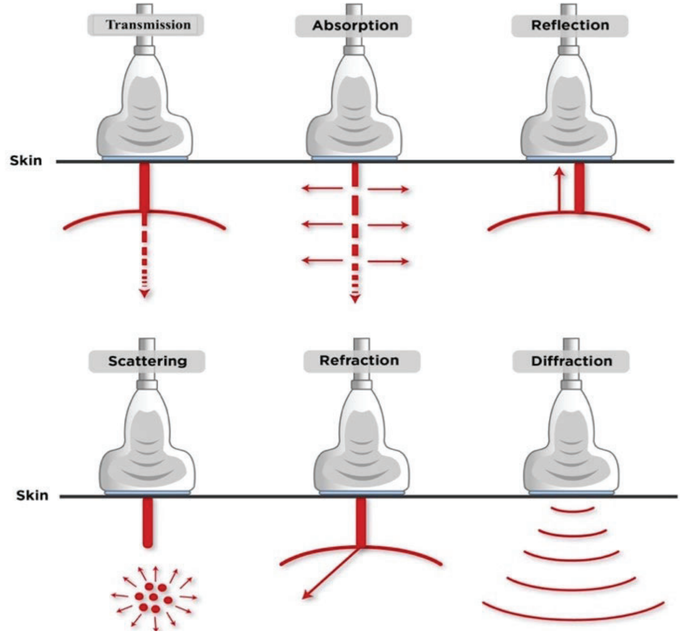

Figure 1.3 Main processes observed in ultrasound.
The six ways an ultrasound probe transmits its signal in the tissue: transmission, absorption, reflection, scattering, refraction, and diffraction. The images show the direction and strength of the ultrasound penetrating into the tissues.

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 the tissues, the greater the amount of reflection. This is why one does not see *aerated* 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 waves, the more hyper-echogenic (or brighter) 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-echogenic (dark) the structures will appear since fewer ultrasound waves are reflected back to the probe (Figure 1.4). *Remember, for 2-D images, the ultrasound wave should be as perpendicular as possible to the structure, and for flow assessment, the probe should be as parallel as possible.*

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Refraction: This is a change in the direction of the ultrasound wave secondary to a change in the density of one medium to another. This phenomenon creates artifacts in the ultrasound image (Figure 1.4).

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

Transmission: This is necessary for one to see various tissues at various depths (Figure 1.5).

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

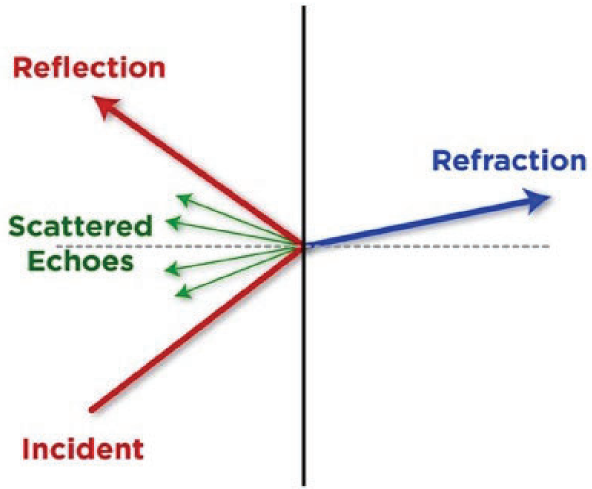

Figure 1.4 Reflection and Refraction.
Reflection occurs when the transducer emits a signal that creates a symmetrical, mirror-like return. Refraction is a result of the signal transmitted from one medium to another. Occasionally artifacts, or scattered echoes, are seen as a result of refraction.

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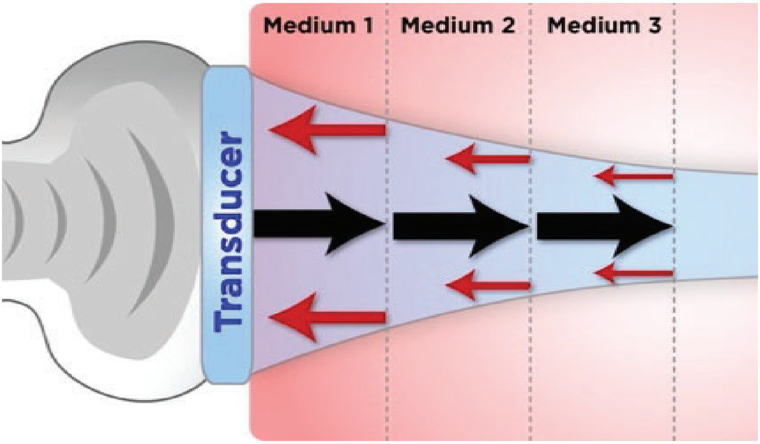

Figure 1.5 Ultrasound Transmission.
The figure demonstrates the loss of ultrasound signal (attenuation) that occurs as it penetrates deeper into tissues.

In addition, it is also important to highlight that ultrasound gel is used between the patient's skin and the transducer footprint. The gel allows a more uniform density between the ultrasound footprint and the patient's skin, which allows for greater transmission.

Transducers

There are three characteristics of transducers that guide probe selection for the desired image acquisition: 1) frequency, 2) insonation footprint, and 3) probe design.

Most often, the choice of the transducer is based on the depth of the structure being imaged, since depth dictates the **frequency** that will be used to insonate. The higher the frequency of the transducer, the less penetration it has; however, the better the resolution. In contrast, the lower the frequency of the transducer crystal, the greater the depth of penetration; however, the resolution will be sacrificed.

The **footprint** is the area of the transducer in which the ultrasound is emitted. This is important since you have to be able to place the probe over the desired area in a manner that allows the ultrasound waves to penetrate the desired tissue. This is particularly relevant when it comes to cardiac

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examinations because a small footprint is required to place the probe between the rib spaces since bone is highly ultrasound reflective.

Finally, the **probe design,** or shape of the probe, can vary based on the area where it is designed to be placed on the body.

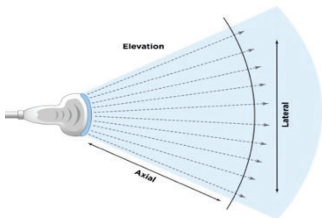
General Probe Types

There are three main probes utilized in point of care ultrasound: low frequency phased array (cardiac), low frequency curved linear (abdominal), and high frequency linear.

Phased Array:

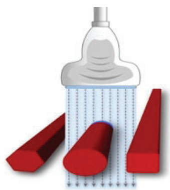
This probe allows for a significantly larger width of image acquisition compared with the footprint. This is achieved by sending directional "phases" of ultrasound wavelengths that are rapidly pulsated and composited together to produce an image. How rapidly the phases are emitted is related to the *frame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

Curved Linear:



This probe has an emitting frequency of 4 to 7 MHz and a large footprint, ideal for abdominal examinations. A wide image is produced because of how the ultrasound waves are emitted (curved).

Linear:



This probe has an emitting frequency of 10 to 27 MHz, is used for superficial structures, and provides the best image resolution.

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Resolution

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

Spatial resolution is the smallest distance between two points that allows a system to identify them as two separate targets or the ability to distinguish two separate points in space (Figure 1.6). 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's path. Lateral resolution is modified by the ultrasound wave amplitude, the image depth, and the gain intensity.

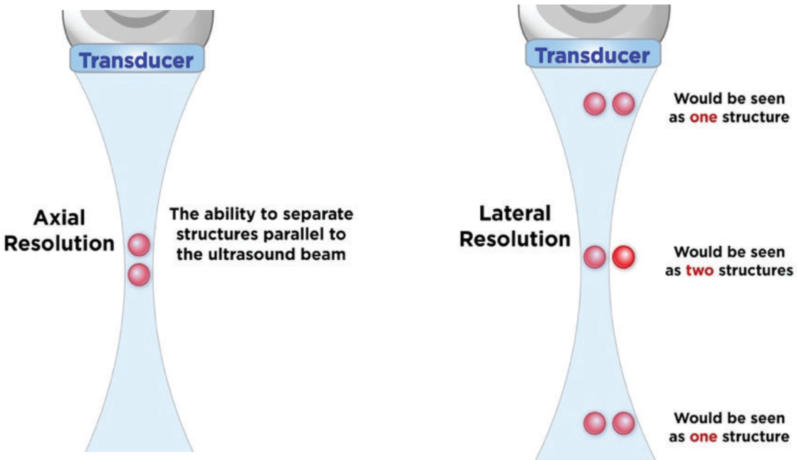

Figure 1.6 Axial vs lateral components of spatial resolution.

Temporal resolution is the ability of a system to accurately track moving targets over time. Any factor that increases time requirements will decrease temporal resolution. Such factors include 1) depth, 2) sweep angle, 3) line density, and 4) lower frequency or pulse repetition frequency (PRF).

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Commonly Used Methods of Improving Ultrasound Images

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. This will result in the highest frequency and thus an improved image resolution.

Gain: Adjusts the overall brightness of the ultrasound image. It is important to note that this is a post-processing adjustment, therefore increasing gain does not improve the differentiation of echogenicity, i.e., the resolution is the same just brighter or darker (you can adjust the power to improve the image differentiation of echogenicity).

Power: Relates to the strength of the voltage spike applied to the crystal for each pulse. Increasing the power output increases the intensity of the beam and, as a result, the strength of the echo that is returned to the transducer.

Focus: Indicates the focal zone of each transducer where the best image resolution can be achieved. This is indicated on the ultrasound system with a small triangle or line to the right of the image. Effort should be taken to position the object of interest within the focal zone to obtain the clearest image.

Time Gain Compensation (TGC): This helps equalize the differences in received reflection amplitudes as the signal is diminished over the reflector depth. TGC allows for adjustment of the amplitude to compensate for the path length differences (it counteracts the fact that fewer wavelengths penetrate to deeper structures resulting in a less echogenic image). You can think of TGC as bands of “horizontal gain.”

Ultrasound Modes

B-Mode (Brightness Mode):

This is the mode used for standard 2-D image creation and real-time scanning. Different levels of gray are shown based on the amplitude of the received ultrasound signals. Typically, the brighter shades represent greater degrees of ultrasound reflection. Since 2-D images are generated from reflection, the best 2-D or B images occur when the ultrasound plane is perpendicular to the structure.

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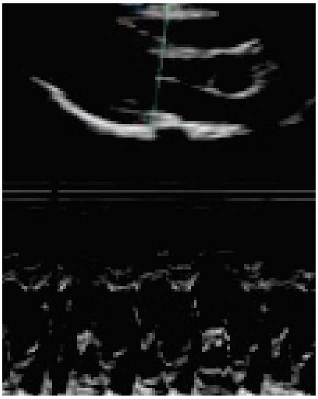

Figure 1.7 M-Mode (Motion Mode)

M-Mode (Motion Mode): This is a graphic B-mode pattern that is a single line time display that represents the motion of structures along the ultrasound beam at 1000 fps. In this mode, the lines of ultrasound reflections or returning echoes are shown in the y-axis, and their changes over time are shown in the x-axis (Figure 1.7). This mode allows you to trace motion (i.e., heart wall motion and vessel wall motion).

Doppler:

This modality displays the change in frequency of a wave resulting from the motion of the source producing the ultrasound reflection (Figure 1.8). The detected change in frequency is termed the Doppler shift. This shift in reflection can be displayed graphically and is audible. In point of care ultrasound, the reflector is often moving blood, but it can also be various other tissues as well.

If the blood is moving away from the transducer, a lower frequency is detected (negative shift), and the spectrum appears below the baseline. Conversely, if the blood is moving toward the transducer, a higher frequency (positive shift) is detected, and the display is shown above the baseline. The amplitude of the signal is proportional to the magnitude of the motion signal (most often blood), indicated by various shades of gray.

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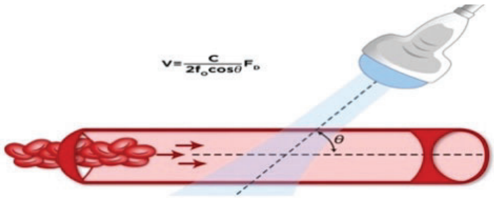

Figure 1.8 Doppler Principle

It is crucial to minimize the angle of the Doppler probe from the direction of flow to be able to assess the direction and velocity appropriately.

The Doppler shift is dependent on the insonating frequency (transducer frequency), the velocity of the moving red blood cells, the angle of the ultrasound beam, and the direction of the moving structure of interest. (Figure 1.8). Ideally, the angle of the ultrasound beam (transducer) should be less than 60 degrees to the pathway of flow being assessed to obtain an accurate and quantifiable evaluation of the motion. It is important to realize that *if the sound beam is perpendicular to the direction of blood flow, there will be no Doppler shift*, and consequently, no display of flow. Thus, optimization of Doppler assessment involves aligning the ultrasound probe plane to be as near to parallel to the flow as possible. If the item being assessed via Doppler (often blood) is moving away from the transducer, a lower frequency is detected (negative shift), and the spectrum appears below the baseline. Conversely, if the item being assessed is moving toward the transducer, a higher frequency (positive shift) is detected, and the display is shown above the baseline. The amplitude of the Doppler signal is proportional to the density of the entity be assessed (most often blood), which is represented by various shades of gray.

There are three main types of Doppler Ultrasound: 1. Pulse-Wave, 2. Continuous Wave, 3. Color Doppler.

Pulse Wave (PW) Doppler:

Pulse wave Doppler is a modality that provides an audible and visual display of motion at a *specific location*. Thus, PW offers the benefit of providing depth discrimination of where the Doppler signal is originating (Figure 1.9). However, because PW involves identifying a velocity sample in a particular location, the transit time required to reach that location must be factored in and produces a limitation on the range

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of velocity values that can be assessed. The spread of this range decreases the further the sample location is from the probe. In summary, PW is useful to assess the velocity at a specific location; however, it is limited by the range of velocities that it can assess.

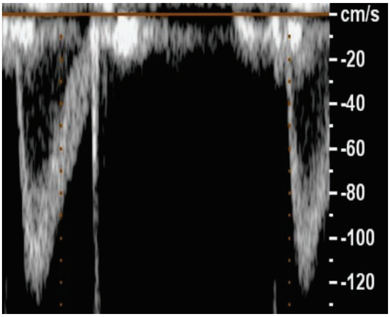

Figure 1.9 Pulse Wave Doppler

PW allows the localization of Doppler signal with a limitation on the range of velocities that can be displayed.

Continuous Wave (CW) Doppler:

CW allows assessment of all the velocities along a Doppler beam path, there is no ability to localize where the velocities originate in this path.

In this modality, ultrasound is constantly sending and receiving Doppler signals along the identified path of insonation (Figure 1.10). The benefit of this modality over PW Doppler is that there is no limitation on the range of velocities that can be assessed. However, the trade-off is the loss of depth localization. In other words, a CW Doppler will show a summation of *all* the velocities along the Doppler beam path (Figure 1.11).

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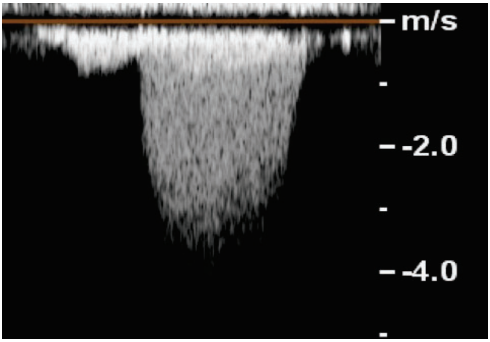

Figure 1.10 Continuous Wave Doppler

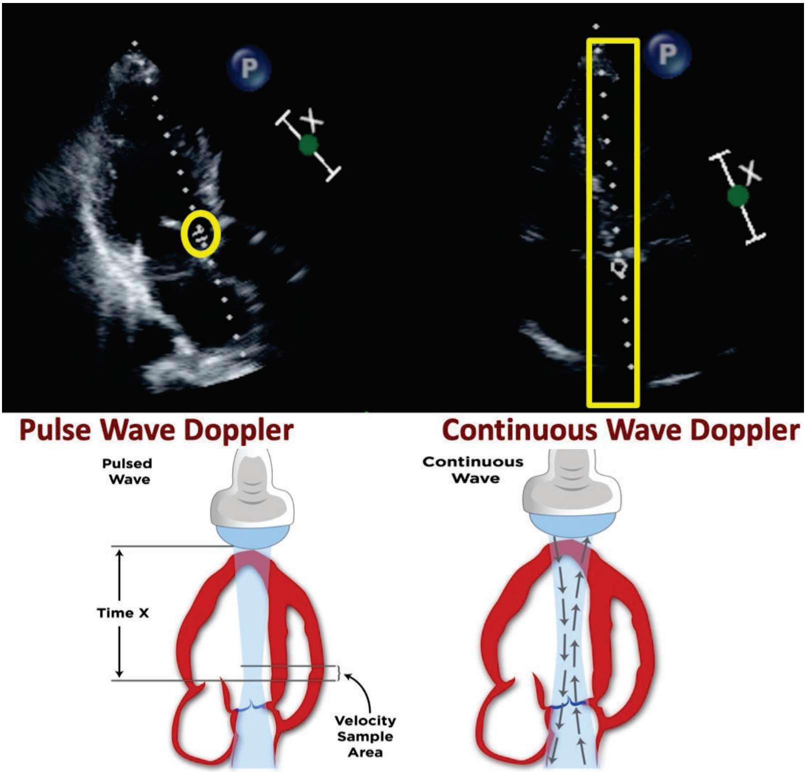

Figure 1.11 Doppler Zones for Pulse Wave and Continuous Wave Doppler

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Color Doppler:

In color Doppler, echoes from positive or negative Doppler shifts (toward or away from the transducer) are displayed with corresponding colors to indicate direction and velocity of flow. This is usually overlaid on a 2-D image. The color Doppler window can be adjusted over any region of the 2-D image. Specifically, a color Doppler represents a window of pulsed wave Doppler signals that have been assigned a color representation for the direction and velocity of flow (Figure 1.12). The brightness of the color represents the velocity of flow, and additional colors are added to indicate the extent of spectral broadening.

Figure 1.12 Color Doppler

A good general rule is the following: *blue color = flow moving away from the transducer / red color = flow moving toward the transducer* (think BART = Blue-Away/ Red-Towards). The range of colors in color Doppler settings represent different velocities. Brighter colors represent higher/faster velocities, while darker colors represent slower velocities. It is important that the limitations of PW Doppler remain with color Doppler. Thus, the color Doppler window has a range of velocities that it can assess, and the spread of this range decreases as one moves the color Doppler window away from the probe. The range of the velocities is shown on the screen with a color legend, typically on the top left of the screen. This range of velocities is called the **Nyquist limit**.

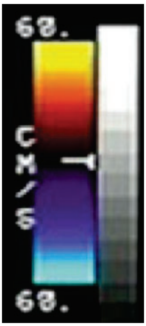

Figure 1.13 Nyquist limit

When the velocity detected passes the Nyquist limit, **aliasing** occurs.

Aliasing is the display of a change in the direction of flow secondary to the Doppler signal surpassing the positive or negative Nyquist limit (Figure 1.13). The result is a complete reverse in the color and velocity value (positive becomes negative and vice versa). On 2-D color imaging, it appears as if the display is cut off, wraps around, and reappears in the opposite region of the display.

It is important to always look at the Nyquist limit when using color Doppler. 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

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make the degree of regurgitation across a cardiac valve appear to be worse by *lowering* the Nyquist limit. Important reference measurements include 60 cm/sec to evaluate cardiac valves and 20 cm/sec to evaluate atrial or venous flow. Also, remember that with all Doppler modalities, the more parallel you are to the area of motion, the better the assessment. Finally, it is important to realize that the use of color Doppler will negatively impact the resolution of the 2-D image directly with the size of the color Doppler window.

Terms for Labeling and Scan Orientation

For each transducer position, the target structures are focused on three probe movements (Figure 1.14).

Rock: Adjusting the long axis of the ultrasound probe (parallel to the ultrasound plane).

Rotation: Clockwise, counterclockwise.

Fan: Adjusting the short axis of the ultrasound probe (perpendicular to the ultrasound plane).

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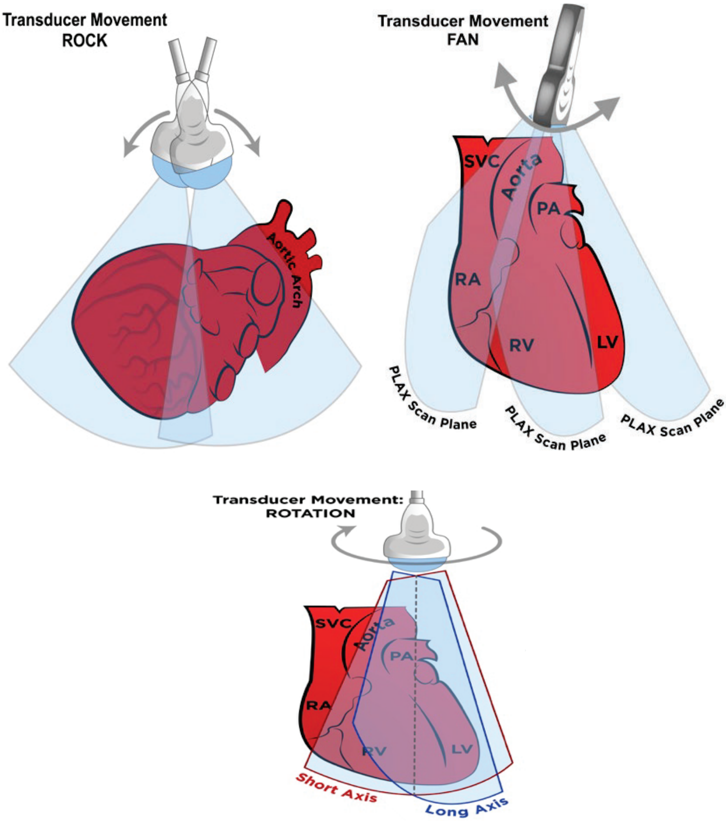

Figure 1.14 Axes for probe manipulation

Ultrasound Probe Indicator Marker

Another important point to become familiar with when learning 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 (for example, left and right of the probe correlate to the left and right of the screen). The indicator is typically marked by a line, bump, or LED light. Always begin by identifying where the indicator of the probe is located, then correlate its position to the indicator marker on the screen. For most point of care ultrasound systems, the default location of the indicator for non-cardiac probes/non-cardiac presets is on the left side of the ultrasound screen. For cardiac presets and the use of the phased array probe,

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the default for most ultrasound machines is to place the indicator on the right of the screen.

To summarize this concept, when carrying out an ultrasound examination, one should always consider two key issues regarding the orientation of anatomic structures as they are viewed on the screen:

1) The relationship of the probe indicator to the image on the screen (indicator-to-screen), and 2) the relationship of the probe indicator to the patient (indicator-to-patient). This book will describe the probe position based on the usual defaults for the probe and presets used to perform the ultrasound examination.

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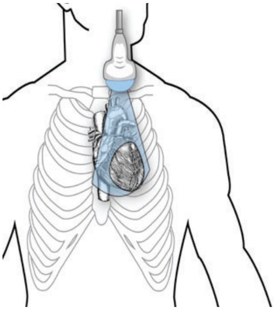
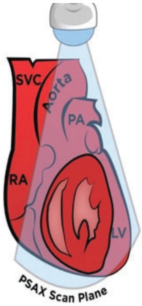
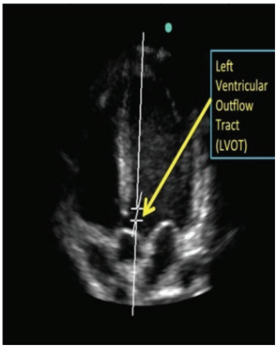
II.

ASSESSMENT OF VOLUME STATUS/ MECHANISM OF HYPOTENSION







Ultrasound provides a variety of techniques to assess volume status, evaluate fluid responsiveness, determine atrial filling pressures, and screen for rapid free fluid collection. This chapter will cover each of these four topics. Each subsection will cover an ultrasound technique used to answer these questions.

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II.A

INFERIOR VENA CAVA DIAMETER AND RESPIRATORY COLLAPSIBILITY

IHAB DOROTTA MBBS, JULIAN HINSON MD AND DAVINDER RAMSINGH MD

The diameter of the inferior vena cava (IVC) has been shown to accurately predict the vascular pressure filling the right atrium—known as the central venous pressure (CVP). Measurements of the IVC diameter correlate well with CVP readings. Please see the table below for the relationship between IVC diameter and the patient's CVP (Figure 2.A.1).

Additionally, measuring the change in the IVC diameter during different phases of respiration (IVC collapsibility) provides more precision with CVP estimation. The IVC diameter changes secondary to variations in pleural pressure during the respiratory cycle and the associated impact on venous return. Specifically, with each *negative inspiratory breath,* the right atrial filling is improved, and the IVC diameter *decreases* (as blood is unloaded). The opposite occurs with positive pressure inspiration. Specifically, the inspiratory phase induces an increase in pleural pressure, which is transmitted to the right atrium and reduces venous return. The result is an inversion of the cyclic changes in the IVC diameter, leading to *increases* during the *inspiratory phase* and *decreases* during the *expiratory phase*.

For CVP estimation, the marker of greater than or less than 50% collapsibility of IVC diameter is used. Please note that the diameter measurements and 50% collapsibility markers remain the same for both negative pressure and positive pressure ventilation. The table shown in Figure 2.A.1 highlights IVC diameter and percent collapsibility to particular ranges of CVP values. Please note that when measuring changes in the IVC diameter, the *maximum diameter* achieved during *expiration* is used in a

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spontaneously breathing patient while the maximum diameter during *inspiration* is used for a *mechanically ventilated patient*.

Of note, an IVC collapsibility of >50% equals a CVP of less than 5 mmHg, and an IVC diameter over 2.5cm with minimal respiratory collapsibility corresponds to a CVP over 15 (Figure 2.A.1).

IVC Size(cm)	Changes with respiration	Estimated meanCVP (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

Figure 2.A.1 Relationship between IVC ultrasound measurements and central venous pressure.

Examination

Ultrasound Window/View: Subxiphoid

Probes Used:

Curved Linear

Phased Array

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Patient Position: supine.

Probe Position: To obtain the appropriate image, either the curved linear or phased array transthoracic probe must be placed in the subxiphoid space with the probe indicator in the 12 o'clock position (refer to Figure 2.A.2). Ideal measurement of the IVC diameter should be just distal to where it merges with the hepatic vein, which is usually *2 to 3 cm from the IVC entry into the right atrium* (Figure 2.A.2). Please note that in low preload states, the IVC can appear collapsed and may be difficult to visualize. In the absence of raised intra-abdominal pressure, such a situation suggests the likelihood of a hypovolemic state. Two-dimensional imaging using the caliber/measure feature or M-Mode can be used to measure IVC diameter/collapsibility.

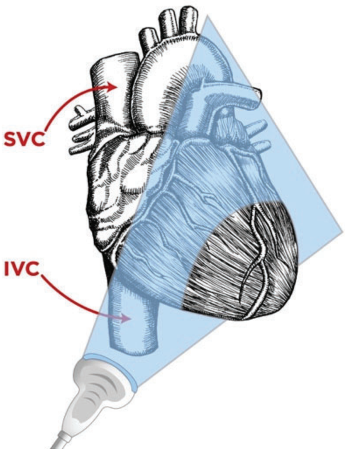

Figure 2.A.2 Probe position and ultrasound plane.
Note that the patient is supine with the probe placed in the subxiphoid space with the indicator in the 12 o'clock position. The IVC will be viewed in a sagittal cross section as shown on the right image.

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II.B.

Left Ventricle End Diastolic Diameter (LVEDD)

Sumit Singh, Matthew Alschuler,
Kelia Cook and Davinder Ramsingh

The diameter and/or the area of the left ventricle *at end-diastole* represents the filling of the left heart and has demonstrated a strong relationship to stroke volume. Using the measure or caliber feature, one can assess the diameter of the left ventricle in end-diastole in either a 2-D or an M-mode image. A good threshold value for a reduced stroke volume state in most adults is a left ventricle end diastolic diameter (LVEDD) of under 4 cm. Full details are shown in the reference table in Figure 2.B.1.

Often this parameter is assessed serially as therapies are administered. A typical example is an assessment for an increase in LVEDD after a fluid bolus or passive leg raise.

Additionally, it should be noted that the cardiac ultrasound views used to obtain LVEDD are the same views that are often used to evaluate systolic LV function (parasternal views). This will be discussed in the cardiac section.

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	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/m^2	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

Figure 2.B.1 Reference table for left ventricular end diastolic diameter measurements.
*Reference: Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, Flachskampf FA, Foster E, Goldstein SA, Kuznetsova T, Lancellotti P, Muraru D, Picard MH, Rietzschel ER, Rudski L, Spencer KT, Tsang W, Voigt JU: Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015; 28: 1-39 e14.


Phased Array

Examination

Ultrasound Window/Views: 1. Parasternal long axis view. 2. Parasternal short axis view.

Probes Used for Examination

Patient Position: Left-Lateral with L arm extended is preferred but the supine position is also feasible.

Probe Position: indicator should be in the 10 to 12 o'clock position.

Left parasternal long axis view: 3rd–4th interspace, left and lateral to the patient's sternum with the indicator (green line on the probe, Figure 2.B.2)

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roughly at the 10 o'clock position, or aiming toward the right shoulder (Figure 2.B.2).

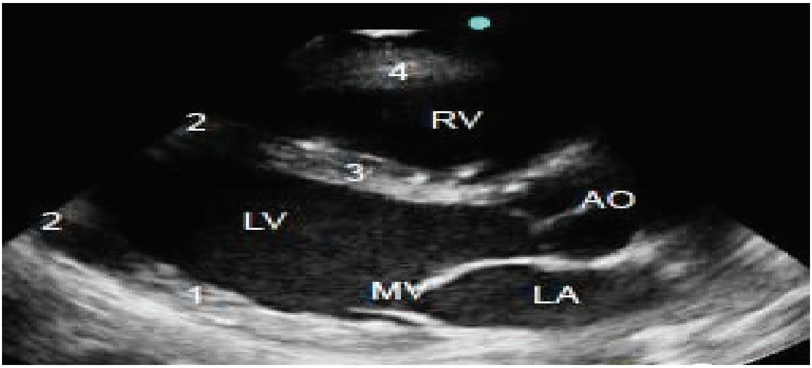

Figure 2.B.2 Parasternal long axis view of the heart. Top right – patient position, top left – probe position in relation to the heart. Bottom – image of the heart.

AO = Aortic Outflow
LV = Left Ventricle
LA = Left Atrium
RV = Right Ventricle
MV = Mitral Valve
PLAX = Parasternal Long Axis

Left parasternal short axis view: 3rd–4th interspace just lateral and left of the patient's sternum with the indicator marker approximately at the 2 o'clock position (green line, Figure 2.B.3) or aiming towards the patient's left shoulder (90 degrees to long axis view). Also, remember that you should adjust the angle to get a good view of the mid-papillary level of the left ventricle. Aiming towards the head will show the mitral valve followed by the aortic valve and aiming towards the feet will show the LV apex. Finally, you can verify that a good cross-section is obtained by making sure the two papillary muscles are equal in size (Figure 2.B.3).

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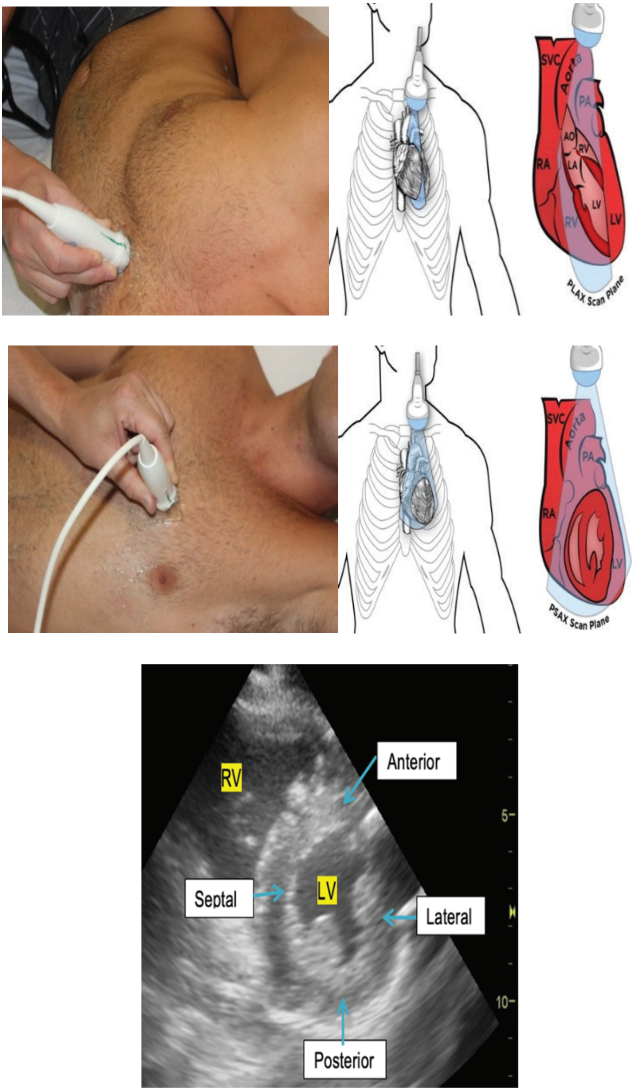

Figure 2.B.3 Parasternal short axis. Top right – patient position, top left – probe position in relation to the heart. Bottom – image of the heart.

LV = Left Ventricle
RV = Right Ventricle
PSAX = Parasternal Short Axis.

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II.C

Respiratory Variation of Velocity Time Integral (VTI)

Jared Staab, Benjamin Gow-Lee and Davinder Ramsingh

The volume of blood traveling through the cardiovascular system can be measured across cardiac and arterial structures via Doppler ultrasound. Specifically, Pulse Wave and Continuous Wave Doppler ultrasound can be used to capture a waveform pattern of the blood traveling across the heart or arterial structures during systole. This waveform is the Doppler representation of all of the velocities assessed, and tracing this waveform produces a parameter called the Velocity Time Integral (VTI).

The VTI of blood flow provides a surrogate for the volume of blood emitted during that cycle. Specifically, a VTI tracing of blood flow represents the collection of velocities of red blood cells as they traveled during the cardiac cycle. This collection of velocities is a surrogate for the volume of blood that traveled during that cycle as well. By measuring the diameter of the structure that the blood flow is transported across one can calculate the volume of flow. For example, obtaining a VTI signal across the left ventricular outflow tract (LVOT) along with measuring the diameter/area of the LVOT will allow one to calculate the stroke volume. Interestingly, one can easily obtain surrogates of stroke volume by assessing VTI waveforms of arterial structures that are easier to insonate. Please note that VTI is used in many ways to provide further insight into how volumes of blood are transferred across the body outside the scope of this text.

For this section, we focus on how one can use this concept to determine a state of fluid responsiveness by looking at the percent change in the VTI value during the respiratory cycle. Integral to this concept is the understanding that the preload of the cardiopulmonary system increases and

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decreases during different phases of the respiratory cycle. We will focus on what occurs during *controlled positive pressure ventilation* as this is a requirement to use VTI variation for fluid responsiveness.

During the inspiratory phase of controlled positive pressure ventilation, the increased intrathoracic pressure will cause the left side of the heart to initially receive additional volume from the pulmonary system. In addition, the positive pressure will assist in LV contraction. Both of these result in an increase in stroke volume during inspiration of a positive pressure breath (definition of this phenomenon being reversed pulsus paradoxus). On the right side of the heart, the intrathoracic pressure increases from a positive pressure breath, which will increase right atrial pressure, causing venous return to decrease. This decreases right ventricular output, which then after two or three heartbeats will manifest in a decrease in left ventricular stroke volume.

One can take advantage of this cardiopulmonary relationship to determine states of fluid responsiveness. If the pressure change in the respiratory tree is consistent (controlled mechanical positive pressure ventilation) and the cardiac rhythm is regular, then the percent change in filling volumes is directly related to one's position on the Frank-Starling curve (preload status). A large percent change (defined as a variation >15%) represents a fluid responsiveness state. This is defined as a volume status state in which a 250 ml fluid bolus will increase stroke volume by at least 10%.

There are many locations that one can sample a VTI waveform to assess for this variation. The most validated location lies across the *left ventricular outflow tract* (LVOT). This is commonly used because the LVOT is less predisposed to pathologic disease that could impact flow assessment compared to other cardiac structures.

It is important to understand that since we are examining for the percent change in VTI, assessment across any arterial structure can also be applied. Doppler ultrasound imaging of the radial, brachial, carotid, and femoral arteries provides information similar to LVOT VTI variation without the same degree of image acquisition difficulty. Additionally, these structures may be more accessible for examination in certain patient care settings.

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Methods of VTI Acquisition

1) VTI using LVOT

Patient Position: Left lateral with left arm extended.

Phased Array

Probe Used:

Probe Position: Placed at the left lateral point of maximal impulse (one or two rib spaces below the nipple), with the probe approximately at the 2 to 3 o'clock position. In the apical five chamber view, place a PW or CW sample volume in the middle of the LVOT adjacent to the aortic valve. The sample cursor should not overlie the valve when using PW Doppler. PW Doppler allows for precise measurement of blood velocity at a specific location. The proper technique ensures there is no valve opening artifact in front of the systolic flow waveform that is shown on the 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. Please review the apical cardiac chapter for more details on this view.

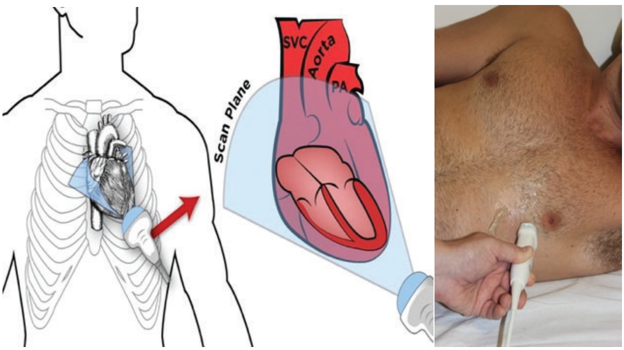

Figure 2.C.1 Location of Doppler Signal for LVOT VTI Assessment (RV= right ventricle, TV = tricuspid valve, RA= right atrium, AV = aortic valve, LA=left atrium, MV = mitral valve, = LV = left ventricle.

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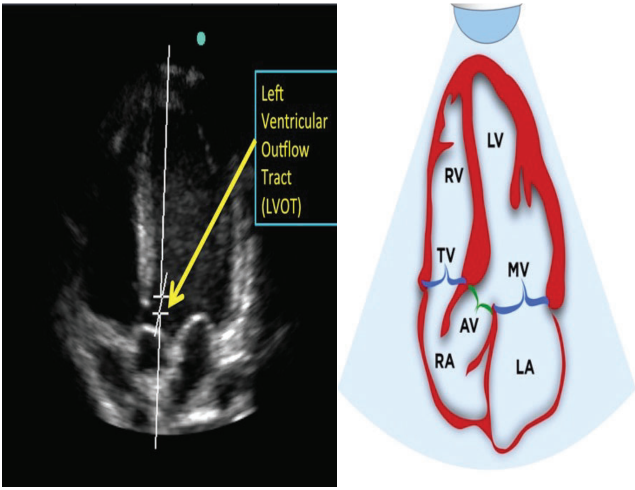

Figure 2.C.2 Doppler waveform pattern for LVOT VTI variation assessment.

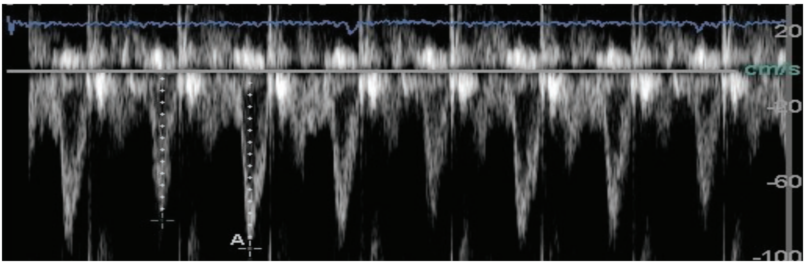

Figure 2.C.3 Doppler of Left Ventricular outflow tract via apical 5 chamber view.

Tips for Apical 5 Chamber View Optimization:

- If the apex of the left ventricle is visualized but not the LVOT, it is likely that scanning is with too steep an angle between the skin and the probe, flattening the probe should bring in the cardiac valves and LVOT.

- If you do not 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.

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- Once the apex is identified, slide the probe medially/laterally to visualize the entire left ventricular chamber before fanning the probe to identify the LVOT.

2) VTI using Arterial Source

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

Doppler Image Optimization:

Remember that to obtain the best Doppler waveform one must be as parallel as possible to the area of blood flow assessment.

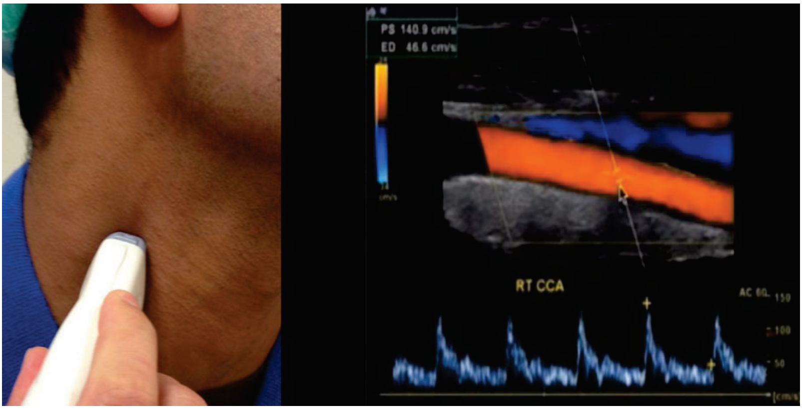

Figure 2.C.4 Assessment of Carotid VTI as a marker for fluid responsiveness.

VTI Variation Calculation:

$$\{(VTImax - VTImin)/ [(VTImax - VTImin)/2]. \times 100\%\}$$

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II.D.

FAST (Focused Assessment with Sonography for Trauma) Examination

Vi Dinh, Seth White and Davinder Ramsingh

Many trauma patients have injuries that are not apparent on the initial physical examination. Indeed, 20 to 40% of patients with significant abdominal injuries may initially have a normal physical examination. The purpose of bedside ultrasound in trauma is to rapidly identify free fluid (usually blood) in the peritoneal, pericardial, or pleural spaces.

Recall that the peritoneum is the serous membrane that forms the lining of the abdominal cavity and overlies most of the intra-abdominal organs. Because of the peritoneal layer, one can appreciate the collection of fluid between organs within the peritoneum, behind (retro-peritoneal), and below it (infra or sub-peritoneal). Peritoneal organs include the stomach, spleen, liver, pancreas (only the tail), and parts of the colon, uterus, fallopian tubes, and ovaries. Retroperitoneal structures include the kidneys, IVC, aorta, and part of the colon. Intraperitoneal structures include the bladder and distal rectum.

The FAST examination can very reliably detect >200 ml of fluid in body cavities. Indications for the FAST examination include acute blunt or penetrating torso trauma, trauma in pregnancy, pediatric trauma (details below), and subacute torso trauma. Utility of this examination may also be useful for the detection of post-surgical/procedural bleeding as well as undifferentiated hypotension.

To successfully perform the FAST examination, one must have a basic understanding of hemorrhage and ultrasound. The sonographic evolution of hemorrhage is dependent on the time of insult. Initially, the free fluid is

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sonolucent (black). A clot forms in 2 to 4 hours and becomes more echogenic (grayer), then returns to being more sonolucent (black) with fibrinolysis at 12–24 hours. On ultrasound, free fluid appears “pointy,” not circular—as if the fluid was contained within a walled organ or structure, and typically forms around the bowel and viscera.

It is important to understand that free intraperitoneal fluid tends to collect in areas formed by peritoneal reflections and mesenteric attachments (paracolic gutters) (Figure 2.D.1). For the upper abdomen, this dependent area is called Morison’s pouch. Morisons pouch is the collection site for abdominal injury above the umbilicus since the paracolic gutters empty here (Figure 2.D.1). This area corresponds to the interface of the liver and the right kidney. Here, blood initially develops at the tip of the liver and then progresses to separate the liver and the right kidney.

Regarding LUQ (left upper quadrant) injuries, free intraperitoneal fluid will initially develop in the left subphrenic space first (not the splenorenal recess) due to the phrenicocolic ligaments. When free fluid is visualized between the spleen and kidney, there is likely to be several hundred milliliters of free fluid.

This is an important point to highlight, because of the paracolic gutters, most injuries above the umbilicus that produce several hundred milliliters of free fluid will produce a positive pathologic finding of free fluid in the RUQ (right upper quadrant), specifically at the kidney/liver interface, which is termed Morison’s pouch. This is why the RUQ view is the most important view 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 examine the most dependent area of the lower abdomen in the supine patient, which is in the pelvic cul-de-sac (Pouch of Douglas).

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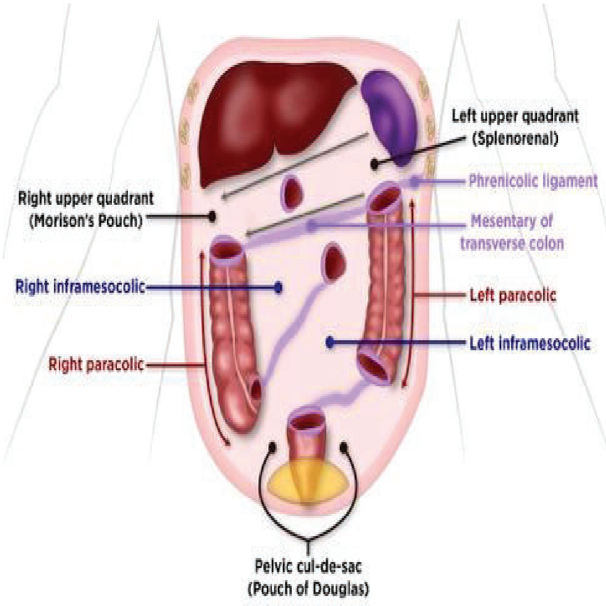

Figure 2.D.1 Relevant Anatomy for FAST examination

A conservative rule of thumb to estimate volume of free fluid is that 1 cm of hypoechoic space = 150ml.

Probes Used for FAST Examination:

Curved Linear

Phased Array

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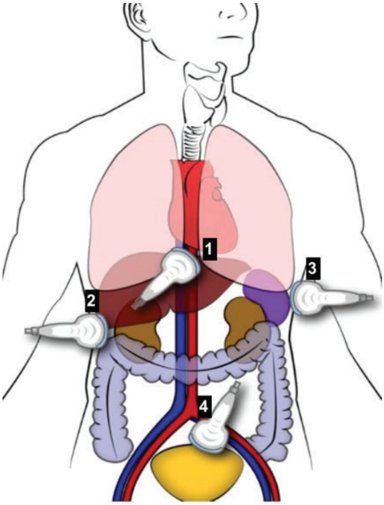
Standard FAST Examination Views:



1. Pericardial View
2. Right Upper Quadrant View
3. Left Upper Quadrant View
4. Suprapubic/Pelvic View

Figure 2.D.2 Overview of FAST examination (four acoustic windows/probe placement positions).

1) Pericardial View

This view is used to look at the interface between the right ventricle and the liver to identify pericardial fluid to 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.

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Figure 2.D.3 Patient and ultrasound probe placement positions for the pericardial view.

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 probe should be placed parallel to the skin of the torso. Remember to press firmly just inferior to the xiphoid process to obtain a better image of the heart. Try moving 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". This causes the diaphragm to flatten and decreases the depth of penetration required to produce the image.

2) Perihepatic (RUQ) View

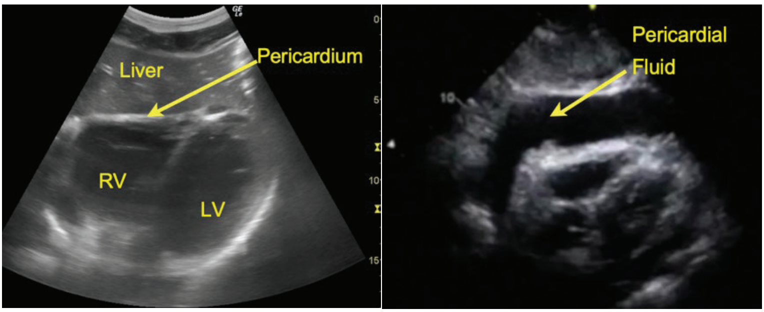

Figure 2.D.4 Normal (left) and abnormal (right) pericardial views.

As stated above, this view is the most important view of the FAST examination when assessing for abdominal injuries above the umbilicus. In this portion of the examination we are evaluating Morison's pouch: the potential space between the liver and the right kidney. When performing the FAST examination, there are four main areas to scan to evaluate for free

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fluid in the RUQ: 1) Pleural space, 2) Infra-diaphragmatic 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.

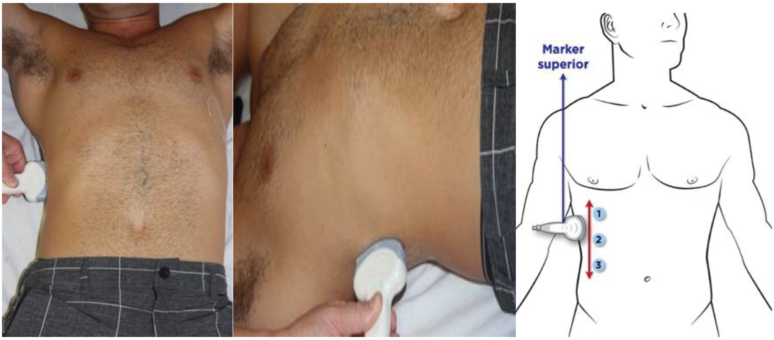

Figure 2.D.5 Patient and ultrasound probe placement positions for the RUQ view.

Probe Position: Probe (either phased array or curved linear) should be placed with the indicator pointing between the 10 and 12 o'clock position, perpendicular to last true rib (right costal margin), initially at the right mid-clavicular line, then down to the mid-axillary line. *The final probe position should be at the mid-axillary line (around 10th rib space).* Following the mid-axillary line up one rib space and below will allow further visualization of necessary structures. The liver will appear homogenous, with medium-level echogenicity, while the kidneys will be identified by a brightly echogenic surface surrounding a hypoechoic to isoechoic parenchyma, with a central hyperechoic core representing the renal sinus.

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Figure 2.D.6 Normal RUQ FAST examination.

3) Perisplenic (LUQ) View

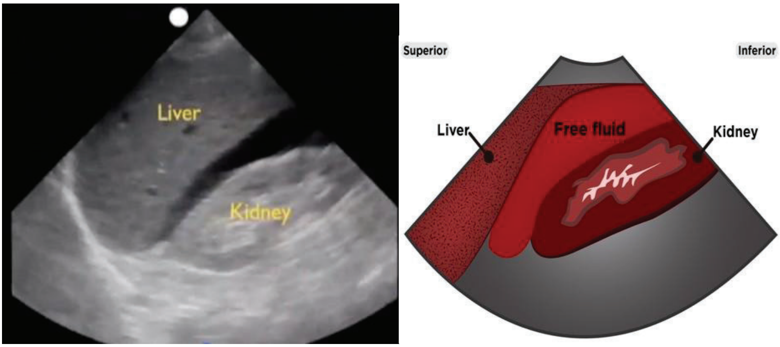

Figure 2.D.7 Abnormal RUQ FAST examination.

This view can be the most challenging to obtain in the FAST examination. LUQ injuries will tend to cause free intraperitoneal fluid to accumulate in the left subphrenic space first (not the splenorenal recess) due to the phrenicocolic ligaments. Only when large amounts of fluid are present, will free fluid accumulate between the spleen and the kidney. In addition, the phrenicocolic ligament restricts the flow of free fluid from the left paracolic gutter to the LUQ, so the fluid spreads across the midline into the RUQ. This is why the RUQ view is the most important in the assessment of upper abdominal injuries.

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

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Figure 2.D.8 Normal LUQ FAST examination.

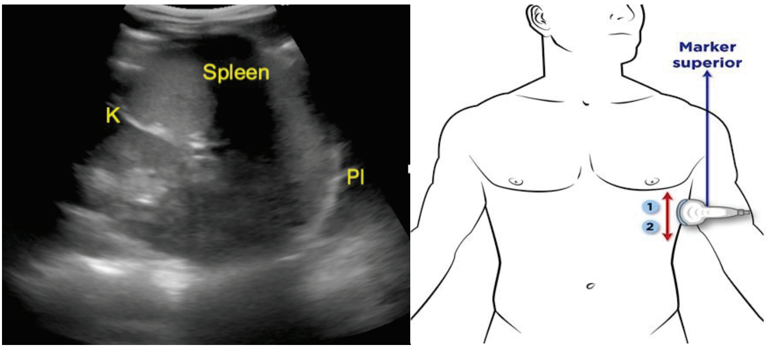

Figure 2.D.9 Normal LUQ FAST examination.

Probe Position: Probe (either phased array or curved linear) should be placed with the indicator pointing to the 12 to 2 o'clock position, perpendicular to ribs at the posterior axillary line or 8th rib space (always angle probe with the ribs). 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 the spleen/kidney, aim the probe more posteriorly (your knuckles should be touching the bed). The spleen is much more homogenous on ultrasound than the kidney, and it contains an echogenic (bright) capsule.

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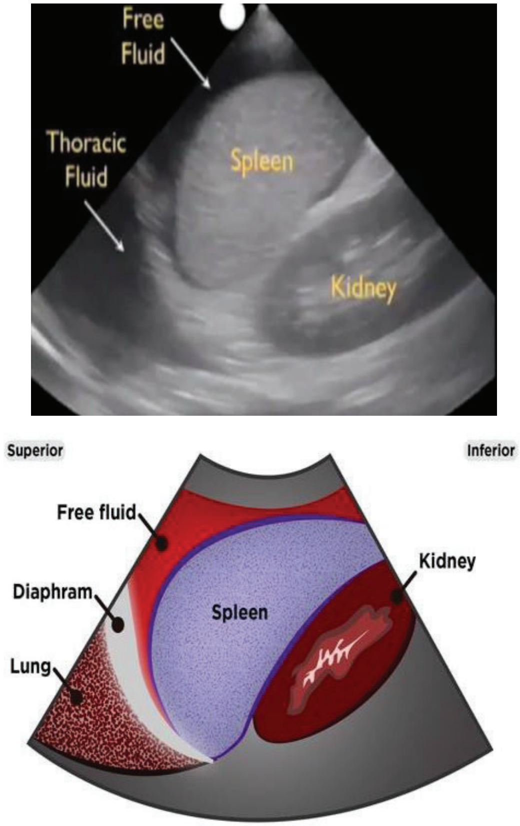

Figure 2.D.10 Abnormal LUQ FAST examination.

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4) Pelvic (Suprapubic) View

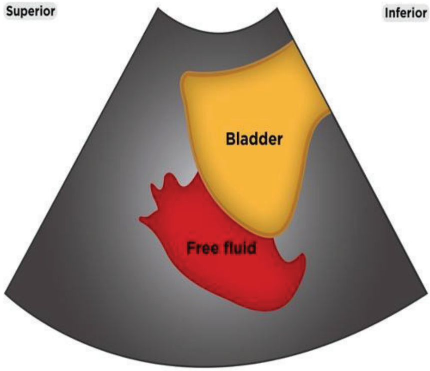

Figure 2.D.11 Location of free fluid in lower abdominal injuries.

This view is used to assess for free fluid in the lower abdomen by scanning the most dependent area, which is the area posterior to the bladder (pouch of Douglas) (Figure 2.D.11.). For injuries below the umbilicus this is the location where free fluid collects. Specifically, the location where free fluid develops for males is between the bladder and rectum (Figure 2.D.12) and for females it is between the uterus and rectum (Figure 2.D.13).

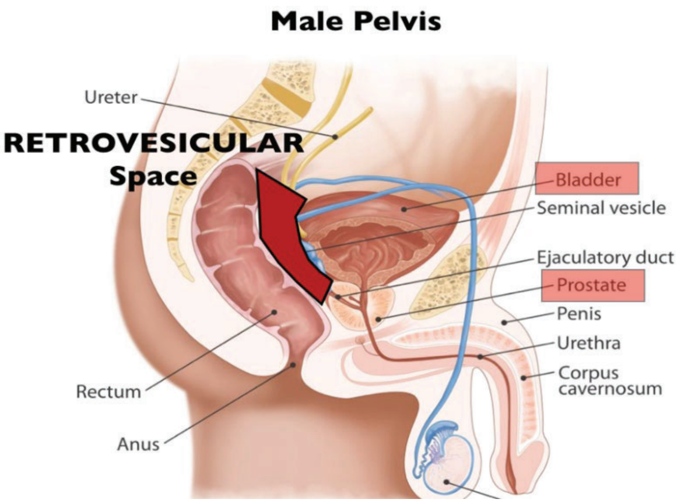

Figure 2.D.12 Relevant male anatomy for suprapubic FAST examination.

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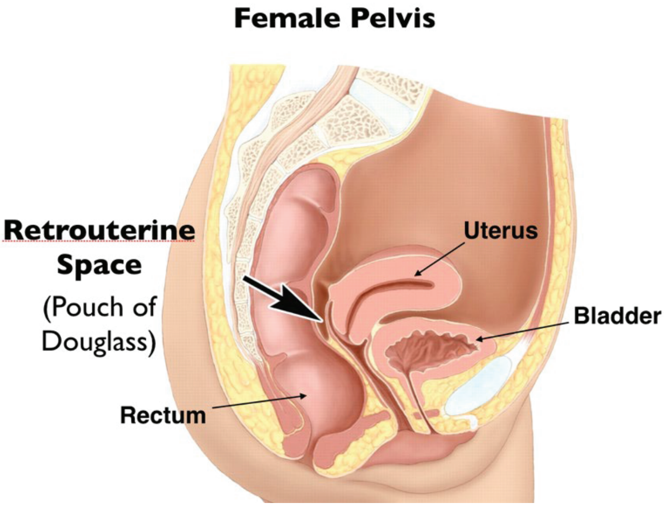

Figure 2.D.13 Relevant female anatomy for suprapubic FAST examination.

In this view, it is very important to scan both the long and short axes (see below) to assess the entire pouch of Douglas. Free fluid will appear similar as described above. Development of free fluid occurs on each side of the bladder and becomes significant (>250 ml) when a continuous strip of fluid is developed in this space. Conservatively, a strip over 1 cm in thickness corresponds to greater than 500 ml and a 2 cm strip corresponds to 1 liter of free fluid.

Please note that a collapsed bladder will make insonation of the pouch of Douglas challenging. Also, it can be normal for premenopausal females to have a small amount of free fluid in this area. However, a continuous strip of free fluid of greater than 0.5 cm should always be of concern.

Bladder Volume

In addition to the assessment of free fluid, these views can be used to determine the amount of volume in the bladder by using the following equation: 0.7 x (supero-inferior diameter) x TS (maximum transverse diameter) x AP (maximum antero-posterior diameter).

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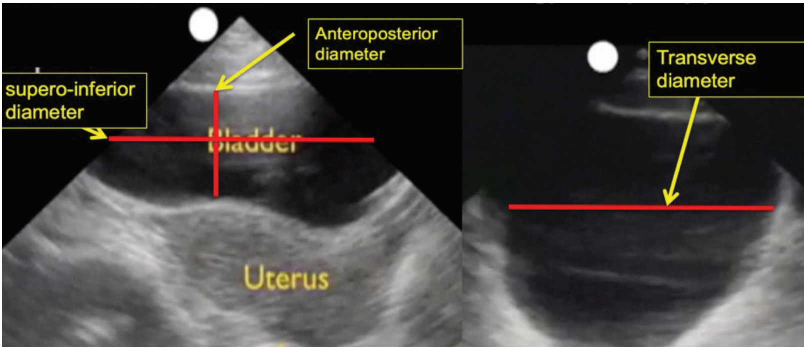

Figure 2.D.14 Estimation of bladder volume.

Patient Position: Supine.

Probe Position: Probe (either phased array or curved linear) should be placed 2 cm 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 the bowels.

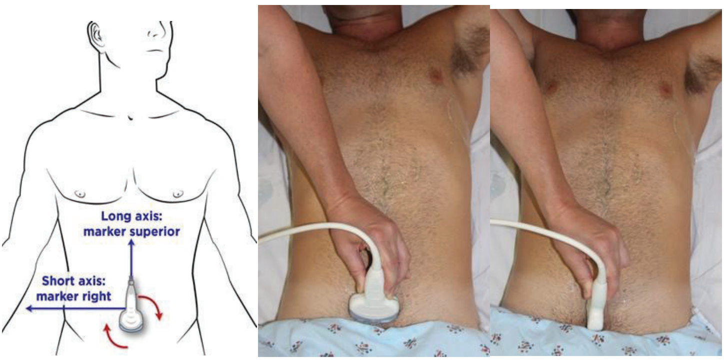

Figure 2.D.15 Probe placement positions for suprapubic FAST examination.

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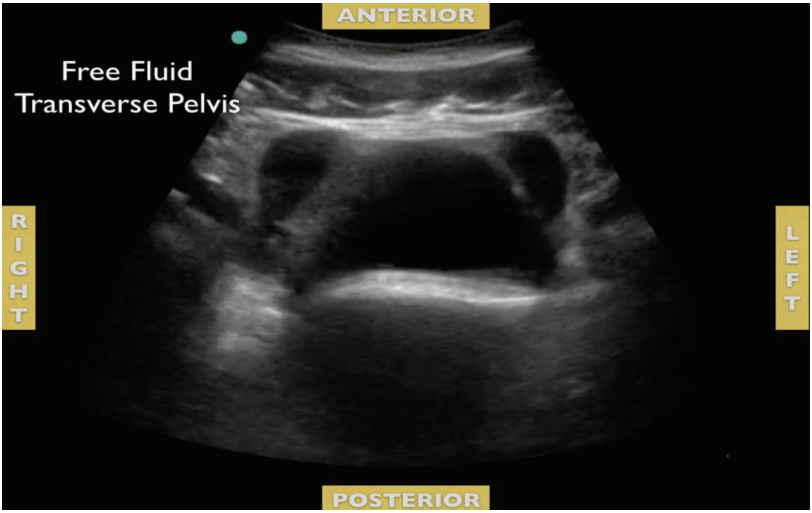

Figure 2.D.16 Normal male transverse suprapubic FAST examination.

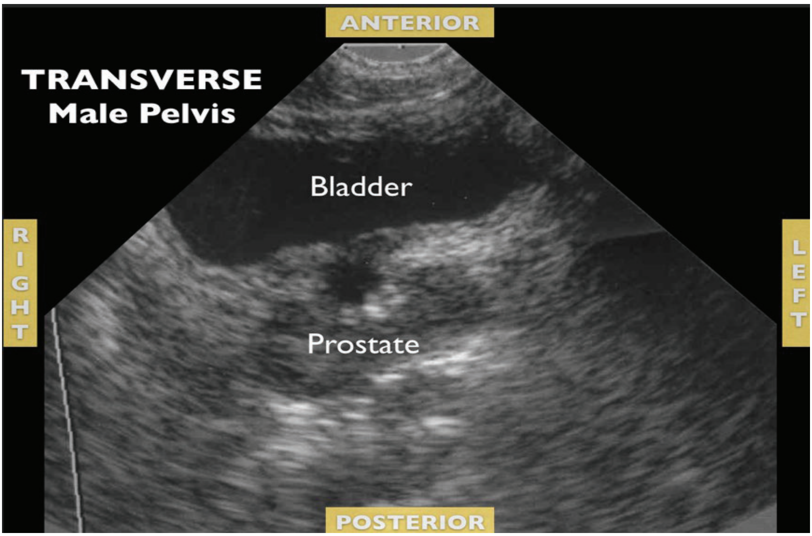

Figure 2.D.17 Normal male longitudinal suprapubic FAST examination.

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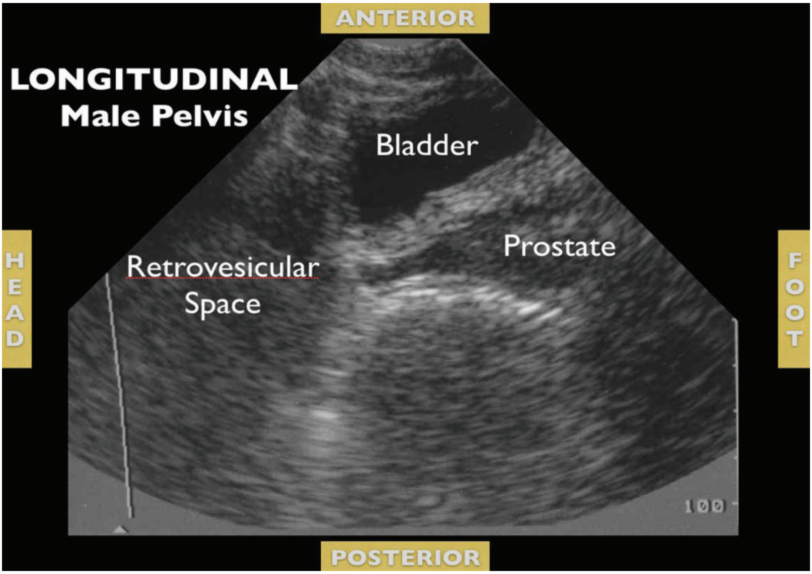

Figure 2.D.18 Abnormal male transverse suprapubic FAST examination.

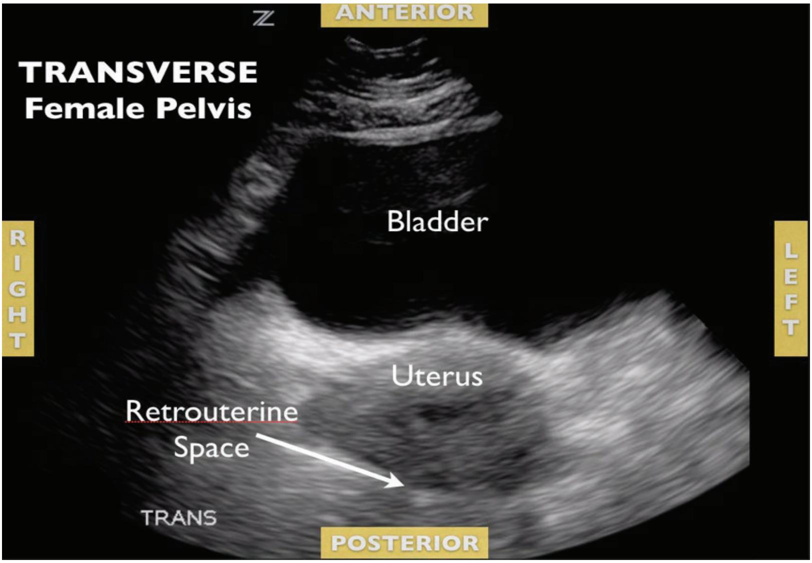

Figure 2.D.19 Abnormal male longitudinal suprapubic FAST examination.

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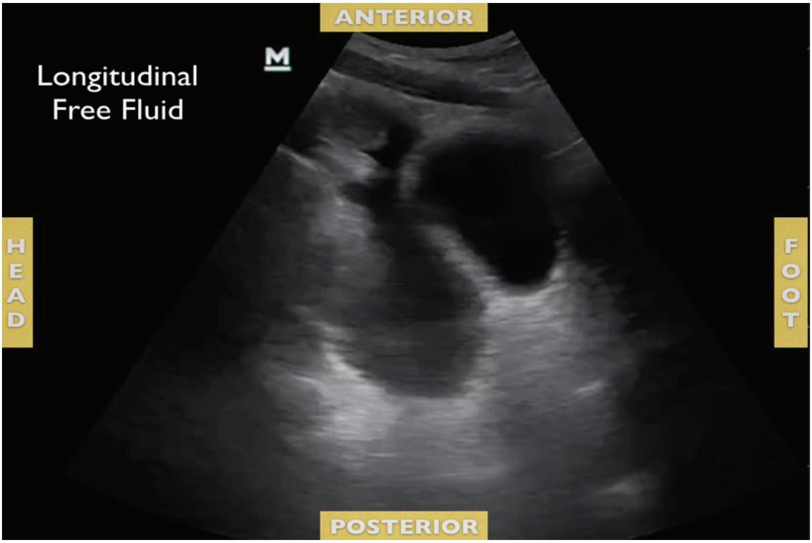

Figure 2.D.20 Normal female transverse suprapubic FAST examination.

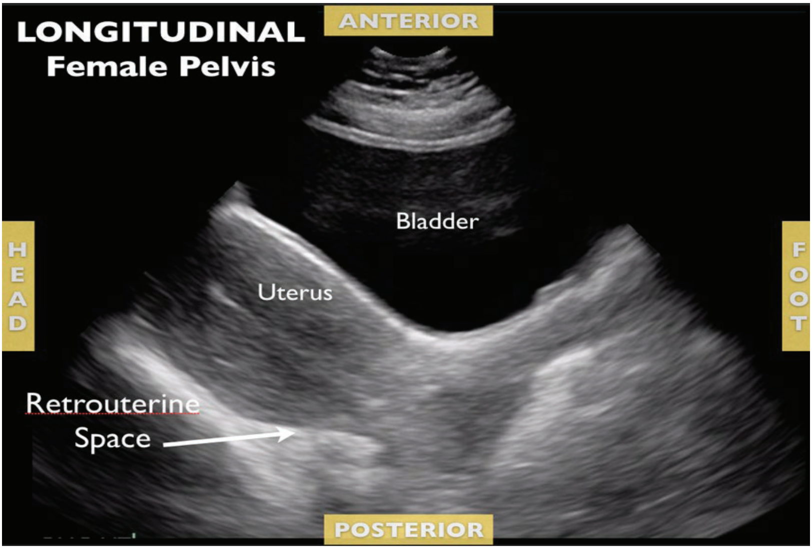

Figure 2.D.21 Normal female longitudinal suprapubic FAST examination.

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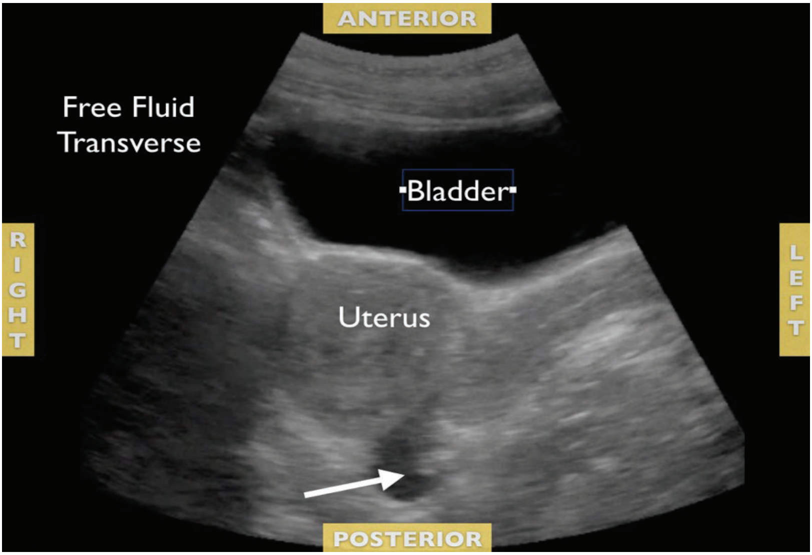

Figure 2.D.22 Abnormal female transverse suprapubic FAST examination.

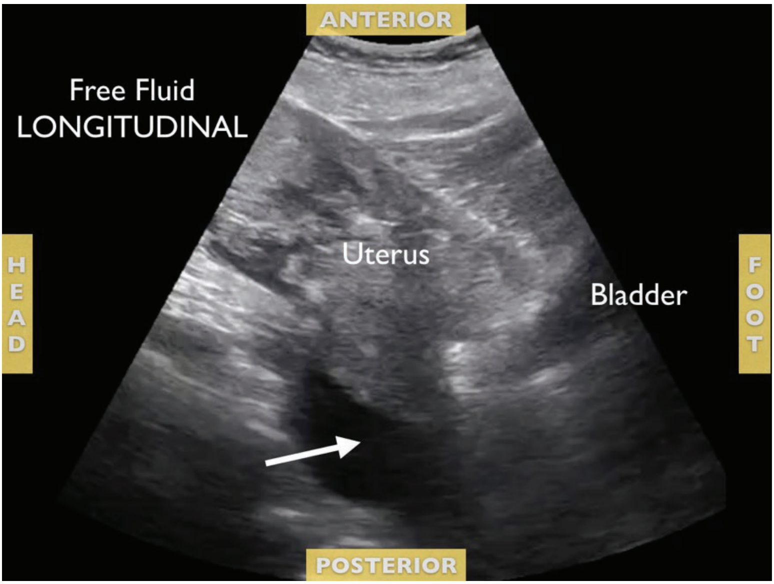

Figure 2.D.23 Abnormal female longitudinal suprapubic FAST examination.

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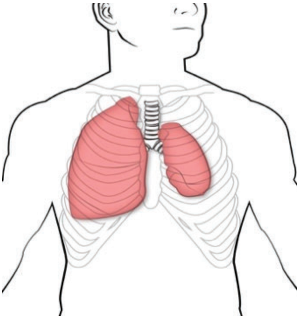
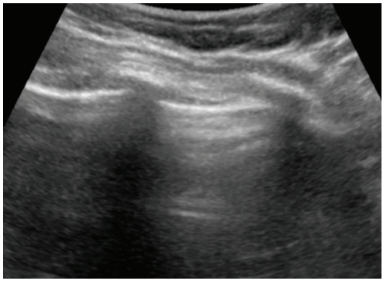
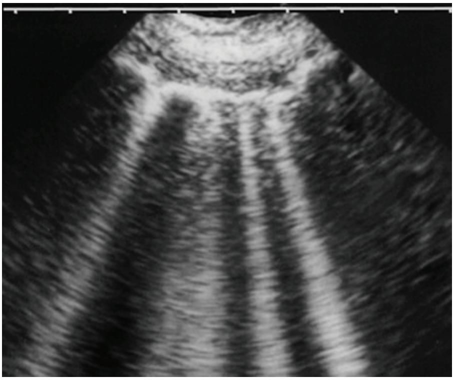
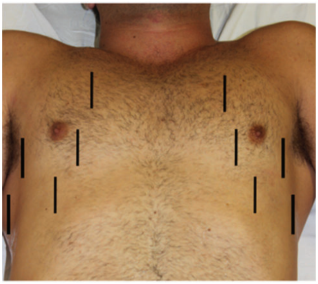
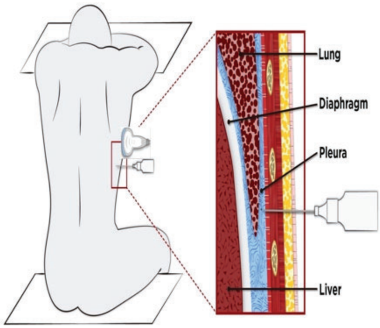
III. Pulmonary Ultrasound











Surface 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. Each of these topics will be discussed in the subsequent chapters.

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III.A

Pulmonary Ultrasound for the Evaluation of Pneumothorax

Jared Staab, Priscilla Vu
and Davinder Ramsingh

Assessment of a pneumothorax via ultrasound is carried out by observing the normal motion of the visceral pleura interfacing or "sliding" with the parietal pleura (Figure 3.A.3). 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 (Figure 3.A.4). It is important to realize that any amount of air will prevent the detection of lung sliding. This is a benefit for the ability to use ultrasound to detect the presence of a pneumothorax (significantly better than a chest X-ray) but also explains why it is a challenge to quantify the size/severity of a pneumothorax via this ultrasound examination.

It is also important to recognize that there are other mechanisms that can demonstrate the absence of lung sliding aside from pneumothorax, including apnea, mainstem intubation, pleurodesis, and bronchial obstruction. One strategy to help differentiate a pneumothorax vs. these other pathologies utilizes the "lung pulse."

In the context of point of care lung ultrasound, the lung pulse is the visualization of the translation of cardiac motion across the lung pleura. It is displayed as a vertical "up/down" motion of the lung pleura that is synchronous to the heart rate. This effect is visualized in situations in which there is no lung motion (absence of lung sliding), but the visceral and parietal are still adjacent (no pneumothorax). It is easier to visualize the lung pulse on the left side rather than the right, given the proximity of the heart. Evaluation for the lung pulse should be included when one detects the

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absence of lung sliding. Additionally, even in the absence of lung sliding, B-lines effectively rule out pneumothorax in the area of insonation.

Probes Used:

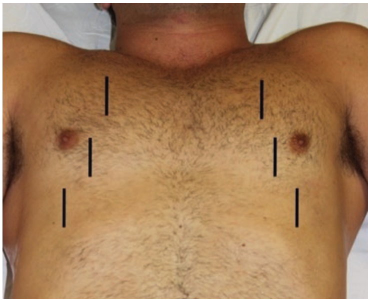

Figure 3.A.1 Patient position and scanning windows.

Because the lung pleura is relatively superficial, the utilization of a high-frequency linear probe will provide the ideal image quality. A low-frequency probe can be used with the understanding that a lower frequency will produce a poorer quality image.

Patient Position: The supine position is most common. In this position, one would scan the three probe placement positions indicated in Figure 3.A.1, which should correspond to the most anterior segments of the chest. If the patient is in another position, realize that one should scan the most anterior areas (where one would think air would go).

High Frequency Linear

Probe Position: Place the linear probe on the anterior chest wall along the mid-clavicular line, starting at the second to third rib space (Figure 3.A.2), and then follow the path indicated in Figure 3.A.1. The probe should be perpendicular to the ribs, with the indicator at the 12 o'clock position. It is important to fan the probe such that the ultrasound plane is perpendicular to the ribs to provide the best visualization of the lung pleura. In addition, one should have two ribs in view (one on each lateral side) to ease the identification of the lung pleura between other fascia layers (Figure 3.A.3). Finally, it is important to scan each of these six regions systematically to be able to match particular zones with the ultrasound scan.

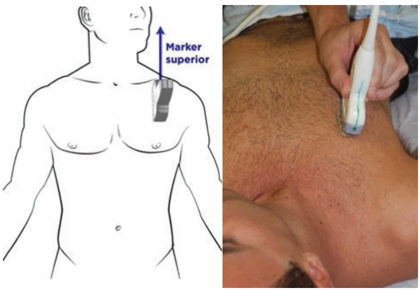

Figure 3.A.2 Probe placement.

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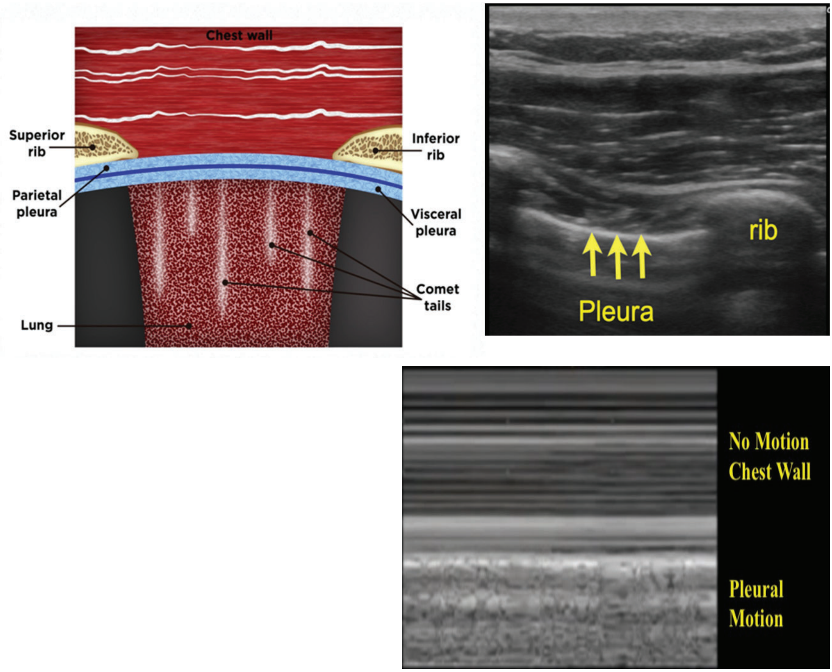

Figure 3.A.3 Normal ultrasound examination.
Notice the generation of motion artifact on the M-Mode Image (bottom) and the identification of the pleura line below the rib on the B-mode Image(top).

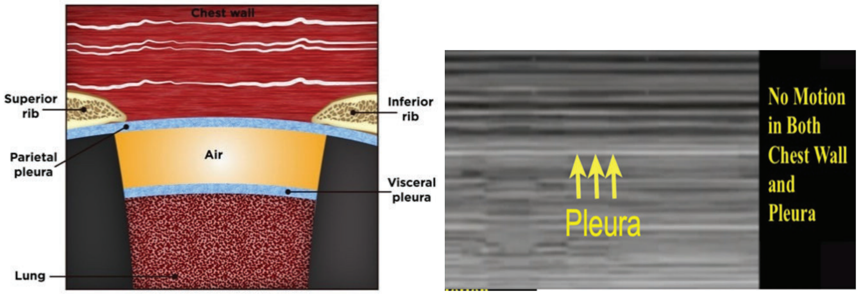

Figure 3.A.4 Abnormal ultrasound examination.
Notice the absence of motion artifact on the M-Mode Image. It is important to have the ribs in view to appropriately identify the lung pleura.

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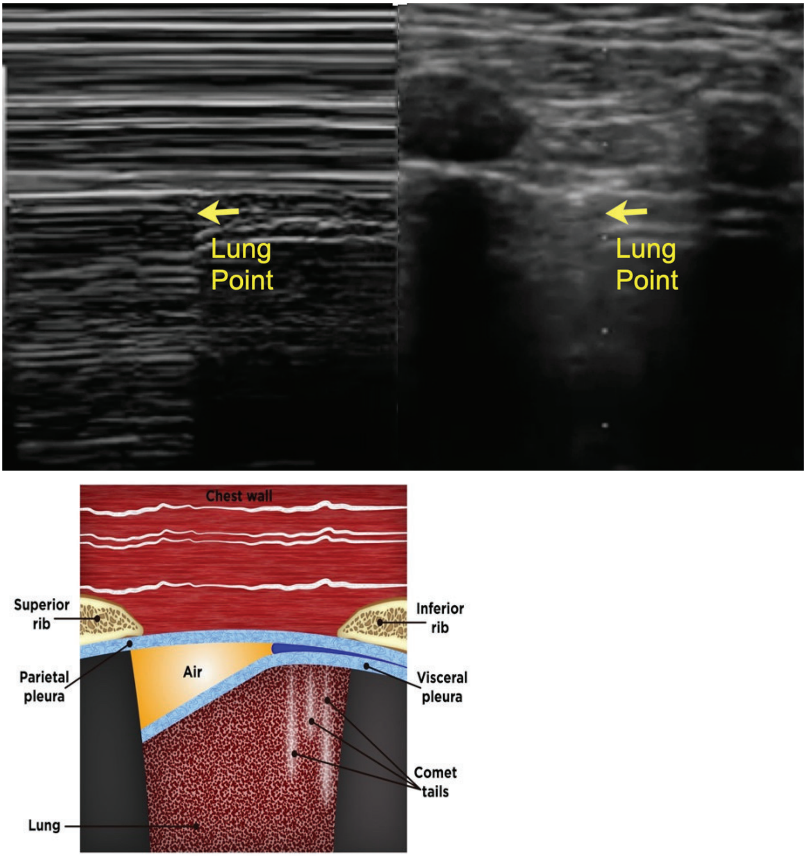

Figure 3.A.5 Lung point.
The lung point is the visualization of lung sliding adjacent to an area of its absence in a continuous ultrasound image (M-mode on the left and B-mode on the right). Identification of the lung point is pathognomonic for a pneumothorax.

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III.B

Pulmonary Ultrasound for the Evaluation of Pleural Effusion

Jay Shen, Benjamin Lew
and Davinder Ramsingh

The identification and quantification of a pleural effusion can be performed with point of care ultrasound. The examination involves placing a low-frequency probe in the dependent areas of the patient's lungs fields. A normal examination (Figure 3.B.1) in this location will visualize the diaphragm (hyperechoic), abdominal structures (liver or spleen), and signs of lung aeration (see section III.C). Normally, one should not be able to clearly visualize the lung parenchyma as the air-filled parenchyma scatters the ultrasound beam. Lung parenchyma can be confirmed by the presence of the bright shimmering hyperechoic pleural line. In the presence of a pleural effusion, however, the dependent areas are filled with fluid and therefore will appear anechoic (black). In addition, the presence of significant amounts of pleural effusion allows for the visualization of the spine vertebra, as the pleural fluid serves as a medium for ultrasound beam propagation. This is known as the "Spine Sign"[1] (Figure 3.B.2).

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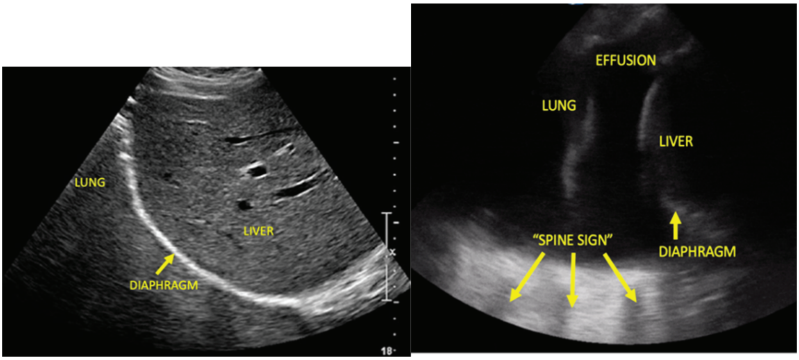

Figure 3.B.1 Normal ultrasound of lung base.

Point of care ultrasound has been demonstrated to be more accurate than chest radiography and may be as accurate as chest computed tomography in detecting pleural effusions[2]. Ultrasound can detect effusions greater than 20 ml and has greater sensitivity, specificity, and accuracy compared to physical examination and chest radiography. Ultrasound can also estimate the effusion size. Many methods have been described to estimate effusion volumes. A common strategy used for these calculations is the determination of the widest space between the diaphragm and the visceral pleura at end-expiration (Figure 3.B.3). A space of greater than 5 cm consistently corresponds to a volume of over 500 ml. Several equations exist for specific volume calculation; one example is

Vol (ml) = 16 X Diameter (mm) (Figure 3.B.3).

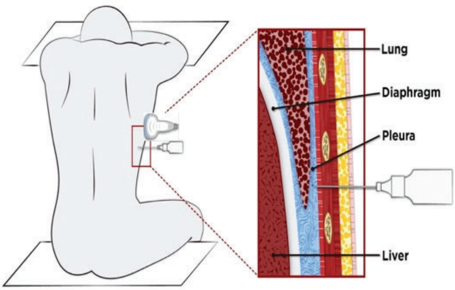

Figure 3.B.2 Pleural effusion ultrasound including "Spine Sign".

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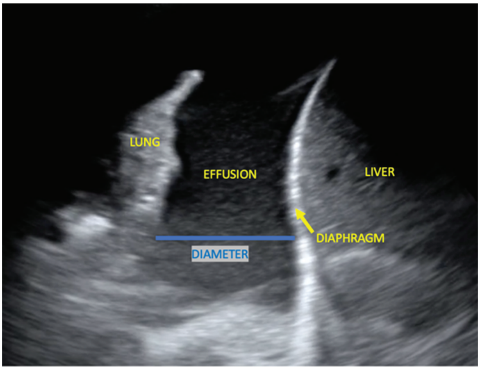

Figure 3.B.3 Measurement for pleural fluid volume estimation.

It is important to highlight the challenges for the exact volume determination of effusion volume via ultrasound. For example, ultrasound measurements will be influenced by the size of the thoracic cavity, as those with larger cavities allow for greater distribution of fluid. Additionally, patient position (upright, supine, lateral decubitus) can influence fluid distribution. Alterations to the position of the diaphragm (examples include abdominal hypertension, phrenic nerve paralysis, and diaphragmatic hernia) can also impact fluid estimation. Despite these limitations, the utility of using ultrasound to detect large effusions remains relevant.

There are four main considerations when performing a chest needle or chest tube insertion for clinically significant pleural effusions: 1) symptoms and size of the effusion, 2) site integrity, 3) coagulation status, and 4) presence of positive pressure mechanical ventilation. As a reminder, *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 500 ml 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.

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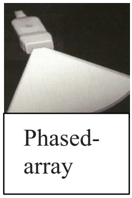
Figure 3.B.4 Thoracentesis procedure to drain a pleural effusion. Needle should be placed above the rib at the level of the pleural fluid.

Probes Used:

A low-frequency probe is required to be able to both detect and quantify pleural effusion in adult patients. This is because of the required depth of penetration for quantification.



Patient Position:

There are two potential positions for pleural effusion evaluation of the dependent areas where the free fluid will collect:

1) Supine with mild torso elevation of 15 to 20 degrees.

2) Upright sitting position.

In the supine position, the dependent areas are along the axillary line. In the upright position, the dependent areas are below the mid-scapula line.

Figure 3.B.5 Probe placement and patient positions.

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Probe Position: Either the curved linear or phased array probe can be used. Both probes offer a lower frequency that will allow an adequate depth of penetration. The curved linear, being of a higher frequency, will provide an improved image quality while still providing sufficient depth of penetration. The phased array probe may also be used if a smaller footprint is required. The indicator should be at the 12 o'clock position, perpendicular to the ribs to provide a longitudinal cross-section. The transducer is oriented to scan between the ribs, as ribs block the transmission of ultrasound. In the supine position, place the ultrasound probe in the posterior axillary line at the 9th rib space to identify the diaphragm and scan the base of the lung fields for effusion. In the upright position, follow the mid-scapula line to the lung base (Figure 3.B.5).

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III.C

Pulmonary Ultrasound Evaluation of Lung Parenchymal Disease

Sumit Singh, McKinzey Martinez and Davinder Ramsingh

Background

Point of care ultrasound of the lung parenchyma is a challenging topic to comprehend. This is in a large part secondary to the fact that, unlike ultrasound of other organ systems (heart, liver, etc.), the ultrasound image produced when examining the lung parenchyma does not intuitively connect with anatomical structures. This is secondary to the acoustic impedance at the air interface within the lung parenchyma. In well-aerated lung tissue, the air interface will produce a significant amount of ultrasound reflection and prevent transmission. Indeed, this degree of reflection can produce a long-path reverberation artifact between the probe and the pleural line, which creates a horizontal line called an A-line (discussed further below). In a normal lung, this uniform "scattering" of ultrasound produces a homogenous isoechoic to hypoechoic gray image below the lung pleural line (similar to the "static" screen of an old television screen). Because of this phenomenon, the ability to use ultrasound to evaluate lung tissue was thought to be ineffective in the past.

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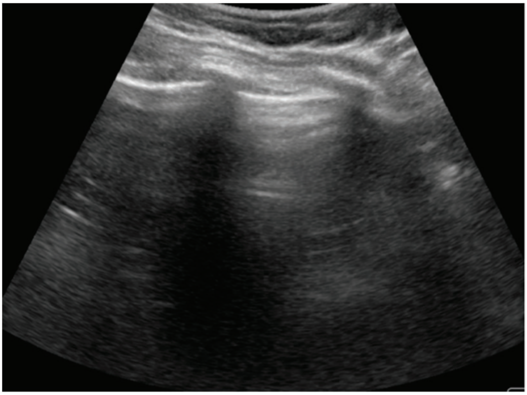

Figure 3.C.1 Normal lung parenchyma ultrasound image. Please note the uniform gray pattern of the lung parenchyma along with the horizontal A lines.

However, further consideration can identify how this phenomenon can actually be used to evaluate for air-space disease within the lung parenchyma. Please note that we identify air-space disease as any process in which the density of the lung tissue is increased because of the lack of aeration. Examples include pulmonary edema, pneumonia/consolidation, atelectasis, and fibrosis.

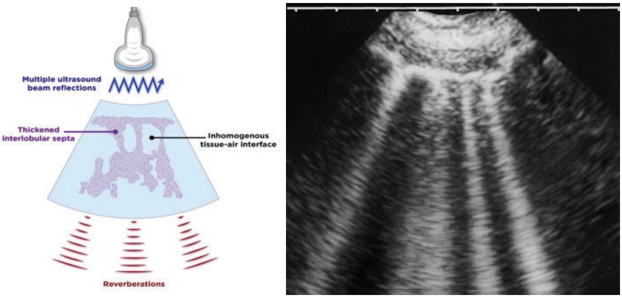

Figure 3.C.2 Abnormal lung parenchymal ultrasound image. Please note the hyperechoic vertical lines originating from the lung pleura.

Pathologies that increase the lung density of the lung parenchyma will allow ultrasound penetration to a further degree compared with areas that are well aerated. This relationship of aerated lung tissue next to non-aerated lung tissue produces a unique relationship in which the ultrasound beams become "trapped" along this plane of tissue density differences (air-space disease). Specifically, the ultrasound beams produce short path reverberation artifacts

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that ultimately produce a hyperechoic vertical line from the lung pleural that extends over 8 cm. These "laser-like" vertical lines should remain hyperechoic throughout the lung parenchyma (ultrasound screen depth should be at least 12 cm) and should move with the respiratory cycle (with pleural sliding). Shallow vertical lines that extend a few cm beyond the long pleural are secondary to artifacts generated from the difference in thickness of the pleura during the respiratory cycle and are termed Z-lines. These can be normal findings and should not be confused with B-lines. This is also why the use of a low-frequency probe (curved linear, micro convex, or phased array) is required to have the appropriate depth of penetration to assess lung parenchyma.

The severity of air-space disease can be evaluated by examining the number of B-lines per lung zone (similar to Kerley B-lines on a chest X-ray). As there is more parenchyma disease, the lines can start to coalesce and become more wedge-shaped, with the ultimate severity presenting as a solid organ appearance (liver/spleen appearance). Usually, more than three B-lines in a lung ultrasound image are used to identify the presence of air-space disease. However, the approach commonly taken for point of care ultrasound evaluation of lung air-space disease is the identification of the number of lung zones that demonstrate a large number of B-lines, with less emphasis on counting the exact number of B-lines.

Additionally, it has been reported that the spaces between B-lines can be assessed to help determine further details regarding the pathology of the air-space disease. Specifically, multiple B-lines that are 7 mm apart are likely to represent interstitial disease versus B-lines 3 mm or less apart represent alveolar disease.

As noted above, it is important to identify other normal artifacts commonly generated with lung ultrasound. One such artifact is called the A-line. A-lines represent the long-path reverberation artifact of lung pleura and are hyperechoic horizontal lines that are *parallel* to the pleural line. The distance from an A-line to the pleural line is equal to the distance between the skin and the pleural line. This measurement may be repeated further down the ultrasound image. The presence of A-lines is a sign of normal aeration; however, it is important to remember that A-lines may also occur in the setting of a pneumothorax. B-lines, however, should not be detected in the presence of a pneumothorax since the pleural air interface prevents ultrasound transmission (Figure 3.C.6). Another artifact that is common with lung ultrasound is short vertical lines that extend only 2 to 3 cm from the lung pleural (Figure 3.C.7). These lines, termed Z-lines, represent the

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differences in the thickness of the lung pleural detected by the ultrasound scan during respiration. Z-lines are much shorter than B-lines and also have A-lines within the same image.

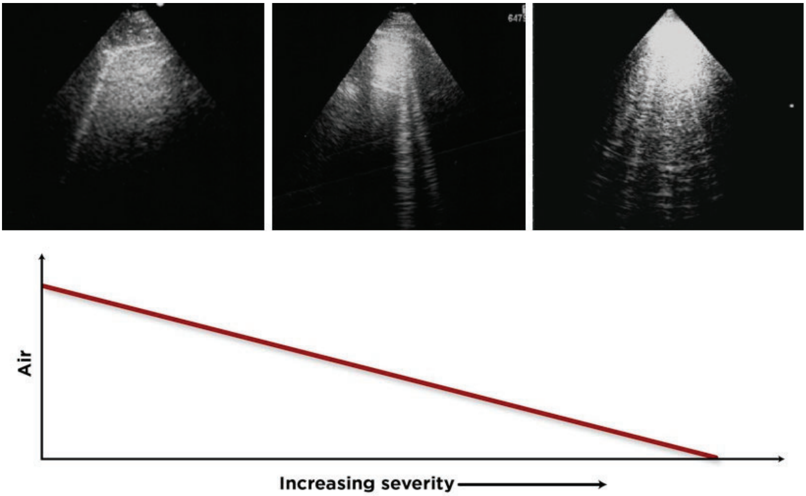

Figure 3.C.3 These three lung parenchymal examinations illustrate how B-lines become more numerous as the alveolar disease worsens. As aeration decreases in segments of the lung, the ultrasound waves reverberate between aerated and non-aerated portions of lung. The graph illustrates this relationship between severity of airspace disease and B-lines.

Lung Parenchyma Ultrasound Examination

Patient Position: Performing the full examination can be very involved (Figure 3.C.4); however, the basic 10-point examination shown below allows for the visualization of the majority of the lung parenchyma in the supine position (Figure 3.C.7). This is a similar examination to that described for pneumothorax evaluation.

Probe Position: Either the curved linear or phased array probe can be used. The indicator should be aimed at the 12 o'clock position, perpendicular to the ribs (similar to the lung pleura examination). 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. During the examination, it is useful to recall the dome structure of the lung to help understand the appropriate angle of the probe

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at each window. Please see the pictures below for further information on the lung parenchyma examination.

Curved Linear (3 to 5 mhz)

Phased Array (2 to 5 mhz)

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

Figure 3.C.4 Report form for a complete lung parenchymal ultrasound examination.

Probes to Use: Since lung ultrasound is essentially the interpretation of artifacts, it is important to turn off the tissue harmonic function on the ultrasound machine. This function filters the artifacts during solid tissue ultrasound examinations. Choosing the lung preset on the ultrasound machine prior to the examination will prevent this issue.

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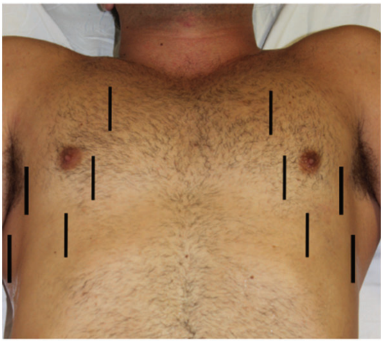

Figure 3.C.5 Ten Point parenchymal ultrasound examination.

Lung Ultrasound Artifacts

A-lines – Defined as horizontal, regularly spaced hyperechogenic lines representing reverberations of the pleural line (Figure 3.C.6).

Z-lines – Short, vertical **comet tail** artifacts arising from the pleural line but *not reaching* (usually only extends 2 to 3 cm) the distal edge of the screen (*these are not B-lines*) (Figure 3.C.7).

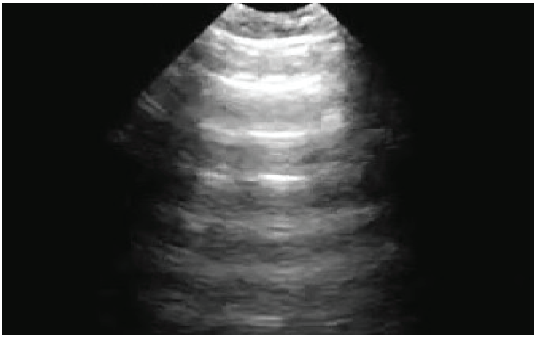

Figure 3.C.6 A-Lines lung parenchymal ultrasound examination.

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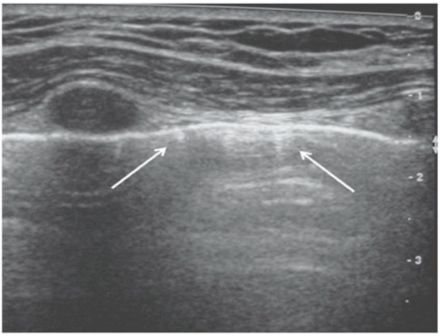

Figure 3.C.7 Z-Lines lung parenchymal ultrasound examination.

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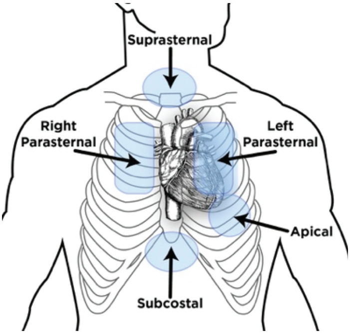
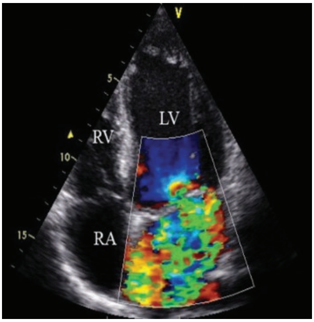
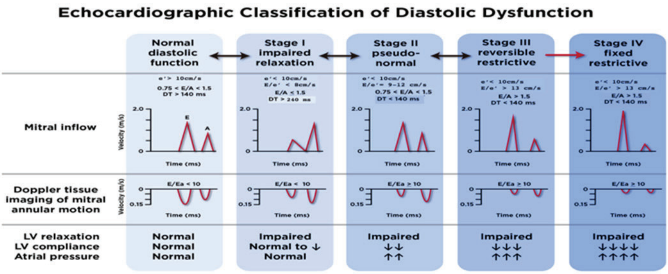
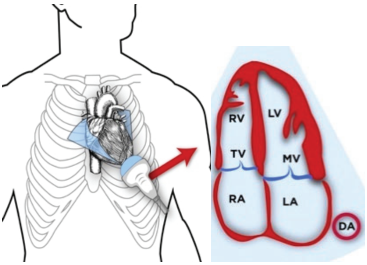
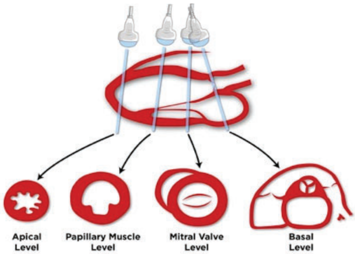
IV. Cardiac Ultrasound











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 of the following subsections will cover a cardiac ultrasound technique used to answer these questions.

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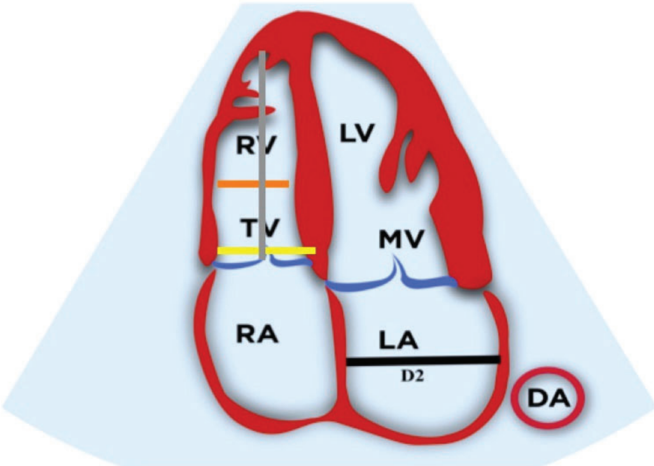
IV.A.

Parasternal Views and Assessment of Left Ventricular Contractility

Ryan Lauer, Carin Mascetti
and Davinder Ramsingh



The cardiac ultrasound examination often begins with the parasternal window because it allows for high-resolution visualization of cardiac structures secondary to both the ultrasound probe's proximity to the heart and the perpendicular orientation between cardiac structures and the ultrasound plane.

There are two major views from this window: 1) parasternal long axis and 2) parasternal short axis. It is important to note that these are not ideal views for assessing blood flow directionality across the cardiac valves since the valves are perpendicular to the ultrasound plane.

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View 1: Parasternal Long Axis View (PLAX):

The parasternal long axis view allows one to assess the following:

1) left atrial (LA) size, 2) mitral valve structure, 3) size/shape/contraction of the left ventricle (LV), 3) structures of the aortic valve and ascending aorta, 4) right ventricle (RV) size/shape/contraction (Figure 4.A.1).

Of these items, one of the most important is **left atrial (LA) size**. Remember, the LA is a storage vessel for the volume of blood that travels to the LV. In most situations, when the LV end diastolic pressure (LVEDP) is elevated (examples include diastolic dysfunction, severe cardiac valve dysfunction, frequent episodes of tachycardia, severe systolic dysfunction, etc.), the abnormal pressure from the LV is relayed to the LA. To compensate for this increased pressure, the LA dilates to hold more volume and generate the necessary pressure to fill the left ventricle. As a result, **LA size** is a gross indicator of major cardiac pathology and elevated LVEDP. LA dilation indicates chronicity in the elevation of LVEDP and thus can be referred to as the “hemoglobin A1C of the heart.”

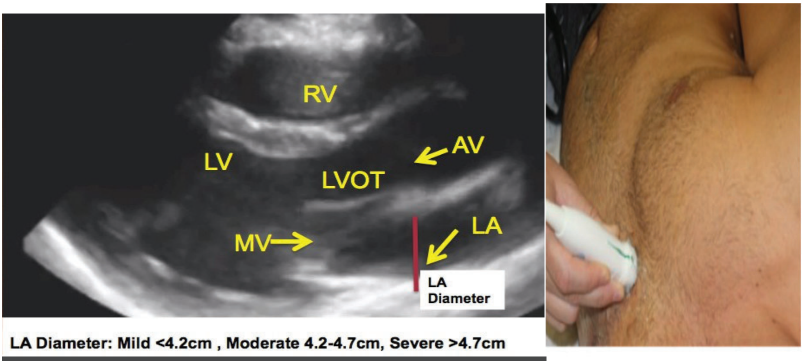

Figure 4.A.1 Parasternal Long Axis View: RV: right ventricle, LV: left ventricle, LVOT: left ventricular outflow tract, AV: aortic valve, MV: mitral valve, LA: left atrium.

Using the parasternal LV long axis view, left atrial diameter can be measured to identify and assess for potential dilation. A normal LA diameter should be less than 4 cm in diameter (Figure 4.A.1). Criteria for classifying the degree of LA dilation can be seen in Figure 4.A.1. A conservative threshold for *severe LA dilation is 5 cm*.

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The parasternal long axis view is also very useful for assessing RV dilation; the RV is normally visualized in this window as a very small structure. An RV diameter greater than 3.3 cm is concerning for dilation. Additionally, this view allows for the assessment of aortic and mitral valve opening and closing, as well as visualization of the ascending aorta.

LV contractility can also be assessed in the PLAX view using the *fractional shortening* method. Fractional shortening (FS) is determined using M-Mode with the plane of view aligned across the LV at the mid-papillary level. The LV internal diameter in end systole (LVSd) is then subtracted from the LV internal diameter in end diastole (LVDd) (Figure 4.A.2). This number can be doubled to provide an estimate of LV ejection fraction.

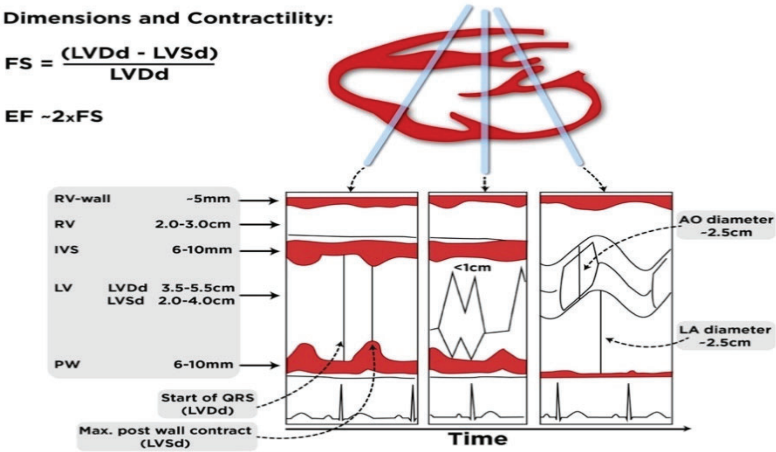

Figure 4.A.2 Fractional shortening calculation via M-Mode. Calculating fractional shortening to determine ejection fraction in the parasternal long axis view. Compare the internal diameters of the left ventricle in end diastole and end systole. The graphic shows the way the ultrasound M-Mode beam should cut the heart in this view.

It is important to realize that this method of assessing contractility only takes into account one of three levels of the LV myocardium and only two of the six LV wall segments, so it may be less accurate when compared to other methods of assessing contractility. This is further discussed below.

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View 2: Parasternal Left Ventricle (LV) Short Axis View (PSAX):

The parasternal short axis view can be used to assess the contractility of both the LV and RV and to detect regional wall motion abnormalities (Figure 4.A.3). The left ventricle can be cross-sectioned into three levels: basal (closest to the atrium), mid-papillary, and apical. The walls of the LV are divided into six sections at the basal and mid-papillary levels: anterior, anterolateral, anteroseptal, inferior (posterior), inferolateral, and inferoseptal. The apical level is divided into four sections: anterior, lateral, inferior, and septal.

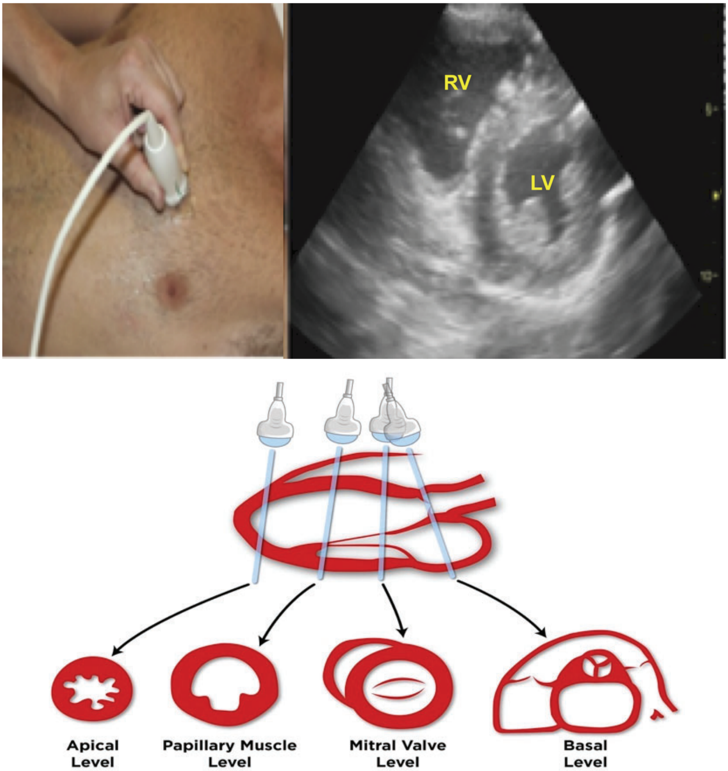

Figure 4.A.3 Parasternal Short Axis Views. These are the different views you will see based on where the ultrasound probe is cutting through the heart. The papillary muscle level is what you want to use to evaluate fractional area change for ejection fraction. You can evaluate the aortic valve by fanning the probe to view the basal level.

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Through an examination of the LV at each of the three levels (basal, papillary, and apical), one can obtain an accurate assessment of LV systolic function. One common method of quantifying systolic function is from the papillary PSAX view by analyzing the percent change in the internal area of the LV from end diastole to end systole. This measured change in area is termed *fractional area change* (FAC) (Figure 4.A.4). The FAC obtains a more accurate image of cardiac contractility as all six cardiac wall segments are visible, compared to the two segments represented in measurements of fractional shortening. Remember that FAC and LV diameters are best measured at the mid-papillary level. The examiner should try to ensure an appropriate cross-section of the LV by obtaining an image in which both papillary muscles appear equal in size and shape.

Fractional Area Change = (End Diastolic Area - End Systolic Area) / End Diastolic Area × 100

Normal is > 50%

To get an estimate of **ejection fraction (EF)**, add 10% to the FAC value.

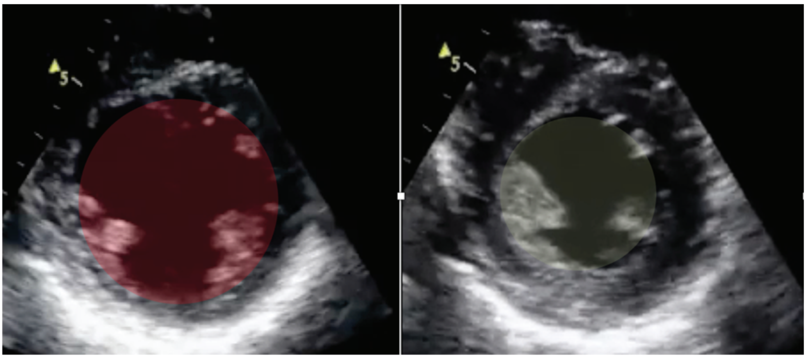

Figure 4.A.4 Fractional Area Change Measurements. The fractional area change (FAC) is best determined in the short axis view at the mid-papillary level. Measuring the end systolic and end diastolic areas and following the formula listed above will calculate ejection fraction.

Additionally, since these views allow for assessment of all the walls/segments of the LV, one can also evaluate for regional wall motion abnormalities suggesting ischemia. For review, the coronary distribution to myocardial structures are listed below:

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Left Anterior Descending (LAD) artery - Anterior and anteroseptal segments of the left ventricle.

Right Coronary Artery (RCA) - Right ventricle, the inferoseptal segments of the LV, most of the inferior segments, and depending on what supplies the posterior interventricular artery, the inferolateral segments (70% of the time the posterior interventricular artery comes from the RCA, 10% from the L circumflex, and 20% of the time it is dual supply).

Circumflex Artery - Lateral segments, and part of the inferior segments when left heart dominant.

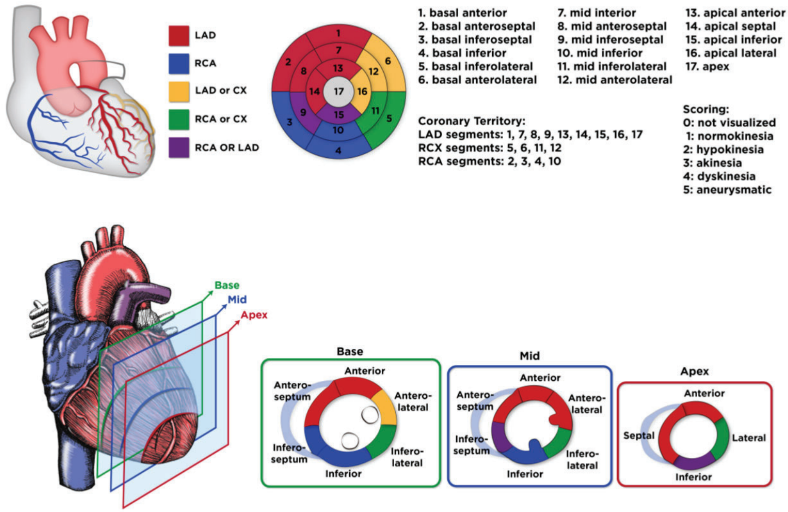

Figure 4.A.5 The parasternal short axis view can be used to evaluate for myocardial ischemia based on coronary distribution and to look for wall motion abnormalities.

Finally, one can use measurements from the PLAX and PSAX views to help in the evaluation of volume status. The diameter and/or area of the LV in end diastole represents the volume status. Using the measurement tool, the LV diameter/area can be assessed in either a standard 2-D image or an M-mode image. For adult men, normal LV end diastolic diameters range from 4.2 to 5.9 cm, and for adult women, the range is from 3.9 to 5.3 cm. Thus, an LV end diastolic diameter of less than 4 cm suggests a reduced volume state. Similarly, normal LV end diastolic areas range from 8 to 14 cm^2 and a reduced LV volume state relates to an area of less than 8 cm^2.

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Methods of Image Acquisition

Patient Position: Left lateral decubitus position with the patient's left arm extended. While this is the ideal patient position, images may be obtained in the supine position.

Probe type: Phased array cardiac probe.

Probe Positions:

Left parasternal long axis view: 3rd-4th interspace just lateral to the left side of the patient's sternum with the indicator approximately at the *10 o'clock position* or aiming at the *right shoulder*.

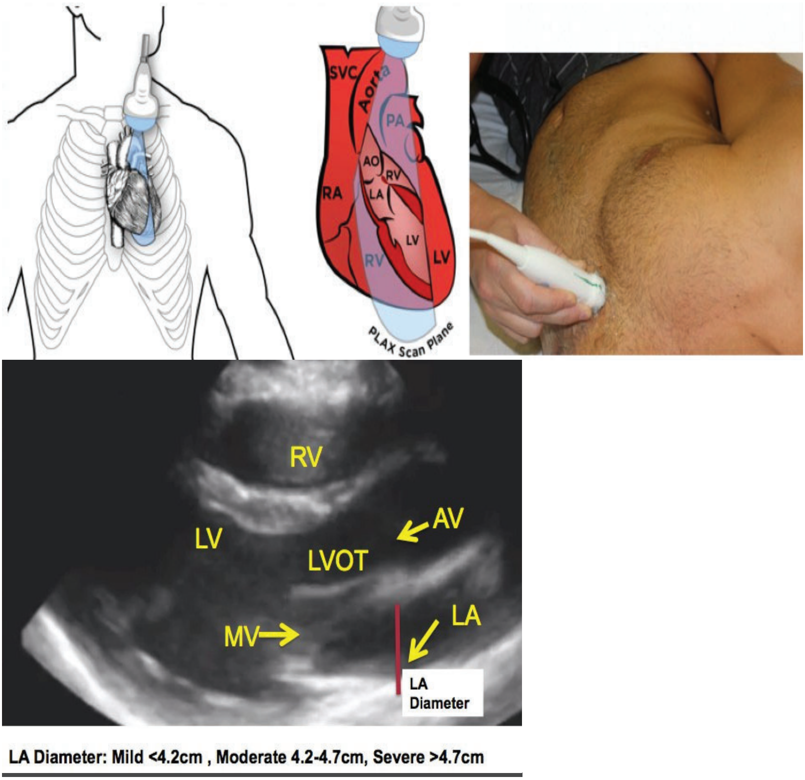

Figure 4.A.6 LV parasternal long axis view and anatomy.

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RV = Right Ventricle
LV = Left Ventricle
MV= Mitral Valve
AV = Aortic Valve
LA = Left atrium
LVOT =Left ventricular outflow tract.

Left parasternal short axis view: 3rd-4th interspace just lateral to the left side of the patient's sternum with the indicator approximately at *the 2 o'clock position* or aiming towards the patient's *left shoulder*. Remember to keep the desired structure in the middle of the screen when rotating 90 degrees from long to short axis view.

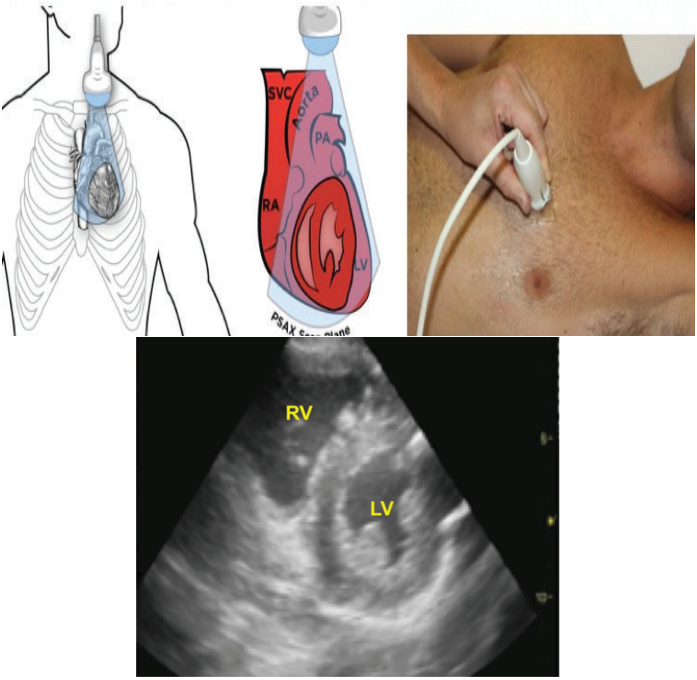

Figure 4.A.7 LV parasternal short axis view and anatomy.

RV = Right Ventricle
LV = Left Ventricle
RA = Right Atrium
PA = Pulmonary Artery
SVC = Superior Vena Cava

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Evaluation of Shock with Point of Care Ultrasound

By using the parasternal short axis view described above, surface ultrasound may be used to rapidly identify and distinguish different mechanisms of shock. Each type of shock will create a different cardiac contraction pattern.

Using Parasternal SAX view to Determine Mechanism of Shock

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

Hypovolemic shock: Decreased LV area/diameter (<8 cm^2 area or 4 cm diameter) from decreased preload and an increased or normal FAC / FS.

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

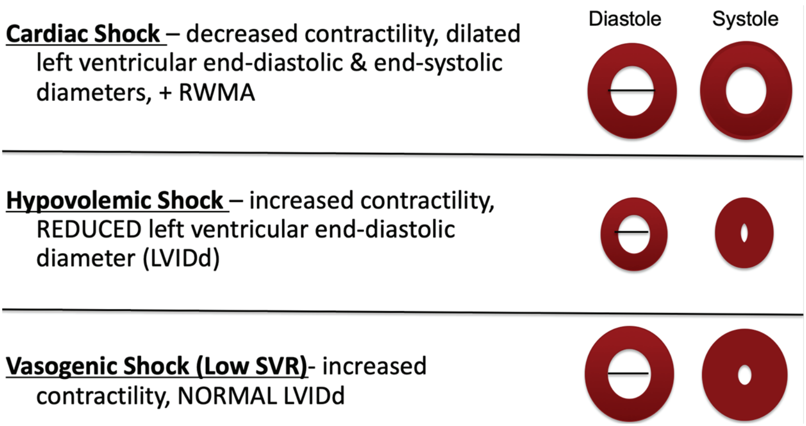

Figure 4.A.8 Evaluation for mechanism of shock from the parasternal short axis view.

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IV.B

Apical Views

Jason Gatling, Ken Neff
and Davinder Ramsingh

The apical window offers a powerful view of the heart because it allows you to compare all cardiac chambers simultaneously. Additionally, since the ultrasound beam is parallel to the flow of blood, this window allows for the assessment of cardiac values via Doppler. In this view, the Doppler beam should lie parallel to blood flow through the mitral, tricuspid, and aortic valves. This allows the largest Doppler shift to be recorded and the strongest signals to be reflected to the Doppler ultrasound transducer. Continued practice repositioning the probe to focus on various portions of the cardiac chambers will provide the novice operator an appreciation of the spatial locations and directions of normal and abnormal blood flow. Always remember that the heart chambers are actually three-dimensional structures, and abnormal flow jets 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 the standard two-dimensional plane, by changing the angle, rotation, and tilt of the transducer.

Along with the assessment of the cardiac valves, the apical views allow for: 1) assessment of diastolic function (to be discussed later), 2) assessment of right ventricle (RV) size and function (to be discussed later), 3) evaluation of left ventricle (LV) segmental wall motion, 4) evaluation of 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 the information possible from this window. These views are: *1) Four Chamber, 2) Five Chamber, and 3) Two Chamber views* (Figure 4.B.1).

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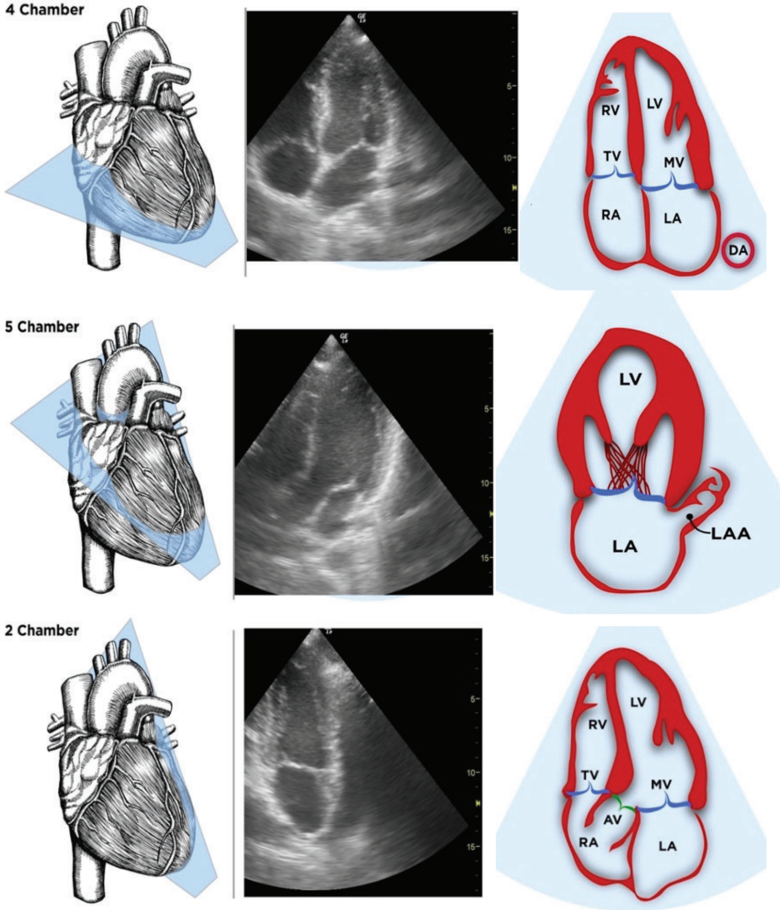

Figure 4.B.1 Three Views from the Apical Window: 4 chamber, 5 chamber, 2 chamber.

One of the most important measurements that can be obtained from this window is left atrial (LA) size (also discussed in the left parasternal long-axis view section). As previously discussed, the LA is a storage vessel for volume to the LV. Typically during diastole, the LV pressure reduces to allow forward flow of blood from the atrium. However, in any situation when the left ventricular end diastolic pressure is elevated (diastolic dysfunction, severe aortic regurgitation, frequent episodes of tachycardia, severe systolic dysfunction, etc.), the increased pressure is relayed to the LA causing

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dilation. 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, with a cutoff diameter of 4.7 cm identifying severe dilation. The LA diameter can be measured in the apical four and two chamber views.

Patient Position: Ideally, the patient should be placed in the left-lateral decubitus position with the left arm extended. However, images may still be obtained in the supine position (Figure 4.B.2).

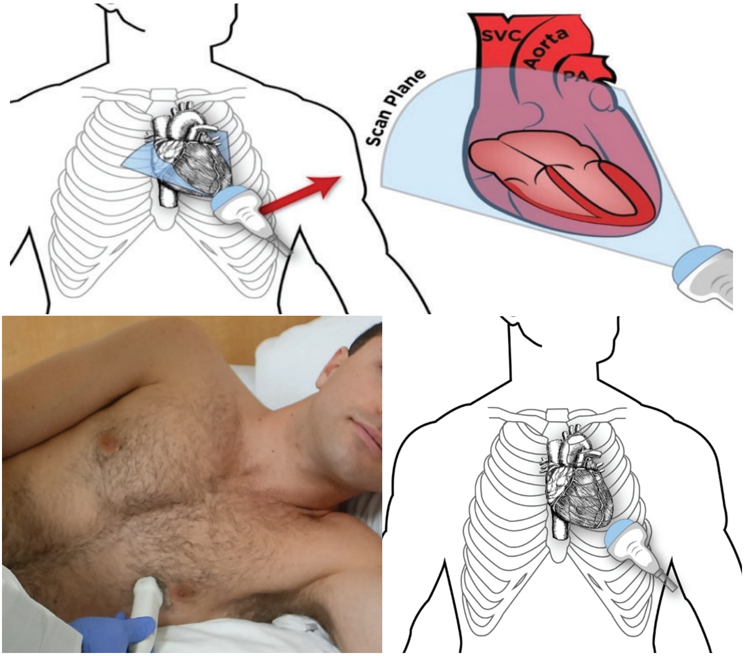

Figure 4.B.2 Probe placement for the apical view imaging.
Use the phase array cardiac probe with patient in left-lateral decubitus position.
The lower image shows the way the probe will be viewing the heart.

Probe Position: The apical window is usually found in the left-lateral portion of the chest at the apex of the heart. The apex correlates with the point of maximal impulse (PMI) and can be located by placing your hand lightly in the area of the apex. The PMI will serve as your starting point; however, small adjustments will need to be made to the transducer to optimize your image. Another good starting point is to go one to two rib spaces caudad, along the same plane as the nipple (5th or 6th rib space).

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Often, the probe needs to be placed more medially than the nipple line if the subject is in the supine position.

4 Chamber (4C) View: The transducer is placed at the cardiac apex with the indicator pointing to the 3 o'clock position. This results in the typical 'heart-shaped' four chamber view where all four cardiac chambers are visualized along with the mitral and tricuspid valves. Ventricular and atrial size can be assessed. Doppler modalities can be used to evaluate for valvular regurgitation and stenosis. Left ventricular diastolic function may be evaluated by aligning pulse wave Doppler over the mitral valve and mitral annulus (these topics will be discussed in a separate section). Also, this view can assess the RV free wall, interventricular septum, and LV lateral wall for systolic function.

Examiners may also use this view to evaluate **RV function** as it provides a good view of the RV chamber. Briefly (see RV function chapter for further details), RV function can be assessed in three different ways. One is by looking at the fractional area change (FAC) 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 mid-level. The second method is by looking at the movement of tricuspid annulus in systole—TAPSE (tricuspid annular plane systolic excursion). This is carried out by measuring the distance of the tricuspid annulus to the right ventricular outflow tract in diastole compared to systole. Normal function is a distance change of more than 1.6 cm. Finally, pulse wave (PW) Doppler can be used 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. Practically speaking, this is done by decreasing the angle between the probe and the skin. The 5th 'chamber' is not a chamber at all, but rather 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 counterclockwise 90 degrees on the cardiac apex (indicator from 3 o'clock to 12 o'clock), it is possible to obtain the two chamber view which shows different segments of

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the LV. In the 2C view, the LV, mitral valve, and LA 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. *Note: this view may be difficult secondary to the size of the footprint of the probe and the ribs.*

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IV.C

Subxiphoid Window

Ryan Lauer, Uoo Kim
and Davinder Ramsingh

The subxiphoid window can provide the most optimal views to visualize the heart in an emergency setting. This is secondary to the fact that the probe placement is away from the thorax, and the window is less dependent on patient positioning. Furthermore, this location is the least likely to have its acoustic window obscured by lung fields. Advanced Cardiovascular Life Support (ACLS) interventions may be provided during insonation from this window.

The traditional view of the subxiphoid window is obtained with the probe placed just under the patient's xiphoid with the transducer facing cephalad and slightly angled to the patient's right side. The left lobe of the liver should be in the near field with the heart visible in the far field of the ultrasound image. This view is ideal for the identification of a pericardial effusion as the ultrasound plane provides the best image of the right side of the pericardium (Figures 4.C.1 and 4.C.2). Free fluid commonly collects in this area of the pericardium as it contains the lower pressure chambers (right atrium and right ventricle) of the heart. Additionally, this view also provides the best image of the interatrial septum.

Importantly, probe manipulation in this window offers the advantage of obtaining views similar to the apical and parasternal windows, which may not be easily accessible during an emergency. In this window, one can assess all four chambers of the heart, detect and quantify pericardial effusions and the degree of cardiac tamponade, as well as assess flow across cardiac valves, the left ventricular outflow tract, and the aorta. Finally, this is the only cardiac window in which one can use the low frequency curved linear (abdominal) probe because the insonation plane is not between rib spaces (Figure 4.C.1).

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This window often requires more pressure with the probe on the body to obtain adequate cardiac imaging compared to the other cardiac windows. Please note the techniques described below to decrease tension at the probe placement location. Also, remember that the cardiac image obtained in the subxiphoid view is produced by insonating through the liver. Placement of the probe over the stomach or bowel will prevent image acquisition secondary to the gas interface (Figure 4.C.3).

Patient Position: Patients routinely lie supine; however, an ideal patient position can be obtained in the Trendelenburg position (limits view obstruction by gas scatter) or in the supine position with both knees flexed (to reduce abdominal tension).

Probe Type: Phased Array or Curved Linear Probe (Figure 4.C.1).

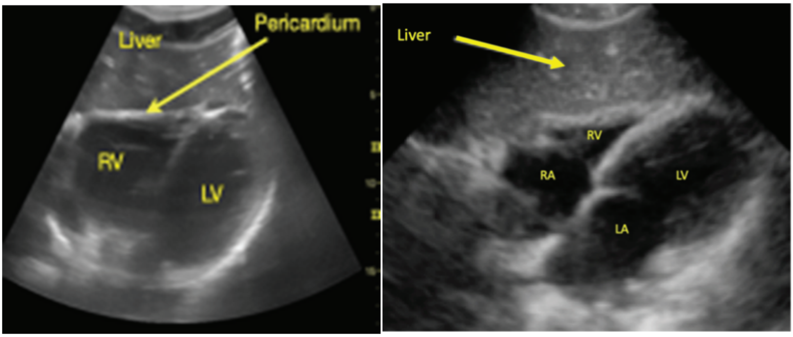

Figure 4.C.1 Traditional subxiphoid ultrasound images: curved linear (left), phased array (right).

Probe Position: The subxiphoid window is found below the xiphoid process. For the traditional view, place the probe in a transverse position (indicator at 3 o'clock) with the most medial portion below the subxiphoid process (Figure 4.C.2). Slide the probe to position the liver in the middle of the ultrasound screen (the liver is the acoustic window in the subxiphoid view). Flatten the probe to be almost parallel with the skin surface and apply downward pressure to visualize cardiac structures. One will likely apply more pressure in this window compared with other cardiac windows. Importantly, do not attempt to visualize cardiac structures if a gas artifact is seen on the ultrasound image (Figure 4.C.3), rather adjust the probe such that the liver is visualized.

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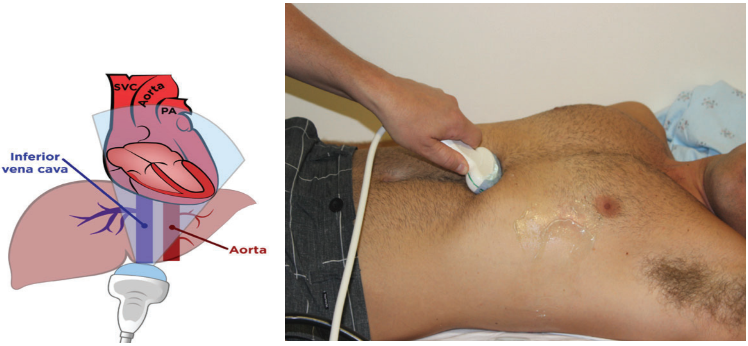

Figure 4.C.2 Probe placement (green line = indicator marker).

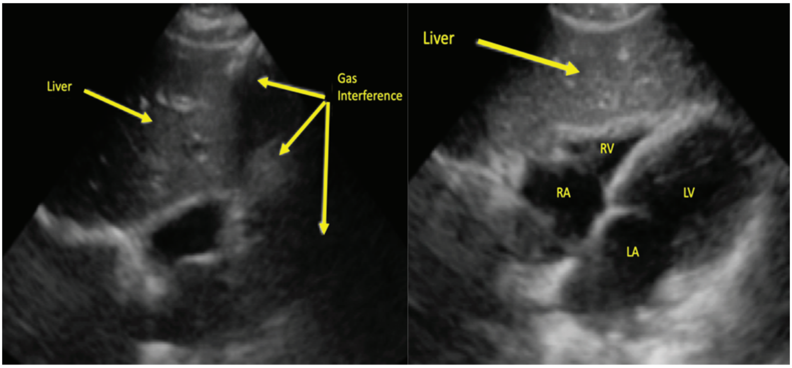

Figure 4.C.3 Impact of abdominal air on subxiphoid cardiac imaging.

Adjacent to the liver will be the heart. By flattening the probe, one can view the heart, as shown in Figure 4.C.1. Please note that flattening the probe may be uncomfortable for patients; so please be considerate of how much pressure is applied.

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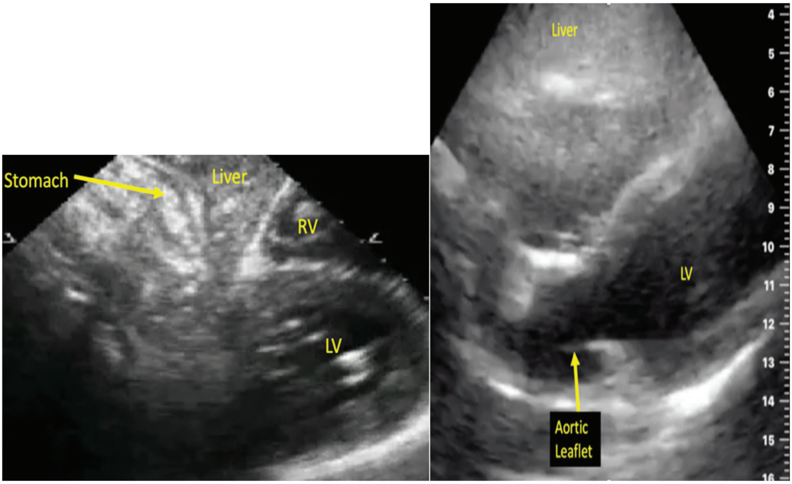

Figure 4.C.4 Additional Cardiac Views from .subxiphoid space: parasternal short axis "like" (left) and apical 5 (right).

Additional cardiac views can be obtained from this space. For example, by rocking the ultrasound probe and possibly a small degree of counterclockwise rotation (3 o'clock to 2 o'clock), one can obtain a view similar to the apical four chamber view from this window (Figure 4.C.4). From this view, further counterclockwise rotation of the probe (12 to 1 o'clock) will produce an image similar to the parasternal short-axis view (Figure 4.C.4). This view is similar in probe and indicator marker placement as the IVC view. However, the probe is rocked such that a cross-section of the heart is visualized instead of abdominal structures. It is important to emphasize that these views are non-traditional cardiac views, and the structures that can be visualized with these maneuvers may vary. Practice with image acquisition from this window, as with all cardiac windows, is essential. Finally, if the liver is clearly identified, and there is no visualization of the pericardium, the possibility of a significant pneumothorax should be considered if the clinical situation fits that diagnosis. Consider using lung ultrasound techniques as described in section III.A to aid in diagnosis. Indeed, cardiac and pulmonary point of care ultrasound techniques are often used in combination for pathology assessment.

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IV.D

How to Obtain Images from a Difficult Patient

Jacques Neelankavil and Davinder Ramsingh

Tips for Parasternal View and Image Optimization

- Optimize patient positioning, ideally in the left lateral decubitus position.
- Move the probe in small circles to find the optimal view between the rib spaces.
- Start with probe adjacent the left sternal border, slide probe slowly away from sternum border when necessary to improve image quality.
- Have the patient take a deep breath and hold after expiration to minimize the volume of air in the lungs.
- Apply adequate pressure with the transducer and use more gel.

Tips for Apical View and Image Optimization

- Optimize patient positioning in the left lateral decubitus position.
- 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.

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- Have the patient take a deep breath and hold after expiration.
- Apply more pressure and use an adequate amount of ultrasound gel.

Tips for Subxiphoid View and Image Optimization

- Use the liver as an acoustic window (without it you will get gas scatter).
- Have the patient take a deep breath and hold it.
- Adjust from center subxiphoid space to the right (to have by gastric air).
- Remember to always optimize the patient's position, if possible. Having the patient flex their knees may decrease the abdominal wall tension and allow for easier image acquisition.
- Apply adequate pressure with the transducer and use more gel.

Scan frequently! Practice makes perfect!

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IV.E.

Evaluation of Cardiac Valves

Jason Gatling, Melissa McCabe
and Davinder Ramsingh

The apical window is routinely used for the evaluation of valvular heart disease. In this view, the Doppler beam is essentially parallel to blood flow through the mitral, tricuspid, and aortic valves. The following section will review Doppler modalities and discuss how they can be used to evaluate valvular pathologies.

Continuous Wave (CW) Doppler is a modality in which the transducer continuously emits and receives ultrasound signals. The resultant waveform is an aggregate of all received Doppler signals. The benefit of continuous emission and receipt is that there is no limitation to the range of velocities that can be assessed. However, travel time cannot be determined and the depth of the returning signals cannot be identified. Therefore, a continuous Doppler waveform measures the velocities along the *entire* Doppler beam (Figure 4.E.1). This modality provides a summation of all the detected returning signals and displays the aggregate of all the Doppler signals detected. To restate, a CW Doppler waveform will show the highest velocities *anywhere* along the Doppler beam identified (Figure 4.E.1).

CW Doppler is used to identify valve *stenosis.* Stenotic valves have an increased velocity of blood flow across the diseased area; CW Doppler quantifies this velocity increase. Velocity measurements and pressure calculations are automated on most modern ultrasound machines. When the continuous Doppler waveform is "traced" to measure the velocity, the ultrasound machine will also report calculated pressure gradients (PG) (Figure 4.E.1), including the max PG and mean PG. Table 1 presents selected diagnostic criteria for various valvular pathologies.

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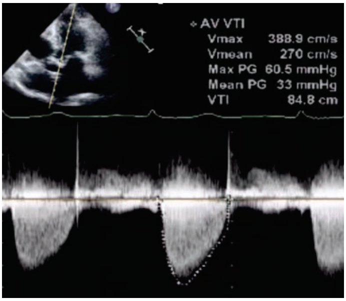

Figure 4.E.1 Continuous Doppler Waveform: The waveform is a summation of all of the velocities along the Doppler beam. Tracing the Doppler signal measures velocities and calculates pressure gradients.

Pulse Wave (PW) Doppler is a modality in which the transducer alternates *(pulsates)* transmission and reception of ultrasound signals. PW Doppler is used to measure low velocity blood flow, as in the assessment of diastolic function (discussed in another section). Pulsed transmission permits evaluation of the time between transmission and receipt of ultrasound signals, as such, a discrete region of the ultrasound plane can be sampled. However, this limits the maximum flow velocity that can be measured. This is called the **Nyquist limit,** which is the peak velocity that can be detected without aliasing. Notably, the closer the sample volume is to the transducer, the higher the maximum velocity that can be detected, or in other words, the wider the range of the Nyquist limit. A comparison of the sampling regions of CW Doppler and PW Doppler is shown in Figure 4.E.2.

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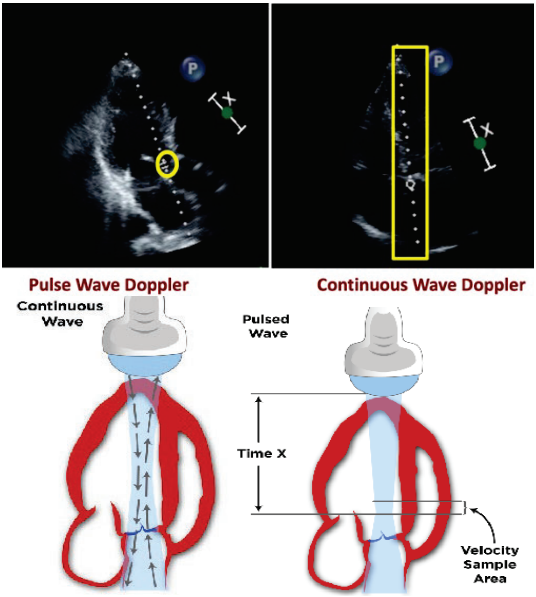

Figure 4.E.2 Location of velocities assessed: PW Doppler samples the velocity of blood flow at a discrete location whereas CW Doppler measures the flow velocity along the entire ultrasound beam.

Color Flow Doppler is a modality that uses PW Doppler to produce a color Doppler flow pattern within a sector of the 2-D ultrasound image. This is commonly used to evaluate for regurgitant flow from the cardiac valves. The colors displayed correspond to the *direction and velocity* of flow. The legend seen in the top right of the screen when color Doppler is engaged defines the range and direction of velocities that correspond to the color map (Figure 4.E.3).

Blue *corresponds to blood flow moving* ***away*** *from the transducer, while* ***red*** *signifies blood flow moving* ***towards*** *the transducer (B.A.R.T).*

For flow *towards* the transducer, low velocities are assigned a dark red, and as velocities increase, the color transitions to yellow. For flow *away* from the transducer, the low velocities are dark blue/purple and transition to light blue as the velocities increase. By convention, the Nyquist limit should be *50 to 60 cm/sec when evaluating cardiac valves.*

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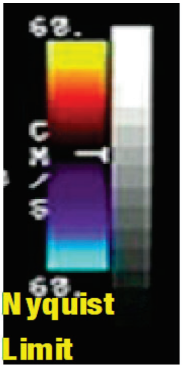

Figure 4.E.3 Color flow Doppler Nyquist limit scale.

The size of the color flow Doppler window also impacts the quality of the 2-D image. As the size of the color flow Doppler window *increases*, the frame rate *decreases*, resulting in a lower quality 2-D ultrasound image.

Assessment of Valvular Regurgitation

In the context of point of care ultrasound, color flow Doppler is the most common technique for assessment of valvular regurgitation. The color flow Doppler sector should cover the valve of interest and the entirety of the chamber receiving regurgitant flow. For example, when evaluating the mitral valve the left atrium should be included within the sector. Analogously, when the aortic valve is evaluated, the left ventricular outflow tract should be included. Using this approach, the area of the regurgitant jet would be compared to the area of the chamber receiving regurgitant flow to determine the *regurgitant fraction.* Note, the regurgitant fraction will not provide an accurate assessment when there is eccentric regurgitant flow. It should be emphasized that regurgitant fraction is only one strategy to evaluate valvular pathology. There are additional modalities that are beyond the scope of this text which provide discrete quantitative assessment of valvular disease. The severity of regurgitation can be assigned based on the criteria listed in Table 1 and examples of regurgitant lesions can be seen in Figure 4.E.4 and Figure 4.E.5.

Assessment of Valvular Stenosis

As stated above, stenotic lesions are most effectively evaluated by using CW Doppler to measure the velocity and calculate the pressure gradient.

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The pressure gradient across the diseased valve is calculated from the velocity using the Bernoulli equation. In its simplest form, the pressure gradient can be estimated using the modified Bernoulli equation: $4v^2$, where v is the maximum velocity of blood flow across the valve. It is these gradients that are used in the evaluation of valvular stenosis. Doppler images of aortic and mitral stenosis are shown in Figure 4.E.6.

A stepwise approach to point of care ultrasound evaluation of valvular pathology is discussed below.

Evaluation of Valve Function

Step 1: Examine 2-D valve structure including leaflet motion and calcification of the annulus and leaflets.

Step 2: Apply color flow Doppler over the entire valve and chamber receiving regurgitant flow.

Step 3: Measure and compare the area of the regurgitant jet to the area of its corresponding chamber.

Step 4: Use CW Doppler to assess for stenosis.

Step 5: Compare findings obtained to the values in Table IV.E.1.

Table IV.E.1: Reference Values for Selected Valvular Pathologies

Pathology	Mild	Moderate	Severe
Mitral Valve			
Regurgitation Regurgitant Fraction – Jet Area : Left Atrial Area (%)	<30	30–49	>50
Stenosis Mean Gradient (mmHg)	<5	5–10	>10
Tricuspid Valve			
Regurgitation Regurgitant Area (cm^2)	--	--	>10

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Stenosis Mean Gradient (mmHg)	Clinically significant > 5		
Aortic Valve			
Regurgitation Regurgitant Fraction Jet Diameter: LVOT Diameter (%)	<25	25–64	>65
Stenosis Mean Gradient (mmHg)	<20	20–40	>40

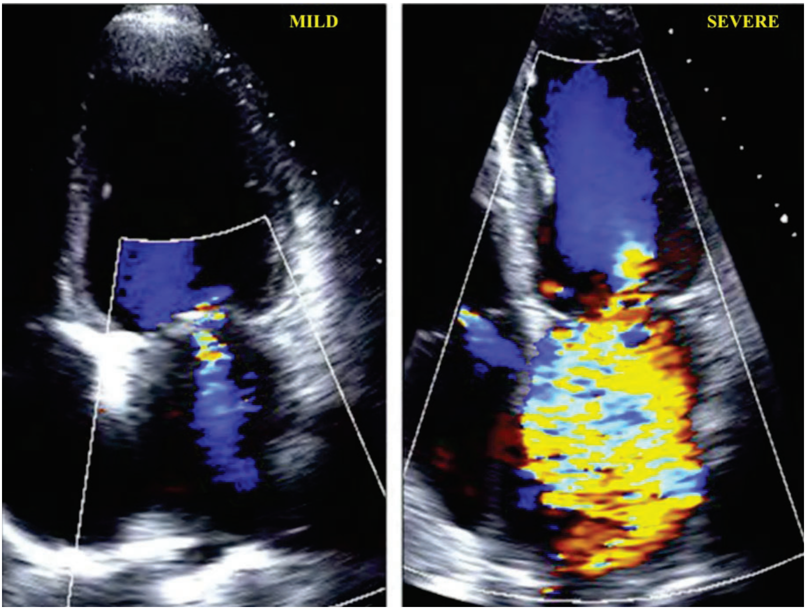

Figure 4.E.4 Examples of mild and severe valvular regurgitation.

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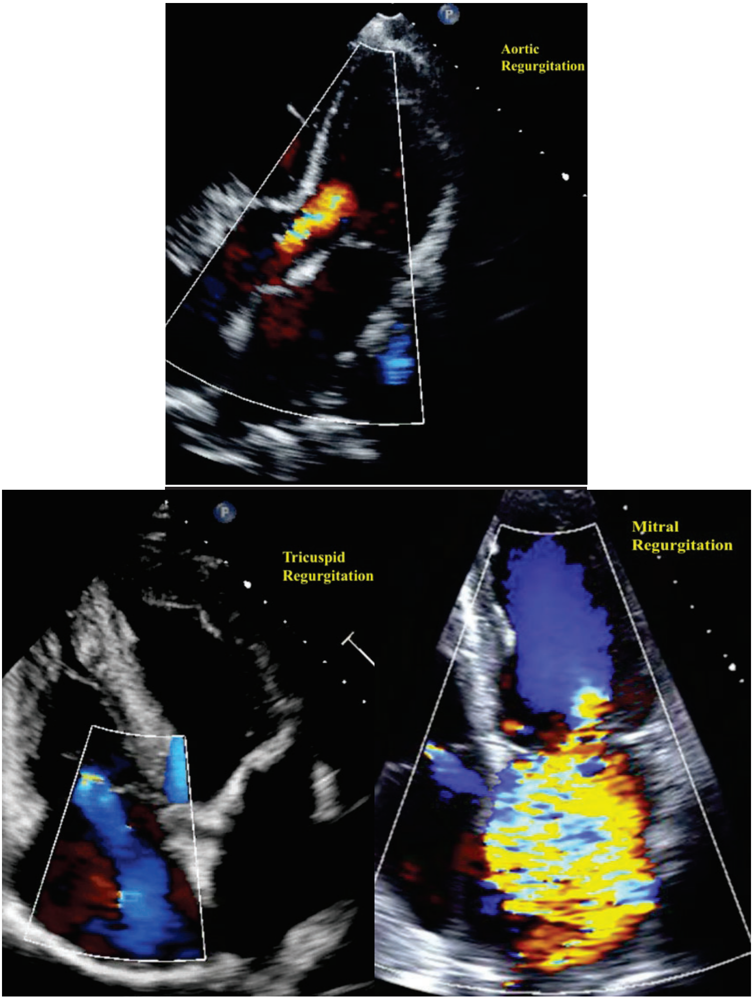

Figure 4.E.5 Evaluation of regurgitant flow using color flow Doppler. Note how the color flow Doppler sector encompasses the entirety of the chamber receiving regurgitant flow.

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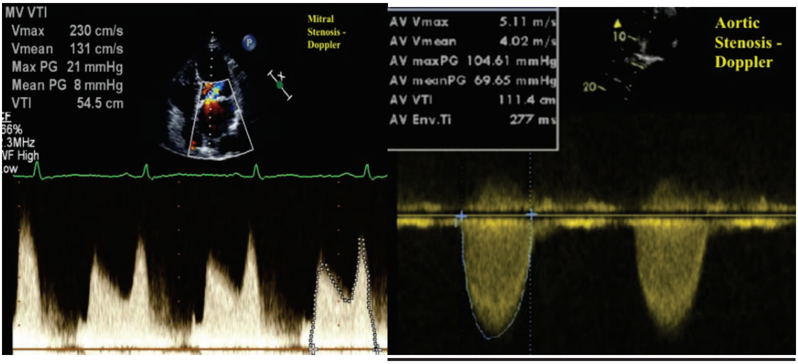

Figure 4.E.6 Continuous Doppler waveforms demonstrating significant mitral and aortic stenosis.

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IV.F

Cardiac Ultrasound for Patients with Heart Failure

Jacques Neelankavil, Gary Stier and Davinder Ramsingh

Patients with heart failure are classified by whether the mechanism is associated with an impairment in systolic function (reduced left ventricular ejection fraction) or with an impairment in diastolic function (reduced ability for left ventricular diastolic relaxation). The two groups are termed as heart failure with *reduced* ejection fraction (HFrEF) or heart failure with *preserved* ejection fraction (HFpEF). Given the fact that the pathophysiology of these two groups is different, the ability to identify the correct mechanism of HF is important. Fortunately, cardiac ultrasound can provide useful techniques to help. This section will discuss how cardiac ultrasound can be used to identify and manage HFrEF and HFpEF patients.

Heart Failure with Reduced Ejection Fraction

Heart failure with reduced ejection fraction (HFrEF) is defined as patients with clinical symptoms of heart failure (shortness of breath, fatigue, edema, cough/wheezing, decreased exercise tolerance) along with cardiac testing demonstrating reduced systolic function. The ejection fraction (EF) cutoff is most often set at 40% (normal >55%). The calculations of fractional shortening and fractional area change, discussed in earlier sections, can be used for this identification.

In patients with HFrEF, the reduced systolic function causes the left ventricle to take on more volume to be able to produce a normal stroke volume. Thus, a common ultrasound marker in patients with HFrEF is a dilated left ventricle. Given this, the markers for determining appropriate filling status become very patient-specific. Importantly, when one is

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assessing this type of patient, the integration of pulmonary and vascular ultrasound topics becomes essential. Specific topics that should be considered include:

- evaluation for pulmonary air-space disease (pulmonary edema) via B line assessment
- determination of right atrial pressure via IVC diameter assessment
- evaluation of right ventricular function
- evaluation of diastolic function

Heart Failure with Preserved Ejection Fraction

Heart failure with preserved systolic function 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 a 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; in fact, these pathologies can coexist and occur independently of each other. Diastolic heart failure occurs when a patient's diastolic dysfunction is severe enough to cause dyspnea and decreased functional status. Symptomatic findings of dyspnea are secondary to venous congestion from elevated pulmonary venous pressure and pulmonary edema.

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

Figure 4.F.1 Characteristics of diastolic vs systolic heart failure.

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Diastolic dysfunction results in a reduced cardiac output despite a normal ejection fraction because the patient has a reduced stroke volume. This results in an elevated left ventricular diastolic and pulmonary venous pressure, which can cause a reduction in lung compliance and an increase in the work of breathing.

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 one were to look at the pressure-volume curve in a patient with diastolic dysfunction, the curve would be seen to shift upward and to the left (Figure 4.F.2). 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 volume of blood that fills the LV and the velocity of blood flow decreases in early diastole, causing the cardiac output to become more dependent on the atrial kick.

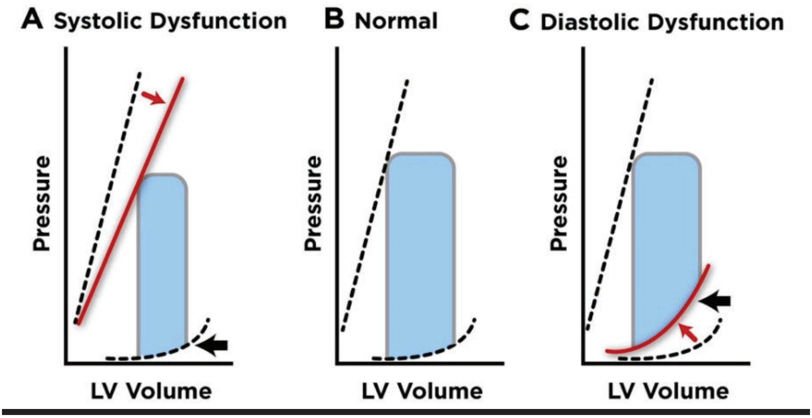

Figure 4.F.2 Pressure volume loops in patients with heart failure.

Ultrasound Assessment of Diastolic Dysfunction

The modality used to assess diastolic function is pulse wave (PW) Doppler ultrasound. Remember that PW Doppler assesses the velocity in a specific area of the ultrasound image (provides depth and location), and the drawback is the limitation in the range of velocities that can be assessed due to the Nyquist limit. Therefore, PW cannot be used to quantify high-velocity

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lesions such as aortic stenosis. The chapter on physics and color Doppler discusses further details on PW Doppler. Specifically, for diastolic function, we will use PW Doppler to assess the mitral inflow of blood from the left atrium to the left ventricle.

To understand the ultrasound assessment of diastolic function, let us review the normal process that occurs in diastole. Diastole consists of four 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 the LV muscle. The majority (80%) of LV filling normally occurs during this phase and is represented by the E wave (E = early filling) on PW Doppler. When both LA and LV pressures at the end of diastole (LVEDP) are normal (low), the deceleration time of the E wave—the time it takes for the E wave to go back to zero from its peak velocity (see images below)—is offset by a certain time period (150–220 ms). 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, causing the deceleration time to be faster (<140 ms). There is subsequently a period of no flow, called diastasis (3), followed by late diastolic filling that 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 in Figure 4.F.3.

Tissue Doppler: The use of tissue Doppler imaging (TDI), which is PW Doppler that is targeted at cardiac tissue motion assessment, is another method of assessing diastolic dysfunction. This method evaluates the motion of the mitral annulus during diastole (termed e'/a' to match mitral inflow). This can be measured by placing the Doppler signal at either the septal or lateral mitral annulus. The use of this parameter is a good screening technique for diastolic dysfunction. By comparing the early filling wave velocity (E wave) of the mitral inflow to the early diastolic mitral annulus motion (e' wave) the degree of diastolic dysfunction can be stratified (Figure 4.F.3). Remember that the waveform will be in the opposite direction as the mitral inflow assessment and is 1/10th the scale compared to the mitral inflow assessment.

The severity of diastolic dysfunction is graded in four stages:

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Grade I: First, is the impaired relaxation state (grade I), there is no elevation of LA pressure, but rather an increase in the duration of time for the LV to fully relax. This results in a shortening of the period of diastasis until it is non-existent. Because the E wave is prolonged over a longer period of time, the peak E velocity is reduced and is actually less than the peak A velocity. In addition, the E wave takes longer to return to zero from its peak, causing the deceleration time to increase (defined as >220 ms).

Grade II: In this stage, the LV does not relax fully, and therefore causes 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. The elevation in the LVEDP now causes the early filling stage of diastole (E wave) to rapidly flow into the LV since it has higher LA pressure to drive it. The way to tell the difference between 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 LVEDP allows equalization of pressures to occur more rapidly than normal.

Grade III: This stage is simply a worsening of the phenomena described in Grade II. The higher elevations in the LA and LVEDP in this stage can be defined by calculating the E/A ratio (a value greater than 2 represents grade III diastolic dysfunction).

Grade IV: This stage is functionally identical to grade III, however, grade IV lacks reversibility (through efforts such as altering heart rate, position, fluid status, etc.).

Diastolic function can be assessed with PW Doppler by placing the signal just distal to the mitral valve. From the resulting waveform, mild versus severe diastolic dysfunction can be inferred: E<A represents mild diastolic dysfunction, while E/A >2 with a deceleration time <140 ms depicts severe diastolic function. The LA should be examined as well to look for any evidence of enlargement, since a large atrium may be secondary to an elevated LVEDP due to diastolic dysfunction. A full description of the stages of severity of diastolic dysfunction is shown in Figure 4.F.3.

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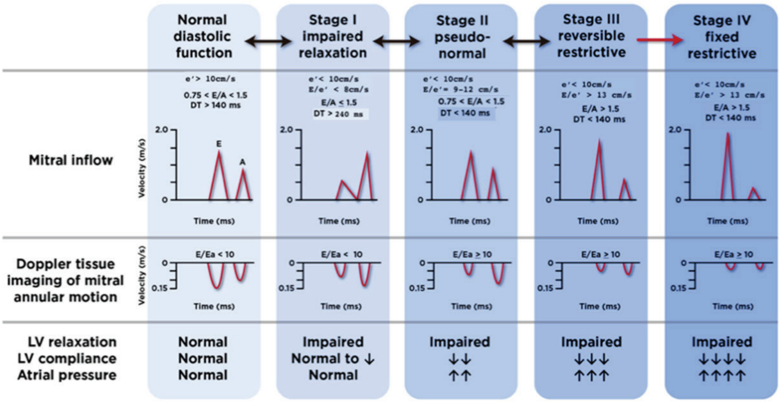

Figure 4.F.3 Classification of diastolic function.

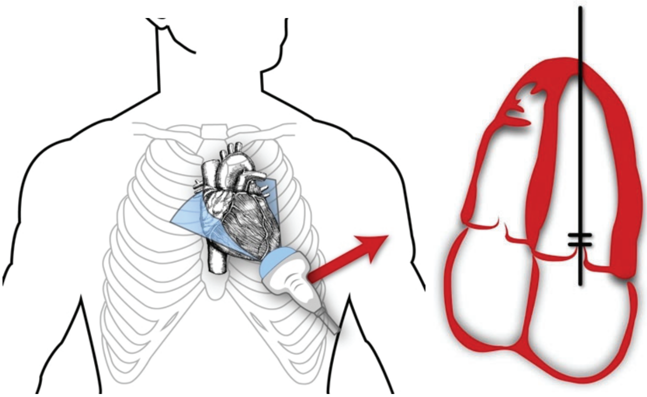

Figure 4.F.4 Probe and Doppler location to assess diastolic function via mitral inflow.

Cardiac Window: The apical four-chamber view (Figure 4.F.4) is the primary view used to assess diastolic function and obtain Doppler assessment of both the diastolic blood flow (E/A) and tissue motion (e').

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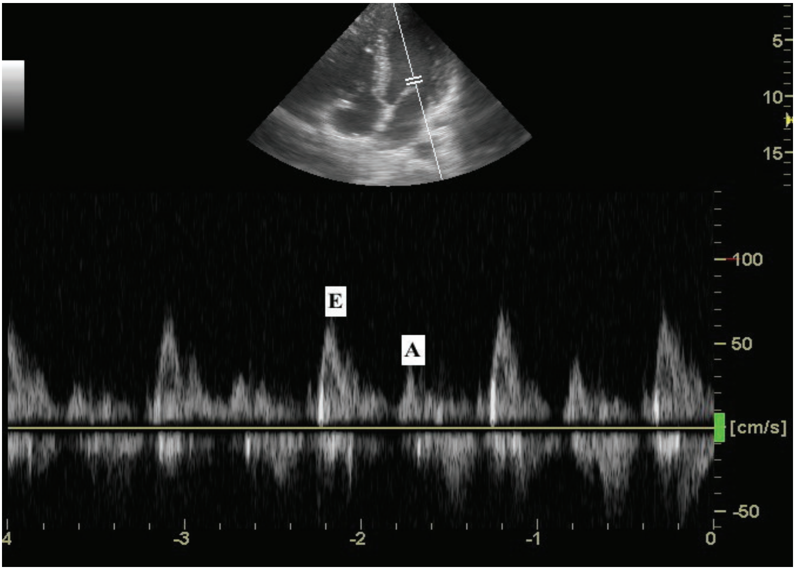

Figure 4.F.5 Ultrasound image of mitral inflow via pulse wave Doppler—E and A waves are noted.

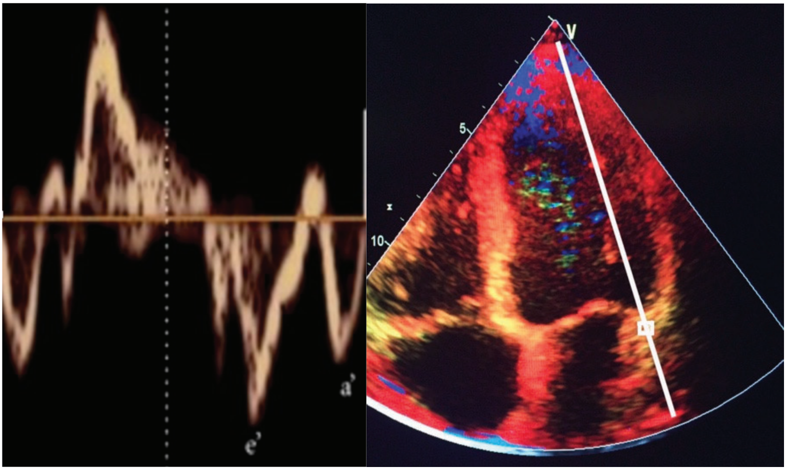

Figure 4.F.6 Ultrasound image of mitral tissue Doppler—e' and a' waves are noted.

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Ventricular Hypertrophy

Hypertrophy of the left ventricle can be associated with patients who have either preserved or reduced EF. Left ventricular hypertrophy, which is defined as enlargement of the ventricular walls, can be divided into concentric and eccentric hypertrophy. Concentric hypertrophy is defined as the thickening of the ventricular myocardium without a corresponding increase in ventricular size (Figure 4.F.7). In concentric hypertrophy, the LV walls are thick, and there are small ventricular filling cavities (increase in LV mass and increase in relative wall thickness). Eccentric hypertrophy is associated with myocardium wall enlargement associated with an increase in ventricular size. The LV walls remain roughly normal in thickness (may be slightly enlarged), and the ventricular cavity has increased in size (increase in LV mass and decrease in relative wall thickness) (Figure 4.F.7). Concentric hypertrophy is more often associated with worse pathophysiologic states than eccentric hypertrophy.

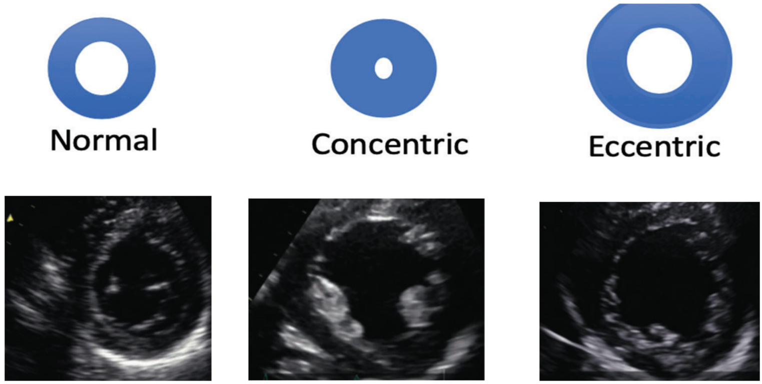

Figure 4.F.7 Ventricular Hypertrophy: Types.

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IV.G.

Assessment of Right Ventricular Dilation and Systolic Function

Jody Chou, Michael Benggon
and Davinder Ramsingh

Most pathologies that impact the right side will cause right ventricular (RV) dilation. This is because the RV is a thin-walled structure, and its primary method to adapt to pathologies is by taking on more volume.

Thus the ability to assess RV dilation is fundamental to RV function assessment

Right Ventricular Dimensions

Gross comparison of right ventricle size to the left ventricle is an important technique to assess cardiac function. The ideal views for this technique are apical 4 chamber and subcostal 4 chamber views. For measurement of the internal diameter of the RV, an RV-focused apical view should be obtained (Figure 4.G.1).

In the apical view, the RV appears cone-shaped and the apex should be visualized. The RV internal diameter should not be more than 2/3 the size of the LV, and its apex should not extend more than 2/3 to the apex of the LV. Specifically, RV dilation is present when the RV diameter is greater than 4.3cm at the base and/or the diameter is greater than 3.5cm at the mid chamber level (Figure 4.G.1). Comparison of the RV size is also a useful technique to rapidly detect RV dilation (Figure 4.G.2).

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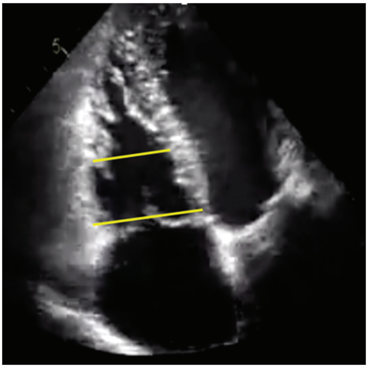

Figure 4.G.1 Right Ventricle Dimension Measurements.

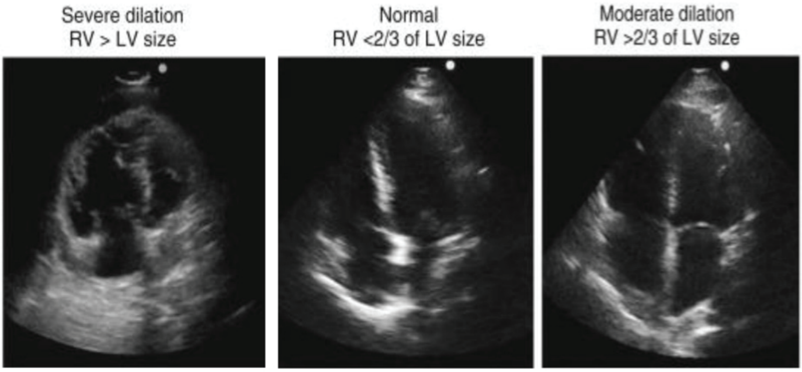

Figure 4.G.2 Right Ventricle Dilation.

Assessment for Elevated RV pressures

Cardiac ultrasound can also be used to evaluate for elevated RV pressures. On examination of the heart in the parasternal short-axis view, if the interventricular septum forms a flattened or "D shaped" left ventricle during systole, there is a concern for elevated right ventricular pressures (Figure 4.G.3).

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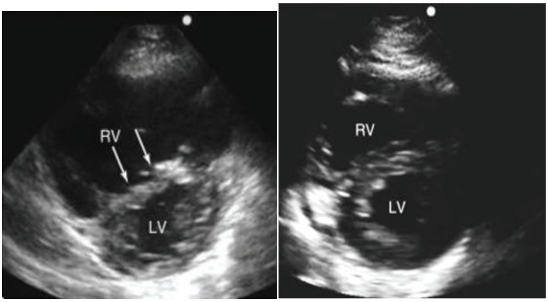

Figure 4.G.3 Assessment of Elevated Right Ventricular Pressures. The image on the left shows a normal interventricular septum and the image on the right shows a flattened “D” shaped interventricular septum concerning for elevated RV pressures.

Assessment of Right Ventricle Systolic Function

Evaluation of right ventricular (RV) systolic function is similar to the concepts discussed for left ventricular (LV) systolic function. However, it is important to note that RV motion in systole is different compared with the LV. The RV is 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. Two common strategies for quantification of RV function are RV fractional area change and tricuspid annular plane systolic excursion.

Right Ventricular Fractional Area Change (FAC): The RV FAC is obtained by tracing the RV endocardium, in systole and diastole, from the annulus along the free wall to the apex, and then back again to the annulus along the interventricular septum while avoiding trabeculations (Figure 4.G.4). Normal FAC is >35%. This technique is best performed in the RV focused apical view.

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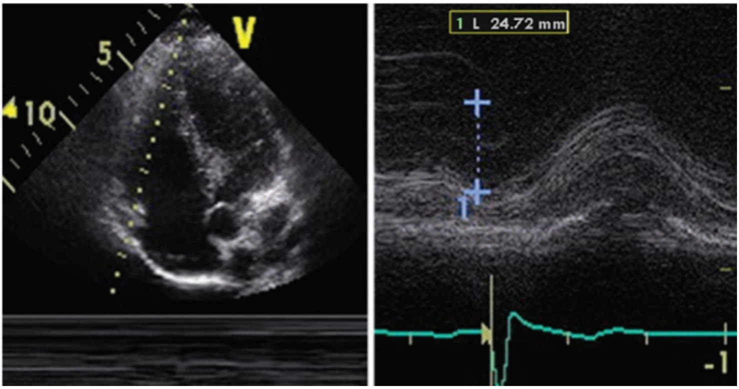
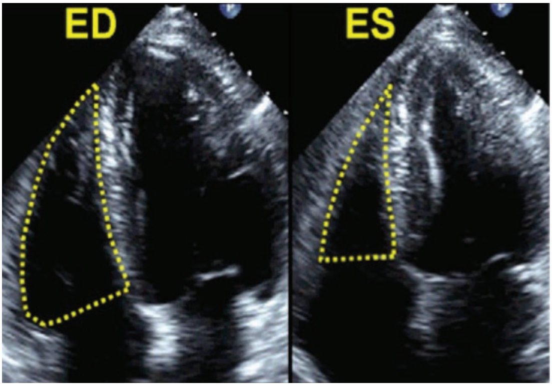


Figure 4.G.4 Right Ventricular Fractional Area Change Measurements.



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

Figure 4.G.5 Tricuspid Annular Plane Systolic Excursion.

Tricuspid Annular Plane Systolic Excursion (TAPSE): TAPSE is acquired by aligning the M-Mode cursor over the tricuspid annulus at the RV free wall allowing measurement of the amount of longitudinal motion of the annulus at the peak of systole (Figure 4.G.5). A distance measurement of less than 16mm is concerning for significant RV systolic dysfunction.

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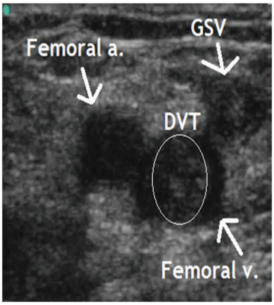
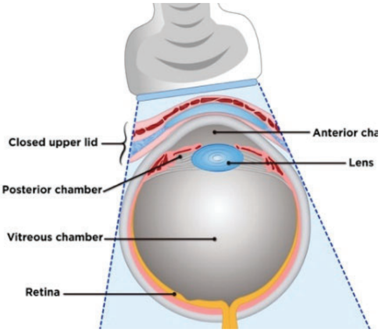
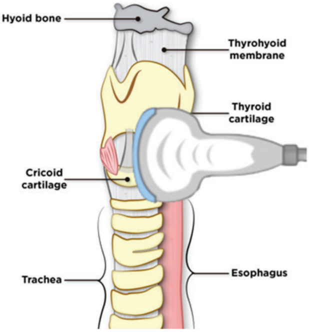
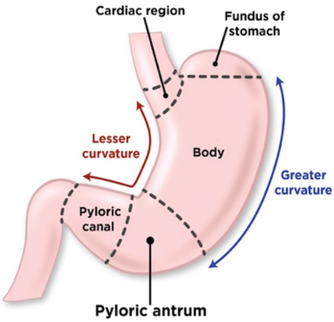
V.

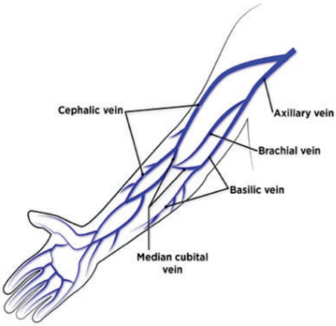
Additional Topics











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V.A

Ultrasound Guided Vascular Access

Darcy Mainville, McKinzey Martinez and Davinder Ramsingh

Obtaining vascular access is a vital procedure for clinicians. Previously, one had to rely on external landmarks to guide placement. This was of concern given the close proximity of venous structures to other important structures such as arteries, nerves, lung pleura, etc. For example, the mechanical complication rates of subclavian or internal jugular veins have been reported at 6 to 11 percent without the use of ultrasound. Additionally, there are many patient comorbidities such as previous venous access, intravenous drug use, and obesity that also negatively impact successful venous access.

Multiple studies have shown the benefit of ultrasound for central venous catheter placement, and the same technique has been extended to the placement of peripheral intravenous catheters. Ultrasound adds to vascular access in many ways: 1) provides knowledge of exact vessel location, 2) allows detection of anatomic variations, 3) helps avoid occluded veins with pre-existing thrombosis.

Probe Selection

Remember that for superficial areas (target less than 8 cm from probe) use of a high frequency (5–12 MHz) flat linear probe with a small footprint 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 on 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.

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Image Optimization

Adjustment of the previously discussed ultrasound settings is crucial to optimize the image. 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 excessive depth beyond the target structure will lower the ultrasound frequency and produce a poorer quality image. Adjustment of the gain such that the blood in the target structure is hypoechoic is standard. 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 evaluating deeper structures. One key difference is that the vein should be more compressible, requiring only minimal pressure to cause vessel occlusion, while arteries retain much of their original shape and appearance. Also, remember that Valsalva maneuvers and Trendelenburg positioning make veins larger but will have minimal effect 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 veind have low velocity flow that will appear more continuous. 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 (Figure 5.A.1). In the transverse view, the ultrasound image provides a 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 cannot see the entire path of the needle. In the 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 needle but does not show surrounding structures.

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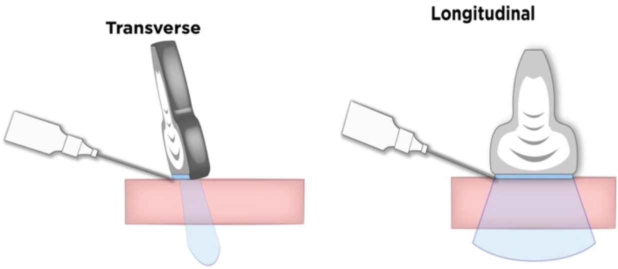

Figure 5.A.1 Approaches for vascular access.

Needle Position and Approach

One approach would be to introduce the catheter at a 45 degree angle to the probe with the catheter entering the skin the same distance from the midline marker (a) of the probe as is the depth of the target structure (b). See figure 5.A.2. For example, if the target structure is 1.5cm deep from the probe, place the needle 1.5cm away from the ultrasound probe. This approach should allow one to see the catheter just as it is entering the vessel. If the angle is too steep, the needle can pass under the probe and potentially go through the vessel and the back wall. If the angle is too shallow, the needle may not reach the vessel and cannulation will be unsuccessful. With a 45-degree approach, it is important to keep in mind that the needle will travel a distance *approximately 35% longer* (c) than the distance from the ultrasound probe (a). Selecting a long enough catheter to reach the vessel at a desired depth must be part of the consideration before placing the needle. With practice one will be able to intuitively adjust both the ultrasound plane and the needle angle trajectory to keep the needle in view throughout the procedure. Finding the tip of the needle is important to avoid inadvertent damage to surrounding structures, rather than simply seeing the effect of the needle on surrounding structures.

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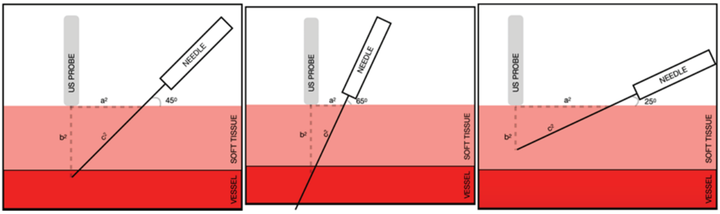

Figure 5.A.2 Needle angle relationship to ultrasound probe for vascular access.

Ultrasound for Central Venous Access

Internal Jugular Vein:

The internal jugular (IJ) 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 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 Trendelenburg position in order to maximally distend the IJ vein when this can be tolerated by the

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patient. The ultrasound machine should be placed in front of the provider to provide a direct line of vision.

Ultrasound guided catheter insertion: One suggested strategy is the following: Start in the transverse view with the dominant hand controlling the needle and the non-dominant hand holding the transducer. Place the vessel in the middle of the transducer and then place the needle in the same plane of the ultrasound image. Please note that this may 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 on the ultrasound image, indenting the tissue overlying the vein or moving the transducer along the axis of the vein while moving the needle slightly (only a few mm) 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.

Figure 5.A.3 Alignment of needle with ultrasound plane.

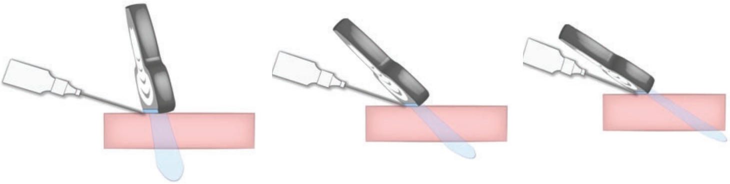

Figure 5.A.4 Fanning technique to visualize needle in transverse view.

If considering the longitudinal plane, the needle is placed in-line with the transducer, such that the entire length of the needle and the tip should be visualized as the vascular structure is accessed. Once the vessel has been successfully catheterized, the transducer can be set aside and the procedure can proceed normally with wire and catheter placement.

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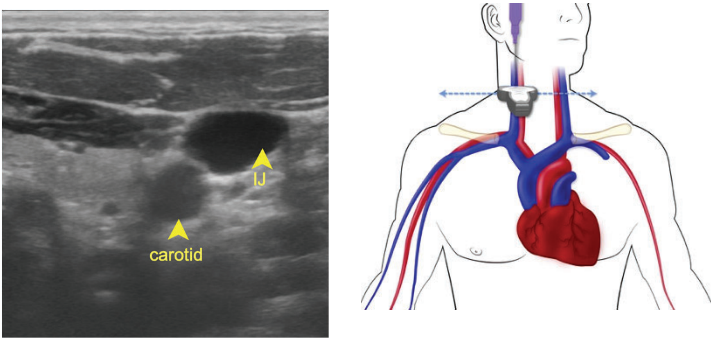

Figure 5.A.5 Ultrasound image for internal jugular access.

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 (SCV) continues behind the medial third of the clavicle. At the junction of the sternoclavicular joint on each side, SCV veins join to the IJ veins and form the innominate vein to the left and brachiocephalic vein to the right side.

Positioning and Preparation: Positioning is key for subclavian vein access. One should again place the patient in the Trendelenburg position 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 preparation to get an idea of the anatomy and to see if these maneuvers listed might help or not.

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. 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 move off the clavicle by slightly increasing the degree of steepness of the needle. This

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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 the lung pleura is not violated. Generally, the approach should not be steeper than 45 degrees. An important strategy when applying ultrasound to SCV access is the ability to follow the vein more laterally to further the distance between the vascular structures and lung pleura.

Femoral Vein

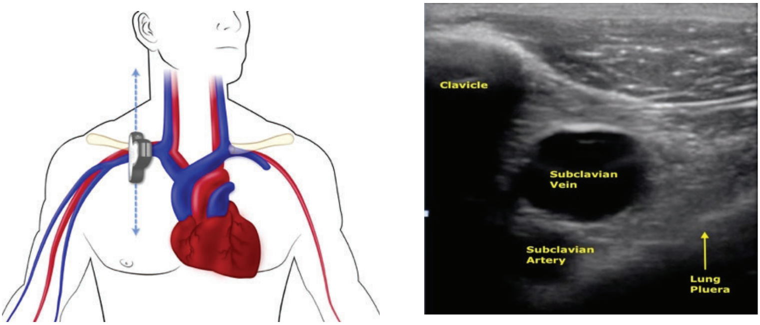

Figure 5.A.6 Ultrasound image for subclavian venous access.

The proximal femoral vein is medial to the femoral artery/nerve, deep to the fascia iliaca, and superficial to the iliopsoas muscle (see Figure 5.A.7). 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. Remember, that minimal pressure on the vein should compress it. If this does not occur, evaluation for venous thrombosis should be considered, which is discussed in a subsequent chapter.

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 SCV, one should have the transducer in the transverse position along the inguinal crease. If the femoral artery and nerve are too deep, the ultrasound image settings should be adjusted appropriately by increasing the depth and

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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 SCV). Also, as with the SCV, 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 2cm below the inguinal ligament and the needle should be directed to the umbilicus.

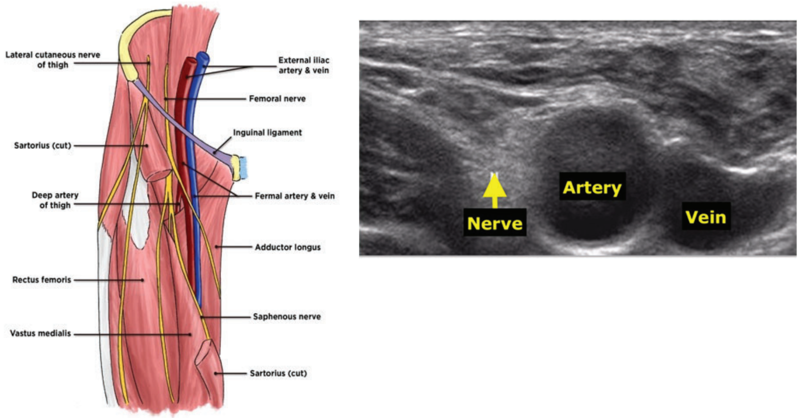

Figure 5.A.7 Ultrasound image for femoral venous access.

Ultrasound for Peripheral Venous Access

Similar to central venous access, peripheral intravenous (IV) access is a critical procedure that can be a challenge in many patient populations. Ultrasound has dramatically impacted the ability to identify peripheral venous structures as well as aid with catherization. For this section we will focus on the peripheral venous structures of the upper extremity.

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 (Figure 5.A.8). 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

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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 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. The cephalic vein can be quite superficial compared with 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.

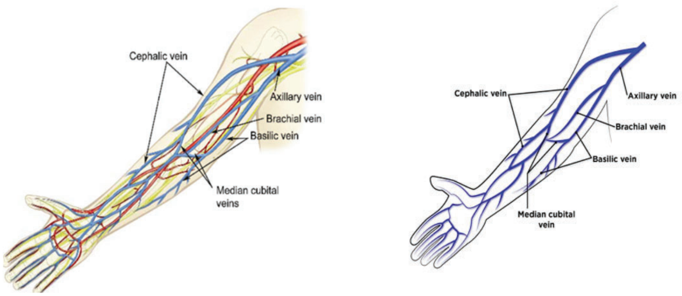

Figure 5.A.8 Ultrasound for upper extremity venous access.

Importantly, the basilic vein is the first choice for Peripherally Inserted Central Cather (PICC) line insertion.

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

Ultrasound Guided Catheter Insertion: The high frequency, linear probe is appropriate for peripheral IV access. 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 ultrasound monitor. Using the transverse axis approach, the vein should be positioned in the middle of screen. It is important to keep in mind the 45 degree approach discussed above. The smaller the catheter being inserted, the more important the ability to find and follow the tip of the needle using ultrasound during the procedure. Once the needle and catheter (in the case of an arterial line or peripheral IV) have entered the vessel, the catheter and needle can slowly be advanced inside the lumen of the vessel under ultrasound guidance. This

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is referred to as the "stop light" technique. This can ensure that the catheter is placed well inside the lumen before trying to advance it manually immediately after entering the vessel. Also, the longitudinal approach is another option and will allow for an easier view of the needle but with no ability to identify surrounding structures.

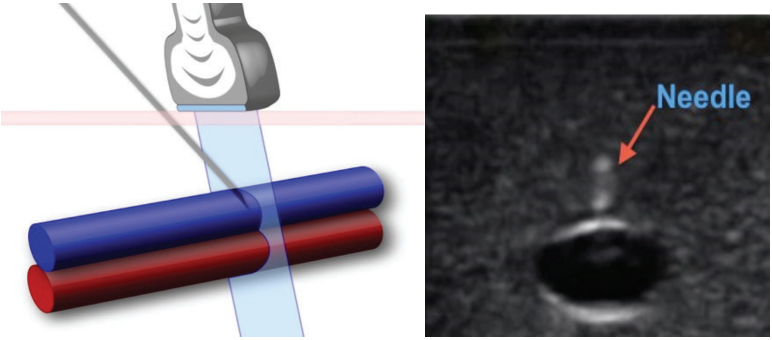

Figure 5.A.9 Ultrasound plane alignment with needle path.

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V.B

Deep Vein Thrombosis Evaluation

Matthew Holsclaw,
Matthew Alschuler and
Davinder Ramsingh

A deep venous thrombosis (DVT) is a blood clot that forms in a **vein deep** in the body (Figure 5.B.1). The most common areas for a DVT to form are the femoral and popliteal veins. Point of care ultrasound has been shown to accurately identify the presence of a proximal DVT above the knee but is less reliable in veins below the knee. For this reason, it is important to use the clinical picture and perform a pre-test probability assessment before scanning. The Wells Criteria is commonly used to screen patients.[1]

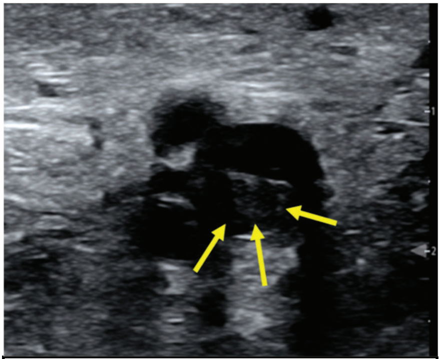

Figure 5.B.1 Venous thrombosis.

The fundamental component of a point of care DVT ultrasound examination is the regional compression ultrasound examination of the femoral and popliteal veins, known as the 2-point compression ultrasound (2-CUS). Specifically, the examination of these veins should be performed at two points in the upper leg: #1 the junction of the greater saphenous vein with the common femoral vein (saphenofemoral junction) and #2 at the femoral to popliteal vein transition. Survey each zone by scanning lengthwise 3 to 4cm.

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Point 1: Common Femoral View

The common femoral vein should be examined 1 to 2 cm above and below the saphenofemoral junction (Figure 5.B.2).

Patient Position: Begin by placing the patient in the reverse Trendelenburg or semi-sitting position. Have the patient flex their hip to 30^{o} and externally rotate their leg.

Figure 5.B.2 Common femoral vein ultrasound around the Saphenofemoral junction.

Probe Position: Linear or low-frequency probe with the indicator transverse to the leg in the inguinal fold. The goal will be to obtain a clear image of the vein in the transverse section. Begin scanning the common femoral vein in 1 to 2cm segments while applying pressure periodically. The vein should compress, as shown in Figure 5.B.3. No compression is concerning for a DVT.

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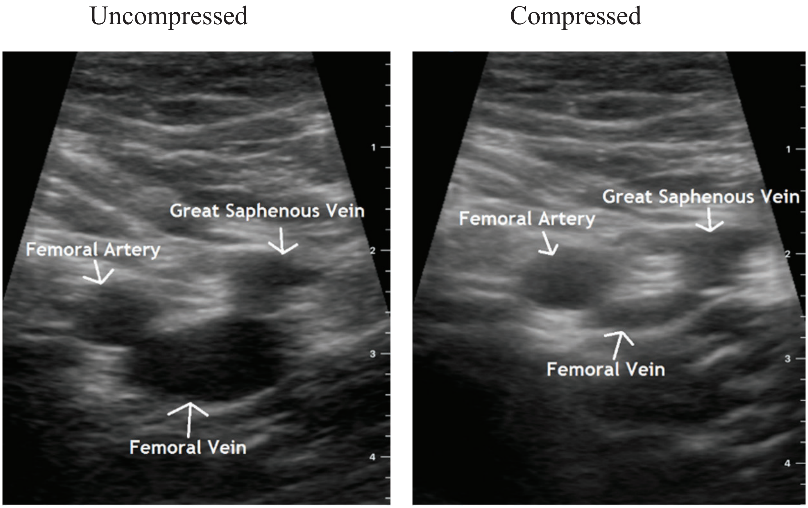

Figure 5.B.3 Compression examination of the common femoral vein.

Point 2: Popliteal View

Patient Position: Have the patient either prone, seated, or in the reverse Trendelenburg position with the knee flexed 10-30 degrees (Figure 5.B.4).

Figure 5.B.4 Compression examination of the popliteal veins.

Probe Position: Place the high frequency range probe with the indicator transverse to the leg behind the knee. Begin scanning the popliteal vein in 1 to 2 cm segments while applying pressure to the vein periodically. Again,

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the vein should compress as shown in Figure 5.B.5. No compression is concerning for a DVT.

Uncompressed Compressed

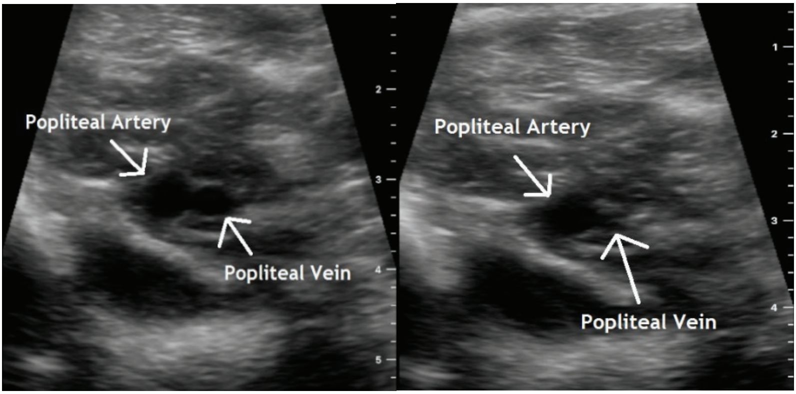

Figure 5.B.5 Compression examination of the popliteal veins.

Tips:

- In this chapter we presented the technique of using a two point compression ultrasound in the POCUS examination of a DVT. This approach allows the practitioner to quickly evaluate the most likely places for a DVT. The sensitivity of this examination can change greatly between users based on experience and technique. Depending on the experience and training of the users, sources found specificities ranging from 96-99%, while sensitivities ranged from 57-100%. If you want to increase the sensitivity of your DVT examination you can use:

1. 3 point compression ultrasound (3-CUS) which includes the femoral vein in the examination.
2. Extended compression ultrasound (ECUS) which does continuous compression ultrasound from the common femoral vein to the popliteal vein.
3. Complete compression ultrasound (CCUS) which includes continuous compression ultrasound from the common femoral vein to the posterior tibial veins.
4. Complete duplex ultrasound (CDUS) which is continuous compression ultrasound from the common femoral vein to the posterior tibial vein

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with Doppler of the common femoral and popliteal veins.

- Use of color Doppler can be helpful for compression examinations that are questionable, but this is more often a component of a complete Doppler examination rather than a POCUS examination. A concerning pattern for a DVT with color Doppler is the loss of phasic (with respiration) blood flow.

- If the patient is obese or if the vein is greater than 8 cm you should consider using a curved linear probe.

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V.C

Ultrasound for the Evaluation of Pulmonary Embolism

Jay Shen, Matthew Buell and Davinder Ramsingh

Point of care ultrasound (POCUS) can be a useful tool for Pulmonary Embolus (PE) evaluation. It is important to note that this examination evaluates the common secondary pathologies that develop from an acute PE, rather than the detection of the embolus in the pulmonary vasculature. When combined with clinical signs and laboratory tests (such as a D-dimer), POCUS can be a valuable resource for evaluating patients with sudden-onset dyspnea. To further increase test accuracy, ultrasound should be used in addition to a clinical prediction rule, such as the Well's score.[1]

Commonly, the POCUS examination for PE evaluation is a three-system examination that includes lung, cardiac, and deep vein evaluation.

The lung examination portion should follow a protocolized strategy to evaluate for air-space disease, pneumothorax, and pleural effusion. Evidence for or against any one of these can adjust your differential. These topics are further discussed in the pulmonary sections. For the lung examination, a PE will exhibit normal lung sliding with minimal B-lines. The presence of air-space disease, absence of lung sliding, and pleural effusions may direct the clinician towards a different cause of dyspnea, but will not exclude PE.

The cardiac examination is focused on evaluating the right ventricle (RV) and its subsequent consequences from the PE. PE leads to increases in pulmonary artery pressures which can lead to dilation and decreased contractility of the RV. To assess for severe RV dilation, one can compare the size of the RV to the LV (Figure 5.C.1). Remember that normally, the

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RV should be 2/3 length and width when compared to the LV. Significant elevation of RV pressures can result in intraventricular septal flattening, which produces a D-shaped LV in the parasternal short-axis view (Figure 5.C.2). This is further discussed in chapter 5. The right and left sides of the heart should also be assessed for the presence of thrombi. Finally, it is important to rule out other cardiac pathologies such as pericardial effusion, LV dysfunction, and severe valvular abnormalities.

The deep vein examination assesses for DVTs by compressing the vein and observing its collapsibility. The complete collapsibility of the vein rules out a DVT in that area (Figure 5.C.3). This is further discussed in section V.B.

Importantly, performing the three-organ examination gives the opportunity to assess not only for a PE, but also allows for the discovery of other etiologies of the patient's instability.

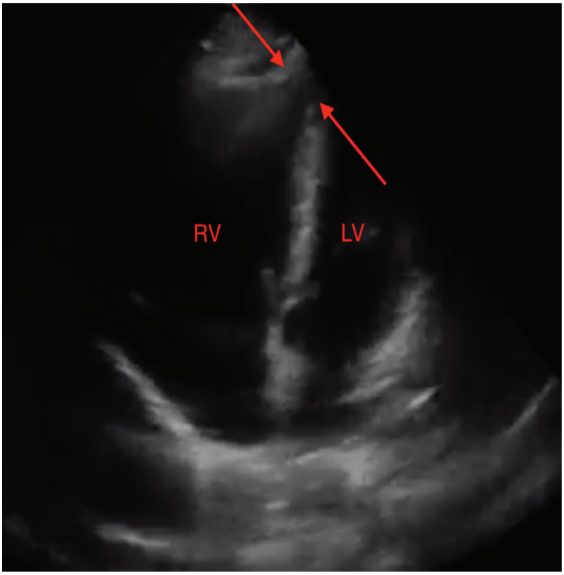

Figure 5.C.1 Dilated RV seen via apical view, with red arrows indicating doming at the apex of the RV. Both the large size and the doming indicate the right heart is dilated which can occur secondary to a PE. The RV is normally 2/3rds the size of the LV and the apex of the RV should be 2/3rds the length of the LV; here the RV is seen to be about twice the size of the LV and the apex extends as far as the LV's apex.
RV: right ventricle; LV: left ventricle.

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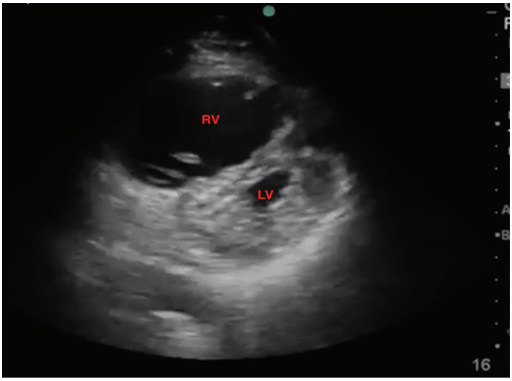

Figure 5.C.2 An example of the D-sign: The dilated RV pushes the interventricular septum into the lumen of the LV, creating a D-like shape in the LV. Normally the septum bows into the RV, but in dilated states this is reversed and the D-sign is created. This is seen in the parasternal short axis view.

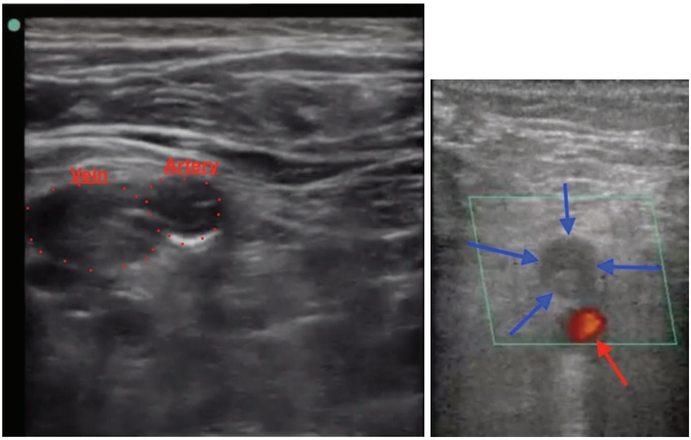

Figure 5.C.3 Examples of thrombosed veins. A normal vein should collapse with pressure; the failure of collapse with pressure that is sufficient to start to deform an artery indicates the vein has a thrombus inside (left image). The use of color Doppler (right image) can be very helpful, notice the color flow pattern in the artery (red arrow) with no color pattern in the thrombosed vein (blue arrows).

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V.D

EVALUATION OF GASTRIC VOLUME

JACQUES NEELANKAVIL, AMISH PARIKH
AND DAVINDER RAMSINGH

Aspiration of gastric contents is a serious complication that is 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) carry significant risk.* 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 has been reported that 38% of all trauma patients have aspirated. Also, there are many illness states and comorbidities that impair gastric emptying.

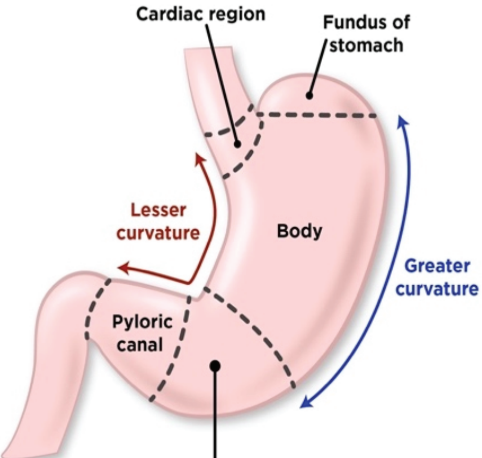

Figure 5.D.1 Gastric anatomy.

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Because of significant complications that can occur from aspiration, a tool to quickly determine the patient's gastric volume would be extremely useful. Fortunately, point of care ultrasound (POCUS) provides such a modality via the assessment of *gastric antrum area*. Several studies have proven that gastric antrum area, measured by POCUS, can easily detect patients with a critical volume of 0.8ml/kg. For our purposes, we will use POCUS to measure the gastric antrum only and not other areas of the stomach. This is because the gastric antrum is the dependent location of the stomach (Figure 5.D.1) and has demonstrated the closest relationship to the increase in gastric volume for volumes of <20 ml to 300 ml.

A subject who has no gastric volume will have a gastric antrum that appears to collapse on itself (area <4 cm^2). This area will incrementally increase in size up until a gastric volume of around 300ml. 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 Patient Position: One should use the curved linear probe. This is because it provides the right combination of frequency, footprint, and depth of penetration. The patient should be in the **right lateral decubitus position,** to adequately interpret the antrum size.

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 abdominal aorta, and the superior mesenteric vessels as internal landmarks. The stomach has a unique ultrasound signature of three hyperechoic layers separated by two hypoechoic layers, which represent the various tissues of the stomach from the mucosa to the serosa (Figure 5.D.2). These structures should be in view to ensure that the gastric antrum location, specifically, is being insonated. Once the ultrasound probe is positioned to visualize the gastric antrum (as described above) one should make small rotations with the probe to obtain the *smallest* cross-sectional area of the antrum. The area of the antrum should be measured at this point (Figure 5.D.3).

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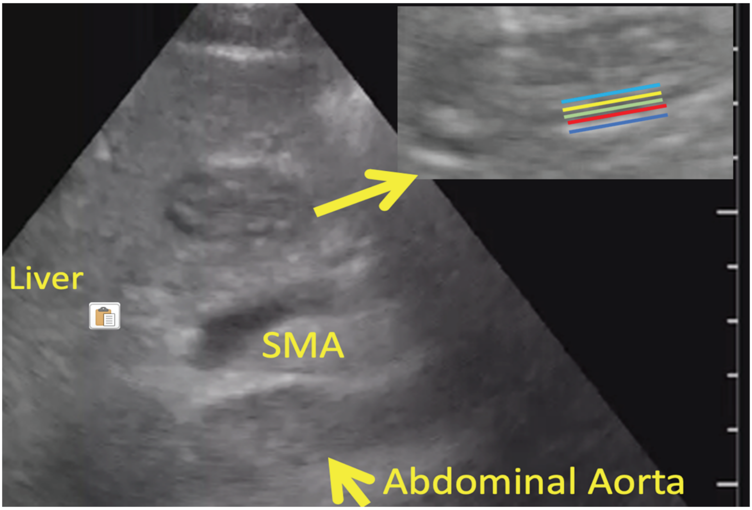

Figure 5.D.2 Gastric antrum.

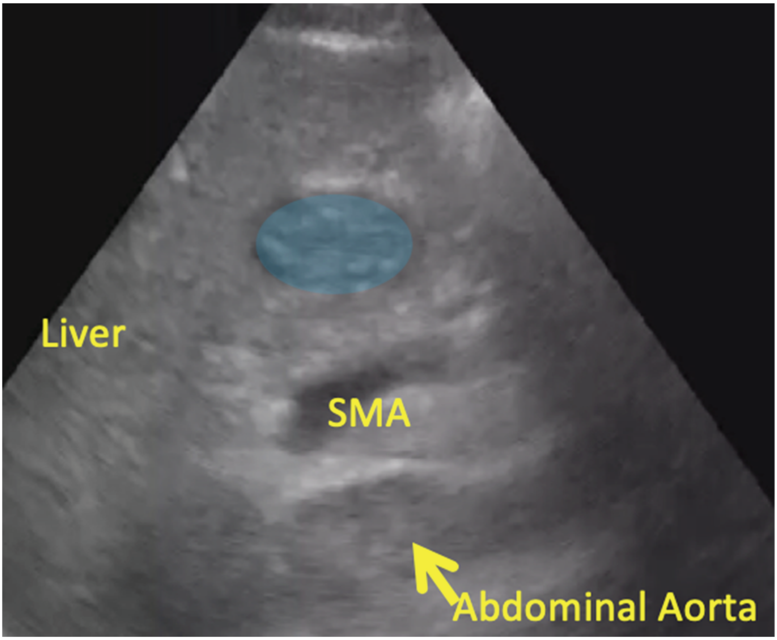

Figure 5.D.3 Gastric antrum area measurement.

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Measurements and Abnormal Image Appearance

The gastric antrum area is calculated by first obtaining the *smallest* possible cross-sectional view. From this view, the *area* should be traced via the ultrasound tools. Alternatively, the anteroposterior and craniocaudal diameters can also be used. One uses the diameter measurements to calculate the cross-sectional area (CSA) using the following equation (REF): *CSA = (AP X CC x π)/4.*

The following values can be used to categorize gastric volumes (Figure: 5.D.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 of over *300 ml.*

Specific gastric volumes can be estimated using the following calculations: Volume (mL) = -372.54 + 282.49*log (CSA from lateral position) - 1.68*weight.

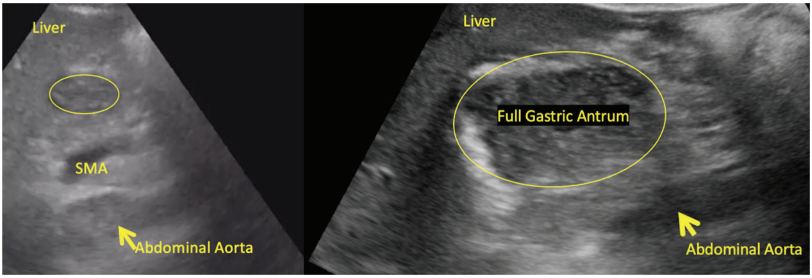

Figure 5.D.4 Comparison of empty (area <4 cm^2) gastric antrum (left) with full (area >10cm^2) gastric antrum.

Regarding the appearance of gastric contents, clear fluids will appear hypoechoic and particulate material (food) appears as a "frosted-glass appearance" (Figure 5.D.5). This frosted-glass appearance is related to air mixed with solid food during mastication. Also, remember that placement of the patient in the *right lateral decubitus* position is required to appropriately interpret gastric antrum measurements.

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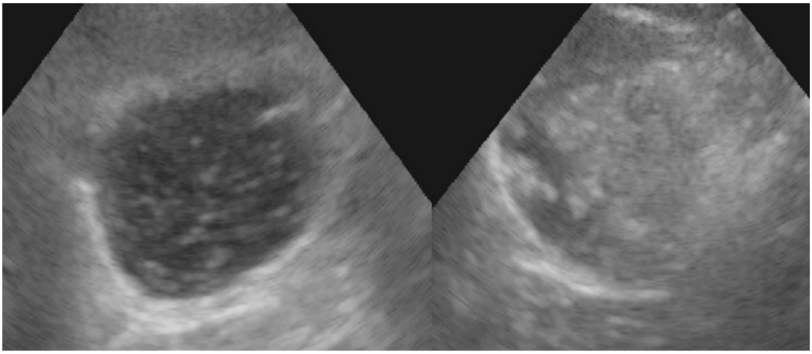

Figure 5.D.5 Comparison of full gastric antrum with fluid (left) vs solid food (right).

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V.E

Intracranial Pressure Assessment

Jay Shen, Seth White,
Benjamin Gow-Lee
and Davinder Ramsingh

Elevated intracranial pressure (ICP) is a challenging and potentially fatal complication. Early intervention in the form of either surgical evacuation or medical management is vital to improve patient outcomes. Unfortunately, the ability to detect elevated intracranial pressure by physical examination alone is difficult and often demonstrates late signs of intracranial hypertension. Diagnosis is often made by cranial computed tomography (CT) or invasive technologies such as external ventricular drains (EVD) or intracranial pressure monitors (i.e., BOLT).

CT has several 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. Additionally, invasive technology placement introduces the possibility of procedural complications (i.e., bleeding), leading to worsening neurological function.

Recently, point of care ultrasound (POCUS) of the optic nerve sheath diameter (ONSD) has been suggested as a possible indicator of elevated ICP. The subarachnoid space around the optic nerve (optic nerve sheath) is continuous with the intracranial subarachnoid space. Thus, any pressure rise within the intracranial compartment will result in dilatation of the optic nerve sheath. Dilatation of the optic nerve sheath has been demonstrated to be an early indicator of elevated ICP. A growing body of evidence has demonstrated the use of POCUS to successfully measure the optic nerve sheath diameter (ONSD), and an association with elevated ICP has been established.

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While the use of POCUS to assess the ONSD has shown promise, this new modality also needs standardization. Some references indicate that ONSD measurements of greater than 5mm are associated with increased ICP[1]. While there is a mild consensus around the *>5 mm* measurement, other references indicate that there may be ethnic[2-3] and pathological (i.e., trauma[4]) variations in the normal ONSD measurement. Furthermore, it is unclear if ONSD measurements are accurate over the course of a patient's treatment. It is possible that the ONSD stays dilated even when a patient's ICPs have normalized after a surgical or medical intervention, although recent studies seem to show continued correlation[5]. Additionally, there is variation regarding the depth at which the measurements are taken, with the literature supporting the range of 3–5 mm behind the globe.[1]

Also, the literature is discordant on which ultrasound plane cross-section of ONSD is the most appropriate. Currently, most studies use a transverse view; however, sagittal and inferior cross sections have also been demonstrated to be effective. The authors demonstrated that the inferior and transverse ultrasound views are the most likely to yield higher quality images.

Relevant anatomy for ONSD assessment via ultrasound is shown in Figure 5.E.1. Specific upper limit normal thresholds for ONSD are 5mm for adults, 4.5mm for children aged 1 - 15 years, and 4.0mm for infants up to 1 year of age.

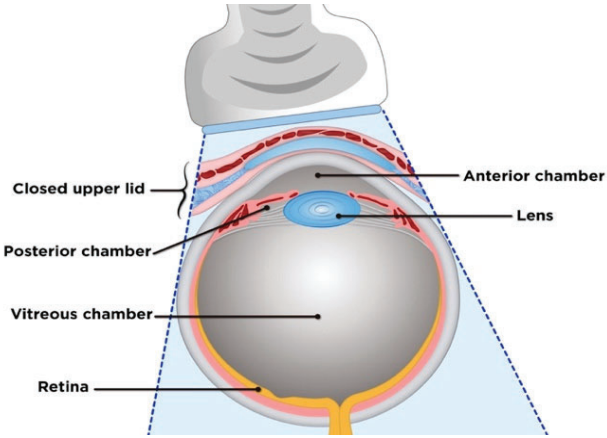

Figure 5.E.1 Relevant anatomy for optic nerve sheath ultrasound examination.

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Examination

Probe Type: High-frequency linear probe only.

Image Acquisition: Transverse, sagittal, and inferior views are highlighted (Figure 5.E.2). With all views, the subject should be instructed to have the eyes closed and in a neutral gaze. The goal of each ultrasound view should be to visualize the following components in the ultrasound image: the posterior globe, optic nerve immediately posterior to the globe, and ONSD.

Transverse view: The ultrasound probe should be placed parallel to the eyelid in the mid-transverse plane of the globe, with the indicator pointing medially. The probe is fanned slightly nasally to adjust for the anatomical direction of the optic nerve. If optimal image quality was not obtained with this technique, the provider should slide the probe superiorly or inferiorly along the eyelid to attempt to improve the image quality. A +/- 10^o tilt superiorly and inferiorly can also be attempted, however, this should be used with caution as it may produce the “inferior view” as described below if the probe is tilted too much.

Sagittal view: The ultrasound probe should be placed perpendicular to the eyelid in the mid-sagittal plane with the indicator pointing in the 12 o’clock position. The probe is fanned slightly nasally to adjust for the anatomical direction of the optic nerve. If optimal image quality was not obtained with this technique, the provider should apply a +/- 10^o tilt medially and laterally to attempt to improve the image quality.

Inferior view: The ultrasound probe should be placed 30^o to 45^o on the inferior eyelid in the transverse axis of the globe with the indicator pointing medially. The probe is fanned slightly nasally to adjust for the anatomical direction of the optic nerve. The probe angle is then increased (in a tail up fashion) to a maximum of 80^o or until the optic nerve and ONSD appear as a circular image.

Conclusion

ONSD ultrasound imaging shows promise, but current data across studies have not come to a true consensus on which view should be optimally used to evaluate ONSD or if the >5mm cut-off can be applied across patient populations and presenting pathology. ONSD using ultrasound as a

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measurement and indicator for intracranial hypertension continues to be an evolving field.

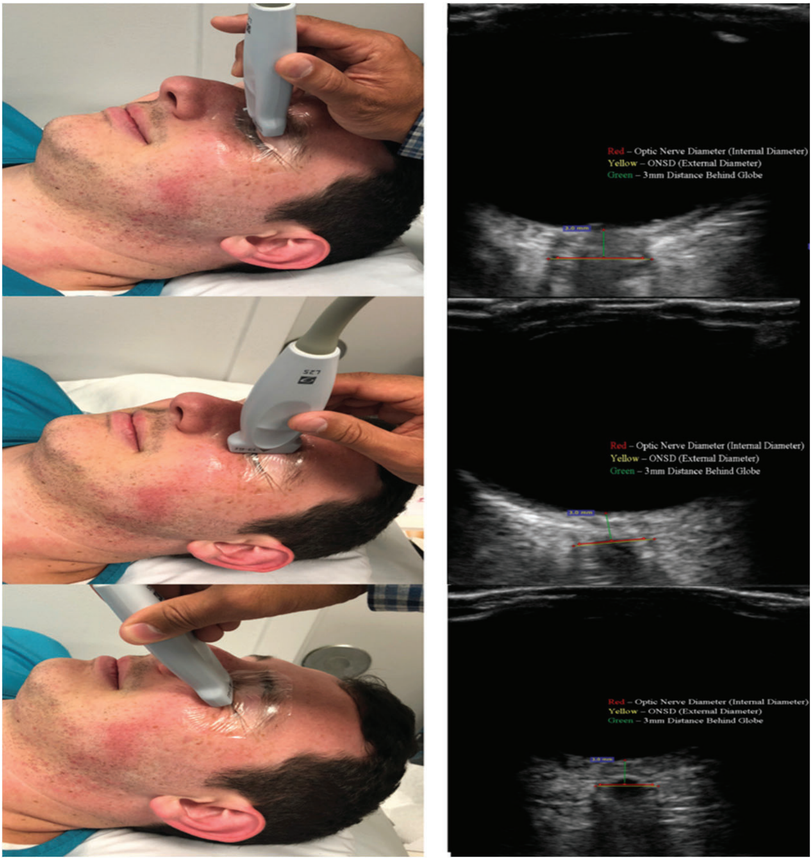

Figure 5.E.2 Ocular ultrasound three views: (transverse (top), sagittal (middle), inferior (bottom).

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V.F

Airway Ultrasound and Localization of Endotracheal Tube

Jared Staab, Matthew Holsclaw and Davinder Ramsingh

Endotracheal Tube Localization

Esophageal intubation is a leading complication of endotracheal intubation leading to death or neurologic damage. Direct visualization of the tracheal tube passing through the glottis is often applied in practice, but technically challenging intubations do not provide optimal viewing of this process. Recently, point of care ultrasound (POCUS) has been proven to reliably detect successful trachea intubation as well as identify unwanted esophageal intubation with 100% sensitivity and specificity.

While there are many techniques to identify trachea vs. esophageal intubation, the ability to determine the appropriate location of the endotracheal tube (ETT) within the airway is a challenge. Indeed, studies have demonstrated the incidence of ETT malposition to be between 15% and 38%.[1-3] Often, these malpositioned ETTs are not recognized after auscultation and clinical examination.[4,5] Malposition of the ETT can result in serious consequences such as: (1) hypoxemia, (2) inadequate ventilation, (3) pneumothorax, (4) barotrauma, (5) atelectasis, and (6) the potential for inappropriate interventions such as chest tube placement.

Fluoroscopy has been used for confirmation of the correct position of the ETT and has demonstrated benefit for the identification of ETT malposition by allowing for measurements of the distance of the ETT within the trachea.[4] However, disadvantages include: (1) exposure to radiation, (2) lack of immediate availability, and (3) the inability to perform frequent examinations.

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POCUS is a new modality, which has demonstrated promise for evaluation of appropriate ETT position. For the perioperative setting, a recent study randomized adult patients to have the ETT placed either in the trachea or the R/L bronchi; the study then compared stethoscope auscultation to a POCUS examination, termed PLUS (Pulmonary tree and Lung expansion Ultrasound Study). Results from this study demonstrated significantly greater sensitivity and specificity with the PLUS examination vs. auscultation for the detection of tracheal versus bronchial intubation.[6] This examination is detailed below.

Probe Type: High-frequency linear probe only.

Examination for Esophageal vs. Tracheal Intubation: Place the ultrasound probe transversely on the anterior neck, just superior to the suprasternal notch, before tracheal intubation (see 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.

Examination for ETT Localization 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 examination, one will deflate and inflate the 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 main stem (lack of lung sliding would indicate improper placement of the ETT in the main stem of the contralateral side).

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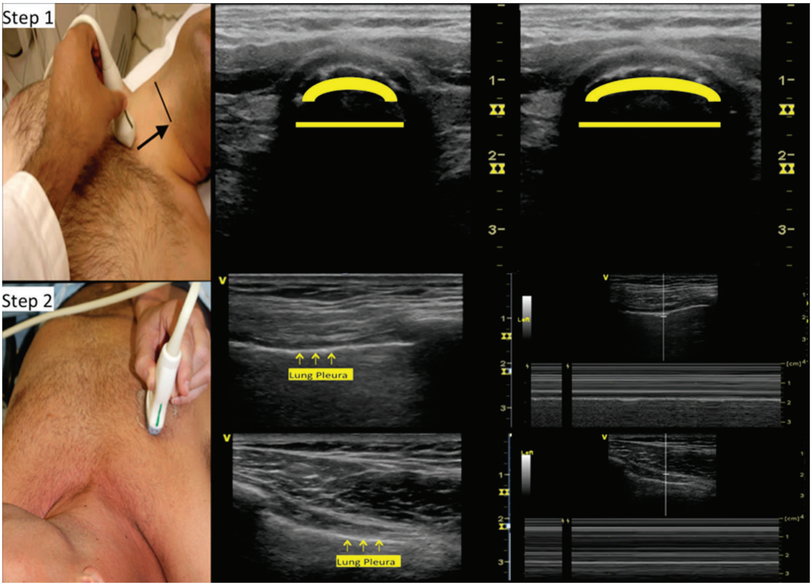

Figure 5.F.1 PLUS (Pulmonary tree and Lung expansion Ultrasound Study) ultrasound examination.

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 the endotracheal cuff is tracheal dilation with balloon inflation. The picture on the left in Figure 5.F.1 step 1 shows a non-dilated trachea, and the one on the right shows a dilated trachea secondary to balloon inflation. The 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 mid-clavicular line bilaterally. Assessment of lung expansion evaluated by detection of the horizontal movement of the two pleural linings with respiration. Use of M-mode facilitates pleural sliding assessment. The top image in Figure 5.F.1 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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Airway Anatomy

In addition to the ability to assist with ETT localization, airway ultrasound can help identify the following structures: tracheal rings, cricoid cartilage, cricothyroid membrane, and thyroid cartilage. Placing the ultrasound probe longitudinally such that the ultrasound plane transects the airway in the sagittal plane will allow for identification of each of these structures (Figure 5.F.2).

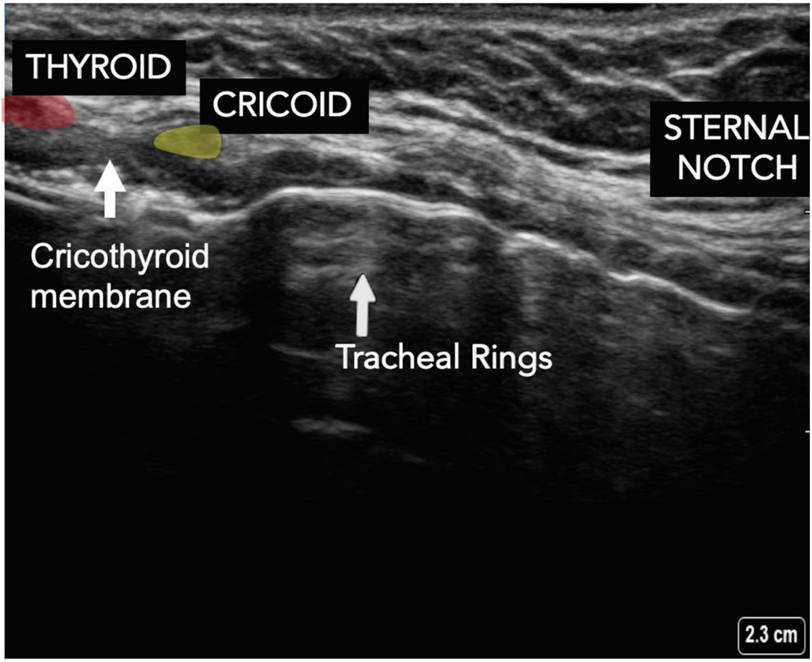

Figure 5.F.2 Airway anatomy.

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V.G

Estimating Right Ventricular Systolic Pressure (RVSP)

Jay Shen, Mariana Gomez, Julian Hinson and Davinder Ramsingh

Right ventricular systolic pressure (RVSP) is useful for the evaluation of the cardiopulmonary system intraoperatively and in intensive care settings. The use of transthoracic ultrasound to estimate RVSP is a non-invasive means that has been found to closely correlate with more accurate invasive forms (i.e., Swan-Ganz) of measuring pulmonary artery pressure. The use of ultrasound to calculate RVSP is an advanced technique, as it builds upon other ultrasound imaging modalities such as estimating CVP utilizing IVC POCUS.

During systole, blood flows from RV through the pulmonary valve into the lungs. However, the tricuspid valve is incompetent and in healthy adults, there is a mild degree of tricuspid regurgitation, pushing blood into the RA during systole. To calculate pulmonary systolic pressure, the Bernoulli principle allows the calculation of a hydrostatic pressure gradient between the RA and RV:

$$P_{RV} + \frac{1}{2}\rho_{RV}^{2} + \rho g y_{RV} = P_{RA} + \frac{1}{2}\rho v_{RA}^{2} + p g y_{RA}$$

Since the differences in density of blood, height, and gravity between RA and RV are negligible, and the velocity of RA is greater than the velocity of RV due to the RA proximity to the tricuspid valve, we can modify the equation to obtain the pulmonary artery pressure (PAP): $PAP = 4 \; x \; v_{TR}^{2}$. Although the modified Bernoulli equation estimates PAP, it does not account for the additional RA pressure the RV needs to overcome to produce a tricuspid regurgitant jet.

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The second step involves attaining the RA pressure (RAP), whether it is through a central venous line or measuring the IVC size using ultrasound (please refer to IVC chapter for further instruction on how to obtain views/measurements). The RAP is then estimated utilizing the table below, Figure 5.G.1.

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

Figure 5.G.1 Relationship between IVC ultrasound measurements and central venous pressure.

To calculate RVSP, we add PAP and RAP: **RVSP=** $4 \times v_{TR}^2$ + **RAP**.

Patient Position: Left lateral with L arm extended (Figure 5.G.2).

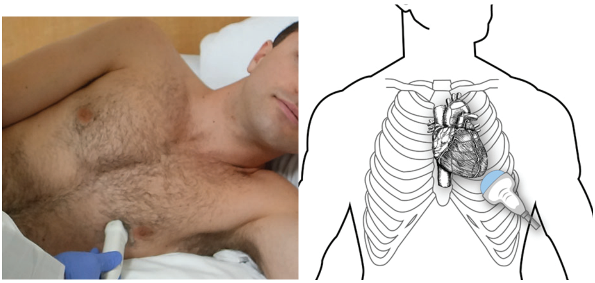

Figure 5.G.2 Probe placement and patient position for the apical view.

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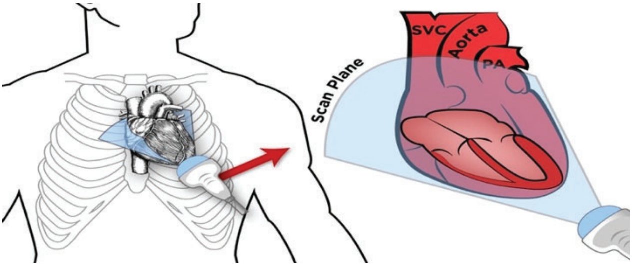

Probe type: phased array cardiac probe (small footprint/low frequency).

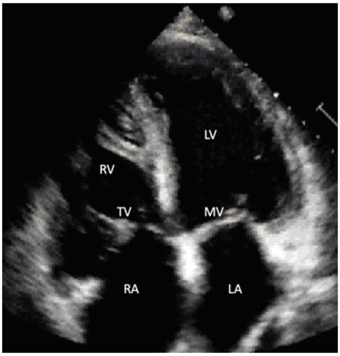

Figure 5.G.3: Apical 4 chamber view with right ventricle emphasized

Probe Position: The transducer is placed at the cardiac apex with the indicator pointing to the 3 o'clock position (5th or 6th rib space). The probe should be "rocked" such that the RV, RA, and tricuspid valve are in the middle of the screen (Figure 5.G.3).

After the image is optimized, one should initiate color Doppler to identify the presence and direction of the tricuspid regurgitation. Once identified one can place the continuous wave (CW) Doppler signal along this regurgitation pathway to assess the peak velocity jet. It is important to acknowledge that this line should be as parallel to the ultrasound plane as possible (see yellow line in Figure 5.G.4).

The Doppler signal should be recorded for similar beats to identify the full signal as demonstrated in Figure 5.G.4. Select the CW Doppler recording with the best signal and measure the velocity from the base to the peak of the trough.

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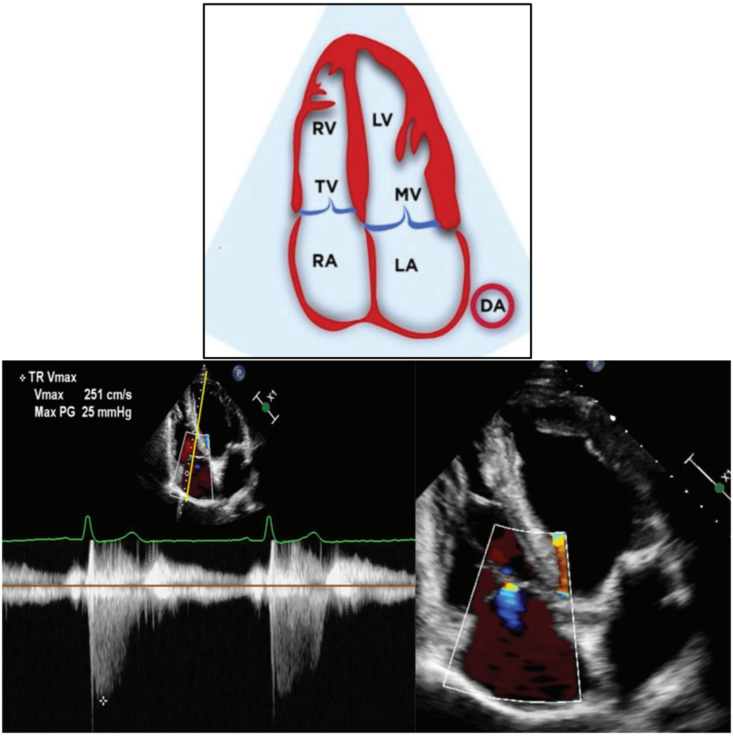

Figure 5.G.4 Color and continuous wave Doppler images of tricuspid regurgitation.

Troubleshooting

Obtaining the tricuspid regurgitation jet may be especially difficult in patients with minimal tricuspid regurgitation. In order to optimize the Doppler signal, one can measure during inspiration as the degree of tricuspid regurgitation is greatest at this time. Raising the patient's legs can also help by increasing venous return and consequently the tricuspid regurgitation signal. Again, it is imperative to catch the jet in multiple areas to make sure the highest velocity is captured in order to not undermine the peak pressure and reduce user dependent error.

Putting it All Together

Utilize the highest tricuspid regurgitation jet velocity obtained from both views and plug into the modified Bernoulli equation to calculate the

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pulmonary artery pressure: $\boldsymbol{PAP = 4 \times v_{TR}^2}$. As mentioned in the introduction, this does not estimate the RVSP, as it does not take into account the additional pressure needed to overcome the RA pressure and produce the tricuspid regurgitant jet. To estimate the RVSP, add the RAP which was obtained from either a central venous line or through estimation using IVC POCUS $\boldsymbol{(RVSP = 4 \times v_{TR}^2 + RAP)}$. In a healthy adult, the tricuspid regurgitation gradient is between 2.8–2.9 m/s or peak systolic pressure of 35–36 mmHg, assuming RA 3–5 mmHg.

Limitations of POCUS to Estimate RVSP

Although RVSP using POCUS has been found to closely estimate the RVSP, there are several limitations to the use of POCUS. First, user dependent error is more frequently a source for inaccurate measurements. This could be due to limited experience resulting in inadequate quantity and quality of jet velocity measurements using different cardiac windows. Fluctuations in pulmonary pressure may also be caused by respiration. Additionally, pre-existing pathology such as tricuspid/pulmonic valve stenosis or congenital cardiac anomalies may affect the accuracy of the estimated RVSP. Pulmonary pressure is related to age and a one size fits all model may not be applicable in all age groups.

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VI

Review

Davinder Ramsingh

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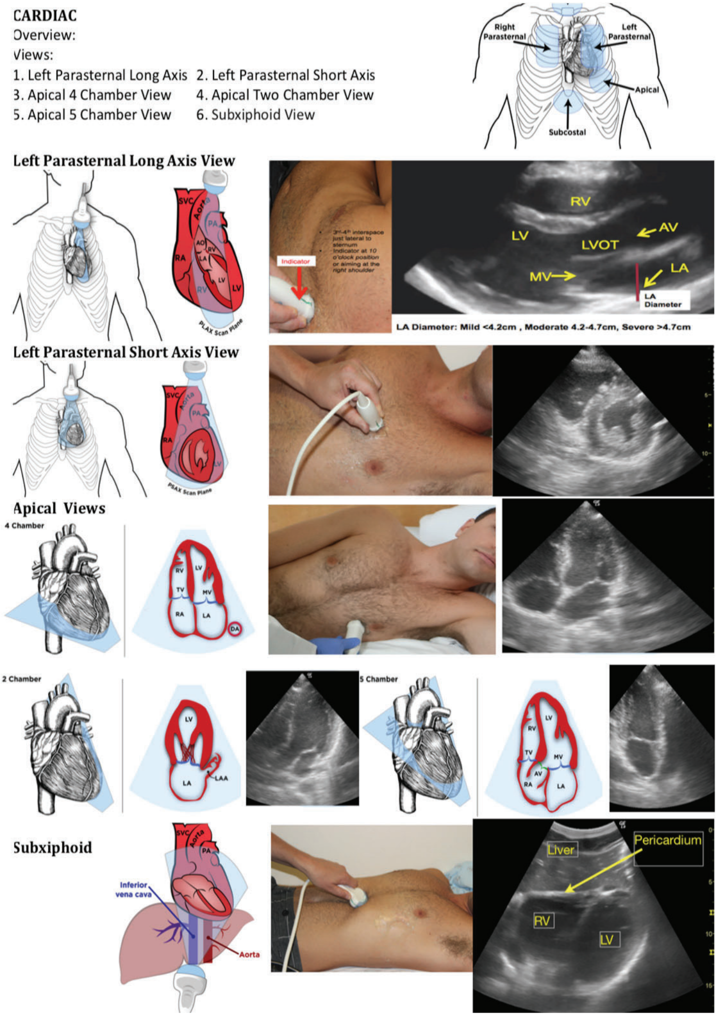
VI.A

FORESIGHT EXAM REVIEW



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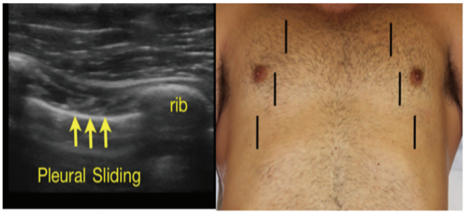
Pulmonary

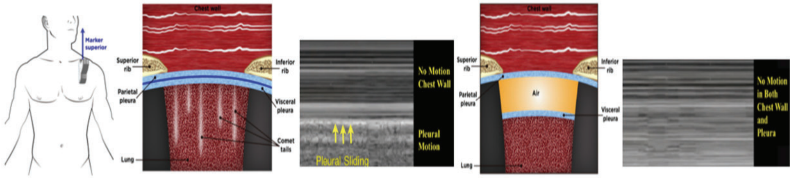
Assessment Categories

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

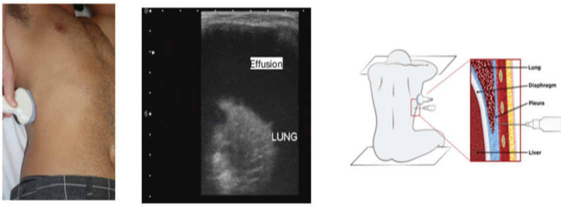


Pulmonary Examination Views

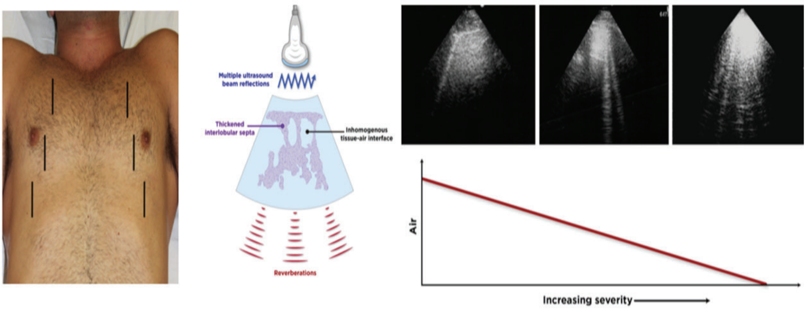
Pneumothorax Evaluation via Pleural Lung Sliding



Pleural Effusion Evaluation



Air Space Evaluation



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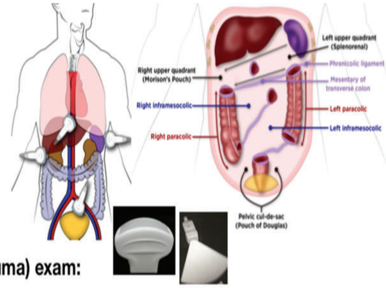
Abdominal

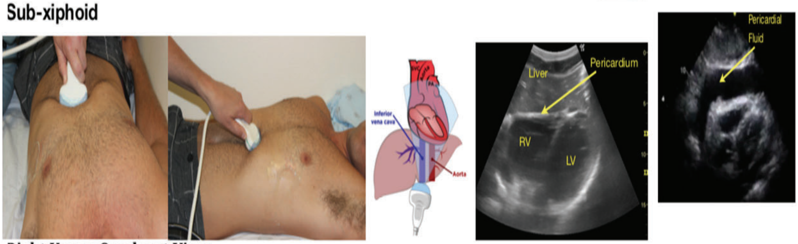
Assessment Categories

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

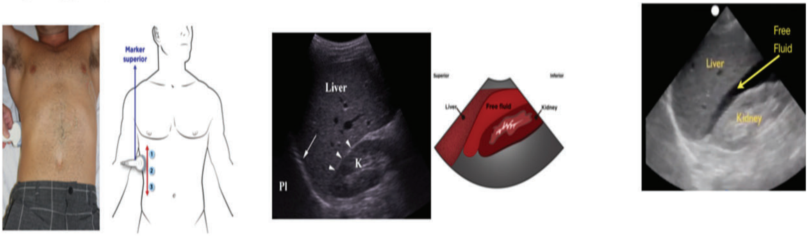


FAST (Focused Assessment with Sonography for Trauma) exam:

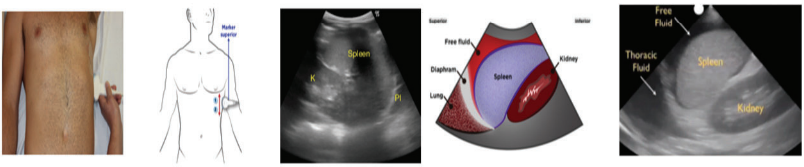
Sub-xiphoid



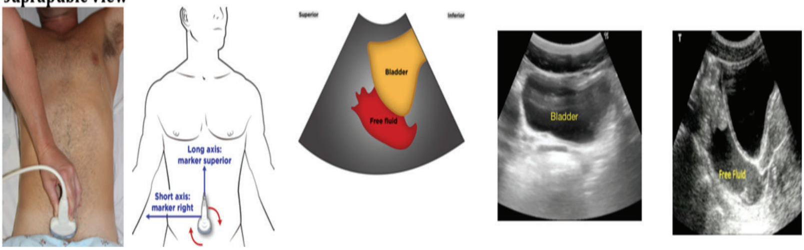
Right Upper Quadrant View



Left Upper Quadrant View



Suprapubic View



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VI.B

Questions and Answers

1. All sound waves are characterized by the following except:

A. frequency (f)
B. wavelength (λ)
C. speed (s)
D. amplitude (A)

Answer: C.

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 the 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 measured in decibels (dB).
Wavelength: The distance traveled between two consecutive peaks or troughs of a wave.
Frequency: Number of wavelengths per unit of 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

2. When the needle is inserted on the short axis all of the following are true except:

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A. A cross-sectional view of the needle will be obtained
B. This is known as the out-of-plane technique
C. This technique results in the needle being imaged on a cross-section appearing as a small dot, which can be difficult to see in real time
D. The needle will cross the ultrasound beam only once
E. All of the above are true

Answer: E.

Important points to the short axis (transverse) approach:
-- It provides a cross-sectional view of the needle.
-- It is known as the out-of-plane technique.
-- The cross-sectional view of the needle 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 it penetrates tissue.

3. When the needle is inserted in the long axis view all of the following are true except:

A. The entire needle can be visualized
B. The operator loses the lateral-medial perspective
C. The operator loses the ability to assess surrounding anatomy
D. All of the above are true

Answer: D.

Important points to the long axis (longitudinal) approach:
-- It provides a view of the entire needle if the ultrasound plane is in the path of the needle.
-- The operator loses the lateral-medial perspective.
-- The operator loses the ability to assess surrounding anatomy.
-- The probe is more often fixed in position during a procedure.

4. Axial resolution is the minimum separation between structures the ultrasound beam can distinguish ________ to its path.

A. Parallel

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B. Perpendicular

Answer: A.

Spatial resolution is the smallest distance that two targets can be separated by *while still allowing 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. Lateral resolution is the minimum separation between structures that are perpendicular to the ultrasound beam path.*

5. Lateral resolution is the minimum separation between structures the ultrasound beam can distinguish _______ to its path.

A. Parallel
B. Perpendicular

Answer: B.

Spatial resolution is the smallest distance that two targets can be separated by *while still allowing 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. Lateral resolution is the minimum separation between structures that are perpendicular to the ultrasound beam path.*

6. All of the following are true of resolution except:

A. Resolution is separated into spatial and temporal
B. Spatial resolution is further divided into axial and lateral
C. Both axial and lateral resolution increase with increased signal frequency
D. All of the above are true

Answer: D.

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

Spatial resolution is the smallest distance by which two targets can be

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separated while still allowing 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. Lateral resolution is the minimum separation between structures that are perpendicular to the ultrasound beam path.

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

7. Axial resolution depends on all of the following except:

A. Wavelength (the smaller the better)
B. Pulse length (the shorter the train of cycles the greater the resolution)
C. The ability to separate structures parallel to the ultrasound beam
D. It decreases with an increase in frequency

Answer: D.

Spatial resolution is the smallest distance by which two targets can be separated while still allowing 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 resolution is impacted by the ultrasound wave amplitude, the image depth, and the gain intensity.

8. Lateral resolution depends on all of the following except:

A. Beam width (the smaller the better)
B. Depth
C. Gain
D. All of the above affect lateral resolution

Answer: D.

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Spatial resolution is the smallest distance by which two targets can be separated while still allowing 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 resolution is impacted by the ultrasound wave amplitude, the image depth, and the gain intensity.

9. 2-D images will show the best resolutions of structures that are ___________ to the probe.

A. Parallel
B. Perpendicular

Answer: B.

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 plane is perpendicular to the structure.

10. Which probe is most appropriate for the Focused Assessment with Sonography in Trauma (FAST) ultrasound examination?

A. 12 MHz high frequency linear probe
B. 2.5 MHz microconvex probe
D. 3–5 MHz curved linear probe

Answer: D.

A low frequency probe is required to allow for adequate depth of penetration. The larger ultrasound sector from a curved linear probe will also provide improved image quality.

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11. An operator tries to visualize the parasternal long axis view of the heart but neglects to apply gel to the transducer. Ultrasound gel is critical for visualization because it:

A. Absorbs heat from tissues that attenuate the ultrasound waves
B. Decreases the acoustic impedance from probe to the skin
C. Keeps the ultrasound wave perpendicular to structures

Answer: B.

Acoustic impedance (AI) is dependent on the density of the material in which sound is propagated. The greater the impedance, the denser the material. The difference in acoustic impedance between tissues is directly related to the magnitude of ultrasound reflection. In other words when the ultrasound interacts with larger differences in densities there will be a large degree of reflection at this depth. Gel is used between the probe and the skin of the subject to reduce the acoustic impedance.

12. The operator suspects abnormal blood flow in the heart. Which mode should he/she utilize to determine the location of the abnormal flow?

A. M-Mode
B. B-Mode
C. Doppler-Modes

Answer: C.

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 the 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 plane is perpendicular to the structure.

M-MODE (motion mode):

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A graphic B-mode pattern that displays a single linear section over time, representing the motion of structures along the ultrasound beam at 1000fps. In this mode the line of ultrasound reflection or returning echoes 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).

DOPPLER-MODES: Pulsed Wave, Continuous Wave, Color.

Color Doppler:
Ultrasound images are usually displayed with grayscale brightness corresponding to their intensities. In color Doppler however, echo signals are displayed with colors corresponding to the direction of flow that their Doppler shifts represent: either positive to (toward) or negative to (away from) the transducer. This is usually overlaid on a 2-D image. A good general rule is the following: BLUE = BLOOD FLOW MOVING AWAY FROM THE TRANSDUCER / RED = BLOOD FLOW MOVING TOWARDS THE TRANSDUCER—THINK BART (Blue Away/Red Towards). The color range in the color Doppler setting represents the range of the velocities. Brighter colors represent faster velocities while darker colors represent the inverse. The measurable range of the velocities is shown above the color range legend on the top left of the screen. This range of velocities is called the Nyquist limit.

Pulsed Wave Doppler:
This modality gives a graphical display of all the velocities within the area sampled. Pulsed 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.

13. A _____ probe is used for cardiac ultrasound with the indicator on the _____ side of the ultrasound screen, based on default settings.

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A. Curved linear, left
B. Phased array, left
C. Curved linear, right
D. Linear, right
E. Phased array, right

Answer: E.

It is important to become familiar with 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, a bump, or 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/ 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, most ultrasound systems place the indicator on the right of the screen by default. To summarize this concept, when doing an ultrasound examination, 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 book describes the probe position based on the usual defaults for the probe and presets used to perform the ultrasound examination.

14. Why is a linear probe used for visualizing more superficial structures rather than the other transducer probes?

A. It has a flat footprint, giving it greater access to the structures
B. It has more power than the other probes, giving it a clearer image
C. It has a higher frequency than the other probes, giving it less depth of penetration
D. It has a higher frequency than the other probes, giving it a greater depth of penetration

Answer: C.

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

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

15. A 2-month-old infant female has been diagnosed with a congenital heart lesion that is causing narrowing along her left ventricle outflow tract to the aorta. The team is trying to evaluate whether the lesion lies before the aortic valve or after to help decide the correct surgical procedure. Use of which ultrasound modality / modalities can be used to help identify the location of the lesion as well as the severity of her pathology?

a. M-Mode
b. Pulse Wave Doppler
c. Continuous Wave Doppler

A. a and b
B. b and c
C. a and c

Answer: B.

A combination of continuous wave and pulse wave Doppler will provide the greatest aid in helping determine the severity of the lesion as well identify the exact location of the pathology within the heart. Specifically, the use of continuous wave Doppler assists in determining the severity of the lesion while pulse wave Doppler reveals the location of the lesion within the heart. Fundamentally, the severity of a valvulopathy is determined by assessing the direction and the velocity of blood flow across cardiac structures. This patient's stenotic aorta would demonstrate an increase in blood flow velocity—with an associated severity measurement using point of care ultrasound (this also will provide the pressure gradient via the Bernoulli Principle). Continuous wave Doppler provides the ability to assess any range of velocities along its Doppler signal path (line placed along the 2-D image by the sonographer). Remember that continuous wave Doppler provides the benefit of having no limitation on the range of velocities it can assess, however, since it provides a summation of all of the velocities along its path it cannot identify where along the Doppler signal line the velocity acceleration is occurring. To determine the location of flow acceleration one can activate pulse wave Doppler and move the sample indicator along the Doppler line and assess where the increase in velocity occurs (would

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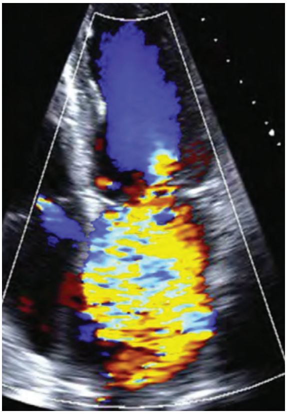
see an increase in Doppler waveform flow pattern). Importantly, because of the velocity range limitation of pulse wave Doppler the flow acceleration may exceed the range of velocities that can be assessed (past the Nyquist limit) and aliasing may occur.

16. Color Doppler can be used to look at the direction of blood flow in a given area. Blue demonstrates blood flow away from the probe, while red shows blood flow toward the probe. What is demonstrated when there is a rapid transition between blue to light blue to yellow to red on the color Doppler image (see picture below)?



A. Flow has exceeded the Nyquist limit
B. Defective ultrasound probe
C. Incorrect ultrasound cut plane

Answer: A.

Remember, the Nyquist limit is the maximum velocity in which the direction and magnitude of flow can be assessed. With color Doppler engaged, one can see the Nyquist limit scale—the maximum positive (red to yellow scale / identifying flow towards the probe) and maximum negative (dark to light blue scale / identifying flow away from the probe)—on the color bar in the top left or right of the screen. When the velocity of flow exceeds the set Nyquist limit value the color pattern will falsely reverse the direction of flow to the highest color designation of flow in the opposite direction. This phenomenon with Doppler ultrasound is called "aliasing" and it represents

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a loss in the ability of the ultrasound to assess the direction and magnitude of flow.

17. A 67-year-old man with Ehlers-Danlos is celebrating his retirement with his wife by going camping at Yosemite National Park. While there, they go hiking for the first time in two years and he realizes he is easily out of breath, something he has noticed for the last year, but never given much thought to. He schedules an appointment with his family physician after he returns from the trip. At his appointment he has a BP of 160/76 with a bisferiens pulse and is noted to have a "bobbing uvula" and "pulsing nail beds." The doctor performs a cardiac TTE to confirm the likely etiology of the patient's symptoms. Which view would be best to identify the most likely finding?

A. Parasternal short axis, red diastolic jet
B. Parasternal short axis, blue diastolic jet
C. Apical, red diastolic jet
D. Apical, blue diastolic jet

Answer: C.

The symptoms of bisferiens pulse, bobbing uvula (Muller's sign) and pulsing nail beds (Quincke's sign) with a wide pulse-pressure all point to aortic regurgitation as the etiology of this man's symptoms. A further hint of the condition is known Ehlers-Danlos diagnosis, which predisposes patients to aortic regurgitation. In order to best see aortic regurgitation, a view parallel to the flow of blood will give the strongest Doppler shift. With traditional cardiac presets (indicator on the right side of the screen) aortic regurgitation will show up as a red jet as the blood flows backward, toward the probe (Remember BART: blue away, red toward). Remember, with the probe at the apex of the heart in the apical view, blood flow should be moving away from the probe (blue) as it travels across the LVOT and aortic valve.

Cardiac

1. Using this view, one is able to best assess the major and minor dimensions of the left ventricle and left atrium while the patient is the supine position:

A. L parasternal long axis view
B. Apical four chamber view

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C. Subcostal view
D. None of the above

Answer: A.

In the supine position, the parasternal long axis view most often provides the best detail of the long axis and short axis of the left ventricle because these structures are perpendicular to the ultrasound plane and the ultrasound probe is closest to the heart in this window. Because of this, one often starts with this window when performing a cardiac ultrasound examination.

2. To assess right ventricular function one can:

A. Assess tricuspid annular plane systolic excursion via parasternal long axis view
B. Assess tricuspid annular plane systolic excursion via parasternal short axis view
C. Assess tricuspid annular plane systolic excursion via the apical 4-C view

Answer: C.

One can use M-mode and 2-D measurements to assess the movement of the tricuspid annulus from diastole to systole. This strategy is termed tricuspid annular plane systolic excursion and a value of less than 16mm suggests reduced RV systolic function.

3. Regarding the Left Ventricle the anterior wall receives primarily oxygenated blood from which vessel:

A. Left Anterior Descending (LAD)
B. Left Circumflex
C. Right Coronary Artery

Answer: A.

LAD supplies Anterior and antero-septal segments.

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

4. Regarding the Left Ventricle the lateral wall receives primarily oxygenated blood from which vessel:

A. Left Anterior Descending (LAD)
B. Left Circumflex
C. Right Coronary Artery

Answer: B.

LAD supplies Anterior and antero-septal segments.

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

5. Regarding Diastolic Function, one can assess normal E (passive diastolic filling) to A (atrial contraction in late diastolic) ratio via which ultrasound technique?

A. Parasternal Long Axis just below the coaptation point of the mitral valve since blood flow is perpendicular to the pulse wave Doppler signal
B. Four Chamber Apical View just below the coaptation point of the mitral valve since blood flow is parallel to the pulse wave Doppler signal
C. Four Chamber Apical View just below the coaptation point of the mitral valve since blood flow is perpendicular to the pulse wave Doppler signal
D. None of the above

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Answer: C.

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.

Four 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' four chamber view. All four cardiac chambers are visualized in the four chamber 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. Left ventricular diastolic function can be assessed by applying pulsed wave Doppler to the mitral valve and pulmonary veins. In this view, the right ventricular free wall, interventricular septum, and left lateral wall can be assessed for systolic motion.

6. One can tell normal diastolic function vs. moderate to severe diastolic dysfunction by which pattern on Mitral Inflow?

A. Normal Diastology has E/A >1 but <2 with a deceleration time >140 ms while a restricted pattern has E/A >2 with a deceleration time <140 ms
B. Normal Diastology has E/A >2 with a deceleration time <140 ms while a restricted pattern has E/A <2 with a deceleration time >140 ms
C. Normal Diastology has E/A >1 but <2 with a deceleration time <140 ms while a restricted pattern has E/A >2 with a deceleration time >140 ms
D. None of the above

Answer: A

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.

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7. The different methods commonly used in the echocardiographic assessment of LV systolic function include all of the following except:

A. Ejection fraction - M-mode LV dimensional method (Fractional Shortening)
B. Fractional Area Change
C. Visual gestalt
D. Doppler measurement of stroke volume...and therefore cardiac output
E. All of the above are valid methods

Answer: E.

All are valid methods to assess LV systolic function.

8. Which view and Doppler technique are used to quantify aortic stenosis?

A. Parasternal long axis and pulse wave Doppler
B. Parasternal long axis and continuous wave Doppler
C. Apical 5 chamber and pulse wave Doppler
D. Apical 5 chamber and continuous wave Doppler

Answer: D.

The Apical 5 chamber view allows one to be parallel to blood flow across the aortic valve. Continuous wave Doppler allows one to obtain the peak and mean gradient values.

9. How can one assess pulmonary systolic pressures using ultrasound?

A. By measuring the peak regurgitate velocity of mitral regurgitation (via Continuous Doppler) and using the Bernoulli equation to translate this to a pressure and then add the estimated RA pressure
B. By measuring the peak regurgitate velocity of the tricuspid regurgitation (via Continuous Doppler) and using the Bernoulli equation to translate this to a pressure and then add the estimated RA pressure
C. By measuring the peak regurgitate velocity of the pulmonic regurgitation (via Continuous Doppler) and using the Bernoulli equation to translate this to a pressure and then add the estimated RA pressure
D. None of the above

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Answer: B.

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).

10. Normal FAC of the right ventricle is?

A. 80%
B. 10%
C. 35%
D. 25%

Answer: C.

Right Ventricular Fractional Area Change (FAC): RV FAC is 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 FAC is >35%.

11. To estimate one's pulmonary artery systolic pressure which of the following parameters is needed?

A. Mitral regurgitation
B. Pulmonic regurgitation
C. Doppler of hepatic or vena cava flow
D. Tricuspid regurgitation

Answer: D.

Doppler ultrasound can also be used to estimate PASP. To do this, your patient must 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

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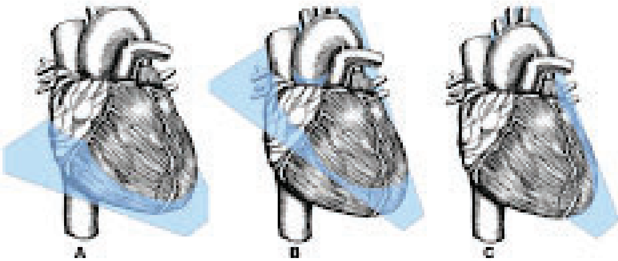
with the same velocity across the pulmonic valve (forward flow) as it will across the tricuspid valve (TR).

12. Which of the following pictures shows the ultrasound plan for the four chamber apical view?



A.
B.
C.

Answer: A.

Figure A shows the apical four chamber, Figure B shows the more anterior apical five chamber ultrasound plane, Figure C shows the apical two chamber ultrasound plane.

13. Volume responsiveness can best be assessed in which cardiac view?

A. Parasternal short axis view (PSAX)
B. Parasternal long axis view (PLAX)
C. Subxiphoid view
D. Apical five chamber view

Answer: D.

Volume responsiveness is best assessed in the Apical five chamber view, by measuring the velocity time integral (VTI) of the left ventricular outflow tract (LVOT). Volume status can also be assessed by imaging Doppler flow patterns across arteries and cardiac structures and obtaining a VTI. The areas commonly assessed are the LVOT and carotid artery.

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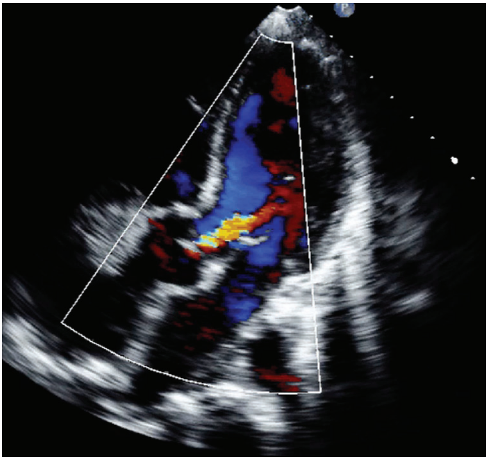
14. What pathology is demonstrated via the Color Doppler/2-D Image below?



A. Mitral regurgitation
B. Tricuspid regurgitation
C. Aortic regurgitation
D. Aortic stenosis

Answer: C.

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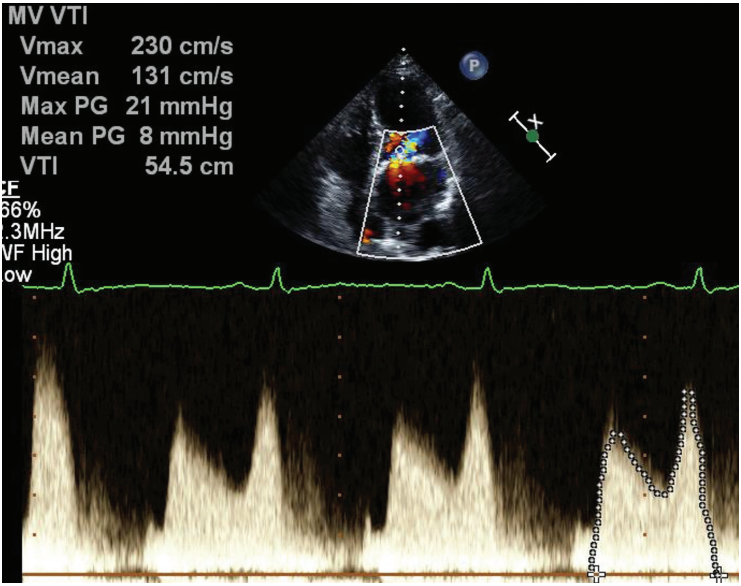
15. What pathology can be seen in the image below?



A. Mitral stenosis
B. Aortic stenosis
C. Mitral calcifications
D. Hypovolemic shock

Answer: A.

16. Which cardiac view is optimal for measuring left ventricle fractional area change to estimate contractility?

A. Parasternal long axis
B. Parasternal short axis, basal level (aortic valve in view)
C. Parasternal short axis, mitral valve level
D. Parasternal short axis, mid-papillary level
E. Parasternal short axis, apical level
F. Apical four chamber view
G. Apical five chamber view
H. Subxiphoid view

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Answer: D.

Parasternal short axis, mid-papillary level. The parasternal short axis view provides the best view for estimating ventricle area change because it provides a view of more ventricular walls. The mid-papillary level is best because one can compare papillary muscle size to assure a correct LV section.

17. What pathology, if any, can be seen here in the image below?

A. Left ventricular dilation
B. Right ventricular dilation
C. Mitral stenosis
D. Aortic stenosis

Answer: B.

This image shows an enlarged right ventricle.

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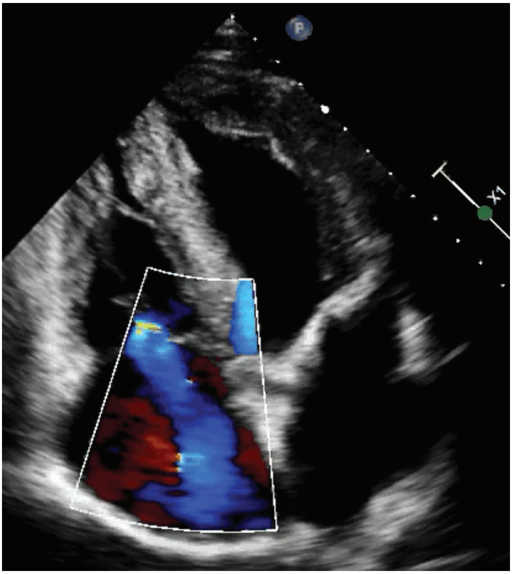
18. What pathology can be seen here in the image below?



A. Mitral stenosis
B. Mitral regurgitation
C. Tricuspid regurgitation
D. Aortic regurgitation

Answer: C.

This apical four chamber image shows the color Doppler window over the tricuspid valve with evidence of regurgitation.

19. Which view can best be used to assess the systolic motion of the right ventricular free wall, the interventricular septum, and the left lateral wall?

A. Apical four chamber
B. Apical five chamber
C. Subxiphoid
D. Parasternal short axis

Answer: A.

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20. Which view can best be used to assess the presence of cardiac tamponade?

A. Apical four chamber
B. Apical five chamber
C. Subxiphoid
D. Parasternal short axis

Answer: C.

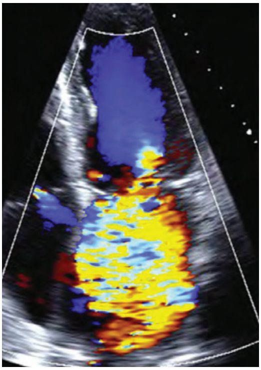
21. When using color Doppler to evaluate valvular regurgitation, what should one keep in mind?

A. Nyquist limit
B. Doppler window size
C. Doppler window location
D. All of the above

Answer: D.

All of the above. Color Doppler is a modified pulse wave Doppler, so one has to keep in mind the Nyquist limit, which is the range of velocities that can be measured. The Doppler window should be placed so the entire valve and area of backflow are encompassed. Doppler window size is inversely associated with image quality, so it should be no larger than necessary.

22. Use the image below to identify the heart condition.



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A. Tricuspid regurgitation
B. Tricuspid stenosis
C. Aortic regurgitation
D. Mitral regurgitation

Answer: D.

Mitral regurgitation is shown in the image. A regurgitant jet can be seen during ventricular systole (mitral valve is closed) coming from the mitral valve into the left atrium.

23. Which view would be most useful for finding pulmonary artery systolic pressure?

A. Subxiphoid
B. Apical
C. Parasternal
D. None of the above

Answer: B.

Doppler of tricuspid regurgitation can be used to find an estimation of pulmonary artery systolic pressure. Use continuous wave Doppler to find the peak velocity of regurgitant blood, the machine will equate this to a pressure using Bernoulli's principle. Once you have the pressure of the regurgitant blood, add the estimation of central venous pressure to get pulmonary artery systolic pressure.

24. Where should the indicator be pointed for a subxiphoid cardiac view?

A. 12 o'clock
B. 3 o'clock
C. 6 o'clock
D. 10 o'clock

Answer: B.

3 o'clock. For a subxiphoid view, a phased array or curvilinear probe

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should be placed under the xiphoid process almost parallel to the skin surface with the indicator pointed to the 3 o'clock position.

25. Which cardiac view is most often used for evaluating for a pericardial effusion?

A. Parasternal long axis
B. Parasternal short axis
C. Apical four chamber
D. Subxiphoid
E. Apical five chamber

Answer: D.

Subxiphoid. The subxiphoid cardiac view provides an ideal view of the anterior pericardium, which is a common location for pericardial effusions.

26. What should be added to the differential if a subxiphoid approach fails to provide images of the heart?

A. Hepatomegaly
B. Ascites
C. Pneumothorax
D. Pericardial effusion

Answer: C.

Pneumothorax. Air attenuates ultrasound waves, blocking images, so all the air between the pleura layers in a pneumothorax would make it hard to obtain a good image. The liver has little effect on ultrasound waves, and in fact is used as an acoustic window for the subxiphoid view, so hepatomegaly should not affect image acquisition. Abdominal fluid in ascites would collect in the hepatorenal recess (Morison's pouch) and is unlikely to affect image acquisition. The subxiphoid view is prime for assessing for pericardial effusion because of its ideal view of the anterior pericardium, the site of most pericardial effusions.

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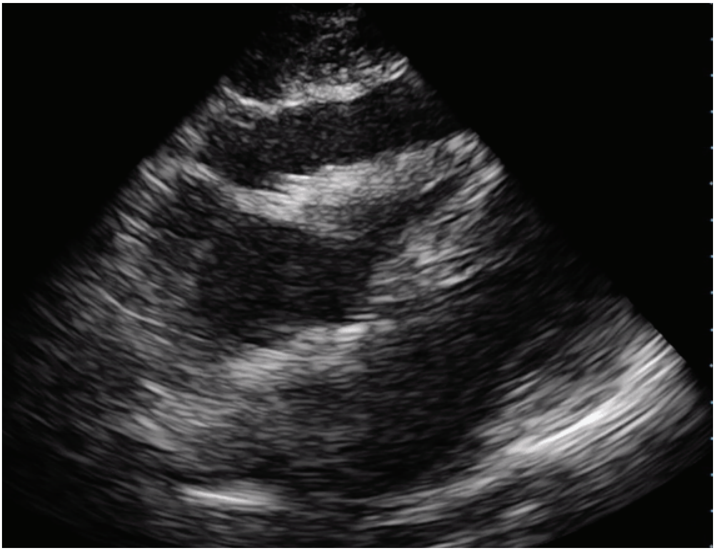
27. Use the image below. What pathology, if any, can be seen here?



A. Pleural effusion
B. Pericardial effusion
C. Aortic stenosis
D. Pulmonic stenosis

Answer: B.

Pericardial effusion. Hypoechoic fluid can be seen around the heart, but within the pericardial sac. This is a pericardial effusion.

28. Diastolic relaxation is an active process.

A. True
B. False

Answer: A.

Diastolic relaxation is an active cardiac muscle contracting process. It is for this reason that moments of decreased oxygen delivery worsen diastolic dysfunction.

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29. A patient presents to your clinic for increasing complaints of exercise intolerance. In order to assess diastolic dysfunction, you do the following:

A. Obtain an apical four chamber view and use pulse wave Doppler to assess the E/A ratio
B. Obtain an apical four chamber view and use continuous Doppler to assess the E/A ratio
C. Obtain a parasternal long axis view and use pulse wave Doppler to assess the E/A ratio
D. Obtain a parasternal long axis view and use continuous wave Doppler to assess the E/A ratio

Answer: A.

The correct answer is A: Obtain an apical four chamber view and use pulse wave Doppler to assess the E/A ratio. To best assess blood flow through the heart, the probe should be placed as parallel to flow as possible. It is for this reason that the apical four chamber view is preferred over the parasternal long axis. Additionally, we want to assess the flow at a specific location, and therefore will use pulse wave Doppler to do so.

30. Diastolic dysfunction grade I is characterized by:

A. Increased LA pressure
B. Increased diastasis time
C. Increased E velocity
D. Increased LV relaxation time

Answer: D.

Increased LV relaxation time is what occurs in grade I. Grade I diastolic dysfunction is also described as an 'impaired relaxation state'. There is no elevation of LA pressure. The reduced compliance of the ventricle will decrease the E velocity and increase the amount of time needed for the left ventricle to relax.

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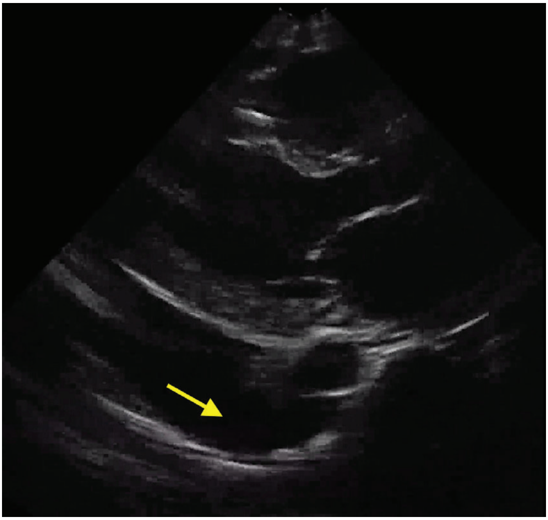
31. Diastolic dysfunction grade II pseudonormalization can be identified by which of the following?

A. Increased deceleration time
B. Decreased left atrial pressure
C. Elevated left ventricular end diastolic pressure
D. Decreased pressure equalization

Answer: C.

The correct answer is: Elevated left ventricular end diastolic pressure LVEDP. In Grade II diastolic dysfunction, the LV does not fully relax, and therefore there is an increase in the LVEDP and secondarily an increase in the LA pressures. With the differences of pressure between the atrium and ventricle reduced, there will be a decrease in the amount of deceleration time necessary for equilibrium to be attained between the two chambers. This pressure of equalization will be increased when compared to normal.

32. A 22-year-old male patient presents to the emergency room after suffering a stab wound to the chest during a gang fight. Vital signs: HR: 100, BP: 80/40. The attending physician uses an ultrasound to look for any damage in the lungs and heart. On the ultrasound image below, what is the yellow arrow identifying?



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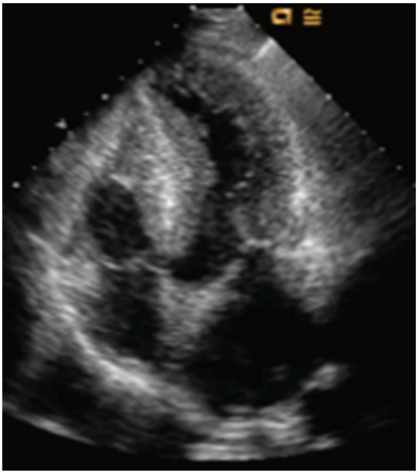
A. Pneumothorax.
B. Pericardial effusion
C. LV hypertrophy
D. Pleural effusion

Answer: D.

The yellow arrow identifies a pleural effusion. A key strategy to identify this as a pleural effusion is the fact that the fluid goes behind the descending aorta.

33. A 14-year-old child presents to the clinic for a routine physical with her pediatrician. Her mother states that the patient seems to "always breathe heavily," vomit often, and clamps her hand on her chest intermittently. When the physician places a stethoscope on the child's chest to listen to her heart, the physician hears a Grade IV murmur, especially when the physician asks the child to do a valsalva maneuver. The physician's point of care cardiac ultrasound shows the image below. What is the most likely diagnosis?



A. Mitral stenosis
B. Aortic dissection
C. Hypertrophic cardiomyopathy
D. Pericardial effusion

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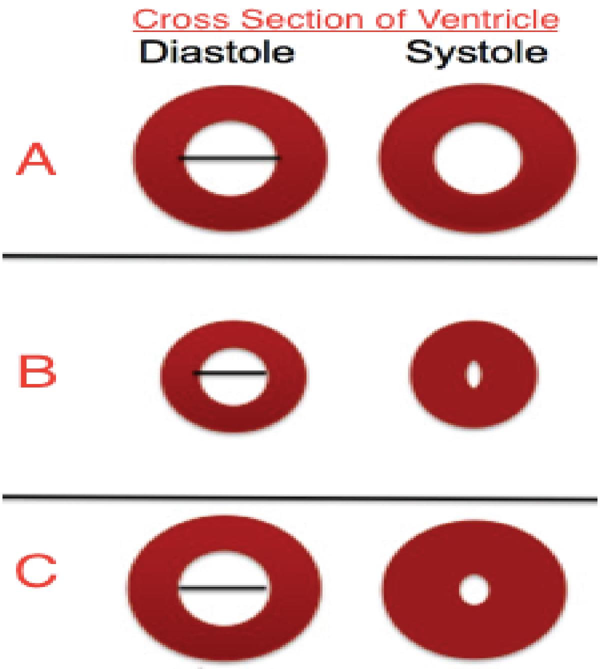
Answer: C.

Hypertrophic Cardiomyopathy (HCM) is one of the most common forms of heart disease found in children and adolescents. The interventricular septum is typically thickened (pictured in the point of care ultrasound capture above), restricting the blood flow out of the heart. Some symptoms seen in HCM patients are dyspnea, angina (chest pain), light-headedness or dizziness, syncope (fainting), palpitations/arrhythmias (irregular heartbeats), excessive sweating or agitation during feeding thought to be due to chest pain.

34. An 84-year-old female who was admitted four days ago is now suspected to have sepsis with a BP of 89/46. She receives a liter fluid bolus with minimal improvement in her BP. Her attending performs a point of care ultrasound examination to confirm the cause of the patient's shock. Which of the following cardiac views and ventricular states would confirm the diagnosis of vasogenic shock?



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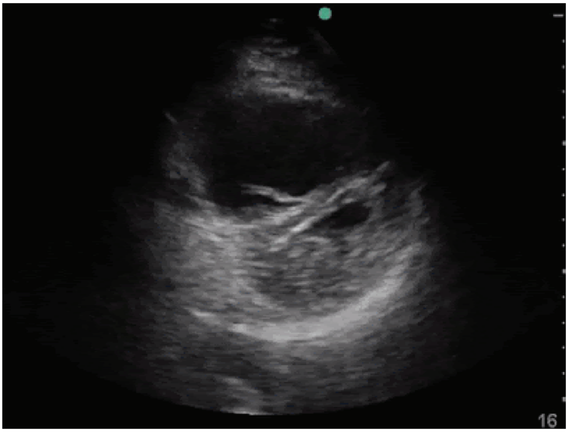
A. Parasternal Long Axis, finding "A"
B. Parasternal Long Axis, finding "B"
C. Parasternal Long Axis, finding "C"
D. Parasternal Short Axis, finding "A"
E. Parasternal Short Axis, finding "B"
F. Parasternal Short Axis, finding "C"

Answer: F.

The patient has hypotension that isn't responding to volume, indicating the etiology of her shock is likely vasogenic. In vasogenic shock the heart will fill normally (normal left ventricular end diastolic diameter) but the contractility will be increased, so the end systolic diameter will be smaller (hyperdynamic state). This is shown in diagram C. The cardiac view used most often to determine the type of shock is the parasternal short axis view. All three of the above findings are examples of parasternal short axis view.

35. A 67-year-old male has a past medical history of COPD and decreased functional status. The parasternal short axis view of his heart is below. What is the most likely pathology to produce this ultrasound image?



A. Aortic stenosis
B. Aortic regurgitation
C. Pulmonary hypertension
D. Hypovolemia
E. Dilation of the LA

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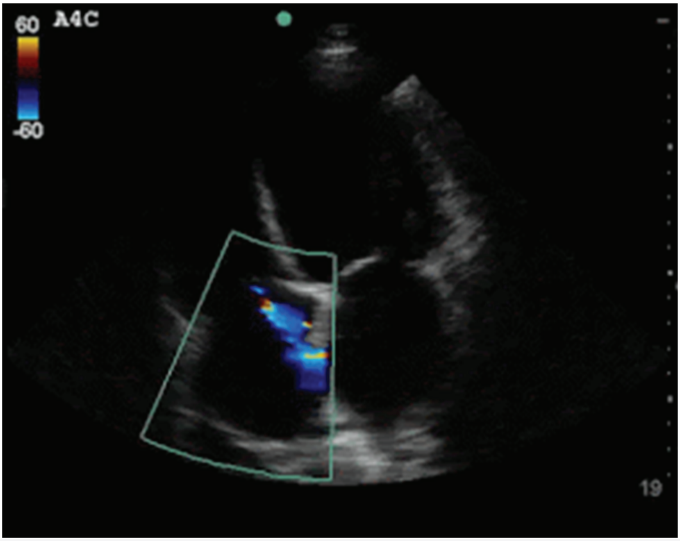
Answer: C.

What is shown on the image is the "D" shape contraction of the LV. This is a characteristic caused by increased pressures in the right ventricle which is most often associated with pulmonary hypertension.

36. A 78-year-old female with a three-year history of flushing and diarrhea presents to her family medicine doctor and reports an onset of dyspnea with exertion that has been getting progressively worse over the last five months. On auscultation you hear a holosystolic murmur at the 4th left parasternal intercostal space. Cardiac ultrasound shows the following image, what is the diagnosis?



A. Tricuspid regurgitation
B. Mitral regurgitation
C. Aortic regurgitation
D. Aortic stenosis

Answer: A.

One of the common complications of carcinoid disease is the development of valvular disease, most commonly tricuspid regurgitation. Carcinoid

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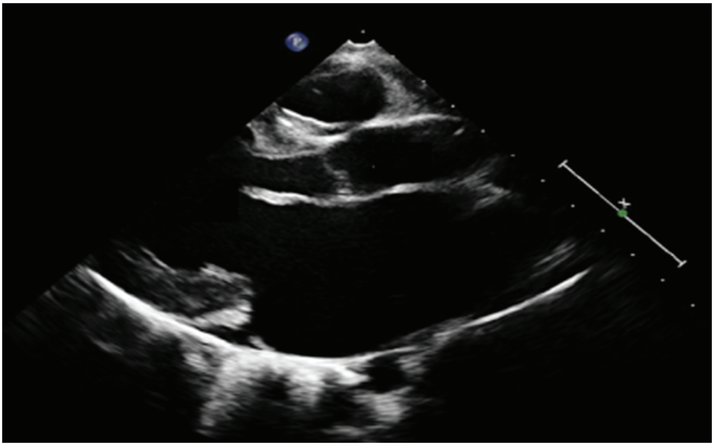
disease will give flushing and diarrhea and when heart failure develops, dyspnea with exertion will present as well. The color Doppler ultrasound image shows tricuspid regurgitation.

37. A 64-year-old female with a four-year history of worsening dyspnea with exertion and orthopnea presents to her family doctor for workup. The physician conducts a cardiac point of care ulstrasound examination where he finds the image below. Which statement is most likely to be true in this patient?



A. The patient has a dilated right ventricle
B. The patient has a dilated left ventricle
C. The patient has a dilated left atrium
D. None of the above

Answer: C.

This parasternal long axis view shows an enlarged left atrium, over 5 cm. Due to its diagnostic significance, examination of the LA is considered "the HbA1c of the heart." LA enlargement indicates an increased left ventricular end diastolic pressure. This increased pressure prevents proper flow from the LA to the LV, resulting in LA expansion to accommodate the extra blood volume. One of the common causes of increased LVEDP is diastolic dysfunction.

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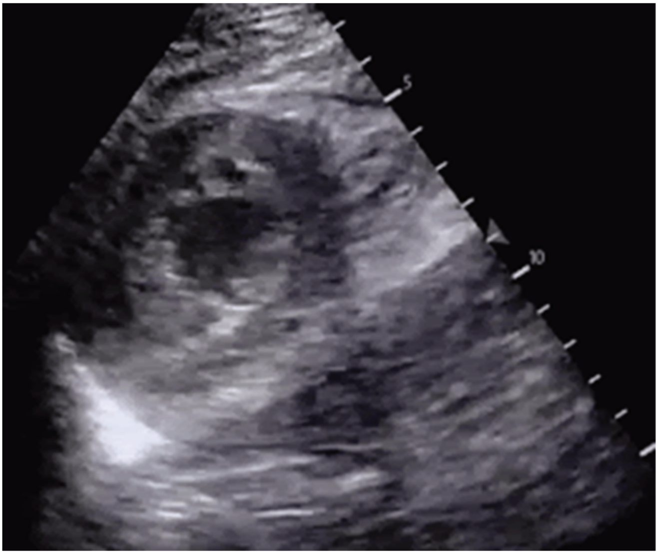
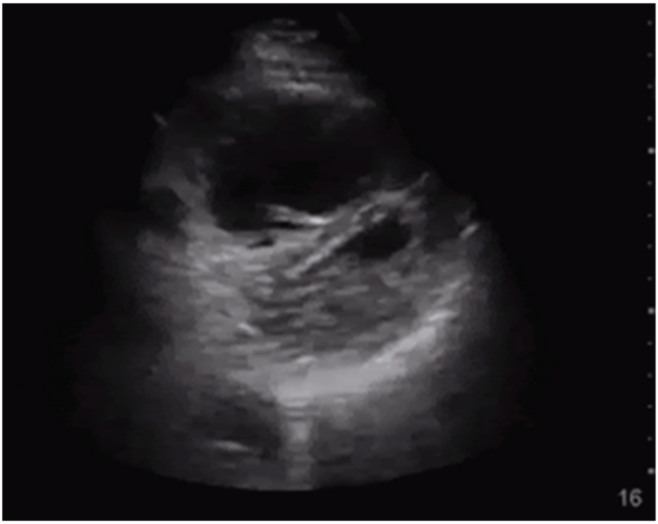
38. You are evaluating a patient with bilateral deep venous thrombi in the ICU. During your assessment, the patient demonstrates worsening shortness of breath, hypoxia, and hypotension. Which point of care ultrasound examination demonstrates the likely diagnosis?



A.



B.

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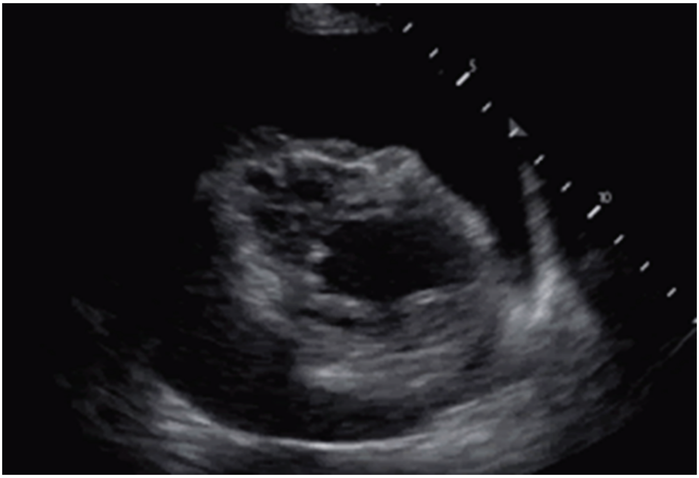
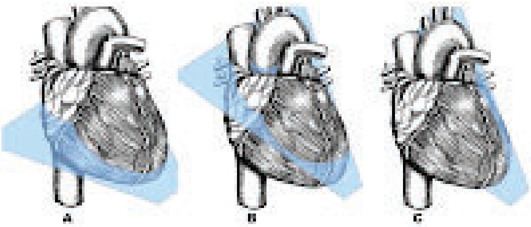


C.

Answer: B.

All of these images represent a short axis view of the heart. Image A shows a hypertrophied left ventricle. Image B shows right ventricular dilation (D-sign), which is a common finding for a pulmonary embolus. Image C shows a large pericardial effusion.

39. Which of the following pictures shows the ultrasound plane for the five chamber apical view?



A.
B.
C.

Answer: B.

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40. This image shows pathology in which valve and can be evaluated most appropriately with which Doppler modality?

A. Aortic stenosis with pulse wave Doppler
B. Aortic stenosis with continuous wave Doppler
C. Aortic stenosis with color Doppler
D. Pulmonic stenosis with pulse wave Doppler
E. Pulmonic stenosis with continuous wave Doppler
F. Pulmonic stenosis with color Doppler

Answer: B.

The image suggests the presence of aortic stenosis, which is best assessed via continuous wave Doppler.

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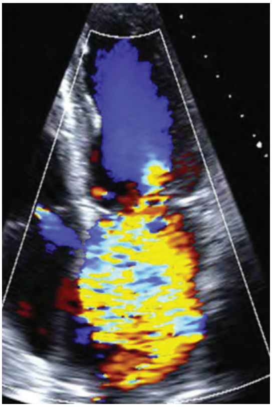
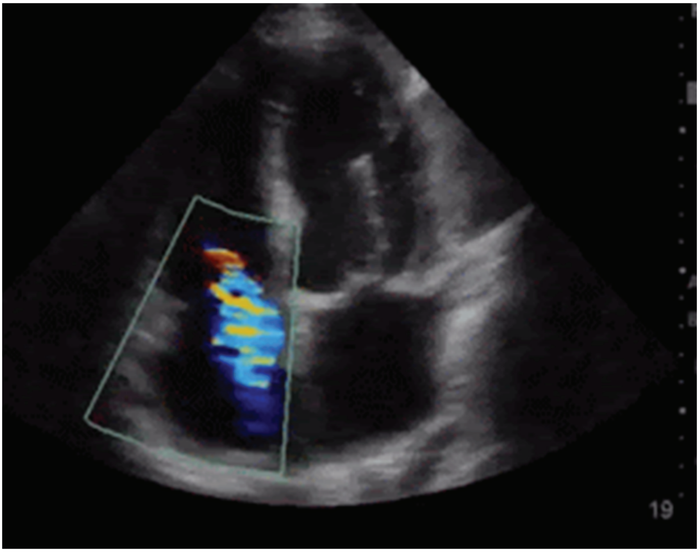
41. Which scan would be most useful for helping determine pulmonary artery systolic pressure?



A.



B.

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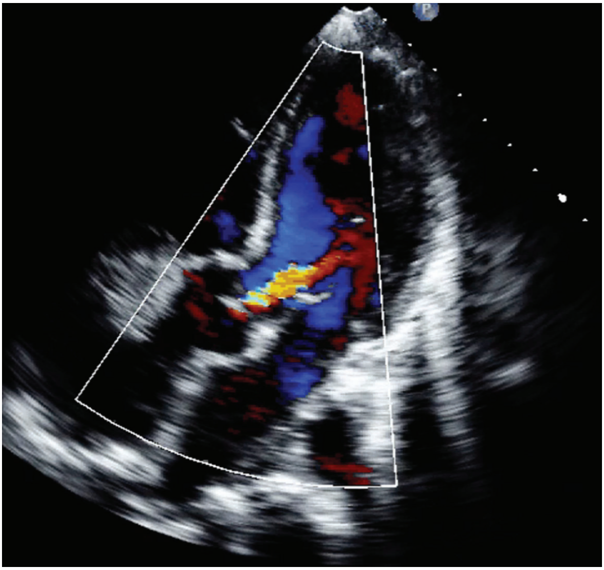

C.

Answer: B.

Doppler of the tricuspid regurgitation velocity is a validated technique to estimate pulmonary artery systolic pressures (PASP). This is shown in image B. Image A shows mitral regurgitation. Image C shows aortic regurgitation.

Pulmonary Ultrasound

1. One can differentiate pneumonia from bilateral pulmonary edema/air-space disease by:

A. Comparing presence/number of A-lines between the two lungs
B. Observing for an increase in B-lines in the diseased lungs
C. Observing for a decrease in B-lines in the diseased lungs
D. None of the above

Answer: B.

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2. If the distance between the lung and the posterior chest wall at the lung base is greater than 5 cm, how much pleural fluid can be drained?

A. >100 ml
B. >200 ml
C. >500 ml
D. No relationship

Answer: C.

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 5cm, one can predict that at least 500 ml 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 × Diameter (mm).

3. A pneumothorax most often results in the absence of lung sliding and the presence of B-lines.

A. True
B. False

Answer: B.

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 (i.e. pneumothorax) scattering the sound and preventing this phenomenon. Therefore, the presence of B-lines rules out the possibility of a pneumothorax.

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4. Which probe best quantifies the amount of pleural effusion?

A. Curved Linear
B. Linear

Answer: A

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.

5. Absence of pleural lung sliding can occur in all of the following situations except:

A. Pneumothorax
B. Apnea
C. Bronchial intubation
D. Bronchial obstruction
E. Pleural adhesion
F. All of the above situations may have absent lung sliding

Answer: F.

It is important to note that the lack of sliding alone is not sufficient to make a diagnosis of pneumothorax. Other causes include apnea, bronchial intubation/obstruction, pleural adhesion, and large infiltrates.

6. A patient with an unknown lung disease comes in for evaluation. Using ultrasound, you notice the presence of a laser-like vertical, hyperechoic image that extends to the bottom of the screen without fading. The patient returns a few weeks later and you notice more of these lines during lung ultrasound. What does this indicate?

A. Development of a pneumothorax
B. Improvement in lung functioning
C. Worsening parenchymal lung disease

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Answer: C.

B-lines are 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 decreased aeration of lung tissue (parenchymal air-space disease). The number of B-lines increases as the air-space disease worsens.

7. When ultrasounding someone who is suspected of having a pleural effusion, you find that the distance between the lung and pleura is 60 mm. What is the estimated amount of fluid that can be drained?

A. 300 ml
B. 960 ml
C. 500 ml
D. 2000 ml

Answer: B.

One can measure the distance between the lung and pleura using ultrasound, which becomes the measurement of diameter. The equation to estimate effusion volume is Vol (ml) = 16 × Diameter (mm).

8. Which ultrasound finding is considered universally specific for pneumothorax?

A. Comet tail
B. Lung pulse
C. Lung point sign
D. Pleural sliding
E. B-lines

Answer: C.

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9. A 50-year-old female has had shortness of breath and sudden chest pain for the past few hours. Fearing a heart attack, she goes to Urgent Care. The physician evaluates the heart and lungs with ultrasound. When looking at the lungs, the physician notices multiple horizontal lines between two hypoechoic columns as well as a lung point. What is the most likely diagnosis?

A. Pneumothorax
B. Pleural effusion
C. Pneumonia
D. COPD

Answer: A.

A patient presenting with A-lines (horizontal lines), absent lung sliding, and a lung point will place pneumothorax as the most likely differential.

10. A 76-year-old female patient is in the pre-anesthesia unit to prepare for an upcoming laparotomy. She has a history of chronic chest pain and chronic cough. The anesthesiologist performs a bedside ultrasound to look at the lungs. There are multiple horizontal lines along the lung pleura as well as some short vertical lines (less than 3 cm). Does the patient present with a concerning pulmonary condition?

A. Yes, because there are vertical lines, she may have pulmonary edema
B. Yes, because there are vertical lines, she may have a pneumothorax
C. No, because there are horizontal and short vertical lines, there is likely no severe pathology

Answer: C.

Z-line artifacts are short vertical (less than 3 cm) hyperechoic lines from the lung pleura. They represent the differences in lung pleura thickness detected during pleural sliding. Horizontal lines are a reverberation artifact from the lung pleura.

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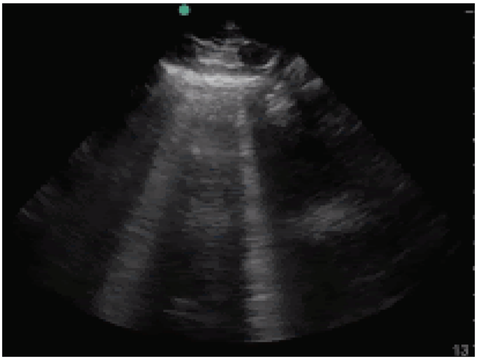
11. A 64-year-old female is sitting up in the PACU after a robotic-assisted laparoscopy. After surgery, the patient's vitals were unstable, with blood pressure of 100/70 and heart rate of 105 bpm. An ultrasound was performed to assess lung functionality. When the patient is sitting upright, where would you place the probe to help rule out a significant pneumothorax?

A. 2nd Intercostal Space; mid-clavicular
B. 5th Intercostal Space; mid-clavicular
C. 2nd Intercostal Space; mid-axillary
D. 5th Intercostal Space; mid-axillary

Answer: A.

Lung Pleura Examination Windows: Remember that a PTX will form at the highest (most anterior) point in the chest. Air typically rises to the top. Thus, if significant pneumothorax (> 30%) is present in a patient, it will be seen in most superior and anterior lobes of the lungs. The highest intercostal space among the choices is 2nd, and the most anterior location would be mid-clavicular. There would be absence of lung sliding in the context of visible A-lines and a lung point.

12. A 77-year-old female with a history of congestive heart failure and COPD presents to the ED with a productive cough and difficulty breathing for the past two weeks. A bilateral ultrasound of her reveals the below ultrasound image only in the lateral right side of the patient, with the remaining lung fields appearing normal. What is the mostly likely diagnosis?



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A. Pneumonia
B. Pulmonary edema
C. Pneumothorax
D. Pleural effusion

Answer: A.

The lung ultrasound demonstrates a significant number of B-lines suggestive of lung air-space disease. Given that this pathology is only shown at one location of the lung, regional causes of air-space disease (such as pneumonia) are more likely compared to diffuse causes of air-space disease like pulmonary edema .

13. A 37-year-old male presents to the ED on an ambulance gurney after sustaining a traumatic injury to the right side of his chest. Ultrasound of his right lung (around 3rd and 4th intercostal space/mid-clavicular line) was done with the M-mode image shown below. What is the most likely diagnosis?

A. Pleural effusion
B. Pulmonary edema
C. Pneumothorax

Answer: C.

The M-mode image shows a lack of motion of the lung pleura. This reported "bar-code" sign supports the diagnosis of a pneumothorax.

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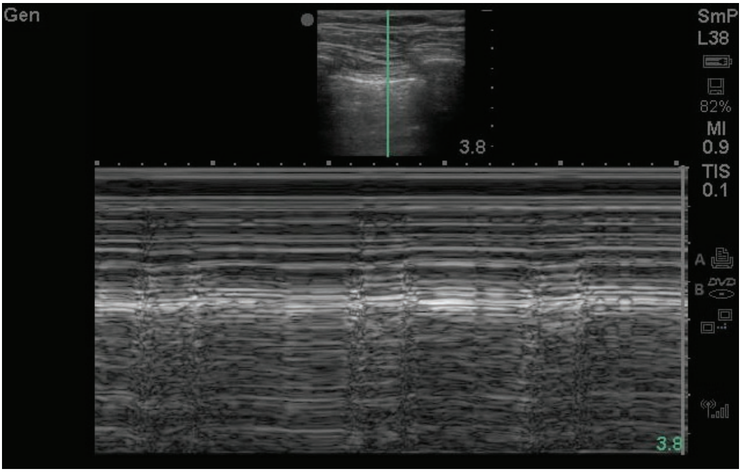
14. A worried parent brings his 7-year-old son into the ED, frantically stating the child has "a collapsed lung." The child appears well, in no acute distress, with stable vital signs. You perform a point of care ultrasound lung examination and find the following. If all lung fields have similar findings, what would you tell the father?



A. "The lung does look to be collapsed." Ask permission to perform needle decompression.
B. "I can't seem to find the ribs, did your son have a surgery?"
C. "The image shows healthy lung sliding. Lung sliding helps rule out the presence of pneumothorax in that area. ."

Answer: C.

This is an example of a healthy lung as can be seen by the "sand on the beach" sign on the M-mode image. M-mode is recording movement along the green line in between the two ribs. The "fuzziness" (the "sand") indicates movement whereas the top barcode-like lines show the superficial skin isn't moving (the water of the ocean). The fact that there is movement between the pleura shows that the pleura are touching, and thus rules out a pneumothorax in this region (it is important to note that other regions must be scanned too).

If there is a lung point present, then this is indicative of a pneumothorax. A lung point is the top of the air space separating the two layers of pleura.

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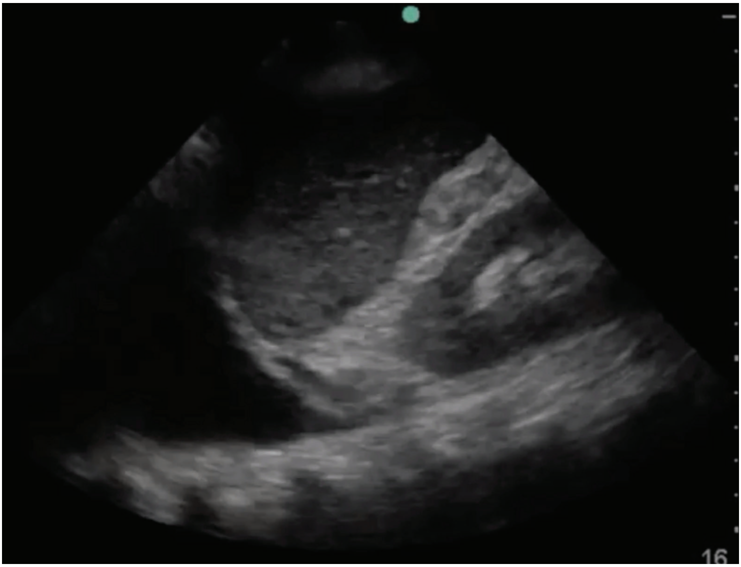
Above the lung point the pleura are touching and the lung point is where they start to separate.

15. A 72-year-old male with a three-year history of progressively worsening dyspnea on exertion finally presents to his PCP for workup. The doctor notices distended jugular veins and upon auscultation hears an S3 and a holosystolic murmur over the apex. The physician performs a point of care ultrasound lung examination and sees the following. Which pathology is shown in the image?



A. Pulmonary edema
B. Pneumothorax
C. COPD exacerbation
D. Pleural effusion

Answer: D.

In this scan, a hypoechoic space (indicating free fluid) can be seen above the diaphragm, indicating it is a pleural effusion. A pleural effusion forms secondary to increased hydrostatic and extravasation of fluid from the lung capillaries.

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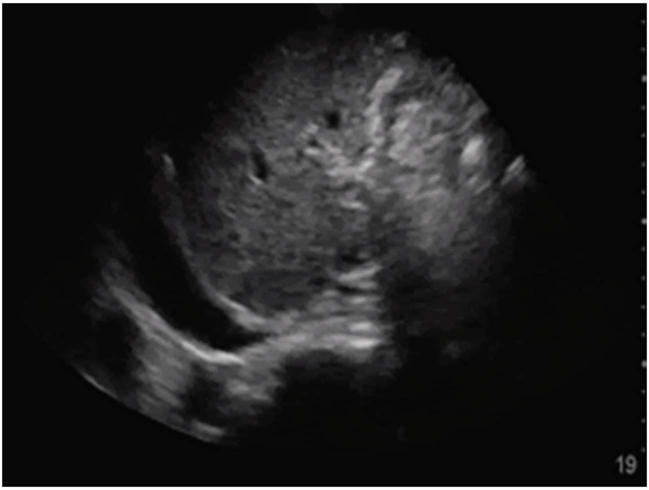
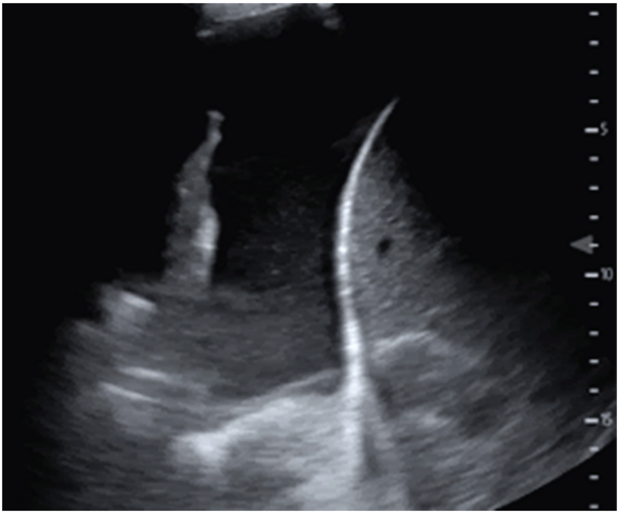
16. A 78-year-old male with a history of CHF comes to the preoperative clinic. The patient reports increased shortness of breath that worsens with exertion and laying down flat. On physical examination, there are decreased breath sounds across both lungs. To further evaluate the severity of lung disease you perform an ultrasound examination. Which image represents the greatest severity?



A.



B.

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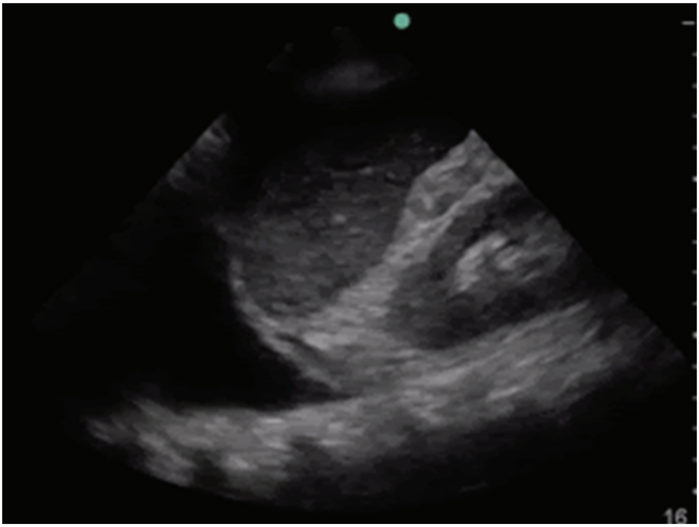
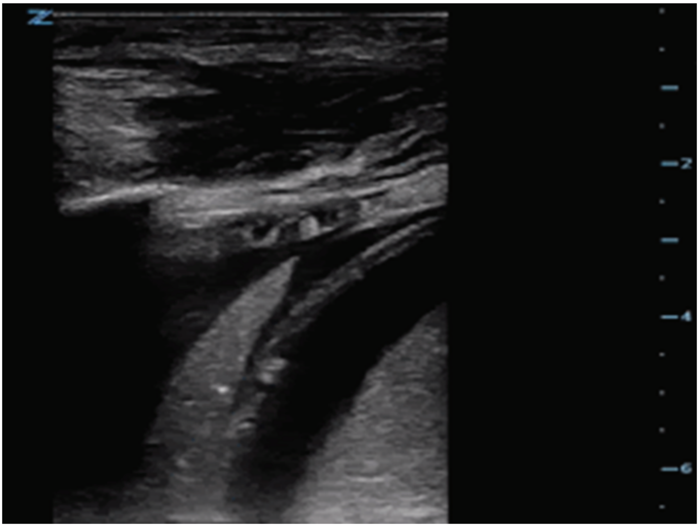


C.



D.

Answer: B.

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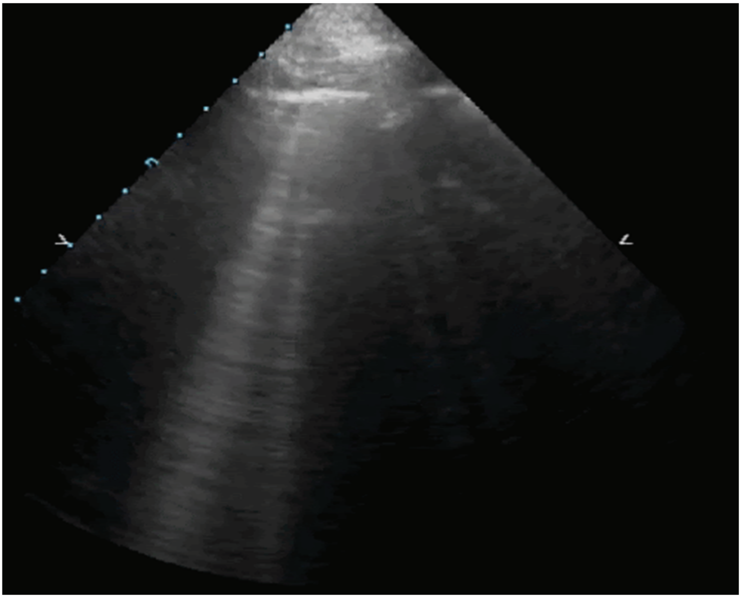
Ultrasound can help identify and quantify pleural effusions. The examination involves placing a low frequency probe in the dependent areas of the patient's lungs fields. A normal examination in this location will visualize the diaphragm (hyperechoic), abdominal structures (liver or spleen), and signs of lung aeration. In the presence of a pleural effusion, the area above the diaphragm is filled with fluid and will appear anechoic (black). A common strategy used for quantifying a pleural effusion is the determination of the widest space between the diaphragm and the visceral pleura at end expiration. A commonly used equation to estimate effusion volume from this measurement is: Vol (ml) = 16 × Diameter (mm). A space of greater than 5 cm is often used clinically as a marker for a large pleural effusion (volume >500 ml). Image B shows the large hypoechoic space indicating the largest pleural effusion.

17. A 32-year-old male presents to the ED with shortness of breath status post motor vehicle collision. You perform a pulmonary examination which includes the images below. Given the findings on ultrasound, what can you rule out?



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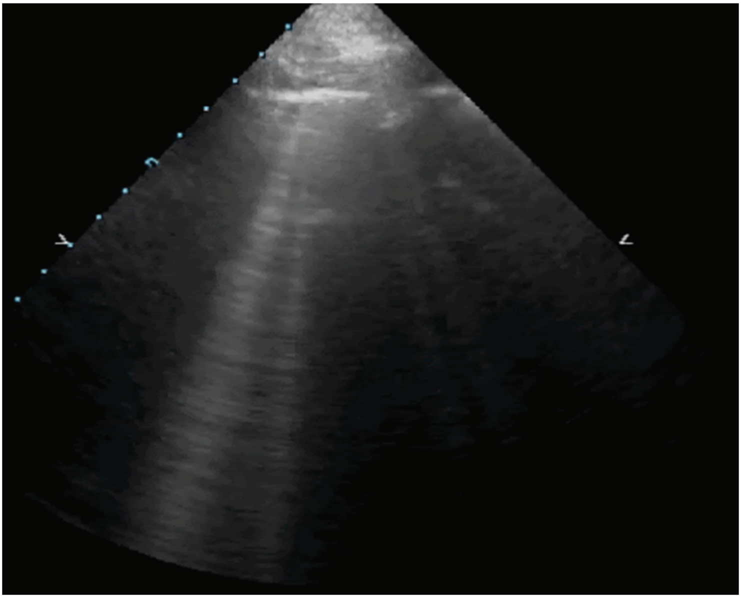
A. Pericardial effusion
B. Pneumothorax
C. Cardiac tamponade
D. Pleural effusion

Answer: B.

The presence of B-lines (seen as the laser-like projections above) rules out any diagnosis of pneumothorax in that area of the lung.

18. The ultrasound examination below suggests which of the following:



A. Pulmonary edema with B-lines
B. Normal exam with Z-lines
C. Normal exam with B-lines
D. Normal exam with A-lines

Answer: A.

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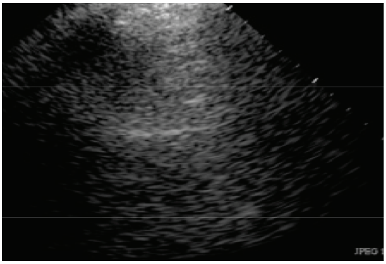
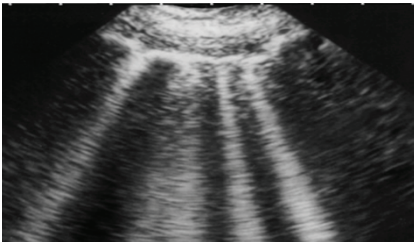
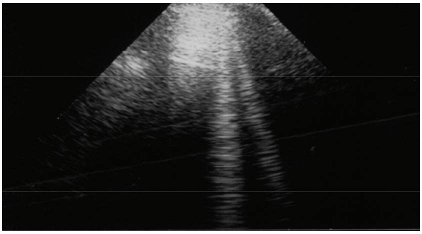
19. Which image below suggests the greatest degree of lung air-space disease?



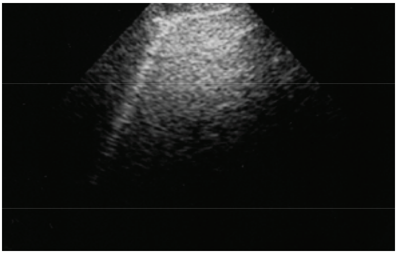
A.



B.



C.



D.

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Answer: B.

Image B represents the greatest number of B-lines, which suggests the greatest amount of air-space disease for the region of lung insonated on this examination.

20. It is straightforward to quantify the size of pneumothorax via point of care ultrasound?

A. True
B. False

Answer: B.

Point of care ultrasound is very sensitive and specific for the detection of a pneumothorax; however, it is challenging to quantify the size of the pneumothorax from routine point of care ultrasound techniques.

Abdominal/ Volume Status/ Additional Topics

1.
A. All of the following structures are retroperitoneal except?

B. Kidney
C. Inferior vena cava
C. Spleen
D. Abdominal aorta

Answer: C.

2. The diaphragm is higher on which side of the body?

A. Right
B. Left

Answer: A.

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3. To optimize a view of Morison's pouch one should have the probe?

A. RUQ of abdomen mid-clavicular line
B. LUQ of abdomen mid-clavicular line
C. RUQ of abdomen mid-axillary line
D. LUQ of abdomen mid-axillary line

Answer: C.

4. The most evidence-based strategy to determine stroke volume is to obtain VTI across which sampling area?

A. Just below mitral valve at the coaptation point
B. 2 mm proximal to the aortic valve opening (Left Ventricle Outflow Tract)
C. Just below tricuspid valve at the coaptation point
D. 2mm distal to the aortic valve

Answer: B.

5. Bladder volumes can be estimated by which formula:

A. 0.7 x (supero-inferior diameter) x TS (maximum transverse diameter) x AP (maximum anteroposterior diameter.
B. 0.5 x (supero-inferior diameter) x TS (maximum transverse diameter) x AP (maximum anteroposterior diameter.
C. 1.2 x (supero-inferior diameter) x TS (maximum transverse diameter) x AP (maximum anteroposterior diameter.
D. None of the above.

Answer: A.

6. IVC diameter should be measured when and where?

A. Should be measured on end expiration (spontaneously breathing patient) and 1 cm distal to the IVC-hepatic vein junction where the anterior and posterior walls are clearly visualized.

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B. Should be measured on end inspiration (spontaneously breathing patient) and 1 cm distal to the IVC-hepatic vein junction where the anterior and posterior walls are clearly visualized.
C. Should be measured on end expiration (spontaneously breathing patient) and 1 cm proximal to the IVC-hepatic vein junction where the anterior and posterior walls are clearly visualized.
D. None of the above.

Answer: A.

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 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 the 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.

7. Which combination of free fluid collection is correct as it pertains to the FAST ultrasound examination?

A. RUQ = Liver/Pleura Interface, LUQ = Splenorenal Interface, Pelvic = Anterior to Bladder
B. RUQ = Liver/Pleura Interface, LUQ = Splenorenal Interface, Pelvic = Inferior to Bladder

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C. RUQ = Liver/Renal Interface, LUQ = Spleen/Pleura Interface, Pelvic = Inferior to Bladder
D. RUQ = Liver/Pleura Interface, LUQ = Spleen/Pleura Interface, Pelvic = Anterior to Bladder

Answer: C.

8. Which picture shows the appropriate probe placement to obtain a view of the IVC?


A


B


C


D

Answer: D.

9. In a patient presenting with signs of circulatory insufficiency, what will a 50% change in IVC diameter to respiration indicate?

A. Hypovolemia
B. Sepsis

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C. Atrial fibrillation
D. COPD

Answer: A.

Reference: FORESIGHT Ebook Page 14.
Please note that in a patient presenting with signs of circulatory insufficiency, a 50% change in IVC diameter to respiration may indicate hypovolemia.

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.

10. An operator obtains a measurement using M-mode echocardiography of the heart in parasternal long axis view through the LV septum and anterior mitral valve leaflet. This measurement is the E-Point Septal Separation (EPSS), which the operator determines is greater than 12mm. What does this EPSS value mean?

A. The EPSS is increased, indicating a low ejection fraction
B. The EPSS is normal, indicating a normal ejection fraction
C. The EPSS is decreased, indicating a high ejection fraction

Answer: A.

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
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

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and 12 mm correlates with a low-normal EF, and any measurement above 12 mm correlates with a low EF.

11. An operator uses POCUS to help determine the volume status of the heart. What should the operator measure?

A. Left ventricular diameter
B. Right ventricular diameter
C. Left atrial diameter
D. Right atrial diameter

Answer: A.

12. The operator wants to determine whether a patient is fluid responsive by measuring the variation of velocity time integral (VTI) after positive pressure ventilation (PPV). Besides the typical location for measurement, what other structures can the operator use to measure the patient's VTI?

A. Carotid artery
B. Radial artery
C. Brachial artery
D. All of the above

Answer: D.

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 less predisposed to pathologic diseases than other cardiac valves or locations. However, new literature also supports that one may assess the variation in VTI waveforms of the radial, brachial, and femoral arteries as a marker of fluid responsiveness as well. The benefit of these locations is that they are technically easier to obtain. It is important to remember that the patient must be receiving controlled mechanical positive pressure ventilation (>7 ml of ideal body weight) and have regular cardiac rhythm to use the variation of VTI waveforms for fluid responsiveness.

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13. The operator measures the patient's VTI before and after mechanical ventilation. He notes a 2% difference in measurement. After giving the patient fluids, the operator observes an unchanged left ventricular end diastolic diameter. What does this information suggest?

A. The patient has decreased stroke volume in response to fluids
B. The patient has an increased stroke volume in response to fluids
C. The patient is not fluid responsive

Answer: C.
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 generated by pulse waveform (PW) or continuous waveform (CW) Doppler ultrasound, is called the velocity time integral (VTI). In this context, the VTI is the collection of velocities from red blood cells as they are 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 the patient is fluid responsive.

14. A 27-year-old male presents to the emergency room after a motor vehicle accident. You perform a FAST examination to determine if there is free fluid in the abdomen. Based on the image below, what can you ascertain from your examination?

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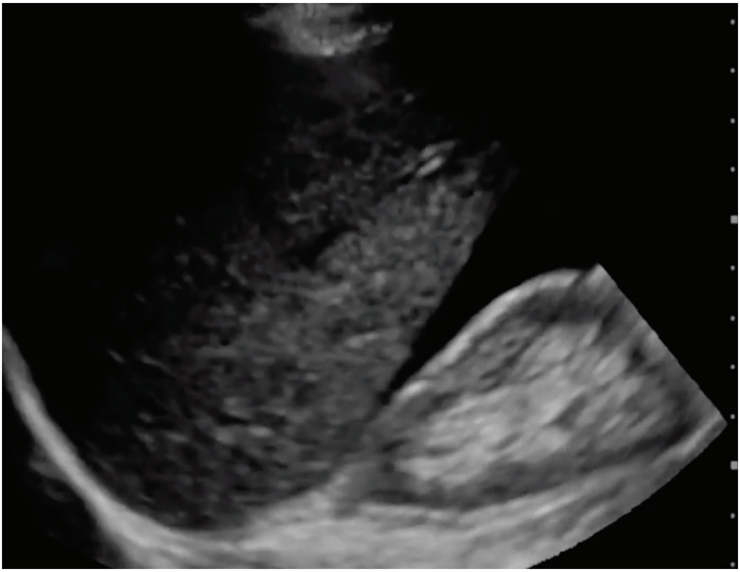

A. There is free fluid in the pouch of Douglas
B. There is free fluid in Morison’s pouch
C. There is free fluid in the pericardial space
D. There is no free fluid in this area

Answer: B

The image shows free fluid between the liver and right kidney (Morison's pouch).

15. A 32-year-old female complains of abdominal pain after giving birth two days ago. You perform a FAST examination to rule out free fluid in the abdomen. What can you surmise from the video below?

A. Free fluid surrounding the heart
B. Free fluid in the splenorenal recess
C. Free fluid in the pleural space
D. Free fluid around the pouch of Douglas

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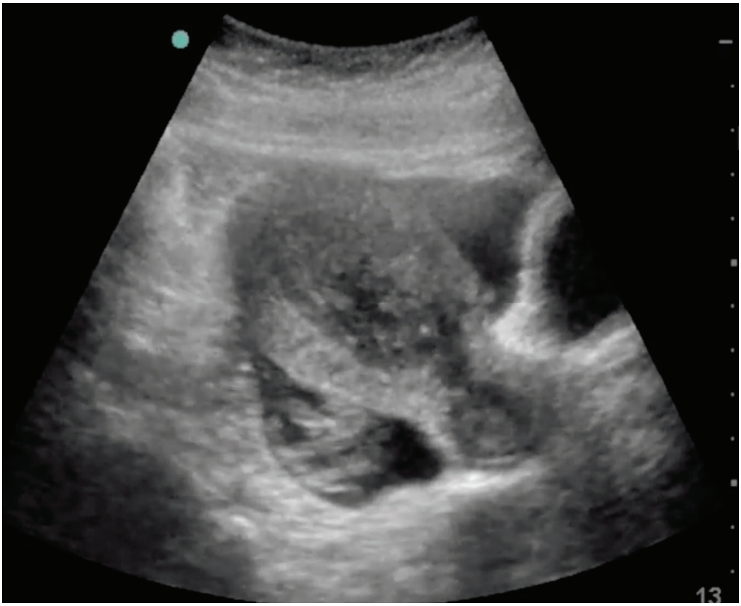

Answer: D.

The image is a Pelvic (Suprapubic) View: This view is used to assess for free fluid in the lower abdomen by scanning the most dependent area of the abdomen, which is the area behind the bladder, in between the uterus and rectum for females (pouch of Douglas). 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 (seen on the transverse view of the bladder).

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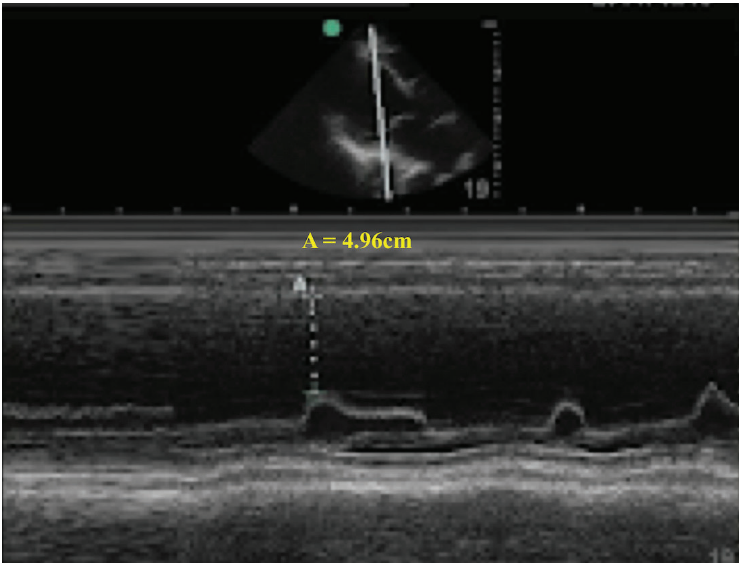
16. Measuring left ventricular end diastolic area is a good indicator of fluid responsiveness.

A. True
B. False

Answer: B.

Left ventricular end diastolic area can be used to determine volume status, as well as cardiac contractility, but is not a good indicator of fluid responsiveness.

17. Use the image below. What does this e-point septal separation suggest?



A. Decreased ejection fraction
B. Normal ejection fraction
C. Increased ejection fraction
D. Hypovolemic
E. Normovolemic
F. Hypervolemic

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Answer: A.

Decreased ejection fraction. The EPSS measurement shows 4.96 cm. Normal EPSS measurements are below 6 mm, low-normal EF correlates with EPSS of 6–12 mm, and low EF is EPSS > 12 mm.

18. Which LV end diastolic diameter suggests a normal stroke volume for a 70 kg adult male?

A. 4 cm
B. 5 cm
C. 6 cm
D. 8 cm

Answer: B.

A normal LV end diastolic diameter is around 5 cm. LV end diastolic diameter under 4 cm suggests a reduced stroke volume state.

19. How is fractional area change (FAC) calculated? EDA = end diastolic area, ESA = end systolic area.

A. (EDA-ESA)/EDA * 100%
B. (ESA-EDA)/ESA * 100%
C. EDA/ESA * 100%
D. ESA/EDA * 100%

*Answer: A. (EDA-ESA)/EDA * 100% = FAC.*

20. A 29-year-old male presents to the Emergency Department for an episode of syncope that occurred while he was out running today. The patient explains that he was running outside for three hours on a hot summer's day. Patient states that he did not drink any water today. If an ultrasound was performed on the patient's IVC, what changes would we likely see to the patient's IVC diameter during inspiration?

A. Increase by ≤ 50%
B. Increase by > 50%

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C. Decrease by > 50%
D. Decrease by ≤ 50%
E. Decrease by <50%
F. No change

Answer: C.

The patient is likely suffering from severe dehydration due to both the excessive loss of fluids (from being in hot weather and exercising) and lack of fluid intake. What we would likely see when he inspires would be a large decrease in IVC diameter (greater than 50%). Inspiration leads to a decrease in intrathoracic pressure (negative pressure) and RA filling improves. The negative intrathoracic pressure pulls blood from the IVC into the RA increasing preload while decreasing the volume in the IVC. (how much depends on the patient's fluid body status).

21. A student is reviewing key landmarks to differentiate the IVC from the abdominal aorta during abdominal ultrasound. Which description is most consistent with the image of the IVC?

A. A hypoechoic region lying to the patient’s right compared to their abdominal aorta, surrounded by a hyperechoic region
B. A hypoechoic region lying to the patient’s left compared to their abdominal aorta, surrounded by a hyperechoic region

Answer: A.

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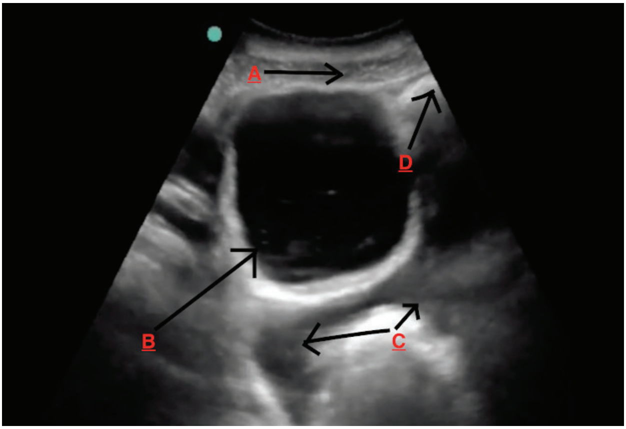
22. A 19-year-old male was sipping lemonade and laying down underneath the shade of a tree on a hot summer day when a tree branch fell onto his lower abdomen. The physician in the ED performs a FAST examination and finds the following in the suprapubic region. Which letter represents extravasated fluid?



A.
B.
C.
D.

Answer: C.

The sign of extravasated blood is fluid beneath the bladder creating the "bowtie sign" where there are two small triangles that are connected under the bladder. This fluid can be seen in the above image. Choice A and D are superficial tissue; choice B, the hypoechoic fluid is urine within the bladder.

23. In a subclavian vein catheter insertion, what techniques should be done before sterile prep?

A. Trendelenberg positioning
B. Roll placed under scapula
C. Ipsilateral arm traction
D. Ultrasound visual of subclavian vein
E. All of the above

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Answer: E.

Trendelenburg position will help make the vein bigger, a roll under the scapula will help make the clavicle more obvious, and ipsilateral arm traction will help give a more direct alignment for easier venous access. Visualization with ultrasound can help to see if these maneuvers helped with subclavian vein access. Also, one can use the ultrasound to access the vein more laterally, decreasing the risk for a pneumothorax.

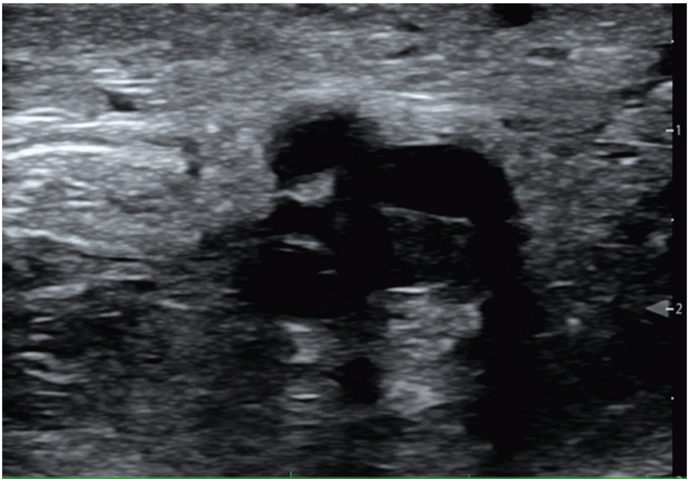
24. Using ultrasound, how can one rule out thrombosis?

A. Assess compressibility using only minimal pressure
B. Follow vein inferiorly to visually check for thrombosis
C. Use color Doppler to assess flow pattern
D. All of the above

Answer: D.

If the vein collapses with only minimal pressure, then there is little chance of thrombosis. A thrombosis is likely if a large force is required to collapse the vein.

25. What is the problem in the image below?



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A. Artery dissection
B. Venous clot
C. Venous extravasation
D. Normal vascular structures

Answer: B.

Clotted veins do not collapse greatly under light compression. They would also show minimal color flow transition with color Doppler. Actual visualization of the clot inside the vessel (hyperechoic to blood) is also possible.

26. What type of probe is needed when trying to ultrasound the eye for intracranial pressure assessment?

A. Linear probe
B. Phased array probe
C. Curved array probe
D. Micro convex probe

Answer: A.

27. While using Point of Care ultrasound to examine both lungs after endotracheal tube placement, you find that the right side has an absence of lung sliding and you are not able to visualize tracheal dilation with cuff inflation. What does this most likely mean?

A. Presence of bilateral ventilation
B. Left mainstem intubation
C. Right mainstem intubation
D. Esophageal intubation

Answer: B.

One common sonographic sign of normal lung ventilation is a back and forth sliding of the parietal and visceral lung pleura, which is referred to as the lung sliding sign. Hence lack of lung sliding may mean improper aeration to that side (possible from a mainstem intubation). Examination

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for tracheal dilation with endotracheal tube cuff inflation can help identify improper endotracheal tube positioning.

28. Before surgery, you decide to use ultrasound to assess for possible aspiration risks. Which anatomical area is of most interest to determine the presence of gastric contents?

A. Pyloric canal
B. Gastric antrum
C. Body of the stomach

Answer: B.

The area of imaging is the gastric/pyloric antrum, this is the section of the stomach that has shown a relationship to gastric volume. Identification of gastric antrum can be obtained by ensuring relative anatomy such as the abdominal aorta and superior mesenteric vessels are in view.

29. What position is the most optimal for imaging of the gastric antrum?

A. Trendelenburg at 15 degrees.
B. Left lateral decubitus position.
C. Right lateral decubitus position.

Answer: C.

The patient should be positioned in the right lateral decubitus position to ensure that the gastric antrum is the most dependent area of the stomach.

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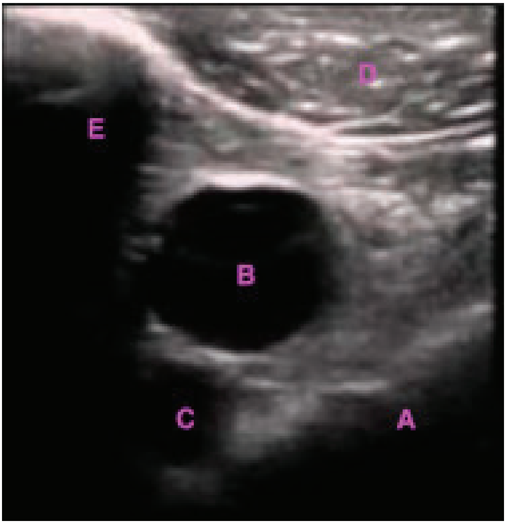
30. An 80-year-old male is brought into the ED for cough and SOB. The patient is bedridden and is unable to take care of himself. It is determined by the Emergency Medicine Physician that a central line needs to be placed in the patient's right subclavian. The rotating student is asked to place the line. In which structure should the student be trying to place the catheter?



A.
B.
C.
D.
E.

Answer: B.

The structure labeled B is the subclavian vein. The subclavian artery is represented as the structure labeled C. Note that the subclavian vein is more superficial compared with the subclavian artery. Structure E is the clavicle. Structure A is located near to the lung pleura. Structure D appears to be muscle.

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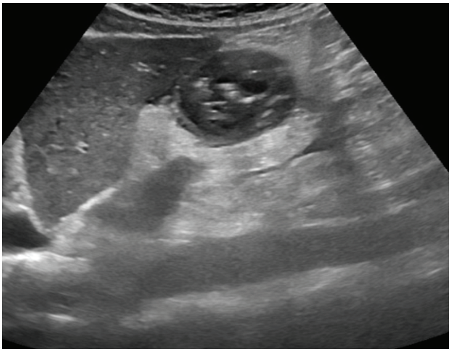
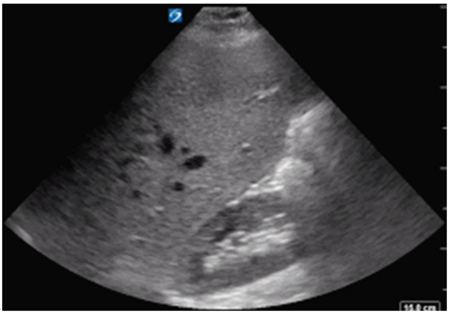
31. An 86-year-old male with dementia presents to the ED for a ground level fall after being knocked over by the neighbor's dog. He denies any head trauma or loss of consciousness and is hemodynamically stable with no signs of bleeding. An enthusiastic orthopedic surgeon wants to take him to surgery for a possible broken hip. Of the following POCUS scans performed by anesthesia in pre-op, which would you find most concerning?

A. 

B. 

C. 

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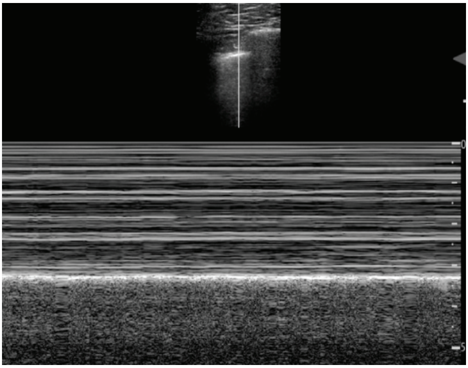
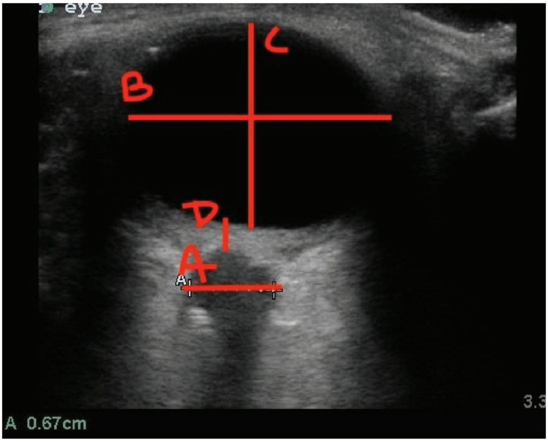


D.

Answer: B.

This image shows a full stomach, seen by the large hypoechoic space with heterogeneous content surrounded by hyperechoic surroundings. The other options are normal findings; A is a normal heart, seen in PLAX view, C is a normal RUQ abdominal ultrasound, and D is a normal M-mode image of positive lung sliding.

32. A 76-year-old male s/p head trauma is being evaluated for elevated intracranial pressure. Where on the ultrasound image should one measure the optic nerve sheath to estimate intracranial pressure?



Answer: A.

This is measuring the optic nerve sheath diameter (ONSD). The optic nerve is seen as a hypoechoic structure posterior to the orbit of the eye. ONSD is measured 3.0 mm posterior to the retina and is normally <5 mm across in adults. The image above shows an ONSD of 6.7 mm indicating increased ICP.

33. A second year medical student is practicing airway ultrasound. Placing the ultrasound probe on her trachea, the following image is obtained. What structure is within the circled region?

A. Internal jugular vein
B. Thyroid
C. Esophagus
D. Internal carotid artery

Answer: C.

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34. In evaluating a patient, which pathology is the most challenging to assess via point of care ultrasound?

A. Intraabdominal free fluid
B. Hypovolemia
C. Pneumothorax
D. Pulmonary reactivity (bronchospasm)
E. Pleural effusion
F. Cardiac valvular disease
G. Decreased cardiac systolic function
H. Gastric contents
I. Deep venous thrombosis
J. Elevated intracranial pressure

Answer: D.

While point of care ultrasound is useful to evaluate many different pathologies, the detection of airway reactivity such as bronchospasm is a challenge to assess via ultrasound.

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