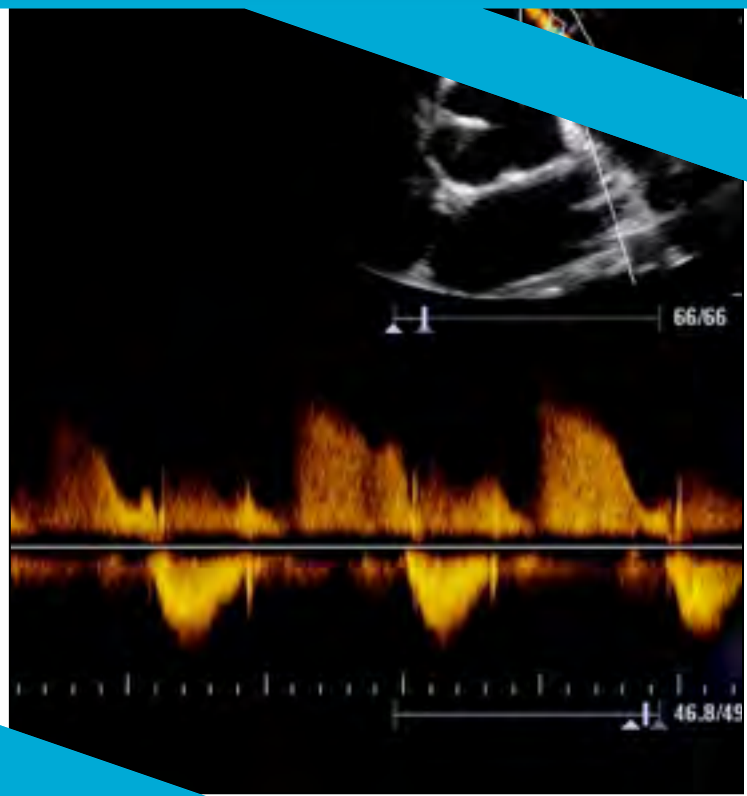
Introduction to Bedside Ultrasound



M. DAWSON
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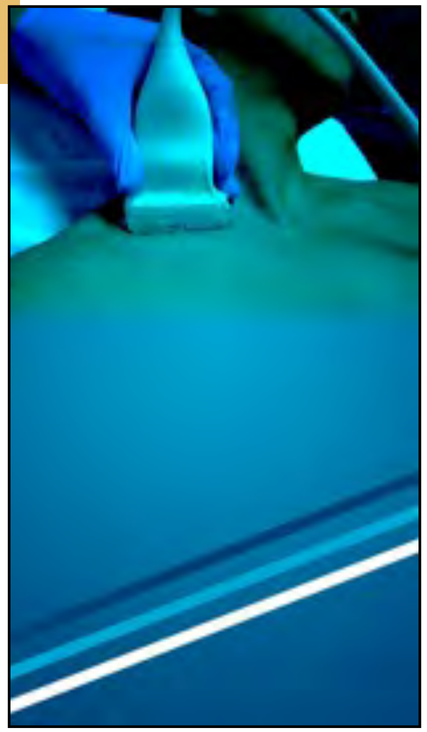
Introduction



Hello and welcome to the Introduction to Bedside Ultrasound digital textbook. This project is the product of an exceptional amount of hard work from a lot of people over a long period of time. We are super excited about this book, but let's face it, we're always super excited. Over the last couple of years, we've worked on several projects, such as The Ultrasound Podcast, The One Minute Ultrasound iPhone App, Castlefest, and Sonocloud. Of all these endeavors, we're probably the most proud of this book because of all the incredible people we were able to collaborate with in its production. The authors are people who we sincerely look up to in the ultrasound world, and we're honored to be able to work with these legends.

It takes a true team to produce an interactive, digital textbook, and working with everyone involved has been amazingly rewarding. We want to especially thank our technical director and designer, Jody, our editor, Brittany, and medical illustrator, Ryan. This certainly wouldn't have been possible without them.

Lastly, we'd like to say thanks to you, the reader, for downloading the book. We hope that it enhances your medical practice and makes a difference in the lives and care of your patients. Now, before you get started, please click above to hear an audio message from us, and, most importantly, to learn how you can help make this book even more awesome.

Chapter 1

FAST/EFAST

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SECTION 1

Introduction

SUMMARY

The FAST exam was first used in trauma in the 1970s

FAST is essential in the Advanced Trauma Life Support (ATLS) protocol

FAST has replaced DPL as the diagnostic modality of choice in evaluating for abdominal hemorrhage

A common occurrence in the emergency department is the patient who has trauma that is not readily apparent on the initial physical exam. Further, the presence of distracting injuries, altered mental status, or intoxication may significantly reduce the sensitivity and specificity of physical examination findings.[1] Due to the inadequacies of the physical examination in the trauma patient, further diagnostic studies are indicated in both blunt and penetrating trauma. Obviously, a hypotensive patient with penetrating abdominal trauma requires an emergent exploratory laparotomy (ex-lap); however, a patient with blunt trauma is another matter. In the past, Diagnostic Peritoneal Lavage (DPL) was employed as a method of determining if intra-abdominal bleeding was occurring, and carried a sensitivity of 87-96% for intraperitoneal hemorrhage.[2-4] It should be noted that up to one third of trauma patients with a positive DPL will have a negative exploratory laparotomy, as there is a high false positive rate with DPL.[5] As little as 20mL of blood mixed with the standard liter of peritoneal lavage fluid will result in a positive DPL.[6] In addition, DPL may carry a higher false positive rate if pelvic fractures are present due to accidental sampling of a retroperitoneal hematoma.[7-9]

In the last 30 years, ultrasound has emerged as an important diagnostic modality in trauma patients. German and Japanese physicians have reportedly been using ultrasound in this setting since the early 1970s[10]; however, it did not gain favor in the United States until the 1980s.[11] Currently, ultrasound and the Focused Assessment with Sonography in Trauma (FAST) exam[12] are employed as part of the Advanced Trauma Life Support (ATLS) protocol developed by the American College of Surgeons.

SECTION 2

FAST Exam

MOVIE 1.1 - FAST How-to

SUMMARY

FAST can be performed in less than 3 min.

Views include the RUQ, Subxiphoid, LUQ, and Pelvic.

FAST exam can before performed with the curvelinear or the phased array probe.

INDICATIONS FOR FAST EXAM

FAST is the imaging modality of choice in the ATLS protocol, performed immediately after the primary survey. The purpose of the FAST is to ultrasonographically evaluate the pericardial and peritoneal spfaces for the presence or absence of blood. In essence, the FAST exam has replaced the DPL in this role. It is less invasive, safe in pregnancy, and does not carry any of the complications associated with DPL. The FAST exam has a sensitivity range of 73-88% and specificity of 98-100%, depending on the operator.[13-15] In the hands of an experienced operator, the specificity approaches 100%. However, because of the range of accuracy, it must be understood that the FAST exam is a screening test that helps determine if the unstable patient has an intra-abdominal injury requiring an emergent exploratory laparotomy. It assesses if there is fluid in the abdomen, most likely blood in the setting of trauma, but the FAST cannot directly assess organs or hollow viscus. This results in the high specificity and slightly lower sensitivity because FAST indirectly evaluates organs and bowel. Ultrasound cannot replace computed tomography (CT), which has much better accuracy with solid organ and bowel injuries. The advantage of the FAST is that it can be reliably performed in fewer than 3 mins,[16] and so it is ideal for decision making during a trauma situation. If a patient is unstable and has a positive FAST, an emergent ex-lap is required. An unstable patient with a negative FAST should prompt a search for other causes of hypotension.

The FAST exam was initially designed for use in the trauma setting; however, there are other situations in which the FAST exam is useful.

Specific indications for a FAST exam include:

- Blunt and penetrating cardiac trauma: early bedside ultrasound is indicated, and early diagnosis of a pericardial effusion significantly improves mortality in both penetrating[17] and blunt[18] cardiac trauma

- Blunt abdominal trauma

- Penetrating abdominal trauma: although the FAST exam was initially designed for blunt abdominal trauma, it appears to be useful in penetrating trauma. FAST has a specificity of 94% and sensitivity of 46% in this setting,[19] and so it is still helpful in determining management. A positive result is a strong predictor that the patient requires an ex-lap.[20-21] The low sensitivity highlights that ultrasound cannot directly evaluate bowel and organ injury, which are most likely in penetrating trauma.

- Ectopic pregnancy: a FAST exam should be performed on every unstable patient with a possible ectopic pregnancy. Free fluid in the abdomen is highly suggestive of an ectopic. A moderate amount of free pelvic fluid has an 86% likelihood of being from an ectopic, and hepatorenal free fluid carried nearly a 100% risk of ectopic in one study.[22] In fact, free fluid may be the only abnormal sonographic finding in roughly 15% of ectopic pregnancies.[23] In a study of 242 women with suspected ectopic pregnancy, emergency medicine physicians identified 10 patients with fluid in Morison's pouch on FAST, 9 of which went to the OR. This resulted in a positive likelihood ratio of 112.[24] Performing a FAST exam can significantly reduce the time to diagnosis and treatment of ectopic pregnancy.[25]

- A FAST exam is indicated in any clinical situation in which a clinician is concerned for intra-abdominal free fluid or hemorrhage. This could include liver failure with ascites, a ruptured ovarian cyst, undifferentiated hypotension, etc. (See RUSH Chapter).

- Ultrasound is indicated in blunt or penetrating chest trauma in order to evaluate for hemo- or pneumothorax. Evaluation of the thorax is part of the extended FAST (EFAST), and will be further discussed at the end of the chapter.

Anatomical Considerations

The FAST exam is performed with the patient lying supine. In this anatomic position, the hepatorenal space (Morison's pouch), splenorenal recess, and pelvis are the most dependent portions of the peritoneal cavity. Any fluid present will most likely accumulate first in Morison's pouch, with any overflow travelling down the right paracolic gutter into the rectovesicular space in males and recto-uterine space (Pouch of Douglas) in females.[26] Similarly, fluid in the splenorenal recess may overflow and travel down the left paracolic gutter into the pelvis or over to Morison's pouch. The FAST exam is completed by imaging these three areas of the abdomen for free fluid and obtaining a subcostal view of the heart to evaluate for a pericar-

GALLERY 1.1 Four Views of Fast Exam

Morison's Pouch

dial effusion. Fluid will appear as a black stripe within the image. Ultrasound can reliably detect 200mL of fluid in the peritoneum,[27] with some evidence showing that as little as 100mL can be detected depending on the operator.[28] There is some evidence that smaller amounts of fluid can be reliably detected if the patient is placed in the Trendelenburg position.[29]

Probe Selection

The 4 views of the FAST exam: Morison's Pouch (RUQ), the splenorenal recess (LUQ), the pelvis (suprapubic area) and the pericardium (subxiphoid)(Gallery 1.1).

Probe Selection: The 3.5MHZ phased array probe can be used, as the transducer can fit into an intercostal space and some feel that images may be more easily obtained without an obscuring rib shadow. A curvilinear probe may also be used, and will carry its own advantages and disadvantages. The advantage is that a wider and clearer image will be obtained, as well as better tissue penetration, but the likelihood of an obscuring rib shadow is higher.

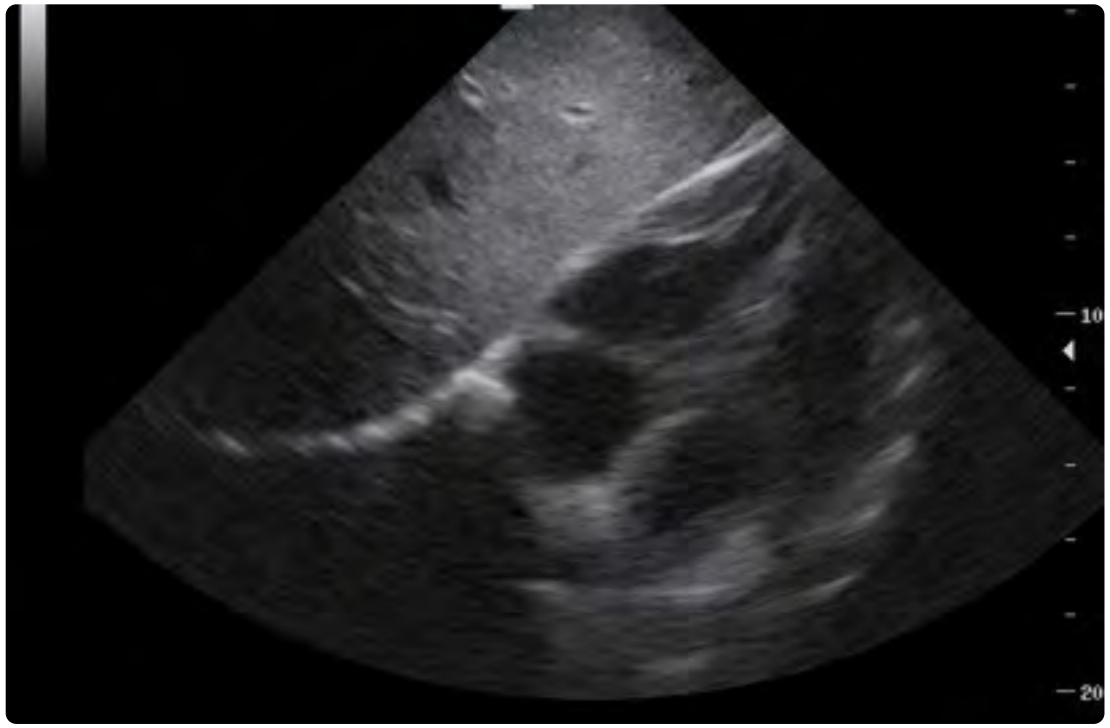
Ultrasound Views and Normal/Abnormal Findings

Pericardial View

The subxiphoid view is obtained by placing the probe just inferior to the xiphoid and directing it towards the patient's head. The probe marker should be aiming towards the patient's right side. Occasionally, the probe may need to be directed towards the patient's left shoulder.

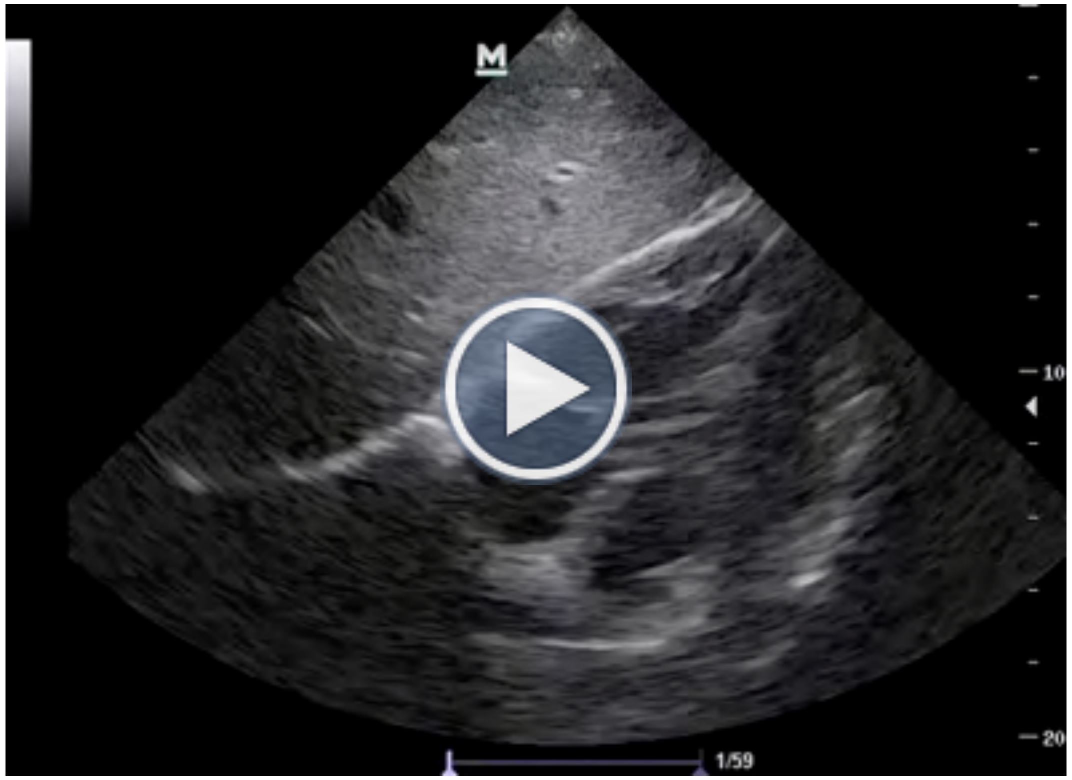
GALLERY 1.2 Pericardial View

GALLERY 1.3 All Four Chambers



The liver is used as the acoustic window for this image, thus the probe may need to be slightly to the right of the patient's xiphoid. It is important to flatten the probe down so that it is roughly flat on the abdominal wall. To do this, the probe is held with a pincer grasp so

MOVIE 1.2 - Normal subxiphoid view



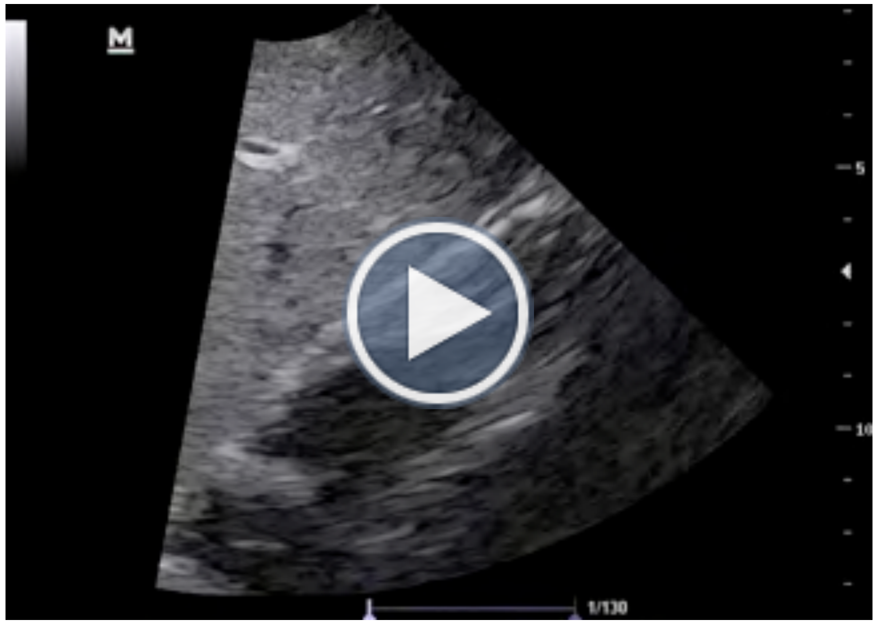
that the operator's hand does not interfere with flattening the probe. (Gallery 1.2)

The resulting image should be a coronal section of the heart in which all 4 chambers are visualized. (Gallery 1.3 and Movie 1.2)

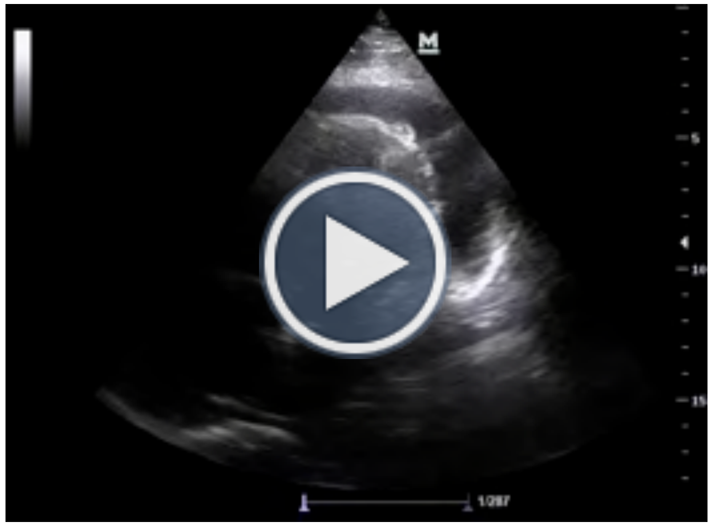
This view can be used to assess chamber size and global cardiac function; however, the main point of interest is to evaluate the pericardium for evidence of effusion.

A normal pericardium should consist of a single hyperechoic (white) line surrounding the heart. (Movie 1.3) A pericardial effusion is present if fluid accumulates within the potential space between the pericardium and the cardiac muscle. On ultrasound, this will appear as a black (anechoic) stripe. (Movie 1.4)

MOVIE 1.3 - Normal pericardium



MOVIE 1.4 - Pericardial effusion



The most feared complication of a pericardial effusion is tamponade, which may develop depending on the amount of fluid and rate of accumulation. Effusions may be acute or chronic, but must be assumed acute in the setting of trauma and hypotension. A small amount of fluid (50-100cc) may cause tamponade if it accumulates rapidly enough.[30] Recall that tamponade physiology occurs if the pressure in the pericardial sac exceeds the right atrial or ventricular filling pressures. If this occurs, the cardiac chambers are unable to fill, and so ejection fraction and cardiac output are reduced. Clinically this is manifested as JVD, tachycardia, hypotension, muffled heart sounds, etc. There are specific findings on ultrasound, such as right atrium or right ventricular collapse, indicative of tamponade physiology (Link to Cardiac Chapter). However, this assessment can be challenging.

MOVIE 1.5 Tamponade with RA Collapse

MOVIE 1.6 Tamponade with RV Collapse

GALLERY 1.4 - RUQ view

The probe should be placed in an oblique angle, such that it will fit into an intercostal space, with the probe marker pointing caudally towards the posterior right axilla.

In the trauma setting, if a patient is hemodynamically unstable and has a pericardial effusion on ultrasound, the patient must be presumed to have cardiac tamponade until proven otherwise.

Morison's Pouch (RUQ View)

The probe is placed at the mid-axillary line between the 8th and 11th ribs. The probe should be placed in an oblique angle, such that it will fit into an intercostal space, with the probe marker pointing cephalad towards the posterior right axilla. The resulting image should include the liver and right kidney interface and superior kidney and diaphragm interface. (Gallery 1.4)

<u>US appearance of normal FAST</u>

The point of interest in this image (Gallery 1.5) is the interface between the liver-kidney and between the liver-diaphragm. The liver and kidney interface represents Morison's Pouch. Morison's Pouch is a potential space, and so on a normal FAST exam, it should not contain any fluid. If fluid were to accumulate within Morison's Pouch, a black stripe would be visualized, appearing to separate the interface between the liver and kidney. The length (in cm) of the anechoic stripe in Morison's Pouch may correlate with the volume of fluid within the peritoneum. A 0.5cm stripe corresponds with roughly 500cc fluid.[10] A 1.0cm stripe correlates with 1000cc fluid.[31] Gallery 1.5, image 3, shows roughly 500-1000cc fluid in Morison's Pouch. A positive FAST can also occur if there is fluid above the liver and under the diaphragm. In the following image (Gallery 1.5), the liver and hyperechoic diaphragm can be seen with a thin stripe of black fluid separating the two. (Movie 1.7)

Splenorenal Recess (LUQ View)

This view is often the most difficult view to obtain during the FAST exam. In the RUQ view, the liver acts as a large acoustic window. In the LUQ, the spleen is much smaller and so provides a smaller window. The spleen is a very posterior structure, thus the best approach to obtain a view is to place the probe at the posterior axillary line. This is often described as the operator placing their knuckles on the bed, implying a more posterior approach. In this fashion the stomach is avoided and the posterior spleen is used as an acoustic window to view the kidney. The next step is to lower the sensing end of the

GALLERY 1.5

The liver and kidney interface represents Morison's Pouch.

MOVIE 1.7 - If fluid were to accumulate within Morison's Pouch, a black stripe would be visualized.

GALLERY 1.6 - Obtaining LUQ View

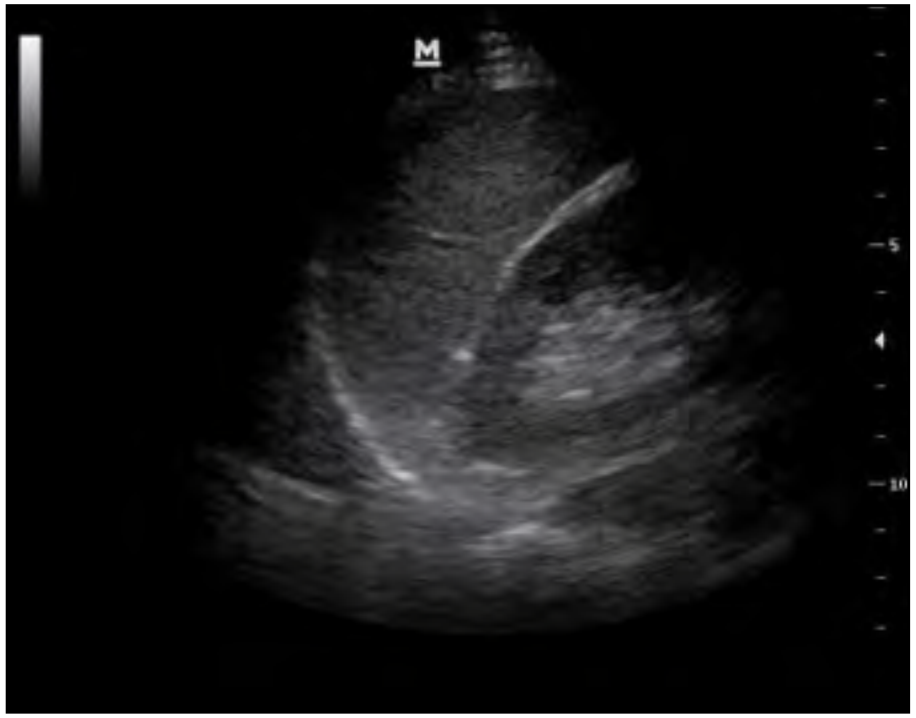
To obtain the LUQ window the operator should start with the hand on the bed.

probe down until it comes into contact with the patient. (Gallery 1.6)

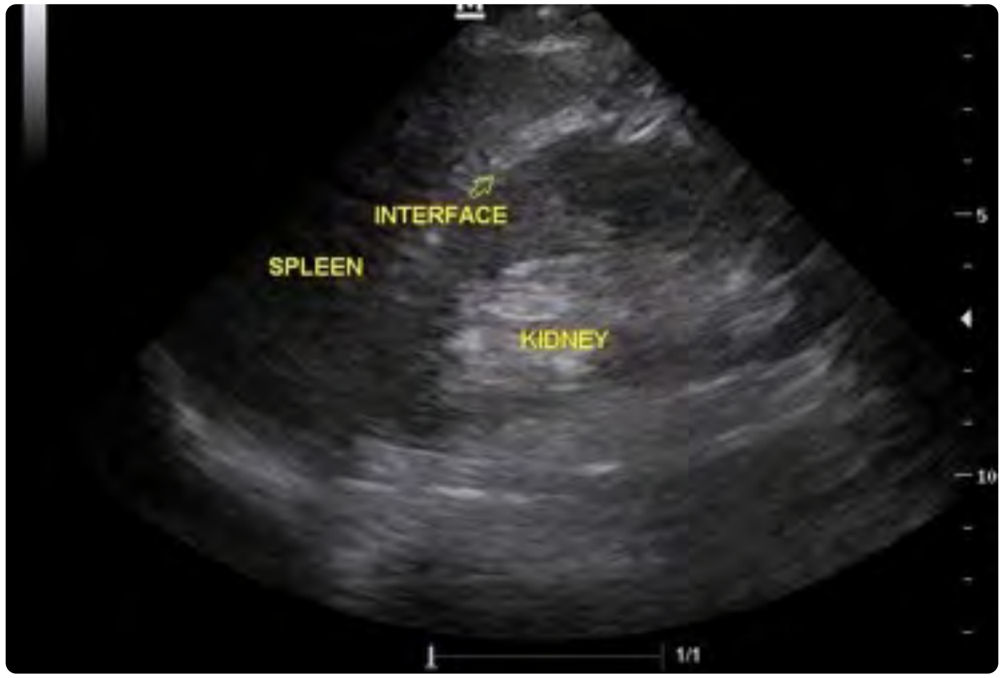
The result is that the transducer will come into contact with the patient at the posterior axillary line, at the 6^{th}-9^{th} rib interspaces. The probe may be rotated slightly clockwise so that the probe fits obliquely within a rib interspace.

In this position, the probe will be lined up through the spleen and kidney to obtain the necessary image. Once properly aligned, the ultrasound view should contain diaphragm, spleen and left kidney. If these are not visible, the probe should be kept in the same alignment, and with the scanning hand still touching the gurney, move the probe caudally up 1-2 rib interspaces or have the patient inspire. The anatomy of a normal LUQ view will appear as:

IMAGE 1.1 - Normal RUQ View



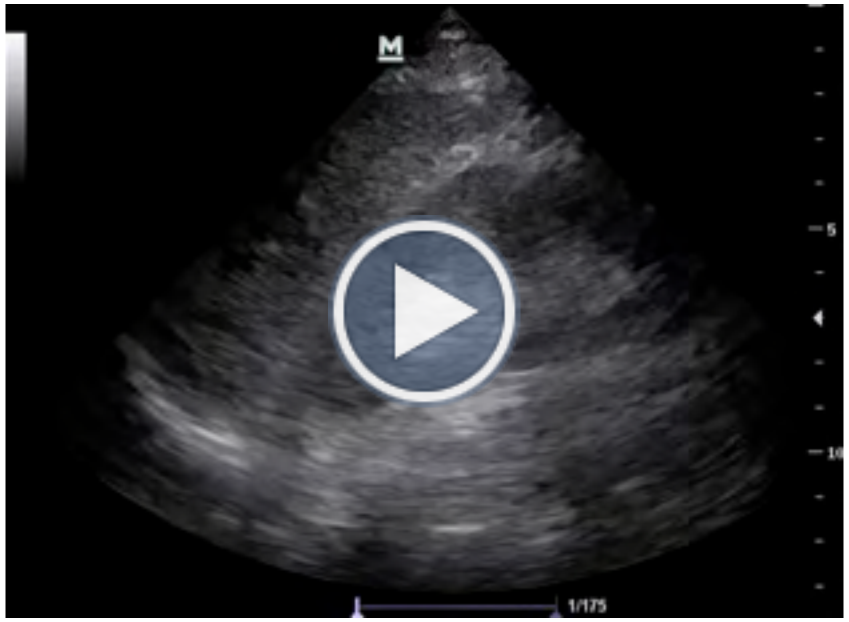
GALLERY 1.7



In the normal FAST, the spleen-renal and spleen-diaphragm interfaces will both be flush without an anechoic stripe.

One Minute Ultrasound FAST Demonstration

MOVIE 1.8 - Normal FAST



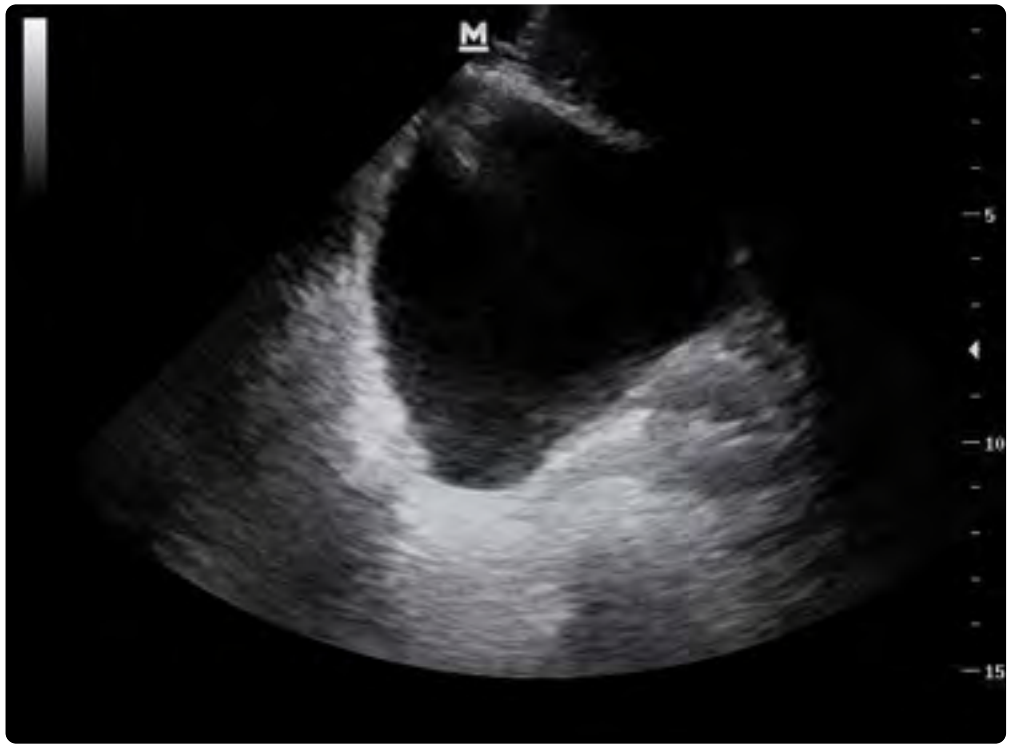
MOVIE 1.9 - Positive LUQ view

The point of interest in the LUQ is the area surrounding the spleen. Fluid may accumulate between the spleen and kidney or between the spleen and diaphragm. In the normal FAST (Movie 1.8), the spleen-renal and spleen-diaphragm interfaces will both be flush without an anechoic stripe. If fluid is present, the interfaces will be widened, and a black stripe of fluid will separate the spleen and kidney or the spleen and diaphragm. (Gallery 1.7 and Movie 1.9)

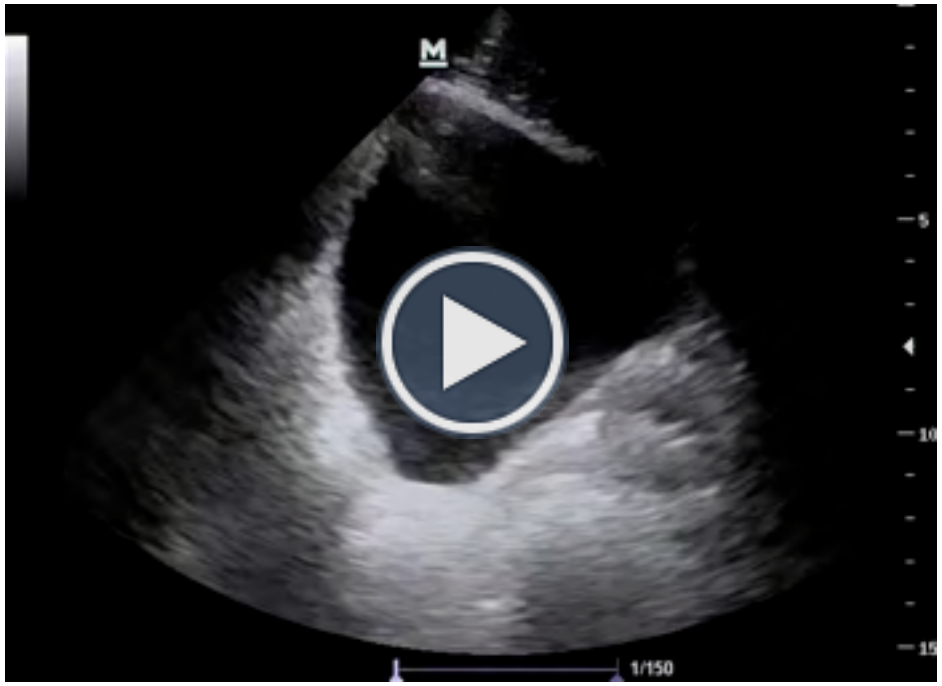
GALLERY 1.8 - Pelvic View

The probe is placed 2cm superior to the symphysis pubis, at midline, with the probe marker pointing towards the patient's head.

GALLERY 1.9 - Male anatomy - Sagittal



MOVIE 1.10 - Male Anatomy - Sagittal



Pelvic Views

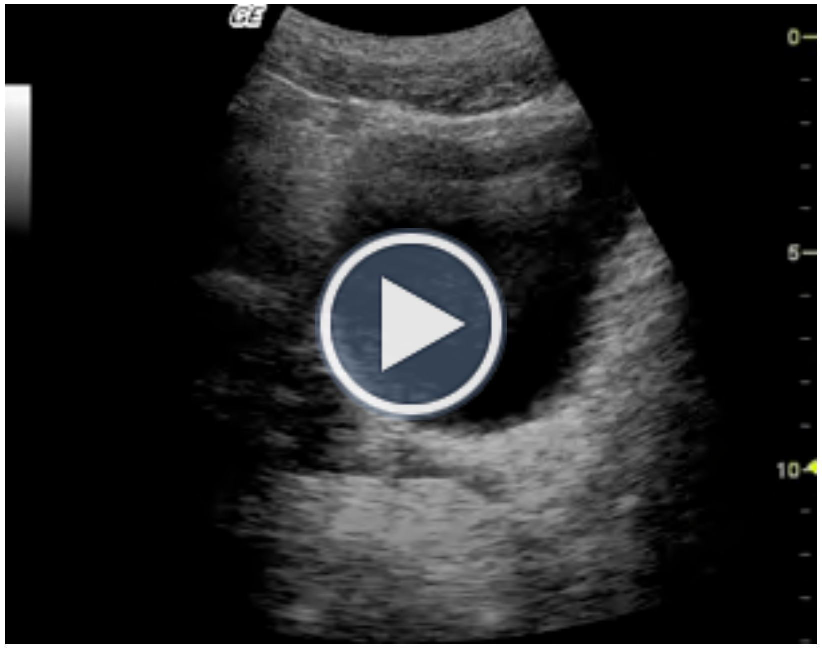
Typically this view is the easiest to obtain in the FAST, and will evaluate for fluid in the pelvis. Imaging the pelvis is different from the other views of the FAST in that the pelvis is imaged in 2 different planes. To obtain the longitudinal view, the probe is placed 2cm superior to the symphysis pubis, at midline, with the probe marker pointing towards the patient's head. (Gallery 1.8) Notice that the prostate is at the caudal end of the bladder. (Gallery 1.9 and Movie 1.10) The prostate is an extra-peritoneal organ, and so its location demarcates the end of the inferior peritoneum.

In the male, free fluid will collect posterior and superior to the bladder in the rectovesicular space. Because the prostate demarcates the inferior peritoneum, fluid will accumulate superior to it and the bladder. In the following, (Movie 1.11) note that the black peritoneal fluid begins at the superior bladder and tracks down to the prostate.

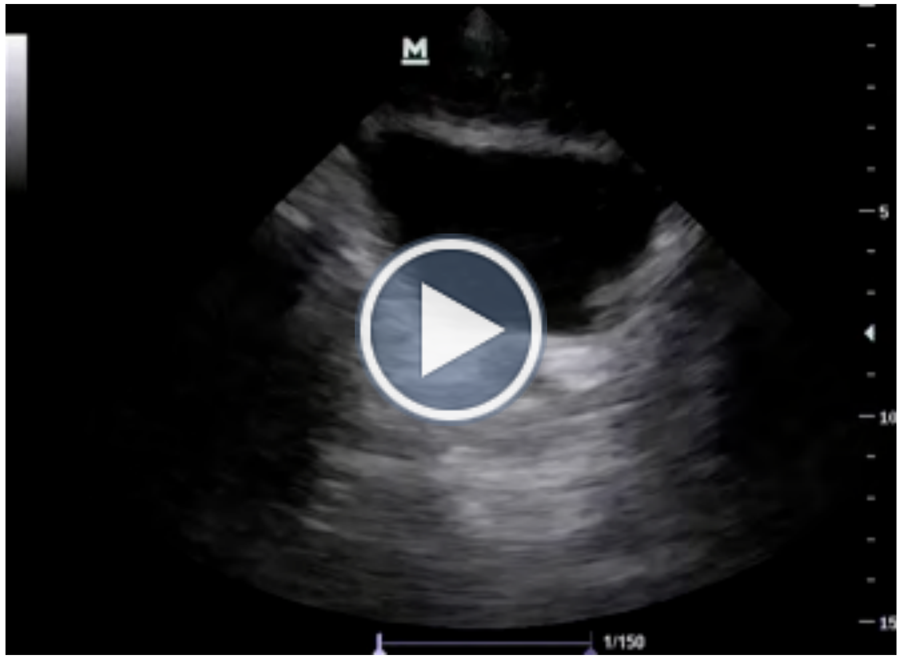
Gallery 1.10

To obtain the transverse view, the probe marker is simply turned 90 counterclockwise and oriented toward the patient's right.

Movie 1.11 - Note that the black peritoneal fluid begins at the superior bladder and tracks down to the prostate.



Movie 1.12



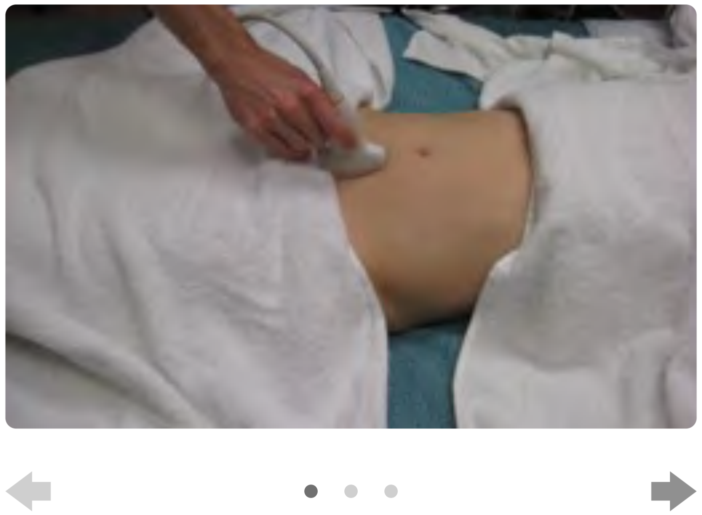
The probe is then rocked cranially so that the prostate is no longer seen and the rectovesicular space behind the bladder can be imaged.

To obtain the transverse view, the probe marker is simply turned 90° counterclockwise and oriented toward the patient's right. (Gallery 1.10)

One pitfall with imaging in the transverse plane in the male is that the sonographer may angle the probe too far caudally (towards the feet) and image the bladder and prostate. As the prostate is an extra-peritoneal organ, the peritoneum is not being imaged, and so the probe must be angled more cranially in order to assess for intraperitoneal fluid. In the following video, note that the bladder and prostate are imaged initially, and the probe is then rocked cranially so that the prostate is no longer seen and the rectovesicular space behind the bladder can be imaged. (Movie 1.12)

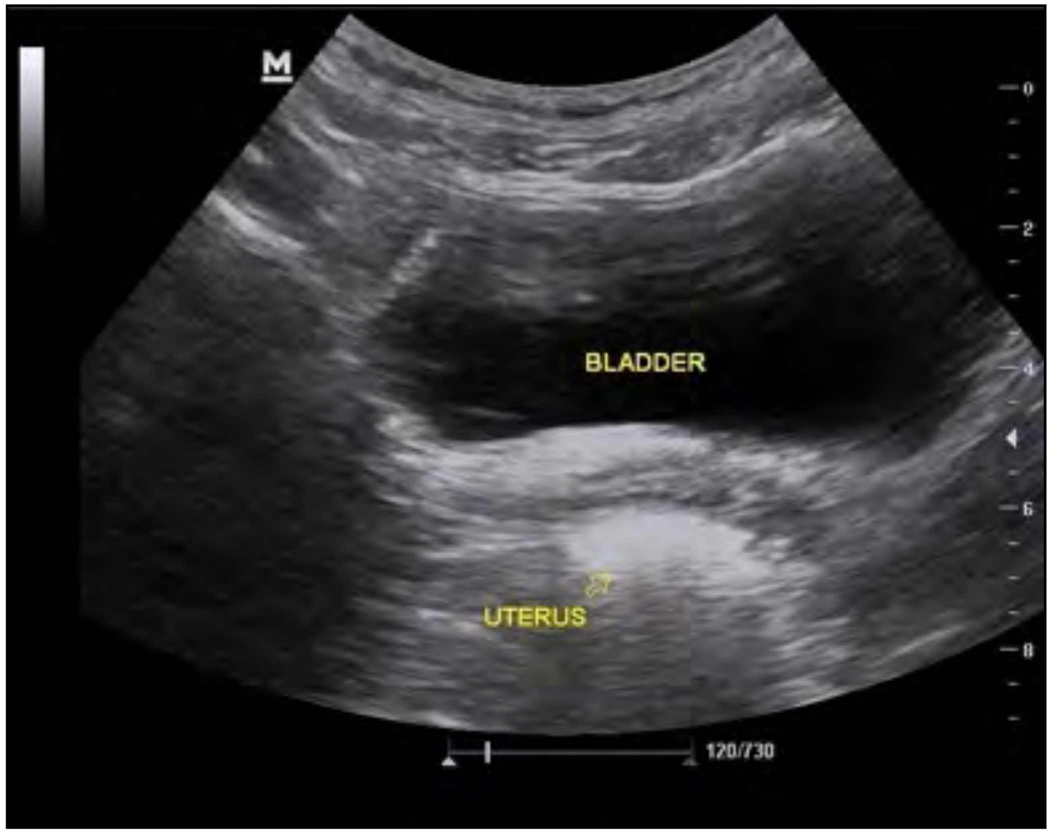
In the female, the uterus will be visible on the pelvic view of the FAST. The probe is placed in the same suprapubic position as described above, with the uterus visualized on the resulting image. In the female, the most dependent portion of the peritoneum is the Pouch of Douglas (rectouterine pouch), and so fluid is most likely to accumulate there.[26] In the resulting longitudinal video, the bladder can be seen at the top of the image, with the uterus posterior and cephalad. (Movie 1.13)

GALLERY 1.11



The following videos show fluid anterior and posterior to the uterus in the Pouch of Douglas. The anechoic area anterior to the uterus represents a pocket of pelvic free fluid. The bladder can be visualized to the right of the screen and is incompletely seen. (Movies 1.14 and 1.15) Again, the probe is turned 90° counterclockwise so that the probe marker is facing towards the patient's right side. This view will show transverse cuts of the bladder and uterus. (Image 1.2) Note that in the transverse plane, the uterus may appear hyperechoic.(Movie 1.17) Here, free pelvic fluid is seen in transverse orientation. (Movie 1.16)

IMAGE 1.2

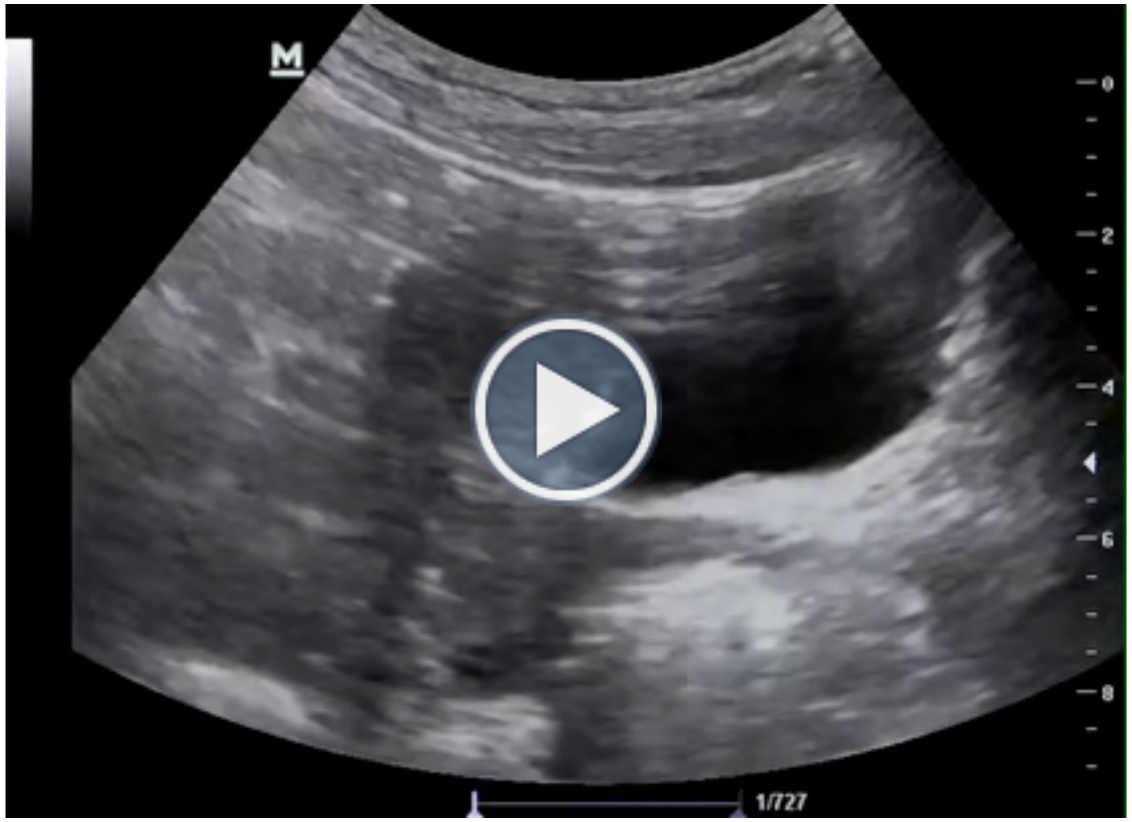


MOVIE 1.14

Fluid anterior and posterior to the uterus in the Pouch of Douglas.

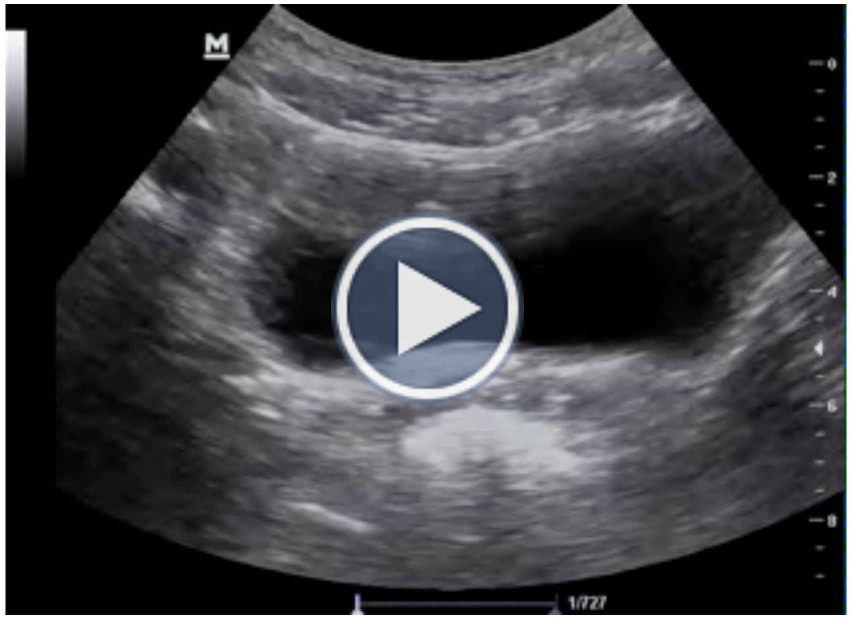
MOVIE 1.15

MOVIE 1.13 - Longitudinal view of female pelvis



The bladder can be seen at the top of the image, with the uterus posterior and cephalad.

MOVIE 1.16



Note that in the transverse plane, the uterus may appear hyperechoic.

MOVIE 1.17

Free pelvic fluid is seen in transverse orientation.

Extended FAST (EFAST)

Summary

The extended fast includes evaluation of the hemithoraces.

The linear probe is used to evaluate for "lung sliding" and pneumothorax.

Directing the abdominal probe cranially from the RUQ and LUQ windows allows for evaluation for pleural fluid/ hemothorax.

In recent years, the extended FAST exam has gained favor in the trauma bay. In addition to the traditional FAST views, the EFAST also images the hemithoraces for pneumo- or hemothorax. In the past, the trauma survey relied on physical exam findings and portable chest radiography (PCXR) to detect these. As discussed previously, physical exam findings are unreliable and breath sounds can often be difficult to auscultate while in a busy trauma bay. For pneumothorax, PCXR carries a sensitivity of 48.8-75.5% and specificity of 100%, whereas ultrasound is 92-98.1% sensitive and 99.4% specific.[32-34] In addition, bedside ultrasound has the advantage of a speedier diagnosis time of 2.9 minutes versus 19.9 for PCXR.[35]

Ultrasound imaging of the pleural-diaphragmatic interface has been shown to be superior to PCXR in detection of hemothorax or pleural effusion. An upright chest x-ray can detect up to a minimum of 50-100mL pleural fluid.[35] However, a supine chest x-ray, which is typically done in the trauma bay, requires much more fluid accumulation before radiographic changes are seen. A pleural fluid amount of 175mL is required before blunting of the costophrenic angle will be seen on supine PCXR.[36-38] Supine ultrasonography of the pleural spaces can detect as little as 20mL of pleural fluid.[39] Ultrasound is more sensitive than PXCR for hemothorax. (See lung chapter)

Ultrasound Views and Normal/Abnormal Findings

Pneumothorax

Evaluation for pneumothorax relies on imaging of the sliding between the visceral and parietal pleura. In a patient without pneumothorax, these two layers will be in direct contact with each other. With respiration, sliding of these two layers can be seen on ultrasound. To perform this examination, a high frequency linear probe is typically used. However, a curvilinear or phased array probe may also be used. The biggest pitfall with this examination is having the image depth set too deep. Unless the patient is extremely obese, a maximum image depth of 4cm should be used. With the patient in the supine position, the probe is placed in the longitudinal position in the 3rd to 4th intercostal space at the midclavicular line on the right and the anterior axillary line on the left. The probe marker should be facing towards the patients head. In this orientation, the ribs and rib shadows can be used as a landmark to find the pleura. The operator should then slide the probe longitudinally until one rib is seen on either side of the image. Immediately posterior to the ribs will be the pleural line. (Gallery 1.12)

In real time, and with normal respirations, the physiologic sliding between the pleura can be visualized. It appears as though it is shimmering and is sometimes referred to as ants marching. (Movie 1.19)

The motion of this sliding artifact is the most common normal sign on ultrasound. Normal lung sliding means that there is no air between the pleura and so excludes pneumothorax.[41-42] Ultrasound M-mode can also be applied and will show a characteristic pattern in that granular artifacts will be seen below the bright pleural line. This is termed the seashore sign and represents normal pleural sliding.

Another sign of a normally functioning lung is the comet tail artifact, or B-line. This is a type of reverberation artifact that arises from distended water-filled interlobular septae under the visceral pleura. As the comet tail is caused by visualization of structures deep to the visceral pleura, they may only be seen if no pneumothorax is present. Comet tail artifact may not always be present, but carries a sensitiv-

Gallery 1.12

The probe is placed in the longitudinal position in the 3rd to 4th intercostal space.

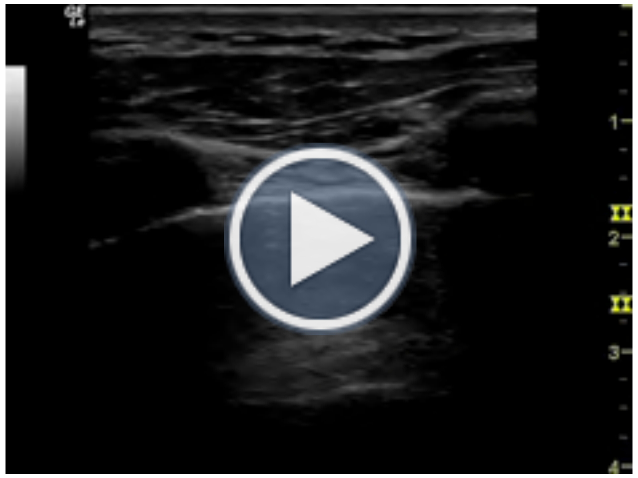
Movie 1.18

In real time, and with normal respirations, the physiologic sliding between the pleura can be visualized. It appears as though it is shimmering and is sometimes referred to as ants marching.

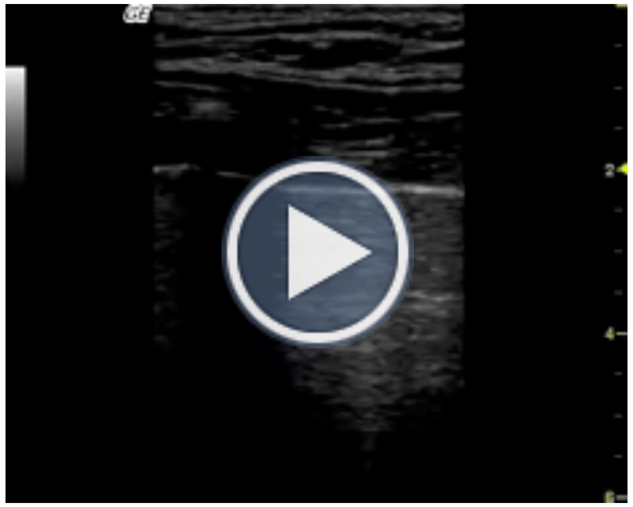
ity of 100% for ruling out pneumothorax when seen.[43] The following video shows comet tail artifacts intermittently with respirations. (Movie 1.20)

If a pneumothorax is present, then no lung sliding will be visualized. (Movies 1.21 and 1.22) As discussed above, the absence of lung sliding is 99.4% specific for pneumothorax.[32-34]

Movie 1.19 Comet tail artifacts



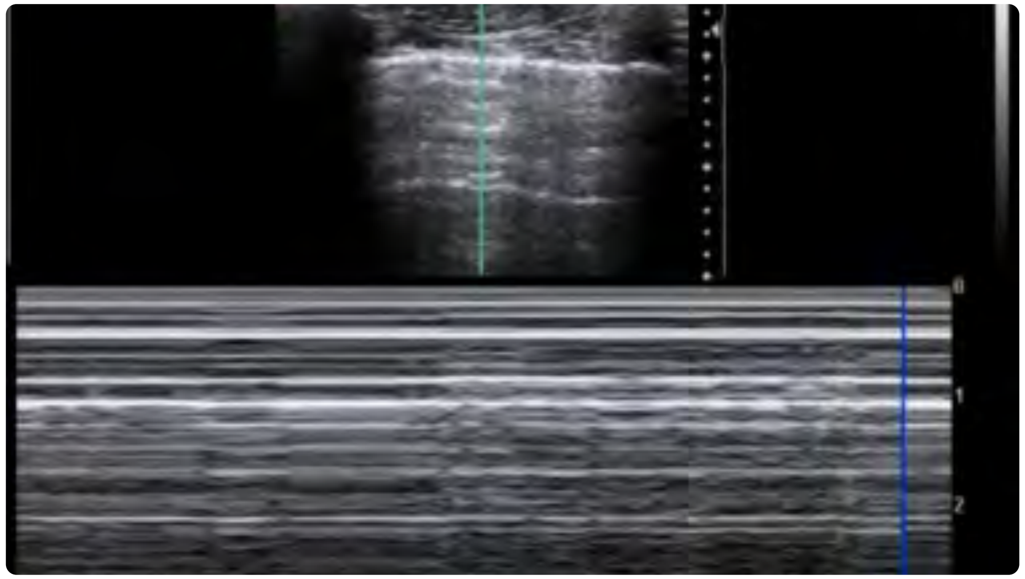
Movie 1.20 - Pneumothorax



Movie 1.21 Pneumothorax

A pneumothorax will show a characteristic appearance on M-mode resulting from reverberation artifact of the ultrasound waves between the pleura and air. Parallel horizontal lines will be seen throughout the image that represents pneumothorax and is called the barcode sign or stratosphere sign. (Gallery 1.13)

GALLERY 1.13



Barcode sign or stratosphere sign.

The lung point can be used to estimate the size of a pneumothorax. The lung point is the transition between expanded and collapsed lung. The lung point can be difficult to find; however, when present, it is 100% specific for pneumothorax.[44] The lung point is the specific point at which the shimmering or ants marching will cease and no pleural sliding will be seen thereafter. In Gallery 1.14, comet tails and sliding artifact can be seen; however, a point is seen thereafter in which there are no comet tails.

Hemothorax

Evaluation for hemothorax uses the same probe and probe position as when assessing Morison's Pouch and the splenorenal recess. Essentially, the normal FAST view of the LUQ and RUQ are obtained then the probe is slid 1-2 rib interspaces up, or simply angled cephalad. In this position, the hyperechoic diaphragm can be seen to overly either the spleen or liver. (Gallery 1.14)

GALLERY 1.14

In this position, the hyperechoic diaphragm can be seen to overly either the spleen or liver.

Some authors suggest using an anterior, subcostal approach, using the liver as an acoustic window into the hemothorax. The presence of fluid in the pleural space can be seen as black fluid superior to diaphragm. (Movies 1.22 and 1.23)

MOVIE 1.22 - Presence of Fluid

MOVIE 1.23 - Presence of Fluid

SUMMARY

In summary, ultrasound has become a reliable and important tool in evaluating the patient with thoracoabdominal trauma. The FAST and EFAST can easily be performed at the bedside and dramatically decrease time to diagnosis and length of stay in the emergency department. These exams can also be used in any non-trauma situation when there is suspected pneumothorax, pleural, pericardial, or peritoneal fluid.

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REFERENCES

1.Schurink GW, Bode PJ, van Luijt PA, et al. The value of physical examination in the diagnosis of patients with blunt abdominal trauma: a retrospective study. Injury. 1997 May;28(4):261-5.

2.Henneman PL, Marx JA, Moore EE, et al. Diagnostic peritoneal lavage: accuracy in predicting necessary laparotomy following blunt and penetrating trauma. The Journal of Trauma. 1990;30(11):1345-55.

3.Meyer DM, Thal ER, Weigelt JA, et al. Evaluation of computed tomography and diagnostic peritoneal lavage in blunt abdominal trauma. The Journal of Trauma. 1989; 29(8):1168-70;[discussion 1170-2].

4.Day AC, Rankin N, Charlesworth P. Diagnostic peritoneal lavage: integration with clinical information to improve diagnostic performance. Journal of Trauma and Acute Care Surger. 1992;32(1):52-7.

5.Bilge A, Sahin M. Diagnostic peritoneal lavage in blunt abdominal trauma. Eur J Surg 1991;157:449–451.

6.Tintinalli JE, Gabor DK, Stapczynski JS. Emergency Medicine: A comprehensive study guide. 6th Edition. New York (NY): The McGraw-Hill Company; 2011:1874.

7.Mendez C, Gubler KD, Maier RV. Diagnostic accuracy of peritoneal lavage in patients with pelvic fractures. Arch Surg. 1994;129:477–482.

8.Hubbard SG, Bivins BA, Sachatello CR, et al. Diagnostic errors with peritoneal lavage in patients with pelvic fractures. Arch Surg 1979;114:844–846.

9.Bivins BA, Sachatello CR, Daughtery ME, et al. Diagnostic peritoneal lavage is superior to clinical evaluation in blunt abdominal trauma. Am Surg 1978;44:637–641.

10.Tiling T, Bouillon B, Schmid A. Ultrasound in blunt abdomino-thoracic trauma. in: Border J, Allgoewer M, Hansen S (eds.), Blunt Multiple Trauma: Comprehensive Pathophysiology and Care. New York: Marcel Dekker; 1990:415-433.

11.Jehle D, Davis E, Evans T, et al. Emergency department sonography by emergency physicians. Am J Emerg Med. 1989;7(6):605-11.

12.Scalea TM, Rodriguez A, Chiu WC, et al. Focused Assessment with Sonography for Trauma (FAST): results from an international consensus conference. J Trauma. 1999;46(3):466-72.

13.Healey MA, Simons RK, Winchell RJ, et al. A prospective evaluation of abdominal ultrasound in blunt trauma: Is it useful? J Trauma 1996;40:875–883.

14.Boulanger BR, Brenneman FD, McLellan BA, et al. A prospective study of emergent abdominal sonography after blunt trauma. J Trauma 1995;39:325–330.

15.McKenney MG, Martin L, Lentz K, et al. 1000 consecutive ultrasounds for blunt abdominal trauma. J Trauma 1996;40:607–612.

16.Boulanger BR, McLellan BA, Brenneman FD, et al. Emergent abdominal sonography as a screening test in a new diagnostic algorithm for blunt trauma. J Trauma 1996;40:867–874.

17.Plummer D, Brunette D, Asinger R, et al. Emergency department echocardiography improves outcome in penetrating cardiac injury. Ann Emerg Med 1992;21:709-12.

18.Schiavone WA, Ghumrawi BK, Catalano DR, et al. The use of echocardiography in the emergency management of nonpenetrating traumatic cardiac rupture. Ann Emerg Med 1991;20:1248-50.

19.Udobi KF, Rodriguez A, Chiu WC, et al. Role of ultrasonography in penetrating abdominal trauma: a prospective clinical study. J Trauma. 2001;50(3):475-9.

20.Boulanger BR, Kearney PA, Tsuei B, et al. The routine use of sonography in penetrating torso injury is beneficial. J Trauma 2001;51:320-5.

21.Tayal VS, Beatty MA, Marx JA, et al. FAST (Focused Assessment With Sonography in Trauma) Accurate for Cardiac and Intraperitoneal Injury in Penetrating Anterior Chest Trauma. J Ultrasound Med 2004;23(4):467-472.

22.Mahony BS, Filly RA, Nyberg DA, et al. Sonographic evaluation of ectopic pregnancy. J Ultrasound Med 1985;4:221-228.

23.Nyberg DA, Hughes MP, Mack LA, et al. Extrauterine findings of ectopic pregnancy of transvaginal US: Importance of echogenic fluid. Radiology 1991;178:823-826.

24.Moore C, Todd WM, O'Brien E, et al. Free fluid in Morison's pouch on bedside ultrasound predicts need for operative intervention in suspected ectopic pregnancy. Acad Emerg Med. 2007;14(8):755-8.

25.Rodgerson JD, Heegaard WG, Plummer D, et al. Emergency department right upper quadrant ultrasound is associated with a reduced time to diagnosis and treatment of ruptured ectopic pregnancies. Acad Emerg Med 2001;8:331-336.

26.Meyers MA. The spread and localization of acute intraperitoneal effusion. Radiology 1970;94:547-554.

27.Branney SW, Wolfe RE, Moore EE, et al. Quantitative sensitivity of ultrasound in detecting free intraperitoneal fluid. J Trauma 1995;39:375–380.

28.Kimura A, Otsuka T. Emergency center ultrasonography in the evaluation of hemoperitoneum: a prospective study. J Trauma 1991;31:20-23.

29.Abrams BJ, et al. Ultrasound for the detection of intraperitoneal fluid: the role of Trendelenburg positioning. Am J Emerg Med. 1999;17(2):117-20.

30.Otto, CM. Textbook of Clinical Echocardiography. 4th edition. Philadelphia, PA: Saunders Elsevier; 2009.

31.Boschert, S. Clinical and Practice Management: Use ultrasound to quickly detect bleeding in the belly. ACEP News, Nov. 2007. Available at http://www.acep.org/content.aspx?id=34000. Accessed June 15, 2012.

32.Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. Acad Emerg Med. 2005;12(9):844-849.

33.Soldati G, Testa A, Sher S, et al. Occult traumatic pneumothorax: diagnostic accuracy of lung ultrasonography in the emergency department. Chest. 2008;133(1):204-211.

34.Kirkpatrick AW, Sirois M, Laupland KB, et al. Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the Extended Focused Assessment with Sonography for Trauma (EFAST). J Trauma. 2004;57(2):288-95.

35.Zhang M, Liu ZH, Yang JX, et al. Rapid detection of pneumothorax by ultrasonograpy in patients with multiple trauma. Crit Care. 2006;10(4):R112.

36.Rubens MB. The pleura: collapse and consolidation. In: Sutton D ed. A textbook of radiology imaging. 4th ed. Edinburgh: Churchill Livingstone; 1987:393.

37.Woodring JH. Recognition of pleural effusion on supine radiographs: how much fluid is required? AJR Am J Roentgenol. 1984;142(1):59-64.

38.Juhl JH. Disease of the pleura, mediastinum, and diaphragm. In: Juhl JH, Crummy AB eds. Essentials of radiologic imaging. 6th ed. Philadelphia, PA: JB Lippincott Company; 1993:1026.

39.Rothlin MA, Naf R, Amgwerd M, et al. Ultrasound in blunt abdominal and thoracic trauma. J Trauma 1993;34:488-95.

40.Ma OJ, Mateer JR. Trauma ultrasound examination versus chest radiography in the detection of hemothorax. Ann Emerg Med. 1997;29(3):312-316.

41.Kirkpatrick AW, Nicolaou S. The sonographic detection of pneumothoraces. In: Kharmy-Jones R, Nathens A, Stern E, eds. Thoracic Trauma and Critical Care. Boston, MA: Kluwer Academic Publishers; 2002:227-234.

42.Lichtenstein DA. Pneumothorax and introduction to ultrasound signs in the lung. In: General Ultrasound in the Critically Ill. 1st ed. Berlin: Springer; 2002:105-115.

43.Lichtenstein D, Mezière G, Biderman P, et al. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. Intensive Care Med. 1999;25(4):383-8.

44.Lichtenstein D., et al. The "lung point": an ultrasound sign specific to pneumothorax. Intensive Care Med. 2000;26:1434-40.

45.

Chapter 2

Basic Cardiac

James Hwang MD, RDMS, RDCS, FACEP

Section 1

Background

Indications for Bedside Echo:

Cardiac Arrest

Unexplained Hypotension

Syncope

Dyspnea

Chest Pain

Trauma

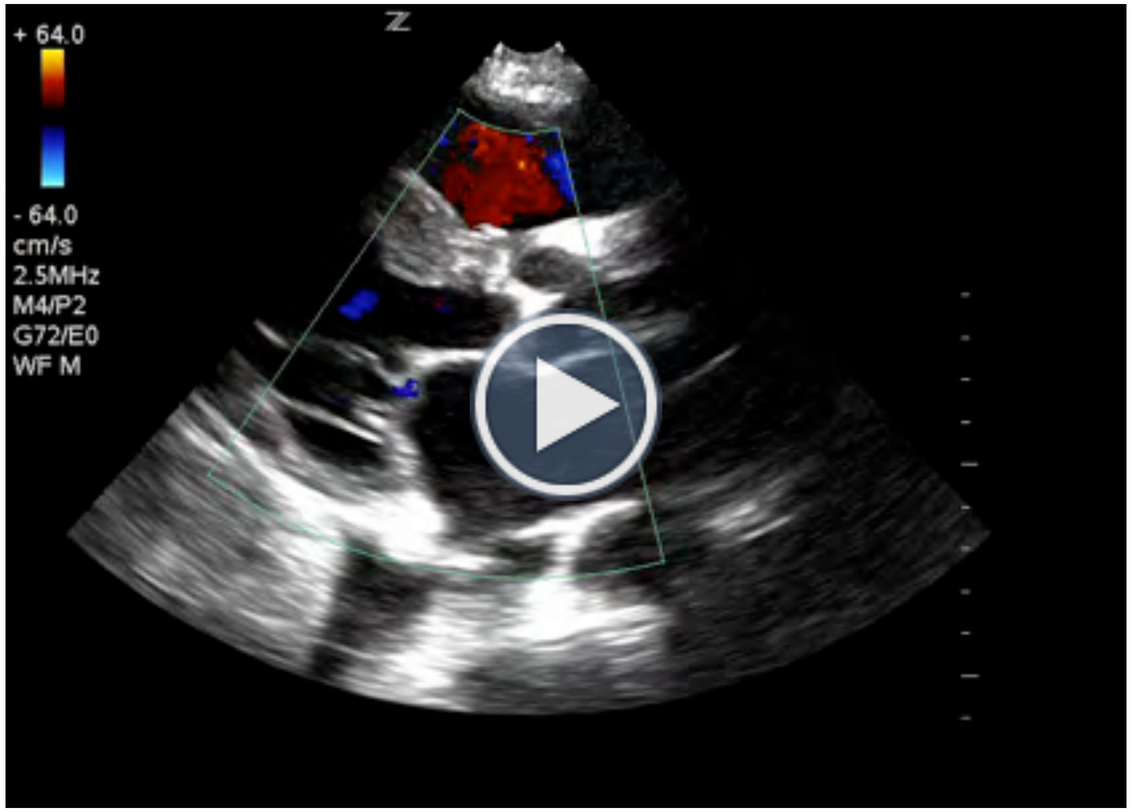
Scope of Basic Cardiac Bedside Ultrasound:

Global Left Ventricular Function

Pericardial Effusions

Right Heart Failure

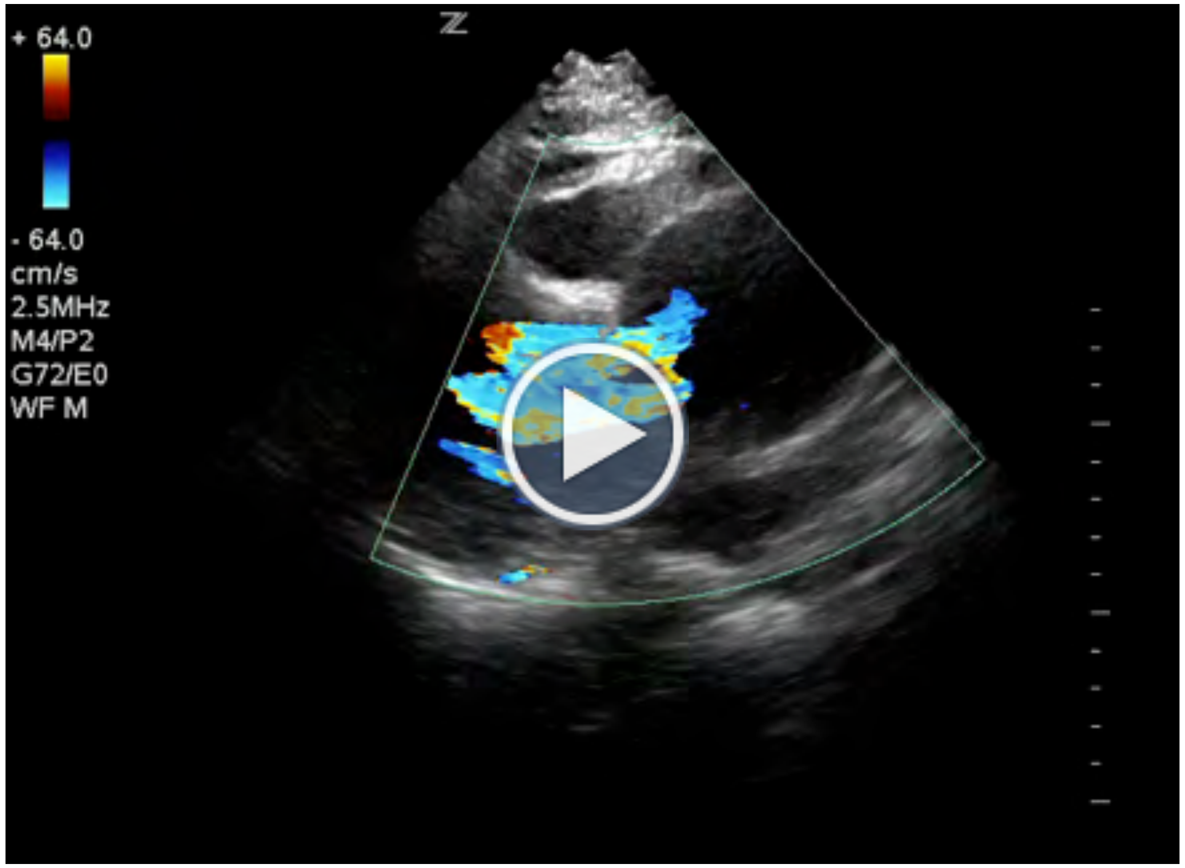
Movie 2.1 - Mitral Regurgitation



Basic echocardiography is a core application of bedside ultrasound and a key element of sonography algorithms, such as the EFAST exam and the RUSH protocol.[1-3] Although comprehending image orientation[4] and acquiring images can be somewhat challenging, clinician performed bedside echocardiography has a major impact on our ability to detect cardiac abnormalities and on patient care, and can be life-saving.[5-6] Bedside echocardiography provides clinicians with time-sensitive anatomic and physiologic information in a variety of cardiac-related scenarios, including cardiac arrest, unexplained hypotension, syncope, shortness of breath, and chest pain.[6-11]

(Movie 2.2). Bedside echocardiography can help clinicians risk-stratify patients and further guide resuscitative efforts.[12-13] At times, the information and disorders noted on bedside cardiac ultrasound

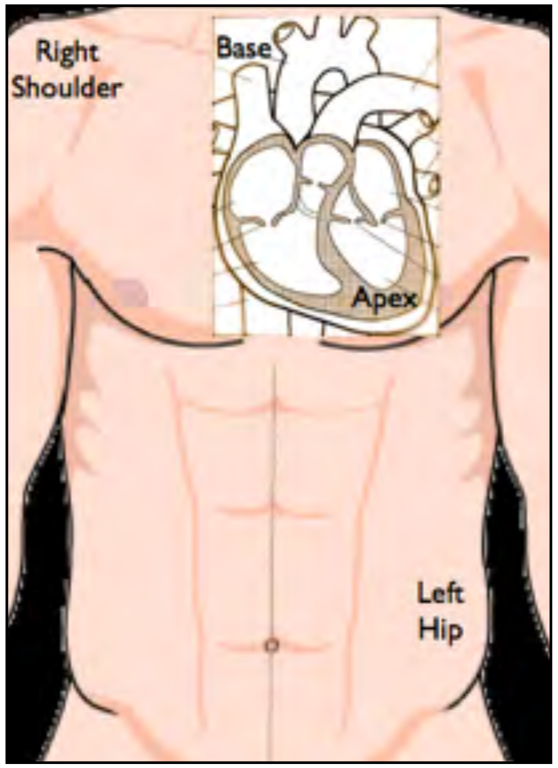
MOVIE 2.2 - Aortic Regurgitation



are vast and may surpass what performing clinicians are able to appreciate and integrate. As per the American Society of Echocardiography (ASE) – American College of Emergency Physicians (ACEP) Consensus Statement, the ability to assess global left ventricular function, to detect pericardial effusions, and to assess for right heart dilatation (chamber sizes) are within the scope of clinicians and can help answer critical patient management questions.[8]

Technique

IMAGE 2.1



The heart lies obliquely in the chest with the apex pointing towards the left hip and the base of the heart oriented towards the right shoulder (Image 2.1). The heart is imaged from multiple different views and the findings seen on one view should be confirmed or refuted with additional views. A 2 to 5-MHz phased array probe is used when attempting to obtain acoustic windows of the heart, as the smaller footprint (flat square face) more easily fits in between the ribs (Image 2.2).

IMAGE 2.2 - Parasternal Long Axis View

BASIC VIEWS:

Subxiphoid/subcostal

Parasternal Long Axis

Parasternal Short Axis

Apical

Tip: Left Lateral Decubitus position will improve view in parasternal and apical views.

IMAGE 2.3

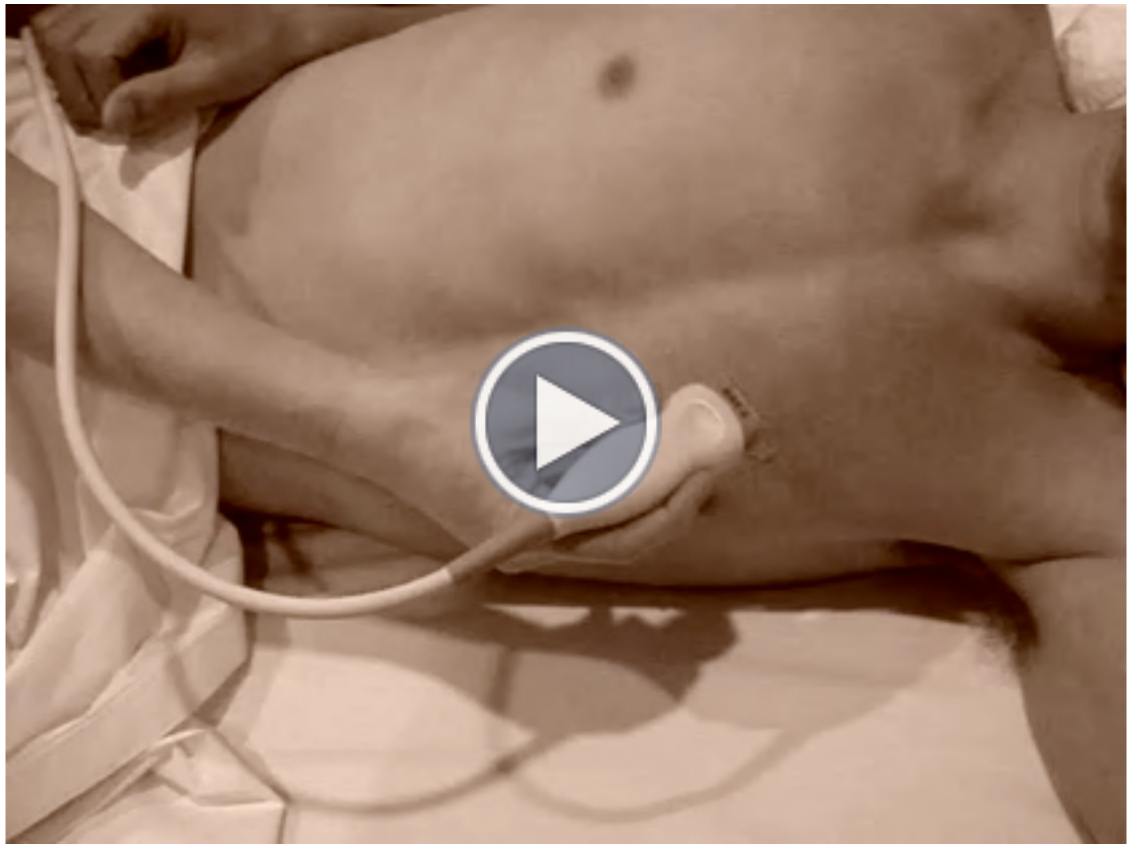
There are four basic cardiac views: parasternal long axis, parasternal short axis, apical 4-chamber, and subcostal. If possible, the patient should be rolled into the left lateral decubitus position, as this brings the heart closer to the anterior chest wall and improves imaging (Image 2.3). The parasternal long axis (PSLA) view is obtained by placing the probe to the left of the sternum with the probe marker pointing towards the patient's right shoulder. The probe is then gently dragged over the chest wall from the 2nd to 5th intercostal spaces, searching for the best acoustic window (Movie 2.3). The PSLA view is consistently obtainable and provides an excellent view of the left atrium (LA), left ventricle (LV), and aortic outflow tract. Once the parasternal long axis view is acquired, the probe can then be rotated clockwise 90° with the probe marker pointing towards the patient's left shoulder to obtain the parasternal short axis (PSSA) view (Movie 2.4). The PSSA view is an ideal view for assessing global LV function. The api-

MOVIE 2.3

MOVIE 2.4

cal 4-chamber (A4C) view is obtained by placing the probe inferior and lateral to the left nipple in men or under the left breast in

MOVIE 2.5

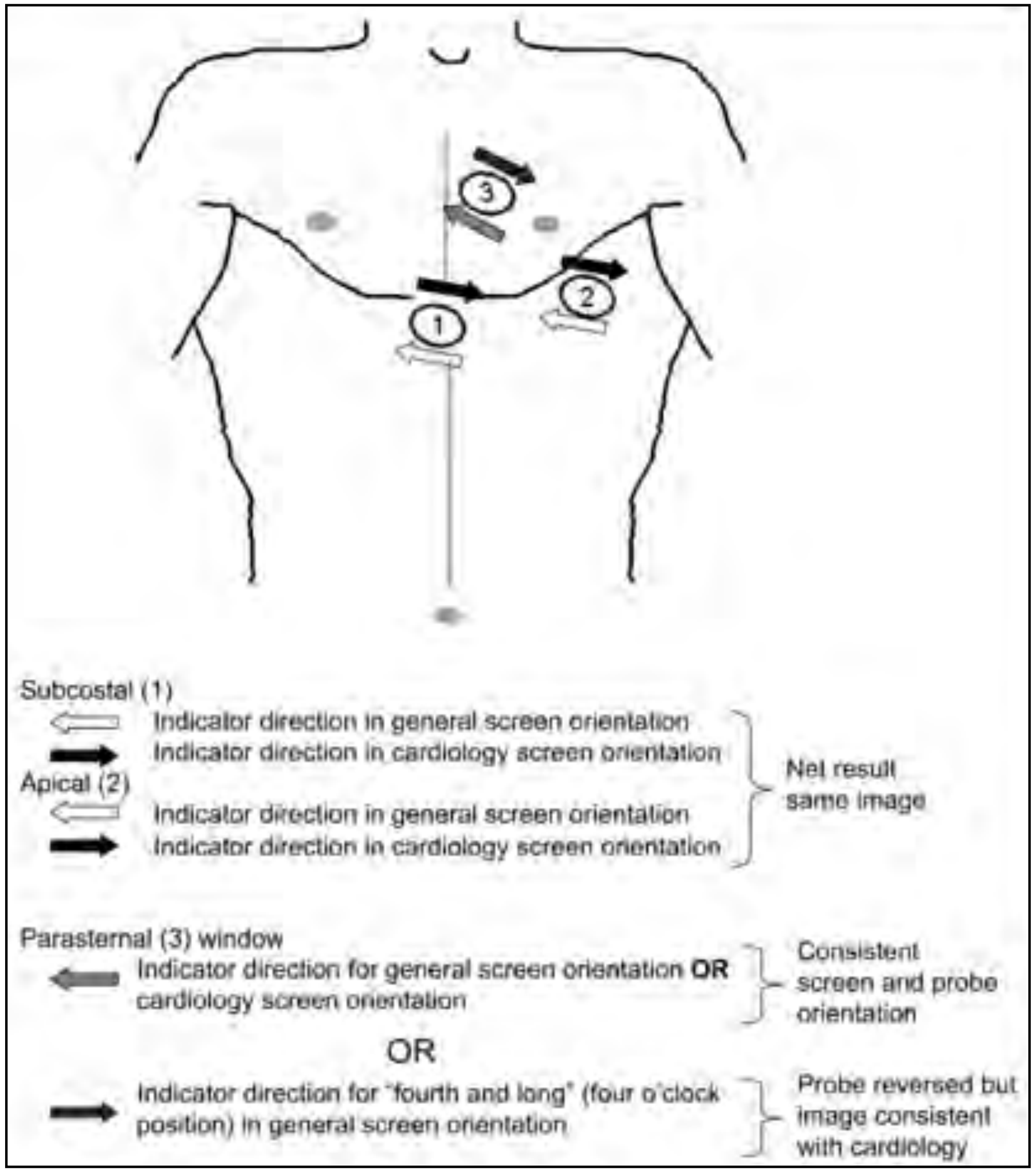


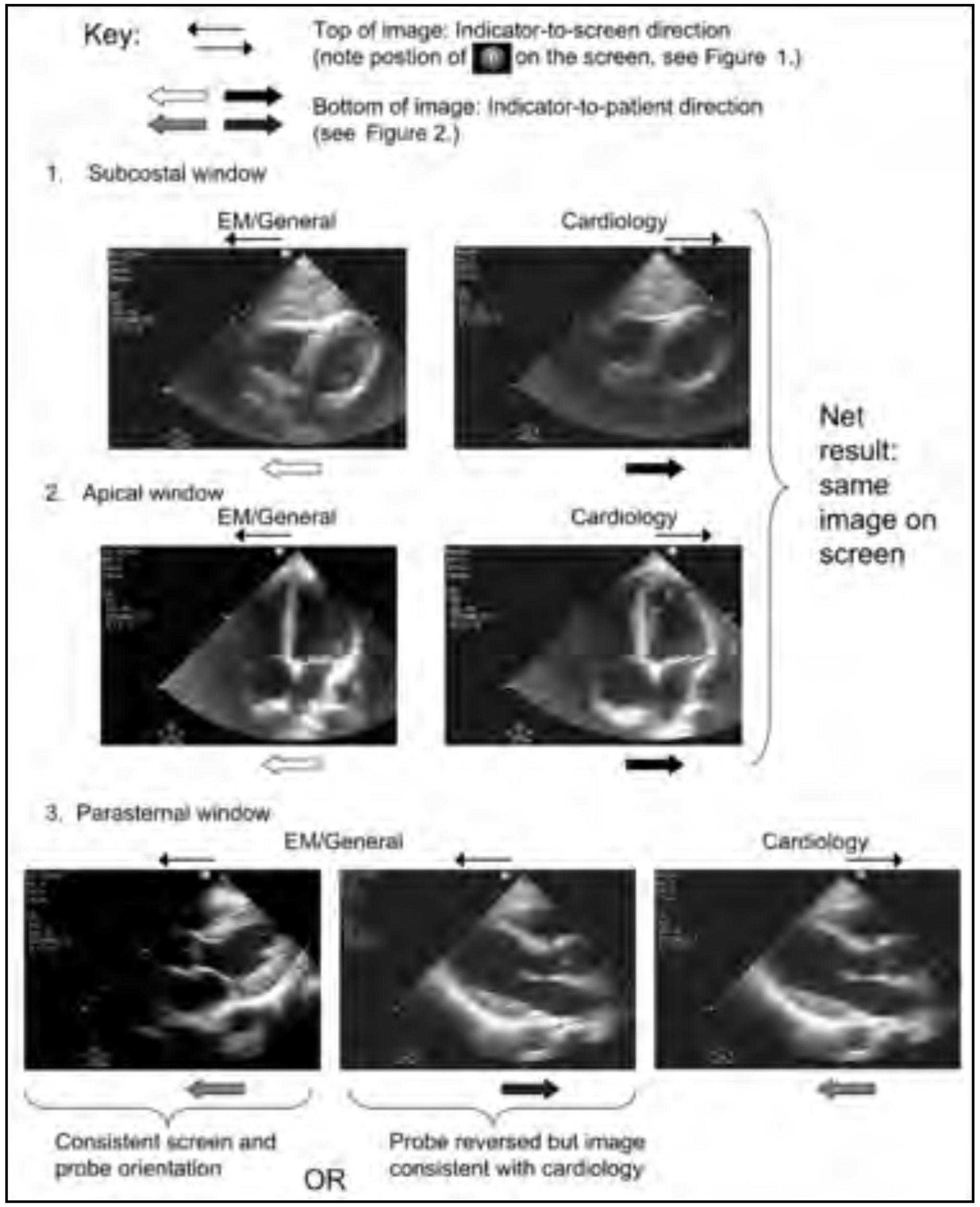
women. The probe marker is pointed towards the patient's left hip and the face of the transducer is angled up towards the base of the heart (Movie 2.5). The A4C view is often the most difficult view to acquire but offers valuable information about all four chambers and their relative sizes. The subcostal view is obtained by placing the probe just below the xiphoid process with the probe marker pointing towards the patient's left hip. The subxiphoid view uses the left lobe of the liver as an acoustic window and involves angling the face of the probe up from the abdomen and into the left chest. Placing the hand over the probe, as opposed to holding the probe like a pencil, as in other views, allows for the requisite angling of the probe where it is almost flat against the abdominal wall (Movie 2.6).

MOVIE 2.6

For a more comprehensive discussion reviewing cardiac ultrasound image orientation, see Moore's Special Contribution: Current Issues with Emergency Cardiac Ultrasound Probe and Image Conventions.[4] (Image 2.4).

IMAGE 2.4



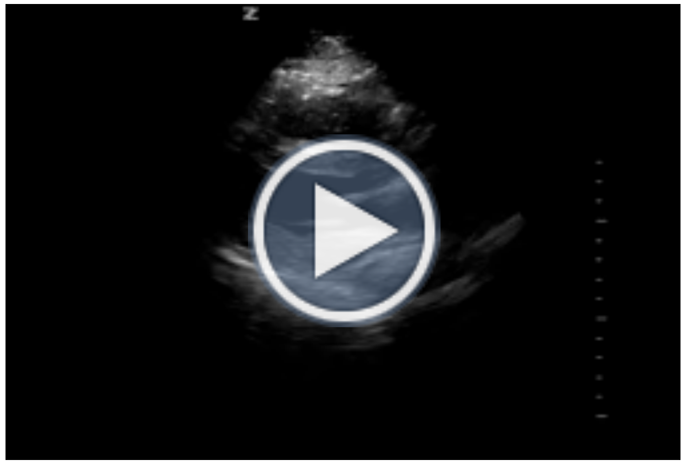


Section 3

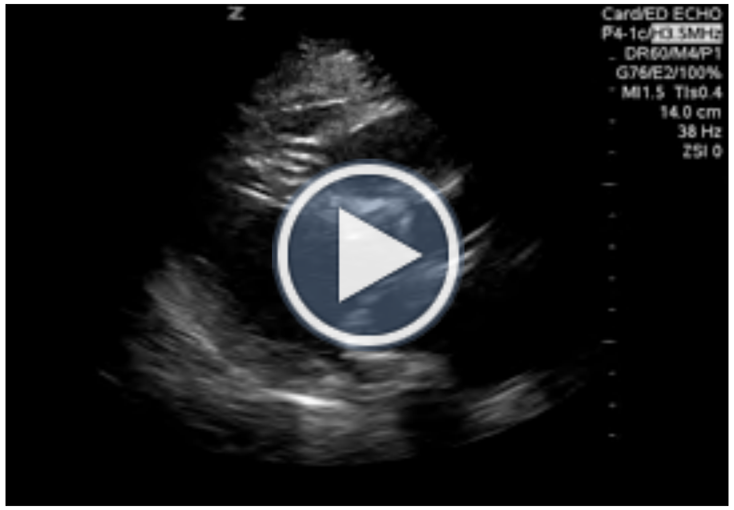
Left Ventricular Function

Assessment of global left ventricular function is a fundamental application of basic bedside echocardiography and helps predict clinical outcomes for a variety of disease states. The ability to assess a patient's overall left ventricular function – from cardiac standstill (Movie 2.7) to a hyperdynamic ejection fraction (Movie 2.8) – allows clinicians to better manage patients who present with chest pain, dyspnea, unexplained hypotension or cardiac arrest.[14-15]

Movie 2.7



Movie 2.8



Summary

Global left ventricular function can be accurately assessed by emergency physicians.

Scenarios where LVF may be useful:

Chest pain

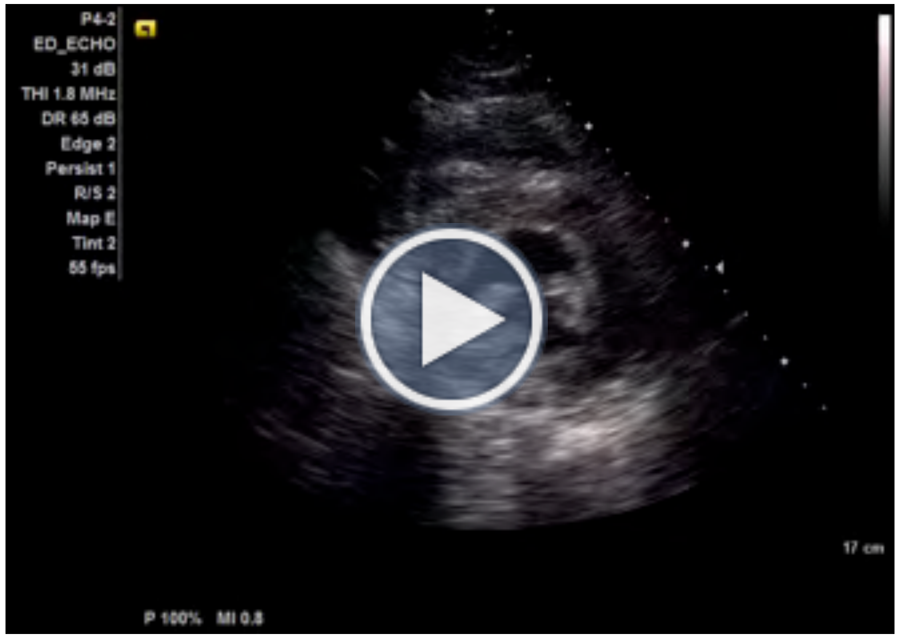
Dyspnea

Unexplained hypotension

Cardiac arrest

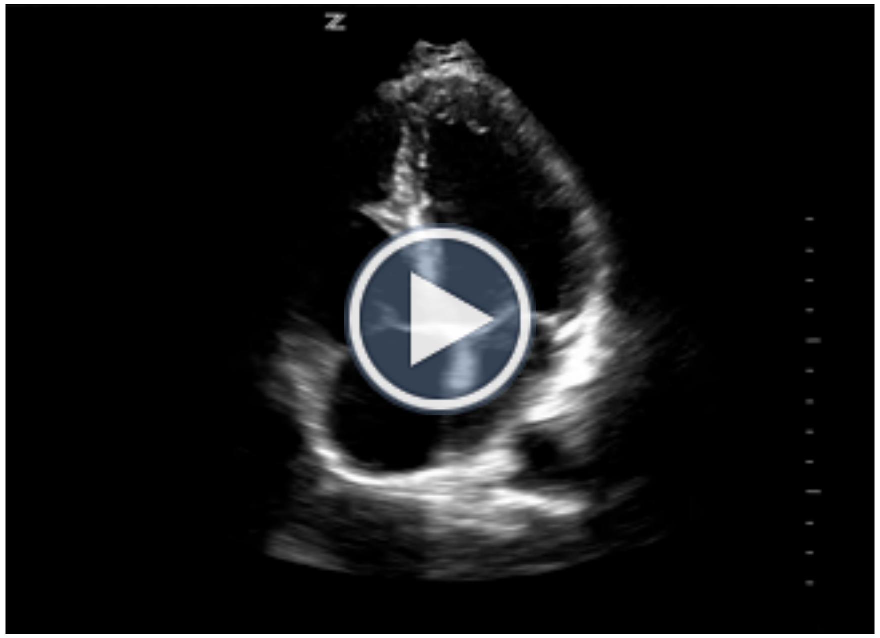
MOVIE 2.9 - Parasternal long

MOVIE 2.10 - Parasternal short

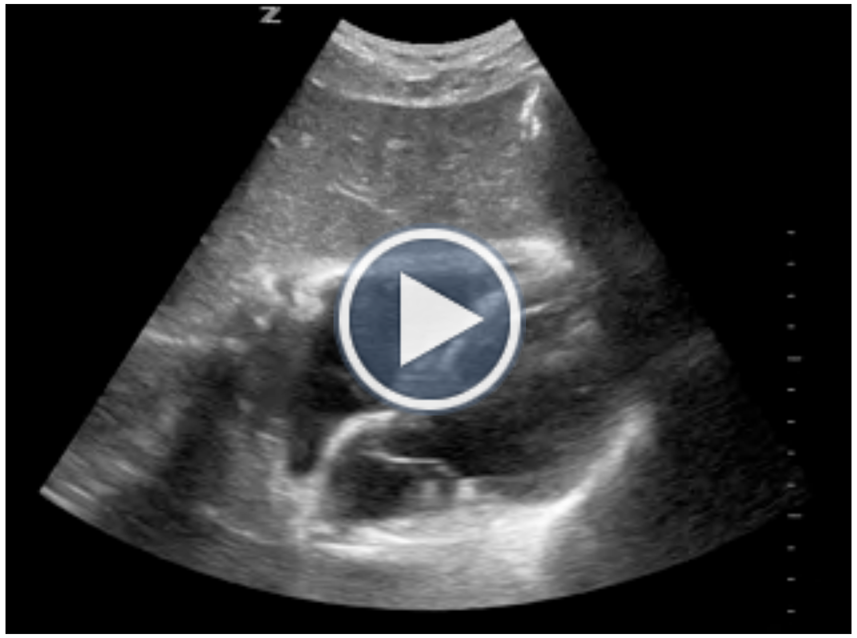


While regional wall motion abnormalities and quantitative measurements may be beyond the scope of some clinicians, the visual (qualitative) estimate of global left ventricular systolic function is not.[8,16]

MOVIE 2.11 - Apical 4



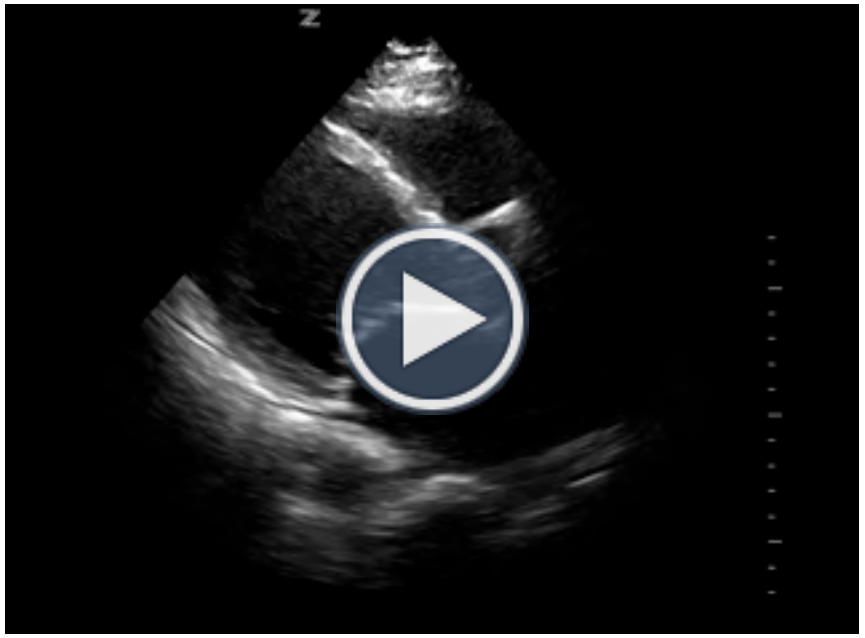
MOVIE 2.12 - Subxiphoid 4



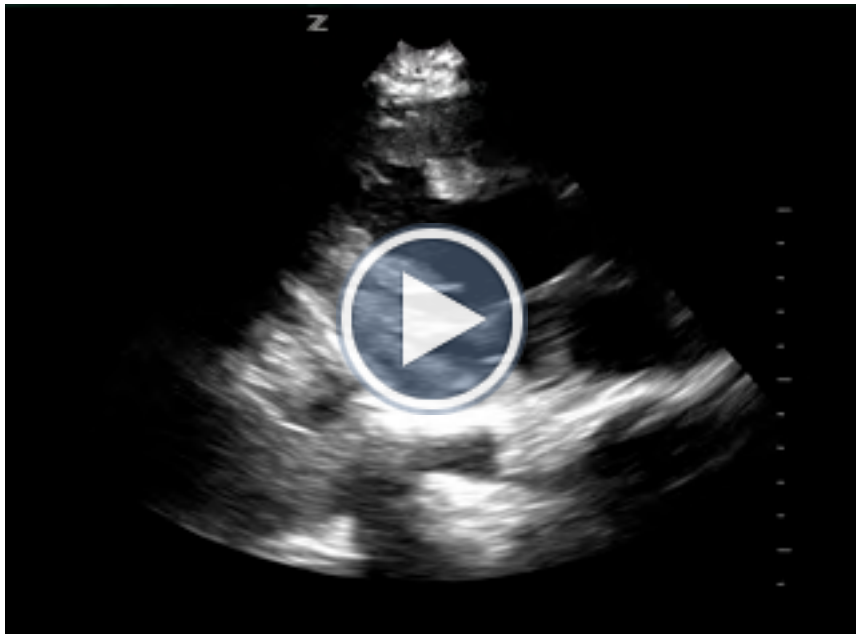
Assessment of systolic function is derived from the visual assessment of endocardial border excursion and myocardial thickening, as seen from multiple views (Movies 2.9-2.12).

MOVIE 2.13 - Severely Depressed EF

MOVIE 2.14 - Severely Depressed EF



MOVIE 2.15 - Moderately Depressed EF

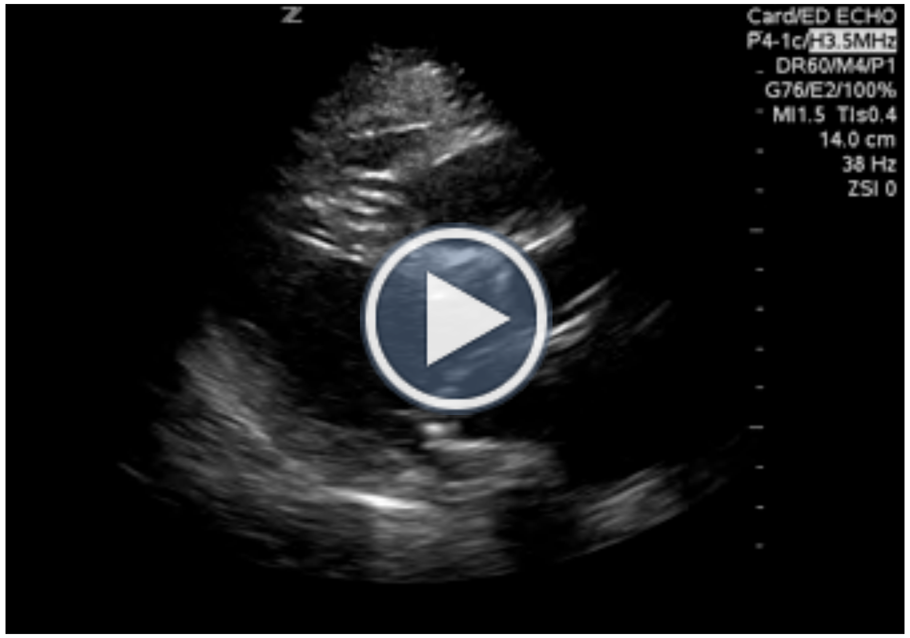


MOVIE 2.16 - Normal EF

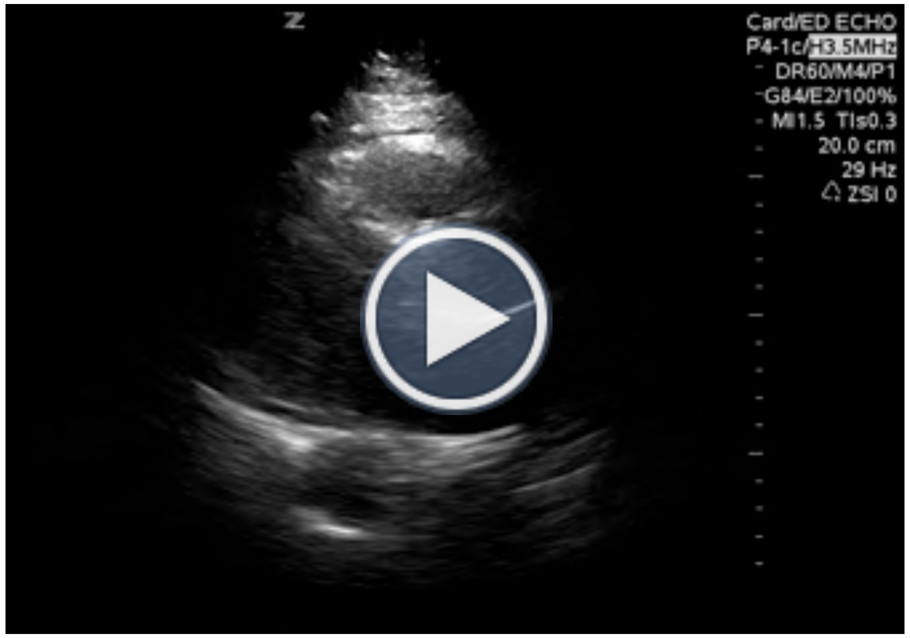
Classification of LV function can be simplified into the following: severely depressed (EF < 30%), mild-moderately depressed (EF 30-55%), and normal (EF > 55%).[15] (Movies 2.13-2.16)

Ejection fractions in excess of 70% are considered hyperdynamic, which may appear as near obliteration of the ventricular cavity during systole (Movie 2.17).

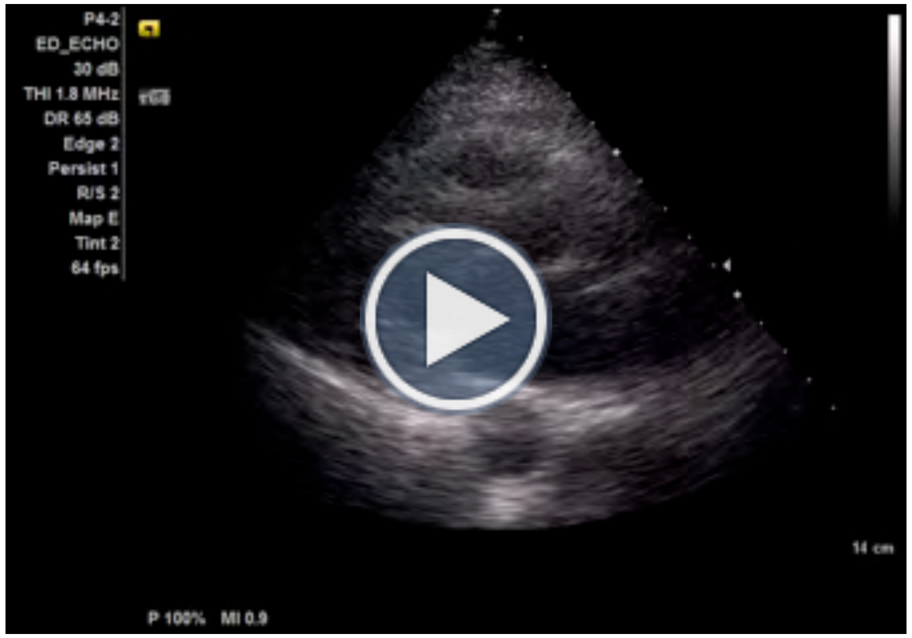
MOVIE 2.17 - Hyperdynamic EF



MOVIE 2.18 - Hyperdynamic EF



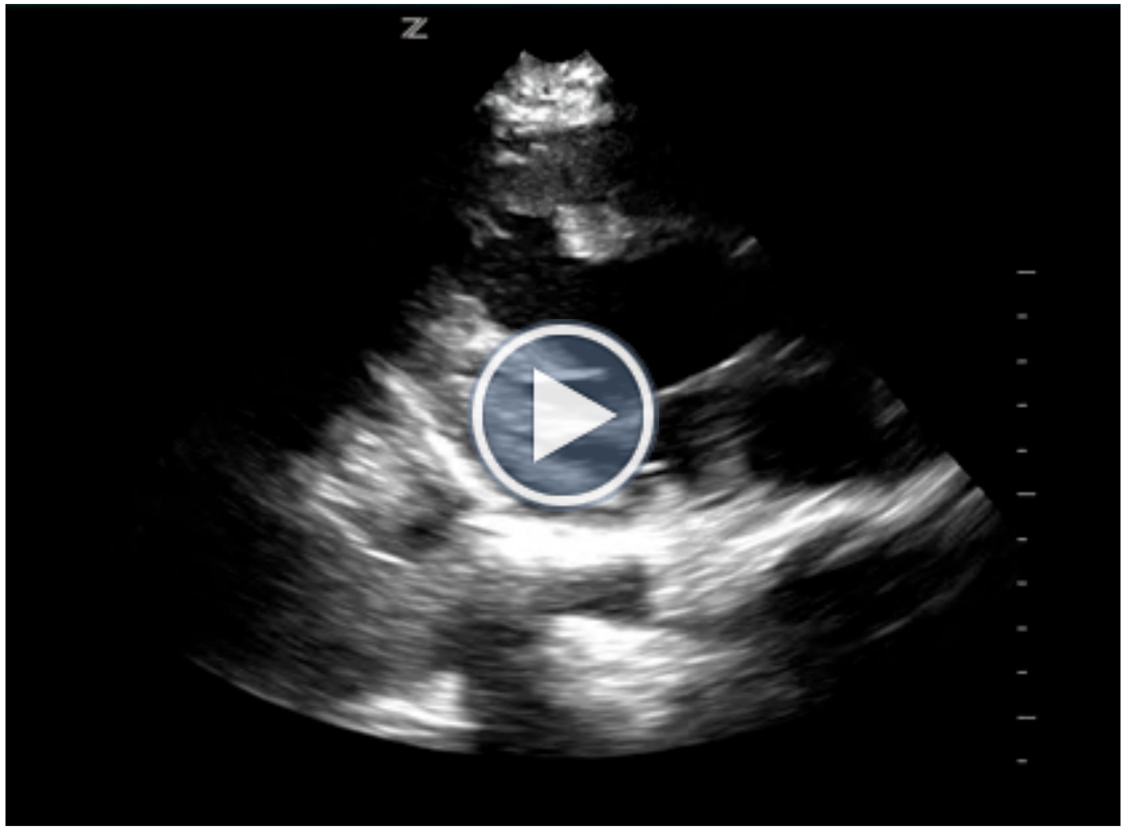
MOVIE 2.19 - Hyperdynamic EF



The finding of a hyperdynamic heart may suggest hypovolemia or vasodilation and should prompt the clinician to initiate volume resuscitation. It is important, however, to differentiate a hyperdynamic heart from one that is tachycardic but with a normal EF% (Movie 2.18-2.19). With appropriate education and training, clinicians can differentiate between normal and severely depressed left ventricular systolic function similar to cardiologists.[15] Moore et al demonstrated that, with focused training, emergency physicians can accurately determine left ventricular function in hypotensive patients.[15]

Although this study showed good agreement between emergency physicians and cardiologists for patients with normal and severely depressed left ventricular function, emergency physicians had more trouble categorizing patients with moderately depressed LV function (Movie 2.20). This validates the ability of clinicians to identify extremes of LV dysfunction, but underscores the need for clinicians to recognize their limitations and to obtain consultative studies when indicated.

MOVIE 2.20



One Minute Ultrasound EPSS Demonstration

SECTION 4

Pericardial Effusion

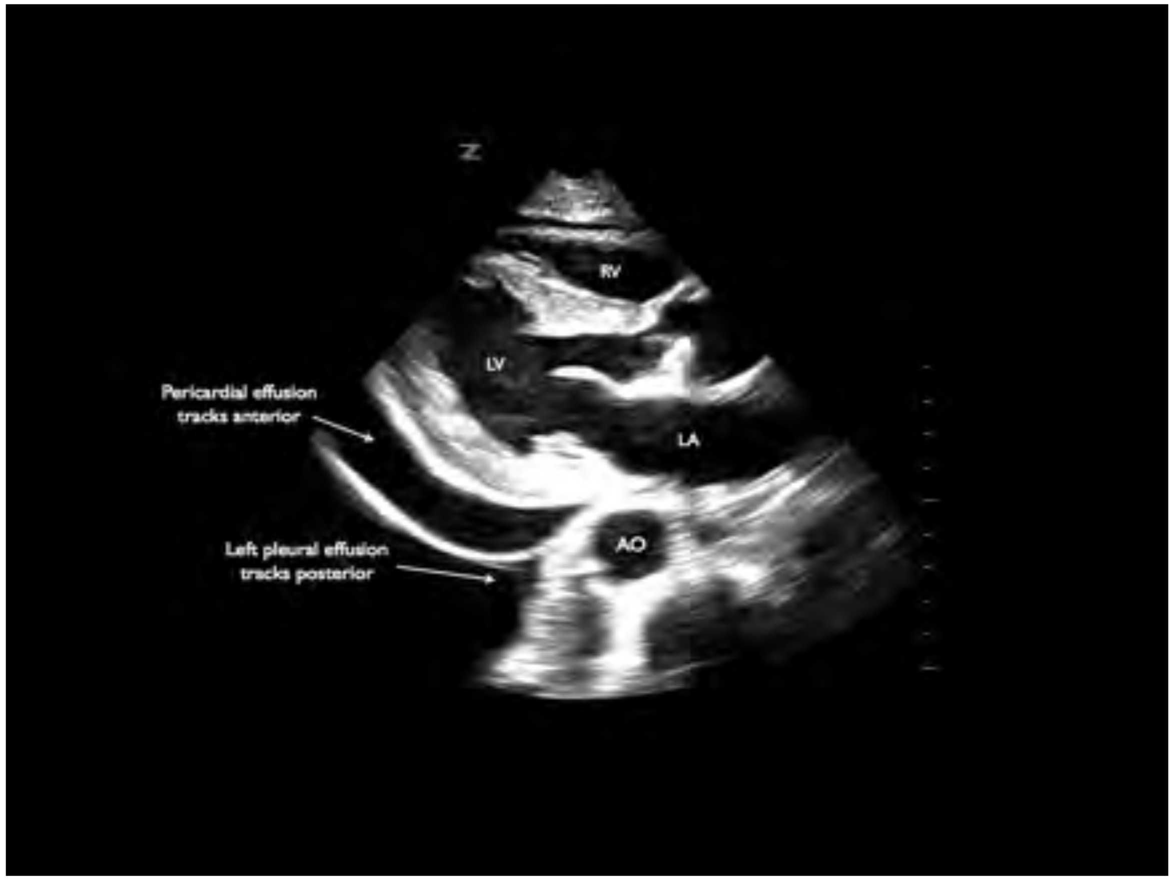
SUMMARY

Ultrasound is an ideal modality for detecting pericardial effusions

Tamponade is a clinical diagnosis that depends more on pressure and physiology than size of effusion

Pericardial and pleural effusions can frequently be differentiated based on location of fluid.

IMAGE 2.5



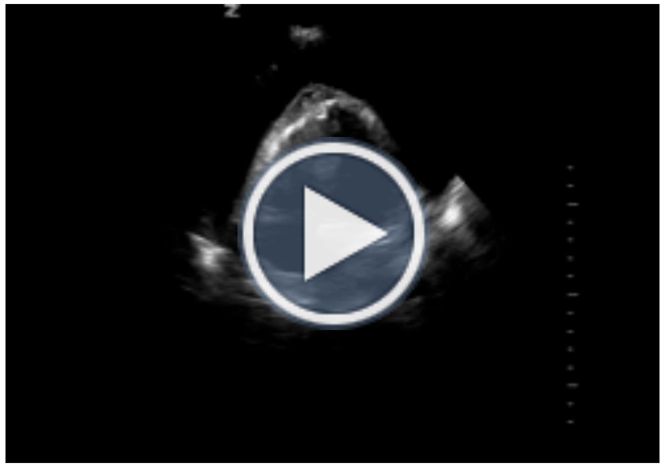
Pericardial fluid typically appears as an anechoic space between the epicardium and the pericardium (Image 2.5). Pericardial effusions are caused by a variety of disorders (infection, malignancy, connective tissue disease, renal failure, trauma) and may also develop after cardiac surgery or invasive cardiac procedures (pacemaker placement, cardiac catheterization). Ultrasound is an ideal modality to assess for the presence of pericardial fluid and its impact on right heart filling.[3,17,18] Pericardial effusions are not an uncommon diagnosis in patients presenting with dyspnea or hypotension.[11,19] Although cardiac tamponade is largely a clinical diagnosis, bedside echocardiography may demonstrate findings suggestive of impending tamponade prior to the development of physical examination findings and hemodynamic compromise.[20-22] The amount of fluid required to impair filling and to cause circulatory failure depends on the rate of accumulation. Pericardial effusions may be graded as:

Small (<0.5cm) (Movies 2.21-2.22)
Moderate (0.5-2.0cm) (Movies 2.23-2.24)
Large (>2cm) (Movies 2.25-2.26)[23-25]

MOVIE 2.21 - Small Effusion

MOVIE 2.23 - Moderate Effusion

MOVIE 2.25 - Large Effusion



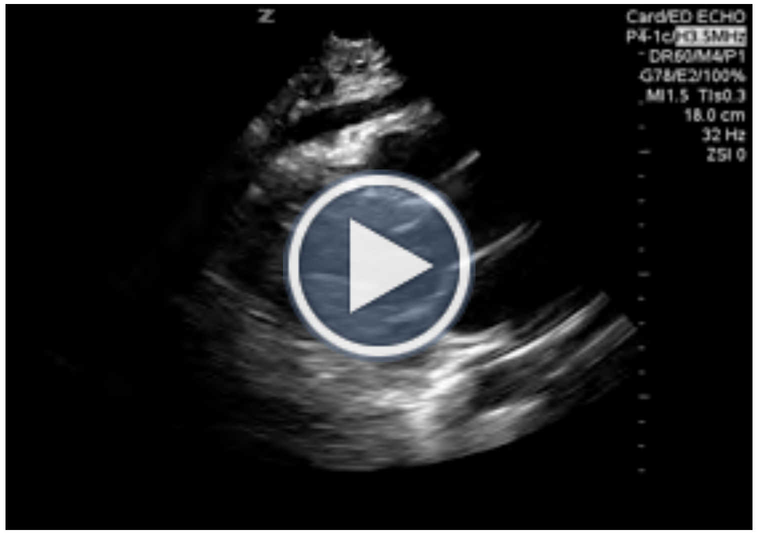
MOVIE 2.22 - Small Effusion

MOVIE 2.24 - Moderate Effusion

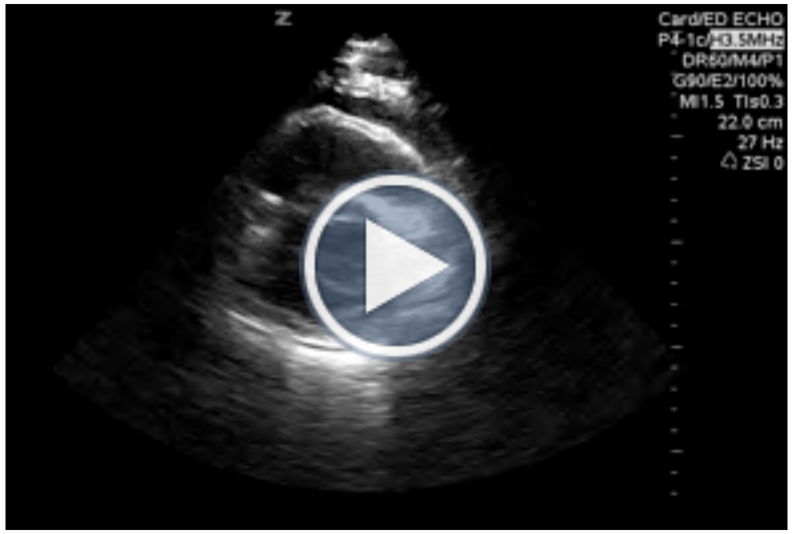
MOVIE 2.26 - Large Effusion

While large effusions are often circumferential, it is important to recognize that effusions can be focal, organized, or loculated (Movies 2.27-2.28).

MOVIE 2.27 - Anterior effusion

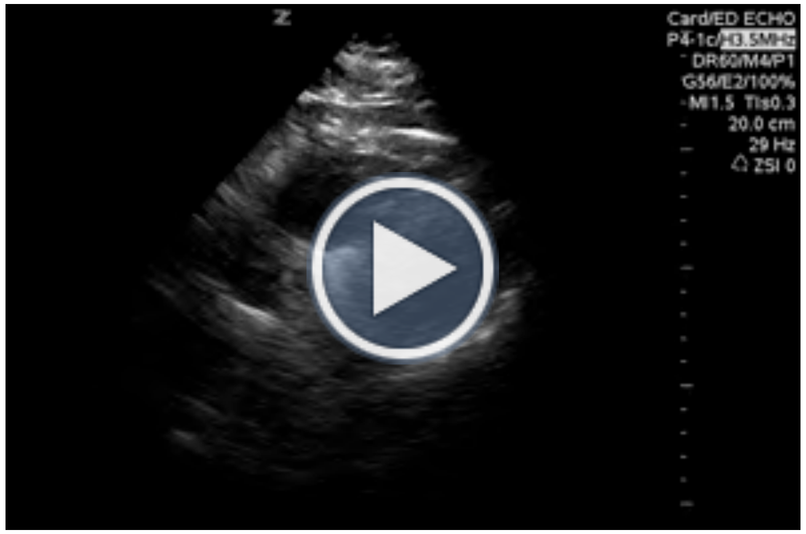


MOVIE 2.28 - Anterior effusion



A potential pitfall is differentiating between epicardial fat pads and true pericardial effusions. Epicardial fat pads are often visualized anteriorly and are mostly hypoechoic in appearance but often have some echogenicity (Movie 2.29).

MOVIE 2.29 - Epicardial fat pad

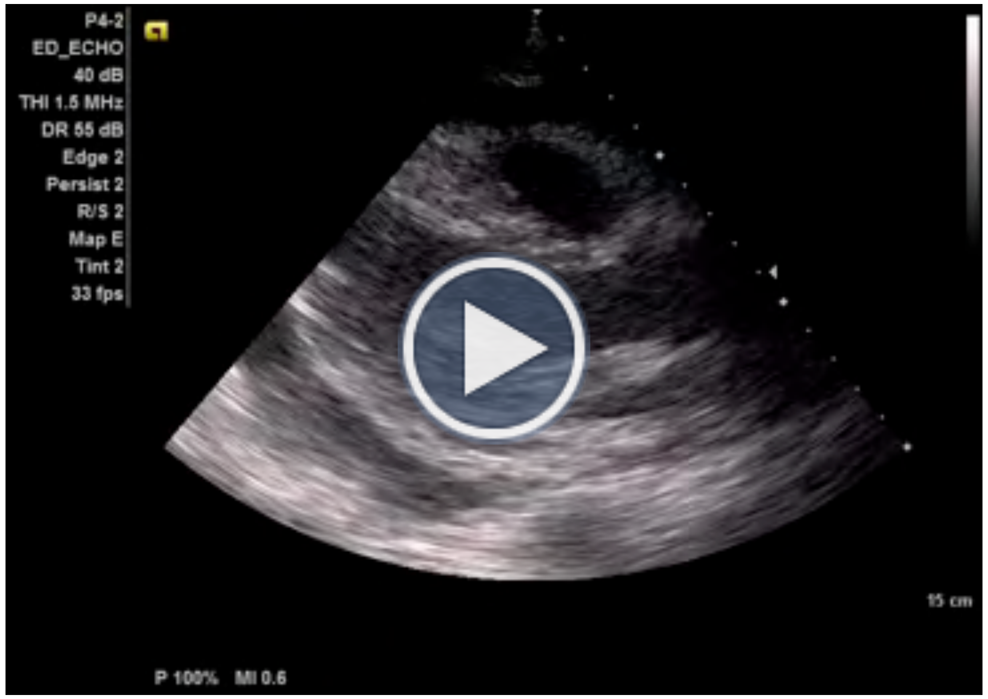


MOVIE 2.30 - RV collapse due to tamponade

Numerous studies have demonstrated that emergency physician–performed emergency echocardiography has sensitivities approaching 100% for the detection of pericardial effusions.[12,19,26] When compared with expert over-read of images, emergency physician–performed emergency echocardiography for effusion has a sensitivity of 96% to 100%, a specificity of 98% to 100%, a positive predictive value of 93% to 100%, and a negative predictive value of 99% to 100%. The echocardiographic findings consistent with cardiac tamponade include the following: right ventricular (RV) free wall inversion during ventricular diastole (the hallmark finding, Image 2.6 & Movies 2.30-2.31); right atrial inversion during ventricular systole (more common and one of the earliest findings); increased respiratory variation of mitral or tricuspid inflow velocities (inspiratory decreases of greater than 25% on mitral inflow or greater than 40% on tricuspid inflow); and a dilated inferior vena cava with decreased respirophasic variation (Movie 2.32).[24-25, 27]

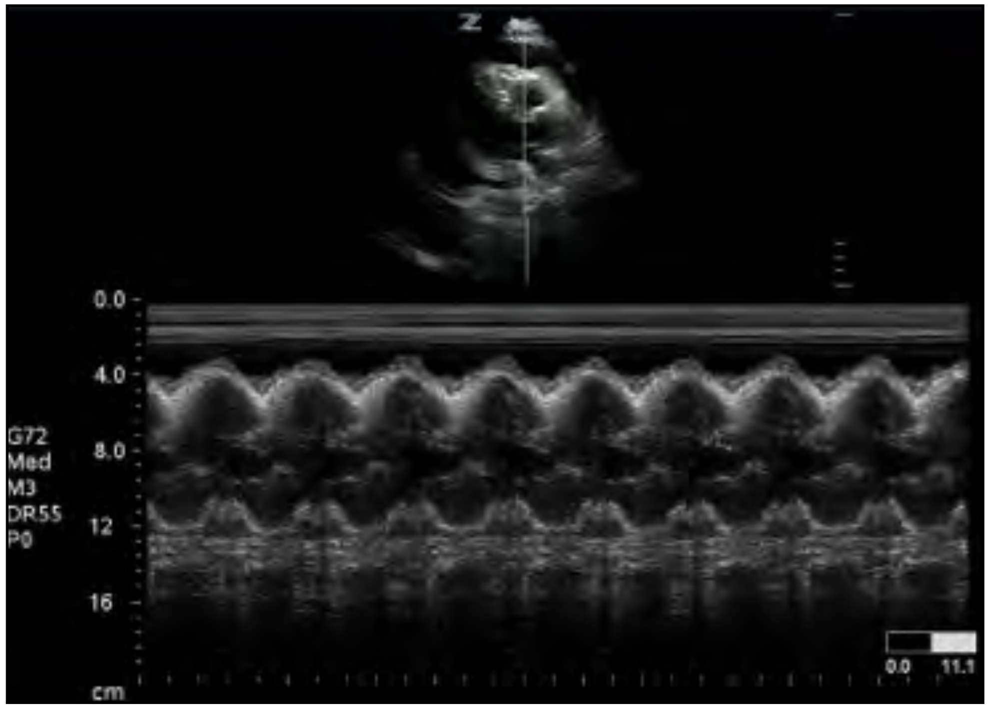
It is important not to confuse ventricular or atrial systole with diastolic collapse. While large pleural effusions may be misinterpreted as pericardial effusions, the descending thoracic aorta can be used to differentiate the two diagnoses. Pleural effusions run posterior or lateral to the descending thoracic aorta, while pericardial effusions track anteriorly or medially (Movies 2.33-2.34).

MOVIE 2.31 - RV Collapse



MOVIE 2.32 - Plethoric IVC in Tamponade

IMAGE 2.6 - RV collapse on M-Mode - Tamponade



MOVIE 2.33 - Right pleural and pericardial effusions

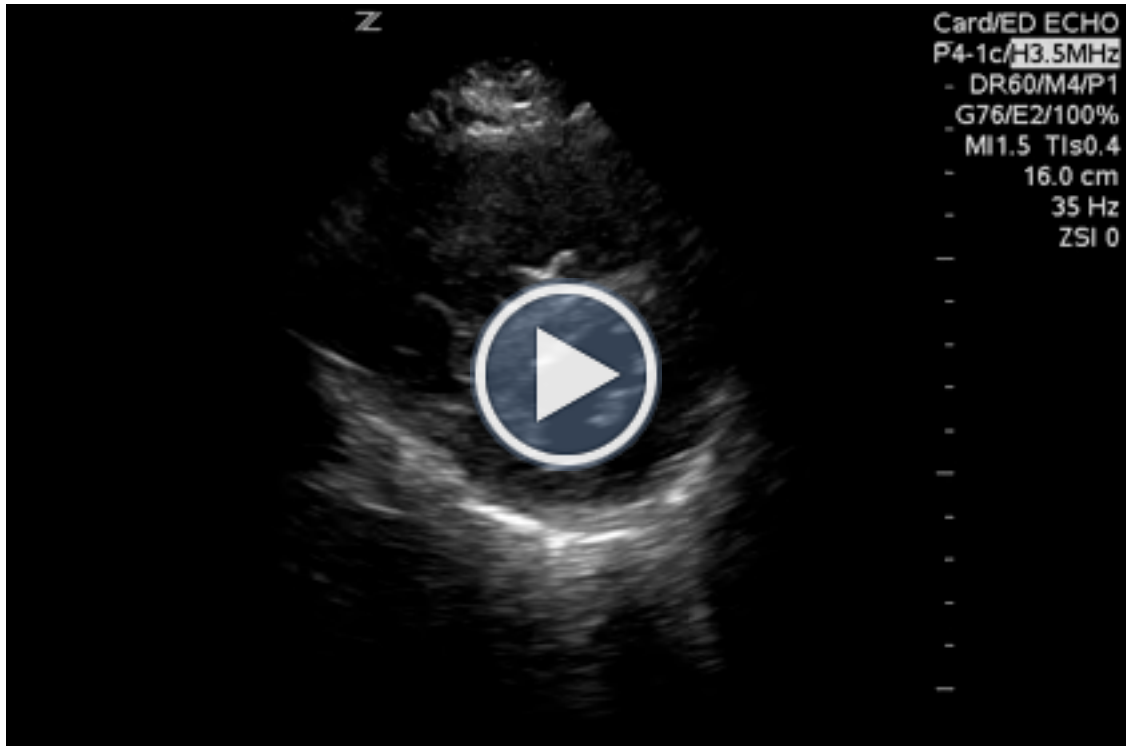
MOVIE 2.34 - Left Pleural and pericardial effusions

SECTION 5

Right Heart Dilatation

Patients with right ventricular dysfunction can be difficult to diagnose and challenging to manage. Patients with right heart failure may worsen with aggressive fluid resuscitation, and identification and reversal of the etiology for RV dysfunction is key.[28-29] The thin-walled right ventricle (RV) is extremely sensitive to load and, as such, small changes in pressure lead to large changes in volume. RV dilatation is the normal response to RV pressure or volume overload.[24] While assessing for RV systolic dysfunction or for paradoxical septal motion (Movie 2.35)

MOVIE 2.35 - Parasternal Short with septal flattening



COMMON CAUSES OF RIGHT HEART DILATATION:

PE

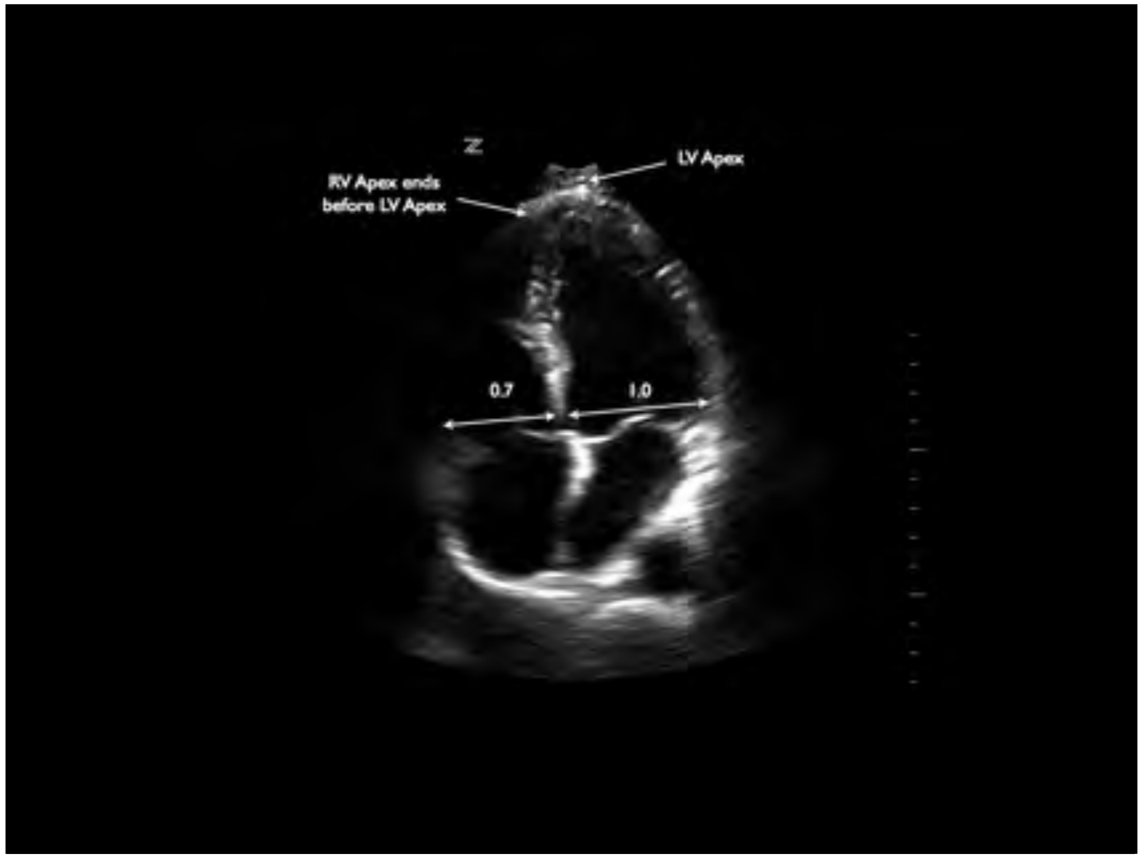
RV infarction

Pulmonary hypertension

COPD

Normal RV:LV ratio is 0.6:1.0

IMAGE 2.7

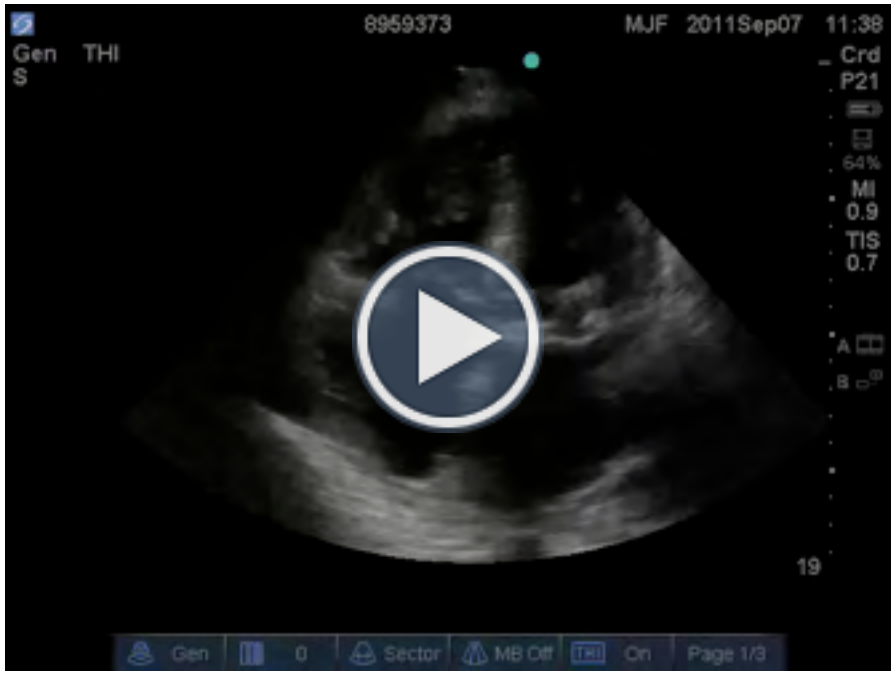


can be challenging for many clinicians, assessing for RV dilatation (chamber size) may not be.[8] Typically, the RV is smaller than the left ventricle, with an RV-to-LV ratio of 0.6:1.0 (Image 2.7).

When the RV is noted to be equal in size to the LV, the RV is moderately dilated (Movie 2.36-2.37).

MOVIE 2.36 - RV dilation

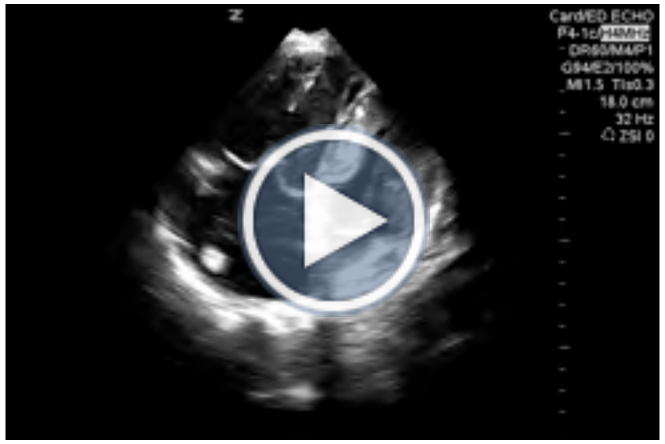
MOVIE 2.37 - RV dilation



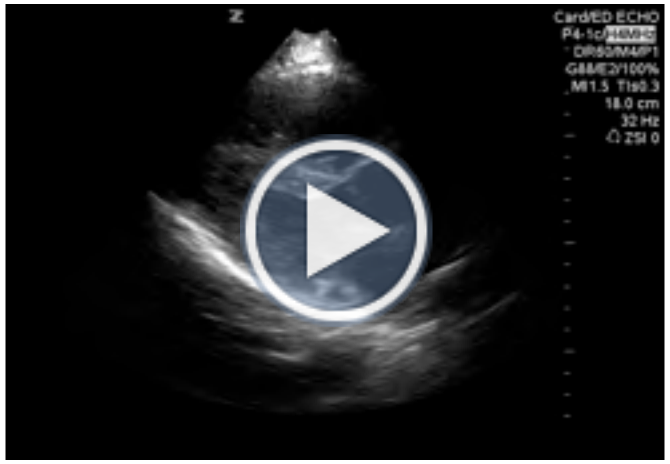
When the RV is larger than the LV, severe RV dilatation is present[30] (Movie 2.38-2.41). The apical 4-chamber view is used to compare RV and LV sizes, and the relative sizes are compared at the tips of the atrioventricular valves in diastole. When RV dilatation is present, the RV apex is shifted closer to – or even encompasses – the LV apex.[25] In the appropriate clinical setting and when combined with other variables, RV dilatation may suggest RV outflow tract obstruction due to pulmonary embolism.[31] Other causes of right ventricular dilatation must also be considered, including RV infarction, pulmonary hypertension, and chronic obstructive pulmonary disease. Bedside echocardiography is not sufficiently sensitive (reported sensitivity of around 60-70%) for the detection of pulmonary embolism and thus, cannot exclude it as a diagnosis.[29,32] Patients with pulmonary embolism and evidence of right-heart dysfunction, however, have increased morbidity and mortality, and bedside echocardiography can be used to risk-stratify and to better manage these patients.[30, 33]

MOVIE 2.38 - RV dilation and failure

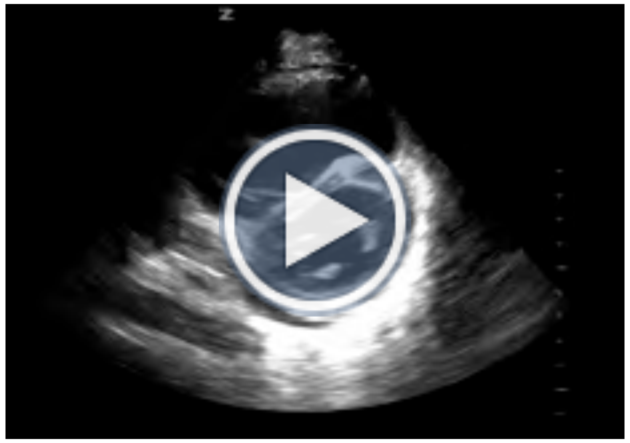
MOVIE 2.39 - RV dilation and failure due to PE - Clot in RA



MOVIE 2.40 - RV dilation and failure



MOVIE 2.41 - RV pressure overload with flattening of septum



SECTION 6

Conclusion

Bedside echocardiography provides clinicians with immediate structural and physiologic data that can be life-saving.[5-6] The ability to assess patients for pericardial effusions, global left ventricular function, and right heart dilatation can provide answers to critical questions, risk-stratify patients, and further guide resuscitative efforts. It is essential, however, to recognize one's limitations when performing basic cardiac ultrasound and to obtain consultant-performed echocardiography when appropriate.

Tell everyone that you just finished another chapter!

Contact us:

SUMMARY

Bedside echocardiography can be life-saving and dead sexy.

It is essential to recognize one's limitations with cardiac ultrasound.

REFERENCES

1.American College of Emergency Physicians. Emergency ultrasound guidelines – 2008. Ann Emerg Med. 2009;53:550-570.

2.Hauser AM. The emerging role of echocardiography in the emergency department. Ann Emerg Med. 1989;18:1298-1303.

3.Mayron R, Gaudio FE, Plummer D, et al. Echocardiography performed by emergency physicians: impact on diagnosis and therapy. Ann Emerg Med. 1988;17:150-154.

4.Moore CL. Special Contribution: Current Issues with Emergency Cardiac Ultrasound Probe and Image Conventions. Acad Emerg Med. 2008;15(3):278-84

5.Kimura BJ, Bocchicchio M, Willis CL, DeMaria AN. Screening cardiac ultrasonographic examination in patients with suspected cardiac disease in the emergency department. Am Heart J. 2001;142(2):324-330.

6.Kaul S, Stratienko AA, Pollack SJ, et al. Value of two-dimensional cardiac ultrasound for determining the basis of hemodynamic compromise in critically ill patients: a prospective study. J Am Soc Echocardiogr 1994;7:598-606.

7.Stahmer SA. The ASE position statement in echocardiography in the emergency department. Acad Emerg Med. 2000;7:306-308.

8.Labovitz AJ, Noble VE, Bierig M, et al. Focused Cardiac Ultrasound in the Emergent Setting: A Consensus Statement of the American Society of Echocardiography and American College of Emergency Physicians. J Am Soc Echocardiogr 2010;23(12):1225-30.

9.Rose JS, Bair AE, Mandavia D, et al. The UHP ultrasound protocol: a novel ultrasound approach to the empiric evaluation of the undifferentiated hypotensive patient. Am J Emerg Med. 2001;19:299-302.

10.Jones AE, Tayal VS, Sullivan DM, et al. Randomized, controlled trial of immediate versus delayed goal-directed ultrasound to identify the cause of nontraumatic hypotension in emergency department patients. Crit Care Med. 2004;32(8):1798-1800.

11.Blaivas M. Incidence of pericardial effusion in patients presenting to the emergency department with unexplained dyspnea. Acad Emerg Med. 2001;8:1143-1146.

12.Mandavia DP, Hoffner RJ, Mahaney K, et al. Bedside echocardiography by emergency physicians. Ann Emerg Med. 2001;38(4):377-382.

13.Blaivas M, Fox J. Outcome in cardiac arrest patients found to have cardiac standstill on the bedside emergency department echocardiogram. Acad Emerg Med. 2001;8:616-621.

14.Jones AE, Tayal VS, Kline JA. Focused training of emergency medicine residents in goal-directed echocardiography: a prospective study. Acad Emerg Med. 2003;10:1054-1058.

15.Moore CL, Rose GA, Tayal VS, et al. Determination of left ventricular function by emergency physician echocardiography of hypotensive patients. Acad Emerg Med. 2002;9:186-193.

16.Randazzo MR, Snoey ER, Levitt AM, et al. Accuracy of emergency physician assessment of left ventricular ejection fraction and central venous pressure using echocardiography. Acad Emerg Med 2003;10(9):973-7.

17.Martin RP, Rakowski H, French J, et al. Localization of pericardial effusion with wide angle phased array echocardiography. Am J Cardiol. 1978;42:904-912.

18.Mazurek B, Jehle D, Martin M. Emergency department echocardiography in the diagnosis and therapy of cardiac tamponade. J Emerg Med. 1991;9:27-31.

19.Tayal VS, Kline JA. Emergency echocardiography to detect pericardial effusion in patients in PEA and near-PEA states. Resuscitation.2003;59(3):315-318.

20.Levine MJ, Lorell BH, Diver DJ, Come PC. Implications of echocardiographically assisted diagnosis of pericardial tamponade in contemporary medical patients: detection before hemodynamic embarrassment. J Am Coll Cardiol. 1991;17:59-65.

21.Tsang TSM, Oh JK, Seward JB. Diagnosis and management of cardiac tamponade in the era of echocardiography. Clin Cardiol. 1999;22:446-452.

22.Blaivas M, Graham S, Lambert MJ. Impending cardiac tamponade: an unseen danger? Am J Emerg Med. 2000;18:339-340.

23.Shabetai R. Pericardial effusion: haemodynamic spectrum. Heart. 2004;90:255-256.

24.Otto CM. Textbook of Clinical Echocardiography. 3rd ed. Philadelphia: Elsevier– Saunders; 2004.

25.ASE Committee Recommendations. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, Developed in Conjunction with the European Association of Echocardiography, a Branch of the European Society of Cardiology. J Am Soc Echocardiography. 2005;18(12):1440-1463.

26.Plummer D, Brunette D, Asinger R, Ruiz E. Emergency department echocardiography improves outcome in penetrating cardiac injury. Ann Emerg Med. 1192;26:709-712.

27.Gillam LD, Guyer DE, Gibson TC, et al. Hydrodynamic compression of the right atrium: a new echocardiographic sign of cardiac tamponade. Circulation. 1983;68:294-301.

28.Kucher N, Goldhaber SZ. Management of massive pulmonary embolism. Circulation 2005;112:e28-32.

29.Torbicki A, Perrier A, Kostantinides S, et al. Guidelines on the diagnosis and management of acute pulmonary embolism. Eur Heart J 2008;29:2276-315.

30.Kasper W, Konstantinides S, Geibel A, et al. Prognostic significance of right ventricular afterload stress detected by echocardiography in patients with clinically suspected pulmonary embolism. Heart. 1997;77:346-349.

31.Nazeyrollas P, Metz D, Jolly D, et al. Use of transthoracic echocardiography combined with clinical and electrocardiographic data to predict acute pulmonary embolism. Eur Heart J. 1996;17:779-786.

32.Roy PM, Colombet I, Durieux P, Chatellier G, Sors H, Meyer G. Systematic review and meta-analysis of strategies for the diagnosis of suspected pulmonary embolism. Br Med J 2005;331:259.

33.Ribiero A, Lindmarler P, Juhlin-Dannfelt A, et al. Echocardiography Doppler in pulmonary embolism: right ventricular dysfunction as a predictor of mortality rate. Am Heart J. 1997;134:479-487.

Chapter 3

Aorta

SECTION 1

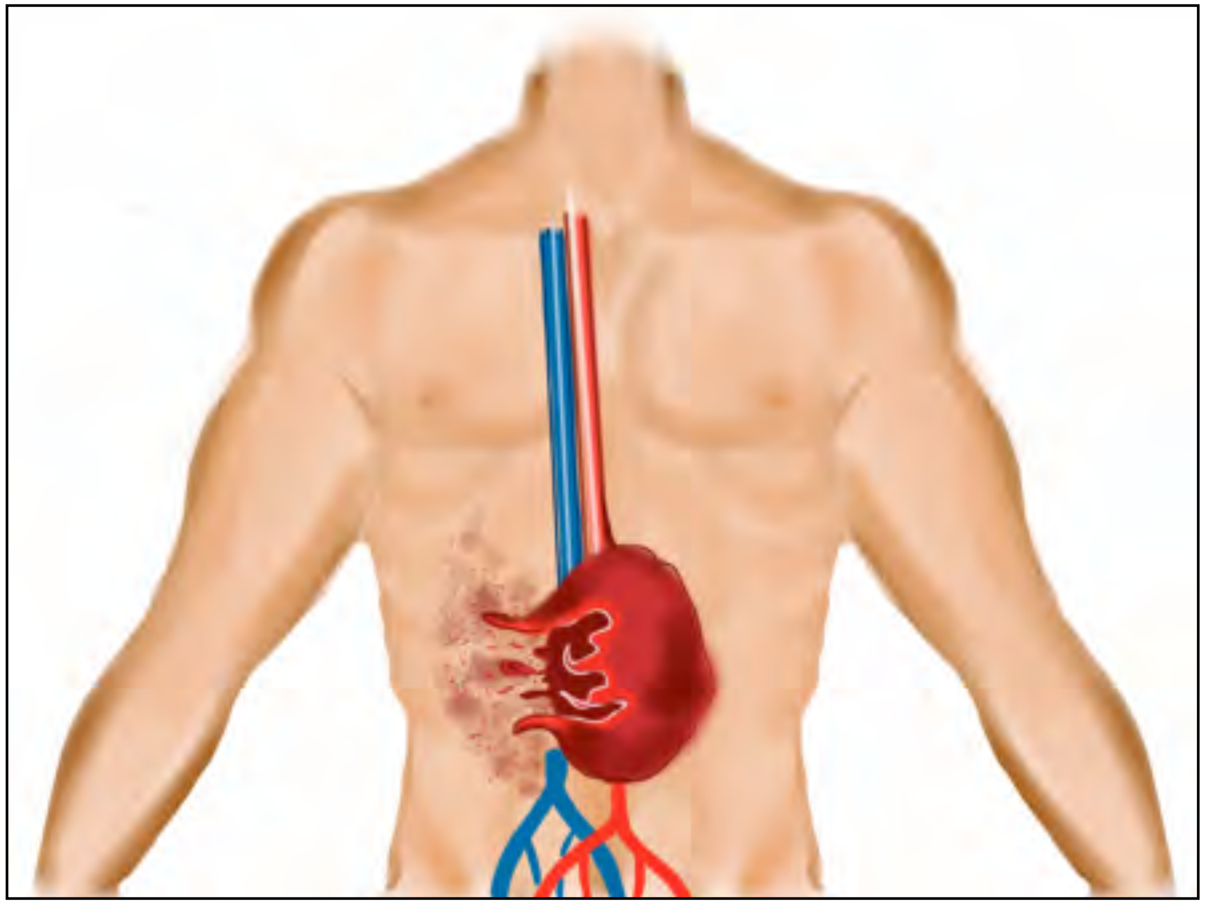
Introduction

Overall mortality of ruptured AAA may exceed 90%

Ruptured AAA may present simply as undifferentiated hypotension

The incidence of abdominal aortic aneurysm (AAA) has been reported to be as high as 36.2 per 100,000 and is increasing.[1] Up to 62% of patients with ruptured aneurysms die before reaching the hospital, and the overall mortality rate after rupture may exceed 90%.[2] An AAA should be suspected in any patient > 60 years with complaints of abdominal or back pain, particularly if they have a history of hypertension or smoking. Ruptured AAA may present as undifferentiated hypotension and rapid diagnosis is essential.

FIGURE 3.1



Section 2

Indications/Anatomy

Indications for AAA scan:

Abdominal pain

Back Pain

Chest Pain

Pulsatile Abdominal Mass

Renal Colic

Syncope

Hypotension

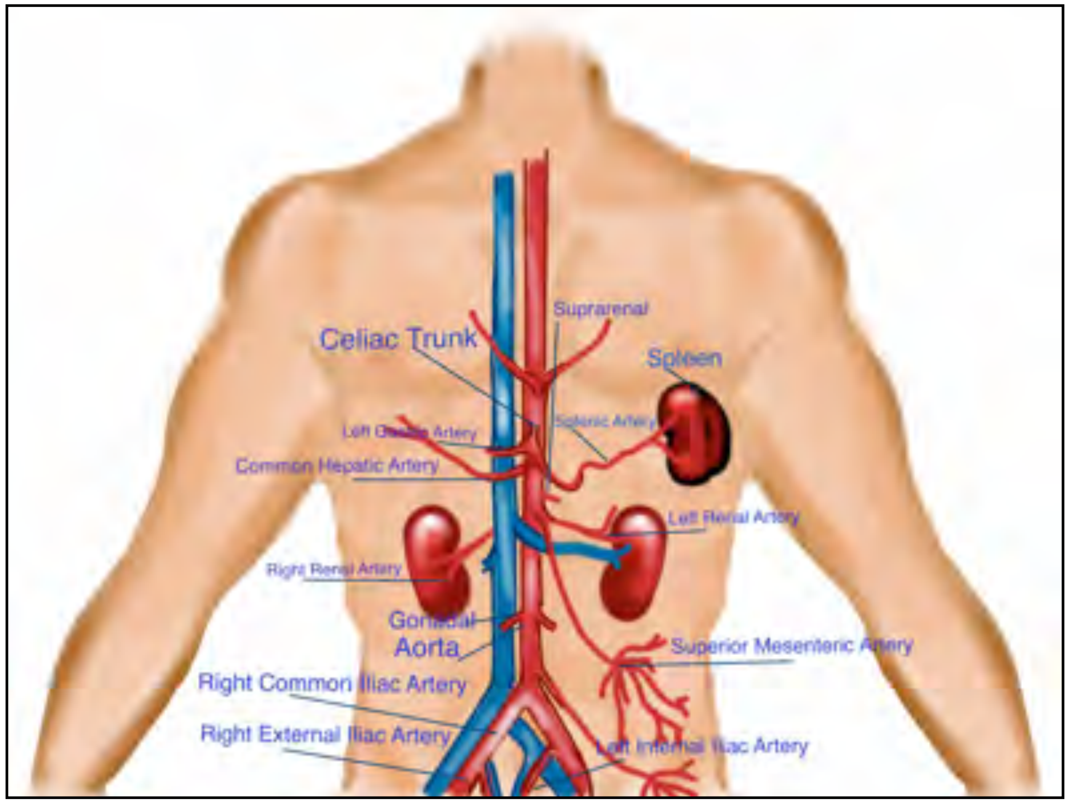
Indications

The main impetus for the scan includes a clinical suspicion for AAA. Indications may include abdominal pain, back pain, chest pain, a pulsatile abdominal mass, "renal colic", syncope, hypotension, weakness, or neurologic changes in the extremities. One high-risk group, in particular, includes older males with hypertension and a history of tobacco abuse.

Relevant Anatomy

The abdominal aorta enters the abdomen through the diaphragm just inferior to the xiphoid process (T12) and bifurcates around the level of the umbilicus (L5). It has a predictable series of branches as pictured below. (Figure 3.2)

Figure 3.2



Aorta and its branches.

The 1st branch off the abdominal aorta is the celiac trunk. (Movie 3.1)

Movie 3.1

Celiac trunk of the proximal aorta

The celiac trunk divides into three vessels, although typically, only the hepatic artery and splenic artery are reliably visualized. The 2nd branch off the abdominal aorta is the superior mesenteric artery (SMA); typically, 1 cm caudal to the celiac trunk. The SMA runs parallel to the abdominal aorta and can be tracked caudally with the abdominal aorta. While the renal arteries may be visualized, the branches of the gonadal and inferior mesenteric arteries are not typically seen with ultrasound. The abdominal aorta ultimately bifurcates into the common iliac vessels around the level of the umbilicus.

SECTION 3

Technique

Curvilinear probe is preferred probe

Scan in transverse and longitudinal all the way through the bifurcation of the iliacs

Use steady pressure to scan through bowel gas

Aneurysms can be fusiform (more common) or saccular

PROBE SELECTION

Curvilinear probe 2-5 MHz (preferable) or phased array probe 1-5 MHz.

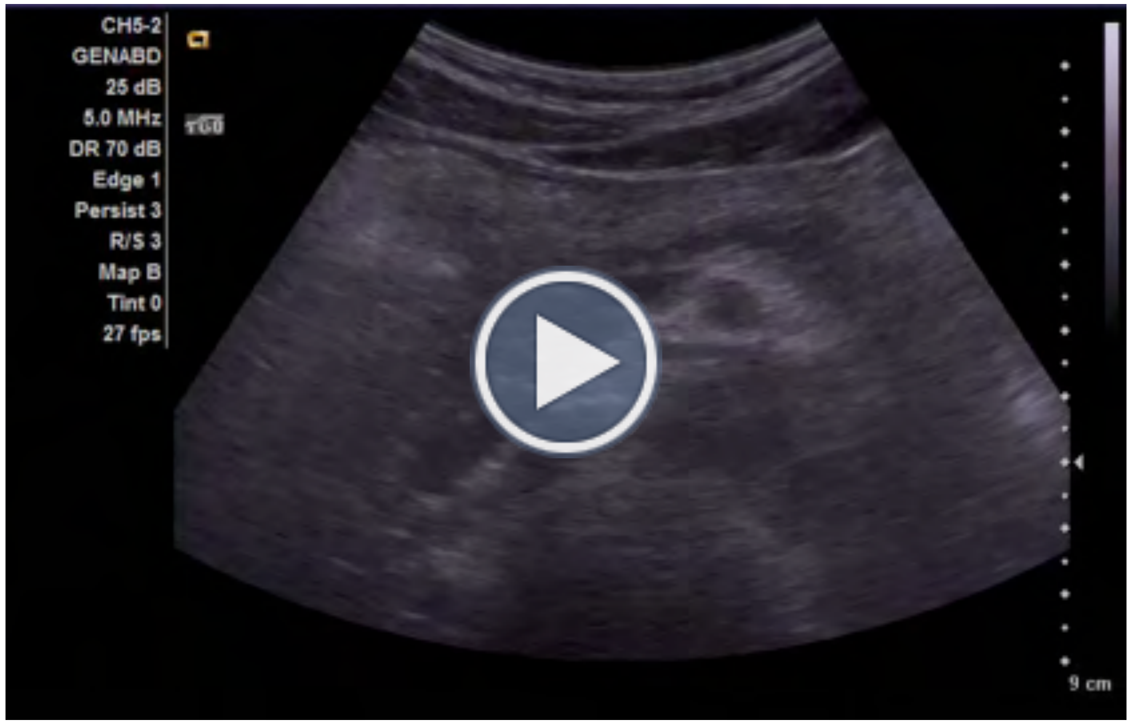
TECHNIQUE

The general approach is to start with the probe indicator pointing to 9 o'clock, immediately caudal to the xiphoid process. This produces a transverse image of the abdominal aorta. You will need to scan from this mid-epigastric location caudally to the bifurcation of the aorta, visualizing the transverse high, mid, and low aorta. (Gallery 3.1, Movies 3.2 and 3.3)

GALLERY 3.1 Technique

Transverse high probe placement

MOVIE 3.2 Normal scan of the transverse aorta



MOVIE 3.3 Iliac bifurcation

Next, you will turn the probe towards the patient's head at 12 o'clock. (Movie 3.4)

MOVIE 3.4 Normal scan of the proximal aorta in longitudinal

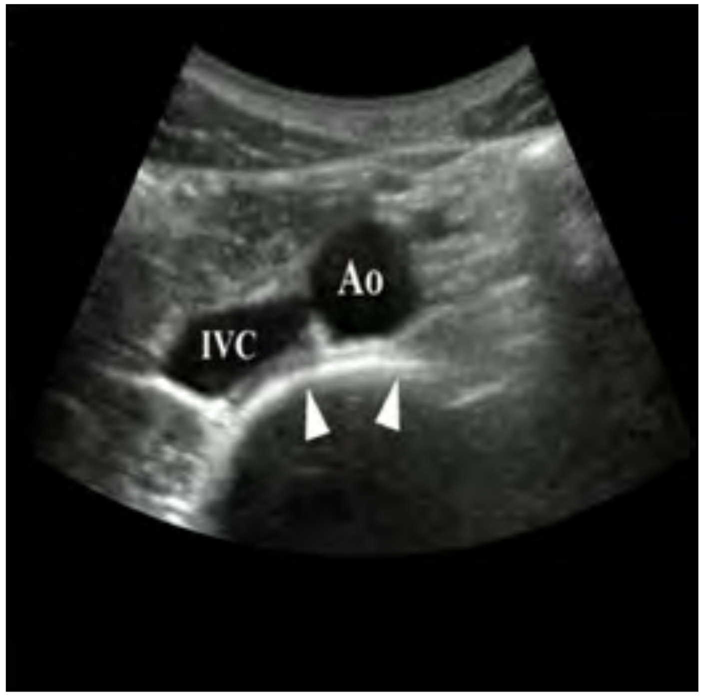
IMAGE 3.1 - Longitudinal probe placement

MOVIE 3.5 - Normal longitudinal scan of the aorta to the bifurcation

This produces a longitudinal view of the aorta. Again, you will scan from the mid-epigastrium to the bifurcation at the umbilicus. (Image 3.1 and Movie 3.5)

To adequately image the aorta, the first step is to identify the vertebral body. The vertebral body is horseshoe-shaped with an intense echogenic anterior surface and posterior shadowing. (Image 3.2)

IMAGE 3.2 - Arrowheads indicating vertebral body on transverse view of the aorta



The aorta is anterior to the vertebral body and slightly to the patient's left (right side of the ultrasound image). The inferior vena cava (IVC) is also anterior to the vertebral body, and to the patient's right.

Scan caudally to the aortic bifurcation with methodical real-time visualization, without skipping any section of the aorta.

As you scan cephalad to caudad (head to toe), identify the following: Celiac trunk, (Movie 3.1), SMA, and Aortic bifurcation. (Gallery 3.2)

GALLERY 3.2 Celiac Trunk, SMA, Aortic Bifurcation

Transverse aorta with celiac trunk (seagull sign); Hep A = hepatic art, Spl A = splenic art, * = aorta)

Turn the probe to the longitudinal plane (pointer to 12 o'clock) to obtain a longitudinal view of the aorta and the associated vessels (celiac and SMA). (Image 3.3)

IMAGE 3.3 - Proximal aorta in longitudinal

The same proximal branches (celiac and SMA) seen in transverse plane should be seen in longitudinal plane.

MOVIE 3.6 - One Minute Ultrasound App - transverse aorta scan demo.

Again, move cephalad to caudad as you scan the entire length of the vessel. (Movie 3.6)

IMPEDIMENTS & SOLUTIONS

Ultrasound of the aorta can be quite difficult depending on bowel gas and body habitus. Imaging impediments due to bowel gas usually originate from the transverse colon, which sits in the epigastrium. If bowel is encountered, apply steady pressure (push down towards the patient's back) with the probe. The bowel may be effectively compressed or undergo peristalsis. You may also try to jiggle the probe to move bowel aside. Another alternative is to fan through windows between loops of bowel. This is accomplished by establishing a good sonographic window, just cephalad to the area obscured by bowel, and tilting the probe toward the feet. Similarly, find a window just caudad to the obstructed area and angle the probe up toward the head.

IMAGE 3.4 - Mid aorta with calipers with IVC marked

Obesity impediments may be addressed by asking the patient to lie completely flat. Have the patient flex their hips and knees to relax the abdominal muscles. Finally, lower the scanning frequency to increase penetration.

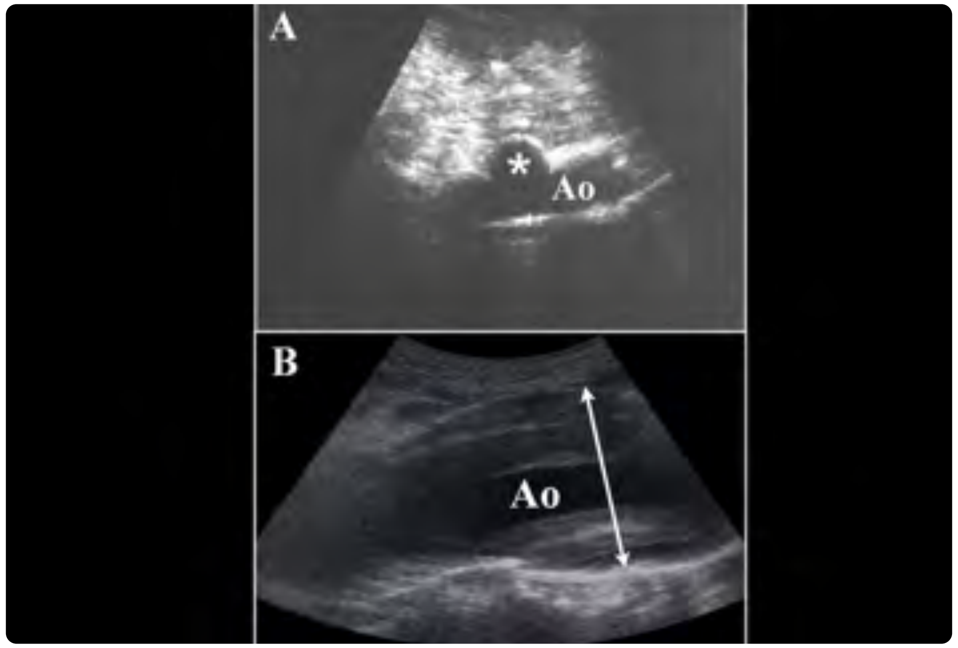
Normal US Findings:

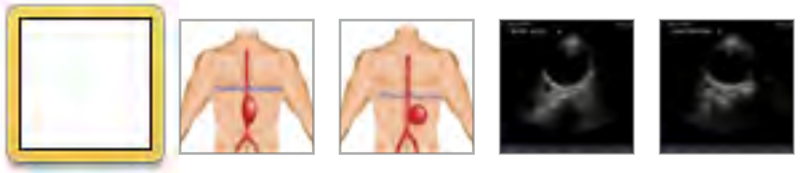
The normal aorta is < 3cm and tapers distally. Appropriate documentation will include a caliper measurement of the proximal, mid and distal aorta. (Image 3.4) Measurements should be taken in the transverse plane, to limit the tangential effect of underestimating diameter on a longitudinal image of the aorta. ALWAYS MEASURE OUTER WALL TO OUTER WALL. A mural thrombus or plaque in the lumen may underestimate the size of the AAA.

Abnormal US Findings: Any aortic measurement >3cm is abnormal; any aorta that fails to taper appropriately as it moves caudally is considered abnormal as well. Of note, the majority of AAAs are INFRARENAL.[3]

There are two types of aneurysm: fusiform and saccular. (Gallery 3.3) Fusiform aneurysms are much more common and involve dilation of the entire circumference of the affected segment of the aorta. (Gallery 3.3 and Movies 3.7-3.11) A saccular aneurysm is an asymmetric outpouching (i.e. sac-like) of the aorta. (Gallery 3.3 and Movie 3.12)

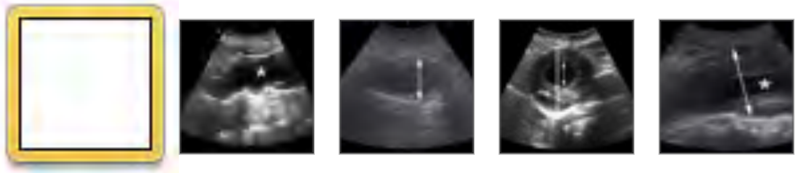
GALLERY 3.3



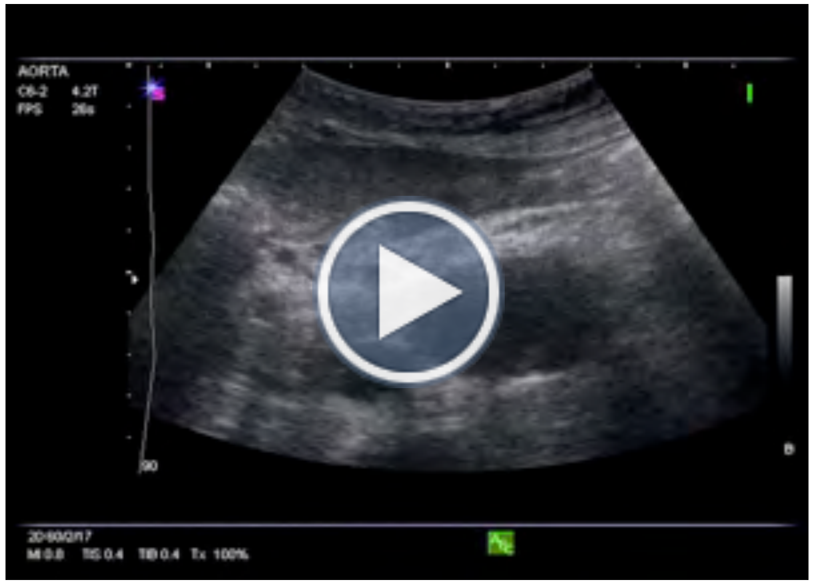


GALLERY 3.4

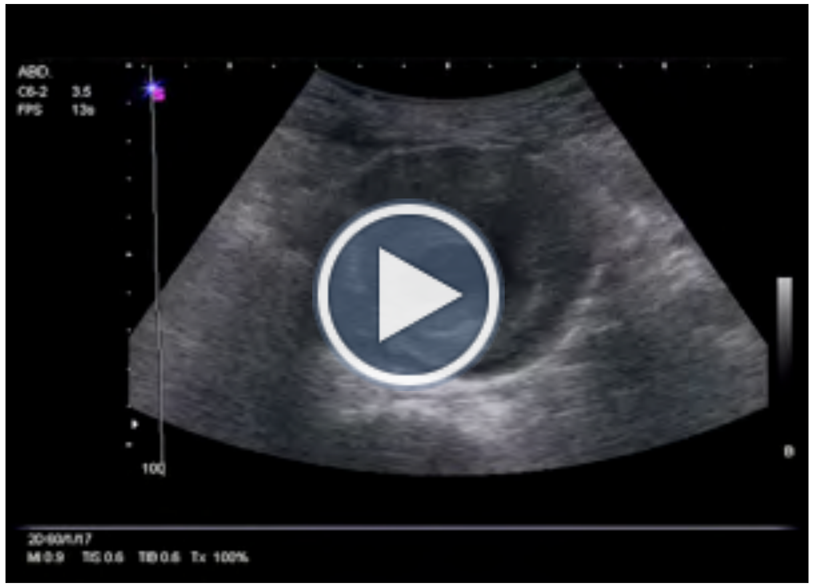
Arrows noting AP diameter of AAA



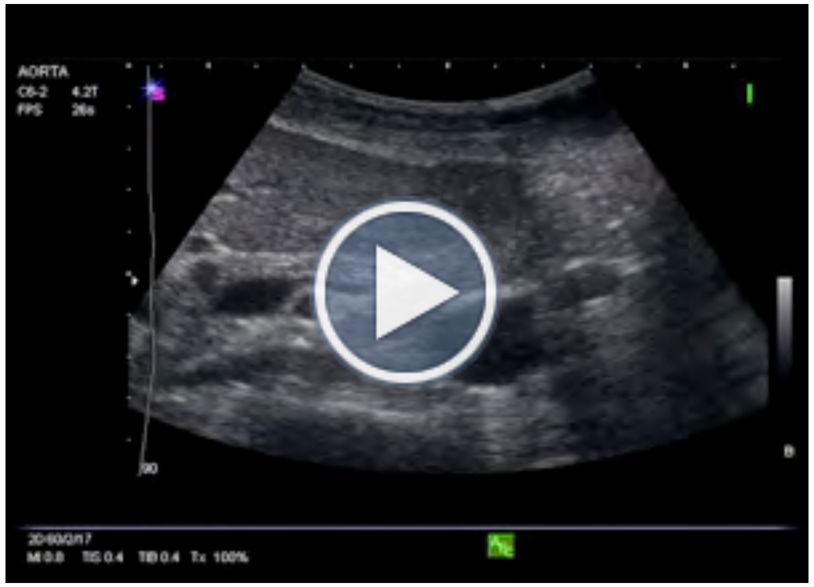
Movie 3.7 - 3.5 cm AAA in transverse



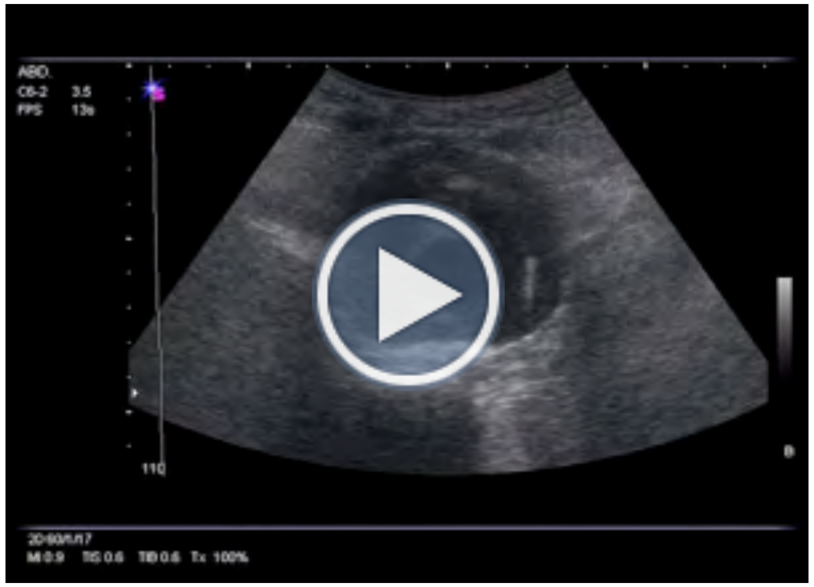
Movie 3.8 - 7 cm AAA in transverse to longitudinal



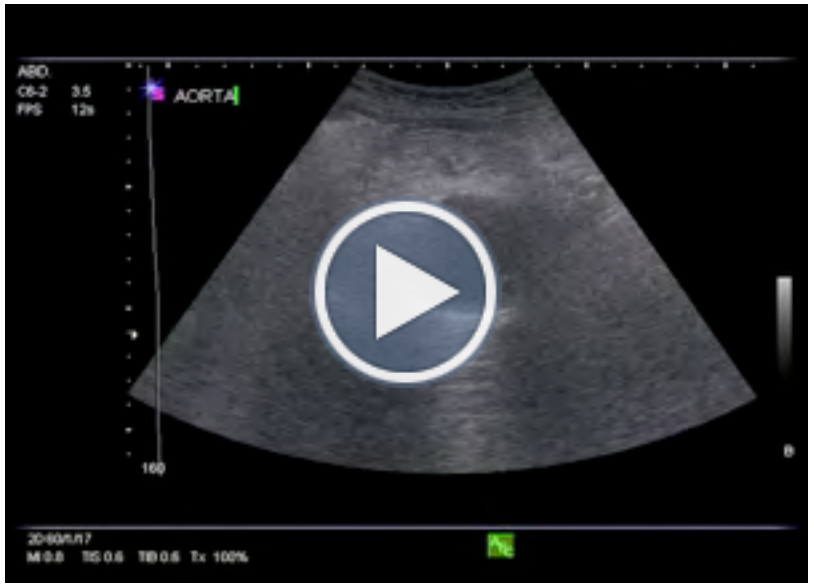
Movie 3.9 - 3.5 cm AAA in transverse to longitudinal



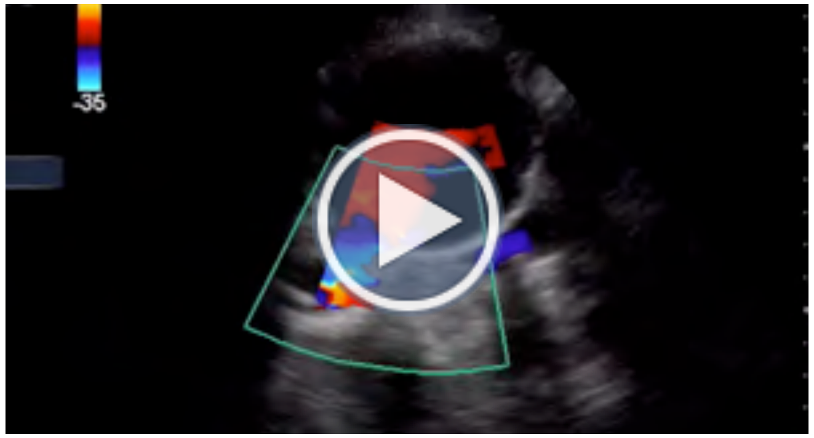
Movie 3.10 - 7 cm AAA in transverse



Movie 3.11 - 6 cm AAA in transverse to longitudinal



Movie 3.12 - Saccular Aneurysm



MOVIE 3.13 - 7cm R common iliac aneurysm

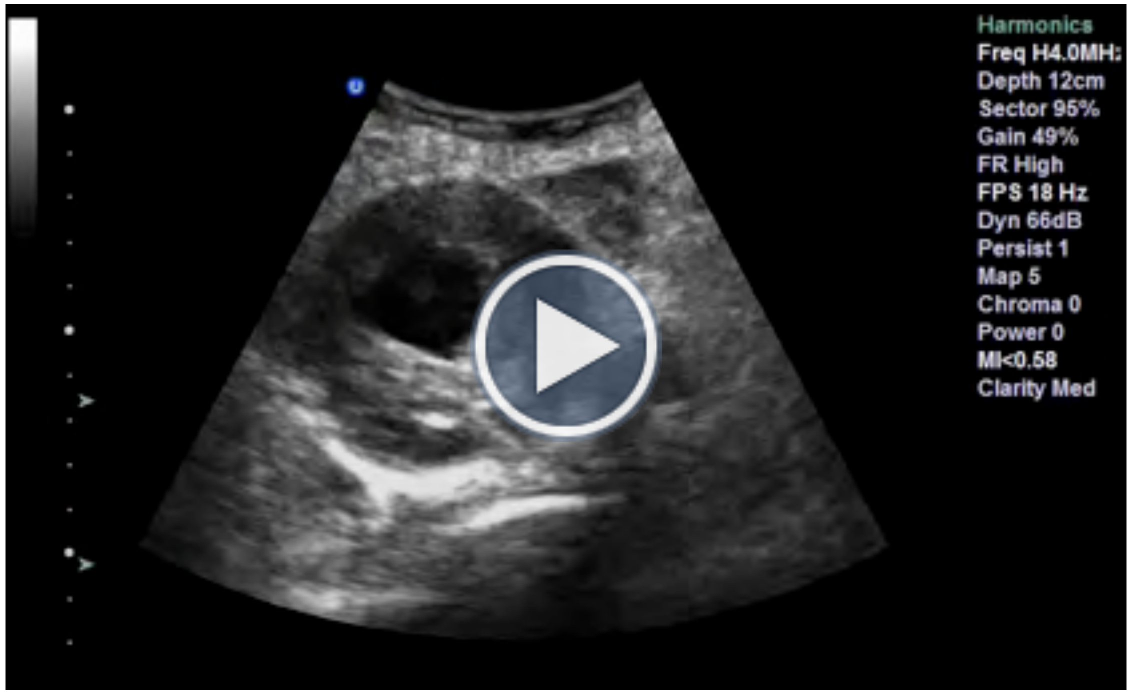


IMAGE 3.5 - 7cm iliac aneurysm marked

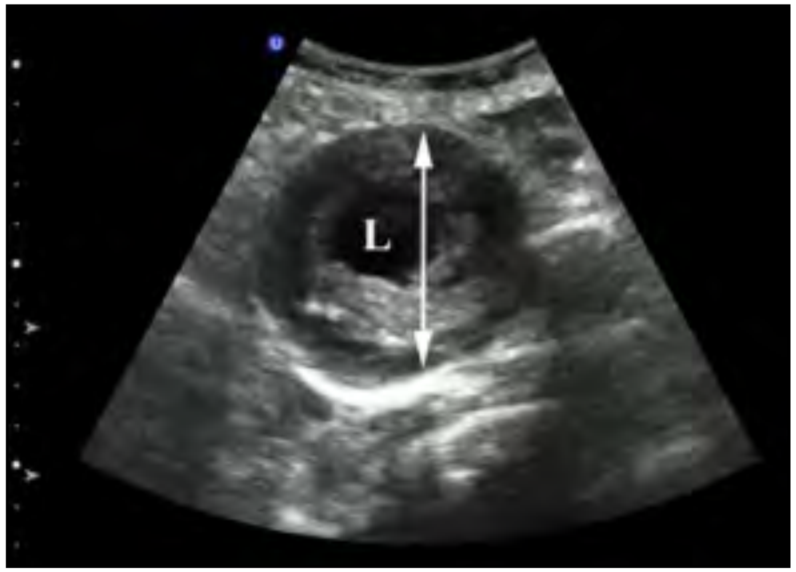
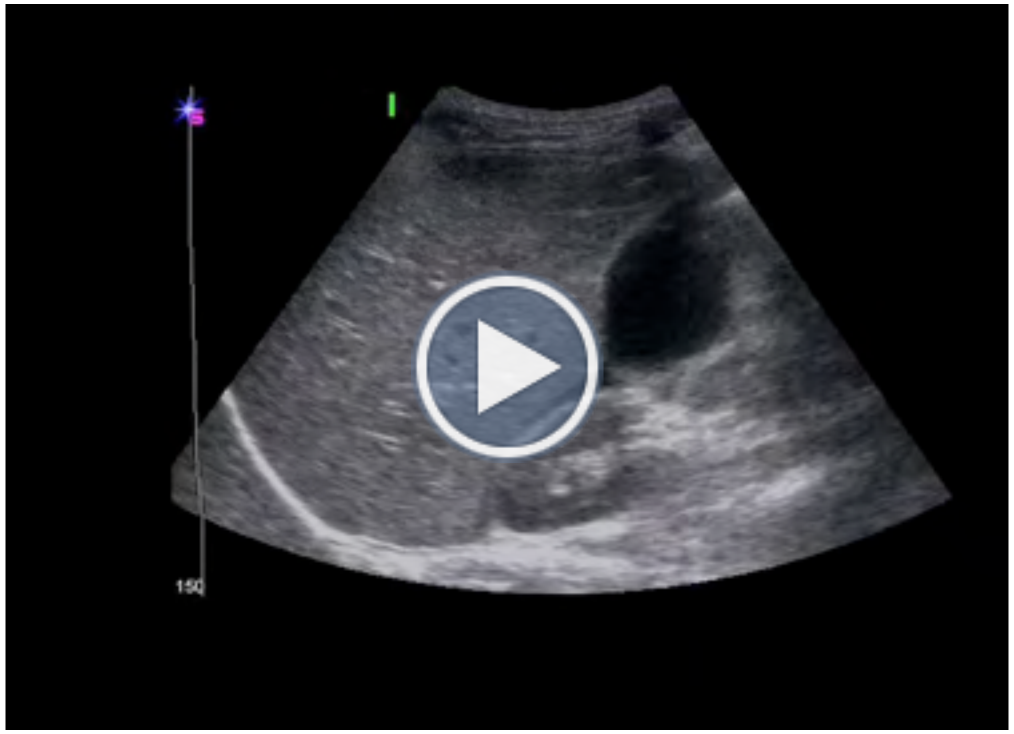


IMAGE 3.6 - Peri-hepatic free fluid (arrowheads)

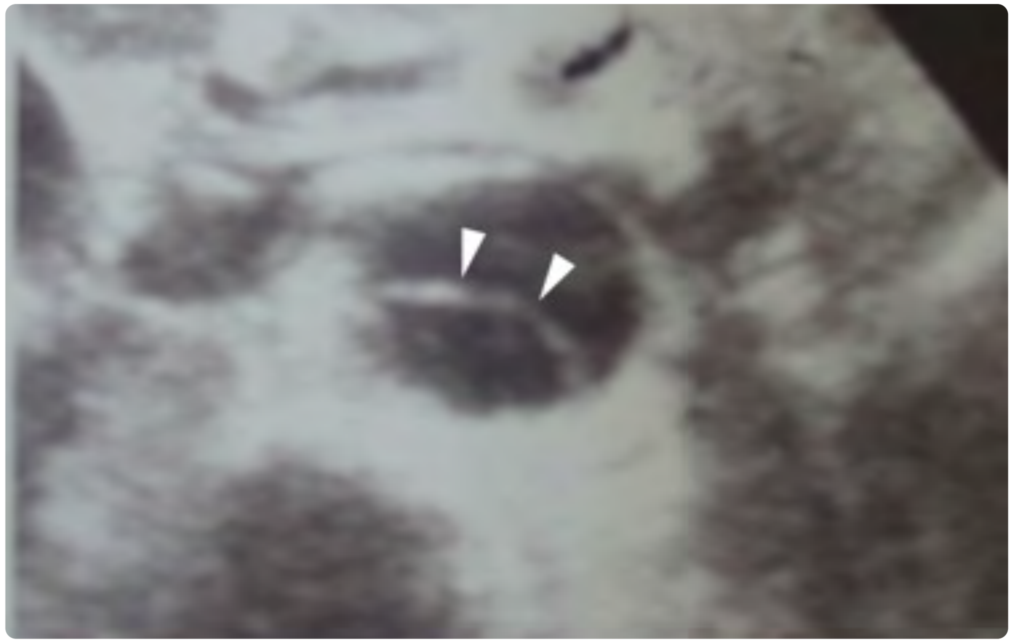
Of note, aneurysms may extend into the iliac arteries as well, so a comprehensive, methodical scan through the bifurcation is recommended. (Image 3.5 and Movie 3.13)

Emergency bedside ultrasound is highly sensitive for the presence of an AAA but has poor sensitivity for acute rupture.[4] Rupture of an AAA most commonly occurs into the retroperitoneal space and may tamponade before the patient becomes unstable. Unfortunately, ultrasound does not reliably identify retroperitoneal blood. (Ultrasound of retroperitoneal bleed) An AAA rupture occasionally is intraperitoneal, with free fluid readily identified by ultrasound. (Image 3.6 and Movie 3.14) This is a particularly ominous finding. An aortic dissection (floating intimal flap) may occasionally be found while performing an US to rule out AAA. (Gallery 3.5 and Movies 3.15 and 3.16)

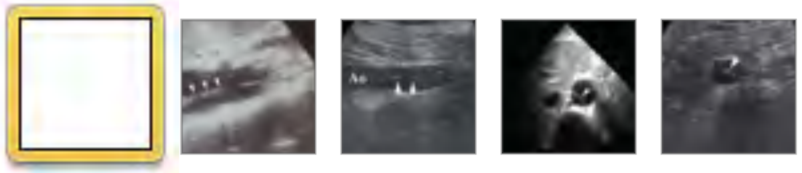
MOVIE 3.14 - Intraperitoneal free fluid in Morison's pouch



GALLERY 3.5 - Ao Dissection

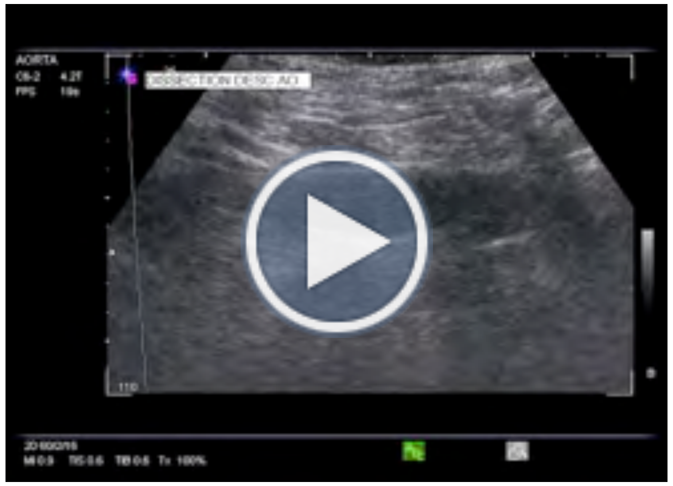


Marked transverse aortic dissection (courtesy of Dr. Chris Moore, Yale School of Medicine)



MOVIE 3.15 - Aortic dissection in longitudinal

MOVIE 3.16 - Aortic dissection longitudinal to transverse



Pearls and Pitfalls

Be sure to measure outer wall to outer wall as thrombus can cause underestimation of aneurysm size.

Retroperitoneal rupture is hard to pick up on ultrasound

Always measure in transverse completely perpendicular to the vessel

Be careful to not mistake the IVC for the Aorta

Dissection flaps are easily overlooked

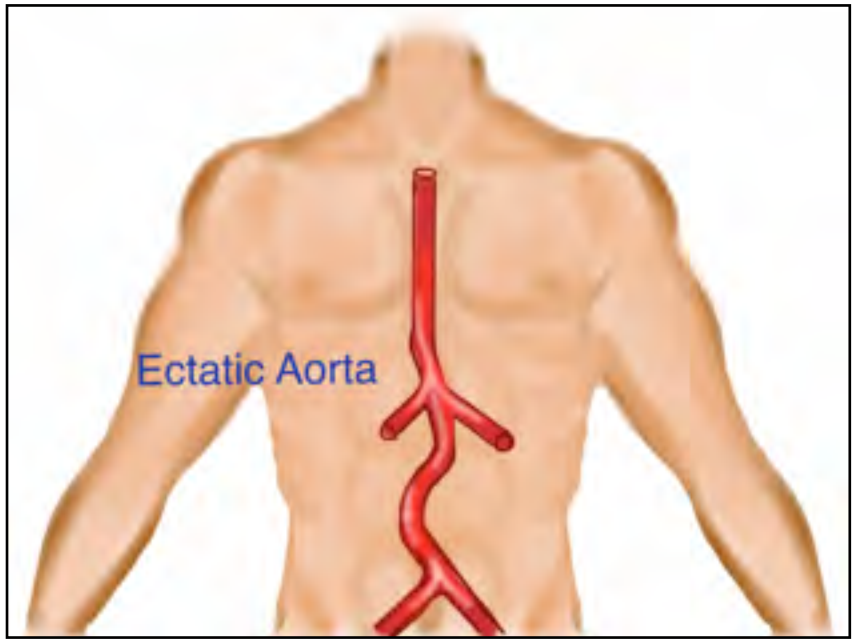
Thrombus within an AAA can be mistaken for the aortic wall, leading to an underestimation of the true AAA diameter. To avoid this error, adjust the gain so that aortic lumen is black. If possible, decrease the dynamic range to improve the contrast between vessel wall and lumen. Be sure to measure outer wall to outer wall.

Another pitfall is to assume an AAA is not ruptured in the absence of free intraperitoneal fluid. Retroperitoneal bleeding, which is a far more common site of rupture, is NOT reliably detected by ultrasound. (Case Study) Note: While ultrasound can reliably detect an AAA, it typically gives no information about rupture.

Saccular aneurysms can be easily missed unless a thorough scan is performed. Systematic, continuous scanning in both longitudinal and transverse planes is essential to prevent a false negative diagnosis.

An ectatic aorta may have irregular course. (Figure 3.3)

FIGURE 3.3 - Ectatic aorta

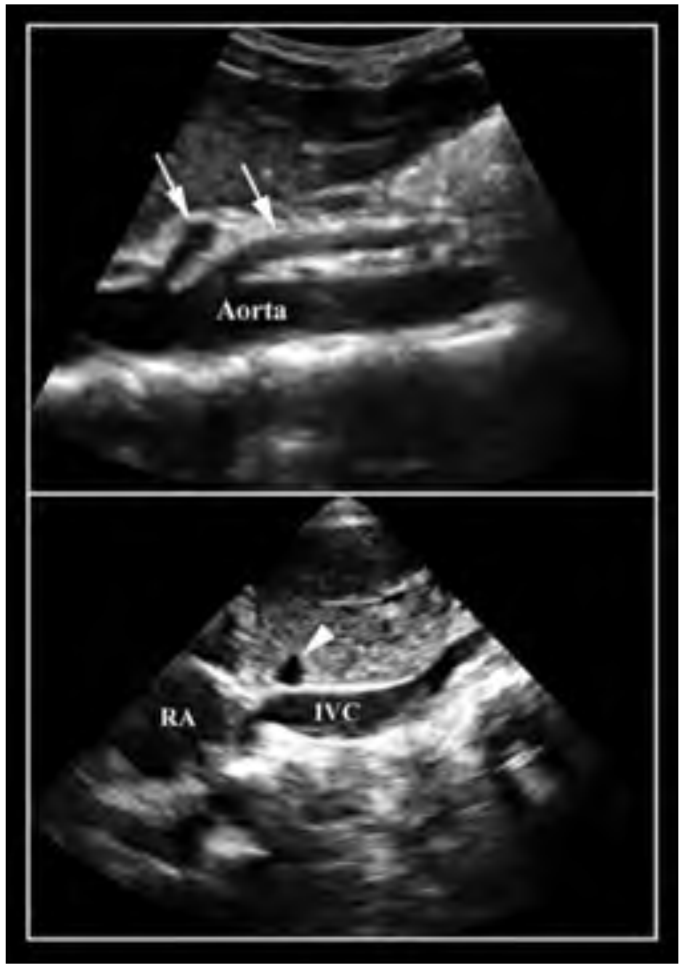


Dynamic scanning, while adjusting for changes in vessel angle, will allow for complete visualization.

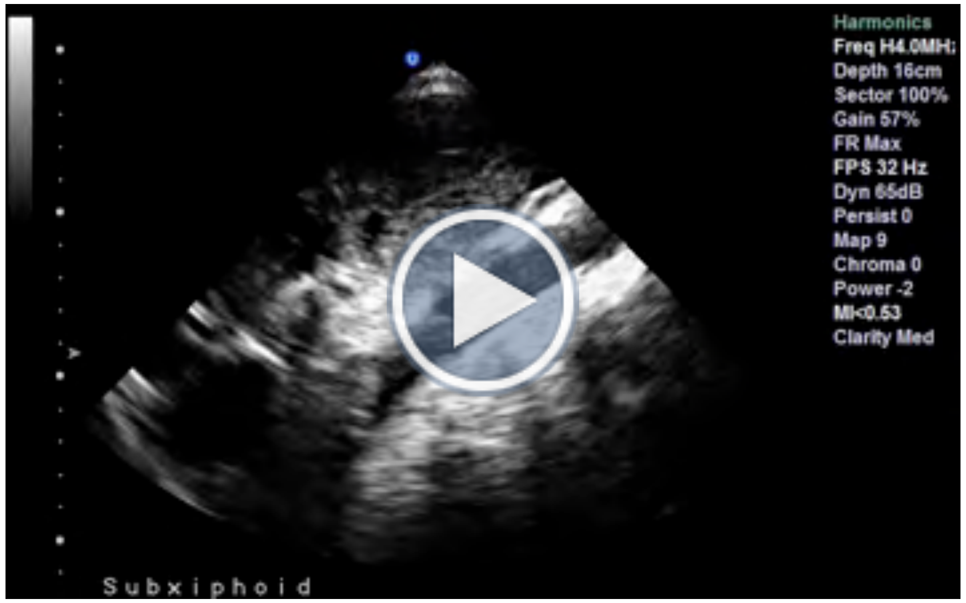
Angled transverse cuts may exaggerate the true aortic diameter. Obtain measurements at 90° to the vessel. Off-axis (tangential) longitudinal cuts underestimate aortic diameter. Caliper measurements should be made in a transverse view only.

Inexperienced sonographers can mistake the IVC for the aorta, especially in long axis because both the aorta and IVC are pulsatile. (Image 3.7 and Movie 3.17)

IMAGE 3.7 - Two panels comparing sono appearance of Aorta vs IVC



MOVIE 3.17 - Comparison of aorta to IVC



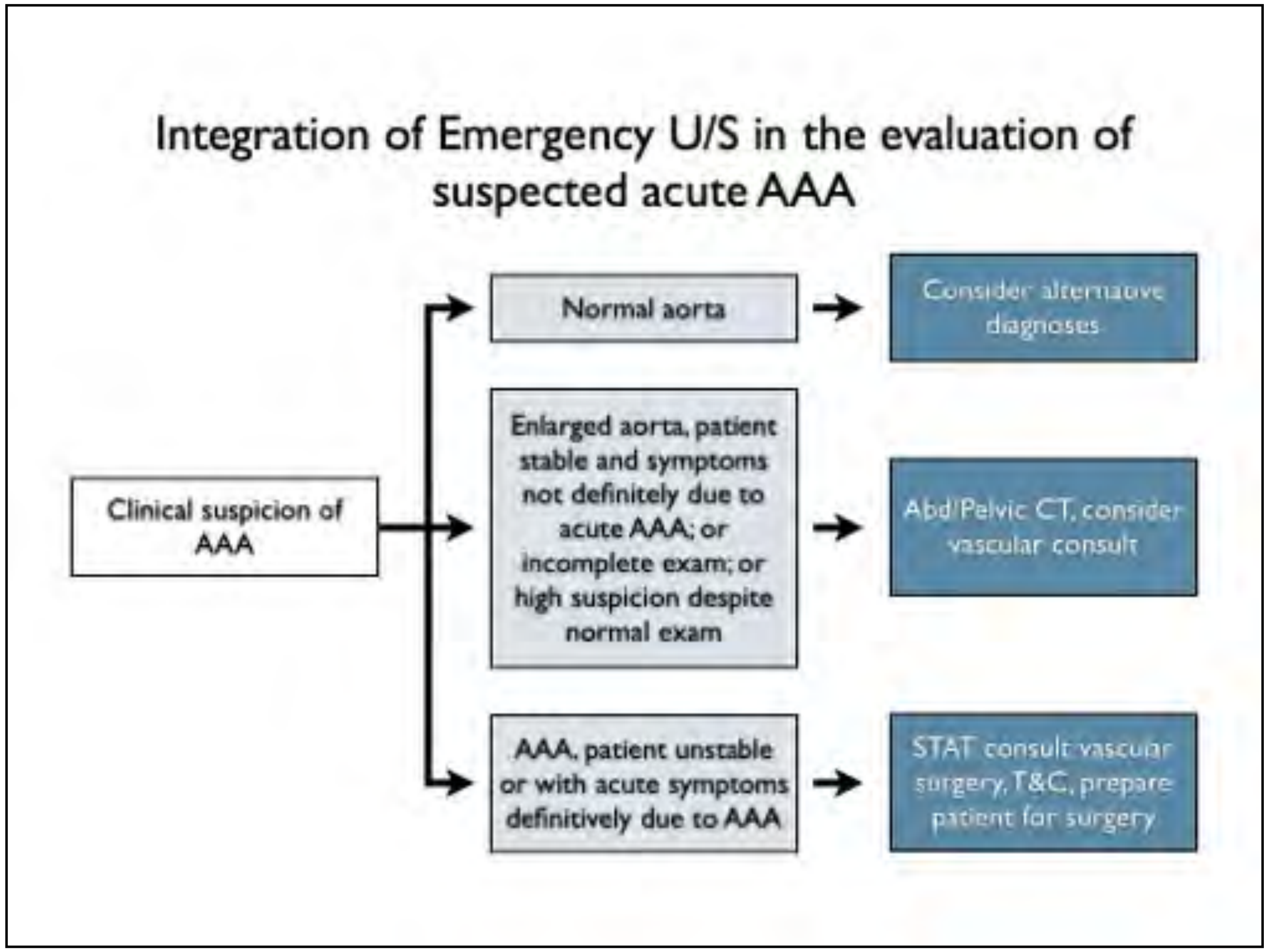
The aorta lies to the patient's left of the IVC. Moreover, the aorta has anterior branches caudal to the liver, while the IVC does not. Finally, the aorta is typically more round, non-compressible, and has brighter, thicker walls than the IVC.

Small aneurysms (< 4.5cm) can rupture, although less frequently than a larger AAA.

If an AAA is identified by US, it still may not be the cause of the patient's symptoms. Consider abdominal, renal or musculoskeletal pathology.

Dissection flaps are easily overlooked. If there is a high clinical suspicion for AAA and the ultrasound is equivocal, obtain a CT (with contrast if no renal impairment).

FIGURE 3.4 - Flowchart of Aorta Ultrasound in the ED



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REFERENCES

1.Bickerstaff LK, Hollier LH, Van Peenen HJ, et al. Abdominal aortic aneurysms: the changing natural history. J Vasc Surg. 1984;1(1):6-12.

2.Ernst CB. Abdominal aortic aneurysm. N Eng J Med. 1993;328(16):1167-1172.

3.Golledge J, Muller J, Daugherty A, et al. Abdominal aortic aneurysms: pathogenesis and implications for management. Arteriosclerosis, Thrombosis and Vascular Biology. 2006;26;2605.

4.Kuhn M, Bonnin RL, Davey MJ, et al. Emergency department ultrasound scanning for abdominal aortic aneurysm: accessible, accurate and advantageous. Ann Emerg Med. 2000;36(3):219-223.

Chapter 4

Lung

Section 1

Introduction

Summary

Lung Ultrasound is a paradigm shift

"The voyage of discovery is not in seeking new landscapes but in having new eyes."

- Marcel Proust

Thoracic ultrasound is one of the more exciting applications for point-of-care ultrasound as it has opened up the possibility for an improvement in the standard of care. For the last several decades the mainstay for initial diagnostic imaging has been the chest radiograph. However, there are some inherent failings with the chest radiograph. First, changes in the chest radiograph image lag behind a patient's clinical picture - sometimes as long as 24 hours behind. Second, while the technology is portable, it requires a technologist, a machine that is usually not housed in the patient's room, image development that takes place in a remote area from the patient, and final image interpretation by a consultant - all of which add complexity and time to the diagnostic imaging process. Finally, given that each chest radiograph involves some small but non-zero exposure to ionizing radiation, there is some risk to the patient, which increases as chest radiography is used to monitor a patient's condition over time and a response to treatment. Thoracic ultrasound has none of these limitations. The biggest challenges for thoracic ultrasound are to get the physician to think in a radically different way about how to visualize pathology and to empower the clinician to feel that the thoracic ultrasound images are an equal, if not a more valid, indication of pathology and disease.

SECTION 2

Basics/Terminology

SUMMARY

Pleural line is bright white line between rib shadows

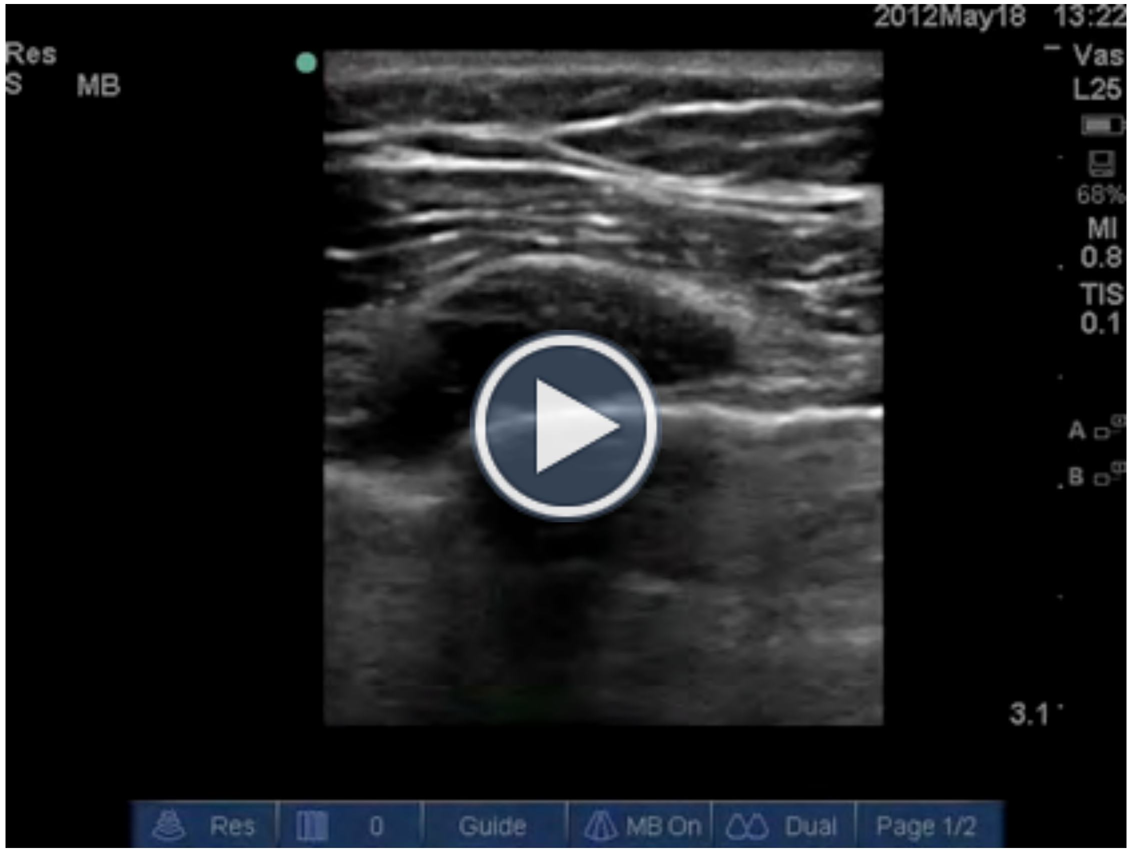
A-Lines represent normal lung

B-Lines represent interstitial fluid

Low Frequency probe is preferred for most thoracic ultrasound (2.5-5 MHz Probe)

It is important to review a few anatomy points and terms before getting started with directed clinical questions for thoracic point-of-care ultrasound. First, anatomy and scan orientation. Rib shadows help to orient the sonographer by serving as a landmark for pleural line identification. As the ribs approach the sternum, they become cartilaginous, and so sound can penetrate through the rib at this point.

MOVIE 4.1



Cartilaginous ribs where pleura can be seen deep to the anterior rib surface

However, usually the ribs are calcified and so cast a shadow as the sound cannot penetrate through bone (Movie 4.2).

Movie 4.2

Calcified bony ribs that cast a shadow.

Movie 4.3

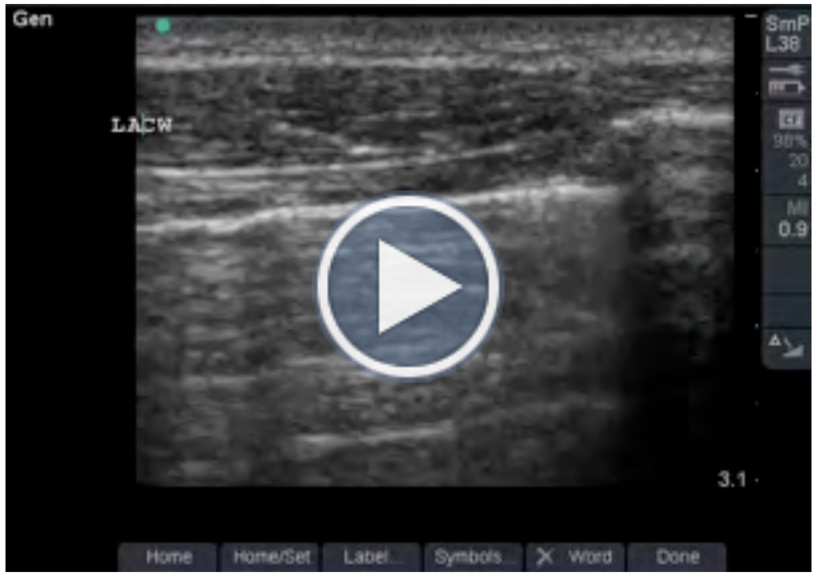
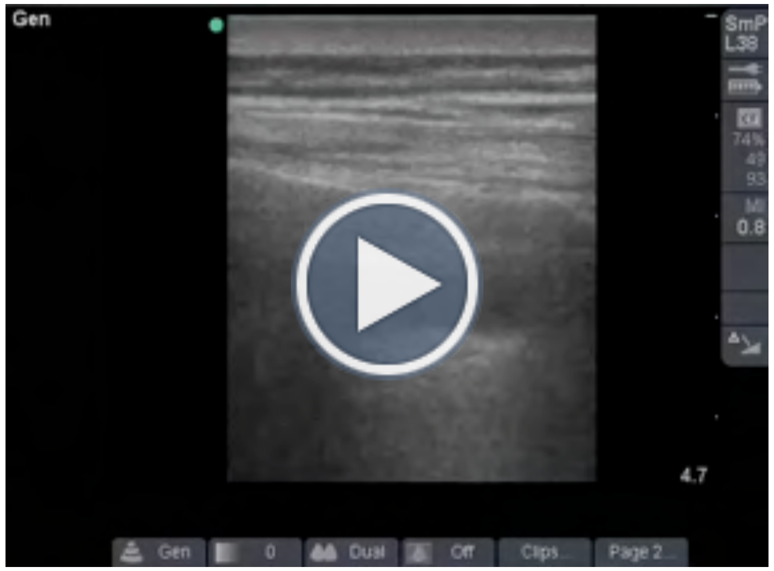


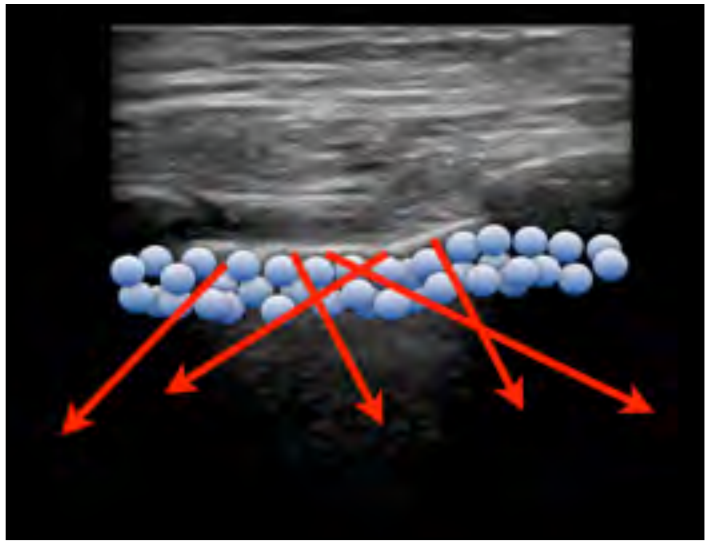
Image of normal pleura - the pleural line must be deep to the rib shadow.

Movie 4.4



Effusion separating visceral from parietal pleura.

Figure 4.1



Drawing demonstrating the disorganized scatter from air - low density air molecules reflect sound in a non-uniform pattern.

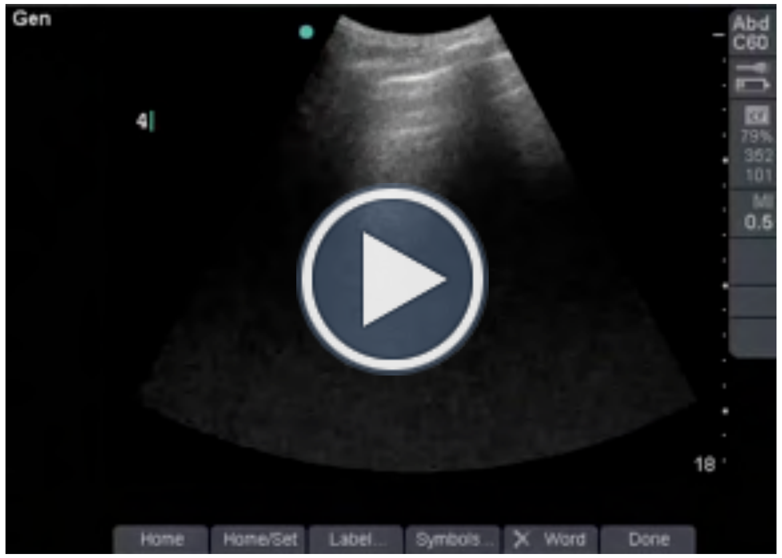
Next, we can identify the pleural line. Because the visceral and parietal pleura are usually closely opposed, it appears as a bright white line (Movie 4.3). If there is an effusion, however, a dark stripe of fluid separates the visceral from the parietal pleura (Movie 4.4). If you see this anteriorly, a large effusion or one that is located anteriorly is suspected.

It is important to remember that a normal lung has well-aerated alveoli and very thin interstitial tissue holding the alveoli together. It is also important to remember that air does not transfer sound well, but instead scatters it so that the sound does not return to the probe in an organized fashion (Figure 4.1).

Movie 4.5

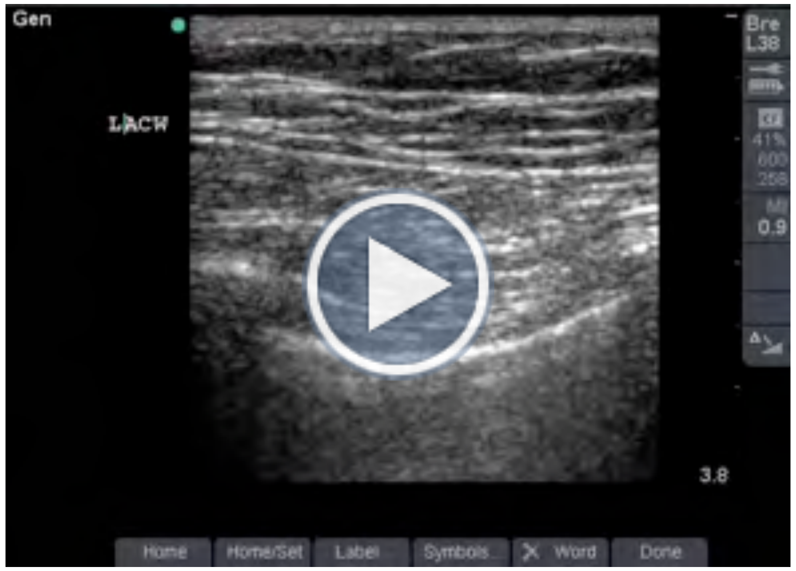
Horizontal A-line reverberations.

Movie 4.6



Vertical B-line artifact.

Movie 4.7



Lung sliding with rib shadows at either edge of the screen.

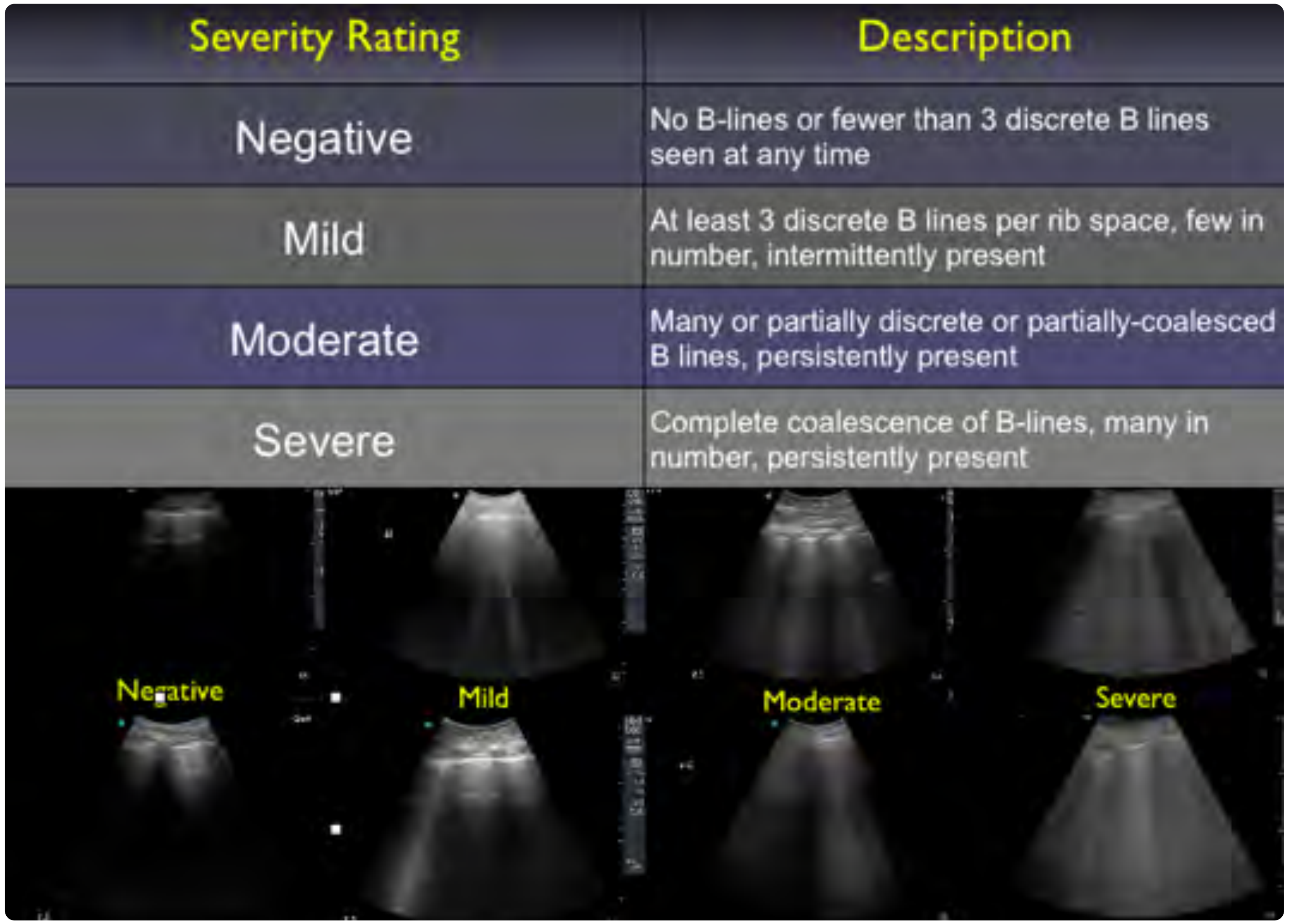
In a well-aerated lung, once the sound goes deep to the pleural line reflection, it is scattered and no organized information is returned to the probe to generate an image. Instead, the bouncing back and forth between the skin surface and the pleural line creates a horizontal reverberation artifact that is called an A-line (Movie 4.5). If there is fluid or thickening of the interstitial tissue, however, the lung behaves more like a solid organ and sound is now able to reflect and refract such that a vertical, laser-like, bright, white line appears that originates from the pleura and is transmitted the full depth of the screen. These vertical lines are called B-lines and are a marker of interstitial thickening (from fluid or fibrosis) or alveolar fluid (Movie 4.6).

There are a few features of B-lines that should be highlighted to ensure that what is seen is truly a marker of interstitial fluid. First, the B-line starts at the pleural line and travels at least to a depth of 18 cm (the minimum depth the screen should be set at when looking for this). In addition, B-lines will move back and forth with respiration as the pleural line moves. Finally, they initially appear as thin, single, vertical lines. As there is more interstitial fluid, the lines can start to coalesce and become more wedge-shaped.

There is a spectrum of B-lines ranging from none (when A-lines are usually seen), to mild, moderate, and severe, when there is often complete coalescence of single B-lines into white curtains of B-lines. (Gallery 4.1)

For most thoracic sonography, using the low frequency probe is preferred. The 2.5 - 5 MHz probe should be used when looking for interstitial disease and when looking for pleural effusions. When looking at the pleural line only, as when evaluating for pneumothorax, the linear probe with its higher resolution pictures can sometimes be helpful. It is also useful for orientation to start with the probe in a longitudinal position and orient with rib shadows at either edge of the screen (Movie 4.7).

GALLERY 4.1 Figures 2-5



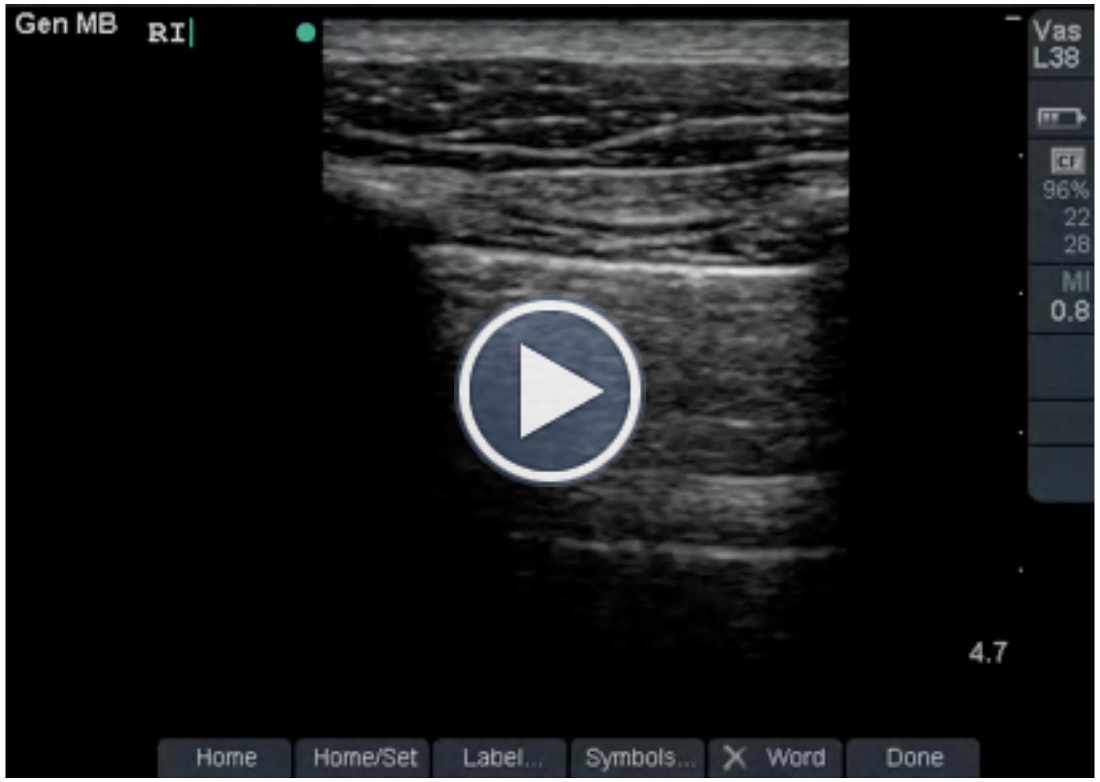
Severity Rating	Description
Negative	No B-lines or fewer than 3 discrete B lines seen at any time
Mild	At least 3 discrete B lines per rib space, few in number, intermittently present
Moderate	Many or partially discrete or partially-coalesced B lines, persistently present
Severe	Complete coalescence of B-lines, many in number, persistently present

Progression of B-line density

SECTION 3

Pneumothorax

MOVIE 4.8



Normal lung sliding

SUMMARY

Lung sliding rules out pneumothorax with nearly 100% sensitivity in the area directly underneath the probe

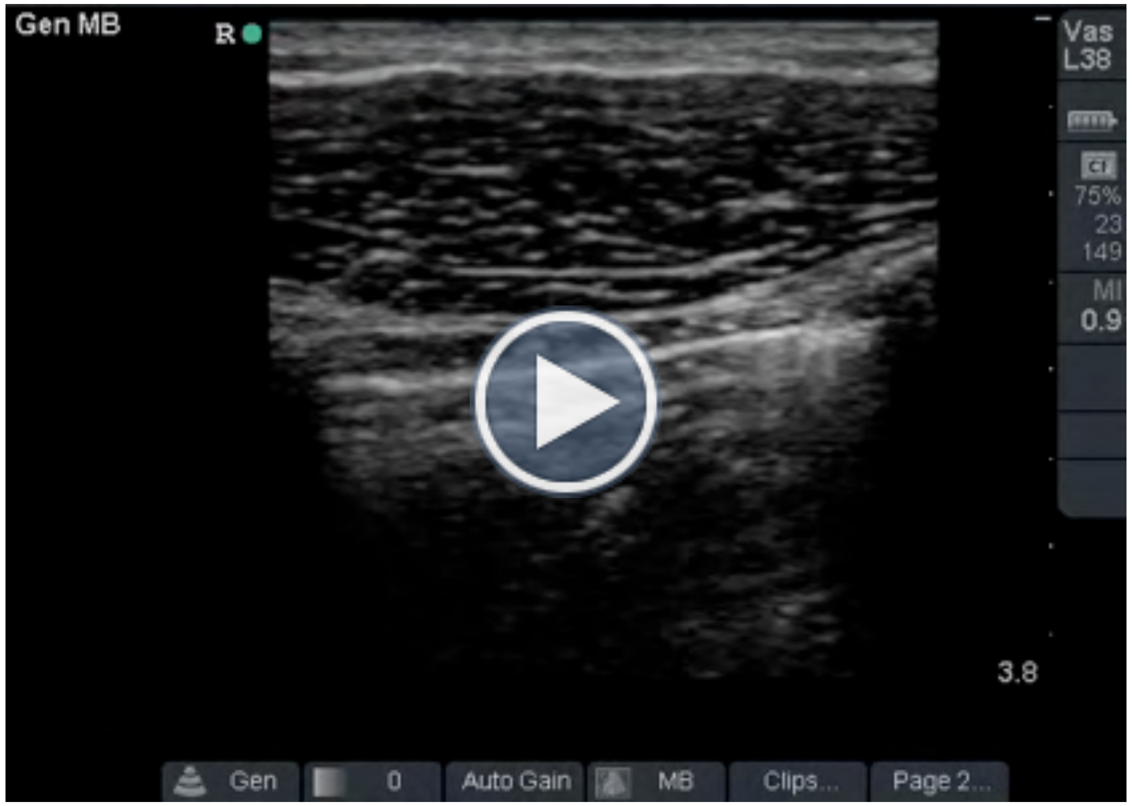
M-Mode may be helpful in identifying pneumothorax as a Barcode Sign instead of the normal Seashore Sign.

A lung point can be used to obtain an estimation of the size of a pneumothorax

One of the simpler and more effective applications for thoracic ultrasound is the evaluation for pneumothorax. The principle is simple. When the visceral and parietal pleura are opposed and respirations are observed, a slip-sliding or shimmering of the visceral on parietal pleura will be observed, essentially ruling out any air below the probe footprint with nearly 100% sensitivity.[1,2] (Movie 4.8) Another indication that the visceral and parietal pleura are touching is that a reverberation artifact between these two closely opposed structures will create a vertical, bright line similar to the B-line described above, but also known in this particular case as a comet-tail (Movie 4.9).

When viewed in m-mode, which portrays points along a line over time, the near field, which is superficial to the pleural line, is not moving and appears as straight lines. The far field, deep to the pleural line, is shimmering back and forth and appears grainy. This is known as the *seashore sign* (Figure 4.6).

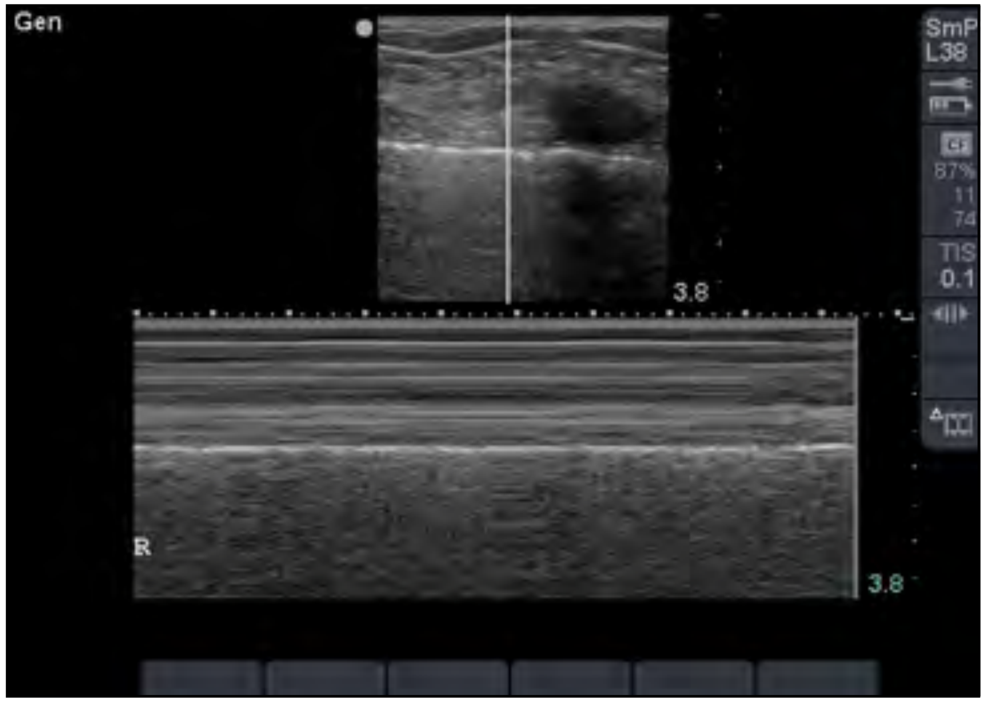
MOVIE 4.9



Comet tail with lung sliding.

When air is interposed between the visceral and parietal pleura, the visceral pleura separates from the parietal pleura. All sound distal to the parietal pleura is scattered and does not return to the ultrasound probe in an organized fashion (Figure 4.1). Therefore, the parietal pleura will be the last structure visualized by the ultrasound machine and will appear as a fixed, bright, white line (Movie 4.10). Deep to the pleural line, the high impedance of the air causes no real image to be generated. Instead, a reverberation artifact can

Figure 4.6

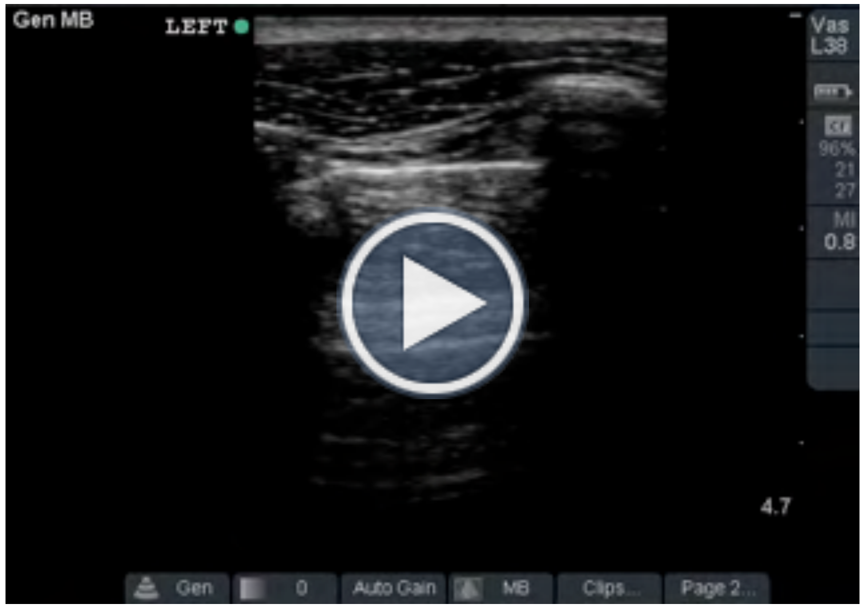


Seashore sign

cause mirroring, and sometimes a reflection of the chest wall can be seen. On m-mode, the chest wall still appears as straight lines, but since no lung sliding is seen, the area deep to the pleural line also appears as straight lines. This is known as the *barcode sign* (Figure 4.7).

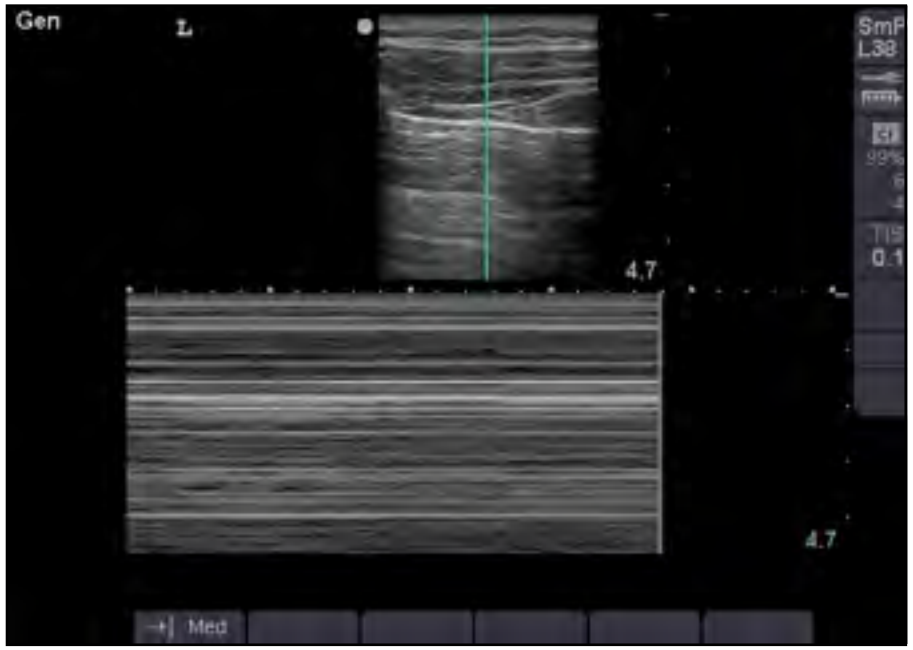
It is important to remember that lack of lung sliding can be seen in several conditions. Any condition that has fixed the pleura with scarring can cause lack of lung sliding. Examples include pleurodesis, surgical scarring, pneumonia with adhesions, and others pathologic diseases. Care must be taken to clinically differentiate these from pneumothorax to minimize false positive interpretations. Occasionally, when the pleura are still opposed but are fixed, comet-tail rever-

Movie 4.10



Here only the fixed parietal pleura is seen. The visceral pleura is somewhere deep to the pocket of air.

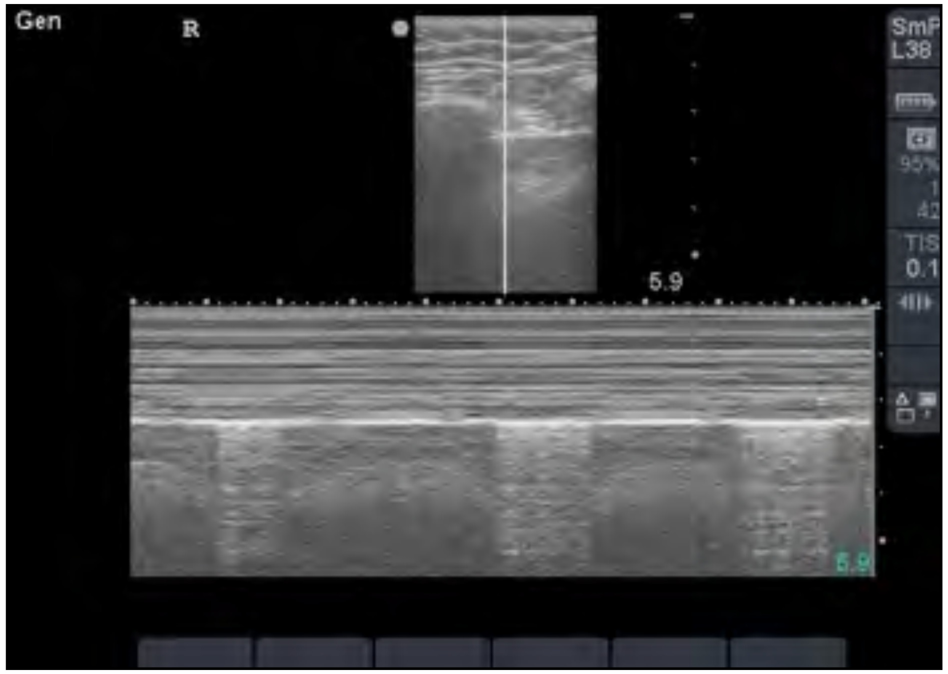
Figure 1.7



Barcode sign

berations can still be seen with absent lung sliding and can help

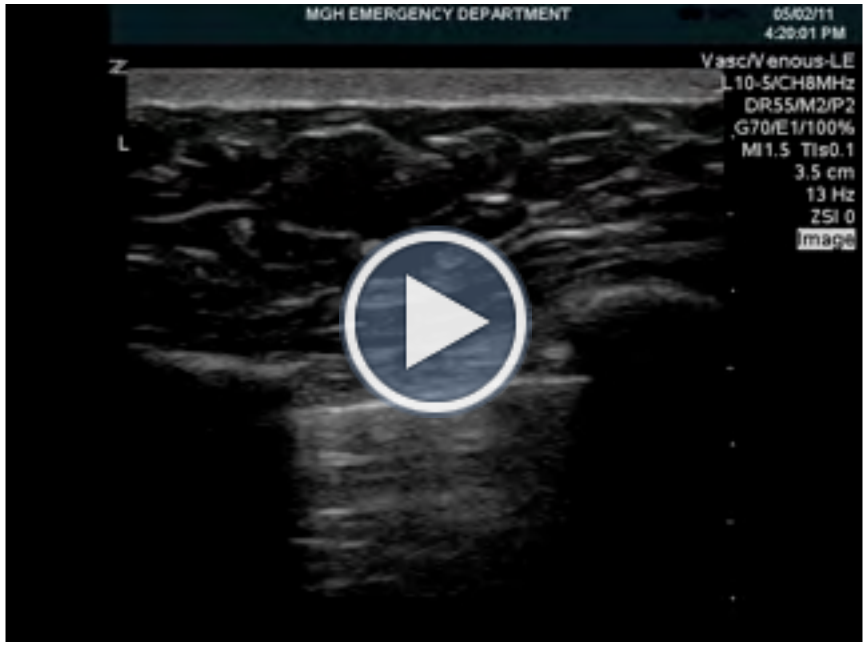
Figure 1.8



M-mode Lung point

point to a false-positive for pneumothorax. When examining a supine patient, the probe should be placed over the anterior rib spaces, as air will tend to layer here. It stands to reason that the more complete the evaluation of the thoracic cavity, the more sensitive the lung ultrasound will be for ruling out pneumothorax. However, studies have shown that the only pneumothoraces that would be missed if the anterior chest wall alone were scanned would be isolated apical pneumothoraces.[3] If there is a high degree of suspicion for a pneumothorax and the anterior chest wall shows lung sliding, scanning superiorly or even supraclavicularly to better evaluate the apices may be helpful. One last finding, which is essentially pathognomonic for pneumothorax, is the lung point sign. This is seen when you scan the position where the visceral pleura reattaches to the chest wall. When the probe is held in this location, one half of the ultrasound screen will demonstrate lung sliding and one half of the screen will show a fixed parietal pleura (Movie 4.11). On m-mode, you will see alternating seashore and barcode signs, which vary with respirations (Figure 4.8). The lung point can be found by moving the probe around the chest wall, from areas of lung sliding to areas without lung sliding, until both are seen in the same location, as the patient breathes (Movie 4.12). This point of reattachment can be followed around the chest wall to demonstrate an estimation of the size of the pneumothorax.

Movie 4.11



Video demonstrating the lung point

Movie 4.12

This video (courtesy of Dr. Fernando Silva) shows how you can use the lung point to estimate the extent of a pneumothorax.

Section 4

Pleural Effusion

Summary

Ultrasound may be superior to chest radiography for detection of pleural effusion.

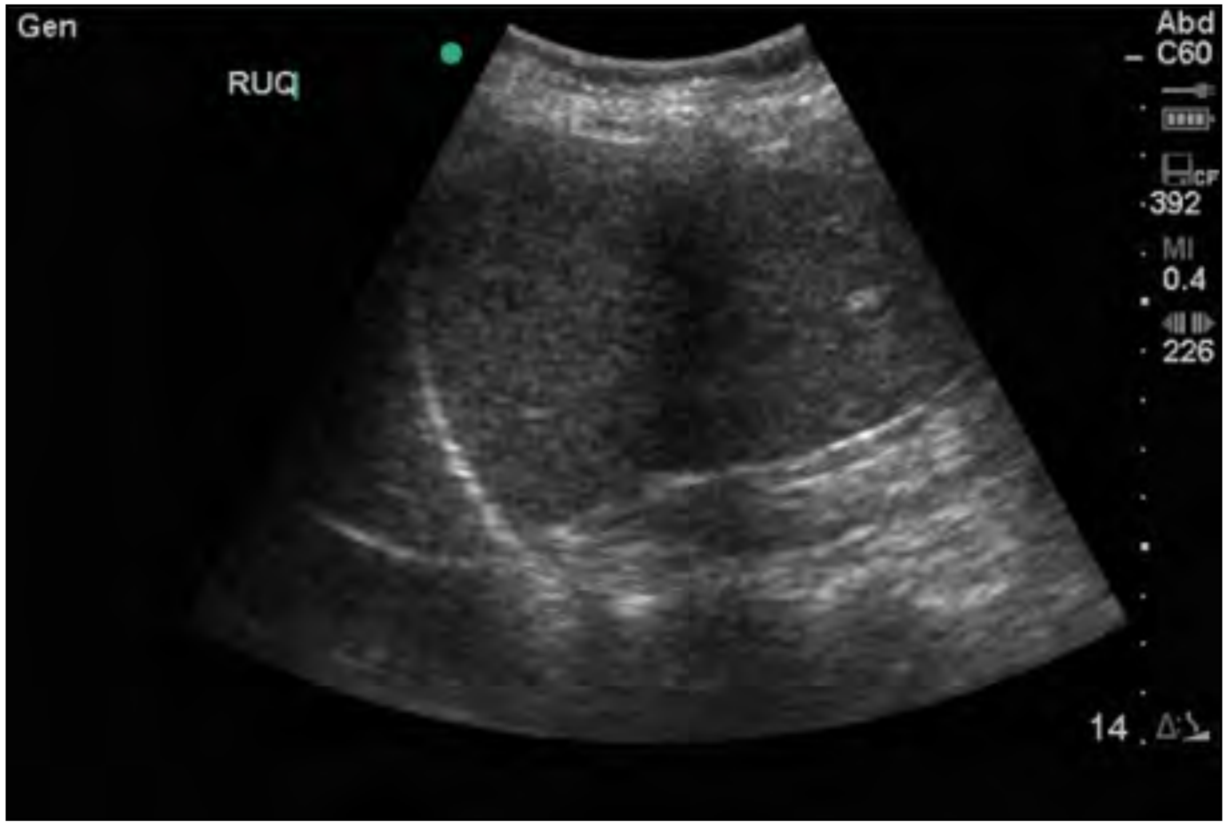
The mirror image sign indicates that there is not a pleural effusion present. The spine sign indicates that there is a pleural effusion present.

Pericardial effusions and pleural effusions can be differentiated based on position of fluid.

Another very simple and very effective application of thoracic sonography is the evaluation for pleural effusion. Again, research has shown not only is lung ultrasound comparable to chest radiography, it may be superior. In addition to its diagnostic value, thoracic ultrasound is able to assist in procedural guidance as well. [4-6]

This application takes advantage, again, of the ability of the well-aerated lung to scatter sound. When looking in the anterior or posterior axillary line in the longitudinal plane with a low frequency probe, the diaphragm should be identified. The diaphragm will be a

Figure 4.9

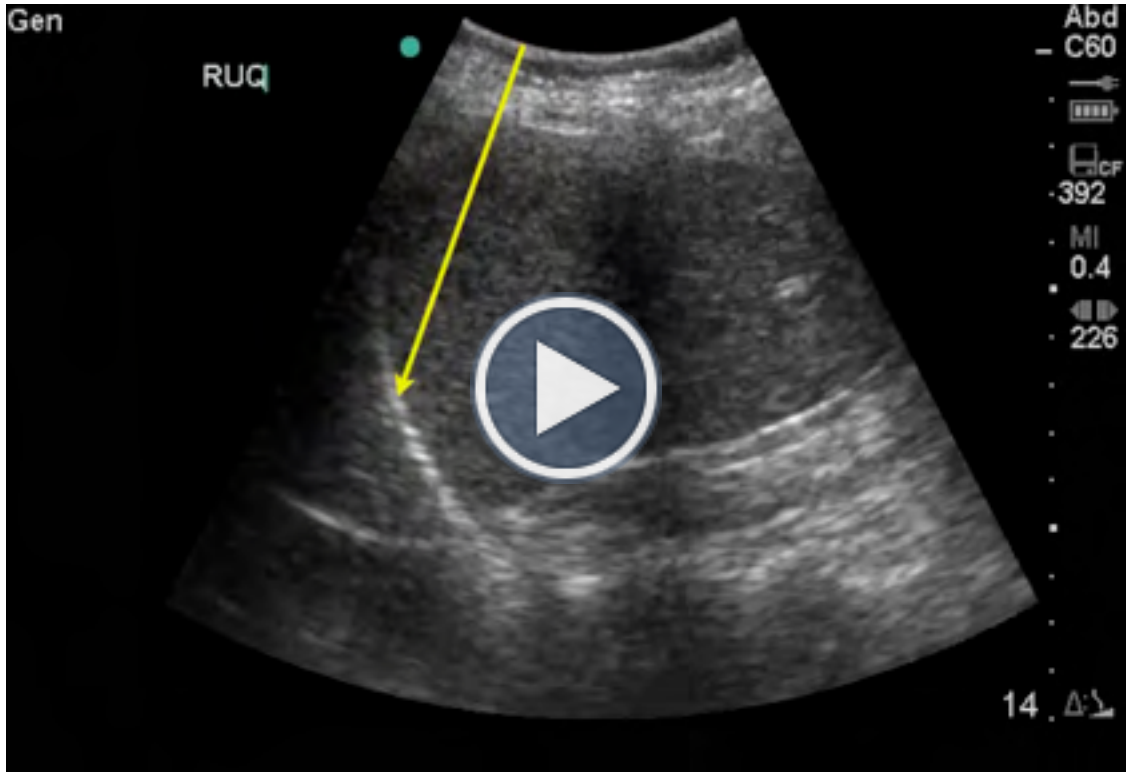


Normal aerated lung with diaphragm highlighted.

bright, white structure that pulls inferiorly with inspiration in a spontaneously breathing patient (Figure 4.9).

If there is air above the diaphragm, as in a normal lung, the sound wave will reflect off of the diaphragm and then be reflected back to the diaphragm after traveling through the liver or spleen tissue (Movie 4.13).

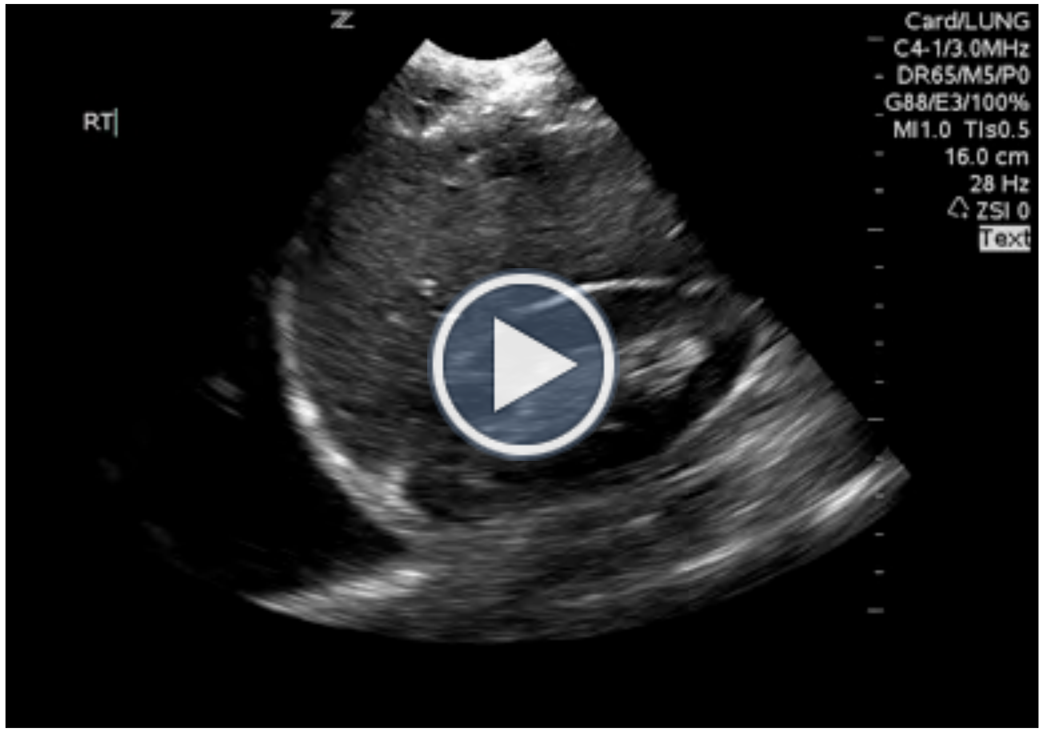
Movie 4.13



Animation demonstrating the reverberation and reflection that takes place with a normal lung and the diaphragm.

In this case, the ultrasound machine will assume the sound wave traveled in a straight line, and so liver tissue reflections will appear both above and below the diaphragm. This phenomenon is called the mirror image, and indicates that there is no pleural effusion and that the lung is well aerated. The lack of a mirror image artifact indicates that there is fluid above the lung, since sound can travel through the fluid and the effusion can be visualized directly (Movie 4.14).

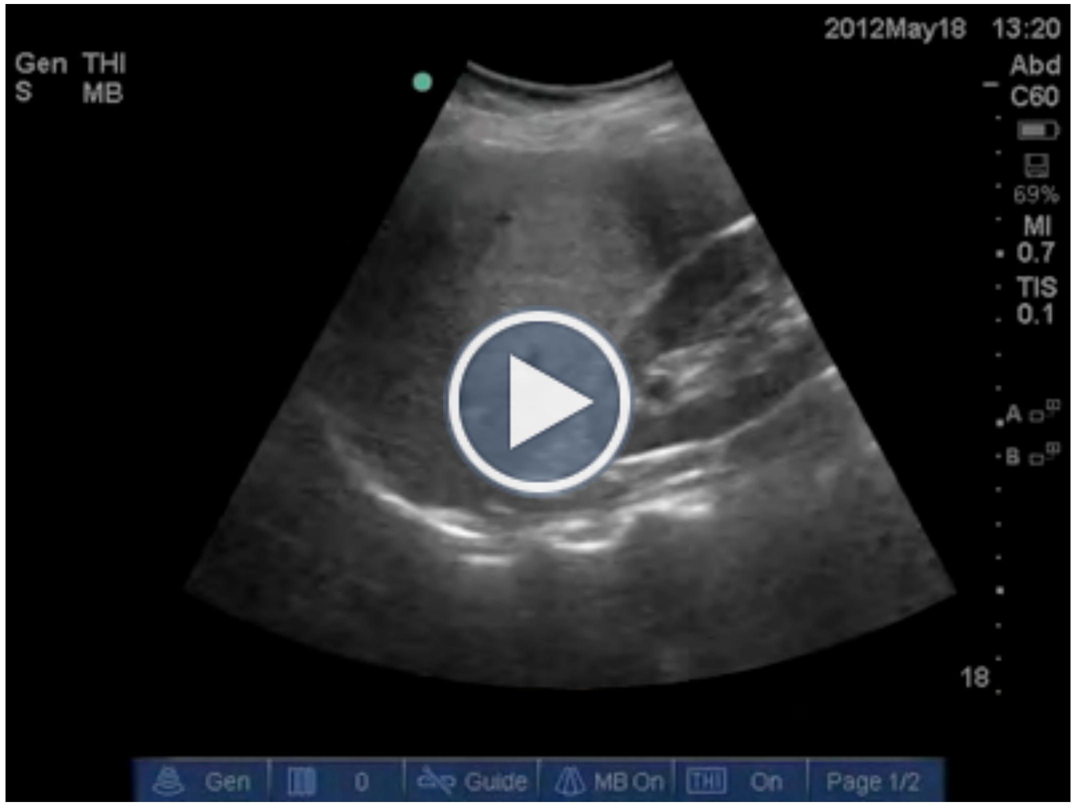
Movie 4.14



Video demonstrating an above the diaphragm-mid-axillary view.

Sometimes, however, the mirror image can be tricky to identify. In this case, we have another way to identify pleural fluid, which is known as the spine sign. This, again, makes use of sound's ability to travel through fluid instead of being scattered by air. The spinous processes and vertebral bodies are deep to the kidney and spleen/liver when looking from the mid-axillary probe position. If the thoracic cavity is full of air, as the diaphragm expands and pulls caudally to aerate the lung, the shadow from the lung will cover the

MOVIE 4.15 - Normal aerated thorax

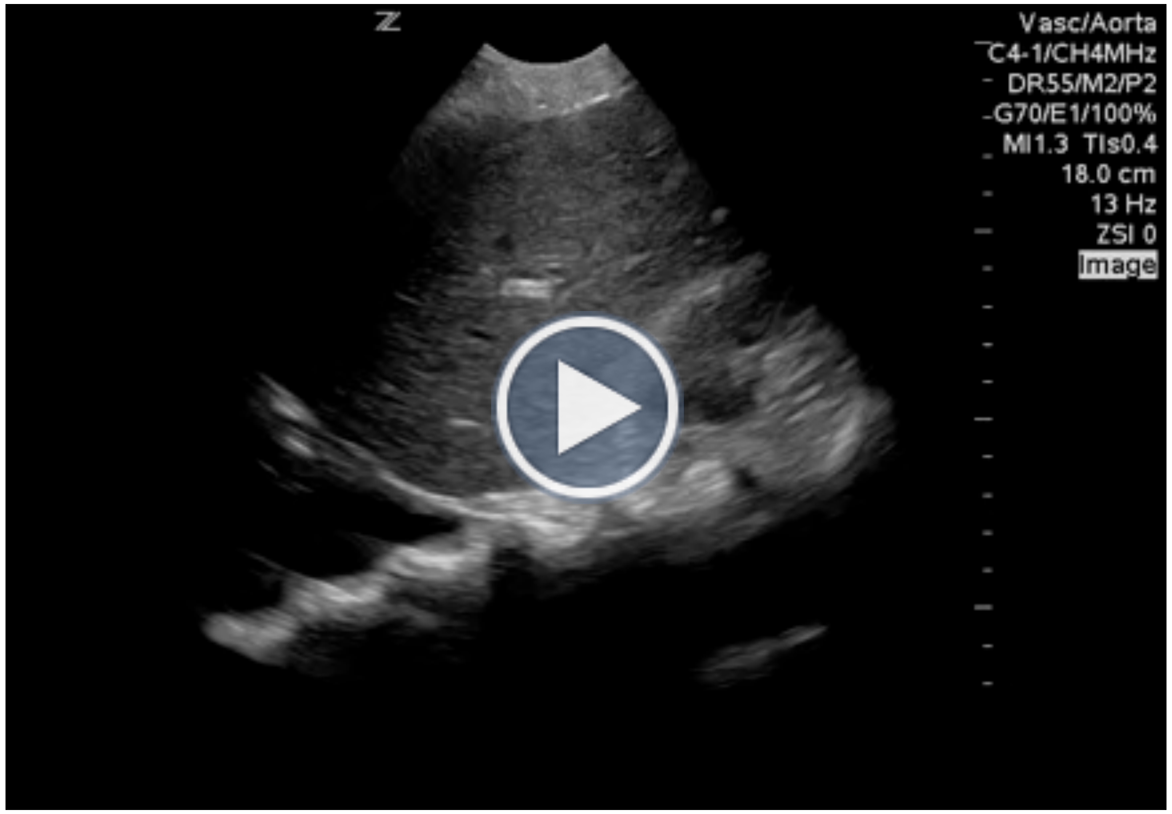


Video demonstrating the diaphragm pulling over the spine reflection and obscuring it indicating the thoracic cavity is full of air.

spine shadows above the diaphragm (Movie 4.15). When the thoracic cavity is full of fluid, sound can travel through the thoracic cavity to the thoracic spine, and so the spine shadows are seen throughout respiration (Movie 4.16).

Pleural effusions can also be visualized in other locations. Left-sided effusions can be seen in the far field of a parasternal long axis cardiac image and taper to the descending thoracic aorta where pericardial effusions would cross anterior to the aorta (Movie 4.17). Right-sided effusions can be seen deep to the diaphragm in a subxiphoid cardiac view (Movie 4.18). And as mentioned earlier, large

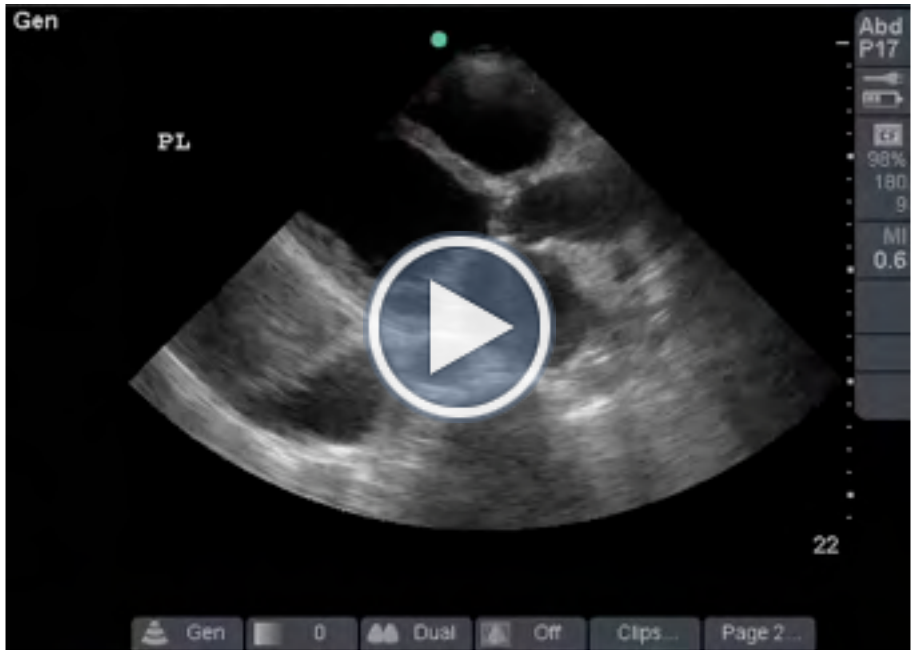
MOVIE 4.16 - Spine Sign - effusion



Video demonstrating the persistent spine reflection throughout respiration indicating the thoracic cavity if fluid filled.

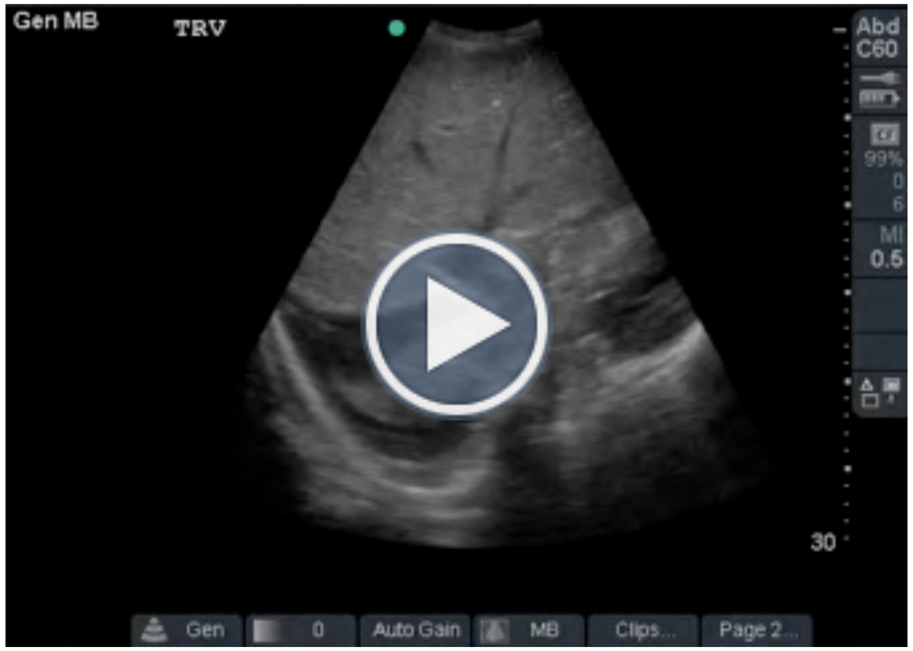
effusions can sometimes be seen when scanning the anterior chest wall (Movie 4.19).

Movie 4.17



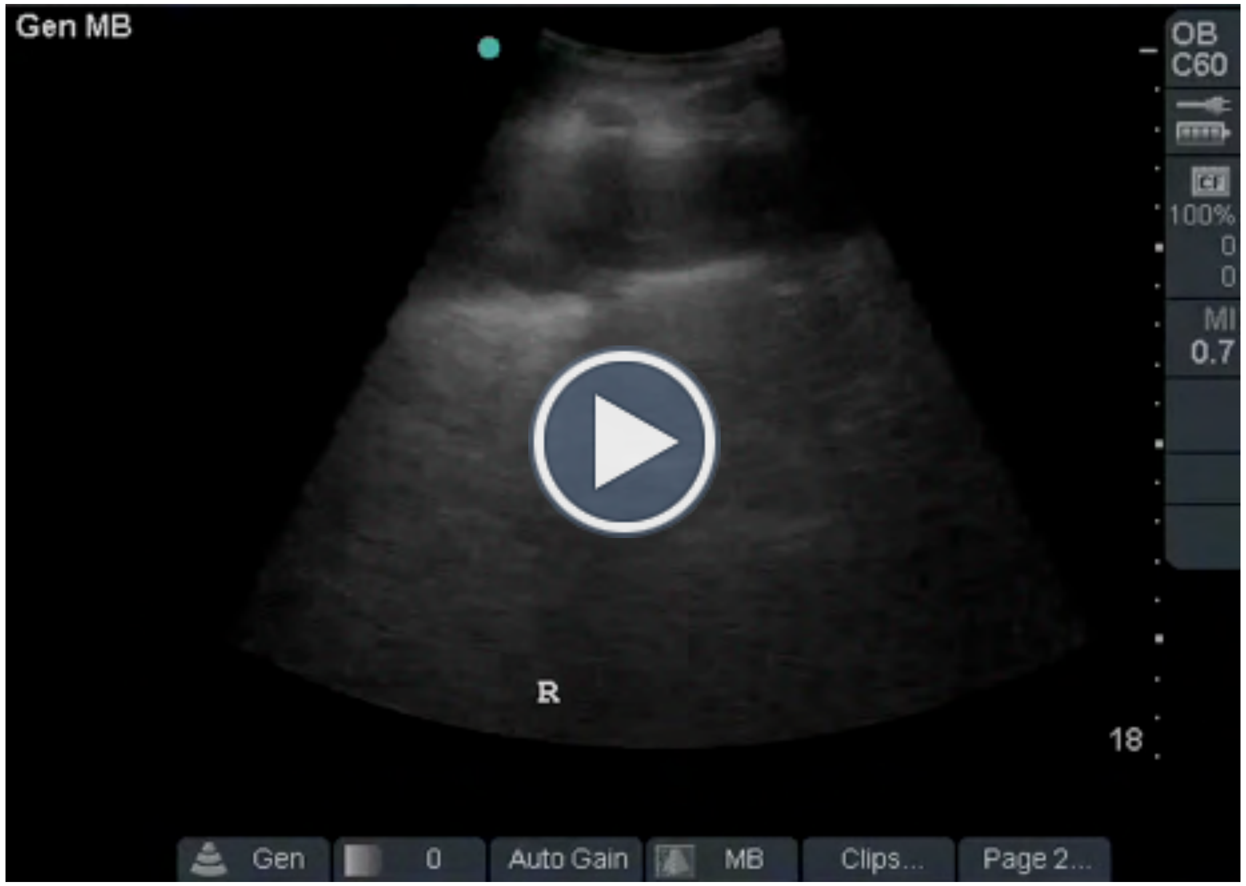
Parasternal long view of the heart - left pleural fluid tapers to the descending thoracic aorta while pericardial fluid would cross anterior to the aorta.

Movie 4.18



Subxiphoid view demonstrating a right pleural effusion above the diaphragm.

Movie 4.19



Pleural effusion seen on anterior chest wall scanning.

Section 5

Interstitial Disease

The ability of thoracic ultrasound to distinguish between aerated lung and lung with interstitial fluid or disease has been well documented.[7-9] Clinical correlation is imperative as interstitial thickening can be a process of pulmonary edema, pulmonary fibrosis, infection or tumor/scarring. In the right clinical scenario, however, pulmonary ultrasound has been shown to be superior to chest radiography in identifying interstitial disease.[10]

The scanning technique uses the low frequency probe to scan in eight zones of the thoracic cavity to get a good sense of the distribution of disease (Figure 4.10).

Summary

Pulmonary ultrasound has been shown to be superior to chest radiography in identifying interstitial disease in the right clinical scenario.

Ultrasound can be used to identify pulmonary edema, pulmonary fibrosis, and infection.

Figure 4.10

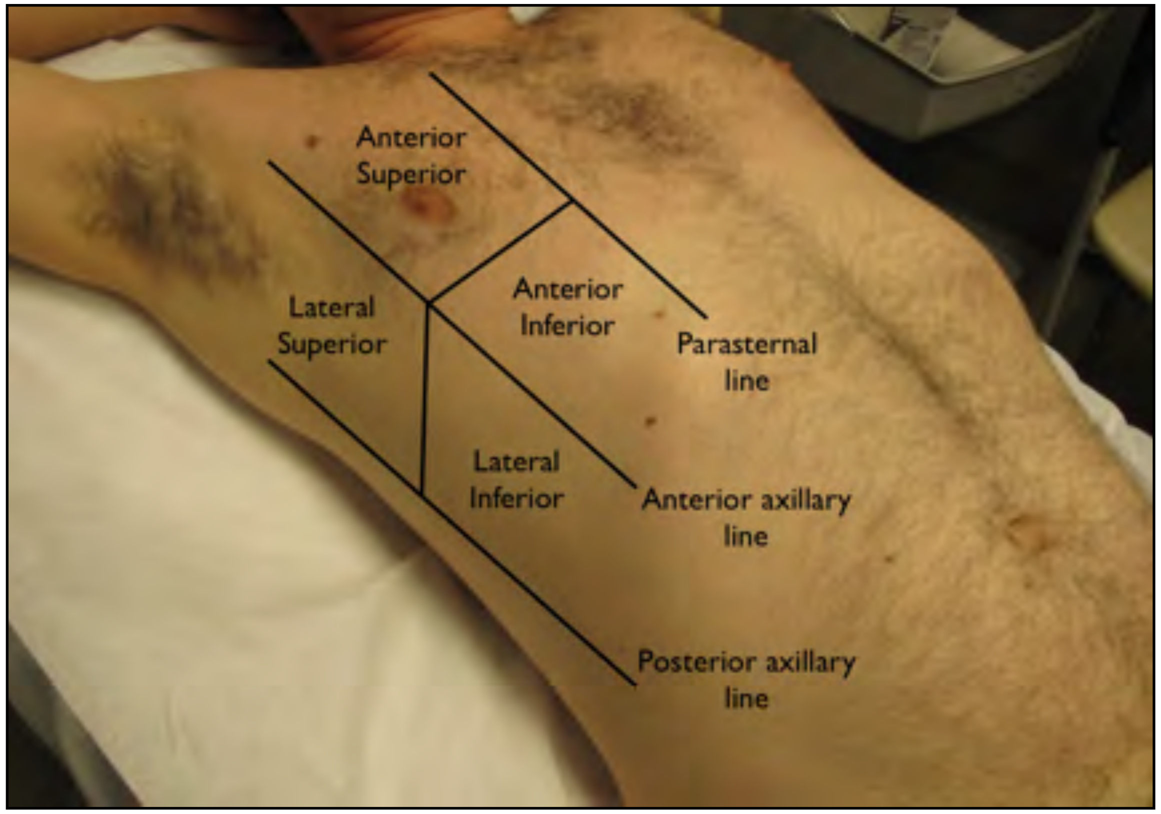
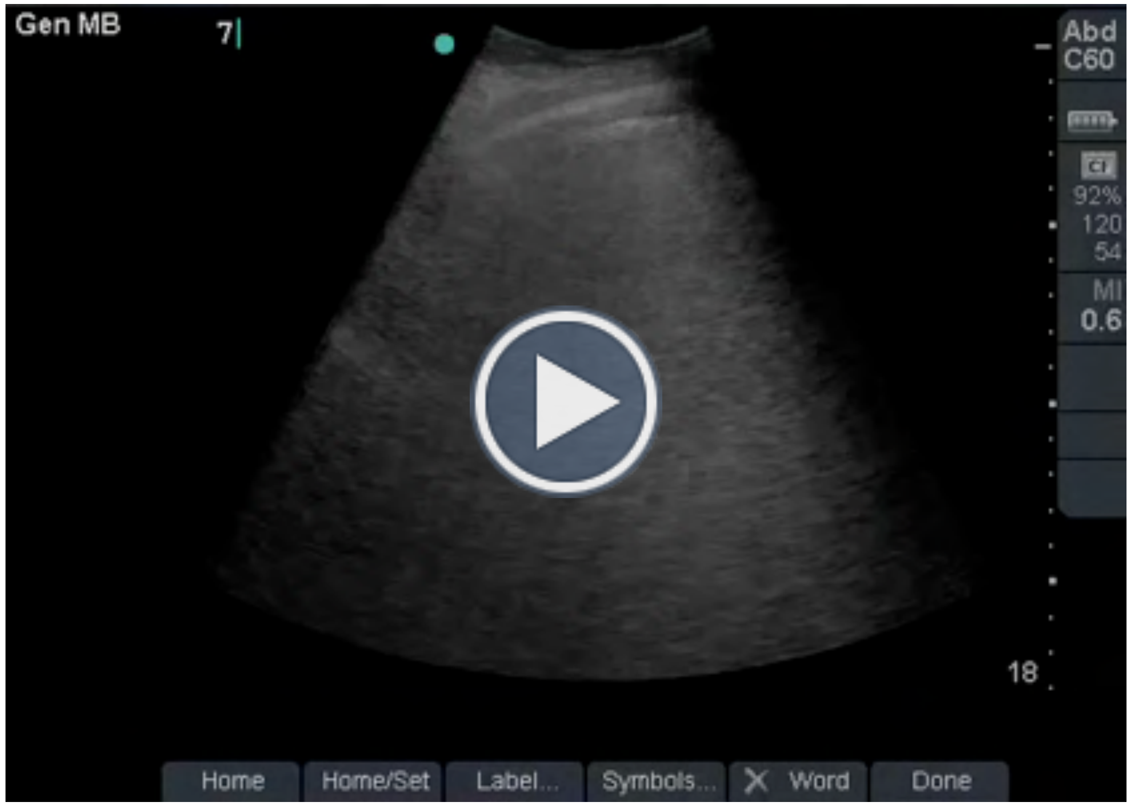


Figure demonstrating the eight scanning zones as described by Dr. Giovanni Volpicelli.

An isolated B-line - especially in the lateral and inferior lung zones - is considered normal or non-pathologic, but more than three B-lines per zone is considered pathologic, and that zone is considered positive for interstitial disease. The more B-lines that are present, the more pathologic the interstitial process, and this holds true across the disease spectrum including pulmonary edema, pulmonary fibrosis, and infection.[8,9,11] (Movie 4.20)

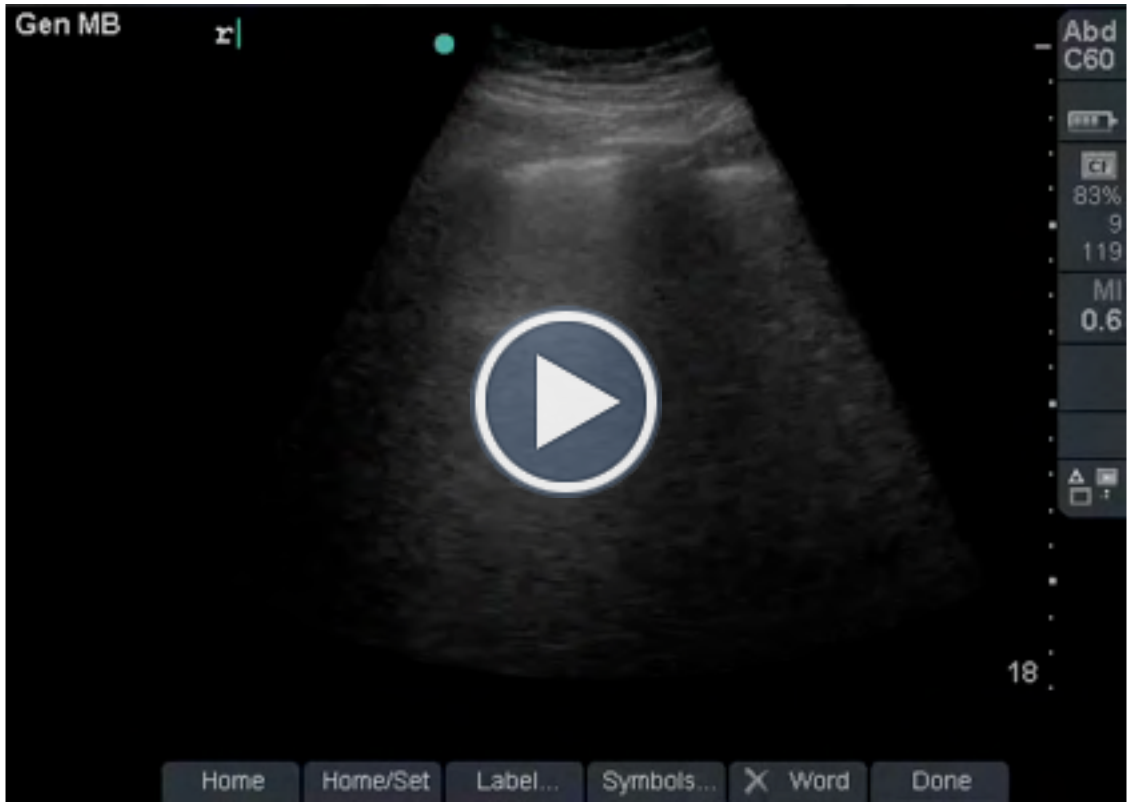
MOVIE 4.20 - B-Lines



Video showing diffuse B-lines. This patient had flash pulmonary edema requiring non-invasive ventilation and afterload reduction.

There are a few clues that the clinician sonographer can use to help distinguish between the different etiologies of interstitial disease. In general, congestive heart failure and pulmonary edema are caused by fluid translocation, and so the pleural line in pulmonary edema will remain thin and regular (Movie 4.21). In contrast, diffuse infection or inflammation causing interstitial disease will tend to affect the pleura as well. In fibrosis, pneumonia, tuberculosis or other diffuse

MOVIE 4.21 - B-Lines

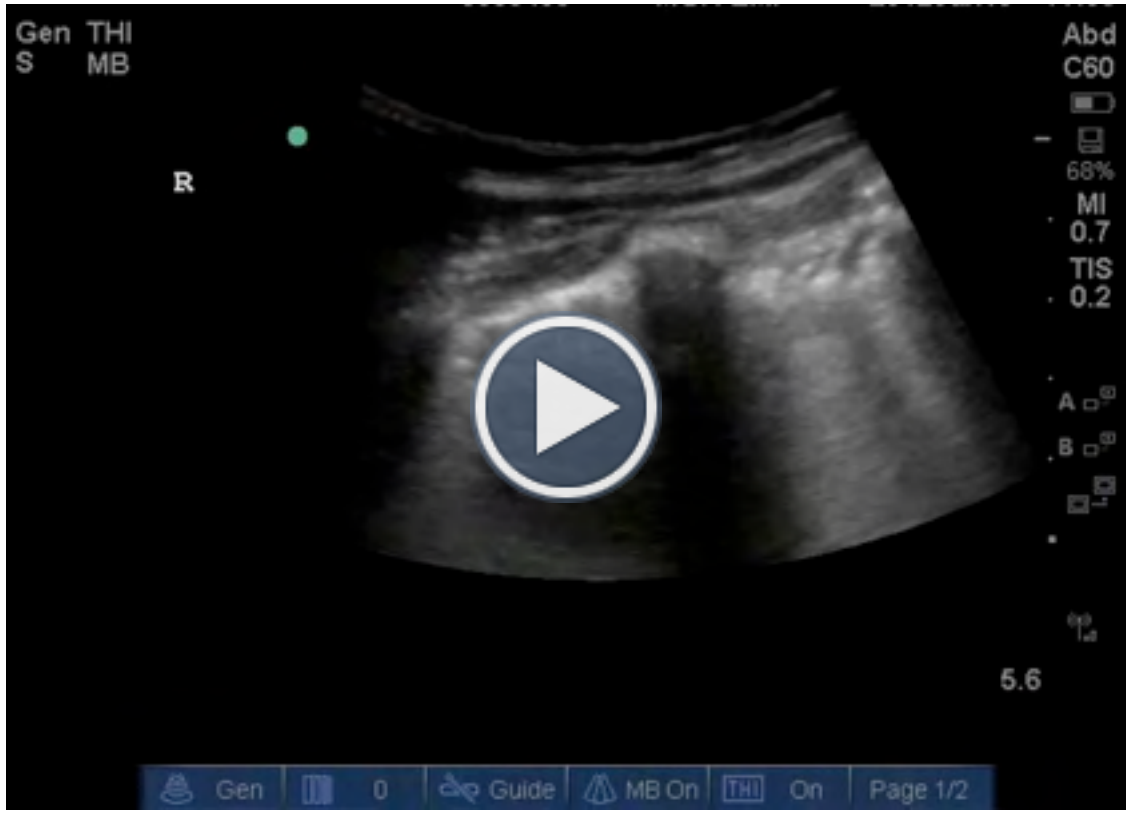


Video showing B-lines and thin pleural line.

pulmonary infectious processes, the pleural line becomes irregular, lumpy and has areas of subpleural fluid collections[12,13] (Movie 4.22).

There is also some interesting evidence demonstrating prognostic value to the number and coalescence of B-lines on the initial evaluation for patients with dyspnea. Patients with high initial B-line scores had a worse prognosis and higher event scores at 16 months than patients with low B-line scores. B-line scores outperformed other echocardiographic variables as a univariate predictor.[14].

Movie 4.22



Video showing B-lines and lumpy bumpy pleural line.

Section 6

Consolidation/Pneumonia

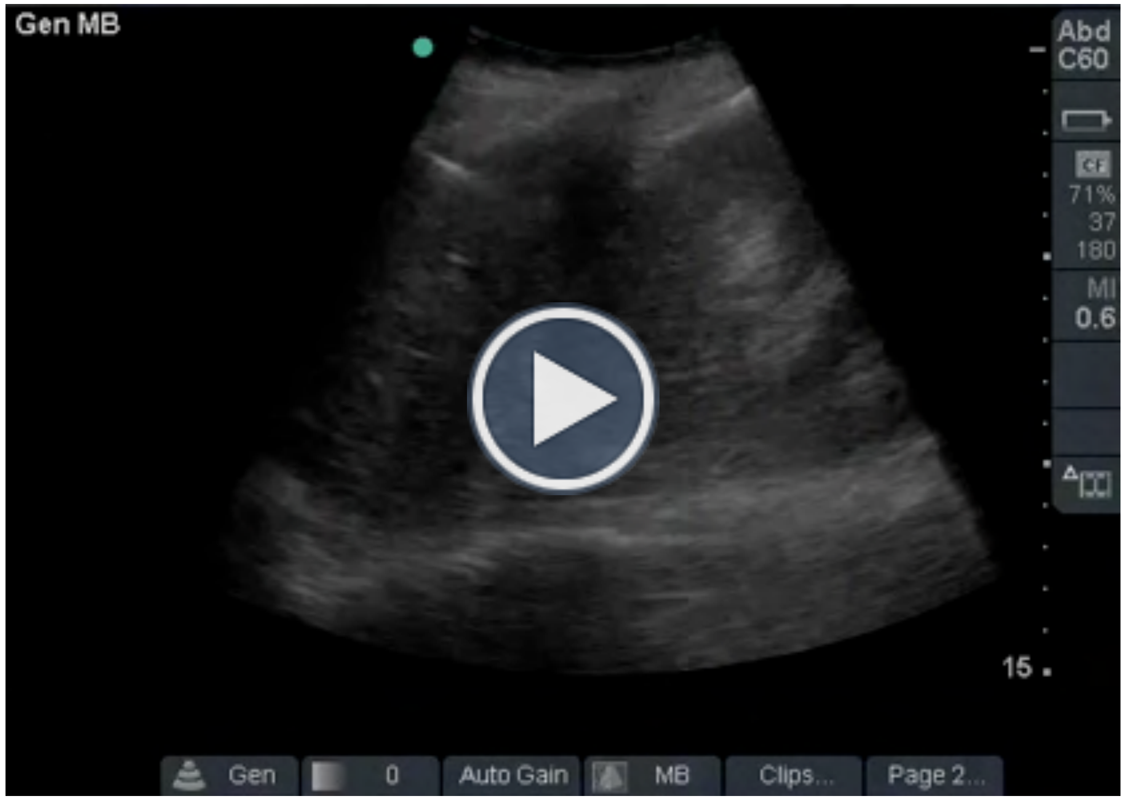
Summary

Lung Sonography is a distinct improvement over chest radiography in the evaluation of pneumonia.

Lung ultrasound can distinguish between lung consolidation and atelectasis

In infection, as the interstitial space starts to consolidate and the alveoli and air-filled space in the lung become filled with fluid or purulent material, sound is transmitted through this tissue in the same way as through other soft tissue density organs in the body, such as the liver. The lung now behaves more as a solid organ and takes the appearance of a liver. This phenomenon is called hepatization, and it is easy to see why (Movie 4.23).

Movie 4.23

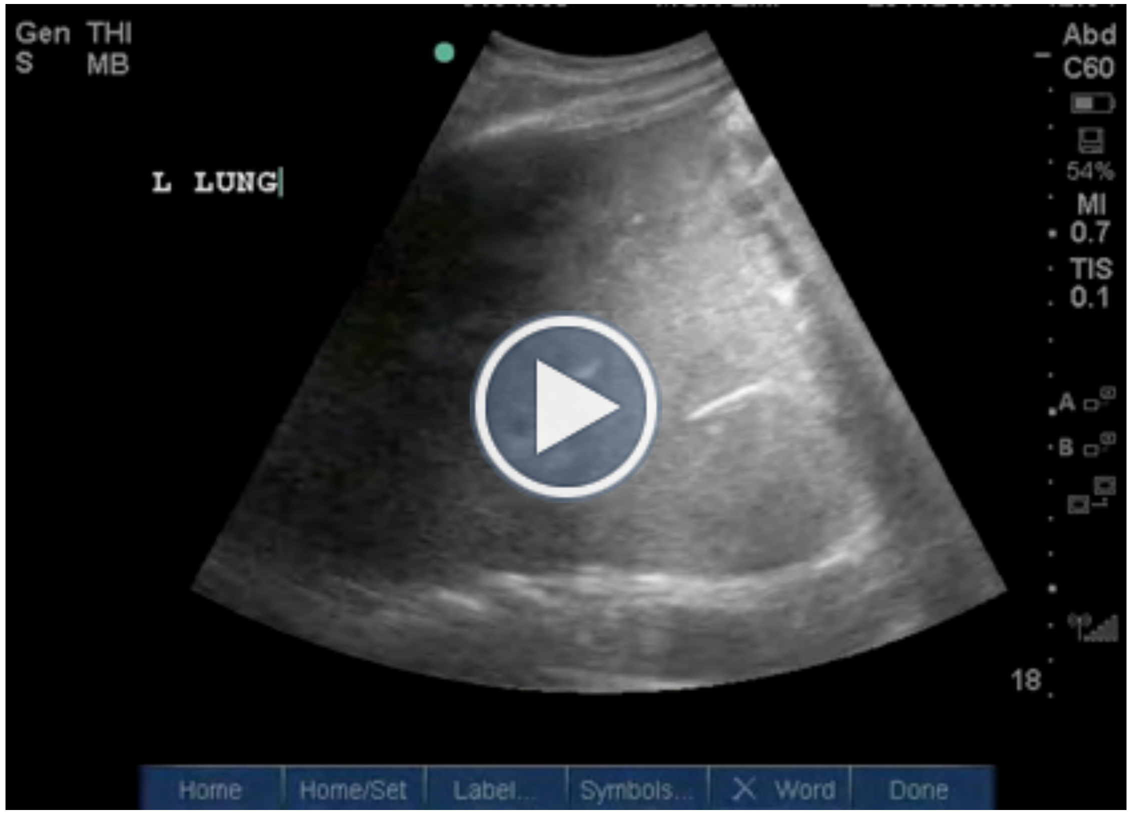


Video showing consolidation.

This finding has been well correlated with areas of consolidation on chest radiographs and with chest computed tomography. Indeed, multiple studies have shown that lung sonography is as sensitive and specific as computed tomography for pneumonia, and it is a distinct improvement over chest radiography.[15-17] In fact, the spectrum of infectious pulmonary disease reliably progresses from focal areas of interstitial disease (i.e. more than three B-lines per rib space in a focal pattern) to areas of coalescence of B-lines and irregular pleural lines to consolidation. This spectrum appears to follow the progression of disease seen on other gold standard diagnostic imaging, such as computed tomography.[10,15-19]

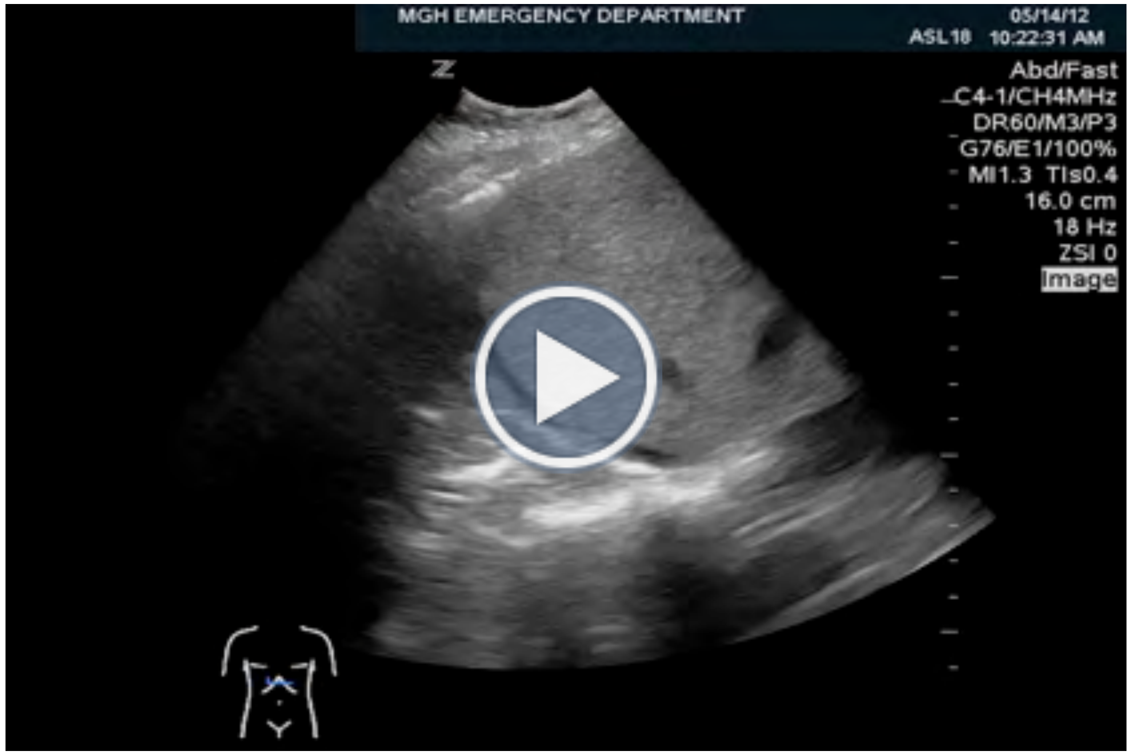
One interesting advantage of lung sonography is that it appears it can distinguish between lung consolidation and atelectasis, which is oftentimes a challenge for chest radiography. For consolidative processes, such as pneumonia or other infectious processes, the bronchi will be generally unobstructed, and because of the distinct difference in tissue density, the air moving in the bronchi with respiration will appear to be a bright, shimmery column, described as mobile air bronchograms (Movie 4.24). In contrast, atelectasis is a result of bronchial plugging, and so the air column within the consolidation is not mobile and is described as static (Movie 4.25).

Movie 4.24



Video showing dynamic air bronchograms

Movie 4.25



Video showing static air bronchograms.

Section 7

Monitoring Pulmonary Function

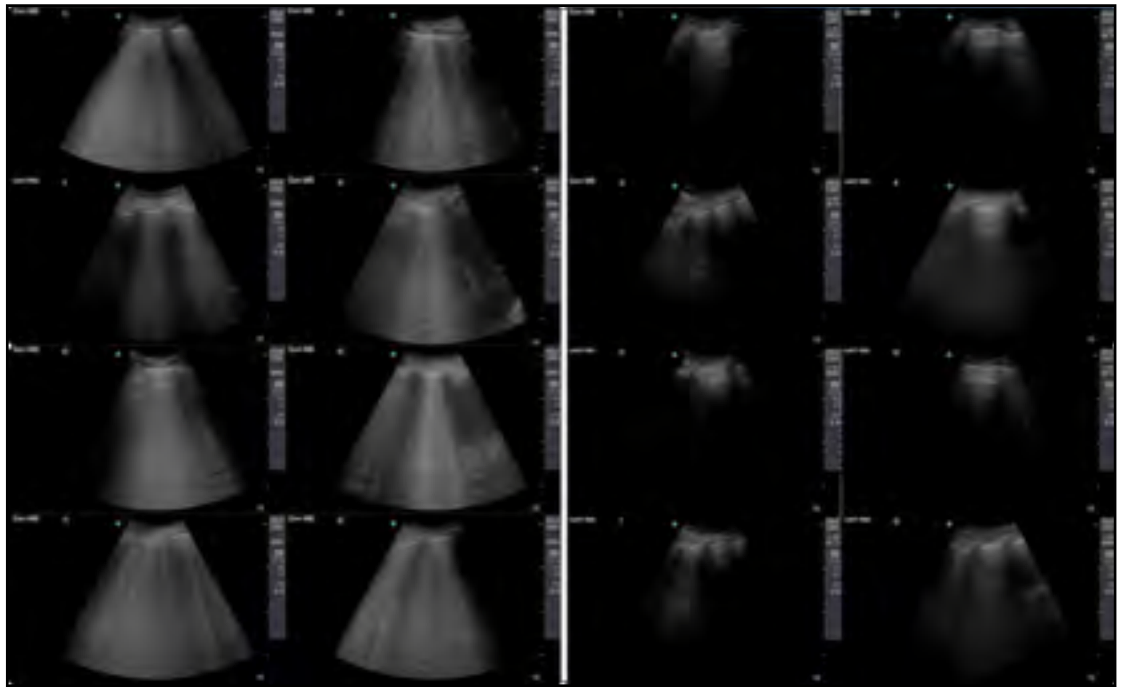
Summary

Fluid overload resolution can be observed in real-time with ultrasound

Lung sonography can replace chest radiography in both emergency and critical care patients!

One of the strengths of pulmonary ultrasound over other forms of pulmonary diagnostic imaging is that the changes appear to resolve in real-time.[20-22] As observed in patients undergoing dialysis, the B-lines of fluid overload appear to resolve in hours.[21] As observed in patients undergoing increases or decreases in the positive end-expiratory pressure settings on ventilators, the consolidation and B-lines appear or disappear rapidly.[22] (Figure 4.11) This real-time monitoring function has the added advantage of being performed with a modality that requires no ionizing radiation, no patient transport and no lag time between image acquisition and interpretation for a trained clinician sonographer. This has led to a series of recent articles looking at whether or not lung sonography could, in fact, replace chest radiography for both emergency and critical care patients.[10,18,19] In our view, the answer is a resounding yes!

Image 4.1



Tell everyone that you just finished another chapter!

Contact Us

REFERENCES

1. Rowan KR, Kirkpatrick AW, Liu D, Forkheim KE, Mayo JR, Nicolaou S. Traumatic pneumothorax detection with thoracic ultrasound: correlation with chest radiography and CT–initial experience. Radiology. 2002;225:210-4.

2. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. Acad Emerg Med. 2005;12:844-9.

3. Ball GC, Kirkpatrick AW, Laupland KB et al. Factors related to the failure of radiographic recognition of occult posttraumatic pneumothoraces. Am J Surg. 2005; 189(5):541-546.

4. Ma OJ, Mateer JR. Trauma ultrasound examination versus chest radiography in the detection of hemothorax. Ann Emerg Med. 1997;29:312,5; discussion 315-6.

5. Eibenberger KL, Dock WI, Ammann ME, Dorffner R, Hormann MF, Grabenwoger F. Quantification of pleural effusions: sonography versus radiography. Radiology. 1994;191:681-4.

6. Grimberg A, Shigueoka DC, Atallah AN, Ajzen S, Iared W. Diagnostic accuracy of sonography for pleural effusion: systematic review. Sao Paulo Med J. 2010;128:90-5.

7. Volpicelli G, Mussa A, Garofalo G, et al. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. Am J Emerg Med. 2006;24:689-96.

8. Agricola E, Bove T, Oppizzi M, et al. "Ultrasound comet-tail images": a marker of pulmonary edema: a comparative study with wedge pressure and extravascular lung water. Chest. 2005;127:1690-5.

9. Liteplo AS, Marill KA, Villen T, Miller RM, Murray AF, Croft PE, Capp R, Noble VE. Emergency thoracic ultrasound in the differentiation of shortness of breath: sonographic B-lines and N-terminal pro-brain type Natriuretic Peptide in Diagnosing Congestive Heart Failure. Acad Emerg Med. 2009;16:201-210.

10. Zanobetti M, Poggioni C, Pini R. Can chest ultrasonography replace standard chest radiography for evaluation of acute dyspnea in the ED? Chest. 2011;139:1140-47.

11. Gargani L, Doveri M, D'Errico L, Frassi F, Bazzichi ML, Delle Sedie A, Scali MC, Monti S, Mondillo S, Bombardieri S, Caramella D, Picano E. Ultrasound lung comets in systemic sclerosis: a chest

sonography hallmark of pulmonary interstitial fibrosis. Rheumatology. 2009;48:1382-1387.

12. Copetti R, Soldati G, Copetti P. Chest sonography: a useful tool to differentiate acute cardiogenic pulmonary edema from acute respiratory distress syndrome. Cardiovasc Ultrasound. 2008; 6:16.

13. Sperandeo M, Varriale A, Sperandeo G, Filabozzi P, Piattelli ML, Carnevale, V, Decuzzi M, Vendemiale G. Transthoracic ultrasound in the evaluation of pulmonary fibrosis: our experience. Ultrasound Med Biol. 2009;35(5):723-9.

14. Frassi F, Gargani L, Tesorio P, Raciti M, Mottola G, Picano E. Prognostic value of extravascular lung water assessed with ultrasound lung comets by chest sonography in patients with dyspnea and/or chest pain. J Cardiac Failure. 2007;13:830-835.

15. Reissig A, Kroegel C. Sonographic diagnosis and follow-up of pneumonia: a prospective study. Respiration. 2007;74(5):537-47.

16. Cortellaro F, Colombo S, Coen D, Duca P. Lung ultrasound is an accurate diagnostic tool for the diagnosis of pneumonia in the emergency department. Emerg Med J. 2012;29(1):19-23.

17. Parlamento S, Copetti R, Di Bartolomeo S. Evaluation of lung ultrasound for the diagnosis of pneumonia in the ED. Am J Emerg Med. 2009;27:379-84.

18. Copetti R. Cattarossi L. Ultrasound diagnosis of pneumonia in children. Radiol Med. 2008;113:190-98.

19. Peris A, Tutino L, Zagli G, et al. The use of point-of-care bedside lung ultrasound significantly reduces the number of radiographs and computed tomography scans in critically ill patients. Anesth Analg. 2010;111:687-92.

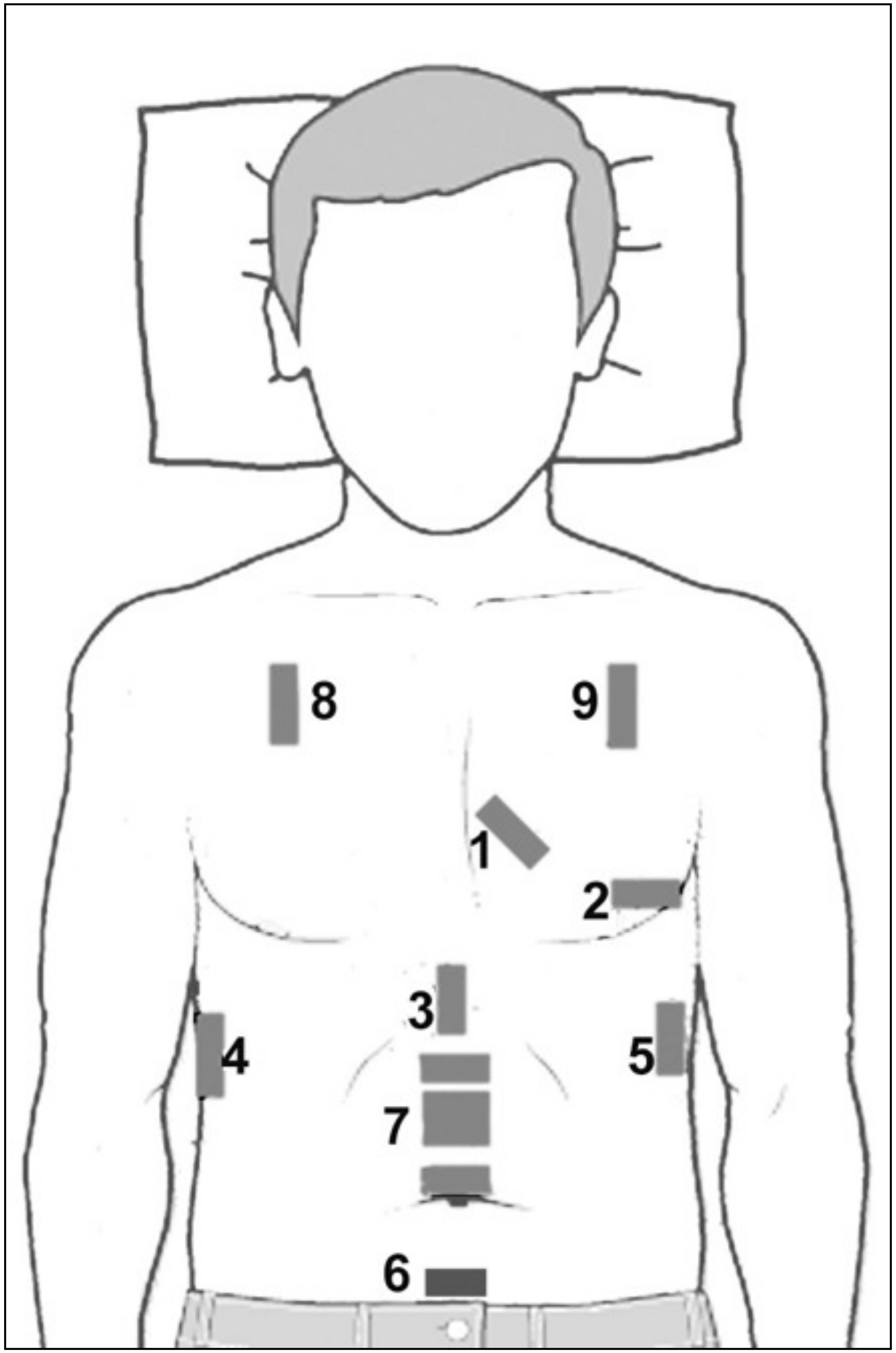
20. Liteplo AS, Murray AF, Kimberly HH, Noble VE. Real-time resolution of sonographic B-lines in a patient with pulmonary edema on continuous positive airway pressure. Am J Emerg Med. 2010;28:541.e5,541.e8

21. Noble VE, Murray AF, Capp R, Sylvia-Reardon MH, Steele DJ, Liteplo A. Ultrasound assessment for extravascular lung water in patients undergoing hemodialysis. Time course for resolution. Chest. 2009;135:1433-9.

22. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. Am J Respir Crit Care Med. 2011;183(3):341-7.

Chapter 5

RUSH



Section 1

Background

Summary

Components of RUSH exam for undifferentiated hypotension:

HI-MAP

Heart

Inferior Vena Cava

Morrison's pouch (FAST)

Aorta

Pneumothorax

It is now the standard of care to perform focused assessment using sonography for trauma (FAST) early in the evaluation of a sick trauma patient. Historically, there has been far less urgency to use ultrasound to evaluate the medical patient with hypotension or signs of shock. The main reasons for this discrepancy are the lack of a universally accepted name for the exam and a standardized sequence of views to obtain. The Rapid Ultrasound for Shock and Hypotension exam (RUSH), first described in 2007, solved this problem with an easy to remember moniker (RUSH) and an acronym (HI-MAP) that serves as a cognitive prompt of the views required.

In 2001, Rose et al. published an ultrasound protocol they had created to evaluate the undifferentiated hypotensive patient.[1] A few years later, Jones et al. studied the effects of early goal-directed ultrasound for ED patients with hypotension.[2] This study showed a reduction in the number of conditions that needed to be ruled out, as well as a quicker time to final diagnosis. Recently, additional articles have discussed the use of focused ultrasound for cardiac arrest and shock patients without obvious etiology.[3-4]

In an effort to aggregate all of the various diagnostic ultrasound techniques applicable to these patients into a memorable approach, Weingart et al. created the RUSH exam.[5] RUSH was designed to be rapid and easy to perform with portable machines found in most emergency departments. The components of the exam are views of the: heart, inferior vena cava (IVC), abdomen and thorax as for the extended FAST exam, and of the aorta. These components can be recalled with the mnemonic *HI-MAP*, which prompts the clinician to scan in sequence the Heart, IVC, Morison's (the FAST exam), Aorta and Pneumothorax. We will discuss each of the components in detail below.

Section 2

Heart

The heart portion of the RUSH exam evaluates for pericardial effusion and tamponade, right ventricular failure as a sign of pulmonary embolism and a qualitative assessment of left ventricular function. Of the views described in the Basic Cardiac chapter, the ones used for the RUSH exam are the parasternal long axis and the four-chamber view (see Movie 5.1 and 5.2).

Movie 5.1 - Parasternal long axis.

Movie 5.2 - Apical four-chamber.

Summary

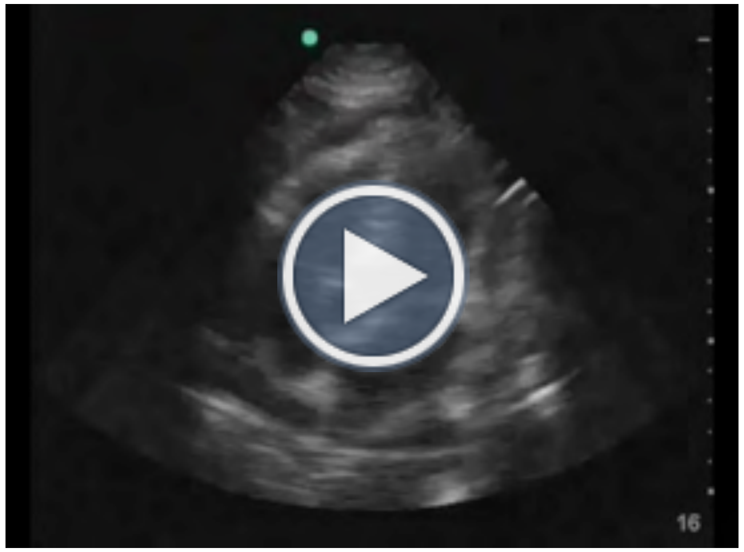
Evaluate for:

Pericardial effusion and tamponade

Right Ventricular Failure

Pulmonary Embolism

MOVIE 5.3 - Pericardial effusion



MOVIE 5.4 - Pericardial tamponade

MOVIE 5.5 - Pericardial tamponade

PERICARDIAL TAMPONADE

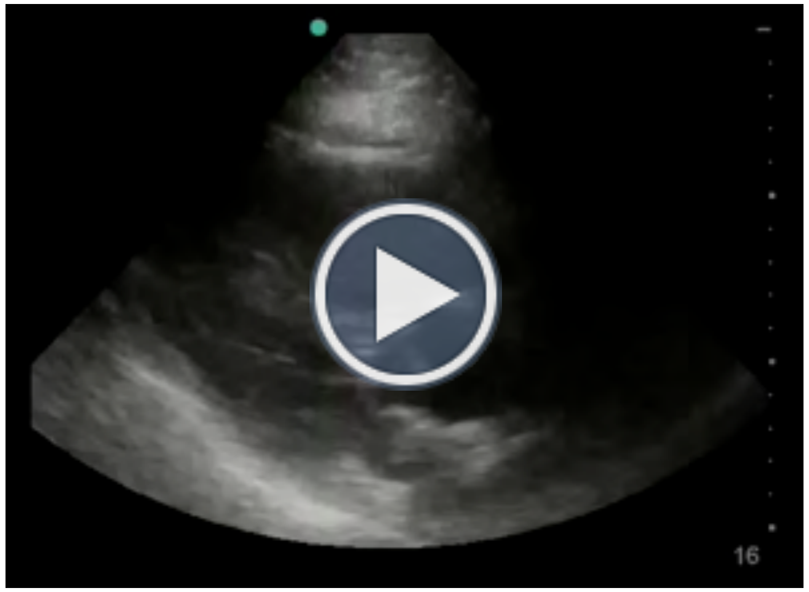
The parasternal long axis view and apical four chamber view are used to assess for pericardial fluid, which is best identified posterior to the left ventricle (LV) and anterior to the descending aorta (see Movie 5.3 and 5.4). In the setting of shock and hypotension, more than trace pericardial fluid should increase your suspicion for pericardial tamponade. However, an experienced ultrasonographer can assess for this condition directly. In the same parasternal long view, if there is collapse of the right atrium during diastole (sensitive) and the right ventricle (RV) during early diastole (specific), then the diagnosis is likely to be tamponade (see Movie 5.5).[6]

If tamponade is diagnosed, ultrasound can be used dynamically to aid in the performance of pericardiocentesis (Link to pericardiocentesis/Procedures chapter). Ideally, a large pocket of fluid with a good amount of space between the pericardium and the heart, without interposed lung, will be identified. This site may be sub-xiphoid, but more often it is on the anterior chest wall. Ultrasound-guided pericardiocentesis is safer than a blind sub-xiphoid procedure.[7]

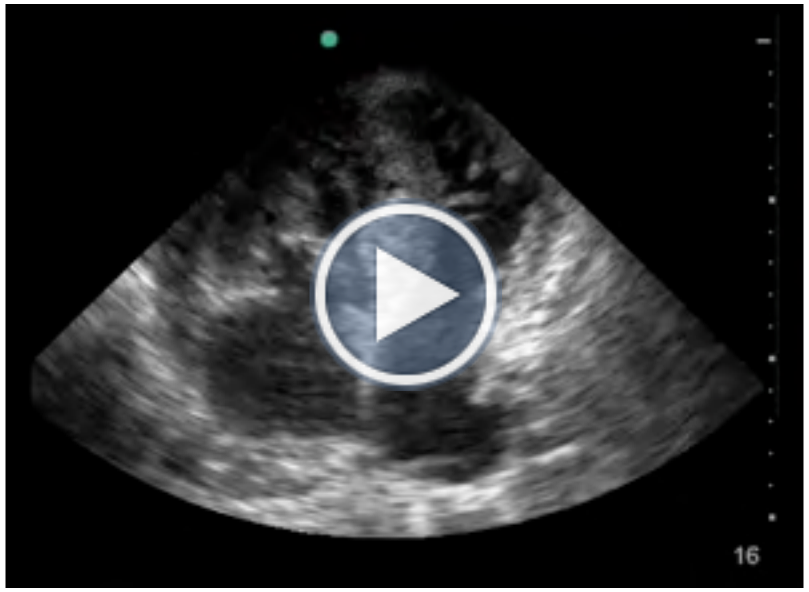
RIGHT VENTRICULAR ENLARGEMENT

Rarely, actual pulmonary artery clot can be visualized during transthoracic echocardiography (TTE), but massive pulmonary embolism is more likely to present with only indirect signs. Signs of acute right ventricular failure (RVF) will often accompany pulmonary embolism significant enough to cause shock. An enlarged right ventricle on the four-chamber view (Movie 5.6) points to RVF as one of the contributors to the patient's shock state. RVF can be caused by many entities, but when it is acute in the setting of shock, the most likely diagnoses are massive pulmonary embolism and right ventricular infarction.

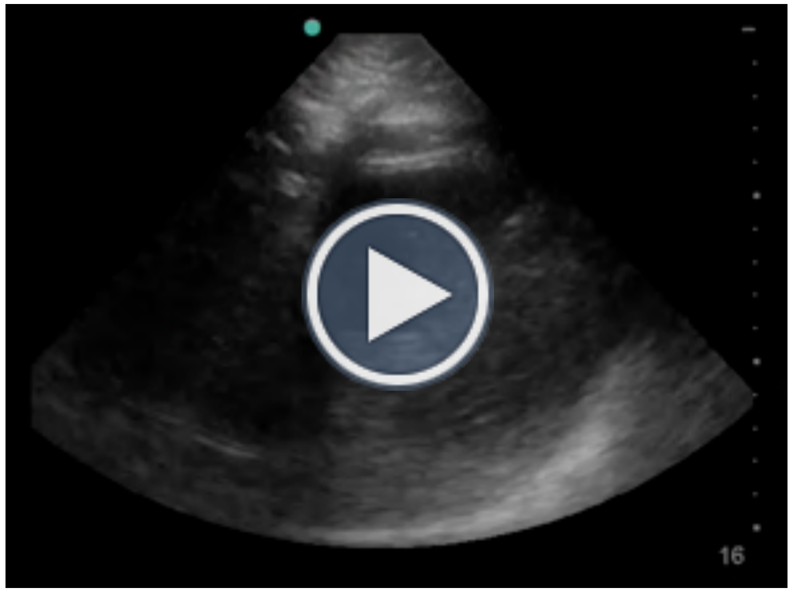
MOVIE 5.6 - Right ventricular failure/ enlargement



MOVIE 5.7 - RV strain



MOVIE 5.8 - RV pressure and volume overload with septal flattening



The right ventricle is normally less than 60 percent of the size of the left ventricle. When the RV size is equal to or larger than the LV, RV strain should be suspected. Another sign of RV strain can be flattening or bowing of the interventricular septal wall that can be seen on the apical four-chamber view (see Movie 5.7). Increased right-sided pressure will also be seen well on the parasternal short axis view, causing a "D" shaped left ventricle (see Movie 5.8).[8]

Enlargement of the right ventricle can also occur from right ventricular infarction. This diagnosis will often present with signs of inferior wall infarction on electrocardiogram and may have associated left ventricular dysfunction. However, cardiogenic shock can occur from isolated right ventricular failure without associated EKG or left ventricular abnormalities.[9]

HYPODYNAMIC LEFT VENTRICLE

In the setting of hypotension, the qualitative assessment of LV function can indicate a cardiogenic cause. Depressed LV function can be the result of a primary problem, e.g. infarction or myopathy, or it can be secondary to conditions such as sepsis or toxins. While more complicated procedures allow a numeric estimate of the ejection fraction, in the setting of hypotension, a visual estimate often suffices.[10]

In parasternal long view, at the level of the papillary muscles, a change in LV chamber size from systole to diastole that is less than 30 percent indicates a severely decreased LV function (see Movie 5.9).

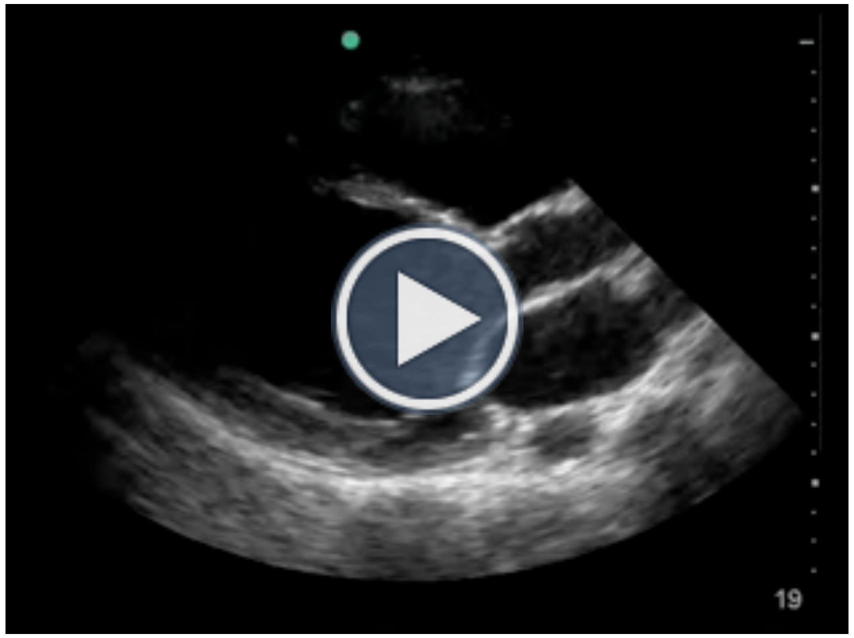
((end diastolic size-end systolic size)/end diastolic size)

In 2002, Moore et al. found that a group of physicians that had witnessed a reasonable number of normal and abnormal exams during a brief training could estimate LV function after a few seconds of seeing the heart's function.[11]

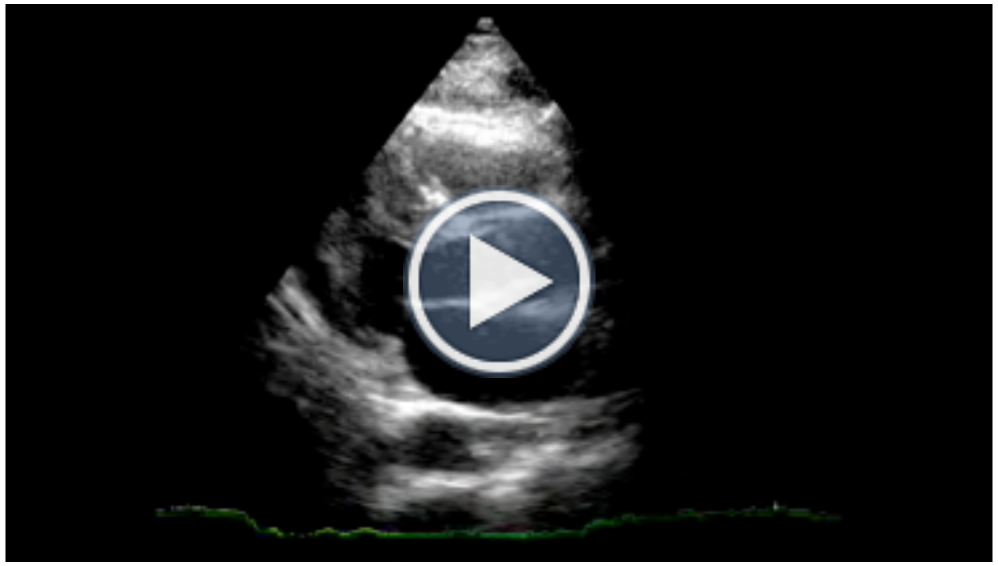
Hyperdynamic Left Ventricle

In the same echocardiographic view just mentioned, if the left ventricular walls change by more than 90 percent between systole and diastole, or if they actually touch at end systole, then the LV is hyperdynamic (see Movie 5.10). This can be seen in hypovolemia, acute blood loss, and often in sepsis prior to the administration of vasopressors. These patients will usually benefit from volume loading.

Movie 5.9 - Severely decreased LV function



Movie 5.10 - Hyperdynamic LV



SECTION 3

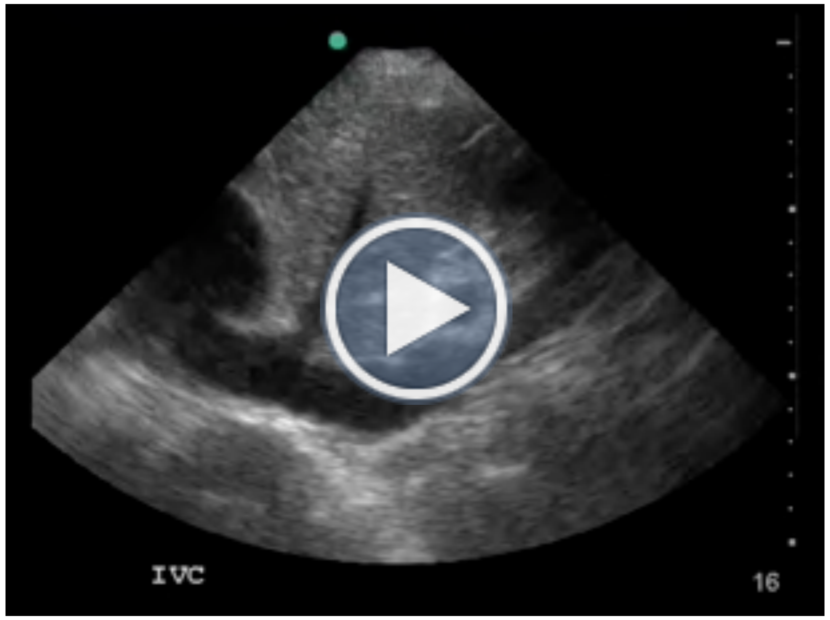
Inferior Vena Cava

The evaluation of the IVC (link to fluid responsiveness) can give an estimate of the volume status of the patient. The exam outlined below is a dynamic evaluation of filling pressures based on respiration. The exam is conducted differently depending on whether the patient is spontaneously breathing or if the patient is on mechanical ventilation.

SPONTANEOUSLY BREATHING PATIENTS

The IVC should first be located in longitudinal orientation in the subxiphoid area. This view is most easily obtained by first obtaining a subxiphoid four-chamber view of the heart and then, with the right atrium centered on the screen, rotating the probe 90 degrees on its axis. Collapsibility of the IVC should be evaluated 2 centimeters below the junction between IVC and right atrium (see Movie 5.11).

MOVIE 5.11 - IVC



SUMMARY

Dynamic changes in IVC can estimate volume status

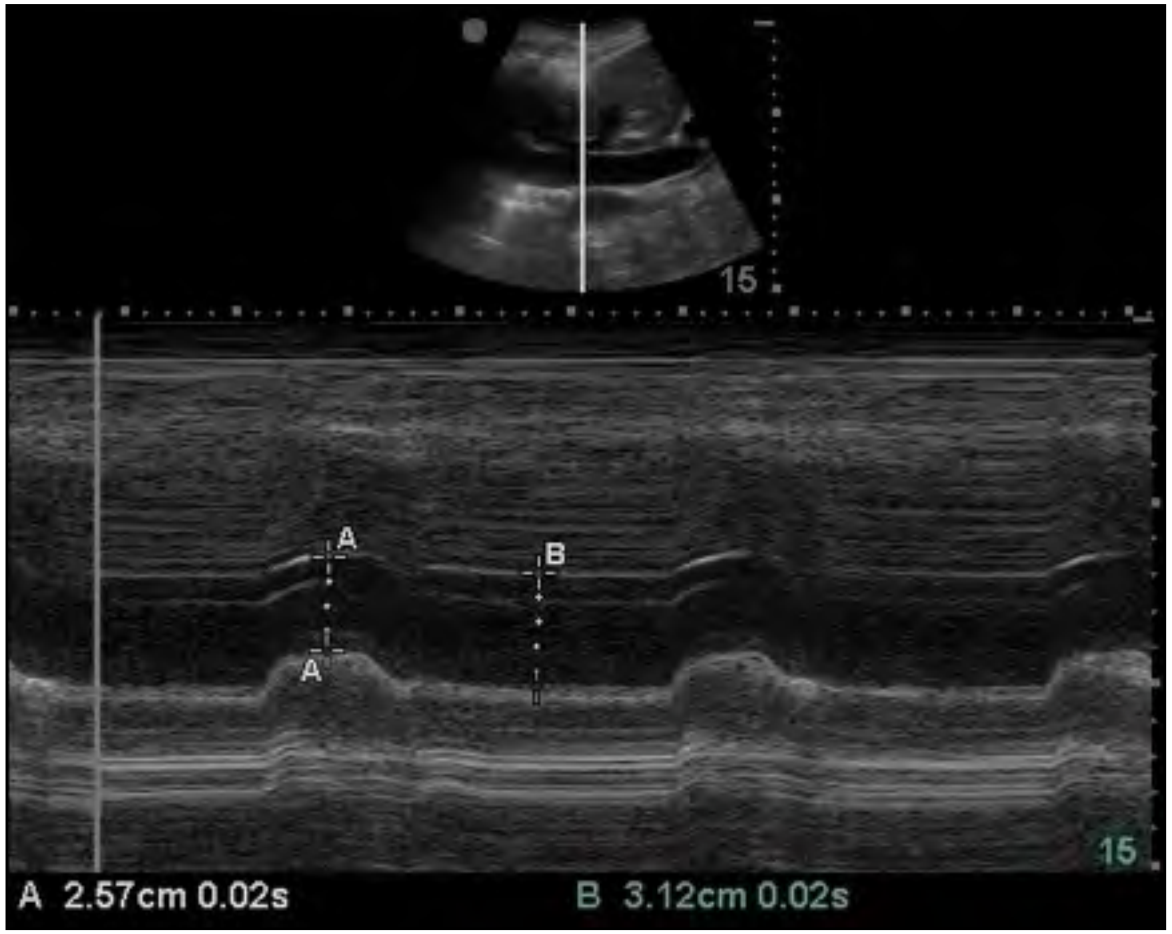
IVC collapses with inspiration in spontaneously breathing patients

IVC collapses with expiration in mechanically ventilated patients

Greater than an 18% change in IVC size in mechanically ventilated patients predicts an increase in cardiac output to a fluid challenge.

Both the diameter of the IVC and the response to inspiratory effort are examined. The latter is often best assessed using M-mode ultrasonography (Image 5.1).

IMAGE 5.1 - IVC M-Mode Measurement



The IVC portion of the exam allows an estimation of the central venous pressure (CVP) and predicts a beneficial response to fluid bolus. An IVC diameter of <1.5 cm with complete inspiratory collapse is associated with a response to volume loading, and these findings are associated with a low CVP (<5) (see Movie 5.12).[12]

MOVIE 5.12 - Low CVP

Conversely, an IVC diameter of >2.5 cm with no inspiratory collapse represents a high CVP (>20) and the patient is unlikely to increase their cardiac output in response to fluid loading.[12] If the patient is intravascularly depleted in this setting, they will need agents to increase their inotropy or decrease their afterload before fluids will be helpful.

MECHANICALLY VENTILATED PATIENTS

In contrast to spontaneously breathing patients, mechanical inspiration causes the IVC to enlarge. The difference between the inspiratory and expiratory size of the IVC can be used to gauge the need for fluid loading. In order to accurately assess the IVC in ventilated patients, they must be sedated enough to not be taking spontaneous breaths during the time of measurement. In addition, the ventilator should be adjusted to deliver 10 ml/kg of tidal volume. Even in patients with acute lung injury, placing a patient on this tidal volume for the ~20 seconds of measurement will cause no ill effects. The patient should be returned to their previous ventilator settings after assessing the IVC.

Many studies have evaluated IVC diameter changes as a measurement of response to fluid loading. [13] Unfortunately, these studies calculated their cut-off points using different formulae. The simpler formula is Barbier's.[13]

((Insp size – Exp Size)/Exp size)

The result is expressed as a percentage; using this formula the cut-off is 18 percent change. Values greater than this predict an increase in cardiac output to a fluid challenge.

Section 4

FAST Exam

Summary

FAST exam can identify causes of hypotension such as:

Ectopic pregnancy

Massive ascites

Ruptured viscus

Spontaneous intraabdominal bleed

Traumatic intraabominal bleed

Intraperitoneal rupture of AAA

Morison's and the FAST Exam

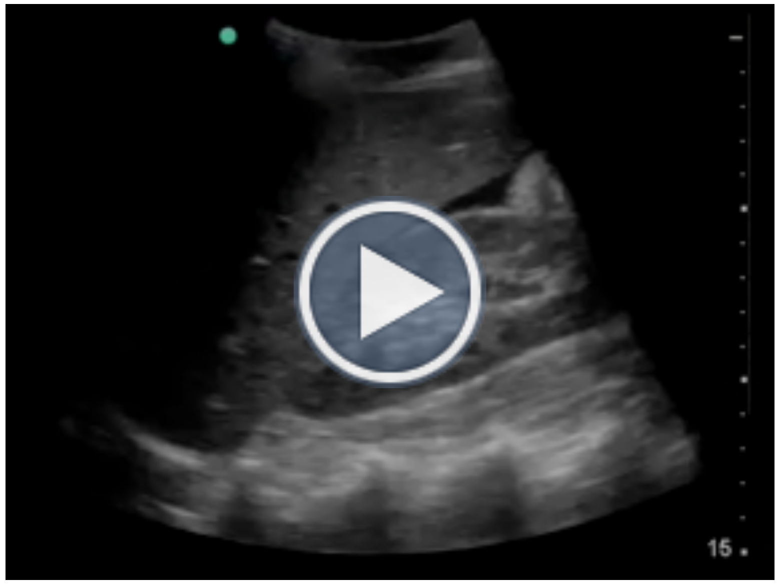
The FAST exam (link to FAST) is perhaps the most well recognized use of point of care ultrasound. Imaging for free fluid in the right upper quadrant, left upper quadrant, and suprapubic area can provide a clue to many etiologies of hypotension, such as ectopic pregnancy, massive ascites, ruptured viscus, spontaneous intraabdominal bleeding, intraperitoneal rupture of an AAA, etc. (see Movies 5.13-5.20). If there is not time to complete all of these views, an image of Morison's pouch with the patient in Trendelenburg position is sensitive for significant intraperitoneal blood or fluid.[14]

When performing the upper quadrant views, sliding the probe up to the thorax allows us to image the interface between lung and diaphragm for hypoechoic fluid or blood in either hemithorax.[15]

Movie 5.13

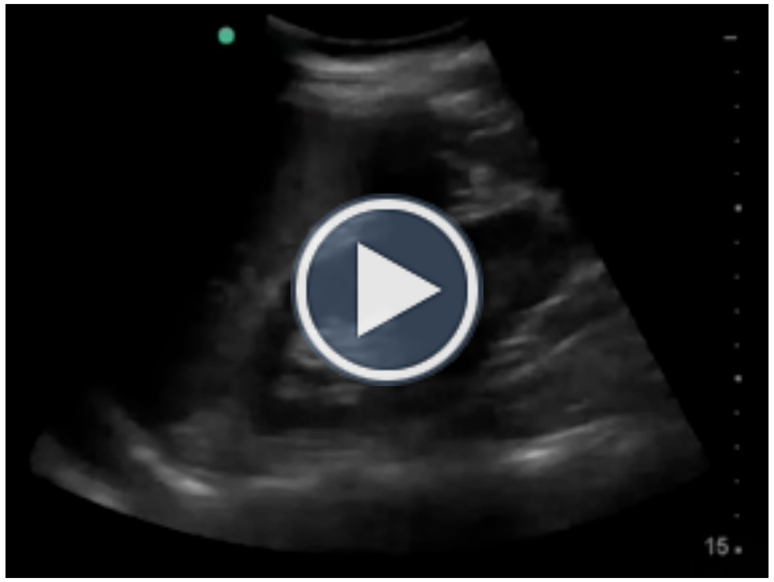
RUQ Normal

Movie 5.14



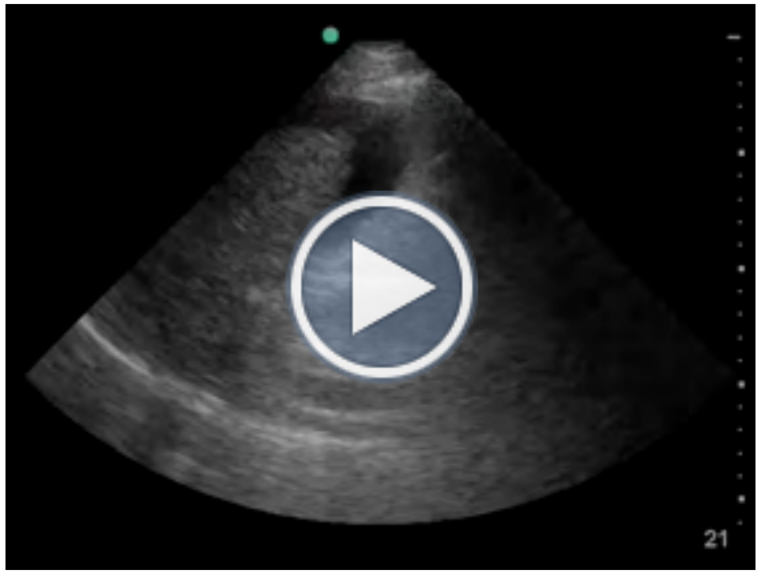
FAST Positive RUQ

Movie 5.15



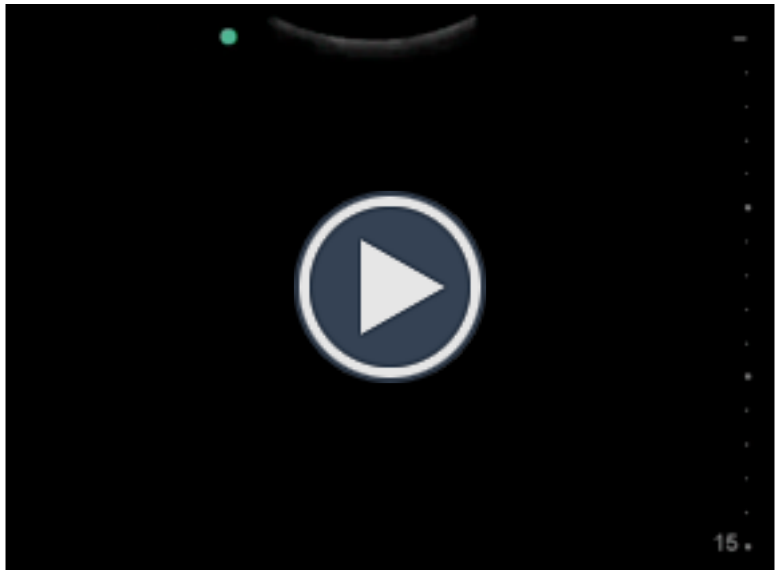
LUQ Normal

Movie 5.16



FAST Positive LUQ

Movie 5.17

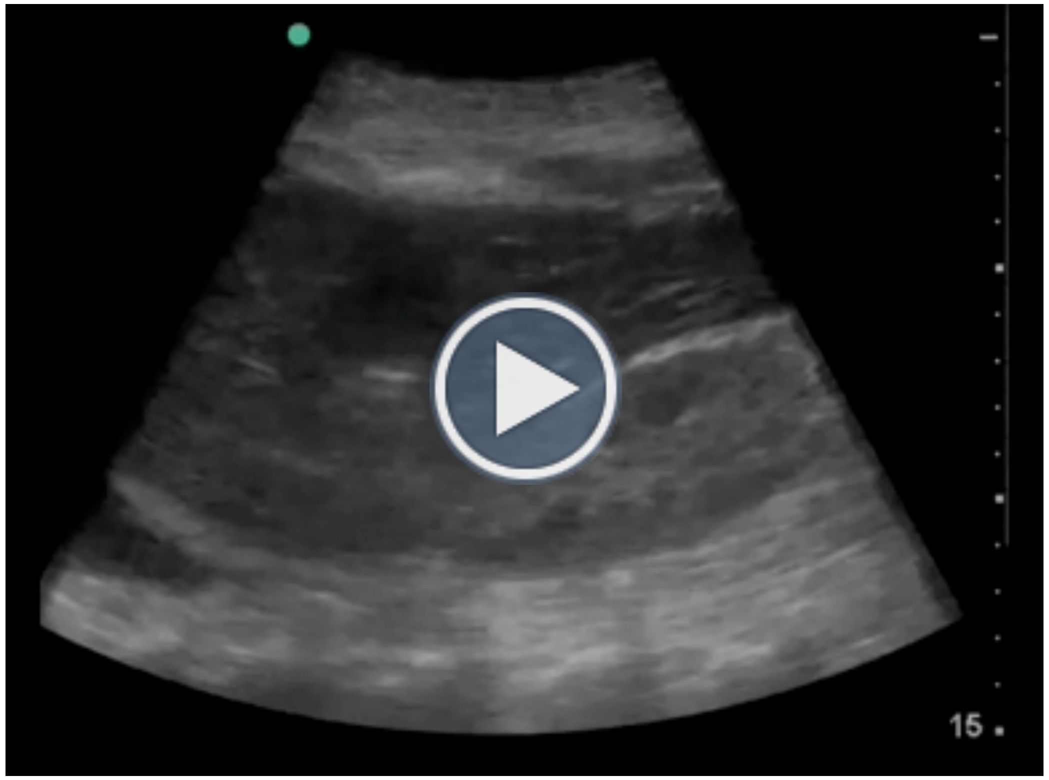


Pelvic Transverse Normal

Movie 5.18

Pelvic Sagittal Normal

Movie 5.19



FAST Positive Right Hemithorax

Movie 5.20

FAST Positive Pelvic

SECTION 5

Aorta

Scanning the abdominal aorta (link to aorta) for aneurysm (AAA) is one of the key emergency ultrasound modalities. We prefer to scan the aorta in transverse orientation at four levels: just below the heart, suprarenal, infrarenal, and just before the iliac bifurcation.[16] By sliding the probe down from the xiphoid to the umbilicus, these four views can be obtained in a continuous and rapid fashion (see Movie 5.21). If the Aorta is >5 cm in any of these views and the patient is in shock, the diagnosis is a ruptured AAA until proven otherwise (see Movie 5.22).

SUMMARY

If aorta >5cm, then a patient in shock has a ruptured AAA until proven otherwise

Scan at 4 levels:

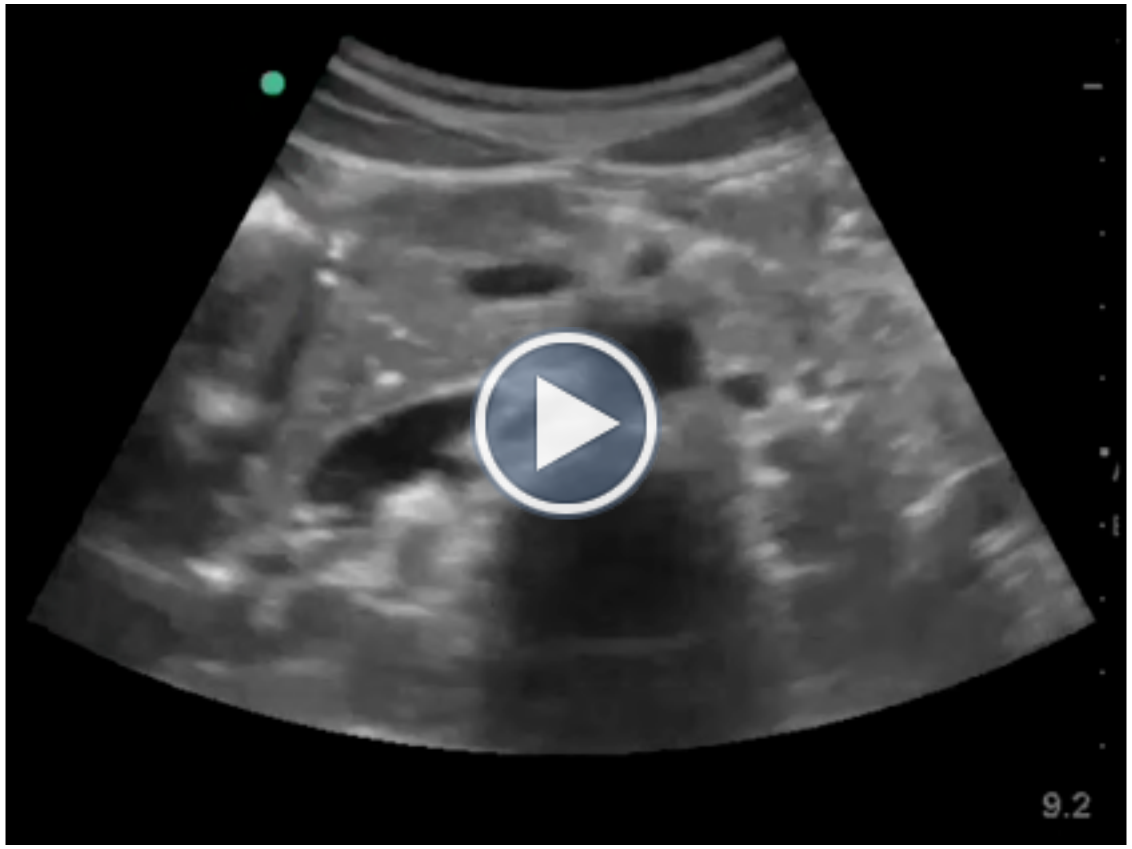
Subxiphoid

Suprarenal

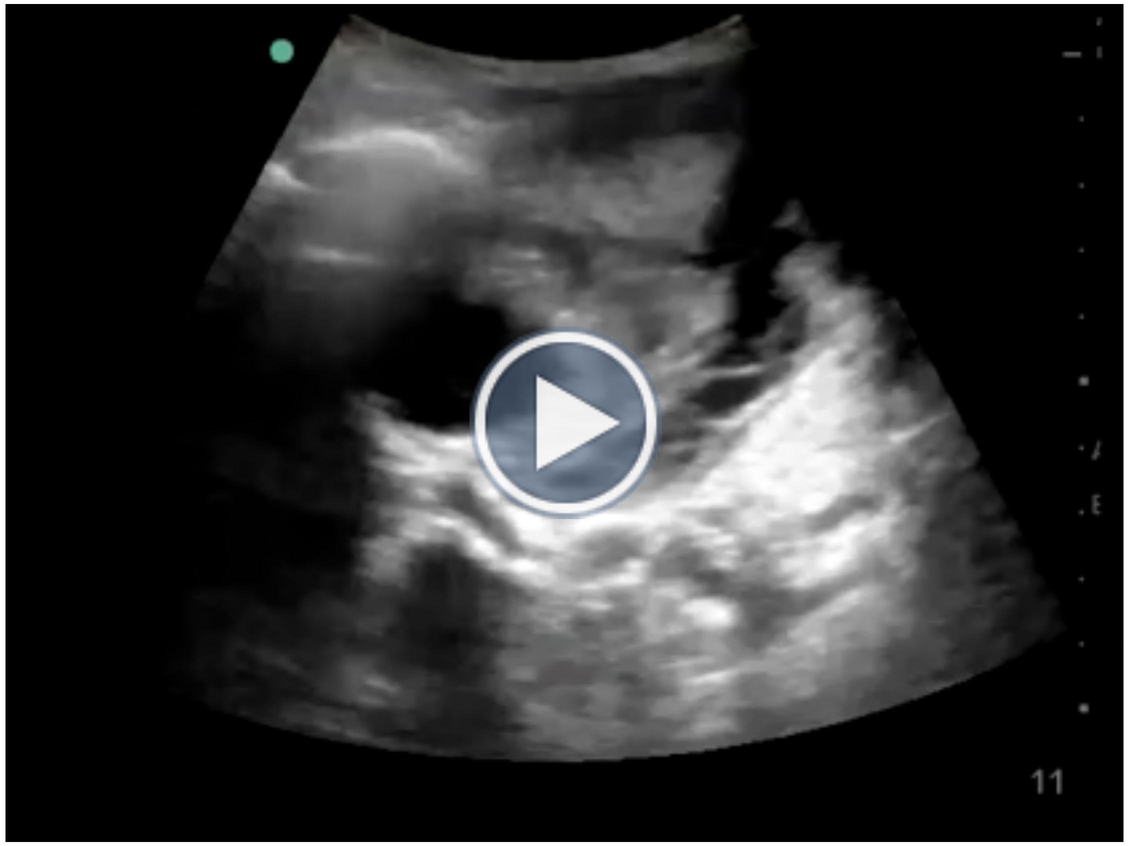
Infrarenal

Just before iliac bifurcation

MOVIE 5.21 - Normal aorta scan in transverse



MOVIE 5.22 - Massive Aortic Aneurysm



Pneumothorax

SUMMARY

Scan from the midclavicular second intercostal space to the last rib

Normal lung will have a shimmering pleural line

Pneumothorax will have a pleural line with loss of shimmering

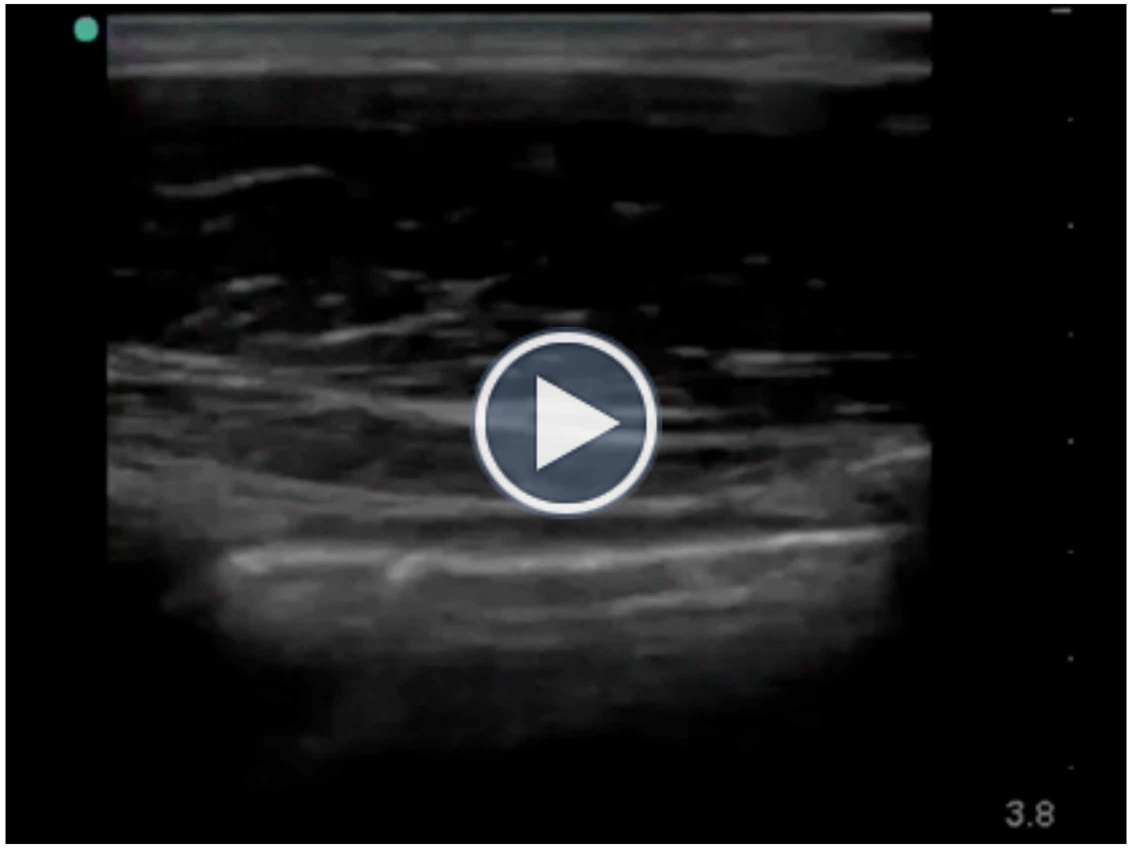
Causes of false positive for pneumothorax:

Mainstem bronchus intubation

Bronchial obstruction

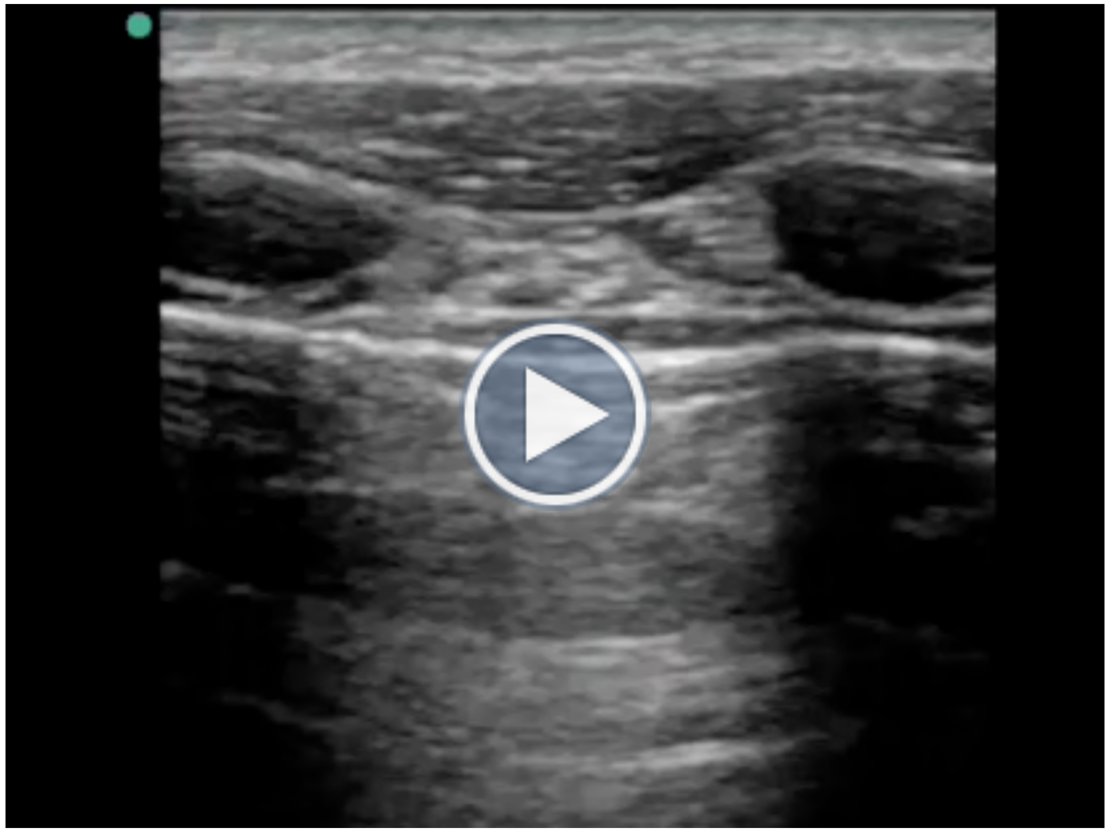
Though far more likely in trauma, tension pneumothorax can be a cause of shock in medical patients as well, especially if the patient has recently had a procedure such as a central line, pacemaker placement, lung biopsy, or thoracentesis. Scan the anterior chest wall of both thoraces with probe held in a parasagittal orientation from the midclavicular second intercostal space to the last rib with a high frequency linear, microconvex or phased array probe. Normally apposed pleural surfaces will appear to slide against one another resulting in a shimmering effect. This is normal lung sliding (see Movie 5.23).

MOVIE 5.23 - Normal lung sliding



In pneumothorax, the pleura are no longer apposed and this sliding will disappear (Movie 5.24). Pathognomonic for pneumothorax is

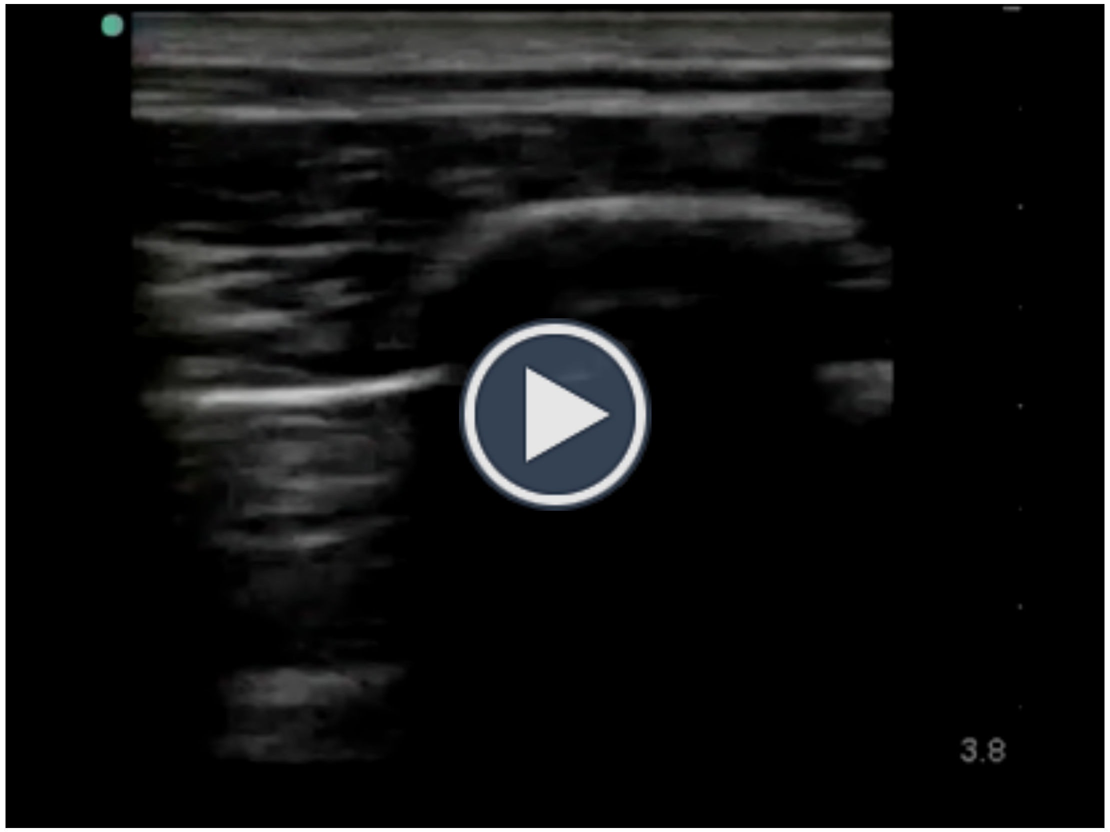
MOVIE 5.24 - Pneumothorax - Loss of lung sliding or shimmering



the transition from normally apposed pleura to pleura separated by the air of a pneumothorax. When this *lung point* is found, you will see normal pleural sliding on one side of your screen with loss of sliding on the other (see Movie 5.25).

We have found imaging in M-mode to make for the easiest interpretation. The seashore sign (see image 5.2), with static lines above and the granular pattern of normal lung movement below the pleura, reassures that there is no pneumothorax at the location of the probe. If the stratosphere sign (image 5.3), with static lines above and below the pleura, is observed, then pneumothorax is likely.[18]

MOVIE 5.25 - Lung point



One caution in intubated patients: abnormal lung sliding can be seen due to decreased lung aeration on the contralateral side with mainstem bronchus intubation and on the ipsilateral side with bronchial obstruction. In these cases, identification of *lung pulse* (see Movie 5.26 and image 5.4), which represents cardiac activity transmitted to normally apposed pleura, indicates that mainstem intubation or bronchial obstruction has resulted in abnormal pleural sliding rather than pneumothorax.[18]

IMAGE 5.2 - Seashore sign - Normal lung

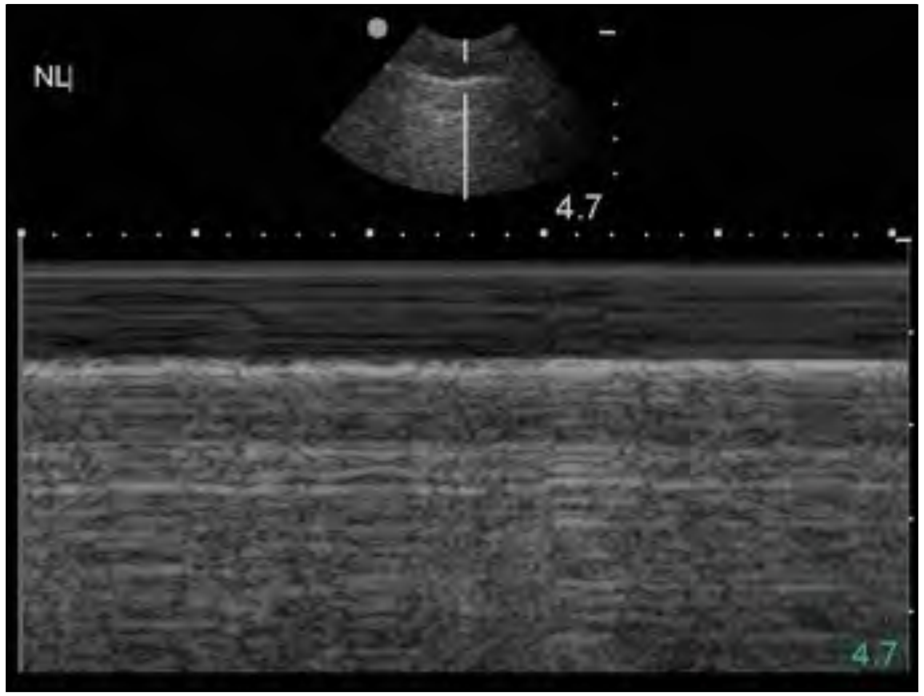
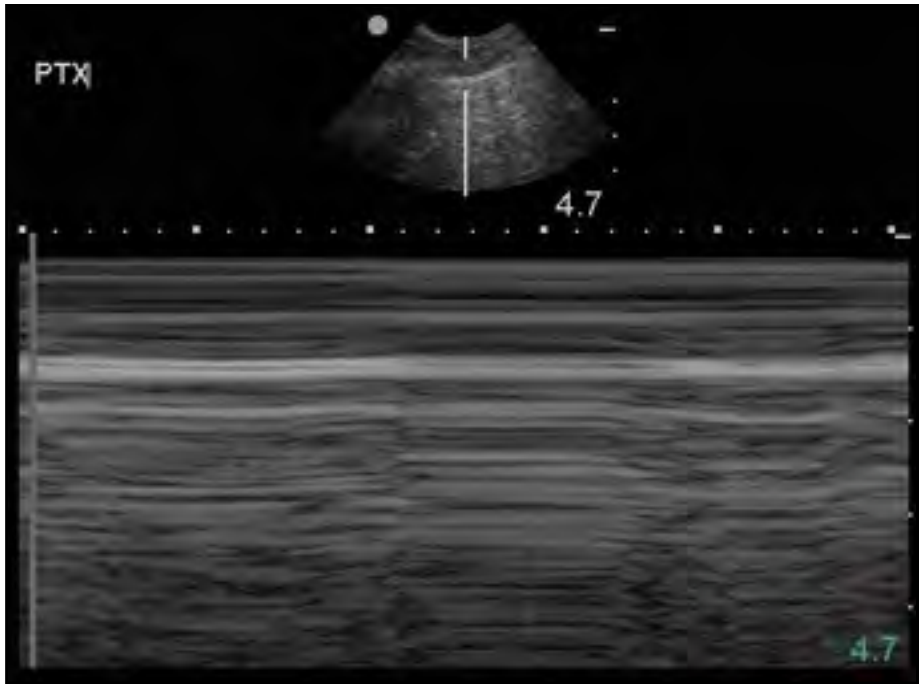


IMAGE 5.3 - Stratosphere or barcode sign - Pneumothorax



MOVIE 5.26 - Lung Pulse

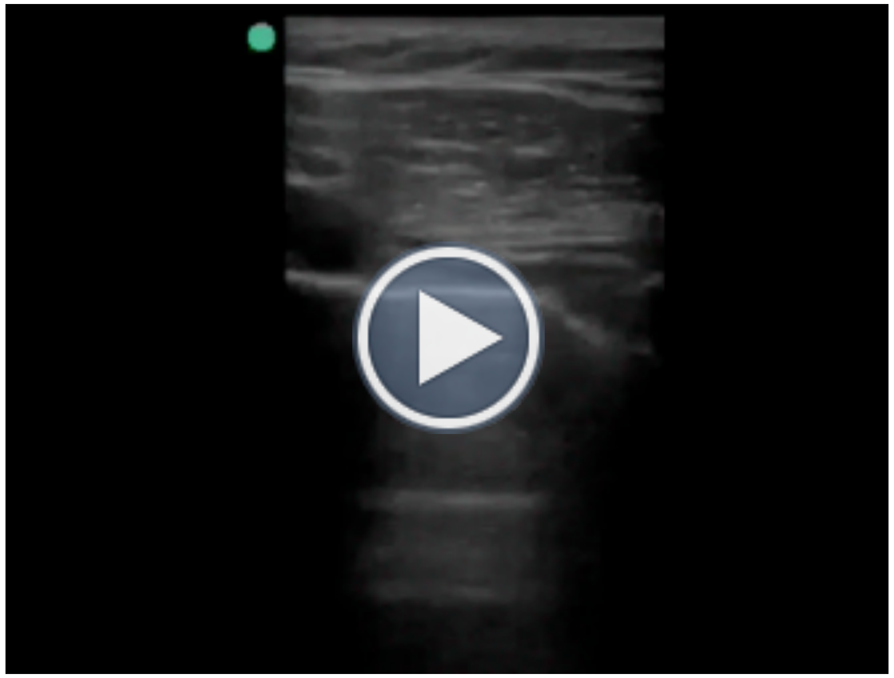
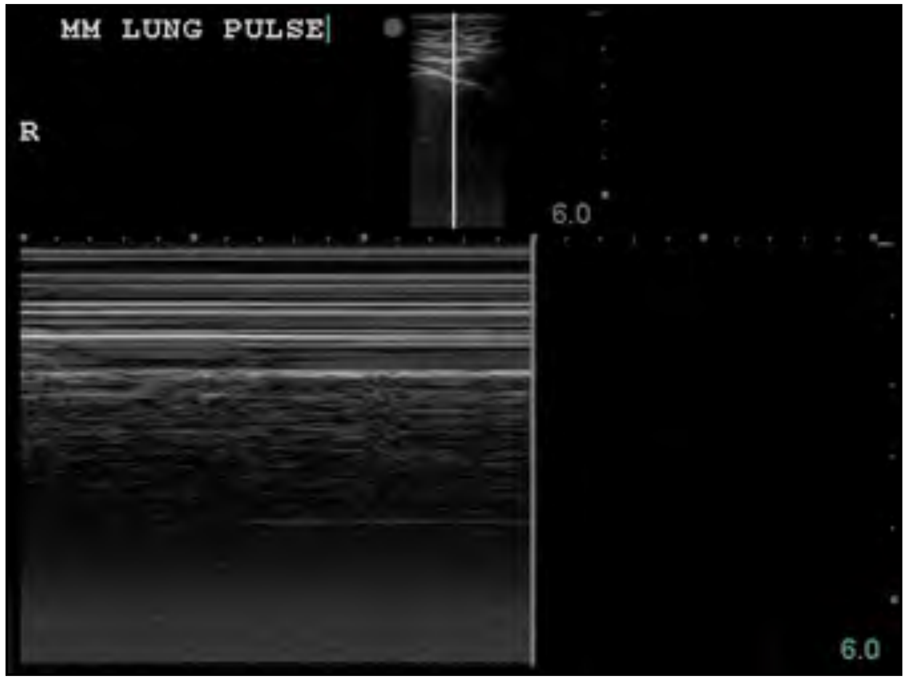


IMAGE 5.4 - Lung Pulse with M-mode



SECTION 7

Sequencing and Conclusion

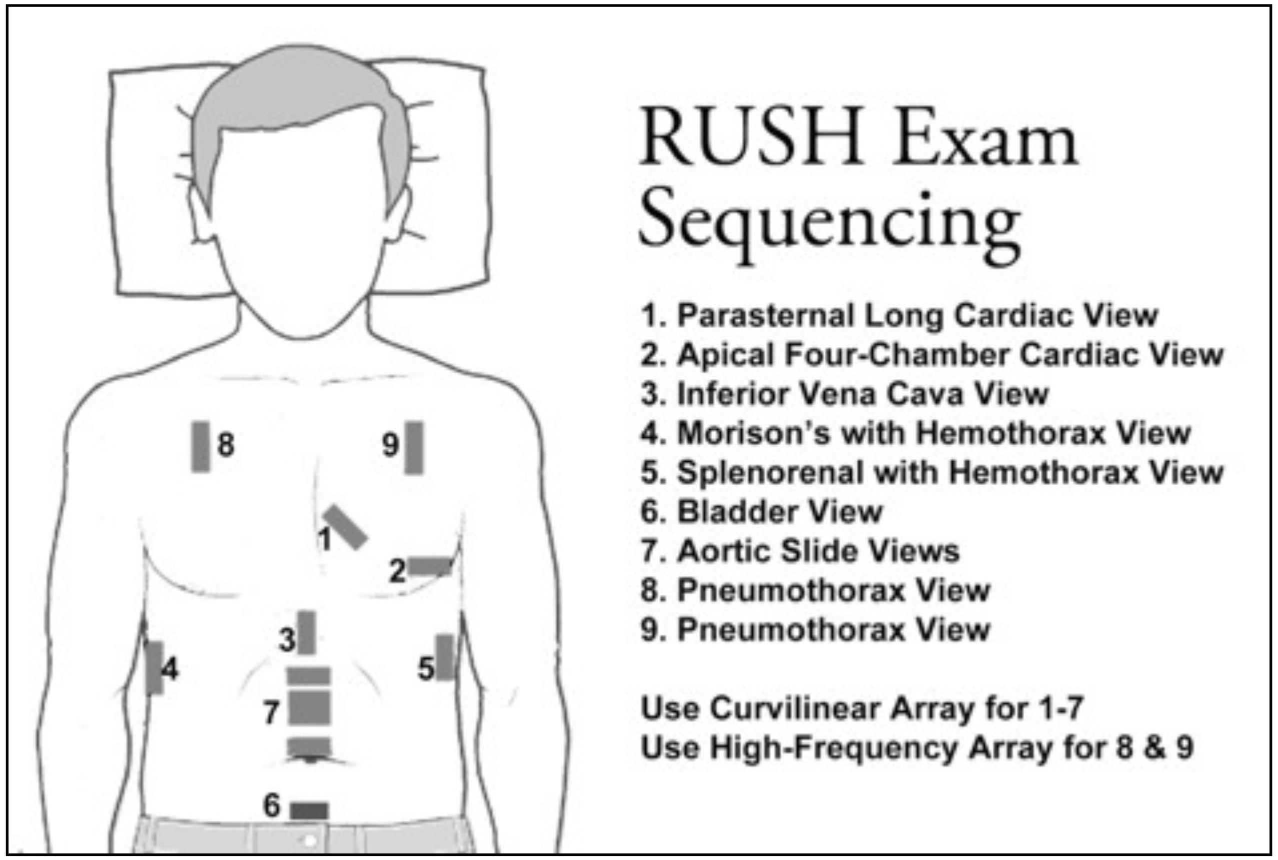
SUMMARY

The entire exam can be done in 2 *minutes*

Remember **HI-MAP** acronym

This entire exam can be completed in less than 2 minutes using readily available portable machines. The HI-MAP acronym serves as a mnemonic prompt to remind us of the sequence of views (see image 5.5).

IMAGE 5.5



1. Heart: Obtain parasternal long view and then apical four chamber cardiac view using a phased array cardiac probe or microconvex probe.

2. IVC: switch to a large curvilinear general-purpose probe to obtain dynamic views of the IVC.

3. Morison's (and FAST): Obtain Morison's and splenorenal views imaging both hemithoraces, and then scan the bladder (transverse and sagittal).

4. Aorta: Increase your depth to find the aorta at the epigastrium; in one motion, scan through entire aorta to bifurcation.

5. Pneumothorax: Scan both sides of the chest for pneumothorax. If unable to image the pleural interface appropriately with large curvilinear probe, switch to a high frequency linear transducer.

Conclusion

The RUSH exam provides a sequenced approach to ultrasound in the critically ill shocked or hypotensive patient. Using the HI-MAP components, we can evaluate for the causes of hypotension and tissue malperfusion and respond appropriately.

The name of the exam, *RUSH*, ought to inspire the same alacrity to perform ultrasound in the sick medical patient as the ubiquitous FAST has in trauma.

REFERENCES

1. Rose JS, Bair AE, Mandavia D, Kinser DJ. The UHP ultrasound protocol: A novel ultrasound approach to the empiric evaluation of the undifferentiated hypotensive patient. *Am J Emerg Med* 2001, Jul;19(4):299-302.

2. Jones AE, Tayal VS, Sullivan DM, Kline JA. Randomized, controlled trial of immediate versus delayed goal-directed ultrasound to identify the cause of nontraumatic hypotension in emergency department patients. *Crit Care Med* 2004, Aug;32(8):1703-8.

3. Hernandez C, Shuler K, Hannan H, Sonyika C, Likourezos A, Marshall J. C.A.U.S.E.: Cardiac arrest ultra-sound exam–a better approach to managing patients in primary non-arrhythmogenic cardiac arrest. *Resuscitation* 2008, Feb;76(2):198-206.

4. Weekes AW. Symptomatic hypotension: ED stabilization and the emerging role of sonography. *EM Practice* 2007, Nov 1;9(11).

5. Weingart SW, Duque DD, Nelson BN. ACEP-EMED home; 3 April 2009. Available from: http://www.webcitation.org/5vyzOaPYU. Accessed 9 January 2011.

6. Singh S, Wann LS, Schuchard GH, Klopfenstein HS, Leimgruber PP, Keelan MH, Brooks HL. Right ventricular and right atrial collapse in patients with cardiac tamponade–a combined echocardiographic and hemodynamic study. *Circulation* 1984;70(6):966-71.

7. Maggiolini S, Bozzano A, Russo P, Vitale G, Osculati G, Cantù E, et al. Echocardiography-guided pericardiocentesis with probe-mounted needle: Report of 53 cases. *J Am Soc Echocardiogr* 2001, Aug;14(8):821-4.

8. Lodato JA, Ward RP, Lang RM. Echocardiographic predictors of pulmonary embolism in patients referred for helical CT. *Echocardiography* 2008, Jul;25(6):584-90.

9. Jacobs AK, Leopold JA, Bates E, Mendes LA, Sleeper LA, White H, et al. Cardiogenic shock caused by right ventricular infarction: A report from the SHOCK registry. *J Am Coll Cardiol* 2003, Apr 16;41(8):1273-9.

10. Pershad J, Myers S, Plouman C, Rosson C, Elam K, Wan J, Chin T. Bedside limited echocardiography by the emergency physician is accurate during evaluation of the critically ill patient. *Pediatrics* 2004, Dec;114(6):e667-71.

11. Moore CL, Rose GA, Tayal VS, Sullivan DM, Arrowood JA, Kline JA. Determination of left ventricular function by emergency physician

echocardiography of hypotensive patients. *Acad Emerg Med* 2002, Mar;9(3):186-93.

12. Adler C, Büttner W, Veh R. [Relations of the ultrasonic image of the inferior vena cava and central venous pressure]. *Aktuelle Gerontol* 1983, Nov;13(6):209-13.

13. Barbier C, Loubières Y, Schmit C, Hayon J, Ricôme JL, Jardin F, Vieillard-Baron A. Respiratory changes in inferior vena cava diameter are helpful in predicting fluid responsiveness in ventilated septic patients. *Intensive* Care *Med* 2004, Sep;30(9):1740-6.

14. Abrams BJ, Sukumvanich P, Seibel R, Moscati R, Jehle D. Ultrasound for the detection of intraperitoneal fluid: The role of trendelenburg positioning. *Am J Emerg Med* 1999, Mar;17(2):117-20.

15. Sisley AC, Rozycki GS, Ballard RB, Namias N, Salomone JP, Feliciano DV. Rapid detection of traumatic effusion using surgeon-performed ultrasonography. *J Trauma* 1998, Feb;44(2):291-6; discussion 296-7.

16. Tayal VS, Graf CD, Gibbs MA. Prospective study of accuracy and outcome of emergency ultrasound for abdominal aortic aneurysm over two years. *Acad Emerg* Med 2003, Aug;10(8):867-71.

17. Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. *Chest* 1995;108:1345-8.

18. Murphy M, Nagdev A, Sisson C. Lack of lung sliding on ultrasound does not always indicate a pneumothorax. *Resuscitation* 2008;77(2):270-270.

Chapter 6

RUQ

SECTION 1

Introduction

SUMMARY

RUQ ultrasound includes evaluation of the presence of gallstones, gallbladder wall thickening, pericholecystic fluid, and common bile duct dilation.

Gallstones are bright intraluminal structures that cast dark shadows

The normal GB wall thickness is <3mm

The normal intraluminal CBD diameter is <7mm

A positive sonographic Murphy's sign is the most sensitive ultrasonographic finding of acute cholecystitis.

The primary tools used in the evaluation of the patient with right upper quadrant (RUQ) pain and suspected hepatobiliary disease are ultrasound, HIDA scanning, computed tomography, ERCP, and MRCP. The primary objectives of the clinical evaluation are to rule out gallstones and differentiate between biliary colic and more serious etiologies, such as acute cholecystitis and choledocholithiasis.

Clinical indications for performing bedside RUQ ultrasound include physical exam findings, including RUQ pain, fever, nausea, vomiting and jaundice. RUQ ultrasound can be utilized when the physician has clinical suspicion for cholelithiasis, biliary colic, acute cholecystitis, or biliary duct obstruction. Data from numerous studies show that the sensitivity of RUQ US for the diagnosis of cholecystitis in the hands of the experienced sonographer can be as high as 90-97% with a specificity of 95%.[1,2] Other studies have shown that the sensitivity of CT scanning may be as low as 94%.[1,3,4] It is clear from the literature that the use of bedside ultrasonography in the hands of an experienced user is the most accurate, speedy and cost efficient way to evaluate RUQ pain. [4-8]

SECTION 2

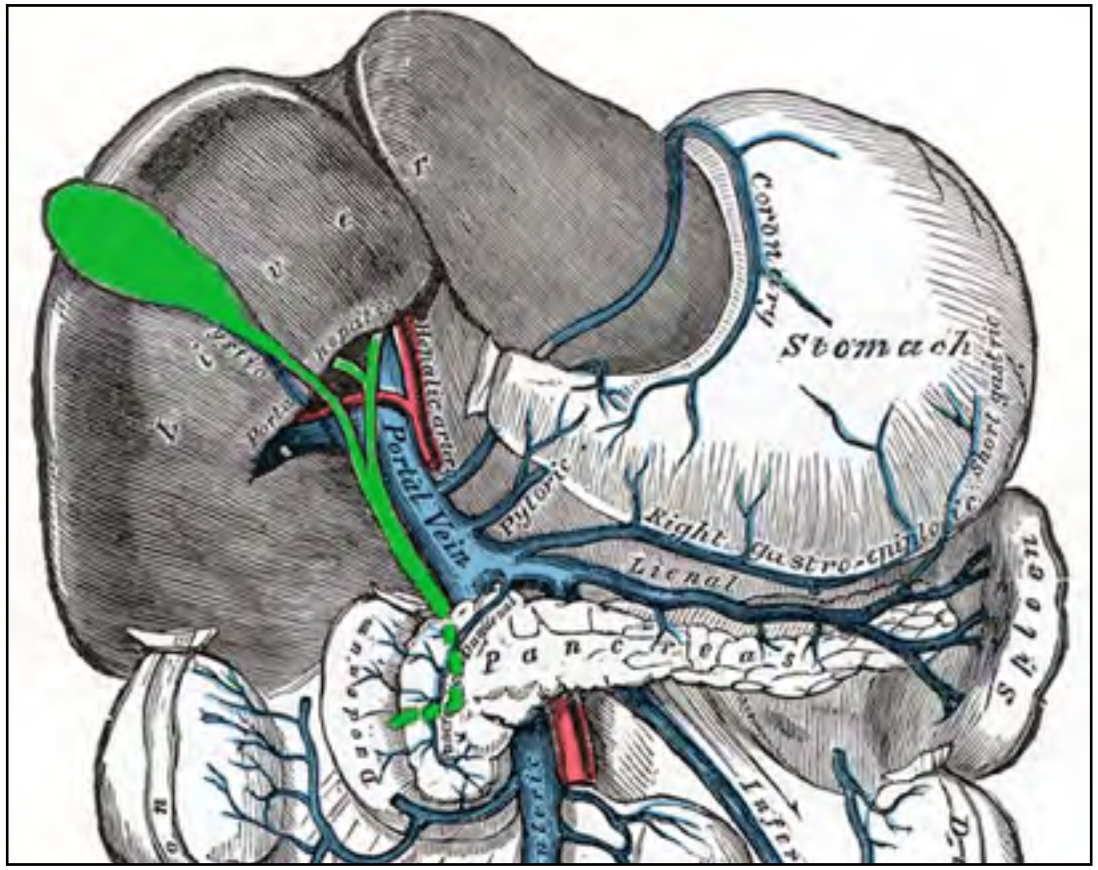
Anatomy

SUMMARY

The right upper quadrant of the abdomen contains a variety of solid and hollow organs. (Image 6.1)

The largest and most predominant is the liver. The liver is bordered superiorly by the diaphragm and inferiorly by the gallbladder (GB), superior pole of the right kidney and duodenum.

IMAGE 6.1



SECTION 3

Patient & Probe Positioning

SUMMARY

The liver is the acoustic window

Moving the patient into the left lateral decubitus position can improve the ability to visualize the gallbladder

Have the patient take a deep breath to improve visualization

The curvilinear probe is preferred

MOVIE 6.1 - How to perform the RUQ ultrasound

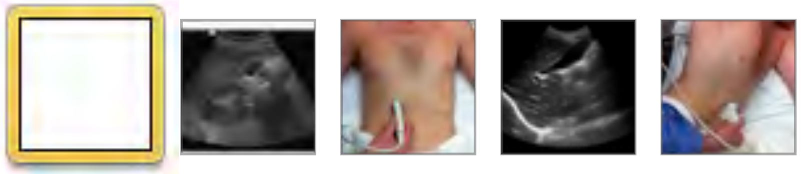
The RUQ scan is performed by placing the probe just inferior to the costal margin, just to the right of midline, with the probe marker oriented to the patient's head or to the right.

One Minute Ultrasound Gallbladder Ultrasound Demo

The liver is utilized as the acoustic window for this view and should appear at the top of the screen. Once identified, the GB should be visualized completely in 2 planes, sagittal and axial. (Gallery 6.1)

Gallery 6.1

The liver is utilized as the acoustic window for this view and should appear at the top of the screen.



The gallbladder may lie beneath the lower right ribs, obscuring its view. In this case, the patient may be asked to take and hold a deep breath in order to move the gallbladder inferiorly. Alternatively, the patient may be placed in the left lateral decubitus position. (Gallery 6.1) By placing the patient into this position, the liver will shift due to gravity and effectively move the GB out from underneath the acoustic interference of the ribs. If you continue to have difficulty visualizing the GB, having the patient take and hold a deep breath will often help as well.

While most people choose to use the curvilinear transducer, the phased array probe may also be used if a curvilinear transducer is not available (Gallery 6.2). The main advantage of using the curvilinear probe is the ability to accurately visualize deeper structures within the abdomen. The larger footprint of the curvilinear transducer also allows the operator to push harder on the patient's abdomen to disperse bowel gas. This level of pressure would be uncomfortable with the phased array probe. The curvilinear probe's footprint is, however, a disadvantage as well because the large footprint can cause more rib shadowing. When evaluating the RUQ and GB, the depth should be adjusted so that important structures fill approximately two thirds of the screen.

Gallery 6.2

Curvilinear transducer

Section 4

Imaging of Gallbladder & Common Bile Duct

Imaging steps:

Visualize the gallbladder

Assess for gallstones and their shadows

Assess for pericholecystic fluid

Measure the GB wall

Measure the common bile duct

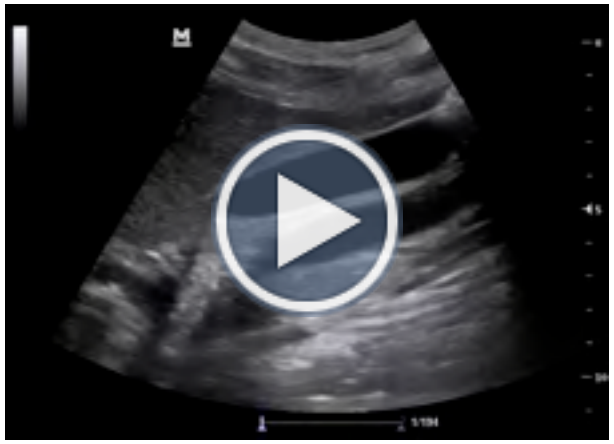
Imaging of the gallbladder and common bile duct (CBD) Consists of 4 main steps:

1. Visualize the GB in two planes.

(See Gallery 6.2).

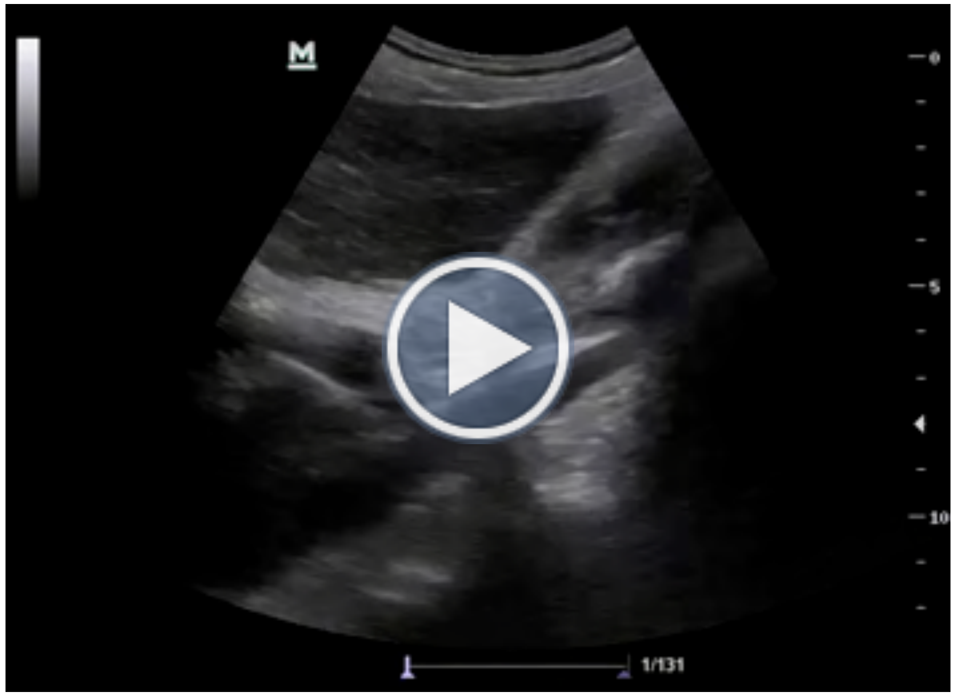
The normal gallbladder is 7-8 cm in length and 2-3 cm in width. It is usually fluid filled. (Movies 6.2,6.3,6.4, and 6.5).

Movie 6.2 - Gallbladder long axis

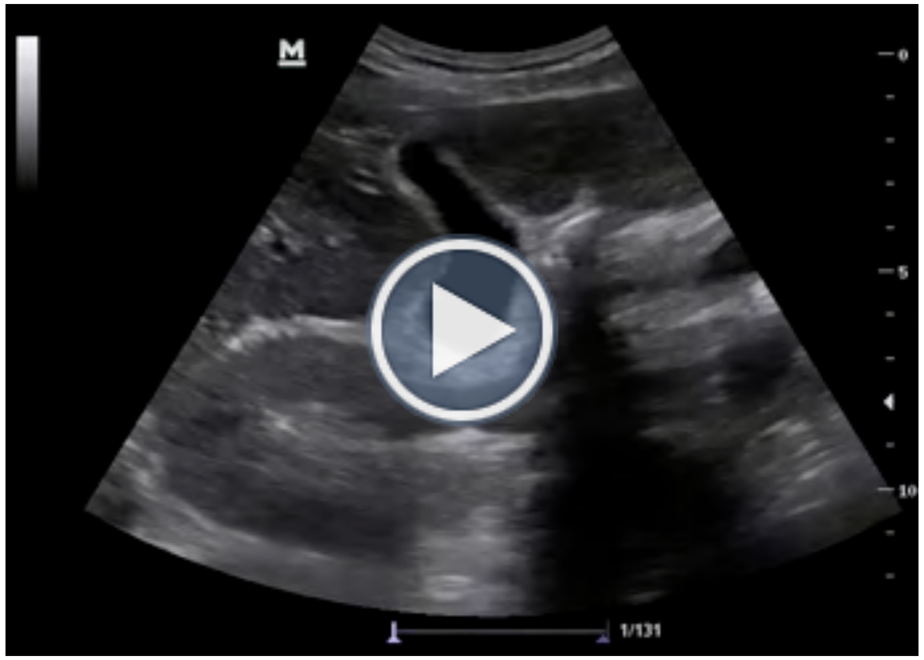


Movie 6.3 - Power doppler showing portal vein

MOVIE 6.4 - Gallbladder long axis



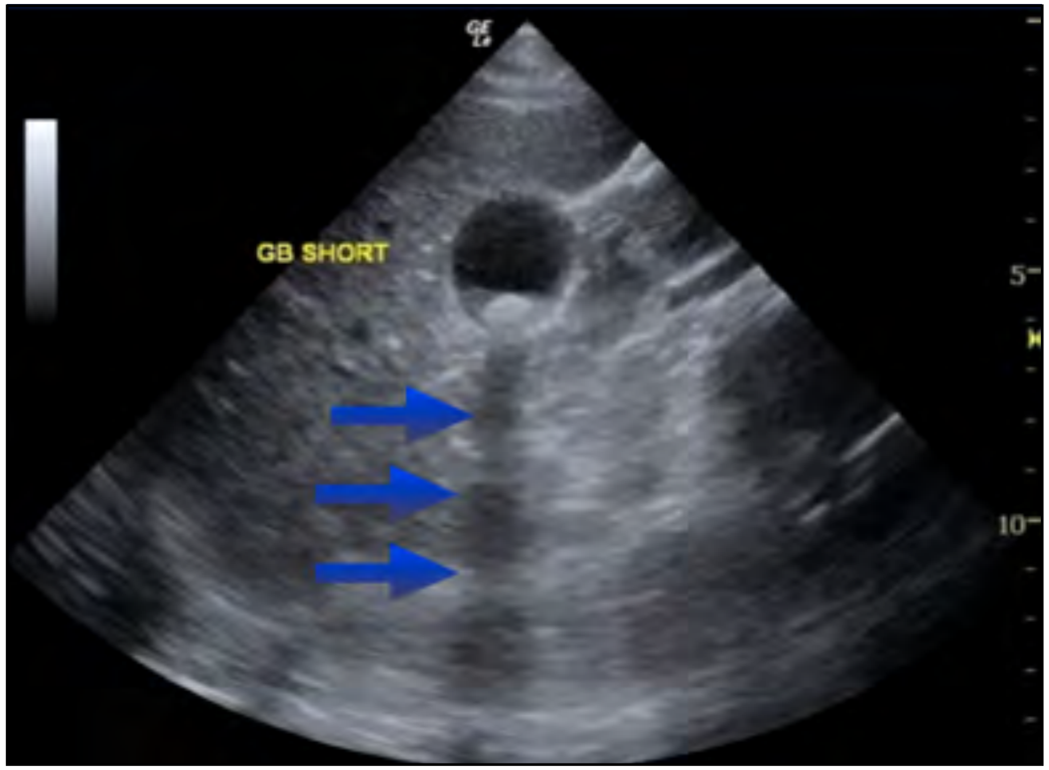
MOVIE 6.5 - Gallbladder short axis



a. Assess for presence or absence of gallstone. (Image 6.2)

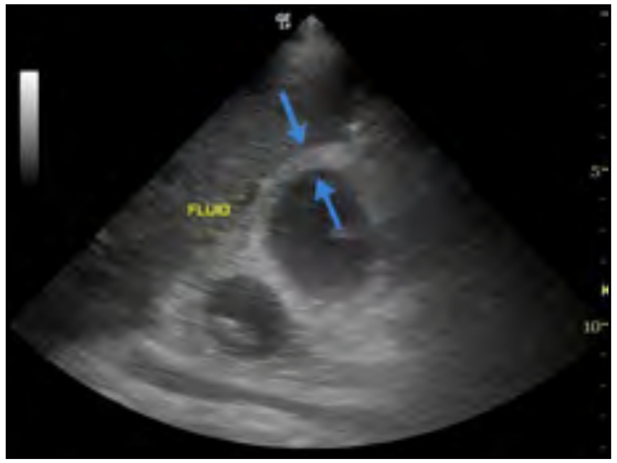
i. If stones are identified, the patient should be moved so that the stones will also move. Failure of movement may be indicative of an impacted stone or a mass.

IMAGE 6.2



b. Assess for presence or absence of pericholecystic fluid. (Image 6.3)

IMAGE 6.3



Caution should be taken in order to not mistake ascitic fluid for pericholecystic fluid. Although hard to differentiate, if you are able to identify fluid throughout the peritoneum, it likely represents ascites.

2. Fan through the GB from the fundus to the neck.

(See Movie 6.2)

3. Measure the anterior GB wall.

a. Greater than 3mm is considered abnormal.[1] (Gallery 6.3)

Gallery 6.3

Normal gallbladder wall

Gallery 6.4

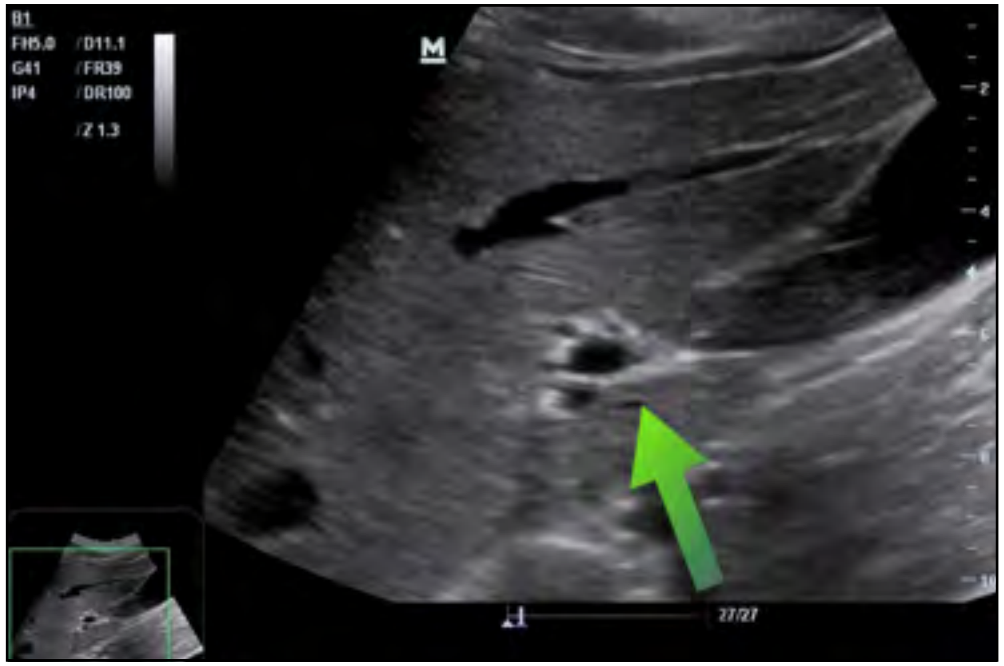
Normal is <7mm

4. Measure the CBD as medially as possible.

a. Measurement of the CBD is made from inner wall to inner wall, an intraluminal diameter. Normal is < 7 mm. (Gallery 6.4). A CBD diameter > 1cm is highly consistent with bile duct obstruction. A general rule of thumb is that the CBD should be less than the first number of the patient's age. Thus, a 50 year old should have a CBD < 5mm, while a 90 year old should have a CBD < 9mm. When finding the CBD, color or power imaging should be used to ensure you are measuring the CBD and not the hepatic artery.

Whenever in doubt about the finding seen on US, a second image should be captured from a different probe position to develop a three dimensional picture in the sonographer's mind.[9,10]

IMAGE 6.4 - Portal triad



Evaluation of the common bile duct can be frustrating for beginner sonographers. Identification of the portal triad will help with identification of the CBD. The portal triad is composed of the main portal vein, hepatic artery and the CBD.

MOVIE 6.6 - Portal triad with color flow

IMAGE 6.5 - Portal triad with CBD measurement

When viewing the GB longitudinally, the neck of the GB should point to the portal triad (Image 6.4). This is commonly referred to as the Mickey Mouse sign. Color or power Doppler may be used at this point in time to help identify the portal vein and hepatic artery. (Movie 6.6 and Image 6.5)

With the indicator pointed to the patient's right, Mickey's right ear will be the common bile duct and the left ear will be the hepatic artery. (Gallery 6.5)

GALLERY 6.5

Use of color flow to identify hepatic artery.

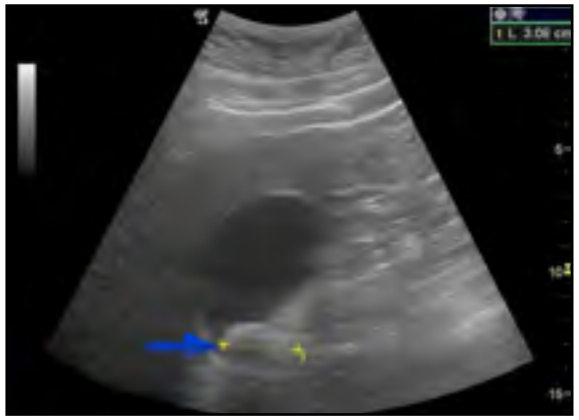
SECTION 5

Gallstones

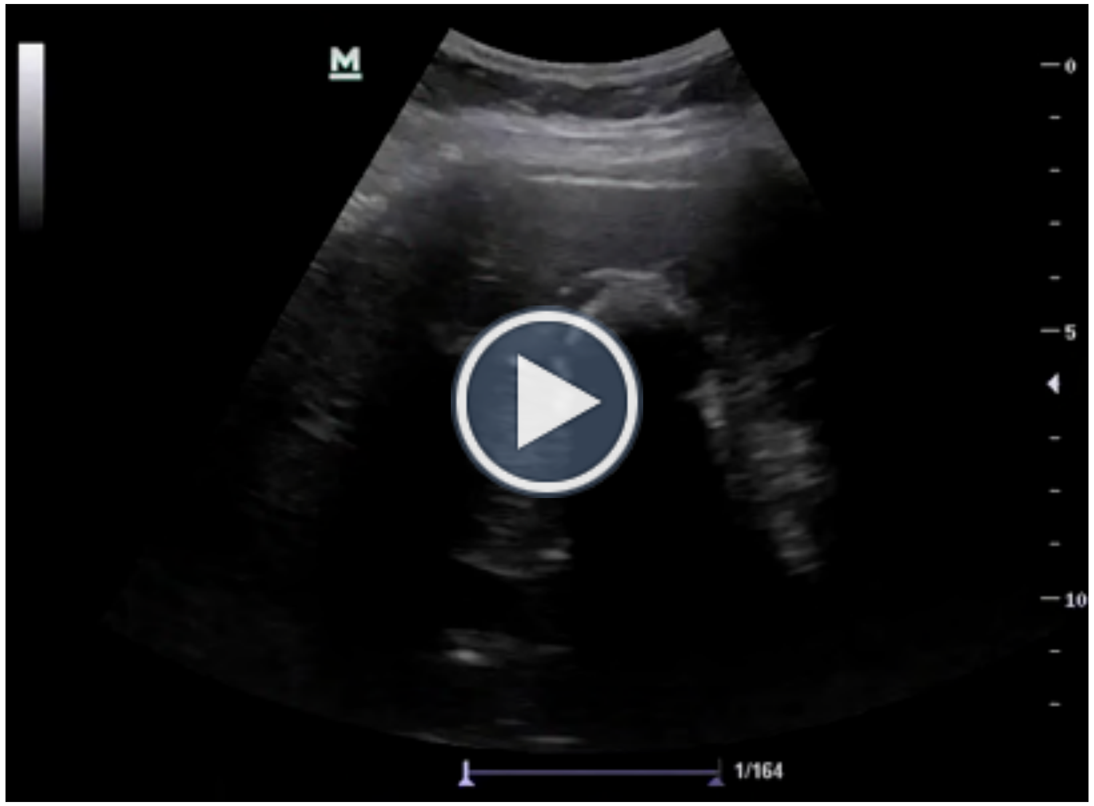
Gallstones will typically appear as echogenic material with acoustic shadowing beneath the gallstones (Images 6.6 and 6.7, Movie 6.7).

IMAGE 6.6

IMAGE 6.7 - Wall Echo Sign (WES)



MOVIE 6.7 - Large gallstone filling GB



SUMMARY

Gallstones are echogenic with posterior shadowing

Gallstones are gravitationally dependent

They will vary in size and may be as large as the gallbladder lumen or so small they are barely identifiable. Shadowing occurs due to the absence of ultrasonic wave transmission through the acoustically stiff stones. In addition to shadowing, gallstones should be found in the most dependent portion of the GB, as they are gravitationally dependent. Shadowing intraluminal structures that do not appear to be gravitationally dependent should heighten the operator's suspicion for GB polyps.

Cholecystitis

SUMMARY

Cholecystitis is a clinical diagnosis

Ultrasound finding suggestive of cholecystitis include:

Increased GB wall thickening

Pericholecystic fluid

Sonographic Murphy's signs (most sensitive)

Cholecystitis is diagnosed by the presence of gallstones and the following:[1]

1. GB WALL THICKNESS GREATER THAN 3 MM
2. PERICHOLECYSTIC FLUID
3. PRESENCE OF A SONOGRAPHIC MURPHY'S SIGN

IMAGE 6.8 - Gallstone with borderline increased wall thickness

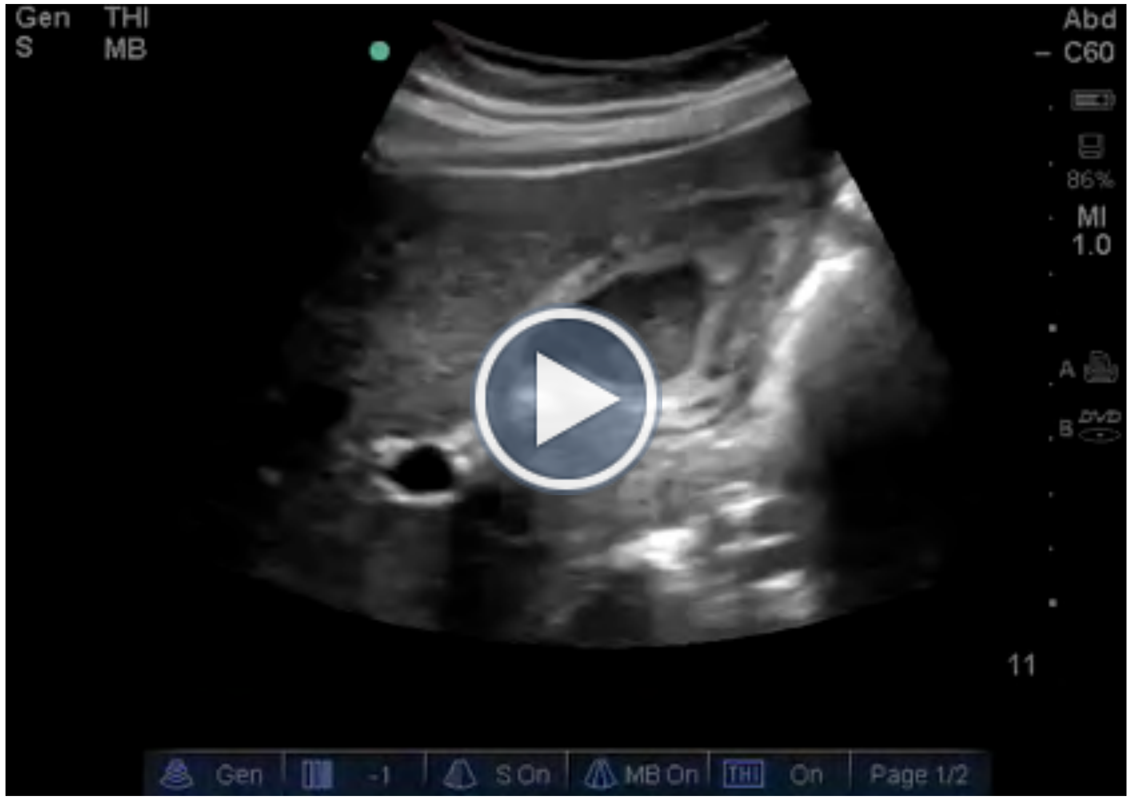
Movie 6.8

Thickened GB wall

Movie 6.10

Gallstone and thickened wall

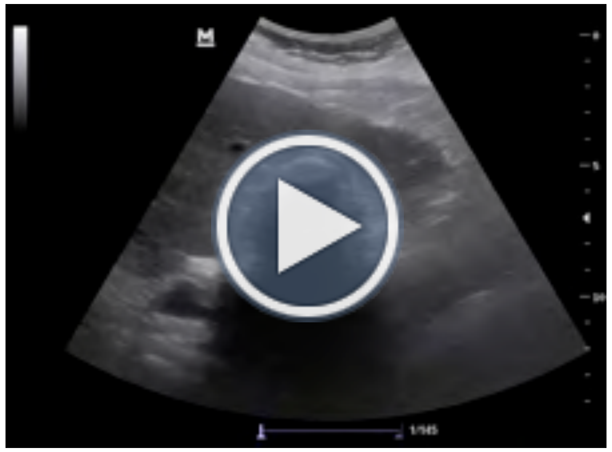
Movie 6.9 - Stone in neck of GB with wall thickening



It is important to remember that gallbladder wall thickening can be found in a variety of clinical settings, including GB contraction from a recent meal, pancreatitis, ascites, and alcoholic hepatitis; therefore, it cannot be considered pathognomonic. However, each additional finding incrementally increases the diagnostic certainty.[3,11,12] Occasionally, the sonographer may observe what is known as the wall echo shadow (WES) sign. This typically occurs in a gallbladder that is filled with gallstones but has contracted, thereby emptying its bile. It will be seen as an echogenic line appearing near the anterior wall of the GB and posterior acoustic shadow. This is a tricky diagnosis and often missed by novice ultrasonographers. The operator should have a heighten suspicion for WES when there is clinical concern for biliary colic but no GB is identifiable on ultrasound. The WES is most often mistaken for bowel wall, and with good reason. (Movies 6.11 and 6.12)

Movie 6.11 - Wall Echo Shadow (WES) Sign

Movie 6.12 - WES



Section 7

Choledocholithiasis

Summary

Sensitivity of US for CBD stones can be as high as 90%

CBD should be <7mm

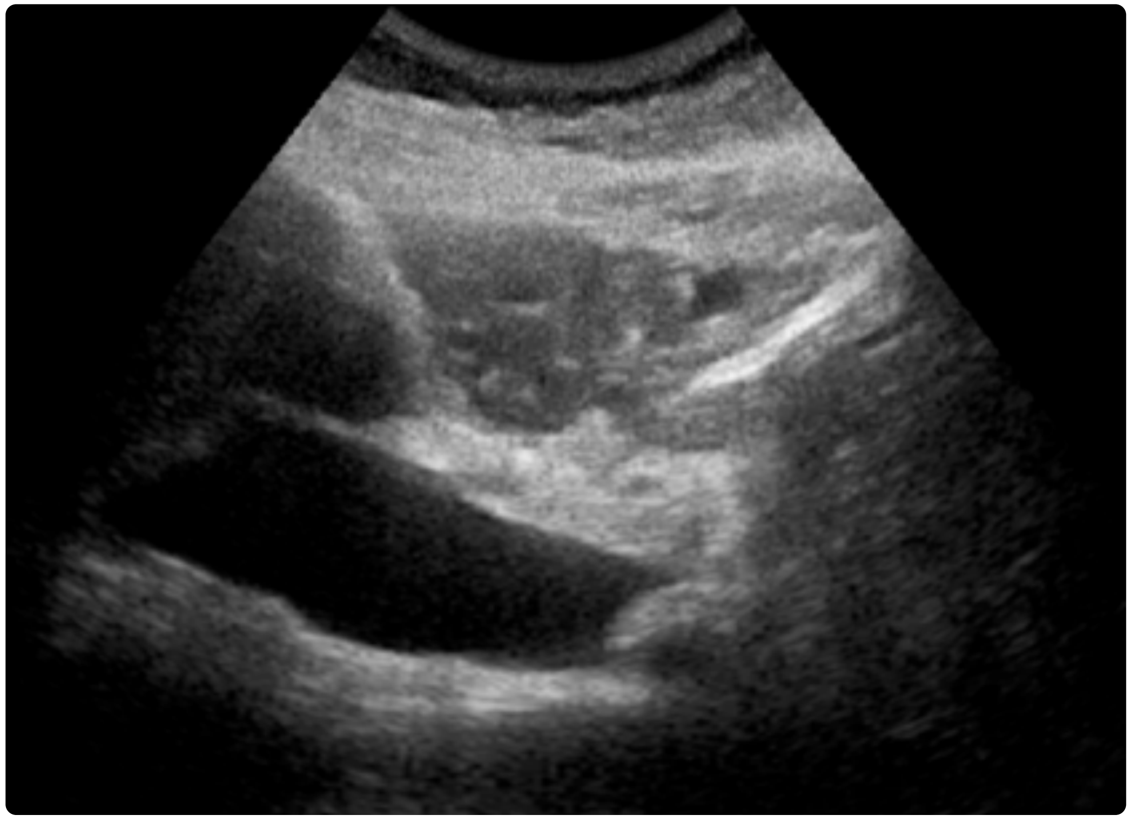
CBD can be up to 10mm in a patient post cholecystectomy

Gallstones may become lodged in the common bile duct as they pass through the CBD to the duodenum. Occasionally the gallstone(s) will become impacted in the ampulla of Vater just before entry into the small intestines, which can cause pancreatitis. Patients with uncomplicated disease may present with normal laboratory tests. However, if the flow of bile is impeded due to this blockage, it can cause abdominal pain, elevated liver enzymes, jaundice or pancreatitis. Furthermore, the stagnant bile can become infected and cause ascending cholangitis, a life threatening condition.

The initial imaging study of choice is again transabdominal ultrasound. The sensitivity of US for CBD stones can be as high as 90%.[5,9,13] Despite this high accuracy, in cases of high pretest probability and a negative bedside ultrasound, a more definitive test should be performed, such as a complete ultrasound or MRCP.

The common bile duct should measure less than 7 mm in diameter in normal individuals. Typical ultrasound findings of choledocholithiasis are a dilated CBD and a dilated gallbladder, often with gallstones in it. Although rare, it is possible to see impacted gallstones in the bile duct. The sensitivity of detecting bile duct stones has been reported as high as 80% .[14] However, the majority of gallstones will lodge at the distal end of the common bile duct, an area which is often obscured by overlying bowel gas. A dilated CBD >7mm (>10mm if the patient has had a cholecystectomy) should raise concern for choledocholithiasis in the correct clinical setting.

Gallery 6.6



Dilated CBD with stone

In summary, bedside ultrasound may be utilized to aid in diagnosis of a variety of diseases in patients presenting with RUQ abdominal pain. However, this exam is one of the most challenging even for advanced sonographers. Thus, a normal exam should not outweigh a high clinical suspicion.

Tell everyone you finished another chapter!

Contact us:

REFERENCES

1.Fox JC, Summers S, Scruggs W, et al. A prospective evaluation of emergency department bedside ultrasonography for the detection of acute cholecystitis. Ann Emerg Med. 2010;115-121.

2.Miller AJ, Delaney KA, Brockman CR, et al. ED ultrasound in hepatobiliary disease. J Emerg Med. 2006; 30:69-74.

3.Ralls P, Colletti P, Lapin S, et al. Real-time sonography in suspected acute cholecystitis. Prospective evaluation of primary and secondary signs. Radiology. 1985;155:767–771.

4.Shea JA, Berlin JA, Escarce JJ, et al. Revised estimates of diagnostic test sensitivity and specificity in suspected biliary tract disease. Arch Intern Med. 1994;154:2573-2581.

5.Young, N, Kinsella S, Raio C, et al. Economic impact of additional radiology after RDMS ED physician performed ultrasound with diagnosis of acute cholecystitis. J Emerg Med. 2010; 38:645-651.

6.Bennett GL, Balthazar EJ. Ultrasound and CT evaluation of emergency gallbladder pathology. Radiol Clin North Am 2003;41(6):1203-1216.

7.De Vargas Macciuca M, Lanciotti S, De Cicco ML, et al. Ultrasonographic and spiral CT evaluation of simple and complicated acute cholecystitis. Radiol Med 2006; 111(2):167-180.

8.Blaivas M, Harwood RA, Lambert MJ. Decreasing length of stay with emergency ultrasound examination of the gallbladder. Acad Emerg Med. 2001;19:32-36.

9.Laing FC, Jeffrey RB, Wing VW. Improved visualization of choledocholithiasis by sonography. AJR Am J Roentgenol 1984;143:949.

10. Smith EA, Dillman JR, Elsayes KM, et al. Cross-sectional imaging of acute and chronic gallbladder inflammatory disease. AJR 2009; 192(1):188-196.

11. Trowbridge RL, Rutkowski NK, Shojania KG. Does this patient have acute cholecystitis? JAMA 2003;289(1):80-86.

12. Strasberg SM. Clinical practice: Acute calculous cholecystitis. N Engl J Med. 2008;358:2804-2811.

13. O'Connor HJ, Hamilton I, Ellis WR, et al. Ultrasound detection of choledocholithiasis: prospective comparison with ERCP in the post cholecystectomy patient. Gastrointest Radiol. 1986;11:161.

14. Wermke W, Schulz HJ. Sonographic diagnosis of bile duct calculi. Results of a prospective study of 222 cases of choledocholithiasis. Ultrachall Med 1987;8:116.

Chapter 7

Renal

SECTION 1

Introduction

ADVANTAGES OF US OVER CT FOR RENAL PATHOLOGY ASSESSMENT:

Shorter length of stay

Lower cost

Improved safety profile

Bedside ultrasound (US) can be utilized in the evaluation of patients with suspected kidney pathology to diagnosis causes of renal colic, renal failure, hematuria, and decreased urine output. In recent years, CT has replaced the physical exam and plain X-ray in the evaluation of these patients. However, ultrasound has many advantages over CT scanning including shorter length of stay, lower cost, and improved safety profiles.[1,2] Rosen and colleagues demonstrated a 147-minute reduction in length of stay when performing ultrasound in the place of CT for the evaluation of renal colic.[1] Furthermore, recent literature on CT utilization has increased physician awareness of the ill effects associated with ionizing radiation exposure from CT scans.[3,4,5] For these reasons, there is growing interest in the use of US instead of CT for the evaluation of flank pain and suspected nephrolithiasis.

Renal US is becoming more commonly used and is considered a safe initial test in the evaluation of suspected nephrolithiasis and renal colic. In practice, US is commonly applied when the clinical suspicion for a kidney stone is high and the concern for another etiology of flank pain, such as an abdominal aortic aneurysm (AAA), is low. Although stones in the kidney are easily visualized on US, when they pass into the ureter and cause pain they are often obscured by bowel gas and not readily seen. For this reason, the diagnosis of nephrolithiasis and renal colic on US is often made by secondary findings such as hydronephrosis.[6]

Other diagnostic dilemmas in utilizing renal US to diagnose nephrolithiasis are the relative inaccuracy of predicting stone passage and the inability to evaluate for alternate causes of flank pain, such as AAA. Although CT may help to predict stone passage and evaluate the aorta, with a recurrent stone rate of 50% in most patients, performing CT scans on every patient with every presentation of flank pain would lead to astronomical radiation exposure.[7] This chapter will focus on the means by which a clinician can apply bedside US to evaluate patients with flank pain and suspected kidney stones, while attempting to minimize the risk of missed diagnoses and improper treatment of impassible stones.

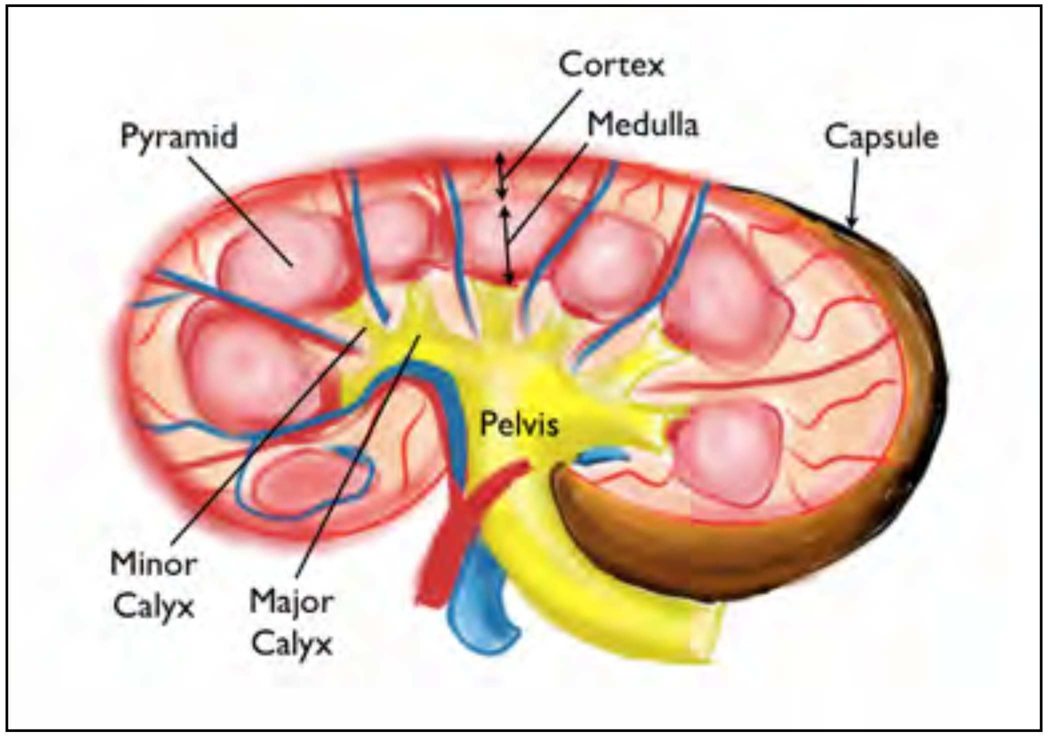
SECTION 2

Renal Anatomy

The kidneys can be divided into two portions: the **renal parenchyma** and the **collecting system**. The renal parenchyma includes the cortex, which contains the filtration components of the glomerulus and the medulla. This is the area where the nephrons are located. The medulla contains the medullary pyramids, which are prominent hypoechoic structures seen on ultrasound, especially in the setting of hydronephrosis. The medullary pyramids contain the distal portions of the nephron and secrete urine into the minor calyces.

The collecting system begins with the minor calyces and ends at the hilum of the kidney where the ureter joins the renal pelvis. There are approximately 8-18 minor calyces that eventually coalesce into major calyces, which drain into the ureter (Images 7.1-7.3).[7]

IMAGE 7.1



TWO PORTIONS OF KIDNEY:

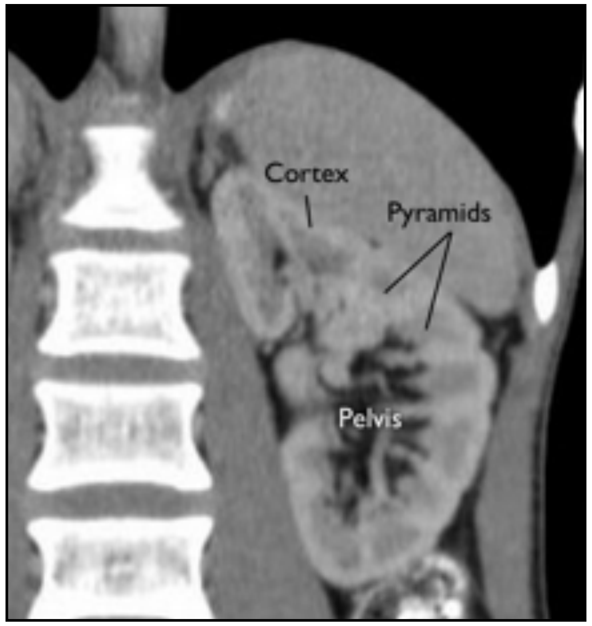
Renal parenchyma

Collecting system

Hydronephrosis is dilation of the collecting system

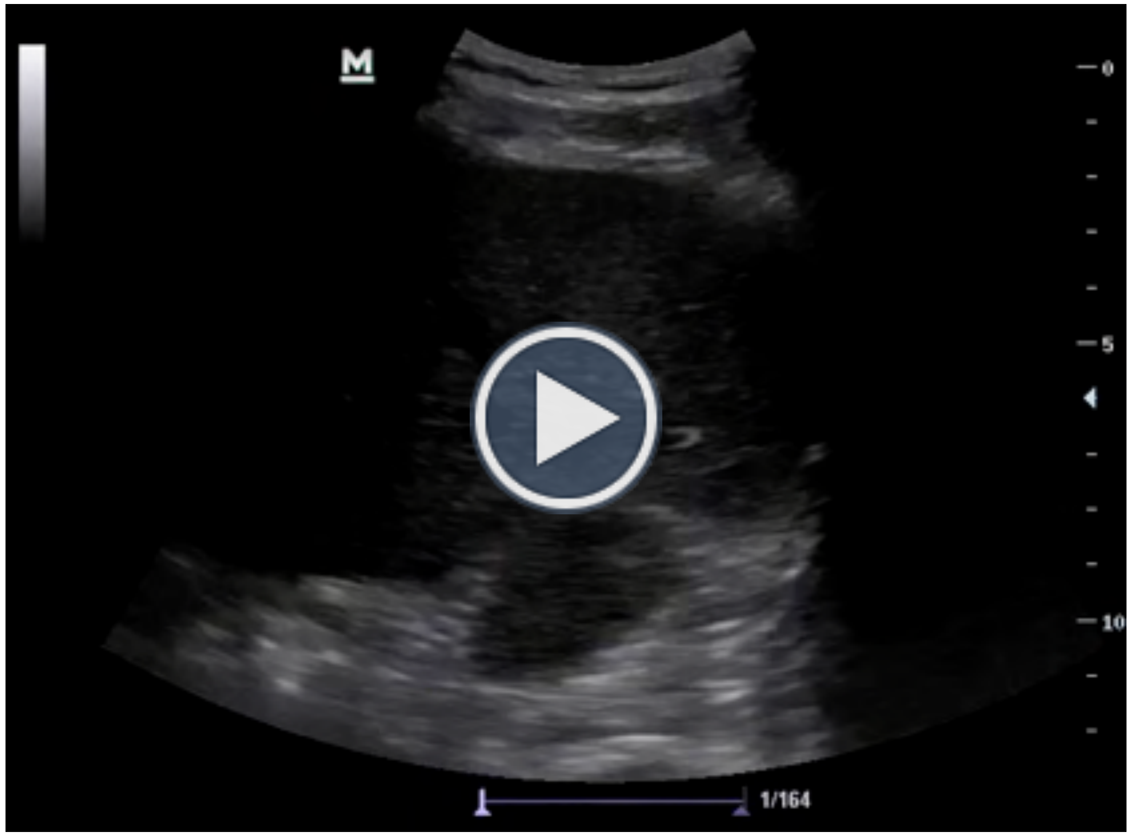
IMAGE 7.2 - Hydronephrosis

IMAGE 7.3



The renal cortex is a bright, or hyperechoic, structure with a ground-glass appearance that is located peripherally to the medulla. Typically, the renal cortex is just slightly darker than the liver or spleen, which are both readily available for comparison, as these organs are used as acoustic windows for visualization. The renal cortex is approximately 1-2 cm in width (Movie 7.1).[8]

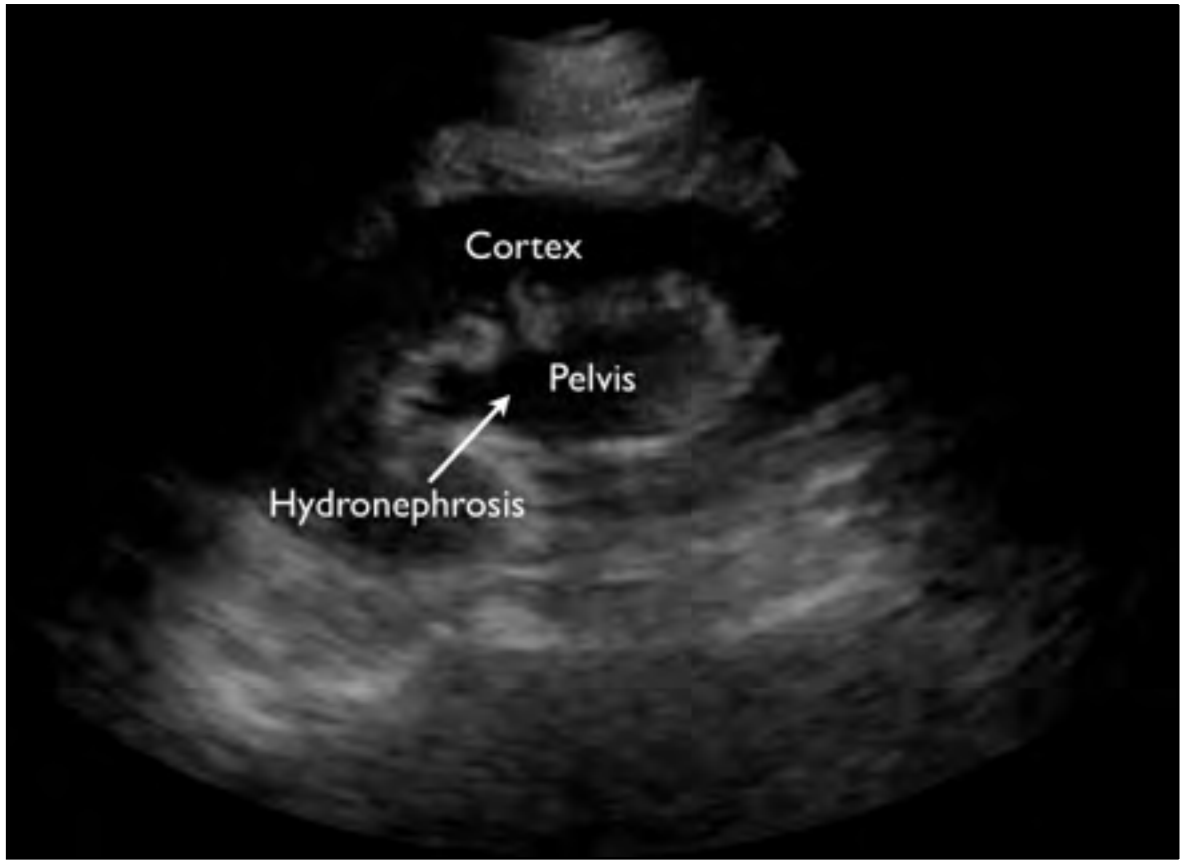
MOVIE 7.1 - Normal kidney



The renal pelvis is brighter, or more hyperechoic, than the cortex and is located centrally. The renal pyramids surround the pelvis and collecting system, which is often not visible in the normal kidney without hydronephrosis. Conversely, in the setting of obstruction and thus hydronephrosis, the collecting system is a dilated, fluid filled, and anechoic structure that dominates the central portion of the kidney (Image 7.3 and 7.4).

Although kidney measurements are not typically performed at the bedside in clinical evaluation of flank pain, they can be helpful in the evaluation of other pathology such as causes of chronic kidney disease (CKD). Normal kidneys measure 9-12cm in length and 4-5cm

IMAGE 7.4



in width with less than a 2cm variation when compared to the patient's other kidney.[9] A large kidney suggests acute renal congestion from causes such as thrombosis, pyelonephritis, or acute renal failure.[10] Conversely, smaller kidneys suggest poor function and CKD.

The appearance and size of the renal cortex can also identify pathology. Normally, the thickness of the renal cortex is 1-2cm. A thin cortex can be seen in severe hydronephrosis and in CKD, whereas a large cortex can sometimes be seen with pyelonephritis. Finally, the difference in echogenicity between the cortex and the pelvis should be well demarcated in a normal kidney. However, chronic kidney disease can obscure this demarcation and cause the kidney to have uniformed echogenicity.[11]

One Minute Ultrasound Renal Ultrasound Demo

Section 3

Image Acquisition

The curvilinear probe is ideal for imaging the kidneys. It uses a lower frequency and thus has improved penetration. This is necessary due to the retroperitoneal location of the kidneys, which must be imaged through acoustic windows such as the liver and the spleen. In situations where a curvilinear probe is not available, a phased array probe may be used as it also has a lower frequency (Gallery 71.).

Gallery 7.1

Curvilinear transducer

Movie 7.2

Renal How-to Video

Summary

Curvilinear probe is preferred

Image in two planes

The left kidney is more posterior and superior

Image bladder in transverse and longitudinal orientation

Have a very low threshold for imaging the aorta in a patient with flank pain

The right kidney should be approached by placing the probe at the midaxillary line at the most inferior intercostal space. The probe marker should initially be oriented towards the patient's head. Often a slight counterclockwise twist will allow the probe footprint to align between the ribs and obliterate any rib shadows in the image. From this position, the probe should be rocked from superior to inferior pole of the kidney and fanned from anterior to posterior to evaluate the entire kidney. Each kidney should be visualized completely in two planes. Thus, after this longitudinal view is obtained, the probe marker should be oriented anteriorly to create a transverse view of the kidney. Again, the probe should be fanned superior and inferior to visualize the entire kidney (Image 7.6, 7.7 and Movie 2.3).

IMAGE 7.5

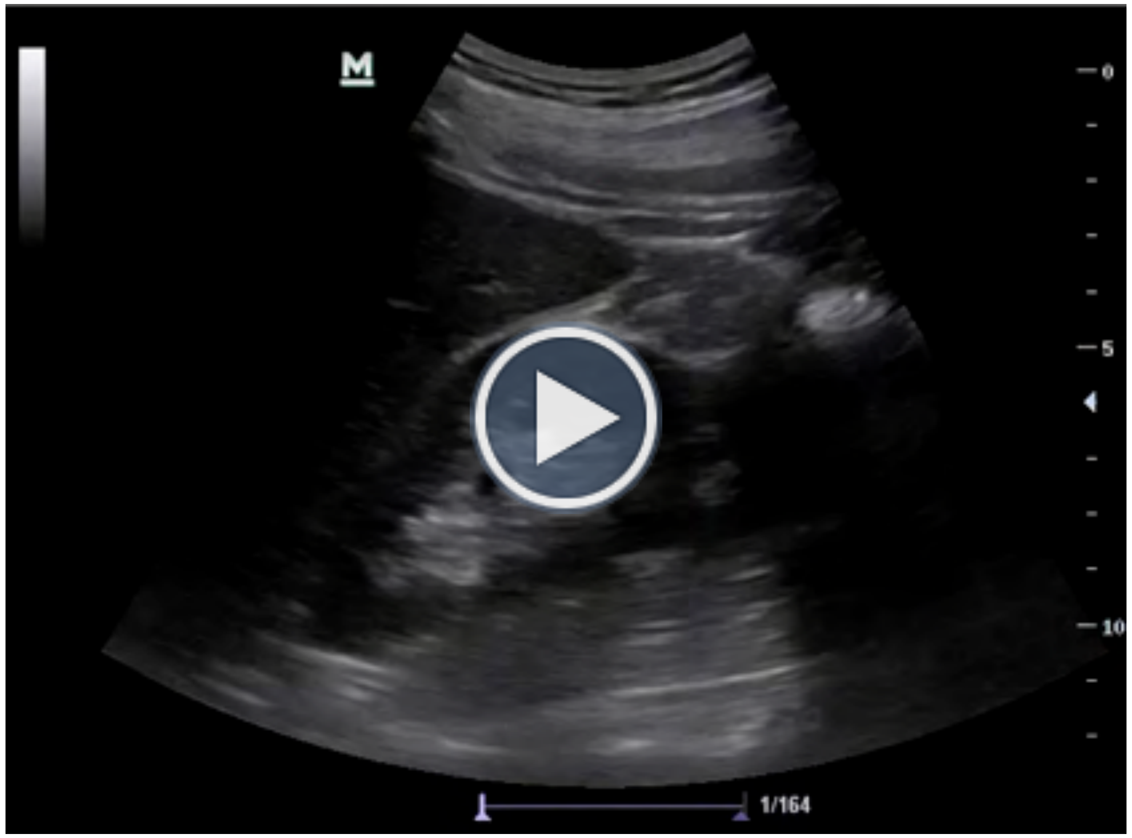
Longitudinal probe placement

IMAGE 7.6

Transverse probe placement

The left kidney uses the spleen as the acoustic window and is therefore more challenging. The probe should be initially placed over the

MOVIE 7.3 - Normal right kidney

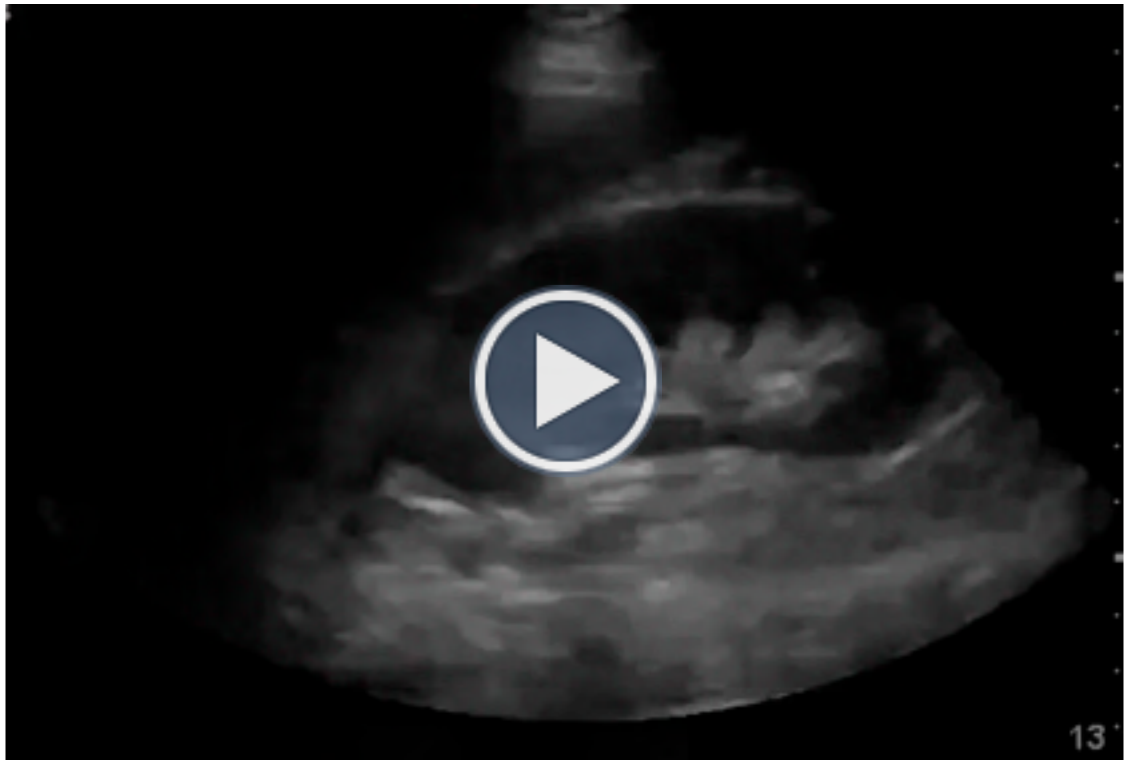


posterior axillary line at the second most inferior intercostal space. Again, the probe will be oriented with the marker towards the patient's head and then anteriorly. The kidney should be visualized entirely in both longitudinal and transverse orientation (Images 7.8, 7.9, and Movie 7.4) .

IMAGE 7.7

IMAGE 7.8

MOVIE 7.4 - Normal left kidney



The bladder is another important structure that should be imaged when assessing for causes of hydronephrosis, renal colic and renal failure. To image the bladder, place the probe just superior to the pubis symphysis and direct the beam of the probe inferiorly, down into the pelvis. Acquire images in the longitudinal and transverse planes (Image 7.10, Movie 7.5 and Image 7.11 and Movie 7.6).

IMAGE 7.9

MOVIE 7.5 - Longitudinal bladder

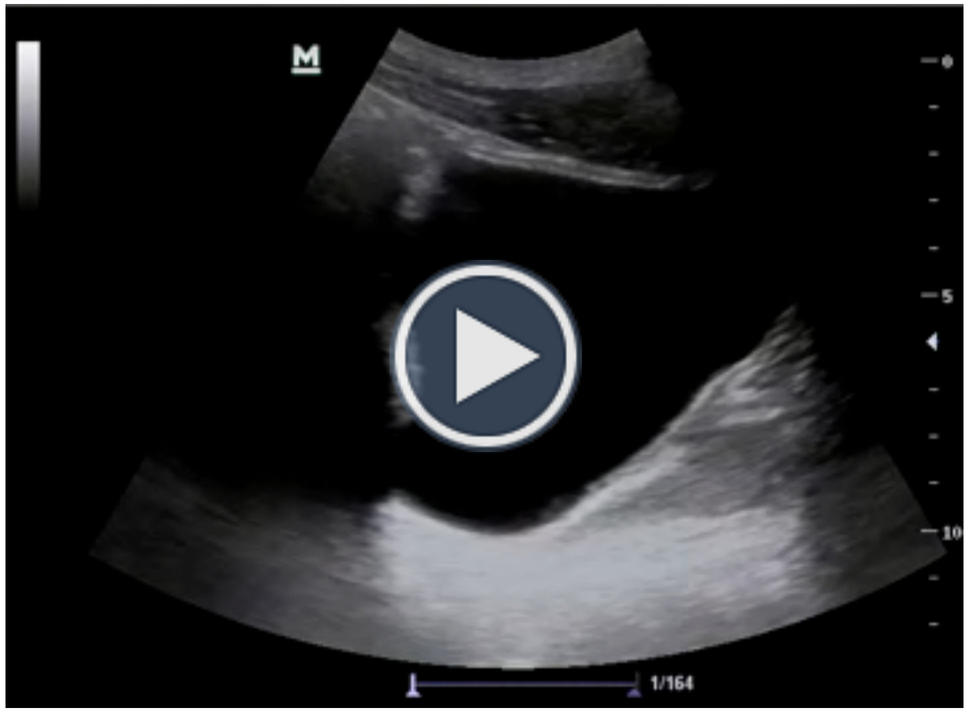
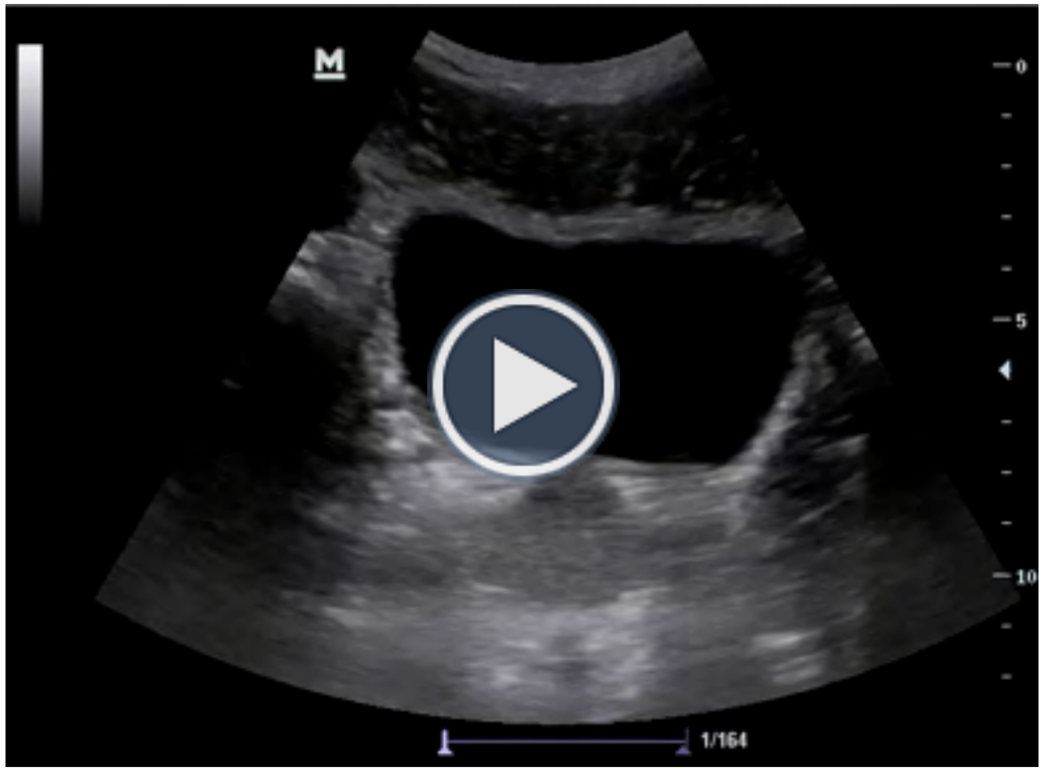


IMAGE 7.10

MOVIE 7.6 - Transverse bladder



The aorta should be imaged in virtually every patient with flank pain and suspected kidney stone. The exam is quick and highly sensitive. (Link to Aorta Chapter).

Pathology

SUMMARY

5-15% of Americans will have a kidney stone at some point in their life

The evaluation of renal colic is focused on secondary signs such as hydronephrosis

Severe hydronephrosis is characterized by cortical thinning

Avoiding CT scans on patients with no or mild hydronephrosis may decrease CT utilization by 73%.

Do not confuse cysts with hydronephrosis

KIDNEY STONES

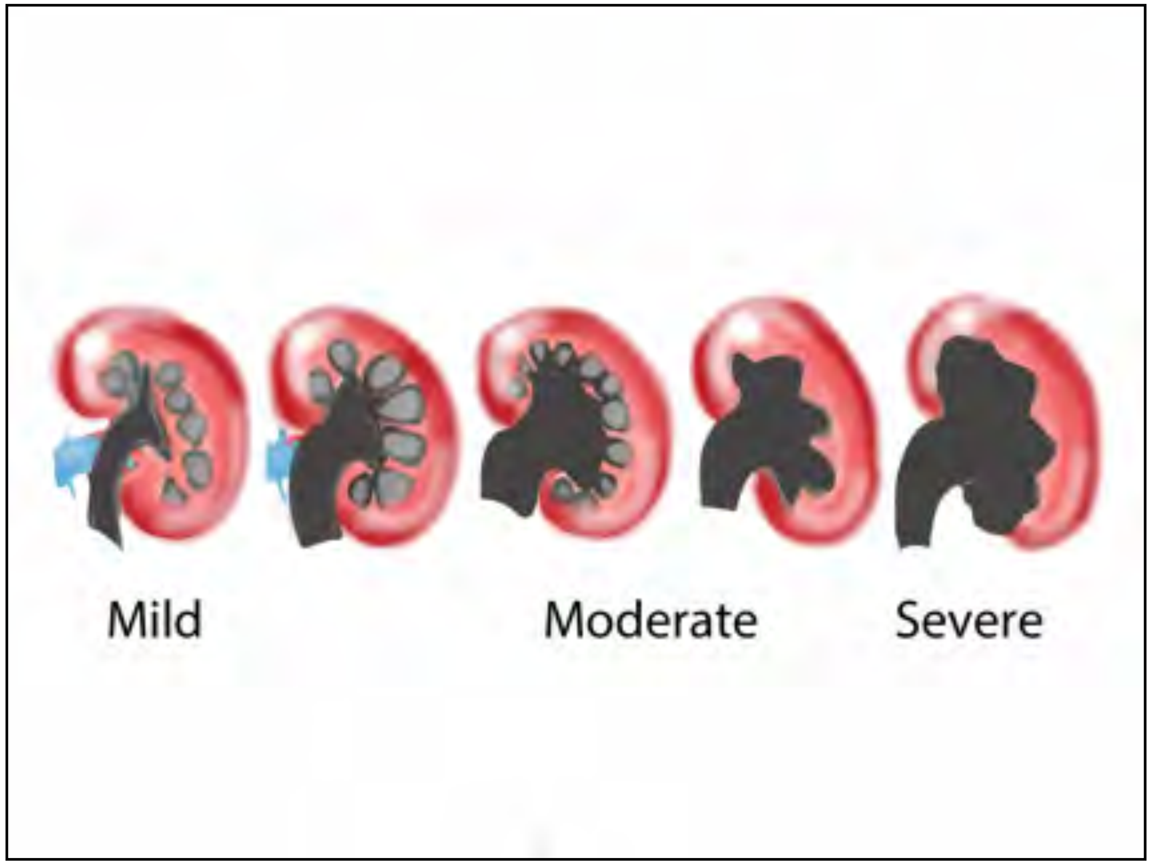
A common indication for bedside renal US is in the evaluation of flank pain and suspected renal colic. It is estimated that 5-15% of Americans will have a kidney stone at some point in their lifetime.[5,12] Symptoms of renal colic include: sudden unilateral flank pain, inability to achieve a comfortable position, radiation of pain to the groin, hematuria/dysuria, and nausea and vomiting.

The ultrasound evaluation of renal colic is directed more towards secondary findings, such as hydronephrosis due to ureteral obstruction. However, kidney stones can sometimes be visualized in the collecting system or in the proximal ureter. Kidney stones appear as hyperechoic structures that vary in size from 1mm-10mm and cast a prominent shadow. Unfortunately, US is not reliable at identifying the actual stone. The sensitivity of ultrasound to identify renal stones in the kidney is about 60-67%.[13,14] The sensitivity is even worse when diagnosing ureteral stones. In a study by Smith et al,[6] ultrasound was reported to be only 19% sensitive for finding ureteral stones.

Due to the relative insensitivity of US diagnosis of actual stones, the operator should instead depend on the presence of unilateral hydronephrosis on the side of pain and a high clinical suspicion for obstructing ureteral stone as more conclusive proof than visualization of the stone itself. Luckily, bedside US has proven to be highly sensitive for the diagnosis of hydronephrosis. The sensitivity of identification of hydronephrosis is 71-97%.[15,16]

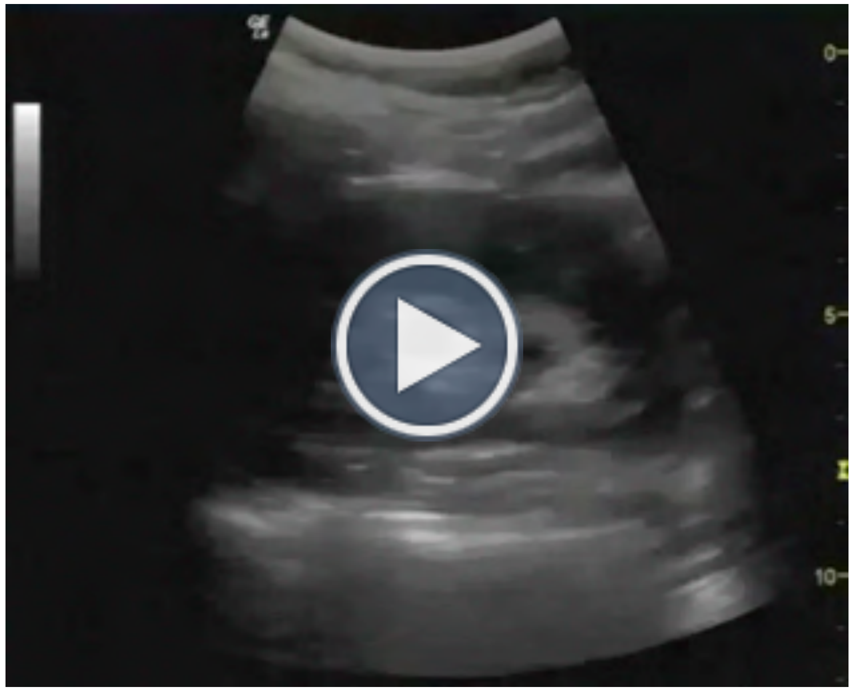
Hydronephrosis is a descriptive finding, not etiology, caused by obstruction of the ureter, bladder, or urethra, and thus urine backup into the renal pelvis. Acutely, this can cause the calyceal system to dilate with urine, which appears anechoic on ultrasound. The severity of hydronephrosis occurs along a spectrum described as mild, moderate or severe, which can be delineated by the renal structures that are affected.[17] Hydronephrosis may appear to be absent in the setting of ureteral obstruction and volume depletion due to the relative lack of backup of urine into the collecting system. For this reason, many physicians provide a patient with a fluid bolus prior to bedside imaging to improve sensitivity.[18]

IMAGE 7.11 - Hydronephrosis

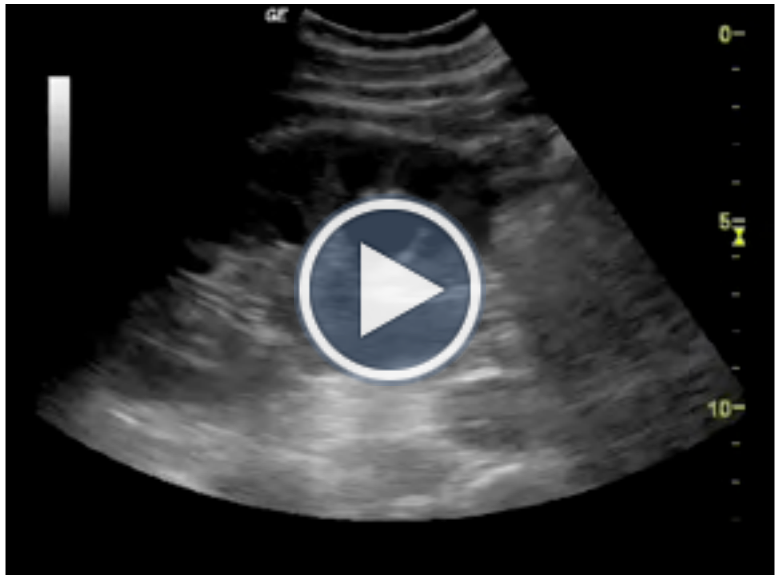


Mild hydronephrosis is characterized by enlargement of the calices with preservation of the renal papillae (Movie 7.7 and 7.8).[17]

MOVIE 7.7 - Mild Hydronephrosis



MOVIE 7.8 - Mild Hydronephrosis

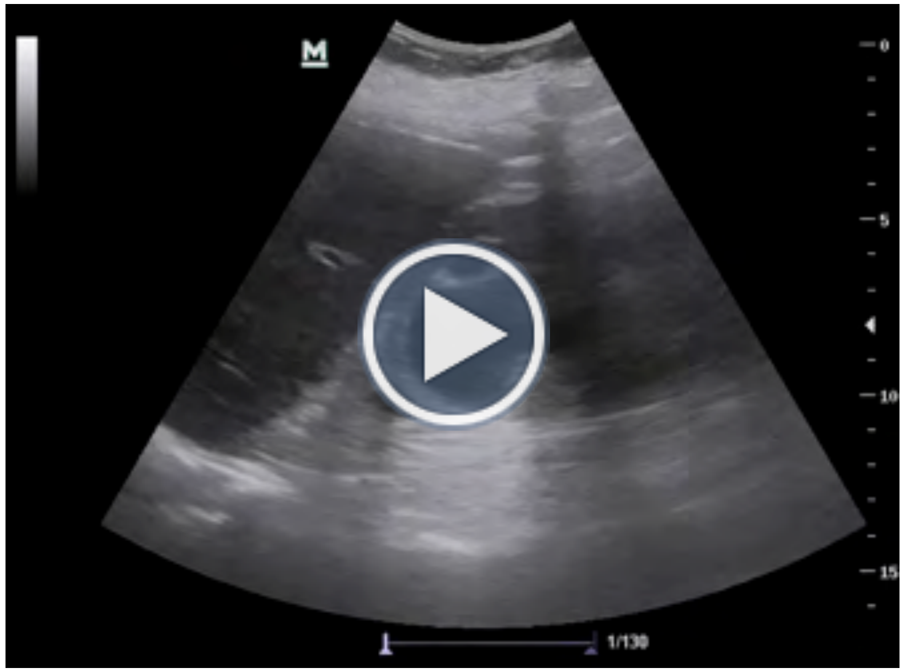


Moderate hydronephrosis is characterized by rounding/blunting of calices with obliteration of the papillae, and often described as having a bear-claw appearance (Movie 7.9).[10,17]

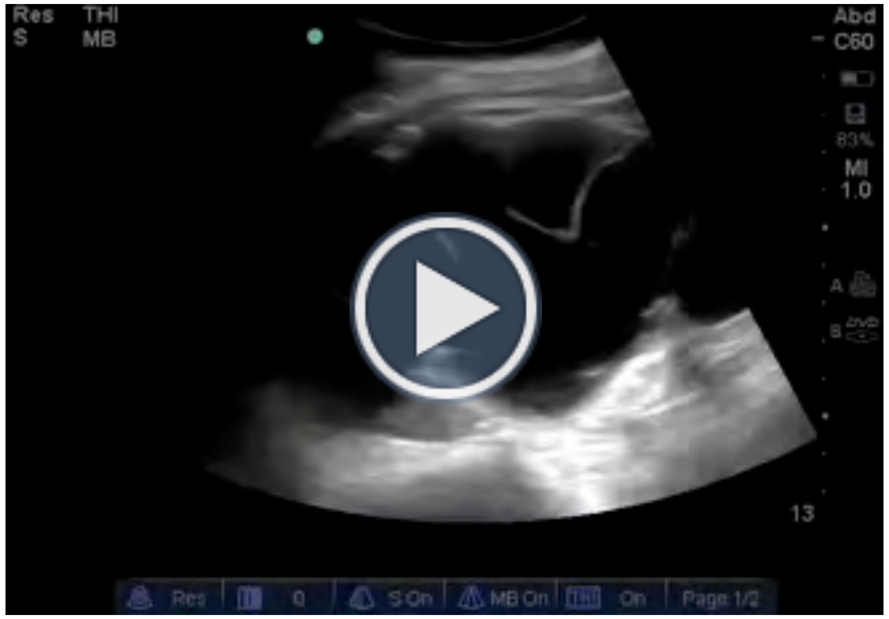
Movie 7.9- Moderate hydronephrosis

Severe hydronephrosis is the most dramatic and is characterized by caliceal ballooning with cortical thinning (Movies 7.10-7.12).[10]

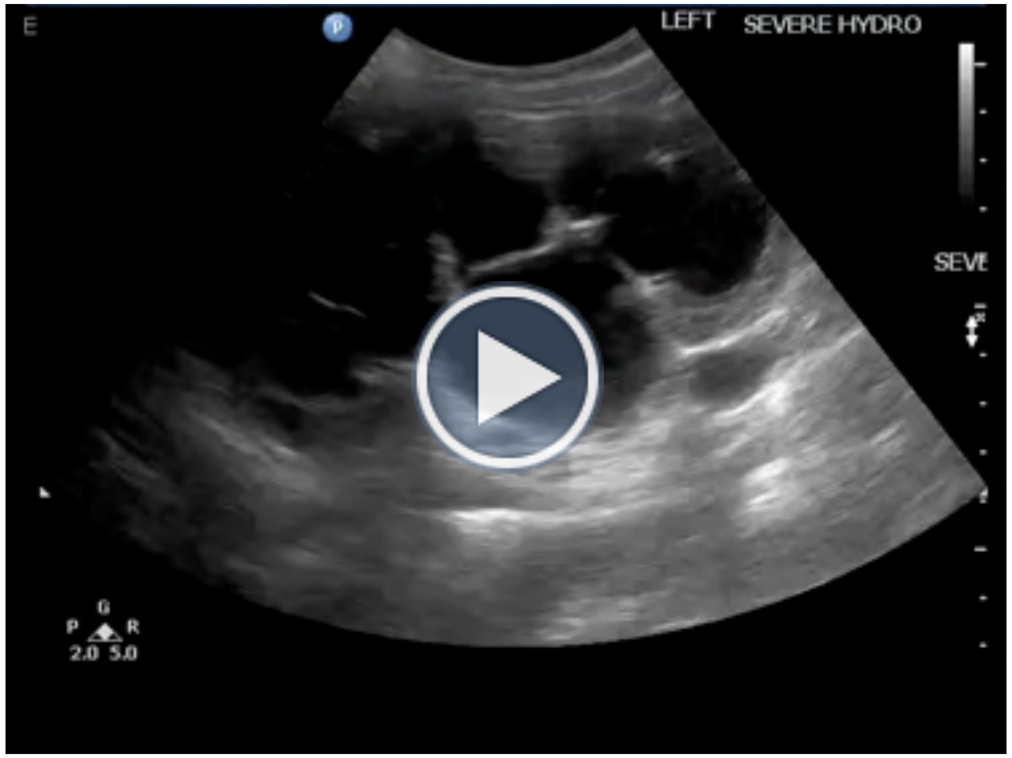
Movie 7.10 - Severe hydronephrosis



Movie 7.11 - Severe hydronephrosis

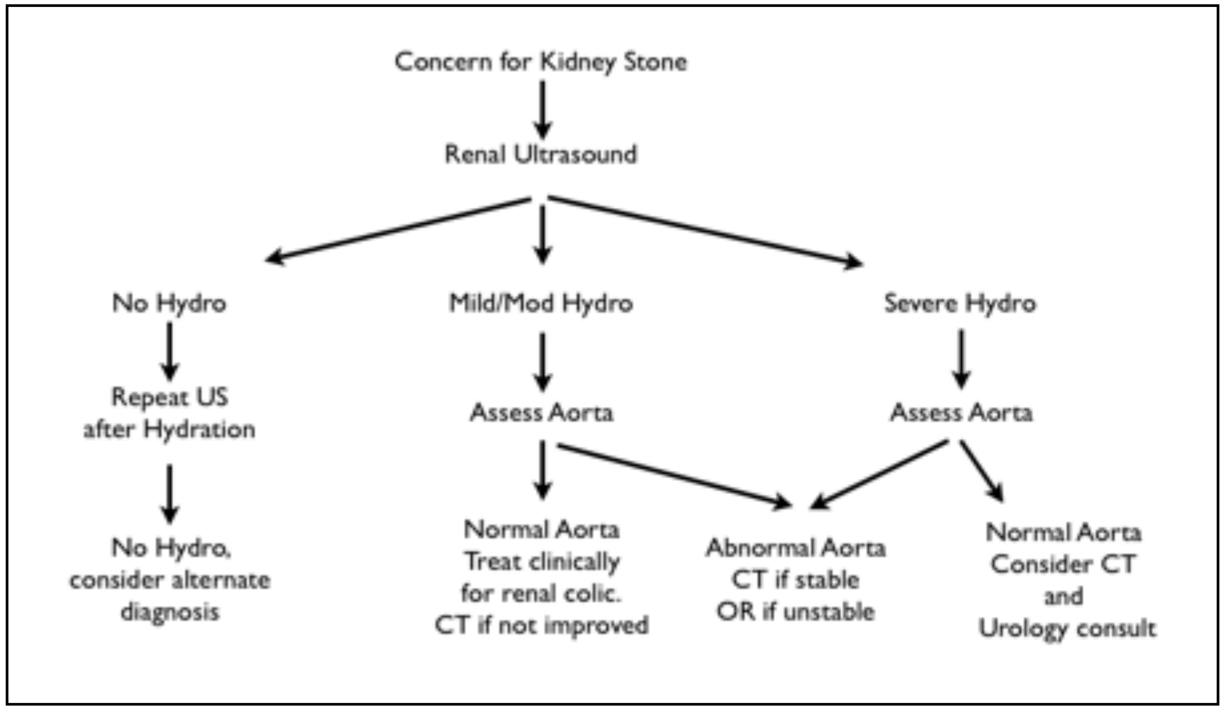


MOVIE 7.12 - Severe hydronephrosis



Unfortunately, there is no correlation between the degree of hydronephrosis and renal function, or extent of ureter obstruction.[10] However, Goertz and Lotterman reported that the degree of hydronephrosis on ultrasound was associated with a proportional increase in stone size and thus the likelihood of stone passage.[17] Typically, small stones <5mm are expected to pass spontaneously and large stones >10mm require surgical intervention for passage. Goertz and Lotterman suggested that patients be separated into less severe hydronephrosis (none or mild) and more severe hydronephrosis (moderate to severe). They noted that patients with more severe hydronephrosis frequently had large stones (>10mm) that were unlikely to spontaneously pass. Conversely, they also found that patients with less severe hydronephrosis could avoid CT scans during their workup, as there were no patients in this group with nephrolithiasis >10mm. Avoiding CT scans on patients with no or mild hydronephrosis thus would decrease CT utilization by 73% and only miss 9% of stones >5mm. Figure 2.1 depicts this approach.[10]

FIGURE 7.1



Renal Cysts:

Renal cysts are the most common renal pathology found on ultrasound.[9] They can be asymptomatic or a cause of flank pain. There are two types of renal cysts, simple or complex.

Simple cysts must meet four criteria:

1. Uniform smooth oval shape.

2. Anechoic center without internal echoes or septation.

3. Well-demarcated border separating it from the surrounding renal parenchyma.

4. Posterior acoustic enhancement, as seen with other fluid filled structures

Failure to meet all four of these criteria would constitute a complex cyst. If there is a complex cyst, consider ordering a CT or MRI, as ultrasound cannot accurately characterize complex cystic masses.[19]

Cortical cysts (Movie 7.13)– note how the anechoic fluid collections are present in the renal parenchyma, not the pelvis. This differentiates renal cysts from hydronephrosis.

Movie 7.13 - Cortical cysts

Renal cysts can be problematic, as they can be mistaken for hydronephrosis. It is important when evaluating for hydronephrosis to image the kidney completely and convince yourself that the fluid filled structure is within the collecting system, as would be seen with hydronephrosis, and not within the cortex, as would be seen with a cyst.

CONCLUSION

In conclusion, renal ultrasound can be used to help diagnosis the etiology of flank pain. It has the benefit of not subjecting the patient to ionizing radiation, but should be appropriately applied. The aorta should virtually always be visualized to ensure the patients flank pain is not due to aortic pathology. In most cases of flank pain, patients with a history of kidney stones, unilateral mild-moderate hydronephrosis and a normal aorta can be treated clinically with appropriate follow-up. A multicenter trial, the Stone Study, is currently investigating the diagnostic accuracy and safety of an ultrasound only approach.

Tell everyone you finished another chapter!

Contact us:

REFERENCES

1.Rosen CL, Brown DFM, Sagarin MJ, et al. Ultrasonography by emergency physicians in patients with suspected ureteral colic. J Emerg Med. 1998;16(6):865-870.

2.Pearle MSP, Calhoun EA, Curhan GC, et al. Urologic diseases in America project: urolithiasis. J Urol. 2005;173:848-57.

3.Smith-Bindman R, Lipson J, Marcus R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med. 2009;169(22):2078-2086.

4.Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, National Research Council. Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. Washington, DC: The National Academies Press; 2006.

5.Einstein AJ, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64- slice computed tomography coronary angiography. JAMA. 2007;298(3):317-323

6.Smith RC, Verga M, McCarthy S, et al. Diagnosis of acute flank pain: value of unenhanced helical CT. AJR Am J Roentgenol. 1996;166(1):97–101.

7.Swadron S, Mandavia DP. Renal ultrasound. In: Ma OJ, Mateer JR, editors. Emergency Ultrasound. New York: McGraw Hill Professional; 2002:197–220.

8.Bluth E, Benson C, Ralls P, et al. Ultrasound: A Practical Approach to Clinical Problems. 2nd edition. New York, NY. 2008:84-111.

9.Brant WE. Ultrasound: The Core Curriculum. Philadelphia, PA: Lippincott Williams & Wilkins, 2001:103-141.

10.Noble V. Renal ultrasound. Emerg Med Clin N Am. 2004:22:641–65.

11.Coleman BG. Ultrasonography of the upper genitourinary tract. UrolClin N Am. 1985;12:633–44.

12.Teichman JM. Clinical practice. Acute renal colic from ureteral calculus. N Engl J Med. 2004;350:684-93.

13.Sinclair D, Wilson S, Toi A, et al. The evaluation of suspected renal colic: ultrasound scan versus excretory urography. Ann Emerg Med. 1989;18:556–9.

14.Sheafor DH, Hertzberg BS, Freed KS, et al. Nonenhanced helical CT and US in the emergency evaluation of patients with renal colic: prospective comparison. Radiology. 2000;217:792–7.

15.Lanoix R, Leak LV, Gaeta T, et al. A preliminary evaluation of emergency ultrasound in the setting of an emergency medicine training program. Am J Emerg Med. 2000;18(1):41–5.

16.Gaspari RJ, Horst K. Emergency ultrasound and urinalysis in the evaluation of flank pain. Acad Emerg Med. 2005;12(12):1180-4.

17.Goertz JK, Lotterman S. Can the degree of hydronephrosis on ultrasound predict kidney stone size? Am J Emerg Med. 2010;28(7):813-816.

18.Middleton W, Kurtz A, Hertzberg B. Ultrasound: The Requisites. 2nd edition. Philadelphia, PA: Mosby; 2004:103-190.

19.Israel GM, Bosniak MA. How I do it: Evaluating renal masses. Radiol. 2005;236: 441-450.

Chapter 8

Pregnancy

While you wait, check out these videos from the One Minute Ultrasound App...

Chapter 9

Physics

Section 1

Basic U/S Physics

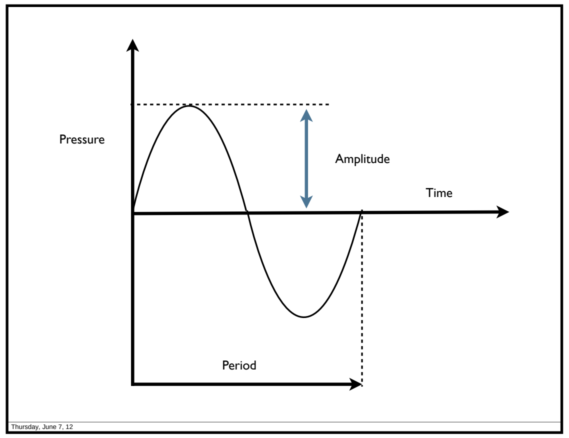
"It is odd, but on the infrequent occasions when I have been called upon in a formal place to play the bongo drums, the introducer never seems to find it necessary to mention that I also do theoretical physics." – Richard Feynman

Preface

A basic understanding of ultrasound physics is essential to reliably acquire quality images and provide accurate interpretations. While many modern point-of-care ultrasound systems limit the operator's ability to adjust the various settings, there remain a number of important features that allow users to customize and, indeed, improve imaging. This chapter will break down basic ultrasound physics into its essential components, with an emphasis on the core concepts of image acquisition as well as the host of imaging artifacts commonly encountered. The format for the chapter will be a series of bullet points supplemented by images and videos. A more in-depth look at the physics of ultrasound may be obtained through the core text, "Understanding Ultrasound Physics" by Sidney Edelman.[1]

Basic Ultrasound Physics:

Figure 9.1



Period and Amplitude of sound wave

- **Amplitude:** The peak pressure of the wave (height); this is the magnitude or strength of the wave (Figure 9.1)

- **Period:** The length of time to complete 1 cycle (Figure 9.1)

FIGURE 9.2 - Wavelength

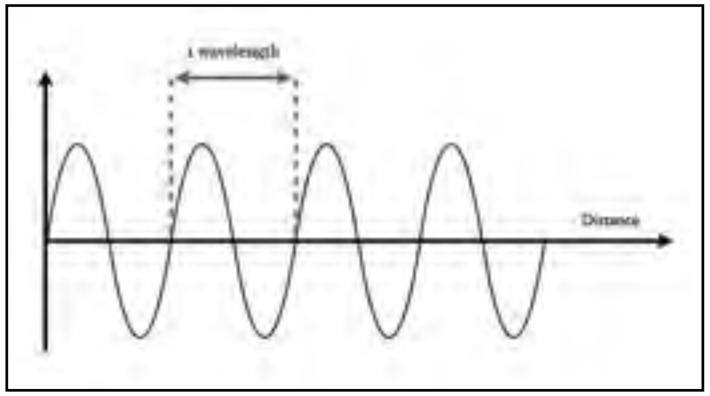
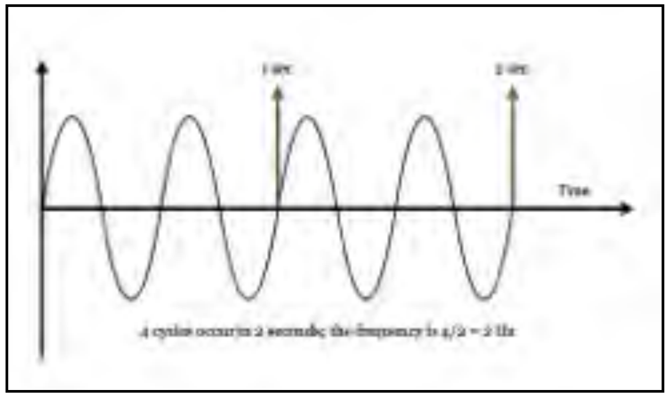


FIGURE 9.3 - Frequency



- **Wavelength:** The distance (length) of a complete cycle (Figure 9.2)

- **Frequency:** The number of cycles per second (Figure 9.3)
  - Hertz (Hz) = 1 cycle/sec
  - Audible sound: 20-20,000 Hz
  - Ultrasound: > 20,000 Hz
  - Diagnostic ultrasound: 2-20 megahertz (MHz) range
  - Determined by the sound source and not the medium it's traveling through
  - Period and frequency are reciprocals (period ⇑, frequency ⇓)

- **Velocity:** Propagation speed of a wave through a medium
  - *Velocity (V) = Frequency (f) X Wavelength (λ)*
  - Velocity is <u>*constant*</u> in a given medium
  - Determined by the characteristics of the <u>*medium*</u> (density⇓velocity and stiffness⇑velocity)
  - Frequency and Wavelength are inversely proportional.
  - Based on the above equation: if frequency⇑, wavelength⇓

- **Power:** the sound <u>*wave's*</u> strength
  - Power ∝ amplitude^2

- **Intensity:** the sound beam's strength as determined by its concentration of energy
  - Equals the power divided by the cross-sectional area (units: watts/cm2)
  - Intensity (I) = Power / beam area

FIGURE 9.4 - Summary of ultrasound physics principles

Parameters	Basic Units	Units	Determined by
period	time	sec, µsec	sound source
frequency	1/time	1/sec, Hz	sound source, sonographer
amplitude	acoustic	dB (& others)	sound source, sonographer
power	work/time	watts	sound source, sonographer
intensity	power/area	watts/cm²	sound source, sonographer
wavelength	distance	mm, cm	source & medium
speed	distance/time	m/sec	medium

Modified from Edelman SK. "Understanding Ultrasound Physics." 3rd Edition. Woodlands, TX: ESP, Inc., 2004

• Sound conduction is dependent on characteristics of the transmission media:

- Density ⇑ then Velocity ⇓ (1500m/s in water)
- Density ⇓ then Velocity ⇑ (330m/s in air)
    - Density is the concentration of mass per unit volume.
- Stiffness ⇑ then Velocity ⇑
    - Stiffness is a material's ability to maintain its shape, even when pressure is applied (bone is stiff, lung tissue not stiff).
- Because bone is very stiff but not dense, it has the fastest propagation speed.
- Generally, with regard to velocity: solids > liquids > gases

• As continuous waves are not capable of producing an image, diagnostic ultrasound is derived from pulsed ultrasound.

• Shorts burst, or pulses, of acoustic energy are produced.

• A **pulse** of ultrasound is a group of cycles:

- These all have a discrete beginning and ending.
- There is the "transmitting" time, or the "on" time.
- There is the "receiving" or "listening" time, or the "off" time.

• There are 5 parameters relevant to pulsed ultrasound:

1. Pulse duration
2. Pulse repetition period
3. Pulse repetition frequency
4. Duty factor
5. Spacial Pulse Length

FIGURE 9.5 - Pulse duration

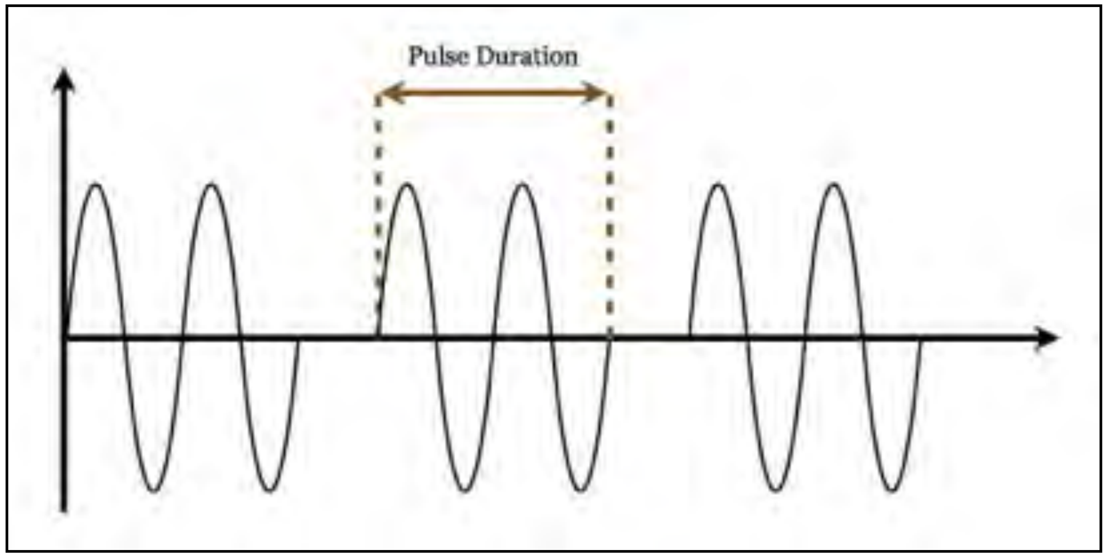
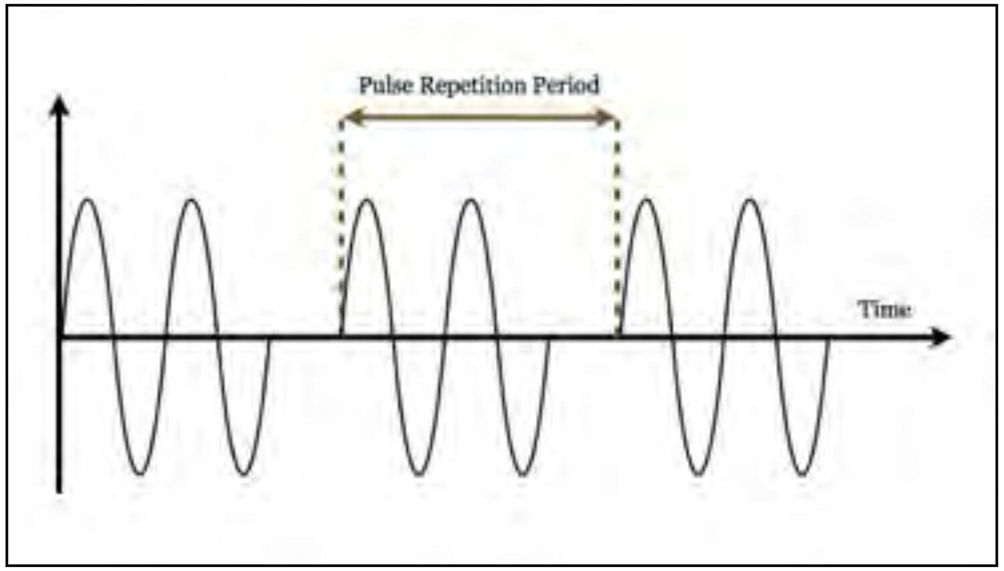


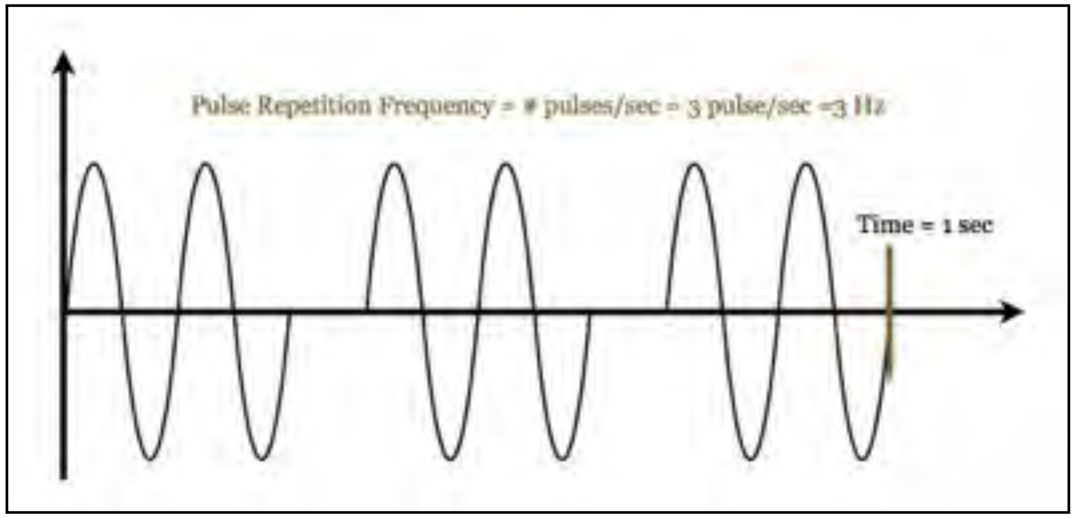
FIGURE 9.6 - Pulse repetition period



- **Pulse duration (PD):** length of time from the beginning to the end of a pulse (Figure 9.5)
  - Determined by the number of cycles ("ringing"), and the period (length of time) of each cycle
  - Fewer cycles = ⇓ ringing
  - Each cycle with a shorter period = ⇑ frequency
  - Shorter pulses mean better images.
  - **PD = # cycles in pulse X period**
  - **PD = # cycles in pulse / frequency**

- **Pulse repetition period (PRP):** length of time from beginning of one pulse to the next (Figure 9.6)
  - Similar to period, but PRP includes the pulse duration *and* the "listening" time.
  - Changed by adjusting the maximum imaging depth (depth of view)
  - Depth ⇑ then PRP ⇑ ("listening" time increases)

FIGURE 9.7 - Pulse repetition frequency



- **Pulse repetition frequency (PRF):** number of pulses per second (Figure 9.7)
    - Similar to frequency, though PRF refers to pulses/sec rather than cycles/sec.
    - Changed by adjusting the maximum imaging depth (depth of view)
    - **Depth ⇑ then PRF ⇓** (listening time increases)
    - **PRF (sec) X PRF (Hz) = 1** (inversely related)
- **Duty factor:** the percentage of time spent producing a pulse
    - Unit-less, ranges between 1.0 (100%) and 0.0 (0%)
    - Changed by adjusting the maximum imaging depth (depth of view)
    - Generally the duty factor is very low, with only a fraction of time spent transmitting a pulse, and much more time listening or receiving.
    - **Duty factor (%) = PD (sec) / PRP (sec) X 100**
    - **PRF ⇑ Duty factor ⇑**
    - **Depth ⇑ Duty factor ⇑**
    - **PRP ⇑ Duty factor ⇓**
    - **PD ⇑ Duty factor ⇑**

FIGURE 9.8 - Spatial pulse length

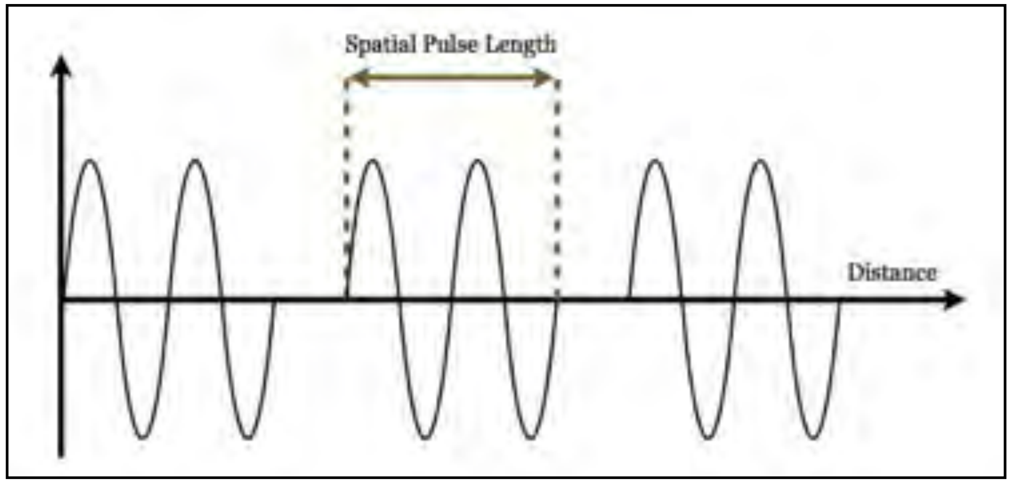


FIGURE 9.9 - Summary of pulsed ultrasound parameters

Parameters	Basic Units	Units	Determined by	Common Values
pulse duration	time	sec, msec	sound source	0.5-3.0 µs
pulse repetition period	time	sec, µs	sound source, sonographer	0.1-1.0 msec
pulse repetition frequency	1/time	1/sec, Hz	sound source, sonographer	1-10 kHz
spatial pulse length	distance	mm, cm	source & medium	0.1-1.0 mm
duty factor	none	none	sound source, sonographer	0.0001-0.01

Modified from Edelman SK. "Understanding Ultrasound Physics." 3rd Edition. Woodlands, TX: ESP, Inc., 2004.

- **Spatial pulse length (SPL):** length or distance of a pulse (8)
  - Similar to wavelength
  - **SPL (mm) = # cycles in pulse X wavelength (mm)**
  - SPL determine longitudinal resolution (more later)
  - **SPL ∝ wavelength**
  - **SPL ∝ 1/frequency**

- Piezoelectric ("Pressure-Electricity") effect: Transmission and Detection
  - When an electrical pulse is applied to a material with piezoelectric properties, it vibrates.
  - These vibrations are transmitted to adjacent tissues as ultrasound (U/S) waves.
  - The U/S waves travel through the medium until they encounter a reflective surface, and a portion of the sound is then reflected back to the source (echo). (Figure 9.10)
  - The returning echo strikes the probe and the piezoelectric material vibrates. This vibration generates an electrical current. The current is then translated by the U/S processor into the grayscale seen on the ultrasound screen. (Figure 9.11)
  - The probes are both transmitters and receivers of sound.

FIGURE 9.10 - Piezoelectric effect

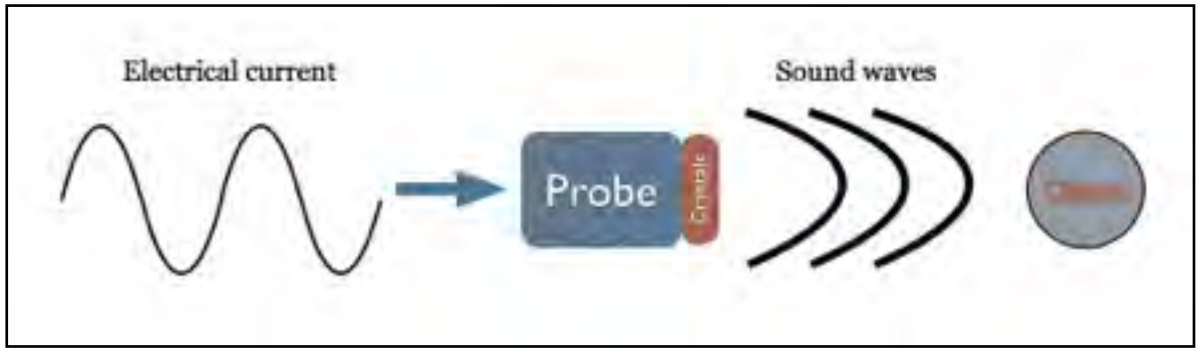
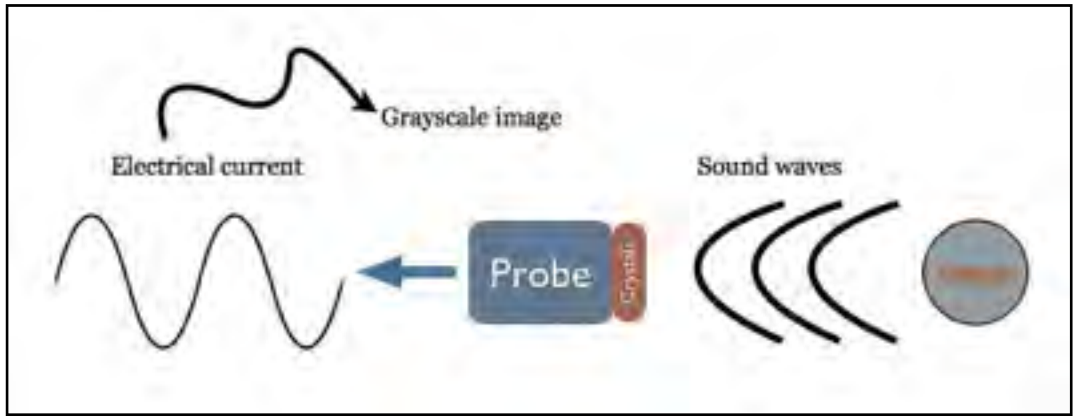


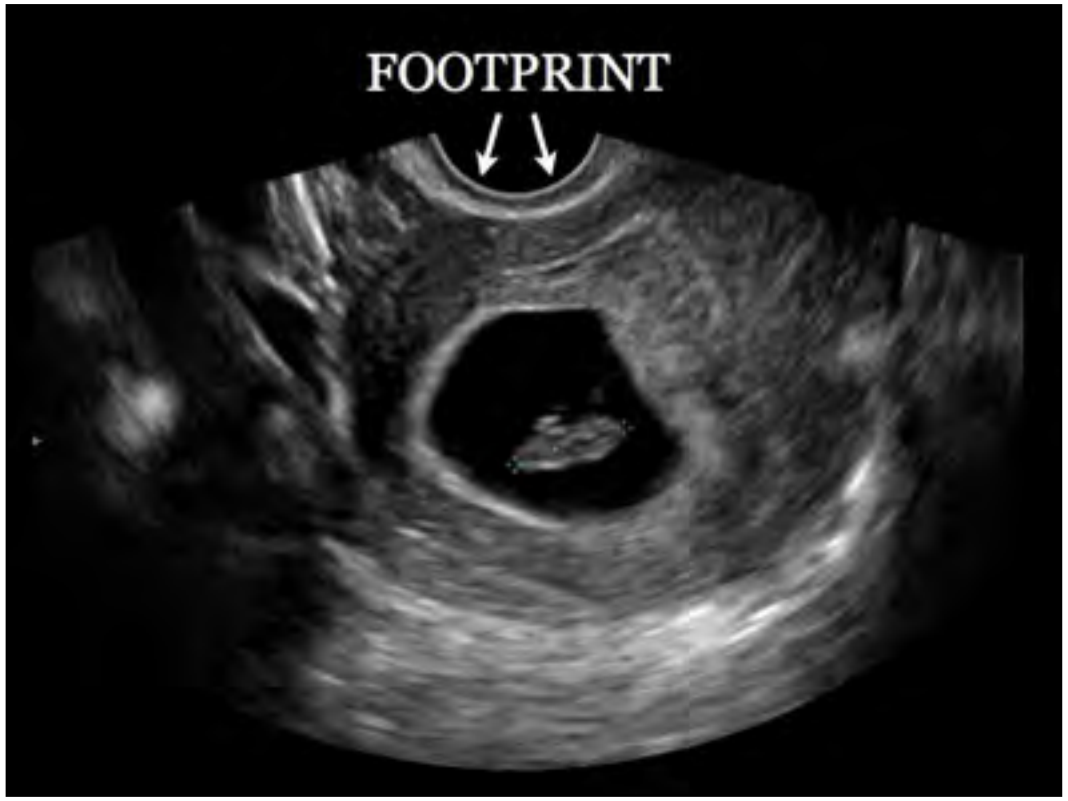
FIGURE 9.11 - Returning signal



Imaging

- **Image Depth:** Calculated by the US machine by the time elapsed between signal pulse and the received echo
- **Direction:** the crystals precisely differentiate the direction of the returning echoes
- The returning echo intensity is proportional to the grayscale assignment of the pixel (dot) of information on the screen; stronger signal, more echoes = brighter dot.
- The surface area of a transducer in contact with the patient is referred to as the "footprint" of the probe. (Figure 9.12)

FIGURE 9.12 - Footprint



SUMMARY:

Important terms:

Attenuation

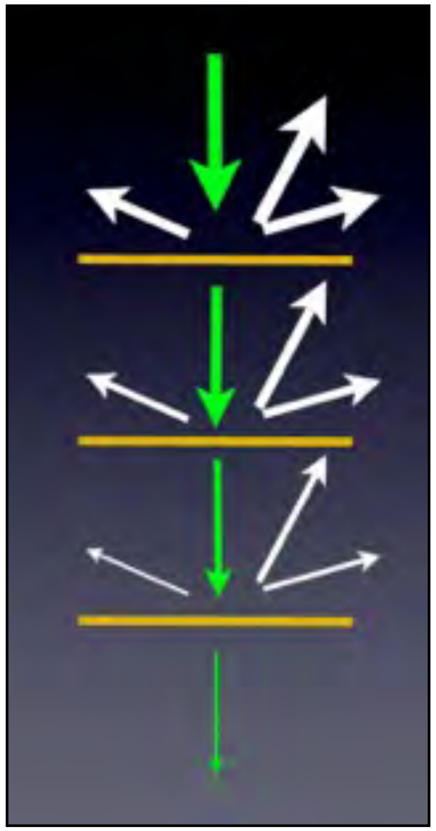
Refraction

Impedance

Angle of insonation

Resolution

FIGURE 9.13 - Attenuation

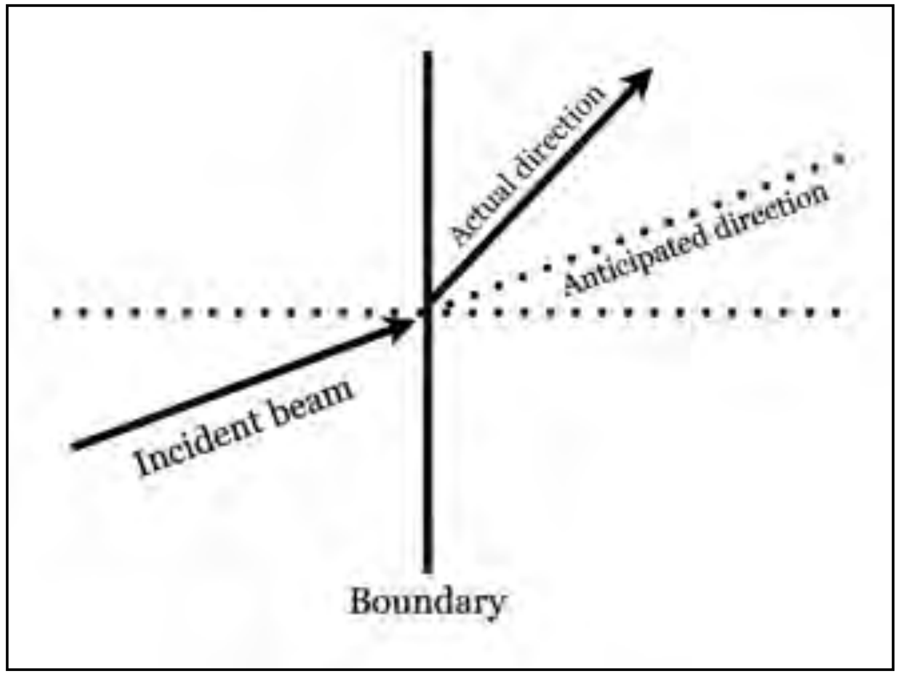


IMPORTANT DEFINITIONS:

Attenuation: (Figure 9.13)

- The loss of US energy (weakening) as it moves through a medium (the body)
- Attenuation results in a decrease in intensity and amplitude.
- Determined by the <u>frequency</u> of the sound and the <u>distance</u> that the sound wave travels
  - Frequency ⥣ Attenuation ⥣
  - Distance ⥣ Attenuation ⥣
- Attenuation of ultrasound waves occurs most commonly by:
  - <u>Absorption</u> = energy converted to another form of energy (e.g. heat); this is the primary component of attenuation in soft tissue (≥ 80%)
  - <u>Reflection</u> = redirection of sound back to the probe; very smooth reflectors (e.g. a mirror) are called specular
  - <u>Scattering</u> = if the boundary between media is irregular, the wave is reflected in a number of different directions; it is diffusely scattered
    - Occurs when the sound wave strikes material so small as to approach the wavelength of the cycles.
    - Seen especially in lung tissue, hence the poor imaging.
    - Frequency ⥣ Scattering ⥣
  - <u>Refraction</u> = redirection of part of the sound wave when it crosses from one medium to another (Figure 9.14)
    - Due to differing propagation speeds between the two media
    - Results in an effect similar to dipping a pencil in water, effectively "bends" the US wave.

FIGURE 9.14 - Refraction



MOVIE 9.1

Note the effects of attenuation (darker image) as the depth increases. Time gain compensation is used to adjust for this.

- **Attenuation coefficient:** amount of attenuation per centimeter of tissue
  - Frequency ⥣ Attenuation Coefficient ⥣
  - Does not change as sound travels in soft tissue

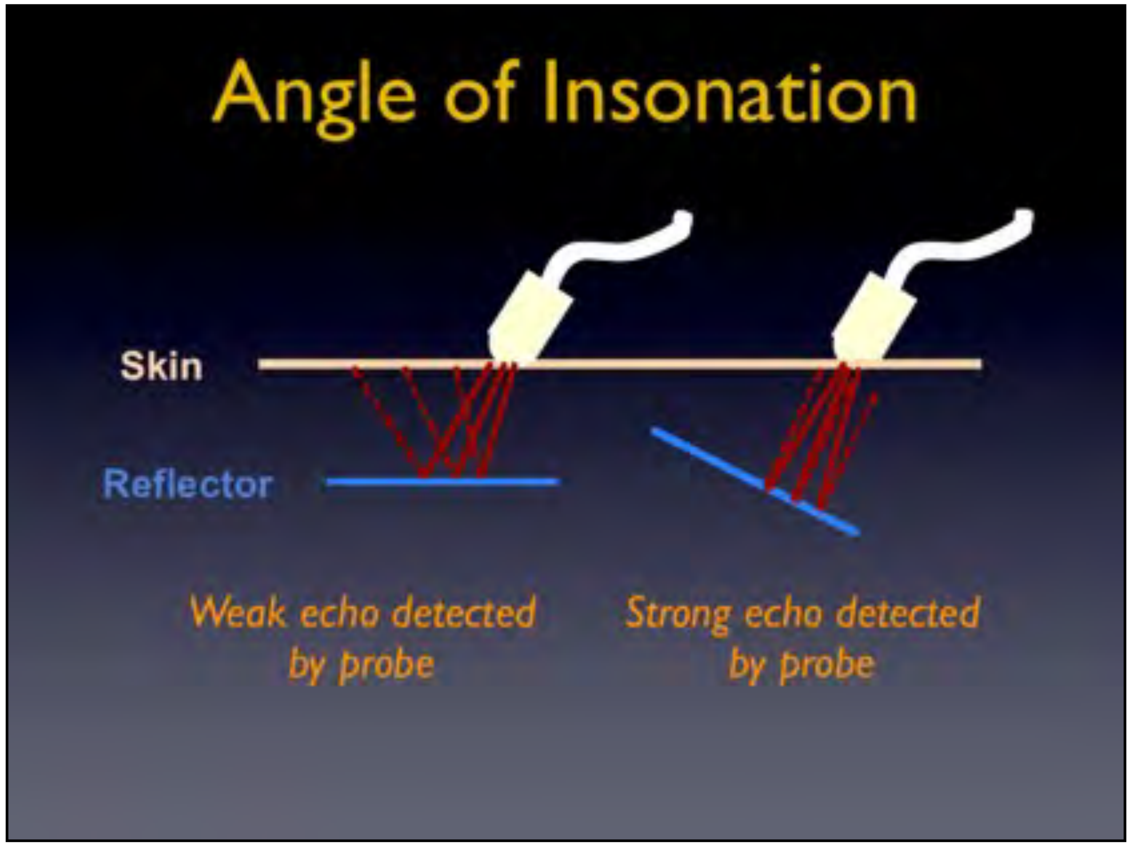
Impedance:

- The resistance to the propagation of sound
- Characteristic of the specific medium
- <u>impedance(rayls) = density(kg/m^3) X propagation speed (m/s)</u>
- Hence, impedance is related to density and propagation speed.
- Relative impedance: Bone>>muscle>fat>blood>water>>>>>air

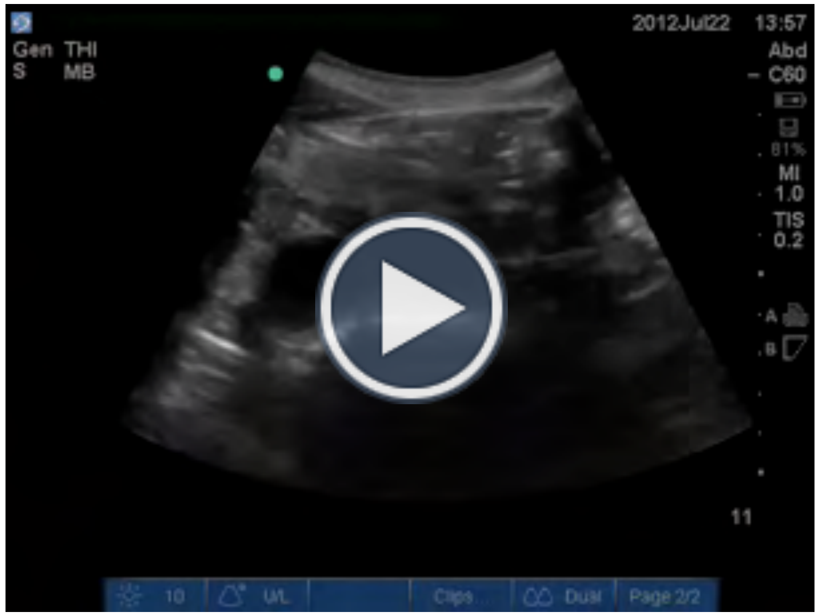
Acoustic Impedance Mismatch:

- Refers to the difference in acoustic impedance of two media at a boundary
- The greater the mismatch, the greater the percentage of ultrasound reflected.
- In other words, the amount of reflection is proportional to the difference in the acoustic impedance between the two media.
  - <u>Intensity reflection coefficient (%) = (reflected intensity/ incident intensity) X 100</u>

FIGURE 9.15 - Angle of insonation (incidence)



MOVIE 9.2



Note the clearer margins to the abdominal aorta as the angle of insonation is adjusted.

Angle of insonation (angle of incidence): (Figure 9.15 and Movie 9.2)

- The angle between the incident ultrasound beam and an imaginary line that is perpendicular to the boundary of the object of interest; important for defining the boundaries of a vessel for a vascular study.
- Translated: need to scan perpendicular to object of interest to maximize returning echoes and improve image quality.

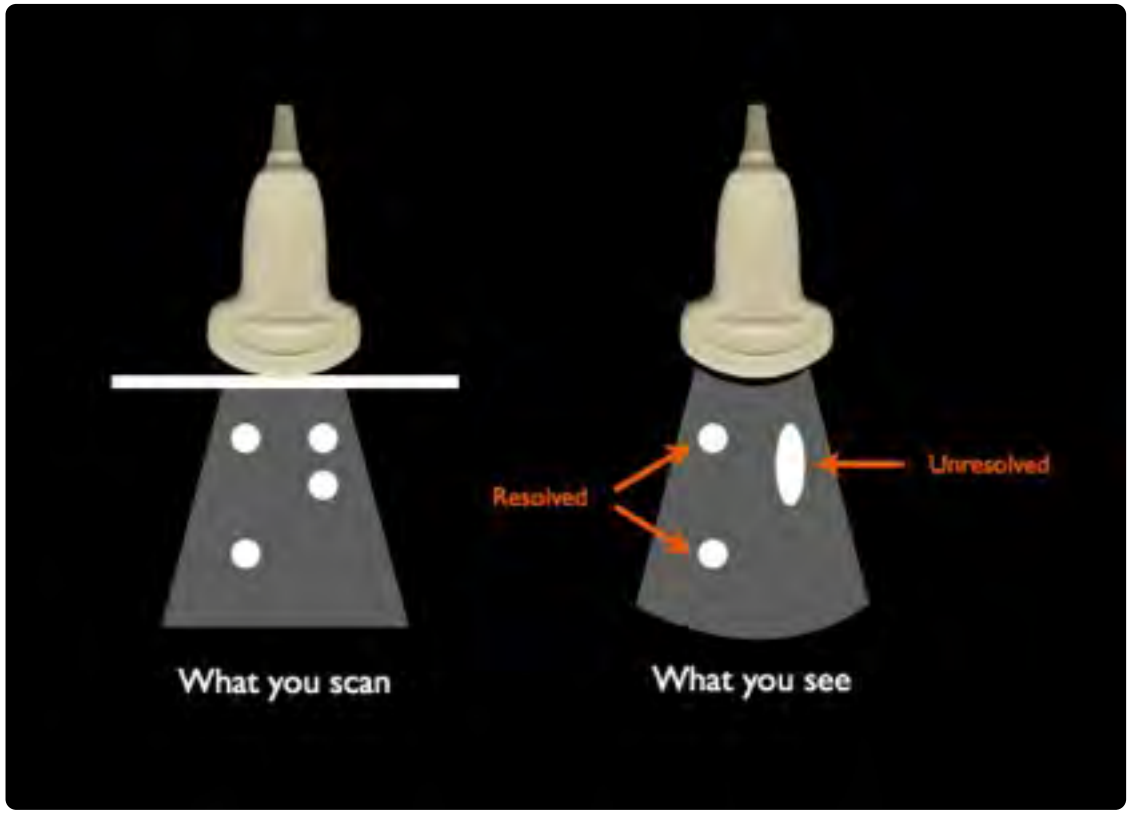
Resolution:

- The ability of the sound waves to discriminate between two different, closely spaced objects
- Axial resolution = refers to the ability to distinguish between two closely spaced objects in a plane *parallel* to the ultrasound beam (resolve shallower and deeper object); also known as longitudinal resolution. (Gallery 9.1)
  - The spatial pulse length is the major determinant of axial resolution; shorter pulses provide better images.

- The higher the frequency, the shorter the wavelength and spatial pulse length, resulting in better axial resolution.

- Lateral resolution = refers to the ability to distinguish between two closely spaced objects in the *horizontal* tissue plane (perpendicular to the ultrasound beam) (Gallery 9.1)
    - The width of the ultrasound beam (array of crystals, distance between individual crystal rays or scan line density) is the major determinant of lateral resolution.
    - More focal zones allows for enhanced resolution at particular depths of the scanning area, improving the lateral resolution; there is also some benefit to increasing the transducer frequency and decreasing the gain.
- Temporal resolution = ability to detect the position of moving objects at various points in time (Gallery 9.1)
    - Synonymous with frame rate
    - More frames/second leads to better temporal resolution; lower frame rates make the video appears choppy or stuttering.
    - Improved by narrowing the imaging sector, decreasing scanning depth, decreasing the line density, and decreasing the number of focal zones.
    - Especially important in cardiac ultrasound

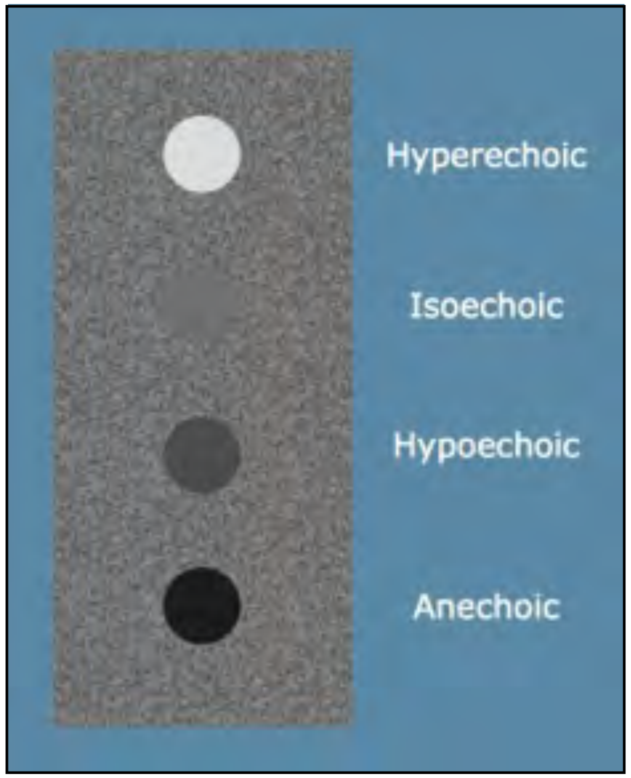
GALLERY 9.1 Various Resolutions



Axial resolution

FIGURE 9.16 - B-mode ultrasound of the aorta

FIGURE 9.17 Echogenicity examples



Scanning Modes:

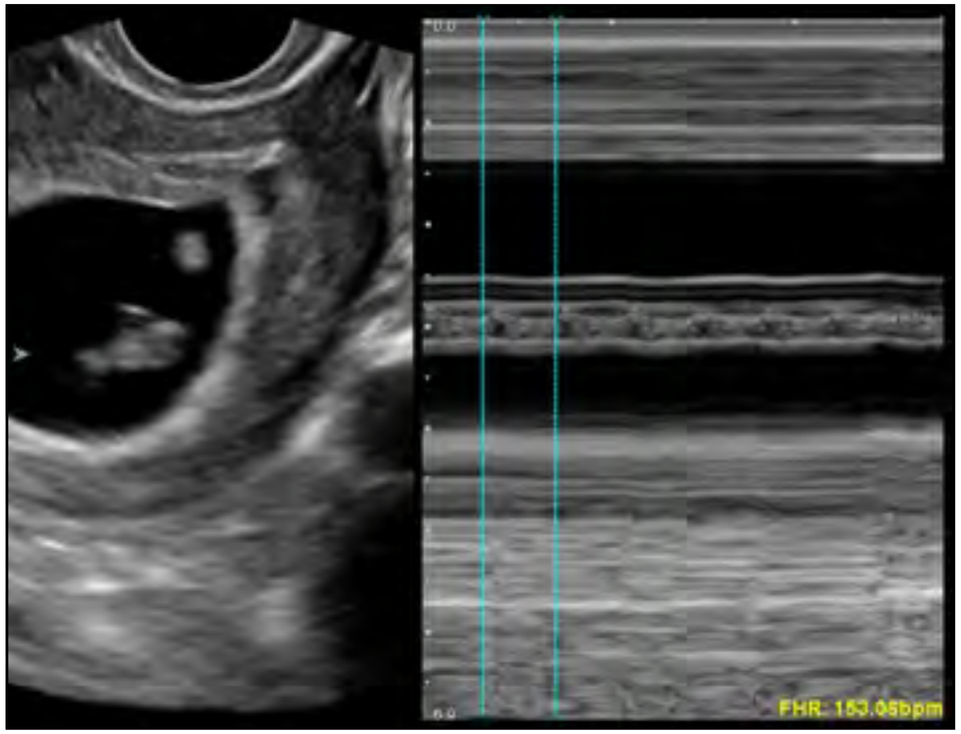
B-mode Ultrasound:

- Grayscale ultrasound (Figure 9.16)
- Most common scanning mode
- "B" = Brightness
- Strong echoes are represented by white dots.
- Absence of echoes are represented by black dots.
- Terminology: (Figure 9.17)
  - _Echogenic_ = bright (white) objects
  - _Anechoic_ = dark (black) objects
  - _Hyperechoic_ = brighter (more white) than comparison structure
  - _Hypoechoic_ = darker (more black) than comparison structure
  - _Isoechoic_ = same echogenicity as comparison structure

M-mode Ultrasound: (Figure 9.18)

- B-mode scanning appears on the left, while a tracing of tissue movement over time appears on the right (depth and time).

FIGURE 9.18 - M-mode being used to determine a fetal heart rate

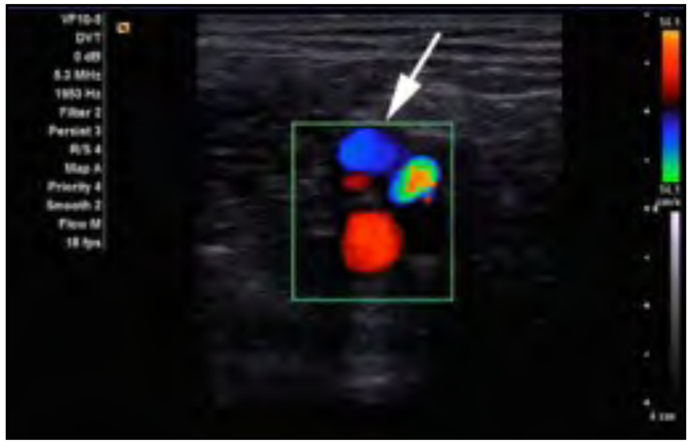


- Vertical axis is depth and corresponds to the B-mode image.
- Horizontal axis represents time.
- Particularly useful in fetal heart rate measurements and cardiac imaging

Color Doppler: (Figure 9.19)

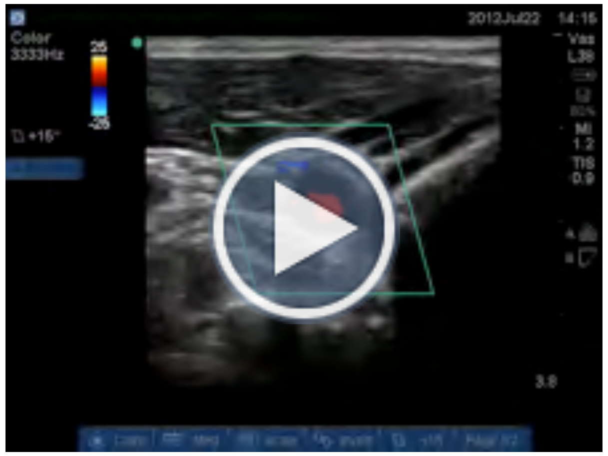
- Measures mean velocity and direction of flow, superimposing color over a B-Mode image
- A color scale display on the side of the screen gives information on mean velocity.

FIGURE 9.19 Color flow doppler of the upper thigh



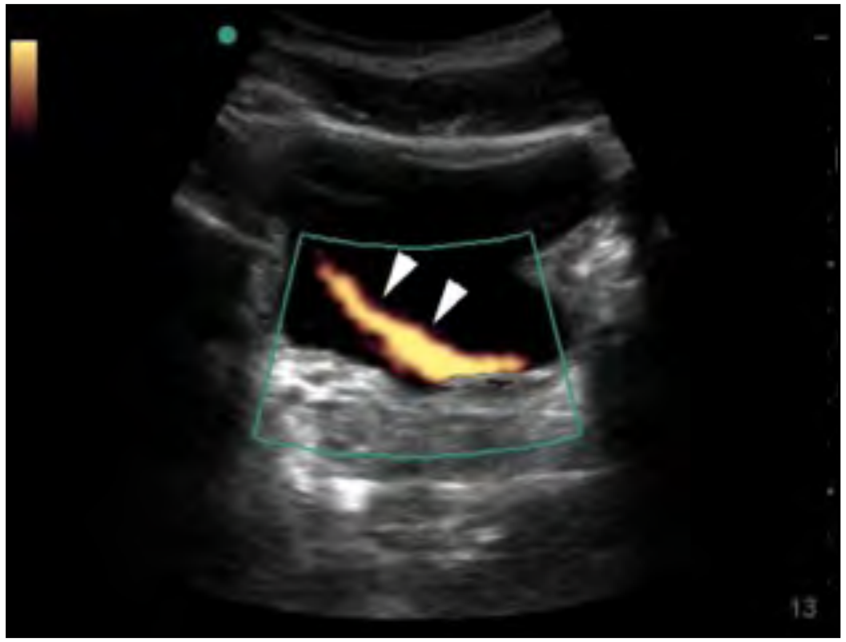
- The color superiorly represents flow toward the probe, and inferiorly represents flow away from the probe.

MOVIE 9.3



Color flow doppler of the carotid artery.

FIGURE 9.20 - Power doppler identifies a ureteral jet



Power Doppler: (Figure 9.20)

- Averages flow over several frames
- Has a greater sensitivity for evaluation of low flow states (e.g. testicular or ovarian flow)
- Gives no information on flow direction

MOVIE 9.4 - Power doppler applied to the bladder, with ureteral jet noted.

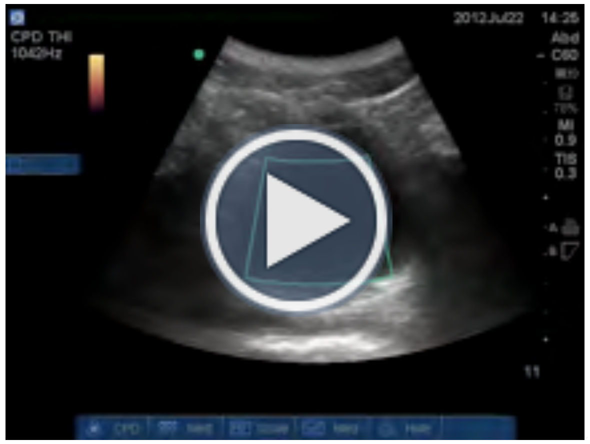
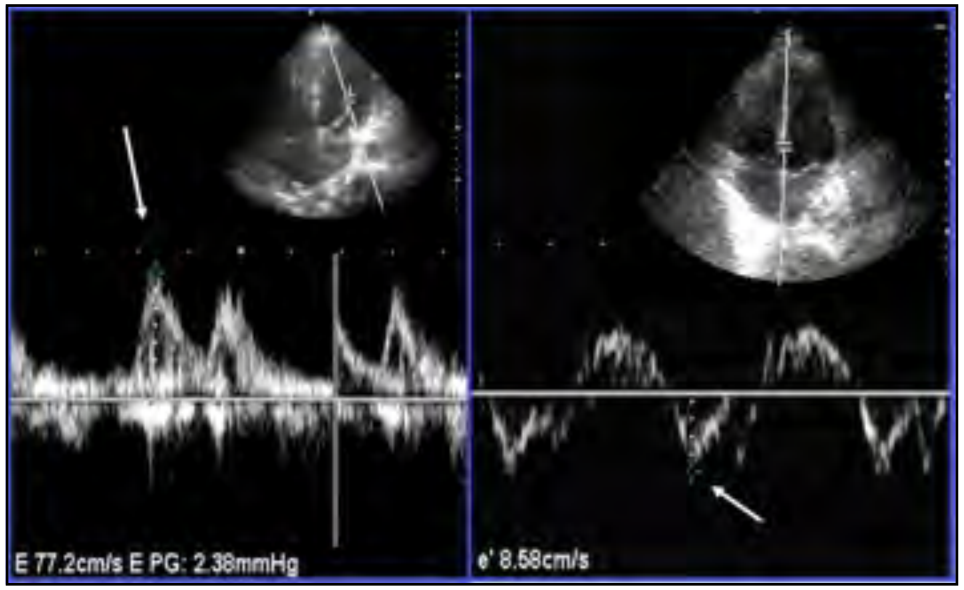


FIGURE 9.21 - Spectral doppler in cardiac imaging



Spectral Doppler: (Figure 9.21)

- Uses continuous or pulsed wave technology
- Quantitative assessment of flow velocity at a single point within the "gate" (pulsed wave) or along the entire line of interrogation (continuous wave)
- Very helpful in cardiac imaging

Important Knobs:

- *Power:* The total energy delivered by the transducer; increasing the power increases the intensity of the ultrasound beam. Typically, the power is fixed to limit potential adverse biologic effects.

- *Gain:* Degree of amplification of the returning signal. Adjustments to gain increase or decrease the overall brightness of returning echoes on the screen. Analogous to the volume knob on a stereo.

-

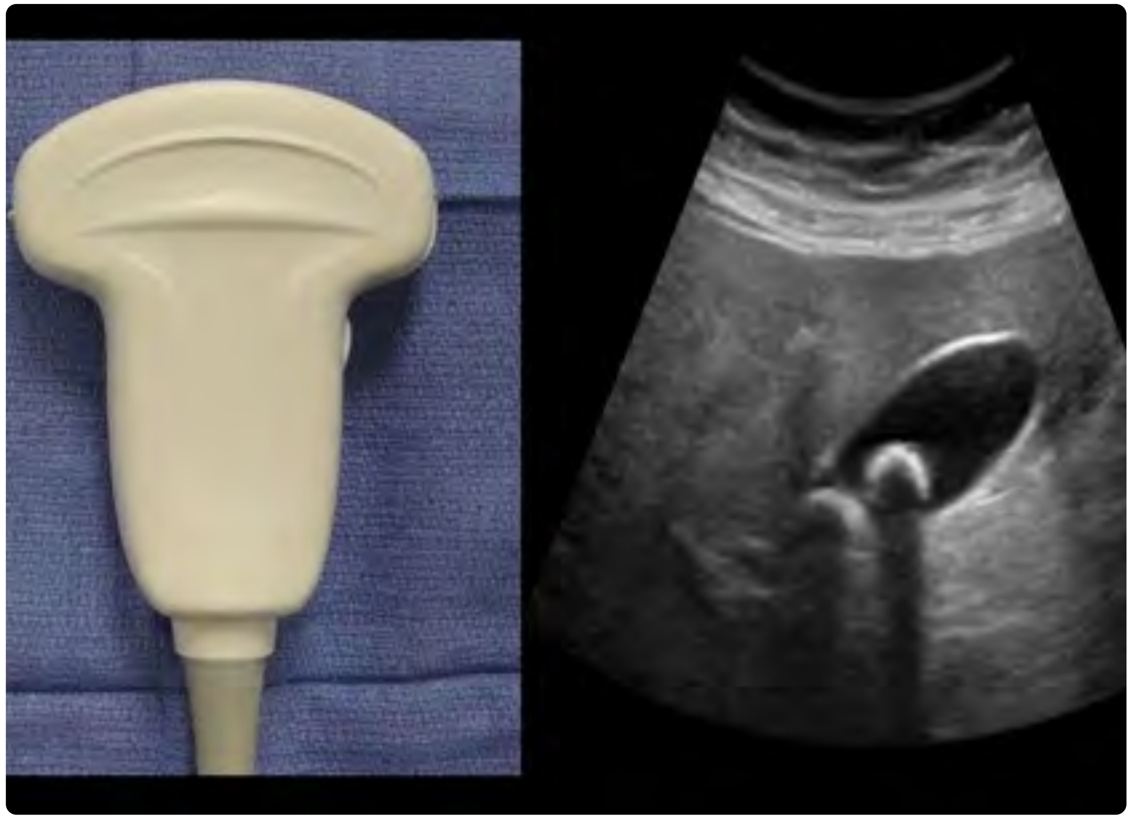
IMAGE 9.1 Time gain compensation sliders

MOVIE 9.5

Adjusting time gain compensation in the far field, and then then near field.

Time Gain Compensation: Typically, a series of "sliders" arranged vertically, allowing preferential adjustments of gain at different levels of tissue. Also known as TGC. (Image 9.1)

GALLERY 9.2 Various Probes



Curvilinear probe and footprint

- *Depth:* Adjusts the field of view to increase or decrease the scanning area.

- *Frequency:* Adjusts the frequency of sound emitted by the probe. The higher the frequency, the better the resolution and the lower the penetration.

- *Focus:* Improves image resolution at a particular level (depth) of the ultrasound screen. Often appears to the right of the image as an arrow (or group of arrows/foci).

- *Dynamic Range:* The range of returning echo intensities that the machine processes in forming the grayscale image (measured in decibels, 30-78 dB). If you decrease the dy namic range, the weaker signals in the spectrum are lost, and there will be greater contrast between black and white (good for vascular studies). A higher dynamic range will give you more "shades of gray," hence more detail regarding the tissue imaged.

- *Tissue harmonics:* The transducer listens for sound waves returning at twice the frequency of the pulse that was emit - ted from the transducer (the second harmonic). This "harmonic frequency" is less susceptible to distortion as compared to the traditional frequency; mainly echoes from deeper structures. Artifacts due to side lobes and scatter are greatly reduced, and are subject to less attenuation.

Basics to Scanning:

The Probes: (Gallery 9.2)

- It is important to note that the range of frequencies for the various probes is quite variable, depending on the particular ultrasound manufacturer.

- *Curved array probe:*

  - Low frequency (common frequency range of 2 to 5 MHz)
  - Sector scanning format
  - Large footprint and scanning area, though decreased resolution with increasing depth.
  - Ideal for all abdominal, retroperitoneal, and OB/GYN studies.

- *Phased array probe:*

  - Low frequency (common frequency range 1 to 5 MHz)
  - Sector scanning format
  - Smaller footprint than the curved array
  - Ideal for cardiac studies

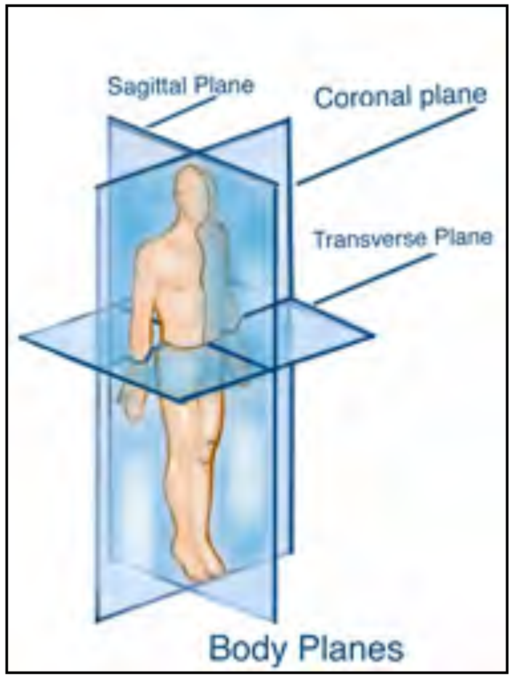
- *Endocavitary probe:*

  - Moderate frequency (common frequency range of 8 to 15 MHz)
  - Small footprint, great resolution
  - Ideal for intraoral or transvaginal studies

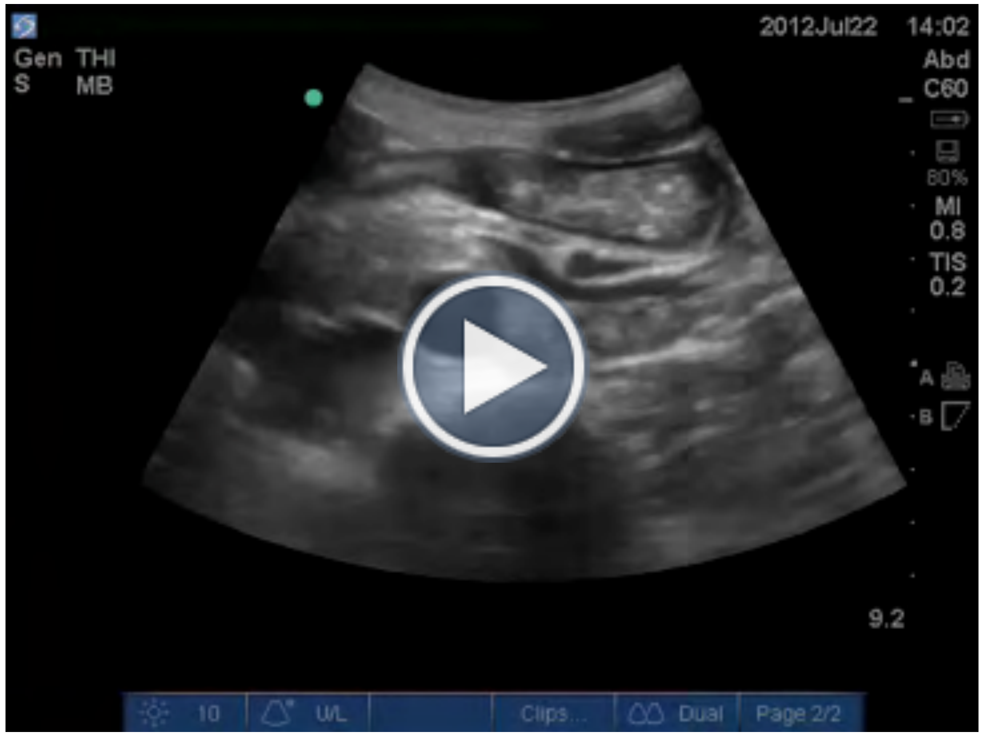
- *Linear array probe:*

  - Higher frequency (common frequency range 5 to 15 MHz)
  - Arrays are parallel, maintaining resolution with increasing depth.
  - Scanning area is limited to the size of the probe.
  - Probe of choice

FIGURE 9.22 - Imaging planes

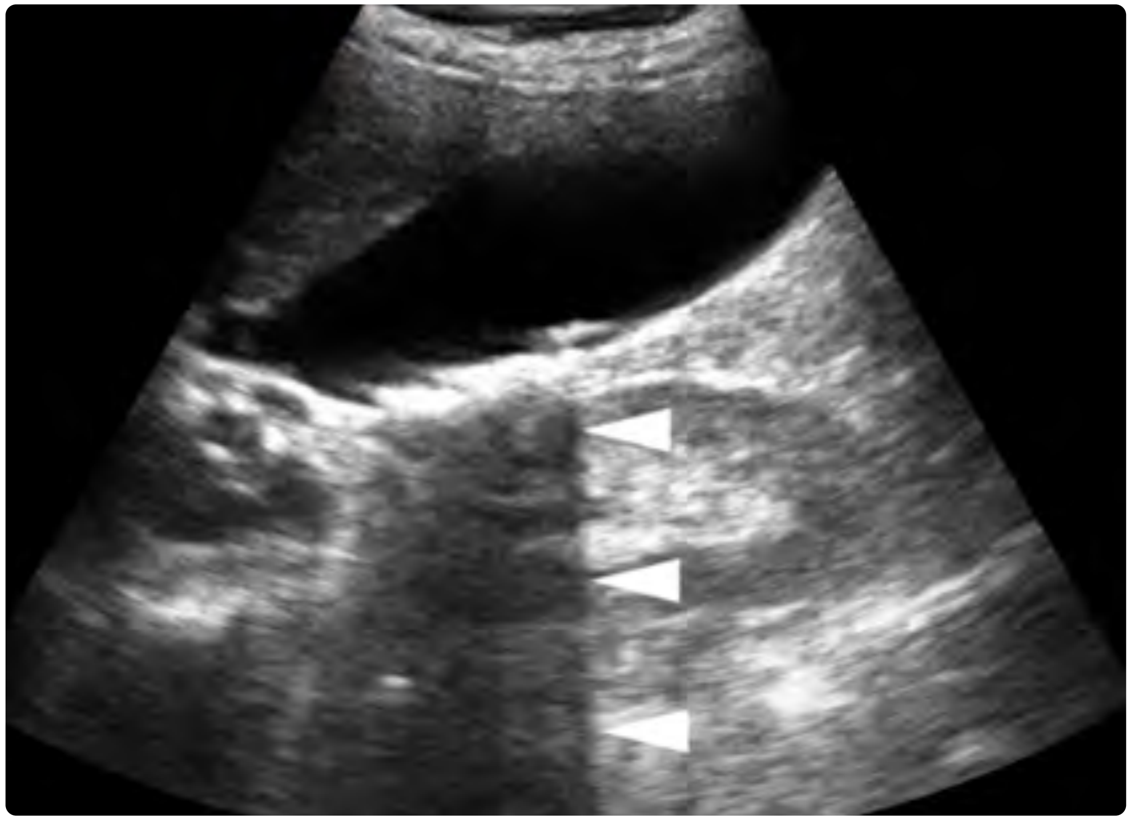


MOVIE 9.6



Moving between a transverse (short-axis) plane to a longitudinal (long-axis) plane.

Gallery 9.3 Artifacts



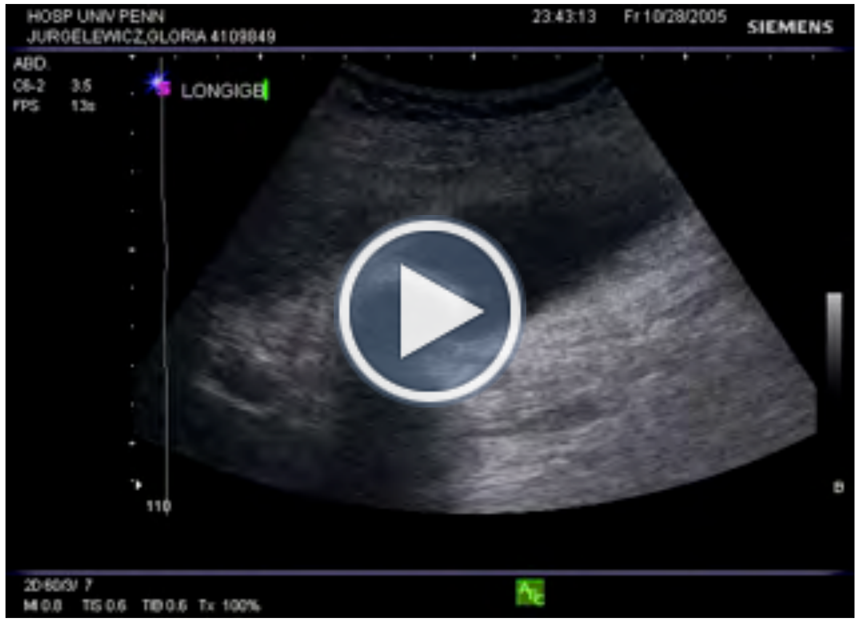
Acoustic shadowing (arrowheads) from gallstones

for vascular access, soft tissue and musculoskeletal, and venous compression studies.

Image Orientation: (Figure 9.22)

- Sagittal (longitudinal) = cephalad to caudad view
- Transverse (axial) = cross-sectional or short-axis view similar to CT
- Coronal = longitudinal view in a lateral plane

Movie 9.7



Acoustic shadowing from a large gallstone.

Artifacts: (Gallery 9.3)

- *Acoustic shadowing:* Caused by failure of the ultrasound beam to pass through an object, resulting in a dark area distal to the reflective or attenuating surface. (Movie 9.6)

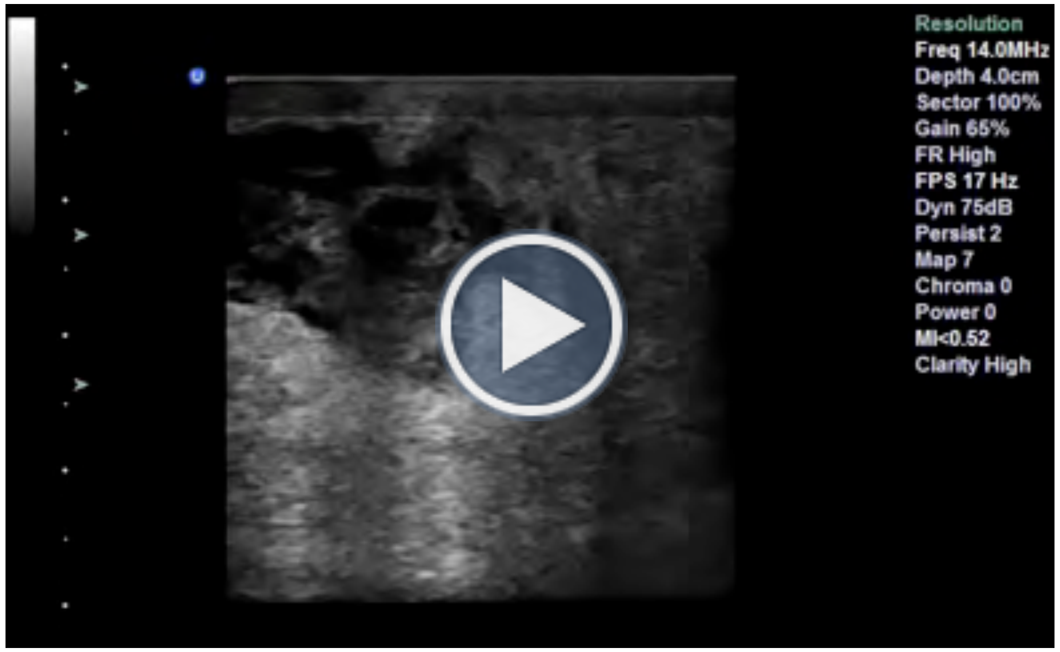
Movie 9.8

Femoral vessels obscured by gain artifact, with improved visualization as the gain is turned down.

- *Gain artifact:* Excessive amplification of the returning echo, such that it may obscure anechoic structures. Again, blood/fluid should be black. Underlying vascular structures may not be identified if the gain is too high. (Movie 9.7)

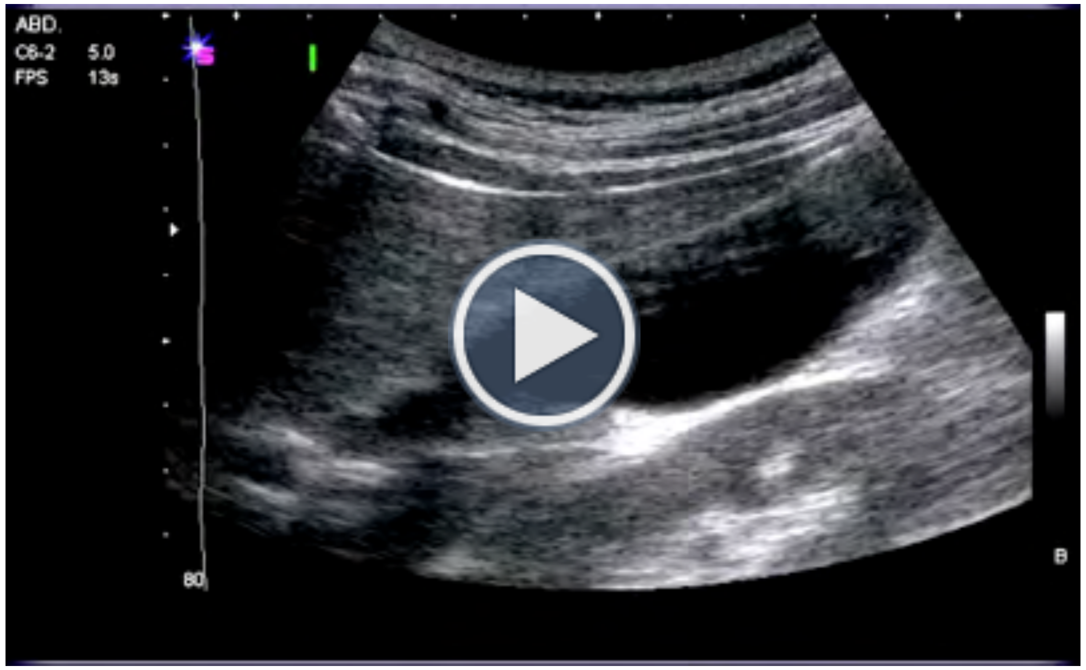
- *Posterior Acoustic Enhancement:* Certain media allow efficient propagation of ultrasound waves (pleural effusions, abscesses, abdominal free fluid, large vessels or fluid-filled organs, etc.). With this increased "through transmission," the tissue behind the media appears more echogenic as compared to the surrounding tissue. In other words, there is less attenuation of the ultrasound wave as it propagates through these types of media.

Movie 9.9



Posterior acoustic enhancement from a cutaneous abscess

Movie 9.10



Reverberation artifact noted on gallbladder exam (extending into the lumen of the gallbladder).

- *Reverberation:* Occurs when there are two reflectors that line parallel to one another and perpendicular to the US wave. Sound gets trapped between these two highly echogenic surfaces, bouncing back and forth (think ping-pong) before finally returning back to the probe. As depth on the US screen is determined by the time elapsed from pulse initiation to reception, the returning echoes are displayed as recurrent bright lines similar to the rungs of a ladder (parallel and equidistant).

- *Ring Down or Comet Tailing:* Two different forms of reverbera tion artifact. Both occur in the setting of two or more strong reflectors that are both very close together, and exist in a medium with high propagation speeds. Ring-down artifacts occur with small structures (gas bubble or, classically, a hollow-bore needle tip) that produce a long, linear echo from the structure. The reverberations of comet tail artifacts are so closely spaced that they actually merge. These may be seen with small, strong reflec - tors such as air, plastic, metal, and calcifications.

- *Mirror artifact:* objects appear on both sides of a strong reflector (such as the diaphragm). Occurs when an ultrasound wave strikes the strong reflector, and a portion of the wave does not travel directly back to the transducer. In stead, it may bounce between the two reflective surfaces, resulting in more time elapsed. Thus, the mirror image (or false image) is displayed on the opposite side of the reflector.

- *Lateral cystic shadowing (edge artifact):* Sound waves encountering a rounded or curved structure, particularly with differing propagation speeds, result in refraction of thewave that does not return to the probe.

Movie 9.12

Ring-down artifact from an 18 gauge angiocatheter.

Movie 9.11

Comet tail artifact on thoracic ultrasound of a patient with pulmonary edema.

Since the wave does not return to the probe, shadow is seen along the edge.

Tell everyone that you finished another chapter!

Contact us:

REFERENCES

1.Edelman SK. Understanding Ultrasound Physics. 4th ed. E.S.P. Ultrasound; 2012.

2.Miele FR. Ultrasound Physics and Instrumentation. 4th ed. Texas: Pegasus Lectures Inc; 2006.

3.Kremkau FW: Diagnostic Ultrasound: Principles and Instruments: 6th ed. Philadelphia, PA: WB Saunders; 2002.

4.Rumack CM, Charboneau JW, Wilson SR: Diagnostic Ultrasound. 2nd ed. Philadelphia, PA: WB Saunders; 1998.

Chapter 10

Cardiac Output

While we work on getting this chapter to you, check out this Cardiac Output video from the One Minute Ultrasound App...

Chapter 11

Diastology

While you're waiting, check out the Ultrasound Podcast episodes on Diastology...

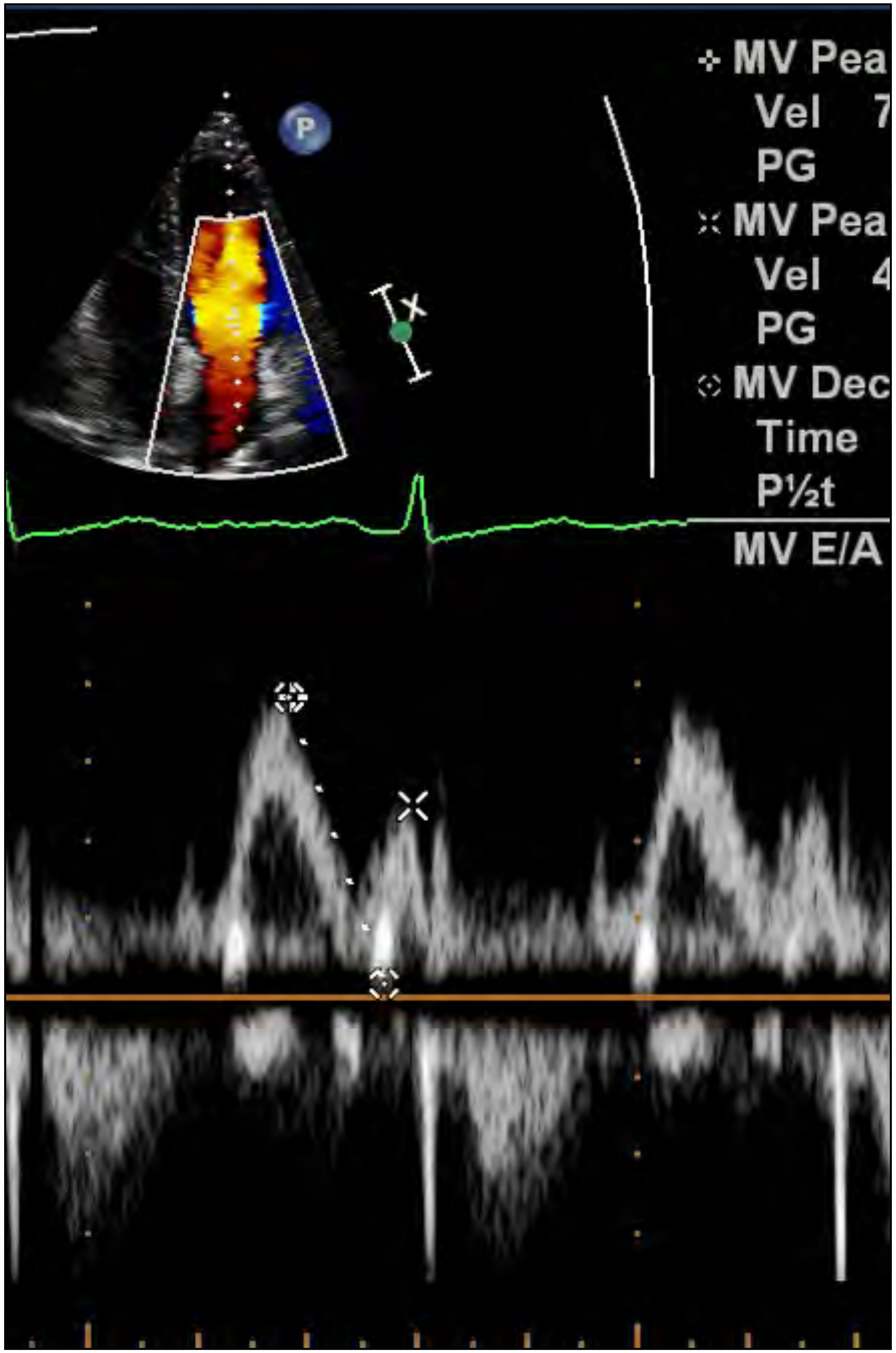
CHAPTER 12

Wall Motion

Why not check out the Ultrasound Podcast on Wall Motion Abnormalities and the One Minute Ultrasound video while you wait?

Chapter 13

Fluid Responsiveness



SECTION 1

Introduction

Administration of an intravenous fluid challenge is a common medical intervention in the hypotensive or hypovolemic patient. Ideally, a fluid challenge increases stroke volume (SV), and thereby increases cardiac output. However, in some circumstances, a fluid challenge may be ineffective or harmful.[1-3] A patient receiving fluid for septic shock may not be fluid responsive after receiving multiple fluid challenges. A patient in cardiogenic shock with pulmonary edema may suffer additional harm by unnecessary administration of intravenous fluid. It is important that the clinician be able to properly assess a patient's likelihood to respond to a fluid challenge. Newer methods incorporating ultrasound into the bedside evaluation may offer a superior assessment than conventional methods.

SUMMARY

"No one has ever measured, not even poets, how much the human heart can hold."

–Zelda Fitzgerald, novelist (1900-1948)

Section 2

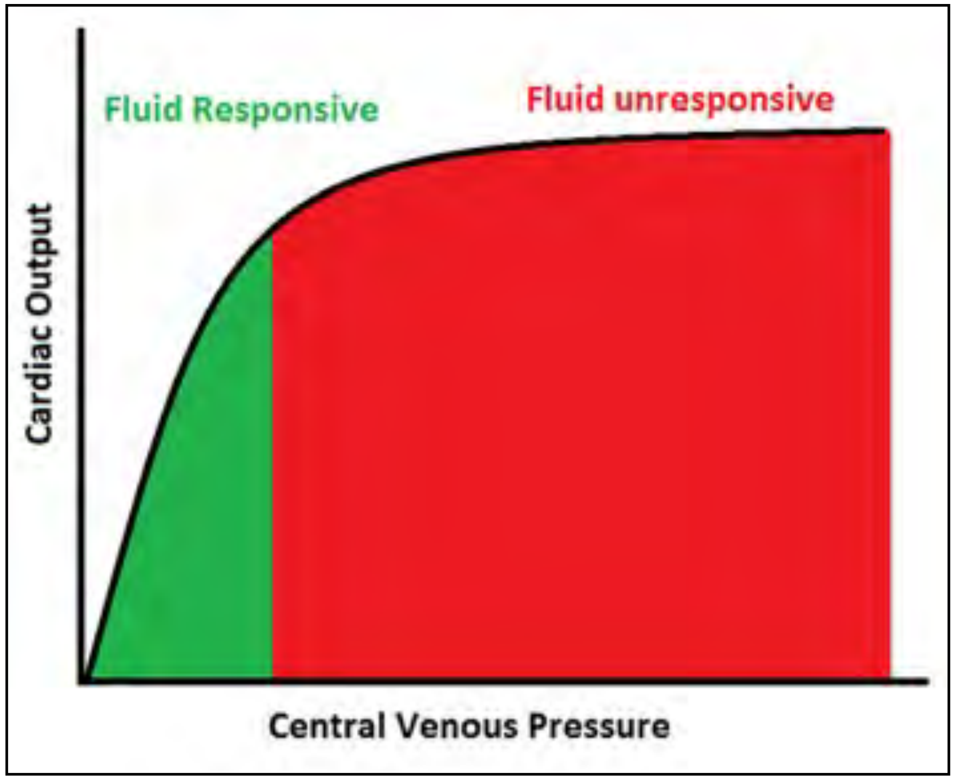
CVP and PAOP

Summary

CVP is an inadequate assessment of fluid responsiveness

Traditional methods of assessment of fluid response have relied on measuring cardiac filling pressures as a way to gauge preload. Central venous pressure (CVP) is a surrogate for right ventricular (RV) end-diastolic pressure, and pulmonary artery occlusion pressure is a surrogate for left ventricular (LV) end-diastolic pressure. Maestrini's Law of the Heart (commonly called the Frank-Starling law) demonstrates that the relationship between ventricular end-diastolic pressure and ventricular end-diastolic volume (cardiac preload) is not linear (Figure 13.1).[4,5] At low filling pressures, one may get large increases in SV for an incremental increase in filling pressure. At high pressures, one may get a minimal increase (or occasionally a decrease) in SV for the same increase in filling pressure. It is for this reason that CVP and pulmonary artery filling pressures are not accurate predictors of fluid responsiveness, despite their widespread clinical use.[6-]

Figure 13.1 - Frank Starling curve



SECTION 3

Assessing fluid responsiveness with ultrasound

SUMMARY

Advantages of Ultrasound over traditional methods of assessing fluid response:

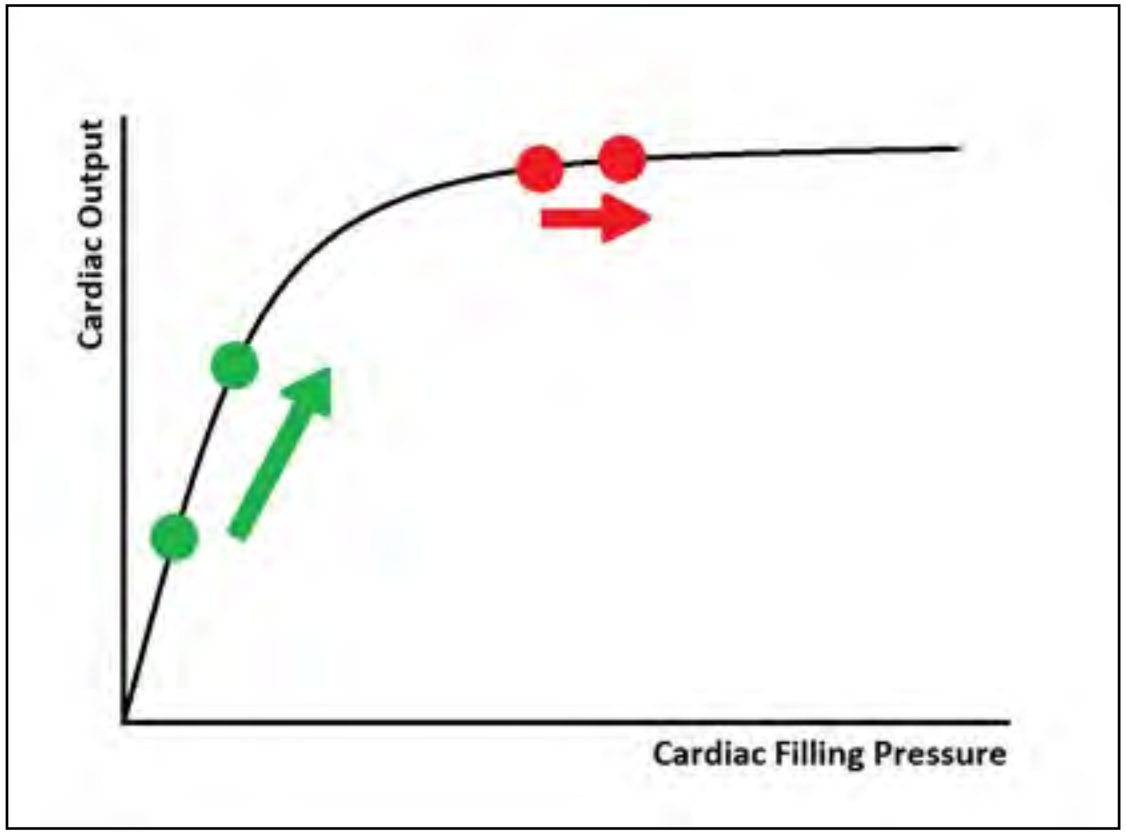
Visualization of ventricular chamber

Ability to quantify parameters that vary dynamically

During respiration, the changes in intrathoracic pressure affect preload.

Ultrasound offers several advantages over traditional methods of assessing fluid response. The ability to qualitatively visualize the ventricular chamber is sometimes more informative of cardiac preload than a measurement of its pressure. Perhaps more important is the ability of ultrasound to quantify parameters that vary dynamically with a perturbation of the cardiac filling pressures. The ability to measure dynamic parameters may inform the clinician whether the patient is situated on the steep part of the Frank-Starling curve or the plateau (Figure 13.2).

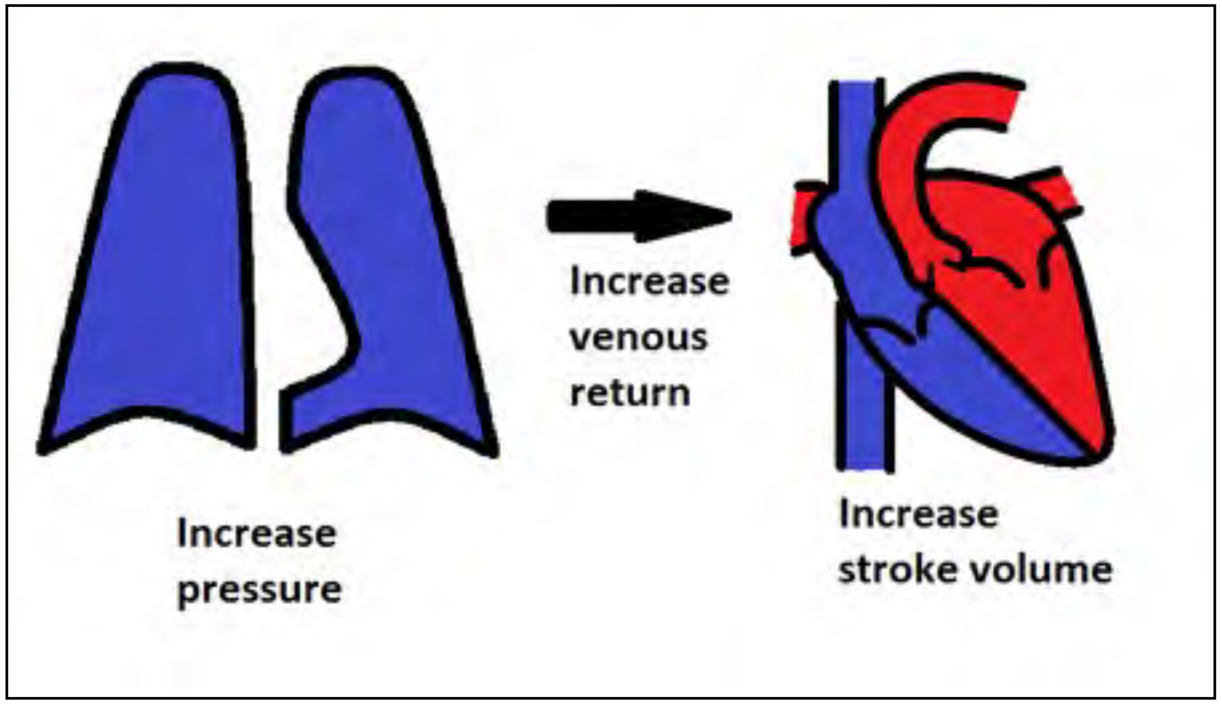
FIGURE 13.2 - Frank starling curve with dynamic parameters



During respiration, the changes in intrathoracic pressure affect preload. In a passively mechanically ventilated patient who is fluid responsive, inspiration increases intrathoracic pressures, which reduces RV preload and SV. After two or three cardiac cycles, this decreased RV stroke volume leads to a decrease in LV preload and stroke volume, which are often observed during expiration. In the same patient, inspiration will lead to increased LV preload and SV due to increased pulmonary venous return of blood (**Figure 13.3**). In a patient who is passively mechanically ventilated and fluid responsive, respiration will induce cyclical changes in SV. In a fluid responsive patient who is not receiving any positive pressure ventilation, inspiration will decrease intrathoracic pressures. SV will still vary with respiration, but will be reversed when compared to the changes noted in the passively mechanically ventilated patient.

Caution must be applied when evaluating the use of parameters that vary with respiration in the patient who is spontaneously breathing. The tidal volumes and deflections of intrathoracic pressures are inconsistent in the spontaneously breathing patient. Patients who are receiving an assisted mode of ventilation or non-invasive positive pressure ventilation may have more complex hemodynamic effects than either unassisted breathing or passive ventilation.[10,11]

FIGURE 13.3 - Respiratory Variation of Stroke Volume



SECTION 4

Inferior Vena Cava

The inferior vena cava (IVC) is a highly compliant blood vessel that empties into the right atrium (RA). Ultrasound evaluation of the IVC may inform the clinician of the CVP.[12] (Illustration 13.1, Movie 13.1 and 13.2)

ILLUSTRATION 13.1

IVC diameter (cm)	Collapse with sniff	CVP (mmHg)
< 2.1	>50%	0-5
		5-10
>2.1	<50%	>10

MOVIE 13.1 - IVC collapsing

SUMMARY

Ultrasound evaluation of the IVC may inform the clinician of the CVP

However, CVP is not terribly useful to predict fluid responsiveness

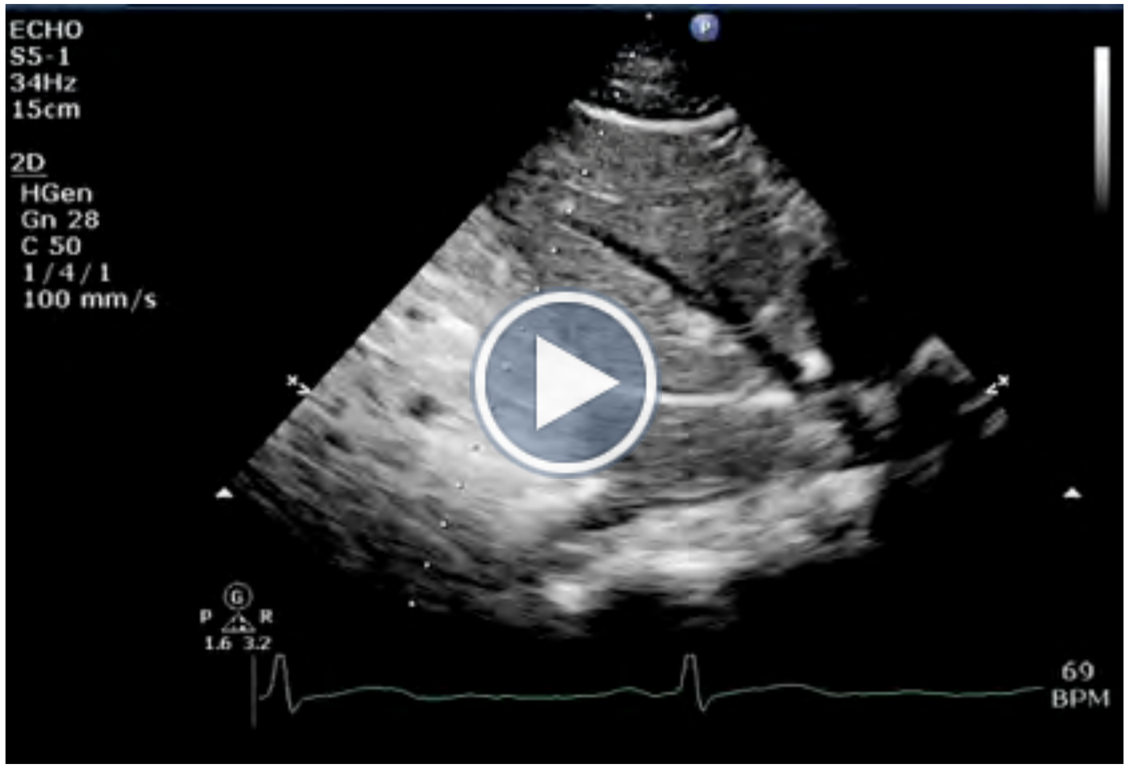
In mechanically ventilated patients a vena cava that distends >18% with passive respiration predicts fluid responsiveness

MOVIE 13.2 - Plethoric IVC

The utility of an ultrasonic estimation of CVP is limited, as CVP is not a terribly useful parameter to predict fluid responsiveness. The IVC runs longitudinally along the spine. The appropriate method to identify the IVC uses either a cardiac or abdominal 2-D ultrasound in the subcostal window. The measurement should be made perpendicular to the long axis of the IVC at end-expiration, just cephalad to the junction of the hepatic veins that lie approximately 5-30 mm proximal to the ostium of the RA (Image 13.1). It is important to not mistake lateral translation of the IVC for collapse (Movie 13.3). Evaluation of respiratory collapse is performed in the non-intubated patient by requesting that the patient perform a sniff maneuver. The degree of IVC collapse is not a reliable estimate of CVP in a patient receiving mechanical ventilation, but it is reasonable in these patients to expect that CVP will be <10 mm Hg if the IVC diameter is < 12mm.[13]

IMAGE 13.1 - Appropriate location for IVC measurement

MOVIE 13.3 - Lateral movement of IVC in longitudinal plane



Although the utility of an estimated CVP is limited, ultrasound can be very informative in predicting fluid response. Barbier and colleagues demonstrated that in mechanically ventilated patients, a vena cava that distends > 18% in diameter (Figure 13.4) with passive respiration is likely to respond to a fluid challenge.[14] In a similar study comprised solely of septic patients receiving mechanical ventilation, Feissel and colleagues demonstrated that a passively ventilated patient with an IVC variability > 12% (Figure 13.5) was likely to respond to fluid.[15] The IVC may not be as informative in patients with abdominal compartment syndrome, pregnancy, or high airway pressures.

One Minute Ultrasound IVC Ultrasound Demonstration

FIGURE 13.4

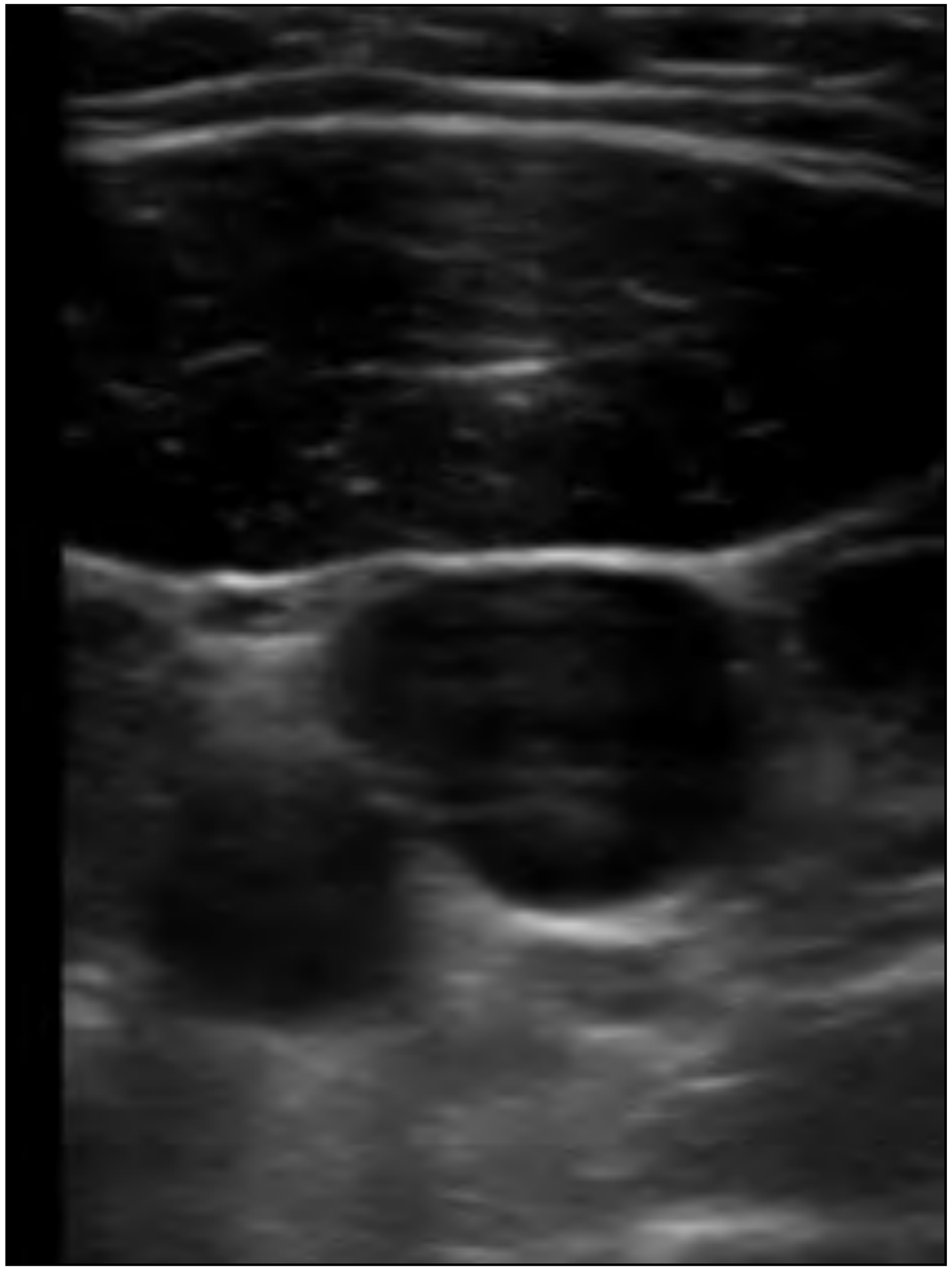
$$\text{Vena Cava Distensibility} = \frac{\text{Dmax} - \text{Dmin}}{\text{Dmin}}$$

FIGURE 13.5

$$\text{Vena Cava Variability} = \frac{\text{Dmax} - \text{Dmin}}{(\text{Dmax} + \text{Dmin}) / 2}$$

SECTION 5

Internal Jugular Vein



SUMMARY

There is growing interest in using ultrasonography of the internal jugular (IJ) vein to assess fluid responsiveness. Historically, clinical assessment of a patient's volume status included an assessment of jugular venous pulsation, a measurement of marginal accuracy and reproducibility.[16] One might surmise that ultrasound evidence of a collapsing or plethoric IJ vein would be as informative as the vena cava. Some clinicians in practice are using ultrasound to predict fluid responsiveness by respiratory collapse of the internal jugular. At the time of writing this text, there is insufficient evidence to support this practice.

Section 6

Diastolic Function

Summary

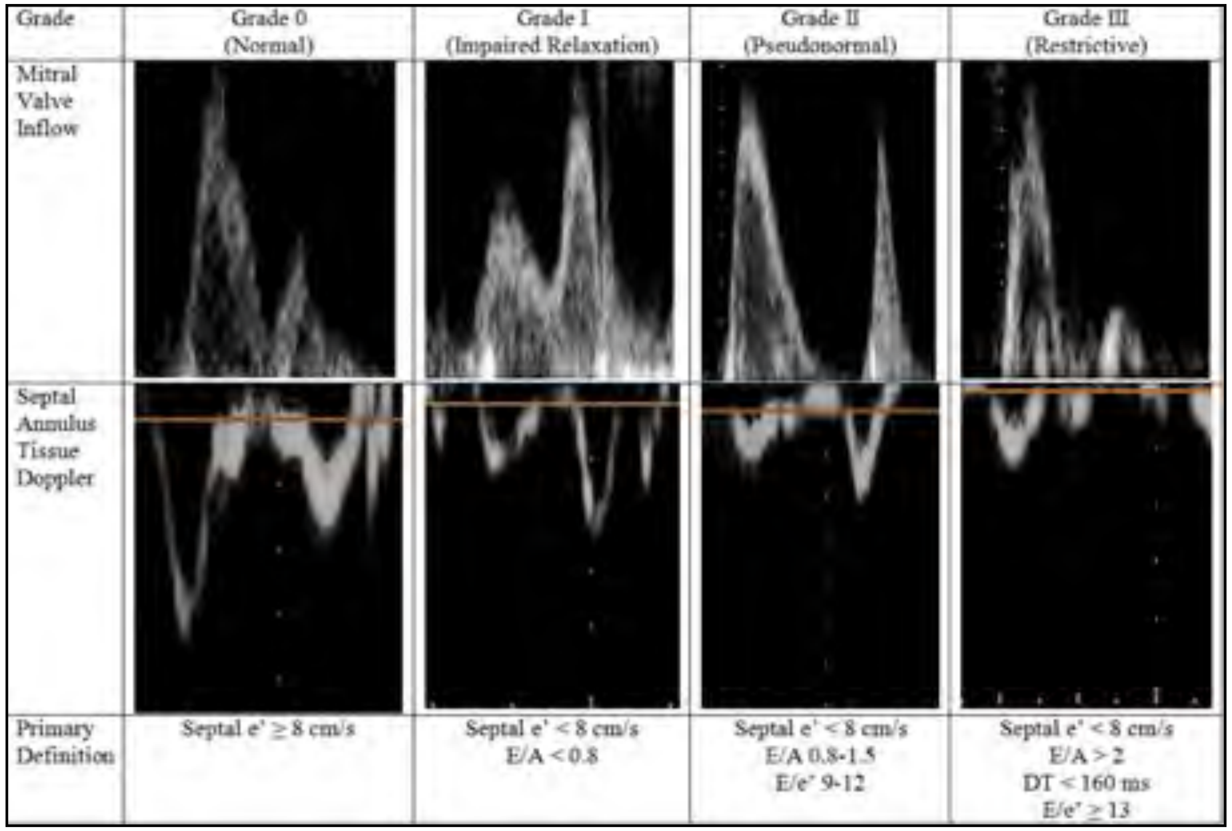
Diastolic function is helpful in determining the risk of a fluid challenge, but does not adequately assess fluid responsiveness.

Apical 4-chamber view is used to obtain the mitral inflow velocity

The mitral annulus tissue doppler is also obtained in the apical 4-chamber view

Assessment of left ventricular diastolic function can be performed using pulse wave Doppler of the mitral inflow and the tissue Doppler of the mitral annulus (Figure 13.6).[17]

Figure 13.6



While not every patient's diastology is easily categorized, one can use the ratio of mitral inflow velocity (E) to mitral annulus velocity (e') during early diastole to estimate left atrial pressures.[18]

The mitral inflow velocity is obtained by transthoracic echocardiography in the apical 4-chamber (A4C) view, or by transesophageal echocardiography in the midesophageal 4-chamber view. (Gallery 13.1)

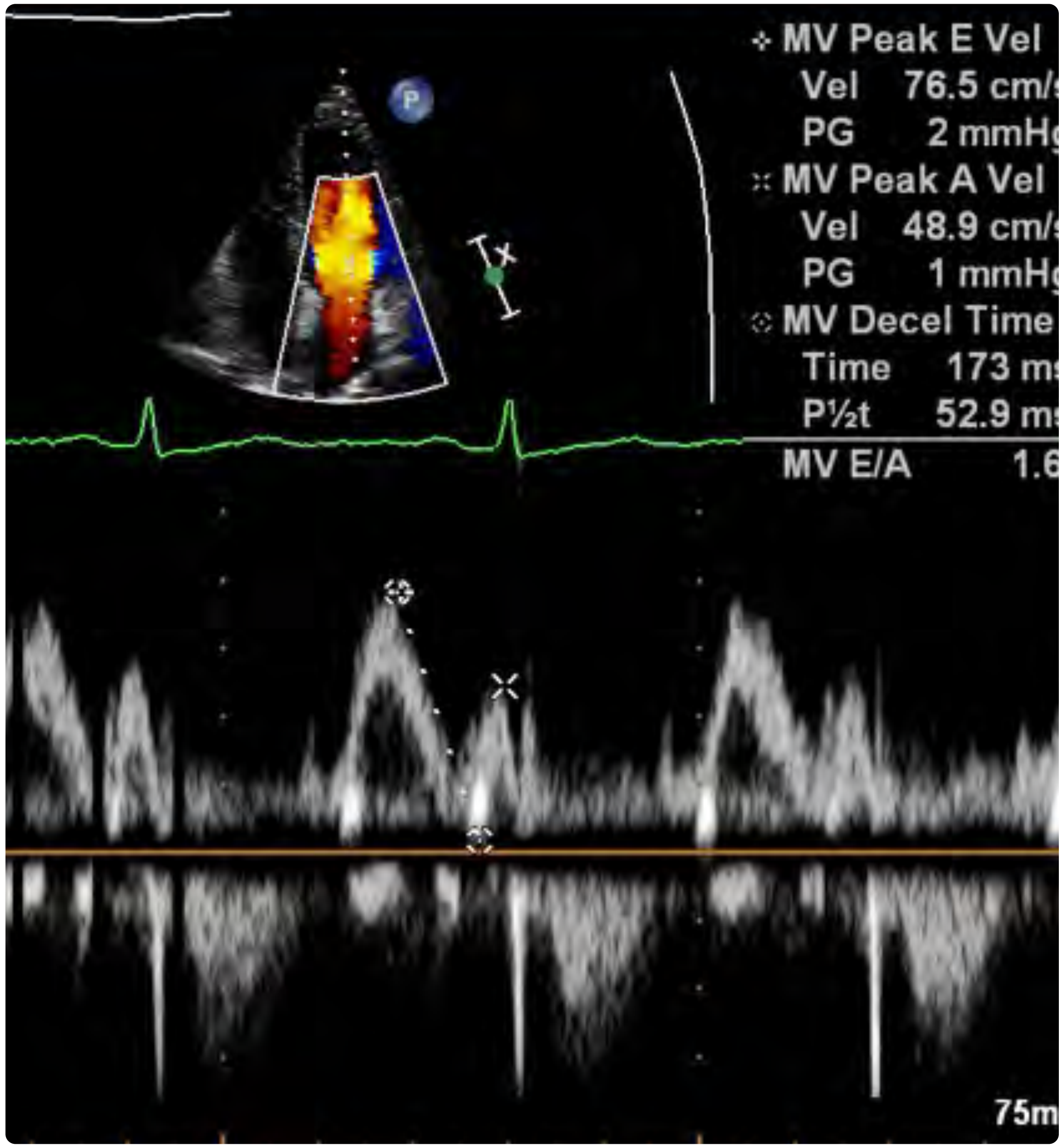
The pulse wave Doppler, with a 1-3mm sample volume, is placed between the mitral leaflet tips during diastole.[17] The mitral annulus tissue Doppler is obtained by transthoracic echocardiography in the A4C view, or by transesophageal echocardiography in the midesophageal 4-chamber view. (Gallery 13.1)

The tissue Doppler sample volume is positioned at or within 1 cm of the septal mitral annulus and adjusted to cover the longitudinal excursion of the mitral annulus (usually 5-10 mm).[17] The E/e′ ratio offers a reasonable estimate of left atrial pressure.   An E/e′ ratio < 8 is

One Minute Ultrasound Diastology Demonstration

MOVIE 13.4 - Lung Ultrasound showing pulmonary edema

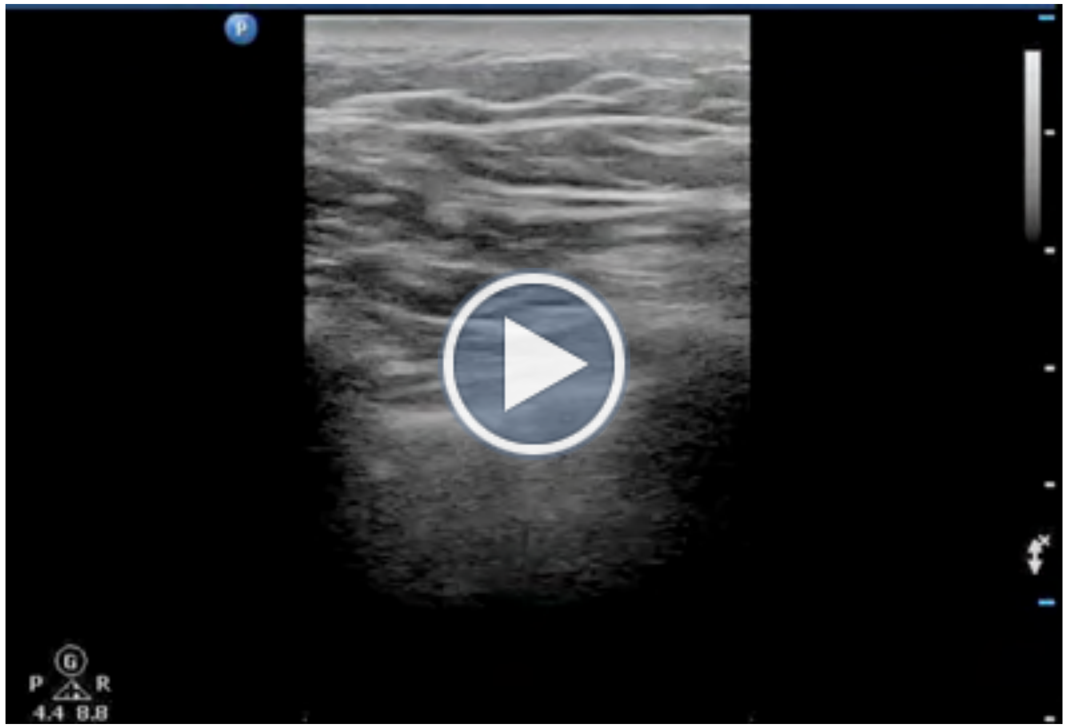
GALLERY 13.1



The mitral inflow velocity is obtained by transthoracic echocardiography in the apical 4-chamber (A4C) view, or by transesophageal echocardiography in the midesophageal 4-chamber view

likely to correlate to a normal left atrial pressure. Conversely, an E/e' ratio > 15 is likely to correlate to an elevated left atrial pressure.[18] Although an assessment of diastolic function and an estimate of left atrial pressure may not necessarily inform the clinician of the likelihood of the patient to respond to fluid, these data are useful when weighing the potential harms of administering a fluid challenge. A patient with an elevated left atrial pressure is at increased risk for pulmonary edema, a finding that can also be assessed with ultrasound (Movies 13.4 and 13.5).[19]

MOVIE 13.5 - Normal Lung Ultrasound

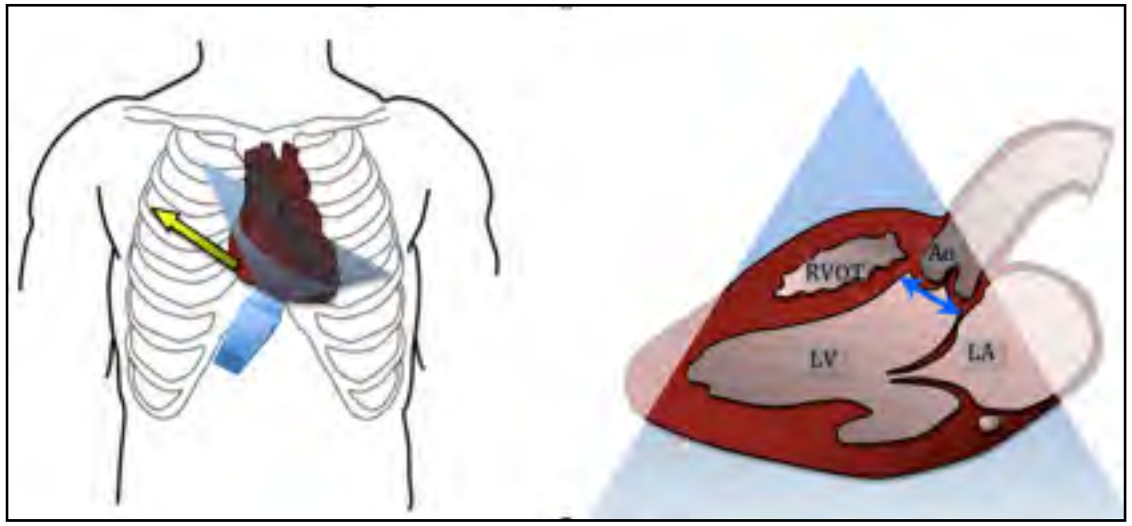


SECTION 7

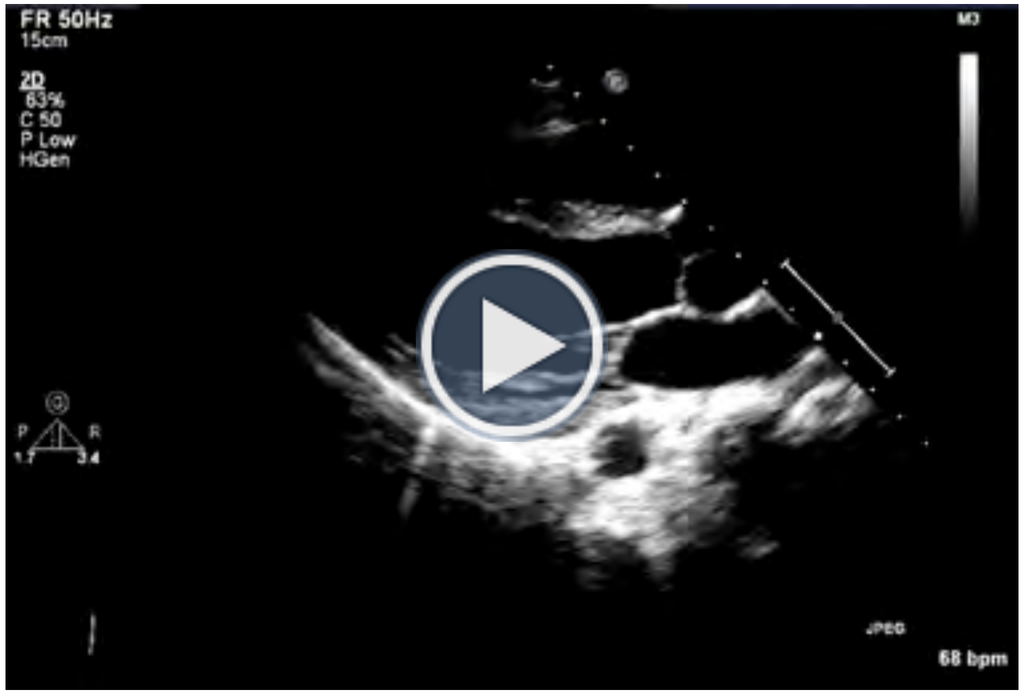
Stroke volume, Aortic blood velocity variation

A clinician can determine left ventricular stroke volume using pulse wave Doppler of the left ventricular outflow tract (LVOT). The LVOT diameter is measured from a parasternal long-axis view (transthoracic) or midesophageal long-axis view (transesophageal) (Figure 13.7, Movies 13.6 and 13.7).

FIGURE 13.7 - Parasternal long-axis view



MOVIE 13.6 - Parasternal long-axis view



SUMMARY

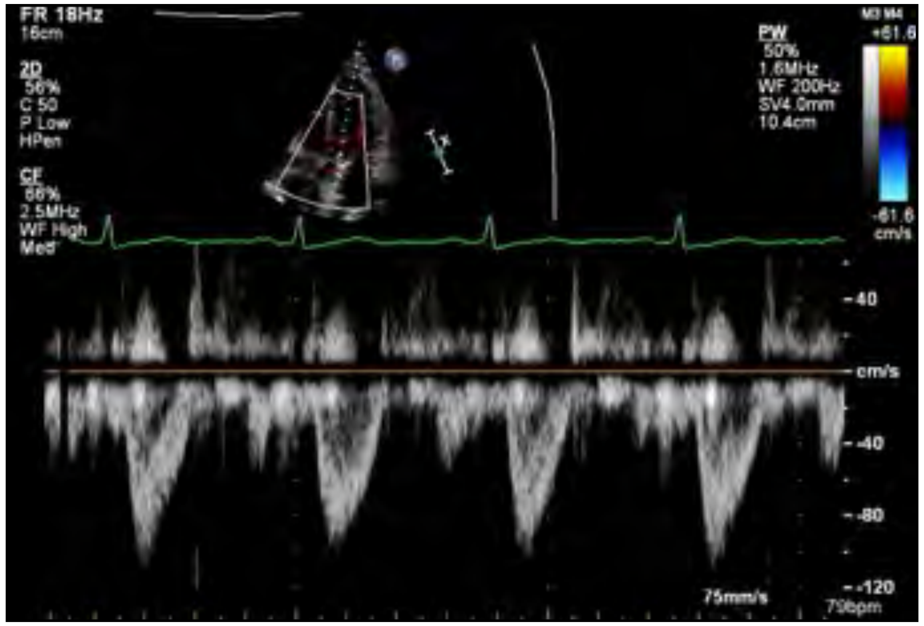
Stroke volume can be measured using pulse wave Doppler of the LVOT in a parasternal long-axis view

Stroke volume variation and aortic flow velocity variations predict fluid responsiveness in passively breathing, mechanically ventilated patients.

MOVIE 13.7 - PLAX With LVOT Diameter

The velocity-time integral (VTI) of LVOT blood velocity is obtained using pulse wave Doppler from a transthoracic apical 5-chamber or apical long axis view (Image 13.4) or from a deep transgastric five chamber view (Movie 13.8 and Image 13.3).

IMAGE 13.2 - LVOT VTI From Apical 5 Chamber



MOVIE 13.8 - LVOT VTI From Deep Transgastric

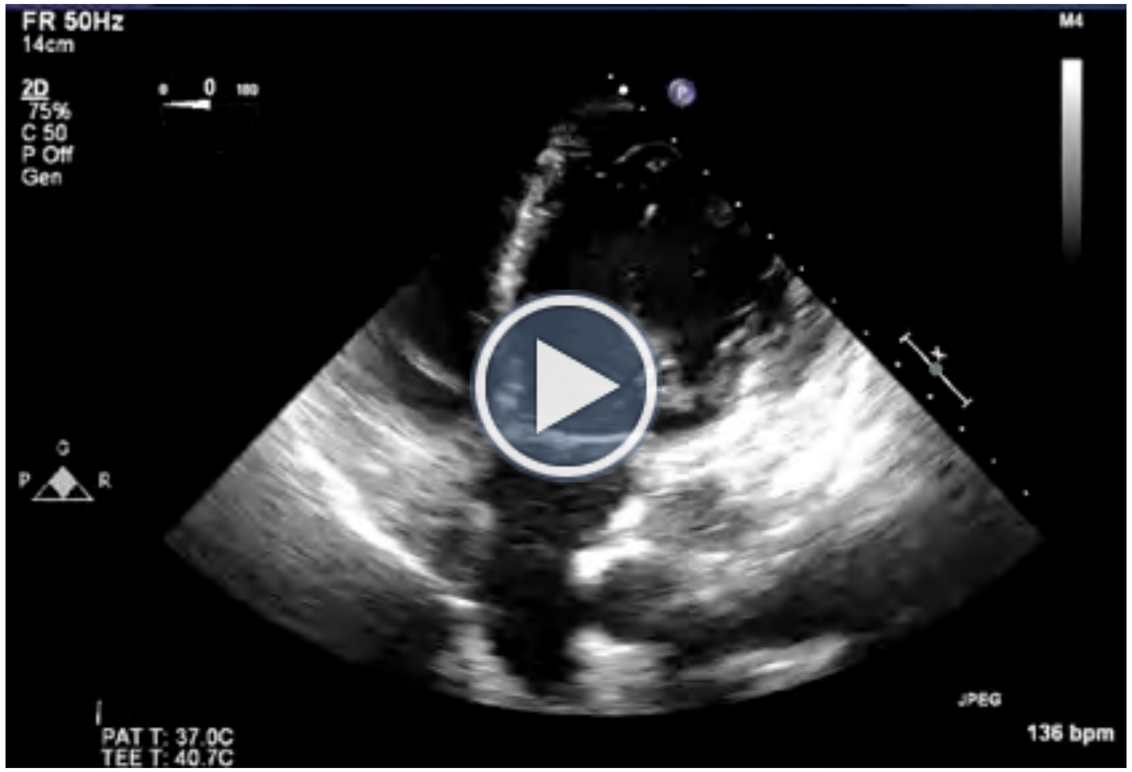
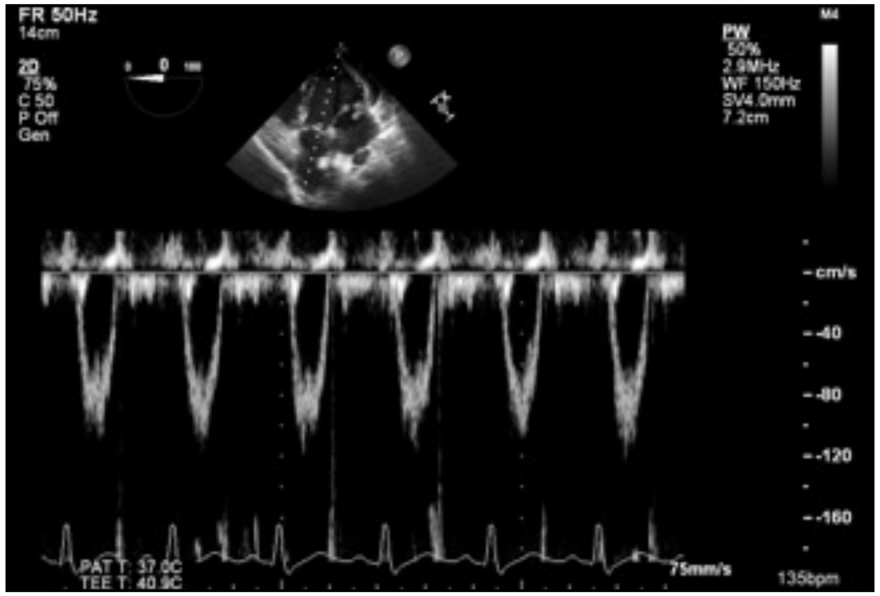
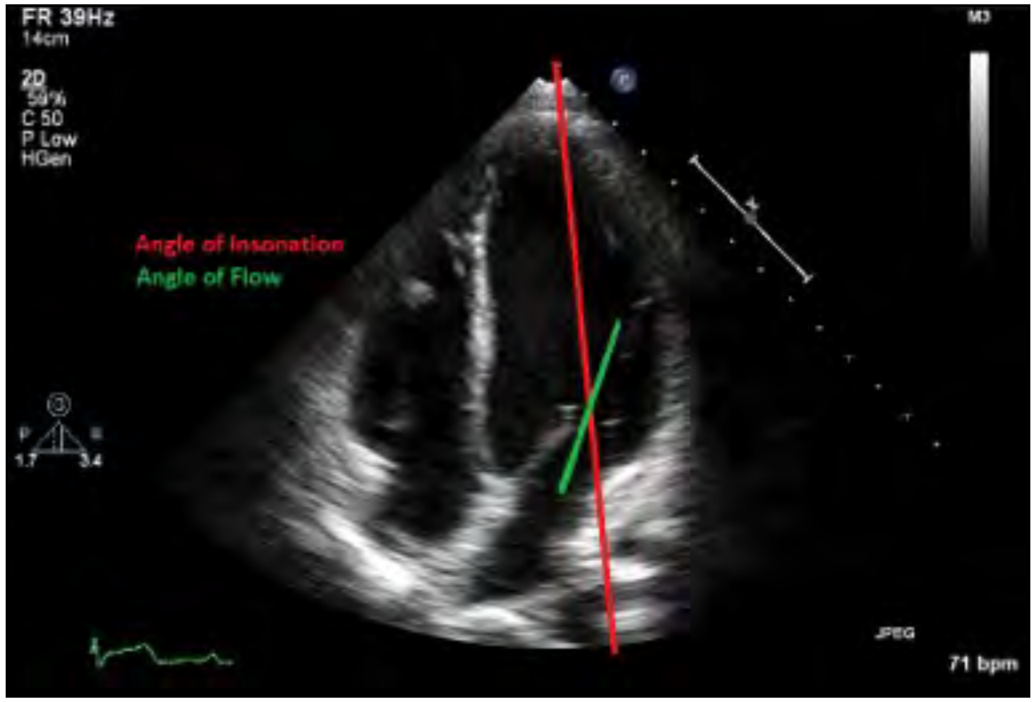


IMAGE 13.3



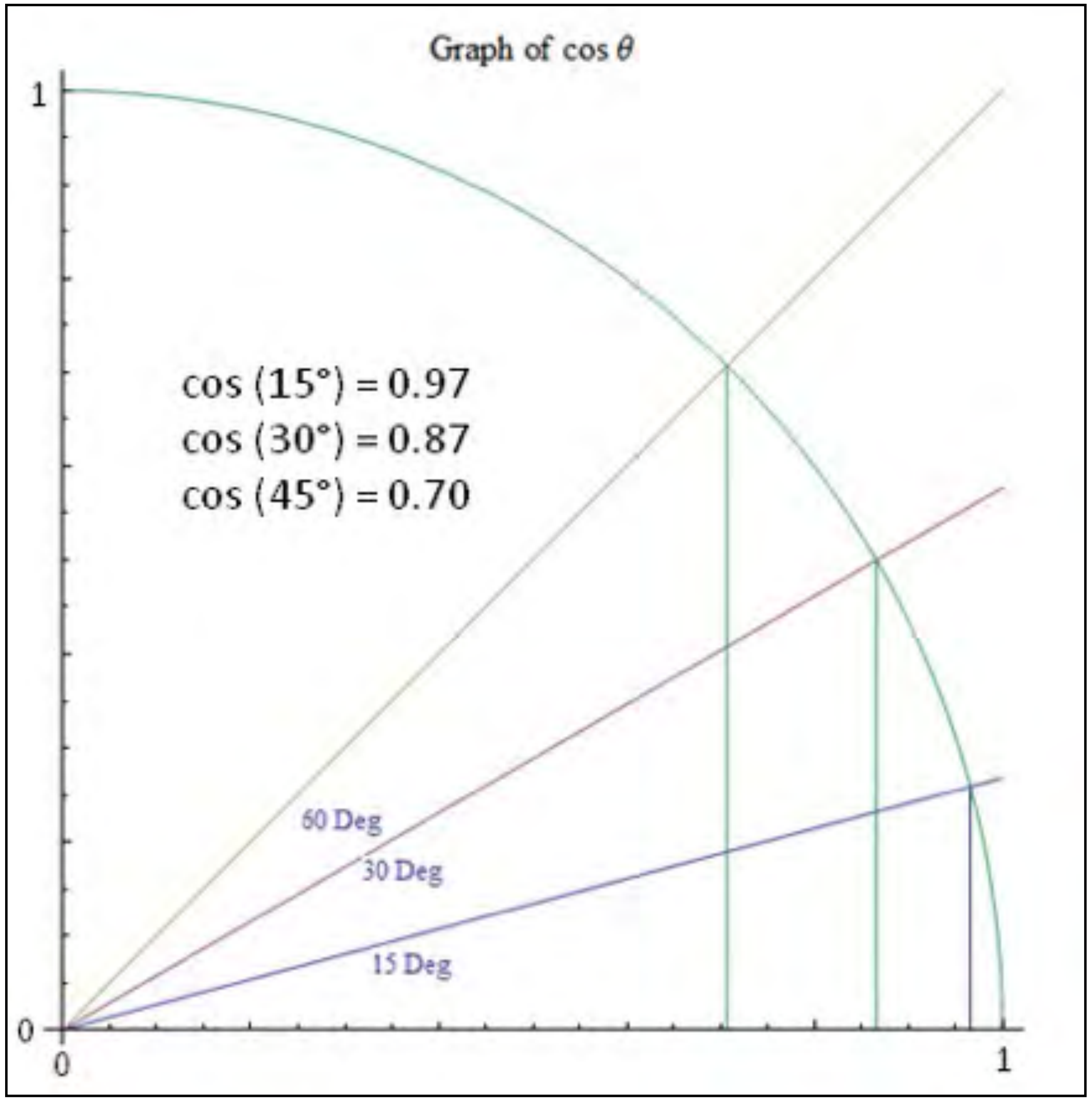
Accurate assessment of SV requires that the pulse wave is placed at the same location where the LVOT diameter is measured. The angle of insonation can greatly affect the velocity of blood flow, which can alter the measured stroke volume (Image 13.4 and Figure 13.8). If the angle of insonation is < 15° from the direction of flow, the measured velocity is > 97% of the true velocity.

IMAGE 13.4



The clinician can use respiratory variation in SV to assess a patient's likelihood to respond to fluid (Images 13.5 and 13.6, Figure 13.9). As the LVOT diameter does not vary with respiration, stroke volume variation is essentially the variation in VTI. As stated above, the angle of insonation will affect the measurement of velocity. However, even if the clinician insonates with an angle >15° from the true direction of flow, it will scale down the measurement equally. Hence, a measurement of velocity that is off by 45° will be consistently de-

FIGURE 13.8 - Diagram of the Angle of Insonation, $\cos\theta$



creased by 30% throughout the entire respiratory cycle. The stroke volume will not be accurate, but the SV variation will remain accurate.

Measuring stroke volume in real-time requires calculation of the velocity-time integral, which requires a software package capable of performing these calculations. In some instances, longitudinal movement of the heart may result in difficulty with appropriate placement

IMAGE 13.5 - LVOT VTI With Respiratory Variation

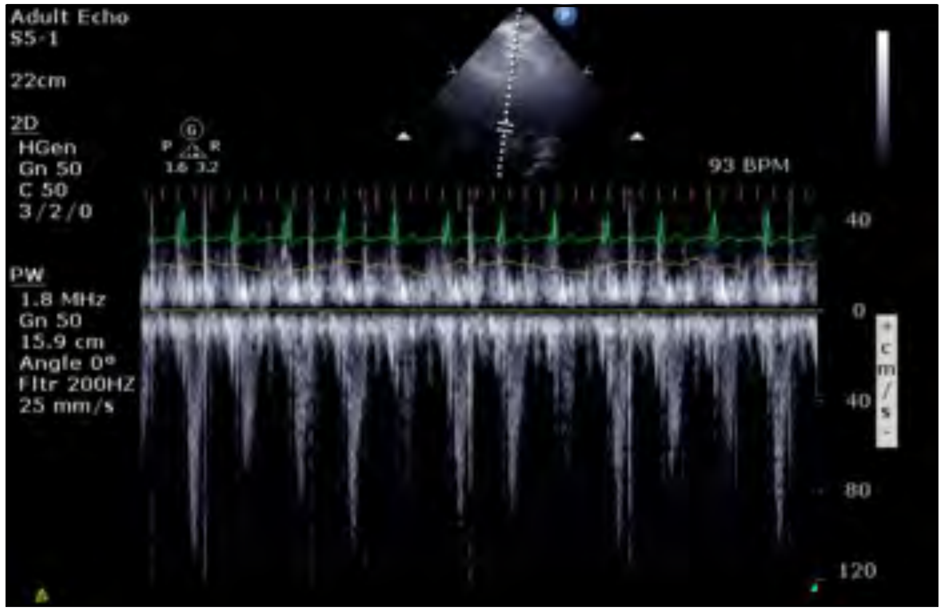


IMAGE 13.6 - LVOT Without Respiratory Variation

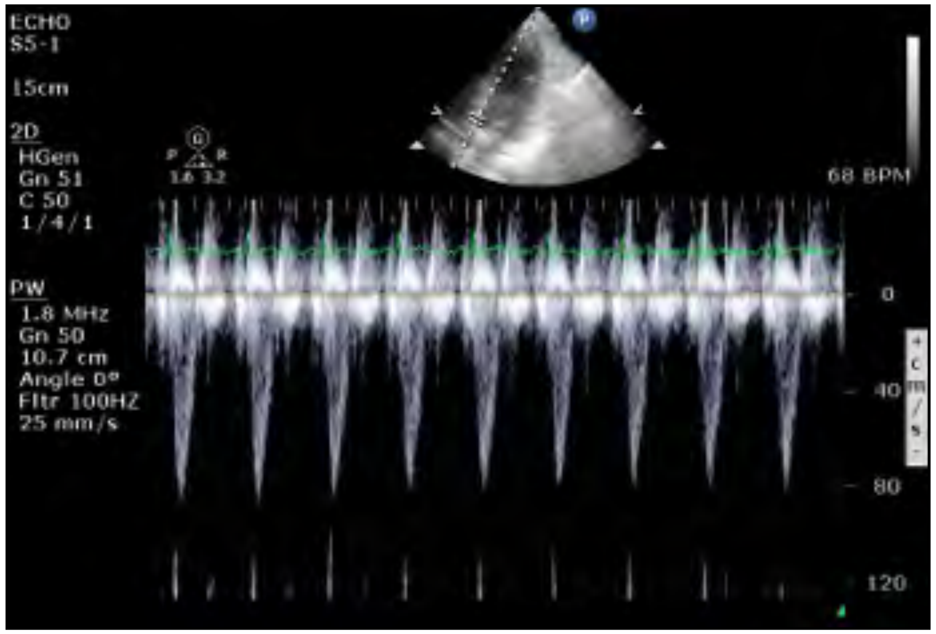
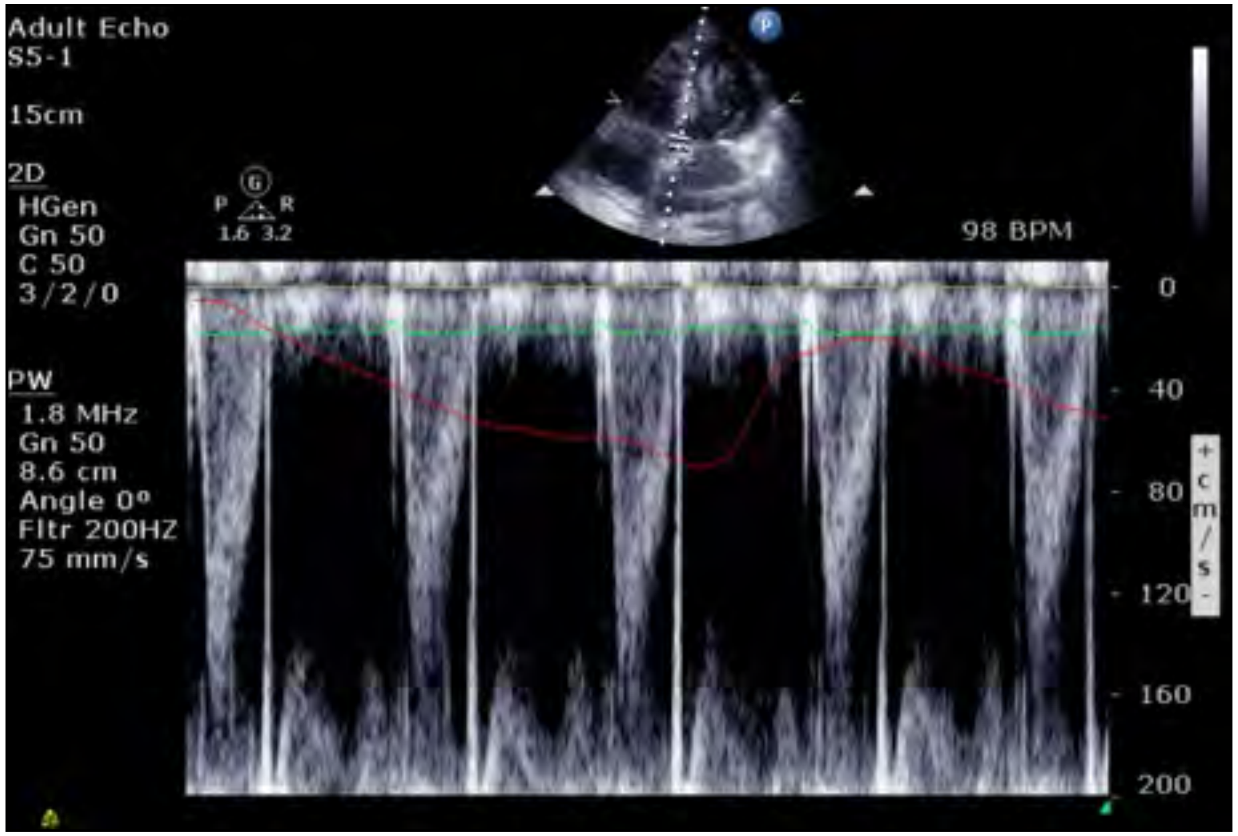


FIGURE 13.9

$$\text{Stroke volume variability} = \frac{\text{VTImax} - \text{VTImin}}{(\text{VTImax} + \text{VTImin})/2}$$

of the sample volume of the pulse wave Doppler. Pulse wave Doppler is also subject to aliasing, which may make measurement of the velocity-time integral difficult or impossible (Image 13.7).

IMAGE 13.7 - Aliased LVOT VTI, With Merging of the Peak With the Aliased Peak.



Perhaps a more useful surrogate measurement is the variation of maximum aortic blood velocity, using continuous wave Doppler. In most patients without significant aortic stenosis, the peak aortic blood

IMAGE 13.8

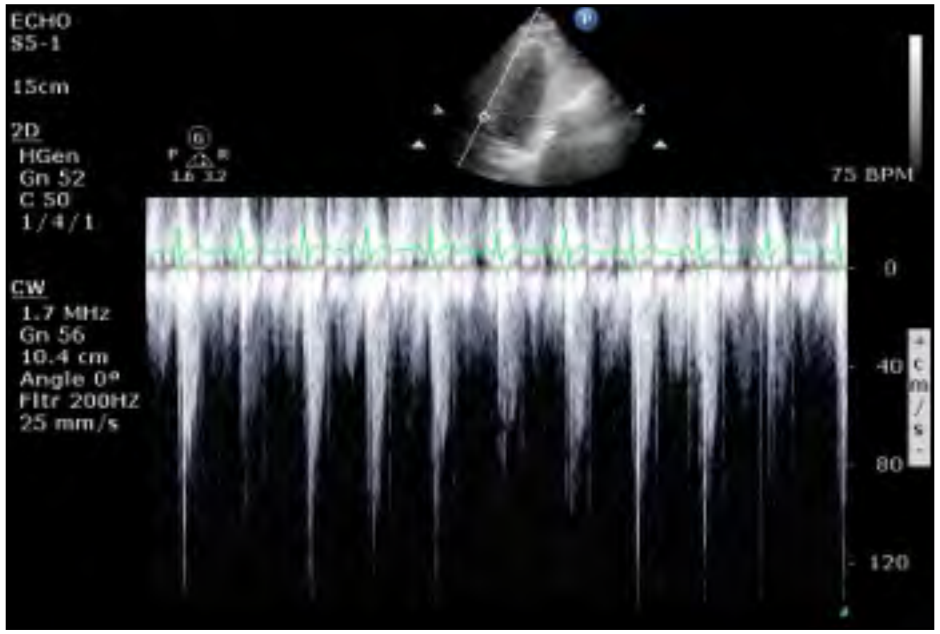


IMAGE 13.9

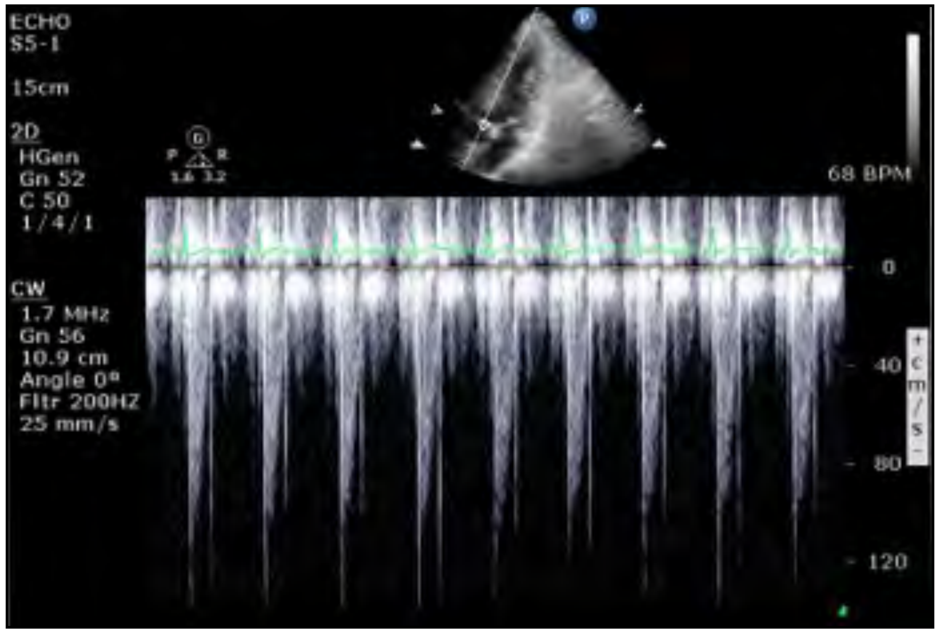


FIGURE 13.10

$$\text{Aortic velocity variability} = \frac{\text{AoVmax} - \text{AoVmin}}{(\text{AoVmax} + \text{AoVmin})/2}$$

velocity will be proportional to the stroke volume (Images 13.8 and 13.9, Figure 13.10). Measurement of aortic blood velocity avoids the problems of aliasing and longitudinal movement of the heart. Another advantage is that a clinician may easily estimate peak velocity variation at bedside without use of a software package.

Ultrasound assessment of stroke volume variation, or its surrogate measurement of aortic velocity variation, appears to be informative of fluid responsiveness for select populations. In passively ventilated patients with septic shock, an aortic blood velocity variation threshold > 12% obtained by transthoracic echocardiography indicated a strong likelihood for fluid responsiveness.[20] A similar study was performed by Monnet and colleagues, using transesophageal assessment of aortic velocity variation. In that study, passively ventilated ICU patients were likely to respond to fluid if their aortic velocity variation was > 18%.[21]

The use of aortic velocity variation or echocardiographic stroke volume variation is not generalizable to all patients. These indices are not useful in a patient with an irregular ventricular rhythm, such as atrial fibrillation or frequent premature ventricular contractions. In such patients, SV will vary depending on diastolic filling time, and will not be informative of fluid responsiveness. For clinicians measuring Doppler velocities with transthoracic echocardiography, care must be taken to ensure that the angle of the probe remains the same throughout the respiratory cycle, as alteration in the angle of insonation may alter the measured velocity. In the same vein, a patient with significant cardiac translation (e.g., a patient with electrical alternans in the setting of a large pericardial effusion) may appear to have large variations in aortic blood velocity, when in reality the only thing that varies is the angle of insonation. Perhaps the most important limitation to the generalizability of ultrasonic assessment of stroke volume variation or aortic velocity variation is that the studies in this area are *limited to passively breathing, mechanically ventilated patients*. Thus, in a patient who is breathing spontaneously, these indices have not been validated. One study, by Skulec and colleagues, has looked at these indices in spontaneously breathing healthy volunteers who were synchronizing their breathing to a metronome to decrease breath-to-breath variability. In these patients, a stroke volume variation of > 17% or an aortic velocity variation >14% predicted fluid response.[22]

Ventricular Size

SUMMARY

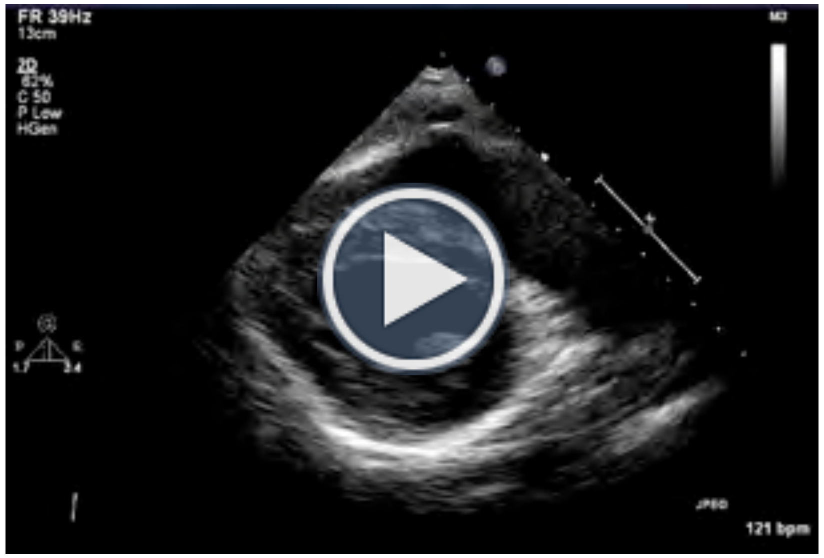
Hyperdynamic hypovolemia is usually associated with preload sensitivity

The literature surrounding the usefulness of visual estimation of the LV for fluid responsiveness is conflicting

Ultrasound can easily obtain images of the heart, whether by transthoracic or transesophageal echocardiography. A clinician can identify hyperdynamic hypovolemia on echocardiography, a finding that is usually associated with preload sensitivity (Movies 13.9 and 13.10). While it may at first seem that a visual estimate of the LV would be the best method of assessing fluid responsiveness, the literature surrounding this are conflicting. Reuter and colleagues demonstrated that left ventricular end-diastolic area was able to predict fluid responsiveness.[23] Contrarily, multiple studies have demonstrated that echocardiographic measurement of the left ventricular area or volume at end-diastole is not useful to predict fluid response.[20,24-26]

MOVIE 13.9 - Normal vs. Hyperdynamic Hypovolemia in PSAX

MOVIE 13.10



Section 9

Passive Leg Raise

Summary

CO and Aortic Velocity with passive leg raise is the only maneuver shown to be accurate in predicting fluid responsiveness in spontaneously breathing patients

Passive leg raise is effectively a reversible fluid bolus

Increase in stroke volume >12.5% correlates with fluid responsiveness

The passive leg raise is a maneuver performed at bedside, which will result in immediate distribution of approximately 300 mL of whole blood into the central venous system. The advantage of this maneuver is that it is effectively a reversible fluid challenge. It is done by assessing cardiac output or SV with the head of the bed elevated to 45°. The head of the bed is immediately lowered to 0° and the legs are elevated 45° for 2 minutes (Figures 13.11 and 13.12).

Figure 13.11

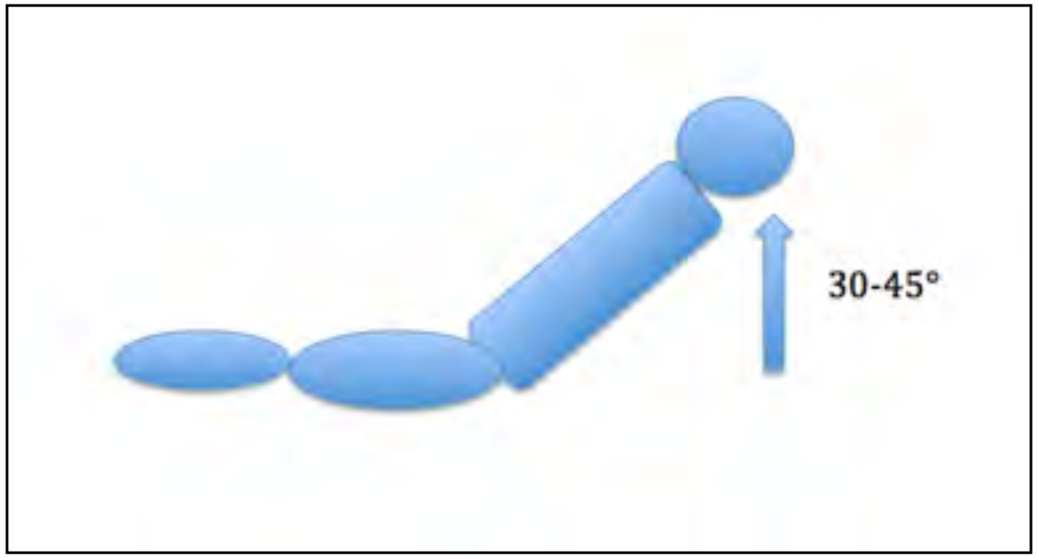
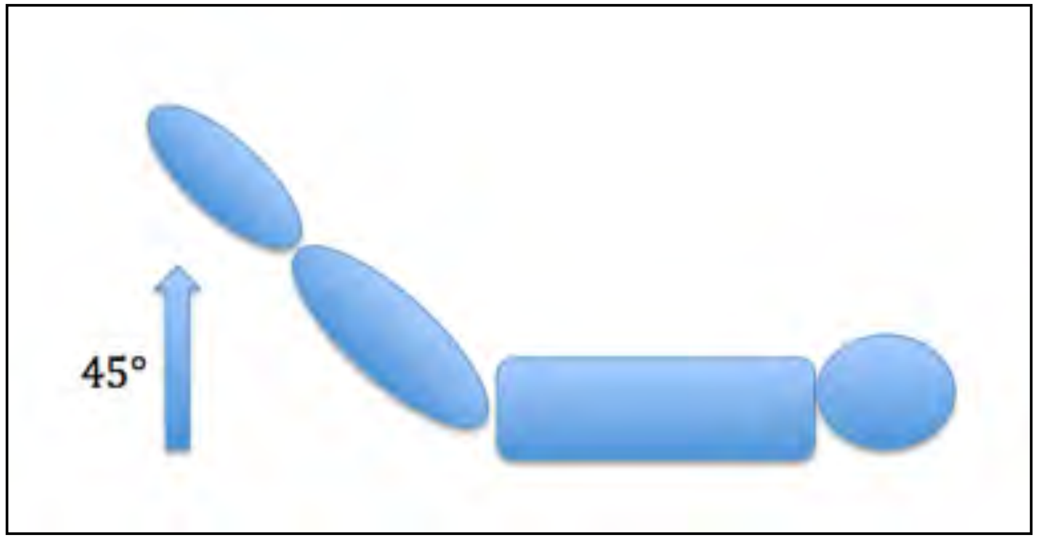


Figure 13.12



The cardiac output or stroke volume is measured again. A patient who has a significant increase in either of these measurements is likely to respond to a fluid challenge. A key advantage of the passive leg raise is its applicability in the spontaneously breathing patient. Lamia and colleagues used the passive leg raise in spontaneously breathing critically ill patients and demonstrated that an increase in stroke volume > 12.5% correlated with fluid responsiveness.[27] Historically, the passive leg raise has been applied successfully in a variety of clinical scenarios, although the application of echocardiography with the passive leg raise is rather recent. One difficulty with transthoracic echocardiographic assessment of stroke volume or cardiac output in the passive leg raise is the possibility to alter the angle of insonation during the maneuver. If the heart experiences translational movement during the maneuver, the measured change in SV could be erroneous. Similarly, if the clinician does not ensure that the probe angulation and location are exactly the same before and after the maneuver, the measurements could be erroneous. The passive leg raise also may not be useful in patients with abdominal compartment syndrome or pregnancy.

One Minute Ultrasound Passive Leg Raise Demo

SECTION 10

Recommendations

SUMMARY

Ultrasound is a useful tool for the clinician faced with the dilemma of whether or not he or she should administer a fluid challenge. In patients who are receiving passive ventilation from mechanical ventilation, the degree of stroke volume variation and the degree of IVC collapse correlate with likelihood to respond to fluid. In spontaneously breathing patients, an increase in SV following a passive leg raise is a good method to predict fluid response. Ultrasound may also be useful in detecting elevated left atrial pressure and pulmonary edema, a frequent complication of fluid administration.

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Section 11

REFERENCES

1 Wiedemann HP, Wheeler AP, Bernard GR, et al. Comparison of two fluid-management strategies in acute lung injury. *N Engl J Med* 2006; 354:2564-2575.

2 Durairaj L, Schmidt GA. Fluid therapy in resuscitated sepsis: less is more. Chest 2008; 133:252-263.

3 Maitland K, Kiguli S, Opoka RO, et al. Mortality after fluid bolus in African children with severe infection. *N Engl J Med* 2011; 364:2483-2495.

4 Starling EH, Visscher MB. The regulation of the energy output of the heart. J Physiol 1927; 62:243-261

5 Editorial: Starling's law survives. *Lancet* 1974; 2:818.

6 Osman D, Ridel C, Ray P, et al. Cardiac filling pressures are not appropriate to predict hemodynamic response to volume challenge. *Crit Care Med* 2007; 35:64-68.

7 Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness? A systematic review of the literature and the tale of seven mares. *Chest* 2008; 134:172-178.

8 Shippy CR, Appel PL, Shoemaker WC. Reliability of clinical monitoring to assess blood volume in critically ill patients. *Crit Care Med* 1984; 12:107-112.

9 Marik PE, Monnet X, Teboul JL. Hemodynamic parameters to guide fluid therapy. *Ann Intensive* Care 2011; 1:1.

10 Grinnan DC, Truwit JD. Clinical review: respiratory mechanics in spontaneous and assisted ventilation. *Crit Care* 2005; 9:472-484.

11 Putensen C, Muders T, Varelmann D, et al. The impact of spontaneous breathing during mechanical ventilation. *Curr Opin Crit Care* 2006; 12:13-18.

12 Brennan JM, Blair JE, Goonewardena S, et al. Reappraisal of the use of inferior vena cava for estimating right atrial pressure. *J Am Soc Echocardiogr* 2007; 20:857-861.

13 Jue J, Chung W, Schiller NB. Does inferior vena cava size predict right atrial pressures in patients receiving mechanical ventilation? *J Am Soc Echocardiogr* 1992; 5:613-619.

14 Barbier C, Loubieres Y, Schmit C, et al. Respiratory changes in inferior vena cava diameter are helpful in predicting fluid responsiveness in ventilated septic patients. *Intensive Care Med* 2004; 30:1740-1746.

15 Feissel M, Michard F, Faller JP, et al. The respiratory variation in inferior vena cava diameter as a guide to fluid therapy. *Intensive Care Med* 2004; 30:1834-1837.

16 Joshua AM, Celermajer DS, Stockler MR. Beauty is in the eye of the examiner: reaching agreement about physical signs and their value. *Intern Med J* 2005; 35:178-187.

17 Nagueh SF, Appleton CP, Gillebert TC, et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *Eur J Echocardiogr* 2009; 10:165-193.

18 Nagueh SF, Middleton KJ, Kopelen HA, et al. Doppler tissue imaging: a noninvasive technique for evaluation of left ventricular relaxation and estimation of filling pressures. *J Am Coll Cardiol* 1997; 30:1527-1533.

19 Agricola E, Bove T, Oppizzi M, et al. "Ultrasound comet-tail images": a marker of pulmonary edema: a comparative study with wedge pressure and extravascular lung water. *Chest* 2005; 127:1690-1695.

20 Feissel M, Michard F, Mangin I, et al. Respiratory changes in aortic blood velocity as an indicator of fluid responsiveness in ventilated patients with septic shock. *Chest* 2001; 119:867-873.

21 Monnet X, Rienzo M, Osman D, et al. Esophageal Doppler monitoring predicts fluid responsiveness in critically ill ventilated patients. *Intensive Care Med* 2005; 31:1195-1201.

22 Skulec R, Cermak O, Skalicka H, et al. Variability of aortic blood flow predicts fluid responsiveness in spontaneously breathing healthy volunteers. *Kardiol Pol* 2009 Mar;67(3):265-71.

23 Reuter DA, Kirchner A, Felbinger TW, et al. Usefulness of left ventricular stroke volume variation to assess fluid responsiveness in patients with reduced cardiac function. *Crit Care Med* 2003 May;31(5):1399-404.

24 Greim CA, Roewer N, Apfel C, et al. Relation of echocardiographic preload indices to stroke volume in critically ill patients with normal and low cardiac index. *Intensive Care Med* 1997; 23:411-416.

25 van Daele ME, Trouwborst A, van Woerkens LC, et al. Transesophageal echocardiographic monitoring of preoperative acute hypervolemic hemodilution. *Anesthesiology* 1994; 81:602-609.

26 Tousignant CP, Walsh F, Mazer CD. The use of transesophageal echocardiography for preload assessment in critically ill patients. *Anesth Analg* 2000; 90:351-355.

27 Lamia B, Ochagavia A, Monnet X, et al. Echocardiographic prediction of volume responsiveness in critically ill patients with spontaneously breathing activity. *Intensive Care Med* 2007; 33:1125-1132.

Chapter 14

R. Heart Failure

Coming Soon...

CHAPTER 15

Transesophageal Echocardiography

Coming Soon...

CHAPTER 16

Central Lines

Coming Soon...

Chapter 17

Procedures

Coming Soon...

Chapter 18

Brachial Plexus Nerve Blocks

Section 1

Introduction

Summary

Ultrasound-guided nerve blocks offer an opportunity for superb pain relief and facilitation of painful procedures with less sedation

A small amount of analgesia or sedation may be helpful

Reposition needle if high injection pressures or paresthesias are experienced

Proper positioning is important

Document pre- and post-block neurovascular exam

Appropriate post-block instructions are important for the patient and other providers taking care of the patient

Choosing the correct block is critical

Overview

Upper extremity nerve blocks, also known as brachial plexus nerve blocks, offer the emergency provider an opportunity to achieve superb pain relief and to facilitate the performance of common emergent procedures without the need for procedural sedation and its attendant risks and resource demands. This chapter is an introduction to ultrasound-guided nerve blocks for the upper extremity,[1] and is intended to introduce providers to basic concepts, rather than serve as a comprehensive resource.

General principles and safety concerns

Emergency providers should be familiar with the use of local anesthetic agents and aware of the cardio- and neuro-toxic properties of the particular agent they choose. Patients should be placed on a cardiac monitor and intravenous access obtained. After examination and consent to the procedure, it is often advantageous to administer an anxiolytic and opioid analgesic or low-dose ketamine. Clinically significant peripheral nerve injury (PNI) is a rare event,[2,3] but care must be taken to inject anesthetic just outside of the epineurium and to attempt to avoid intraneural injection. If the patient reports painful paresthesias, high injection pressures or other worrisome symptoms, the injection should be stopped and the needle repositioned. In addition, post-block neurologic examination and proper instructions for patients regarding care of the blocked limb are essential, as is communication with any consulting services who may care for the patient. Although ultrasound -guidance in conjunction with appropriate agents and dosing should be sufficient to prevent local anesthetic systemic toxicity (LAST),[4] lipid emulsion products and standard ACLS equipment should be readily available in the case of an unanticipated event.[5,6,7]

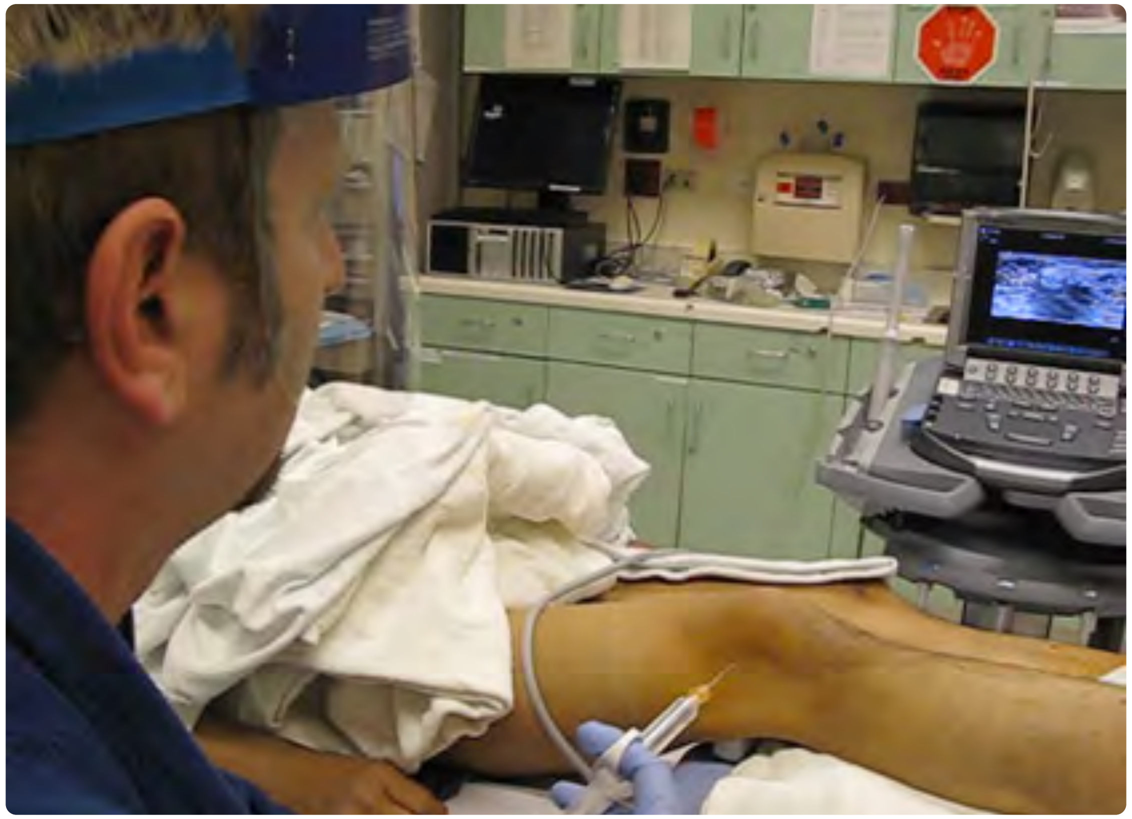
Set-up and equipment

The ultrasound system should be positioned on the opposite side of the patient from the provider, with the screen in good position to allow optimal movement of the provider's visual axis between patient and display. Standard long-beveled facet needles can be used, although short-beveled blunt needles may be preferable, if available, as there is some limited evidence that they are less likely to produce PNI.[8,9] The provider may choose to perform the procedure as a single operator, with needle directly attached to syringe (hand-on-syringe technique). Alternatively, the procedure may be performed with an assistant, with needle attached to extension tubing and syringe, and the assistant responsible for aspirating and injecting from the syringe (hand-on-needle technique). For single-shot injections, as opposed to catheter placements for anesthetic infusions, the use of sterile gloves, sterile preparation of the skin with chlorhexidine, and preparation of the transducer with an adherent sterile dressing and sterile lubricant is considered sufficient antiseptic technique. (Gallery 18.1)

Block Aftercare and Interdisciplinary Concerns

Thorough documentation of pre- and post-block neurovascular exams is essential. Block type, anesthetic used, and time of block should be noted in the patient's chart, and the anatomic area should be marked on the patient with a surgical marking pen. Patients

Gallery 18.1



Allow optimal movement of the provider's visual axis between patient and display.

should have the affected limb immobilized and be instructed on care of the extremity, including appropriate weight-bearing limitations and follow-up precautions.

Choosing a block

Blocks of the brachial plexus can be performed at multiple different locations, and choosing the right location for a given patient's clinical condition is critical to ensure success. In general, the interscalene block is ideal for shoulder and upper arm conditions, the supra- or infra-clavicular block for distal arm, elbow, forearm or wrist injuries, and the axillary block for wrist and hand injuries. Targeted blocks of the median, ulnar and radial nerves in the mid-forearm provide excellent anesthesia for hand injuries and procedures, but are not effective for conditions proximal to the hand and will not be covered in this chapter.

Section 2

The Interscalene Block

Summary

ED applications:

Relief of painful procedures of the shoulder and proximal arm including:
shoulder dislocation
drainage of deltoid abscess
pain relief for proximal and mid-humeral fractures

Use color Doppler to identify vessels
Attempt to achieve circumferential spread through the interscalene groove
Use 10-15mL of anesthetic

Indications

Pain relief and facilitation of painful procedures in the shoulder and proximal upper arm. Typical ED applications include: reduction of glenohumeral dislocation, drainage of deltoid abscess, pain relief for proximal and mid-humeral fractures.

Complications

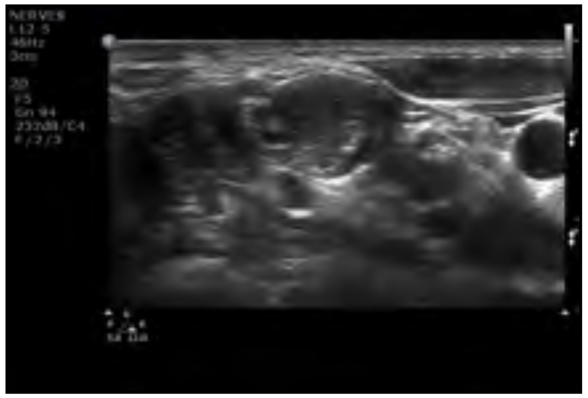
Though low-dose ultrasound-guided blocks may have different characteristics,[10] temporary phrenic nerve paralysis is an anticipated complication of nerve-stimulator techniques for interscalene block, and providers should avoid this approach in patients with respiratory compromise. Recurrent laryngeal nerve blockade and Horner's syndrome can also occur with this approach.

Scanning Technique

The brachial plexus is identified in the interscalene groove (between the anterior and middle scalene muscles). (Images 18.1 and 18.2 and Movie 18.1)

Image 18.1

Image 18.2

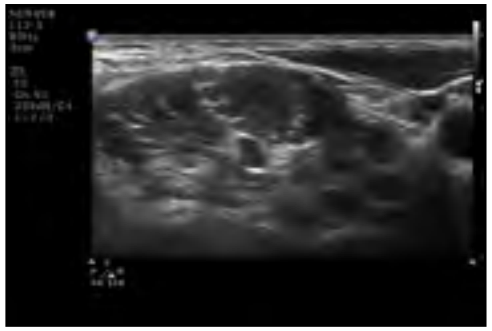


MOVIE 18.1

This is best accomplished with a high frequency linear transducer, oriented in a transverse plane. (Image 18.3) The appropriate site for injection can be located using the following technique: The great vessels (carotid artery and internal jugular vein) are identified at the level of the larynx, and the transducer is moved laterally until the lateral border of the sternocleidomastoid is identified. The anterior and middle scalene muscles are located deep to the lateral edge of the sternocleidomastoid, and the roots of the brachial plexus are located between these muscles in the interscalene groove. Typically the 5th through 7th cervical roots (C5-C7) are easily seen, oriented in a vertical fashion, giving rise to the "traffic light" sign. (Image 18.4) The 8th cervical root (C8) is seen less frequently and should not be confused for the vertebral artery that can sometimes be visualized deep to C7. Care should be taken to use color Doppler to identify any vessels coursing through the target area, as inadvertent intra-arterial injection in the cervical vessels is particularly worrisome for inducing local anesthetic systemic toxicity.

IMAGE 18.3

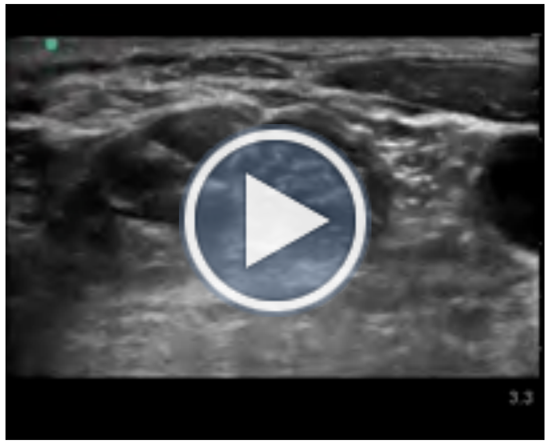
IMAGE 18.4



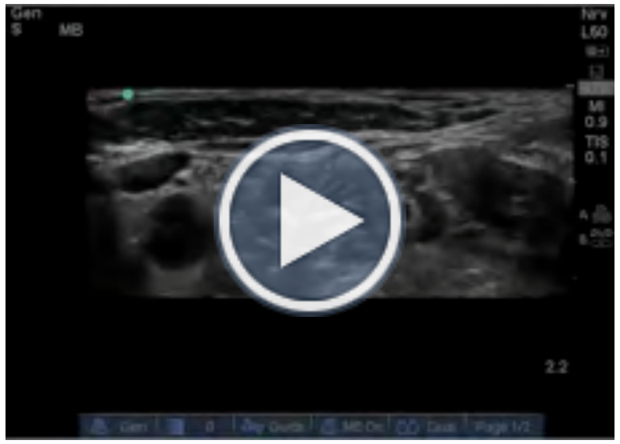
INJECTION TECHNIQUE

The interscalene block can be performed using an in-plane or out-of-plane technique. The goal is to achieve circumferential spread of local anesthetic through the interscalene groove. (Movies 18.2 and 18.3) There is tremendous debate about the minimum effective volume (MEV) to achieve a complete interscalene block.[11,12] In the emergency department (ED), a total volume of 10-15 mL of anesthetic solu-

MOVIE 18.2



MOVIE 18.3



tion is almost always sufficient to achieve an adequate level of analgesia for facilitation of painful procedures and/or significant relief of pain.

Block Effects

The motor and sensory block associated with the interscalene technique typically affects the shoulder and proximal upper arm more dramatically than the elbow, forearm, wrist or hand. The C8 & T1 dermatomes are often spared, and this block is therefore not ideal for upper arm procedures distal to the upper arm.

Section 3

The Supraclavicular Block

Summary

ED applications:
Reduction of distal humerus fractures
Elbow dislocations
Repair of complex lacerations
I&D of large abscesses or debridement of burns

Use color doppler to identify vessels
Use in-plane approach to avoid pleural puncture
10-15mL of anesthetic is usually sufficient

Indications

The supraclavicular block has been nicknamed "the spinal of the arm" due to the dense degree of anesthesia obtained from the mid-upper arm through the elbow, forearm, wrist and hand. Typical ED applications include: reduction of distal humerus fractures and elbow dislocations, repair of complex lacerations, incision and drainage of large abscesses or debridement of burns.

Complications

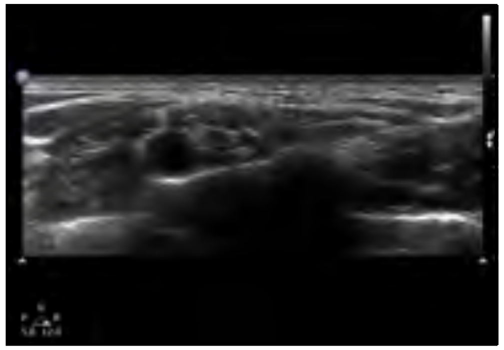
Temporary phrenic nerve paralysis can occur, though less frequently than with the interscalene approach, and providers should generally avoid this block in patients with respiratory compromise.

Scanning Technique

The brachial plexus is identified just lateral to the subclavian artery in the supraclavicular fossa. This is best accomplished with a high frequency linear transducer, oriented in an oblique coronal plane just cephalad to the clavicle. (Image 18.5) The trunks of the brachial plexus are located just lateral and superficial to the subclavian artery, resting on the first rib and superficial to the apex of the lung.

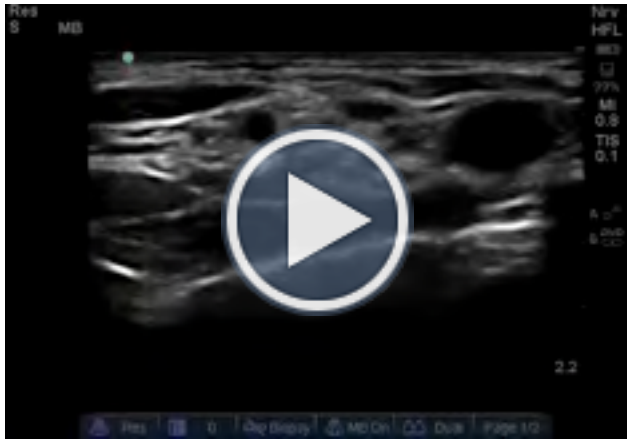
Image 18.5

Image 18.6

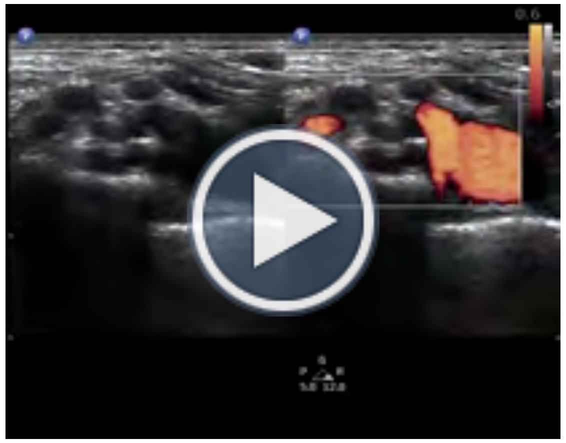


(Image 18.6 and Movie 18.4) Color Doppler is useful to ensure identification of the transverse cervical artery and other arterial structures in the field of view. (Movie 18.5)

MOVIE 18.4



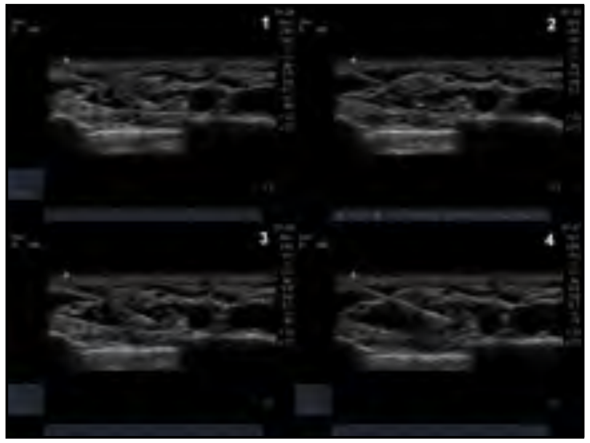
MOVIE 18.5



INJECTION TECHNIQUE

The supraclavicular block is best performed using an in-plane technique to ensure visualization of the entire needle and to avoid puncture of the pleura. The needle is inserted from the lateral aspect of the transducer and the initial injection is ideally performed just deep to the plexus where it rests on the first rib, (an added level of protection from pleural violation).[13] (Image 18.7 and Image 18.8 and Movie 18.6)

IMAGE 18.7



MOVIE 18.6

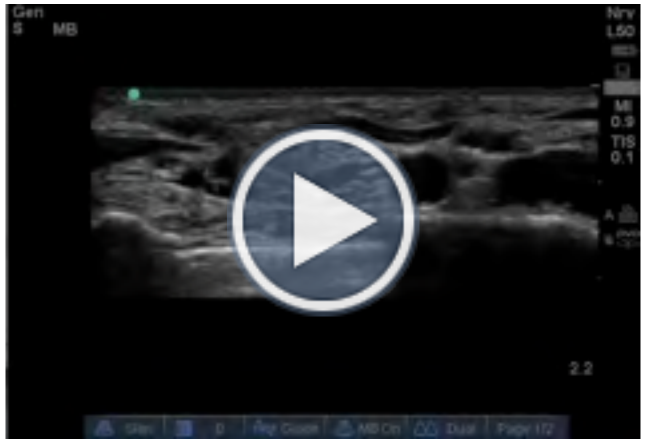


IMAGE 18.8

The goal is to achieve circumferential spread, and while volumes of approximately 30 mL may be necessary for a complete block,[14] a total volume of 10-15 mL of anesthetic solution is almost always sufficient to achieve an adequate level of analgesia for facilitation of painful procedures and/or significant relief of pain.

BLOCK EFFECTS

The motor and sensory block associated with the supraclavicular technique typically affects the mid-upper arm, elbow, forearm, wrist and hand. The shoulder is often, but not invariably, affected as well, and should the provider wish to avoid an interscalene block, the supraclavicular block can represent a potential alternative in these cases.

Section 4

The Infraclavicular Block

Summary

ED applications:
Reduction of distal humerus fractures
Elbow dislocations
Repair of complex lacerations
I&D of large abscesses
Debridement of burns

15-20mL of anesthetic is usually sufficient

Indications

The infraclavicular block results in dense anesthesia from the mid-upper arm through the elbow, forearm, wrist and hand. Typical ED applications include: reduction of distal humerus fractures and elbow dislocations, repair of complex lacerations, incision and drainage of large abscesses or debridement of burns. The lack of phrenic nerve involvement and the ability to perform this block using in-plane or out-of-plane approaches make it an attractive alternative to the supraclavicular block.

Scanning Technique

A high frequency linear transducer is placed in the deltopectoral groove, just caudal to the clavicle in a sagittal plane. [FIG13] The lateral, posterior and medial cords of the brachial plexus are identified surrounding the axillary artery, deep to the pectoral major and minor muscles. [VID7]

Injection Technique

The infraclavicular block can be performed using an in-plane or out-of-plane technique. Needle visualization can be challenging given the greater target depth as compared to other approaches to the brachial plexus. The goal is to achieve a U-shaped distribution of anesthetic solution around the axillary artery with a single posterior injection.[15,16] [FIG14, VID8] While volumes of approximately 35 mL may be necessary for a complete block,[17] 15-20 mL of anesthetic solution is almost always sufficient to achieve an adequate level of analgesia for facilitation of painful procedures and/or significant relief of pain.

Block Effects

The motor and sensory block associated with the infraclavicular technique typically affects the mid-upper arm, elbow, forearm, wrist and hand. The proximal arm and shoulder are not affected, and this block should not be performed if anesthesia in this region is necessary.

SECTION 5

The Axillary Block

SUMMARY:

ED applications:
Reduction of distal radius fractures
Wrist fractures/dislocations
Repair of complex lacerations

The radial, ulnar, median, and musculocutaneous nerves can be identified

15-20mL of anesthetic is usually sufficient

Indications: The axillary block targets the peripheral branches of the brachial plexus and results in anesthesia to the forearm, wrist and hand. Typical ED applications include: reduction of distal radius fractures, wrist fractures/dislocations, and repair of complex lacerations. If complete forearm anesthesia is desired, the musculocutaneous nerve, which travels in a separate fascial compartment at this level, must be blocked separately from the median, ulnar and radial nerves.

Scanning Technique: A high frequency linear transducer is placed in the axilla in a sagittal plane. [FIG15] The radial, ulnar and median nerves are identified surrounding the axillary artery, [VID9] and the musculocutaneous nerve is visualized separately within the coracobrachialis muscle. [VID10]

Injection Technique: The axillary block can be performed using an in-plane or out-of-plane technique. A total volume of 15-20 mL of anesthetic solution is almost always sufficient to achieve an adequate level of analgesia.

Block Effects: The block associated with the axillary technique typically affects the forearm, wrist and hand. The proximal arm and shoulder are not affected and the elbow is variably affected, and this block should not be performed if anesthesia in these regions is desired.

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REFERENCES

1. Russon K, Pickworth T, Harrop-Griffiths W. Upper limb blocks. Anaesthesia. 2010 Apr;65(S1):48-56.

2. Fredrickson MJ, Kilfoyle DH. Neurological complication analysis of 1000 ultrasound guided peripheral nerve blocks for elective orthopaedic surgery: a prospective study. Anaesthesia. 2009;64:836–44.

3. Liu SS, Zayas VM, Gordon MA, et al. A prospective, randomized, controlled trial comparing ultrasound versus nerve stimulator guidance for interscalene block for ambulatory shoulder surgery for postoperative neurological symptoms. Anesth Analg. 2009 Jul;109(1):265-71.

4. Sites BD, Taenzer AH, Herrick MD, et al. Incidence of local anesthetic systemic toxicity and postoperative neurologic symptoms associated with 12,668 ultrasound-guided nerve blocks: an analysis from a prospective clinical registry [published online ahead of print June 14 2012]. Reg Anesth Pain Med. 2012. http://journals.lww.com/rapm/Abstract/publishahead/Incidence_of_Local_Anesthetic_Systemic_Toxicity.99729.aspx Accessed July 18, 2012.

5. Wolfe JW, Butterworth JF. Local anesthetic systemic toxicity: update on mechanisms and treatment. Curr Opin Anaesthesiol. 2011 Oct;24(5):561-6.

6. Mercado P, Weinberg GL. Local anesthetic systemic toxicity: prevention and treatment. Anesthesiol Clin. 2011 Jun;29(2):233-42.

7. Weinberg GL. Treatment of local anesthetic systemic toxicity (LAST). Reg Anesth Pain Med. 2010 Mar-Apr;35(2):188-93.

8. Macias G, Razza F, Peretti GM, et al. Nervous lesions as neurologic complications in regional anaesthesiologic block: an experimental model. Chir Organi Mov. 2000;85:265–71.

9. Selander D, Dhuner KG, Lundborg G. Peripheral nerve injury due to injection needles used for regional anesthesia. An experimental study of the acute effects of needle point trauma. Acta Anaesthesiol Scand. 1977;21:182–8.

10. Renes SH, Rettig HC, Gielen MJ, et al. Ultrasound-guided low-dose interscalene brachial plexus block reduces the incidence of hemidiaphragmatic paresis. Reg Anesth Pain Med. 2009 Sep-Oct;34(5):498-502.

11. Riazi S, Carmichael N, Awad I, et al. Effect of local anaesthetic volume (20 vs 5 ml) on the efficacy and respiratory consequences of ultrasound-guided interscalene brachial plexus block. Br J Anaesth. 2008 Oct;101(4):549-56.

12. Smith HM, Duncan CM, Hebl JR. Clinical utility of low-volume ultrasound-guided interscalene blockade: contraindications reconsidered. J Ultrasound Med. 2009. Sep;28(9):1251-8.

13. Soares LG, Brull R, Lai J, et al. Eight ball, corner pocket: the optimal needle position for ultrasound-guided supraclavicular block. Reg Anesth Pain Med. 2007 Jan-Feb;32(1):94-5.

14. Tran de QH, Dugani S, Correa JA, et al. Minimum effective volume of lidocaine for ultrasound-guided supraclavicular block. Reg Anesth Pain Med. 2011 Sep-Oct;36(5):466-9.

15. De Tran QH, Bertini P, Zaouter C, et al. A prospective, randomized comparison between single- and double-injection ultrasound-guided infraclavicular brachial plexus block. Reg Anesth Pain Med. 2010 Jan-Feb;35(1):16-21.

16. Fredrickson MJ, Wolstencroft P, Kejriwal R, et al. Single versus triple injection ultrasound-guided infraclavicular block: confirmation of the effectiveness of the single injection technique. Anesth Analg. 2010 Nov;111(5):1325-7.

17. Tran de QH, Dugani S, Dyachenko A, et al. Minimum effective volume of lidocaine for ultrasound-guided infraclavicular block. Reg Anesth Pain Med. 2011 Mar-Apr;36(2):190-4.

18.

Chapter 19

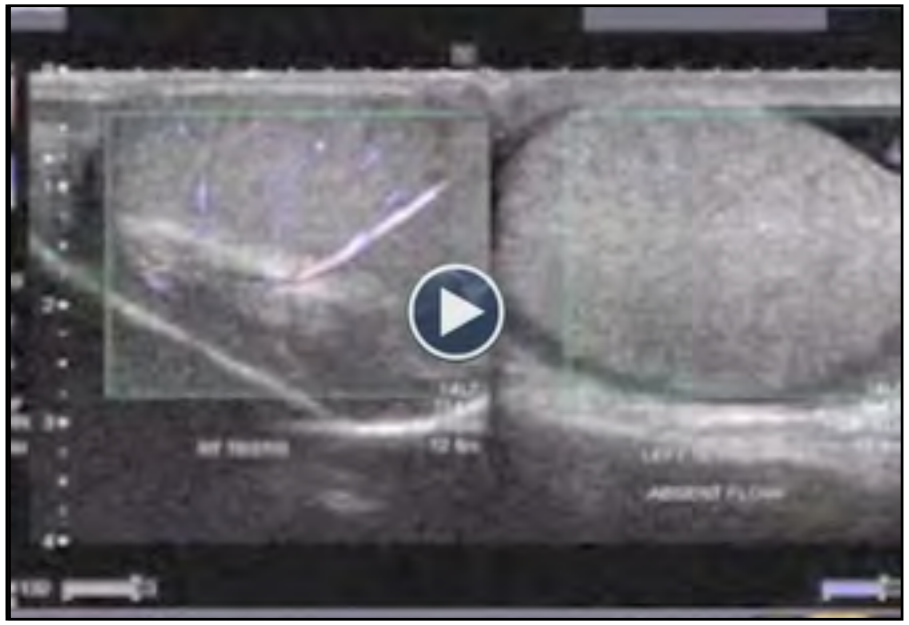
Peripheral Nerve Blocks

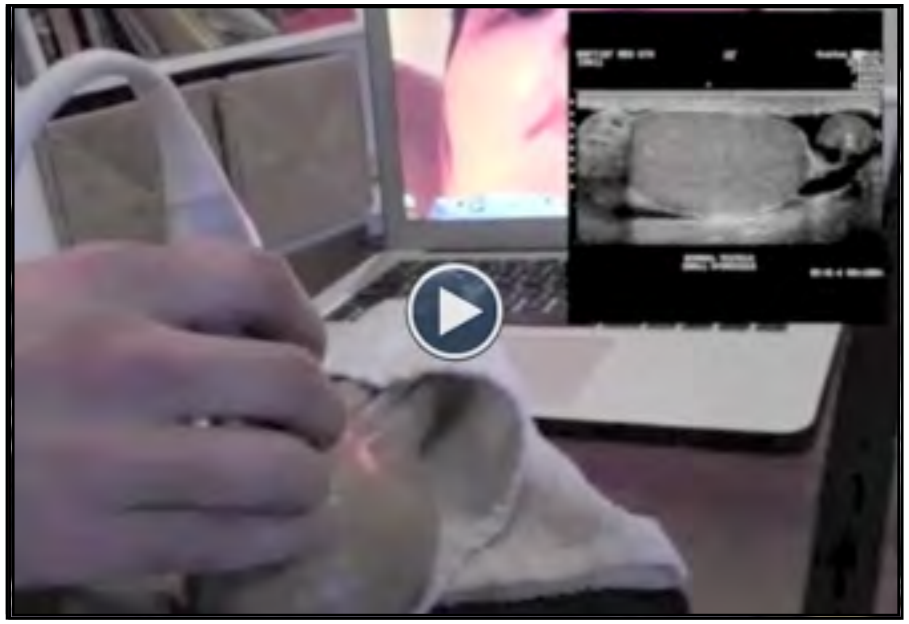
Coming Soon...

Chapter 20

Testicular

While you wait, check out the Ultrasound Podcast testicular episodes 1 and 2...





CHAPTER 21

Small Bowel Obstruction

Check out the One Minute SBO video below...

Chapter 22

Appendicitis

Why not check out the Appendicitis Ultrasound Podcast episode while you wait?

CHAPTER 23

MSK Basics

Coming Soon...

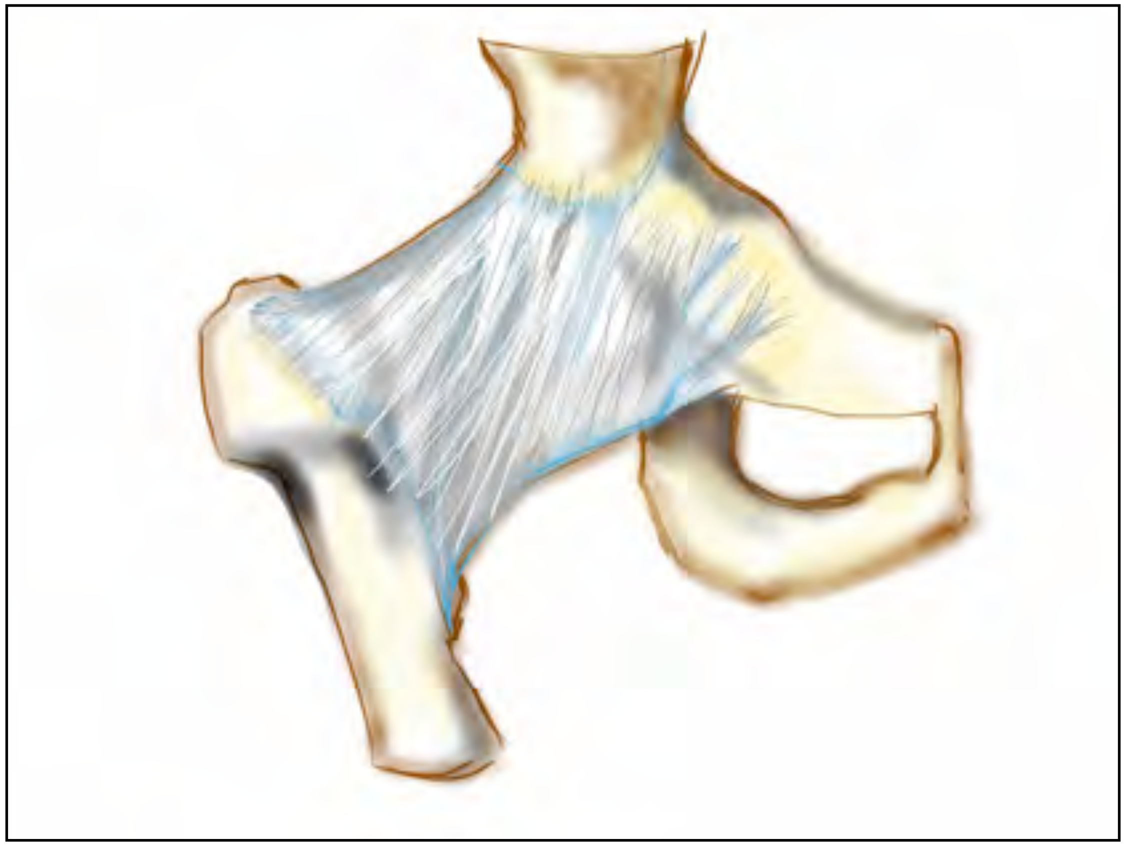
CHAPTER 24

Hip

Section 1

Intro

Image 24.1



Summary:

The articulation between the acetabulum and the head of the femur is surrounded by a complex array of musculature and neurovascular structures. (Image 24.1) Many of these structures are superficial and can be evaluated with ultrasonography. The primary structures to be evaluated are the bones, joint capsule, muscles, tendon and bursa. The unaffected hip should be examined for a normal comparison.

The examination of the hip should be focused on a specific region as directed by clinical findings. The evaluation of the anterior hip begins over the femoral head and neck. The frequency of transducer needed depends on the body habitus of the patient. A high frequency linear probe is ideal for enhanced detail of superficial structures in a non-obese patient. (Image 24.2)

IMAGE 24.2 - High frequency linear probe

SUMMARY:

The high frequency linear probe or curvilinear probe should be used depending on the size of the patient

Place the probe at a 30 degree angle to the femur to visualize the hip joint

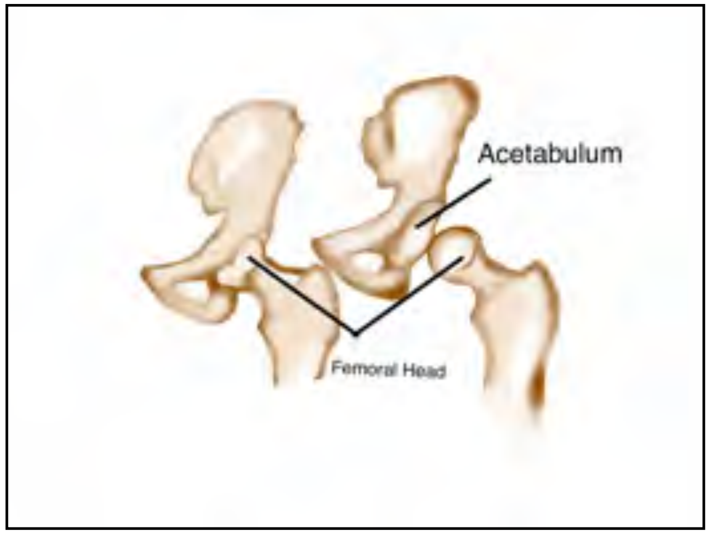
A hip effusion appears convex

On the other hand, a lower frequency, curvilinear probe may be needed in larger patients to achieve the depth needed to perform the exam. (Image 24.3)

IMAGE 24.3 - Curvilinear probe

The proximal femur and the acetabulum of the pelvis make up the hip joint. (Image 24.4).

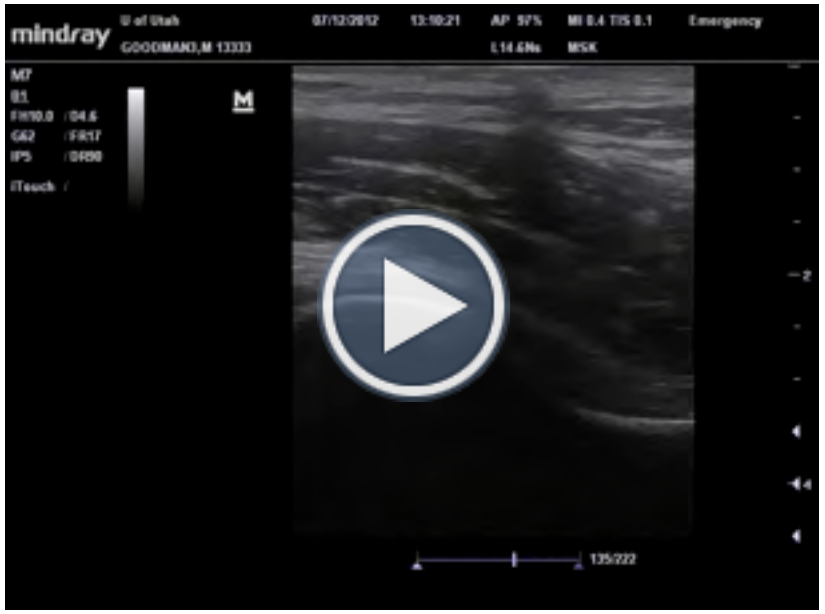
IMAGE 24.4



The femoral neck is located in an oblique sagittal plane, approximately 30° off the long axis of the femoral shaft. Visualize the hip joint in long axis, which includes the femoral head, neck, and acetabulum. (Image 24.5) Use the femoral head as a landmark to find this view. The femoral head should be smooth and uniform and in close approximation to the acetabulum. The hyperechoic, triangular shaped labrum can be visualized between the femur and the acetabulum. (Movie 24.1)

IMAGE 24.5 - 30 degree off axis of femur

MOVIE 24.1 - Normal hip joint



The anterior joint capsule extends superficially and caudally to the femoral neck and inserts distally on the intertrochanteric line. A reflection of the anterior capsule returns posterior to form the posterior joint capsule.[1] The normal hip contains only a small amount of fluid in the anterior joint recess. (Image 24.6, 24.7)

IMAGE 24.6 - Normal hip joint

IMAGE 24.7 - Normal hip joint

The physiologic fluid in the normal hip joint creates a stripe sign between the anterior and posterior reflection of the joint capsule. Presence of the stripe sign excludes pathologic effusion.[1] (Image 24.8)

IMAGE 24.8 - Normal hip with stripe sign

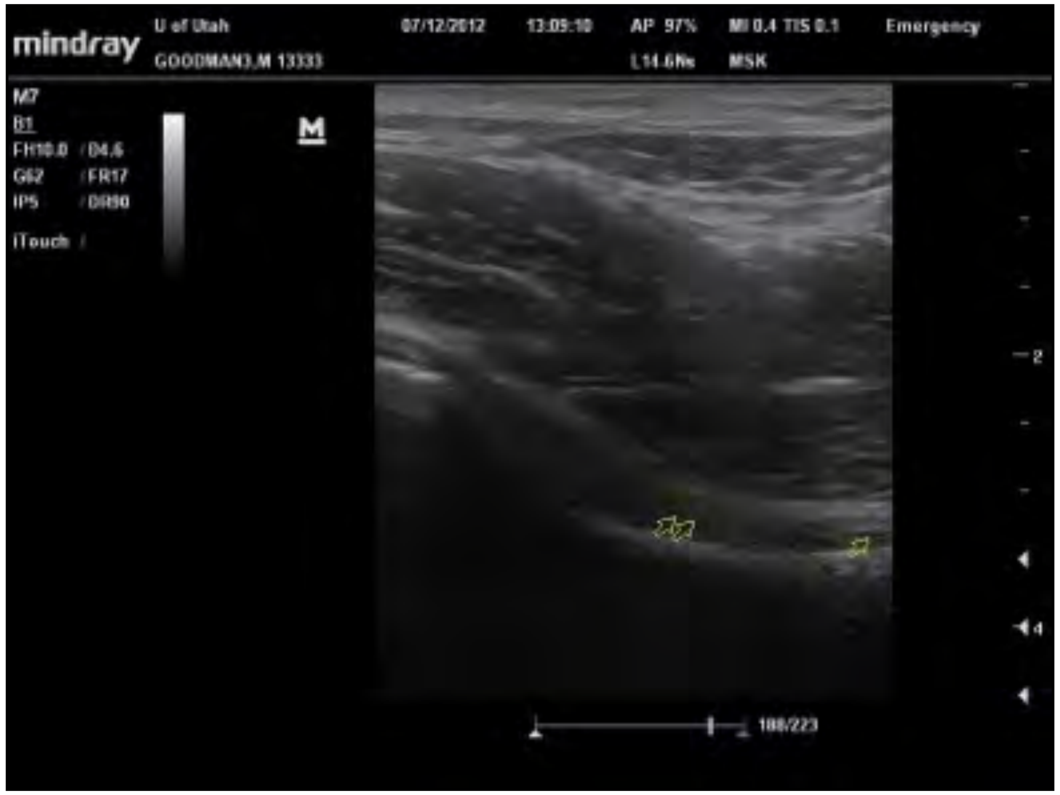
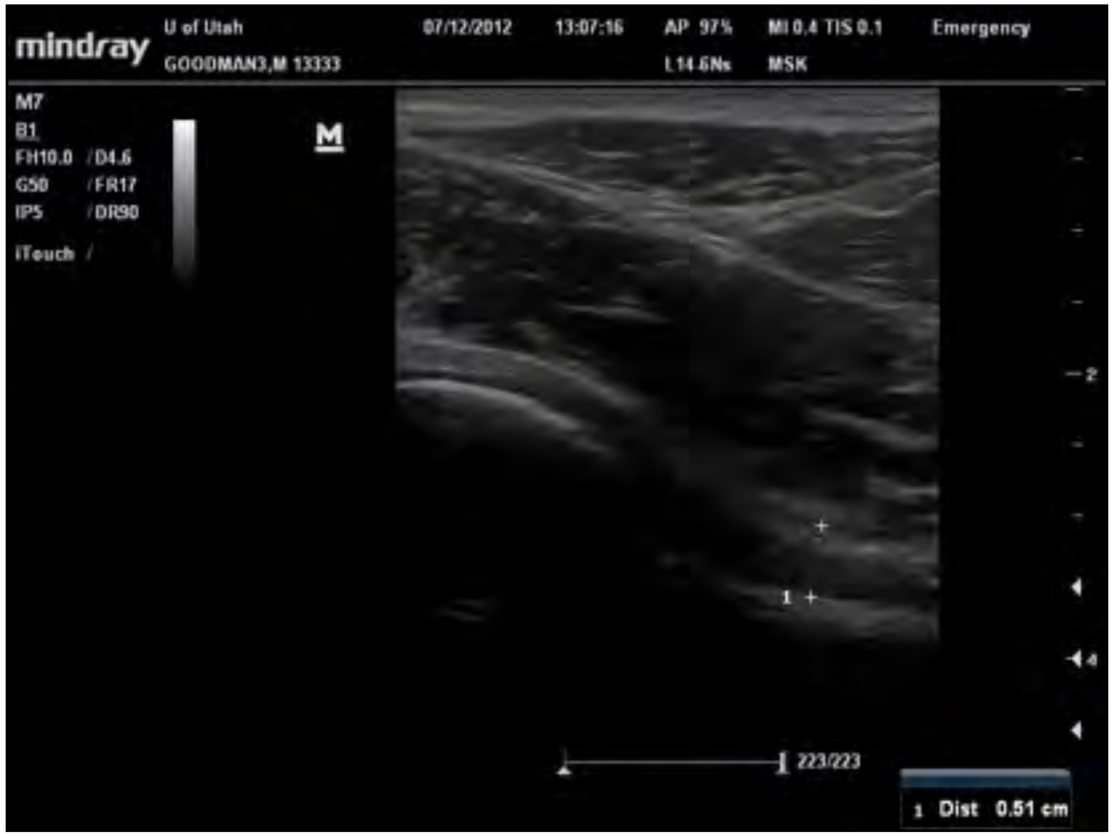


IMAGE 24.9 - Normal hip with joint capsule <7mm



The normal anterior joint capsule appears concave, whereas an effusion creates a distention of the capsule, resulting in a convex appearance. (Hip effusion) Measurement from the cortex of the femoral neck to the outer capsule is less than 7mm in a normal joint, with less than 1-2mm difference between the affected and unaffected sides.[2-6] (Image 5.9)

Nerves and Vasculature

SUMMARY:

From lateral to medial you should identify:

Femoral nerve

Femoral artery

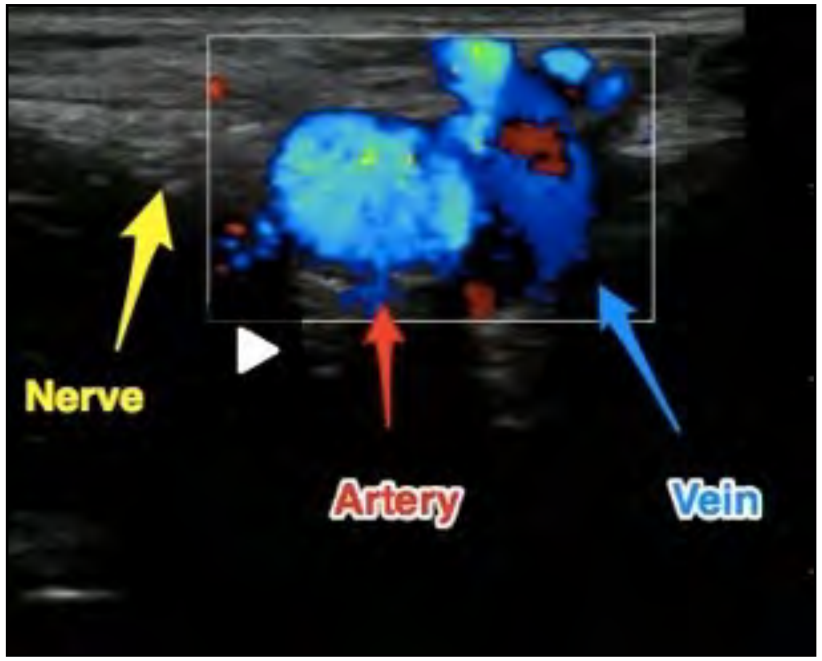
Femoral vein

Use color flow and compressibility to differentiate the structures

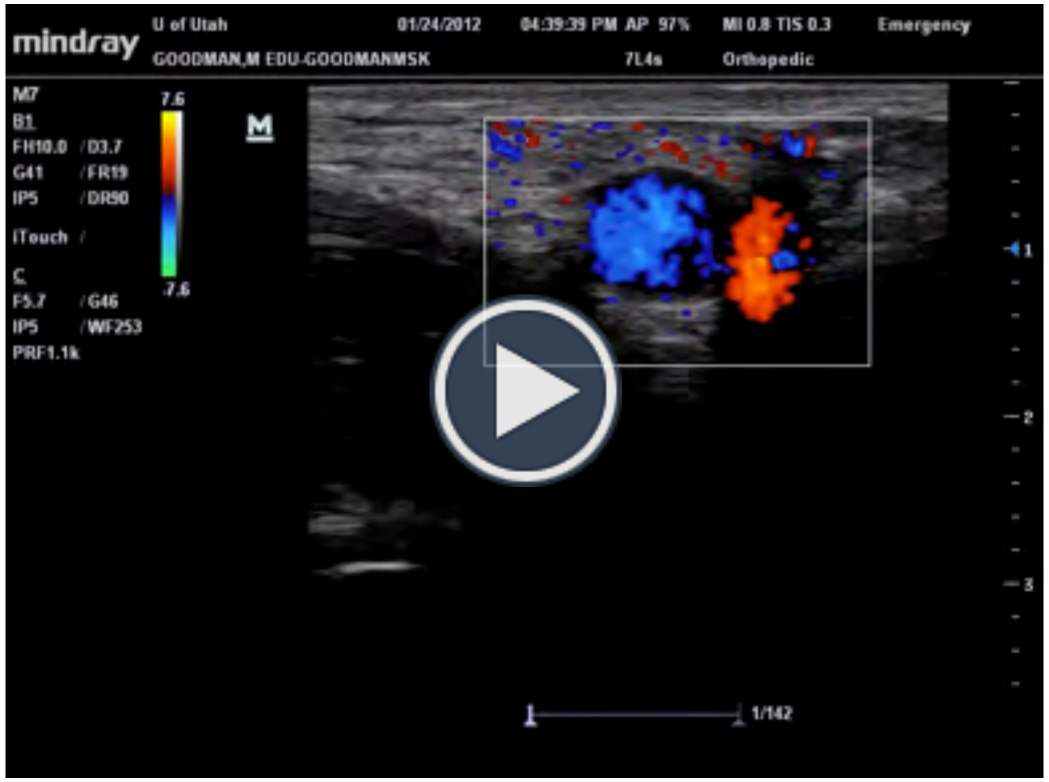
The femoral neurovascular bundle lies medial and superficial to the femoral head. The femoral nerve is the most lateral structure, with the femoral artery and vein being more medial. The femoral nerve has a hypoechoic honeycomb appearance when viewed in transverse. Color flow can be used to better differentiate vascular structures. (Image 24.10, 24.11, Movie 24.2) The vein will be compressible, while the artery will not. (Movie 24.3)

IMAGE 24.10

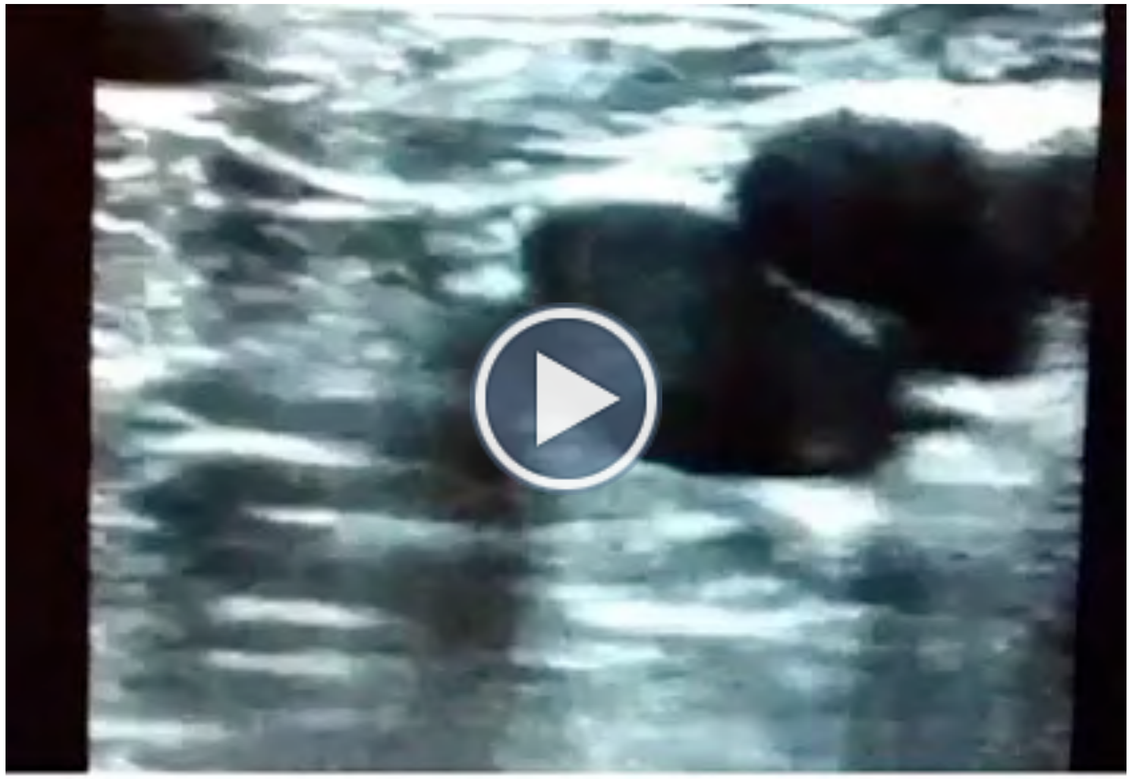
IMAGE 24.11



Movie 24.2



Movie 24.3



Muscle and Bursa

ANTERIOR:

The iliopsoas tendon overlies the femoral head and neck, lateral to the femoral neurovascular bundle. The iliopsoas bursa lies between the anterior joint capsule and the iliopsoas tendon and will not be visible in normal states.[7] (Image 24.12)

IMAGE 24.12

SUMMARY:

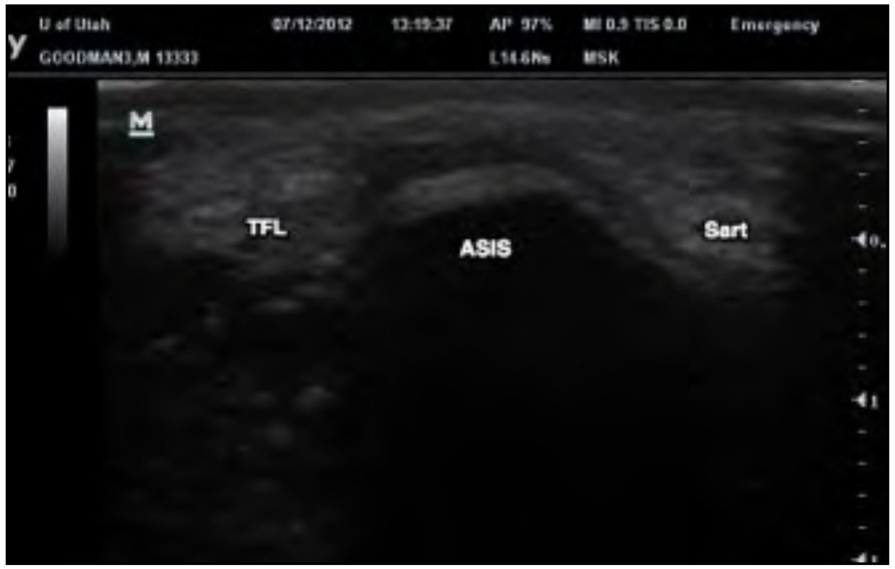
The iliopsoas bursa is not visible in normal states

The anterior, lateral, and posterior hip should be evaluated

The sartorius and the tensor fasciae latae can be visualized superficial to the anterior superior iliac spine (ASIS) (Image 24.13, 24.14).

IMAGE 24.13

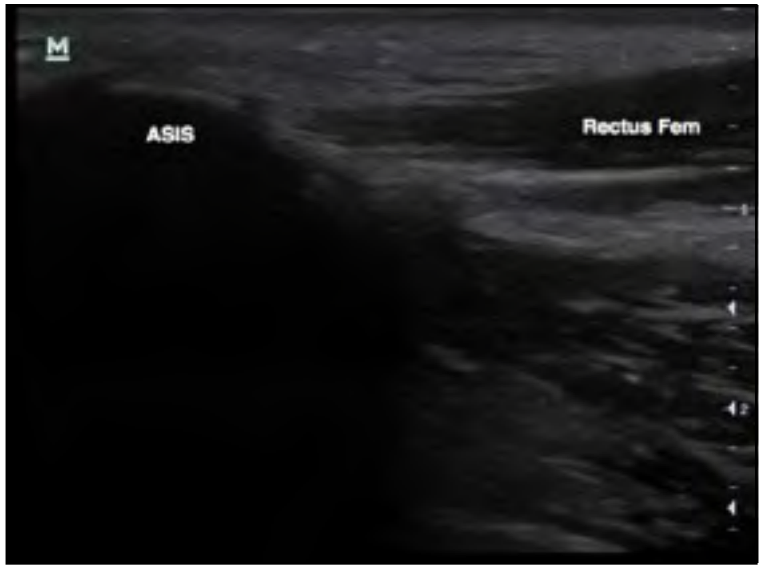
IMAGE 24.14



The rectus femoris can be visualized from its origin on the anterior inferior iliac spine and followed distally between the tensor fasciae latae and the sartorius. (Image 24.15,24.16)

IMAGE 24.15

IMAGE 24.16



Lateral:

The lateral hip, and region surrounding the greater trochanter, can be evaluated by placing the transducer over the superior femur in a transverse plane and by moving the transducer posteriorly and later-

Movie 24.4

ally. (Movie 24.4) Having the patient lie on the opposite hip will make this region easier to visualize.[7] Move the transducer to a coronal-oblique plane, (Image 24.17) and identify the greater trochanter with the gluteus maximus overlying the trochanteric bursa. (Image 24.18) The iliotibial track can be seen superficially and laterally as a hyperechoic structure overlying the gluteus medius. (Image 24.19) Transverse images over the greater trochanter show the gluteus medius tendon laterally, with the gluteus maximus posterior and superficial to a portion of the gluteus medius tendon. (Image 24.20) The bursa surrounding the greater trochanter will not be visualized in most asymptomatic patients.[7]

Image 24.17

Image 24.18

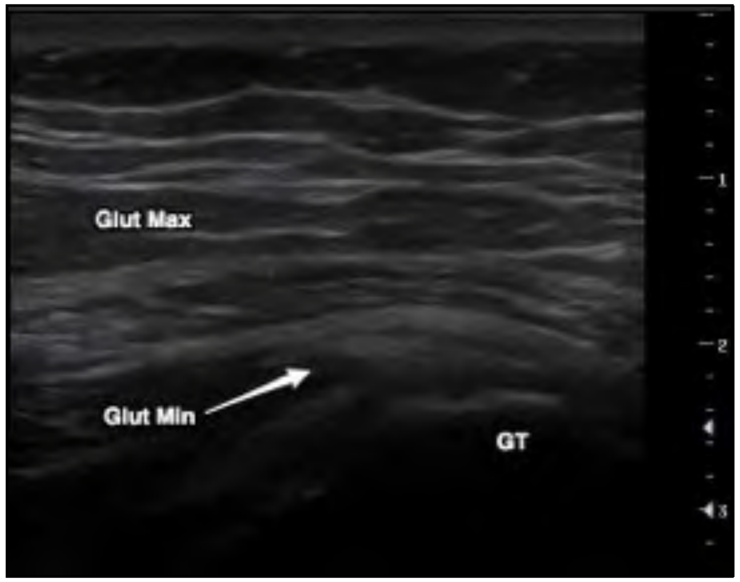


IMAGE 24.19

IMAGE 24.20

POSTERIOR:

Place the patient in the prone position and start with the ultrasound probe over the ischial tuberosity. The gluteus maximus will be overlying the ischial tuberosity. (Image 24.21) The conjoined tendon of the hamstrings muscle group can be identified at their origin on the lateral ischial tuberosity. (Image 24.21) The sciatic nerve is located laterally. (24.22)

IMAGE 24.21

IMAGE 24.22

Effusions of the hip joint are visualized in the anterior view. An effusion appears as a dark, hypoechoic fluid collection lifting the anterior joint capsule off the femoral head and neck (Hip effusion). Placing the leg in abduction and flexion may help to enhance small effusions.[6] (Image 24.23) A distance of greater than 5mm between the femoral neck and outer capsule in a child, and greater than 7mm in an adult has been used as diagnostic criteria for a hip effusion.[1-3,7,8] (Image 24.24)

IMAGE 24.23

IMAGE 24.24

SUMMARY:

Placing the leg in abduction and flexion may help to enhance small effusions

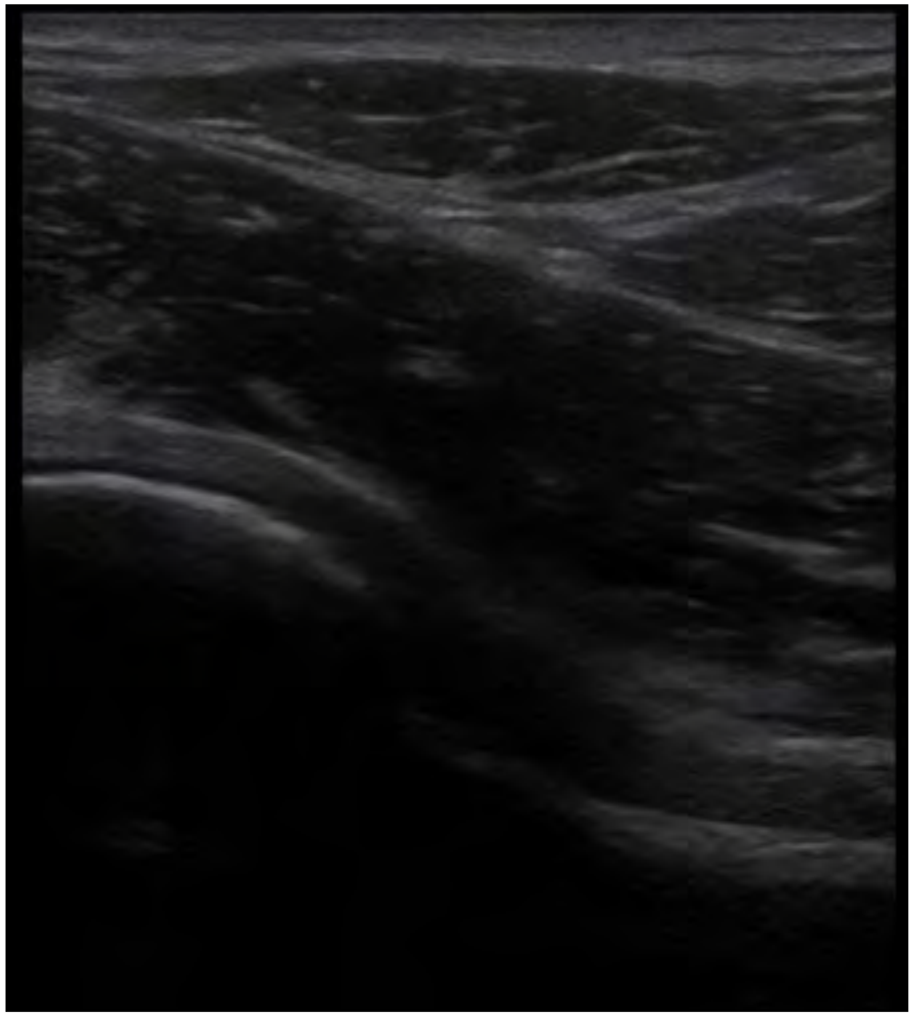
An effusion of 7mm in adults and 5mm in children is considered pathologic

Compare sides for asymmetry

Hip dislocation can be assessed with ultrasound

Compare to the asymptomatic side for asymmetry, with greater than 1.46-2 mm of difference in children and 1mm in adults being concerning for effusion, respectively.[4,7,9,10] Use a transverse-oblique view to examine the femoral head and anterior recess of the joint in cross section. (Image 24.25)

IMAGE 24.25



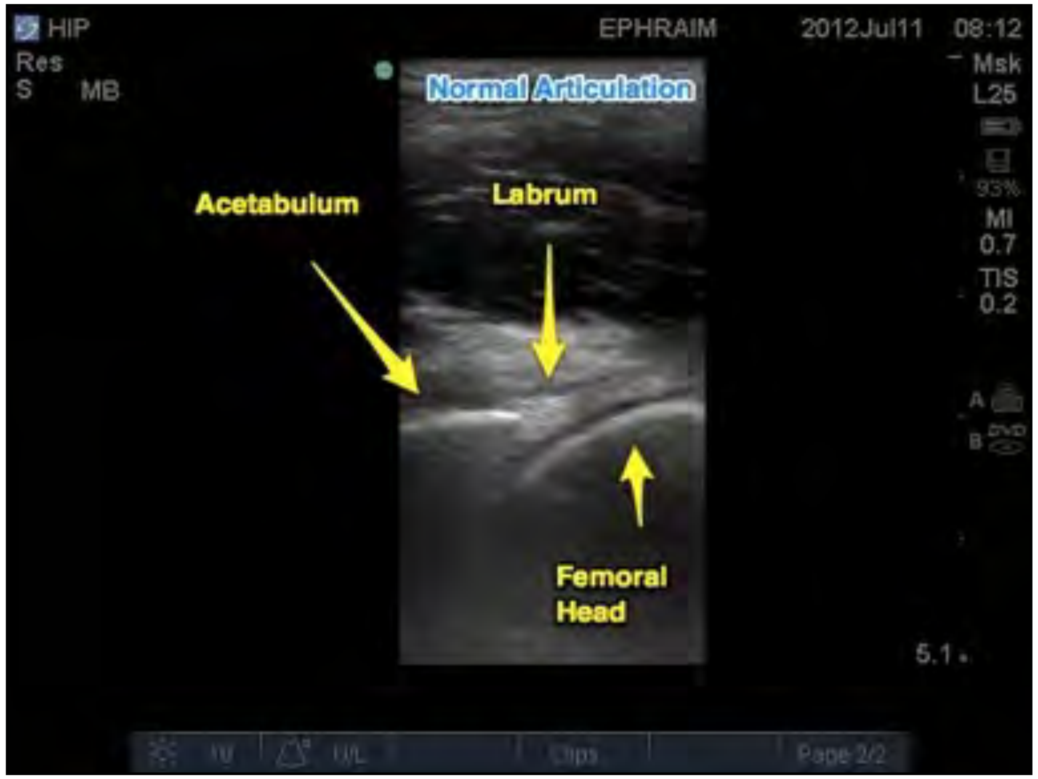
Hip effusions can appear as hypoechoic, hyperechoic or mixed echogenicity.[11] (Complex hip effusion). Ultrasound characteristics of a hip effusion lack the sensitivity and specificity to distinguish a septic from an aseptic process.[5,6] When suspicion of a septic process is high, arthrocentesis should be performed.

Dislocation of the hip joint can be confirmed by ultrasound of the hip anteriorly.(24.26)

IMAGE 24.26

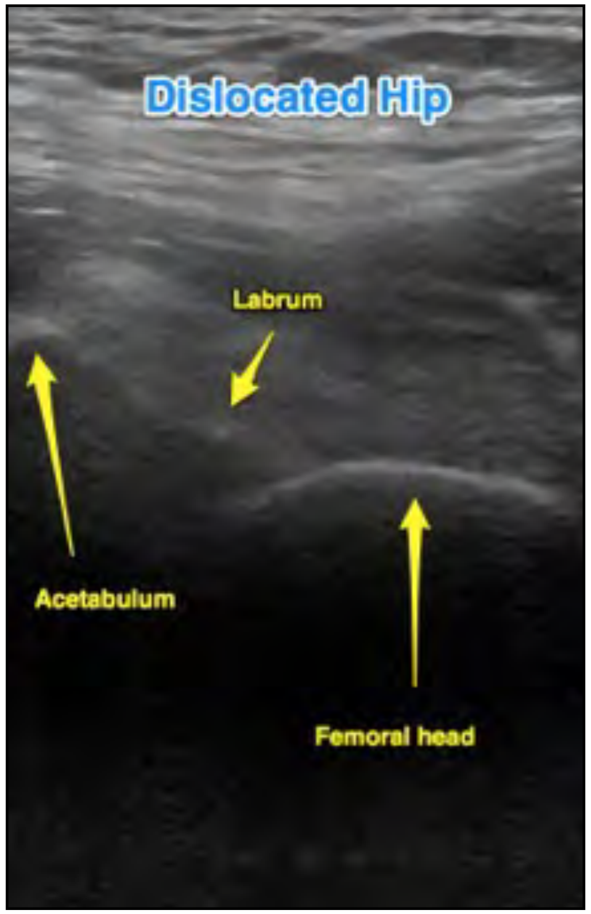
A loss of the normal alignment between the femoral head and acetabulum confirms dislocation.[12] Reduction can be confirmed using a similar view. (Image 24.27, Movie 24.5, Image 24.28, Movie 24.6)

IMAGE 24.27 - Normal hip

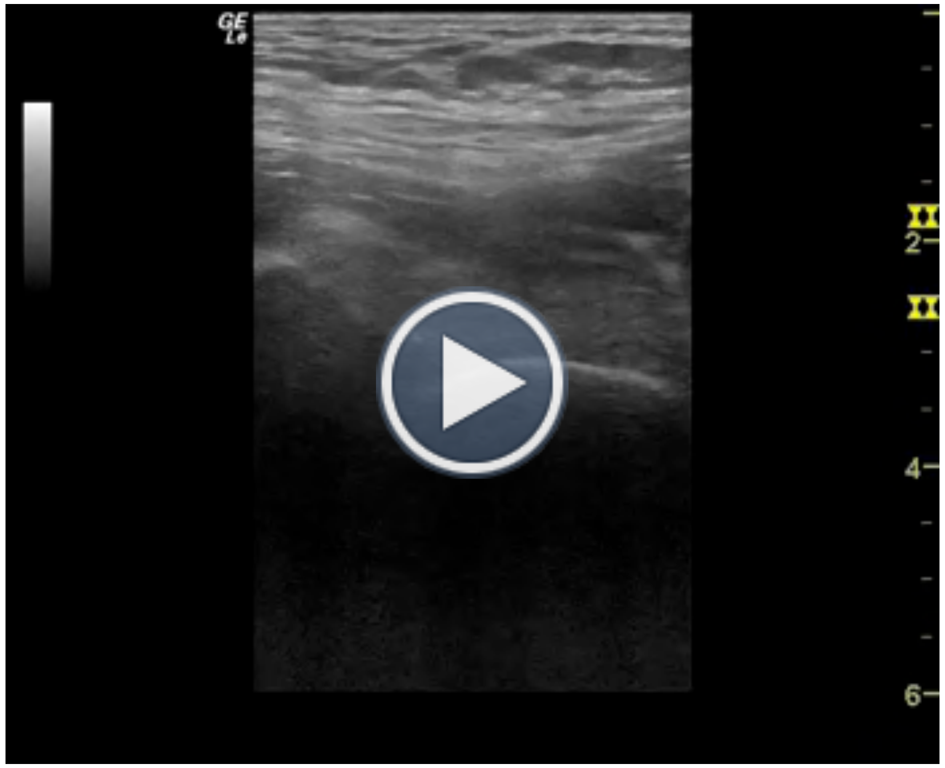


MOVIE 24.5 - Normal hip articulation

IMAGE 24.28 - Dislocated hip



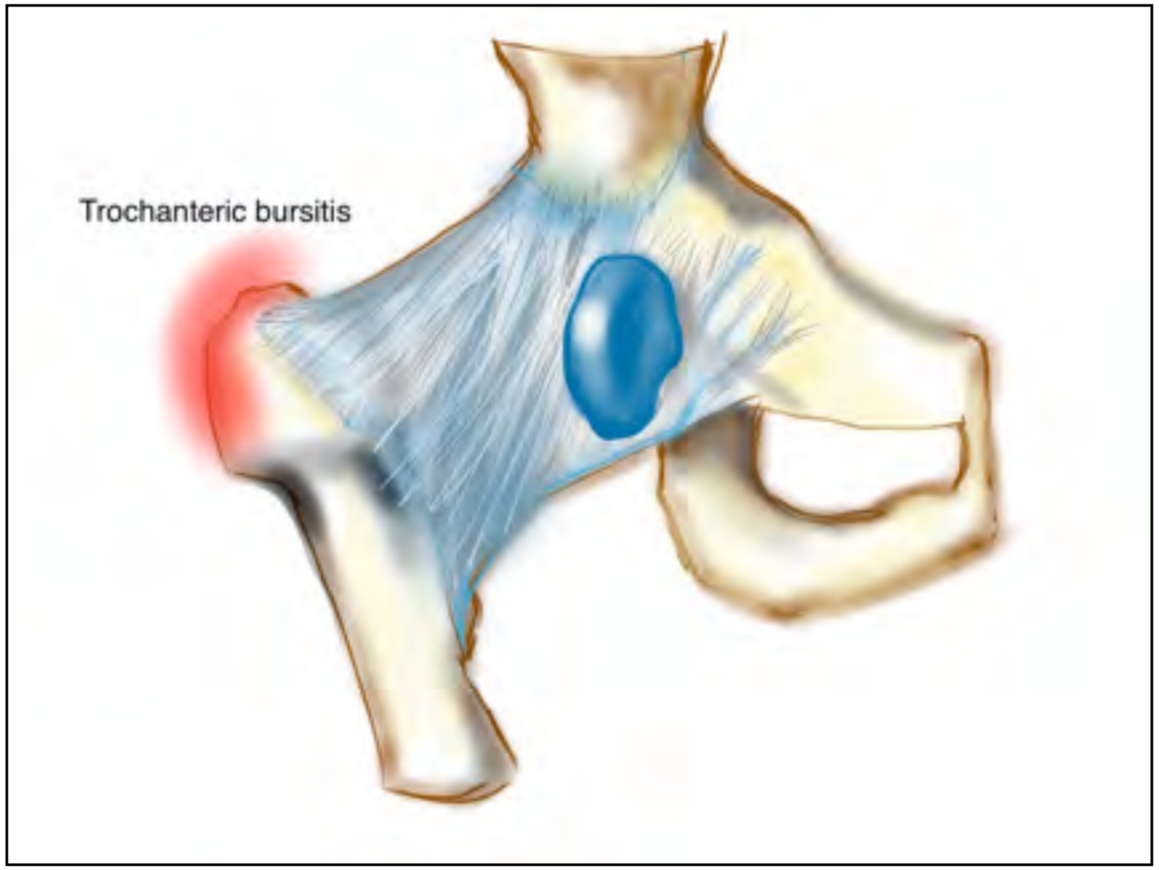
MOVIE 24.6 - Dislocated hip



Placing the probe so that it is bridging between the pubic bones can image the pubic symphysis. (Image 24.29) Ultrasound can detect widening of the pubic symphysis in a trauma patient, indicating an open book pelvic fracture.[13] The normal pubic symphysis measures less than 2.5 cm in width.[13]

IMAGE 24.29

IMAGE 24.30



The bursa surrounding the hip can be evaluated for abnormalities by ultrasound. (Image 24.30) Bursitis is suggested by distention of the bursa, pain with transducer pressure, and hyperemia with color or power Doppler.[14,15] There may be fluid in normal bursae and the presence of fluid alone cannot diagnose an inflammatory bursitis.[2] When evaluating greater trochanteric pain, there is a high degree of correlation between ultrasound, MRI and surgical findings.[16] (Trochanteric bursitis) The iliopsoas bursae is located on top of the iliopsoas tendon and anterior to the hip joint. (Iliopsoas bursitis) Iliopsoas bursitis can be evaluated initially with ultrasound; however, MRI is superior in accuracy when compared to surgical findings. It is also superior for evaluating communication with the hip joint, which can occur in 15% of patients.[17,18]

Inguinal lymphadenopathy may be encountered when imaging medial to the anterior hip, surrounding the femoral neurovascular bundle. Lymph nodes appear as a hyperechoic hilum with a surrounding hypoechoic cortex, with blood flow visible on color flow imaging.[11] Normal lymph nodes measure less than 15mm. Enlarged nodes or nodes with an abnormal pattern of vascular flow may be benign or malignant, but require additional evaluation and possible biopsy.[19,20] (Enlarged lymph nodes)

Transient synovitis is characterized by pain and decreased range of motion, presenting without trauma in children with hip pain.[21,22] The ultrasound findings of transient synovitis include intracapsular effusion and increased distance between the anterior joint capsule and the femoral neck 2mm greater than the unaffected side. [1,4,5] (Transient synovitis) Once an effusion is diagnosed, ultrasound lacks sensitivity to differentiate transient synovitis from septic arthritis, and further diagnostic testing, including possible arthrocentesis, is required. [21,22-28]

Section 6

Limitations

Ultrasound exam of the hip is limited by the deep location of some structures, making a thorough exam in patients with a larger body habitus difficult. The use of ultrasound for femoral fractures and labral pathology is limited, as only a partial view of the joint can be obtained in the best of circumstances. As in other joints, the ultrasound characteristics of a hip effusion lack the sensitivity to differentiate an infectious from inflammatory process.

Tell everyone that you finished another chapter!

Contact us:

REFERENCES

1) Robben SG, Lequin MH, Diepstraten AF, et al. Anterior joint capsule of the normal hip and in children with transient synovitis: US study with anatomic and histologic correlation. Radiology. 1999 Feb;210(2):499-507.

2) Schmidt H, Schicke B, Gromnica-Ihle. Standard reference values for musculoskeletal ultrasonography. Ann Rheum Dis. 2004;63:988-94.

3) Koski JM, Anttila PJ, Isomäki HA. Ultrasonography of the adult hip joint. Scand J Rheumatol. 1989;18(2):113-7.

4) Haueisen DC, Weiner DS, Weiner SD. The characterization of "transient synovitis of the hip" in children. J Pediatr Orthop. 1986 Jan-Feb;6(1):11-7.

5) Terjesen T, Osthus P. Ultrasound in the diagnosis and follow-up of transient synovitis of the hip. J Pediatr Orthop. 1991;11:608–613.

6) Rohrschneider WK, Fuchs G, Tröger J. Ultrasonographic evaluation of the anterior recess in the normal hip: a prospective study on 166 asymptomatic children. Pediatr Radiol. 1996 Sep;26(9):629-34.

7) Beggs I, Bianchi S, Bueno A, et al. Musculoskeletal Ultrasound Technical Guidelines IV. Hip. European Society of Musculoskeletal Radiology. Available at http://www.essr.org/html/img/pool/hip.pdf. Acessed on May 26, 2012.

8) Moss SG, Schweitzer ME, Jacobson JA, et al. Hip joint fluid: detection and distribution at MR imaging and US with cadaveric correlation. Radiology. 1998 Jul;208(1):43-8.

9) Tien YC, Yang CY, Chih HW. The normal width of anterior hip synovial recess in children. J Pediatr Orthop. 2000. Mar-Apr;20(2):264-6.

10) Koski JM, Anttila P, Hämäläinen M, et al. Hip joint ultrasonography: correlation with intra-articular effusion and synovitis. Br J Rheumatol. 1990 Jun;29(3):189-92.

11) Jacobson, JA. Fundamentals of musculoskeletal ultrasound. Philadelphia, PA: Saunders/Elsevier, 2007.

12) Zimny MH, Walters BL, Bahl A. Bedside ultrasound for hip dislocations [published online ahead of print April 21, 2012]. J Emerg Med. 2012. http://www.jem-journal.com/article/S0736-4679(12)00233-8/abstract

13) Bauman M, Marinaro J, Tawil I, et al. Ultrasonographic determination of pubic symphyseal widening in trauma: the FAST-PS study. J Emerg Med. 2011 May;40(5):528-33.

14) Iagnocco A, Filippucci E, Meenagh G, et al. Ultrasound imaging for the rheumatologist III. Ultrasonography of the hip. Clin Exp Rheumatol. 2006 May-Jun;24(3):229-32.

15) Walther M, Harms H, Krenn V, et al. Synovial tissue of the hip at power Doppler US: correlation between vascularity and power Doppler US signal. Radiology. 2002;225: 225-31.

16) Fearon AM, Scarvell JM, Cook JL, et al. Does ultrasound correlate with surgical or histologic findings in greater trochanteric pain syndrome? A pilot study. Clin Orthop Relat Res. 2010 Jul;468(7):1838-44.

17) Wunderbaldinger P, Bremer C, Schellenberger E, et al. Imaging features of iliopsoas bursitis. Eur Radiol. 2002 Feb;12(2):409-15.

18) Bianchi S, Martinoli C, Keller A, et al. Giant iliopsoas bursitis: sonographic findings with magnetic resonance correlations. J Clin Ultrasound. 2002 Sep;30(7):437-41.

19) Grey AC, Carrington BM, Hulse PA, et al. Magnetic resonance appearance of normal inguinal nodes. Clin Radiol. 2000 Feb;55(2):124-30.

20) Vassallo P, Wernecke K, Roos N, et al. Differentiation of benign from malignant superficial lymphadenopathy: the role of high-resolution US. Radiology. 1992 Apr;183(1):215-20.

21) Alexander JE, Seibert JJ, Aronson J, et al. A protocol of plain radiographs, hip ultrasonography, and triple phase bone scintigraphy in the evaluation of the painful pediatric hip. Clin Pediatr. 1988;27:175–181.

22) Alexander JE, Seibert JJ, Glasier CM, et al. High-resolution hip ultrasound in the limping child. JCU. 1989;17:19–24.

23) Zamzam MM. The role of ultrasound in differentiating septic arthritis from transient synovitis of the hip in children. J Pediatr Orthop B. 2006 Nov;15(6):418-22.

24) Zawin JK, Hoffer FA, Rand FF, et al. Joint effusion in children with an irritable hip: US diagnosis and aspiration. Radiology. 1993;187:459–463.

25) Haueisen DC, Weiner DS, Weiner SD. The characterization of "transient synovitis of the hip" in children. Pediatr Orthop. 1986 Jan-Feb;6(1):11-7.

26) Terjesen T, Osthus P. Ultrasound in the diagnosis and follow-up of transient synovitis of the hip. J Pediatr Orthop. 1991;11:608–613.

27) Merino R, de Inocencio J, García-Consuegra J. Differentiation between transient synovitis and septic arthritis of the hip with clinical and ultrasound criteria. An Pediatr (Barc). 2010 Oct;73(4):189-93.

28) Strouse PJ, DiPietro MA, Adler RS. Pediatric hip effusions: evaluation with power Doppler sonography. Radiology. 1998 Mar;206(3):731-5.

Chapter 25

Shoulder

SECTION 1
Bones

SUMMARY

Bones of Shoulder are superficial and relatively easy to assess for fracture

Ultrasound can be used to assess for shoulder dislocation and evaluate reduction success.

Ultrasound can assess space between bones such as in the AC and SC joints.

The shoulder is a complex joint that gives up a fair amount of strength for the trade off of mobility. This leads to injury not infrequently. However, the superficiality of the structures involved lends it nicely to sonography of these injuries. (3-D shoulder anatomy animation)
The main structures to be examined via ultrasound include the bones, muscles, tendons, and bursa. (Video tutorial of rotator cuff anatomy)

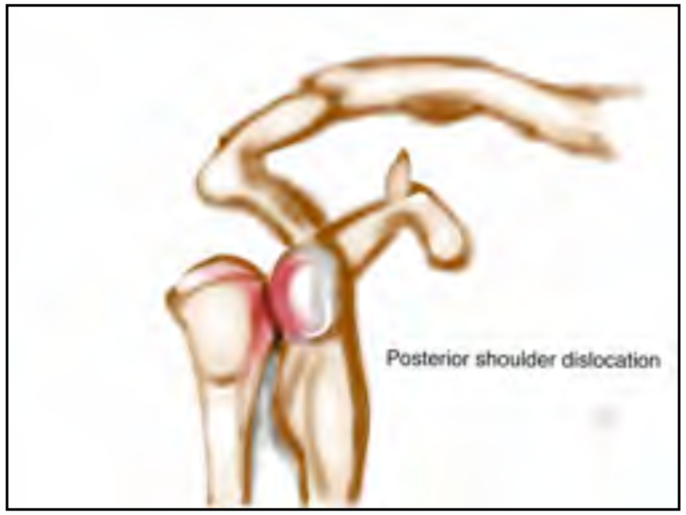
IMAGE 25.1

HUMERAL HEAD:

The humeral head can be assessed via sonography for superficial fracture and dislocation (Image 25.1). There are limitations, as fractures within the joint may be missed, but humeral neck fractures and superficial humeral head fractures can be diagnosed relatively consistently. (Humeral fracture on ultrasound missed by x-ray)

Greater tuberosity fractures, which sometimes are missed on x-ray, can be identified on ultrasound as a cortical stepoff. (greater tuberosity fracture).[1]

Dislocation:



Movie 25.1 One Minute Ultrasound Demonstration of Dislocation Evaluation

Shoulder dislocation can be readily assessed via ultrasound from multiple approaches. From the posterior approach, the probe is slid up the lateral portion of the humerus until the head is in view just inferior to the acromion. At this point, the probe is slid posterior to obtain a view of the humeral head, labrum, and glenoid.

With this view, the anterior-posterior distance of the humerus from the glenoid rim can be measured. A normal shoulder will have the humeral head approximately .5-1cm posterior to the glenoid. However, the best way to assess what is normal for your patient is to scan the unaffected side first and use that distance as normal. If the humeral head is quite a bit more posterior on the affected side, then consider posterior dislocation. If the humerus is anterior to the glenoid, then this represents an anterior dislocation, the more common of the two. (Case report with ultrasound image)

When this anterior dislocation is identified, this is a good view in which to perform an ultrasound-guided injection of anesthetic into the joint. (Video demonstration)

This can frequently allow reduction of the shoulder without sedation and has the benefit of avoiding complications related to sedation.[2,3,4] Although there exists the possibility of joint infection, a recent review found no reported cases of this.[5] Dynamic ultrasound evaluation also allows real time feedback of the position of the humeral head while attempting reduction. Frequently you will not feel the clunk that is normally associated with reduction, which makes this real-time ultrasound feedback very valuable. At least one series has shown bedside ultrasound to be accurate in determining whether reduction has been successful (Ultrasound before and after reduction).[6] Shoulder dislocation can also be assessed from the anterior view by visualizing the relationship of the coracoid to the humeral head.

CLAVICLE:

The clavicle is a superficial bone that is easily evaluated with ultrasound for fracture or dislocation (Clavicle fractures).

The distance between the acromioclavicular (AC) joint and sternoclavicular (SC) joint can also be assessed with ultrasound for separation and dislocation. These can be most easily found by simply palpating the joint first. The normal AC joint is approximately 1-3mm, with >6mm being pathologic for adults. [7,8,9] (AC joint evaluation)

The more important distance is the difference between affected and unaffected sides, which should be no more than 2-3mm.[10,11] The nor-

GALLERY 25.1 - Normal AC

AC

GALLERY 25.2

Clavicle Short Axis

mal coracoclavicular distance is 11-12mm.[11] The right and left should be <5mm different. (Acromioclavicular and coracoclavicular anatomy) Other pathologic processes of the AC joint include osteoarthrosis, cysts, and infections.[12]

Muscles/Tendons

SUMMARY

Tendon tears usually appear hypoechoic

Evaluation of the various tendons include:

Supraspinatus

Infraspinatus/Teres Minor

Subscapularis

Biceps Tendon

The rotator cuff may seem like an intimidating structure when taken as a whole, but the component parts can each be assessed via sonography with relative ease. (rotator cuff anatomy video)

SUPRASPINATUS:

The supraspinatus is located just inferior to the acromion, coming out from under it laterally to attach on the greater tuberosity. In order to ultrasound a larger portion of it, the patient is positioned with the back of the hand against the opposite back pocket.(Image 25.4, Video 25.2) This maneuver, the Crass position, pulls the supraspinatus out from under the acromion (Video demonstration of supraspinatus evaluation)

IMAGE 25.2 Supraspinatus Coming From Underneath Acromion

IMAGE 25.3 Supraspinatus

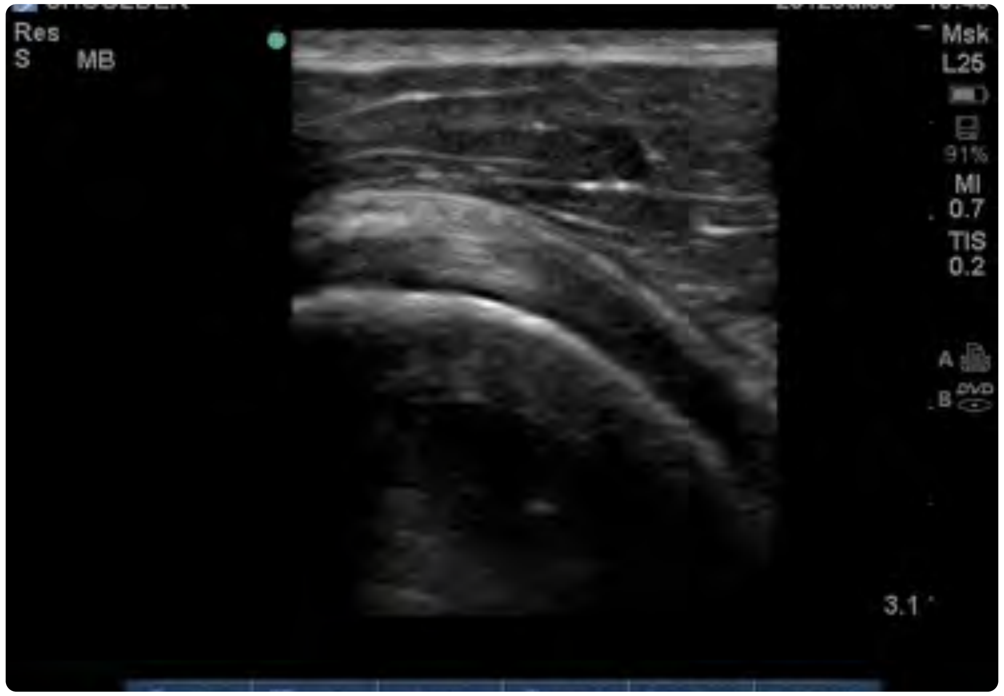
IMAGE 25.4 Crass Position

MOVIE 25.2 Crass Manuever

It can then be evaluated in both the long and short axes for tears or tendinosis (supraspinatus tear). A tendon tear will be a hypoechoic or anechoic region within the muscle fibers and can be partial or full thickness. The appearance of a tear and tendinosis can overlap, with both sometimes appearing hypoechoic. Calcific tendinosis will have a discrete area of hyperechoic calcium with shadowing (Calcific tendinosis).In general, a tear is usually more anechoic, homogeneous, well-defined, and associated with a bony irregularity.[13] Tendinosis, however, will frequently show swelling and heterogeneity, be hypoechoic instead of anechoic, and have no bony irregularity. If the tendon irregularity is immediately adjacent to a cortical irregularity of the greater tuberosity, then this is highly suggestive of a tear instead of tendinosis.[13,14] (Various supraspinatus tears)

The supraspinatus tendon is the most commonly torn tendon of the rotator cuff, and care should be taken to evaluate it fully, as tears often occur more anteriorly, near the rotator interval[15] (Supraspinatus evaluation with examples of various pathology). You can be sure you are anterior enough when you are able to also visualize the biceps tendon.

GALLERY 25.3 - Subscapularis



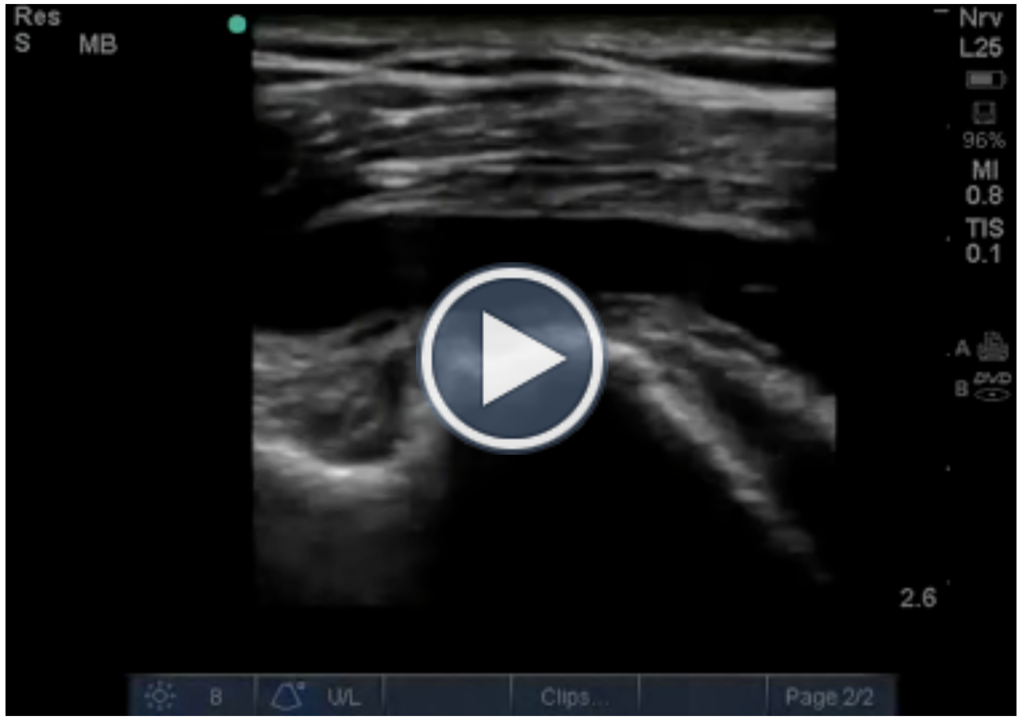
SUBSCAPULARIS:

From the supraspinatus, the ultrasound probe can be moved just inferior and slightly medially to visualize the subscapularis (Gallery 25.3) (Subscapularis examination video).

The subscapularis tendon runs from its medial muscle to attach laterally at the lesser tuberosity (Subscapularis muscle).

The biceps groove, including the greater and lesser tuberosity, as well as the biceps tendon can be used as a landmark. Having the patient rotate the shoulder externally will pull the tendon more laterally and bring it perpendicular to the probe, thus enhancing the image by decreasing anisotropy. This external rotation maneuver will also make a subscapularis tear, which normally occurs at the lesser tuberosity, more prominent. (Movie) There are usually other pathologies present, as subscapularis tears rarely happen in isolation.[16] (Video case of subscapularis tear)

MOVIE 25.3 - Subscapularis tear



GALLERY 25.4 - Biceps tendon

BICEPS TENDON:

From the subscapularis view, it is relatively easy to identify the biceps tendon. The subscapularis attaches to the lesser tuberosity, which is the medial border of the biceps groove. (Subscapularis muscle) The biceps tendon is within this groove, just lateral to the lesser tuberosity, with the greater tuberosity making up the lateral border of the groove. (Biceps tendon anatomy)

By having the patient sit with the palm up on the thigh, the biceps groove is rotated in an anterior orientation that makes it accessible by ultrasound. (Gallery 25.4)

The tendon can be assessed in both the long and short axes in this position. (Video of biceps tendon evaluation)

Tendinosis and tears of the biceps tendon can be appreciated on ultrasound. They have a similar appearance to tears of other tendons discussed. (Biceps tendon rupture images) A full thickness tear will appear as an empty bicipital groove, as the tendon is retracted from the groove.[17] Clinically, the patient may have a Popeye's Deformity with a complete biceps tendon rupture.

Biceps tendon dislocation will also have the appearance of an empty bicipital groove, so it is important to look for the tendon adjacent to the groove to differentiate tear from dislocation.[18] (Video case of biceps tendon dislocation) It is also important to tilt the probe back and forth during evaluation of the biceps tendon in the short axis, as anisotropy can give the appearance of an empty groove as well.

A joint effusion of the glenohumeral joint is frequently seen as fluid surrounding the biceps tendon due to the fact that the tendon sheath communicates with the glenohumeral joint. If a joint effusion does not move with pressure and has increased blood flow, then it may represent synovitis instead of an effusion.[19] Pain with pressure in the area and an effusion that is very localized would suggest synovitis over effusion as well.

Infraspinatus/Teres Minor:

The infraspinatus and teres minor make up the posterior rotator cuff. The patient should be positioned with the arm resting palm up on the thigh. If the probe is placed just inferior to the scapular spine, these muscles and tendons can be viewed just posterior to the gle-

Gallery 25.5 - Infraspinatus

noid running distally to attach to the greater tuberosity. (Gallery 25.5)

They should be evaluated both in the long axis and short axis. (Video of infraspinatus evaluation)

A tear or tendinosis of these tendons will have an appearance similar to a tear of the other tendons.

Section 3

Bursa and Other Pathology

Summary

Subacromial-subdeltoid bursa is difficult to see when normal as it is a potential space

Shoulder pathology that can be diagnosed with ultrasound:

Infraspinatus atrophy

Calcific tendinosis

Impingement syndrome

Adhesive Capsulitis

Others

Bursa:

The subacromial-subdeltoid bursa is a bursal sac filled with fluid that lies beneath the acromion and deltoid as well as above the rotator cuff in order to protect the rotator cuff. Its ultrasound appearance is subtle, as it is more of a potential space if no pathology is present. However, with pathology such as a rotator cuff tear, bursitis, proliferative disorders, amyloidosis, or impingement syndrome, it can become distended and more easily recognizable on ultrasound. (subacromial bursitis) The diagnosis of subacromial bursal fluid (Movie 25.4 and Movie 25.5) is made when the walls of the bursa are separated by more than 1-2mm.[20] Injection of the subacromial bursa is discussed in the Ultrasound Guided Injections chapter.

Other Pathology:

Infraspinatus atrophy is a condition that may result from either a rotator cuff tear with poor biomechanics or a suprascapular nerve impingement.[13] It is diagnosed by decreased area, which is normally twice that of the teres minor.[21]

Calcific tendinosis is a process that most commonly affects the supraspinatus. It is usually from degeneration and has a hyperechoic appearance with shadows in the majority of cases.

Impingement syndrome is strongly suggested when there is pooling of subacromial bursal fluid during active elevation of the arm at the acromion tip.[22] The most common impingement syndrome is that of the supraspinatus, as it travels underneath the acromion. It is caused by narrowing of this space and leads to tendinosis, occasional tear, and bursal fluid.[13] (Impingement evaluation with ultrasound)

MOVIE 25.4 - Impingement Test

MOVIE 25.5 - No Impingement Present

Adhesive capsulitis can be thought of as a more severe form of impingement syndrome that manifests sonographically as continuous limitation of the sliding of the supraspinatus under the acromion.[13] This continued limitation of the sliding movement of the supraspinatus tendon against the acromion was found to be 91% sensitive and 100% specific in one study.[23] Thickening of the coracohumeral ligament has also been shown to strongly correlate with adhesive capsulitis.[24]

Studies have demonstrated many other pathologies of the shoulder that can be diagnosed or treated with ultrasound guidance. These include, but are not limited to, paralabral cysts, labral tears, amyloidosis, quadrilateral space syndrome, pectoralis tendon tears, malignant lymph nodes, neuromas, elastofibrosis, and bony metastasis.[25, 26, 27, 28, 29, 30, 31, 32]

As technology improves and we gain more experience, we will undoubtedly find other uses for ultrasound to diagnose and treat disease and injury of the shoulder.

Tell everyone that you finished another chapter!

Contact us:

REFERENCES

1. Patten RM, Mack LA, Wang KY, Lingel J. Nondisplaced fractures of the greater tuberosity of the humerus: sonographic detection. Radiology. 1992;182:201-204.

2. Miller SL, Cleeman E, Auerbach J, Flatow EL. Comparison of intra-articular lidocaine and intravenous sedation for reduction of shoulder dislocation: a randomized, prospective study. J Bone Joint Surg Am. Dec 2002;84-A(12):2135-2139.

3. Orlinsky M, Shon S, Chiang C, Chan L, Carter P. Comparative study of intra-articular lidocaine and intravenous meperidine/diazepam for shoulder dislocations. J Emerg Med. Apr 2002;22(3):241-245.

4. Fitch RW, Kuhn JE. Intraarticular lidocaine versus intravenous procedures sedation with narcotics and benzodiazepines for reduction of the dislocated shoulder: a systematic review. Acad Emerg Med. Aug 2008;15(8):703-708.

5. Ng VK, Hames H, Millard WM. Use of intra-articular lidocaine as analgesia in anterior shoulder dislocation: a review and meta-analysis of the literature. Can J Rural Med. Fall 2009;14(4):145-149.

6. Blakeley CJ, Spencer O, Newman-Saunders T, Hashemi K. A novel use of portable ultrasound in the management of shoulder dislocation. Emerg Med J. 2009;26:662-663.

7. Bosworth BM. Complete acromioclavicular dislocation. N Eng J Med. 1949; 241(6):221-225.

8. Kiner A. Diagnosis and management of grade II acromioclavicular joint separation. Clinical Chiropractic. 2004:724-30.

9. Keats T, Pope T. The acromioclavicular joint: normal variation and the diagnosis of dislocation. Skeletal Radiology. 1988:17(3); 159-162.

10. Harris JH Jr, Harris WH, West OC. Radiology of Emergency Medicine. 4th ed, Philadelphia, PA: Lippincott, Williams & Wilkins; 2000.

11. Manaster BJ, Disler DG,May DA, et al. Musculoskeletal imaging: the requisites. 3rd ed. Mosby; 2006.

12. Ferri M, Finlay K, Popowich T, et al. Sonographic examination of the acromioclavicular and sternoclavicular joints. J Clin Ultrasound. 2005;33:345-355.

13. Jacobson J. Fundamentals of musculoskeletal ultrasound. Saunders Elsevier 2007.

14. Jacobson JA, Lancaster S, Prasad A, et al. Full-thickness and partial-thickness supraspinatus tendon tears: Value of US signs in diagnosis. Radiology 2004; 230: 234-242.

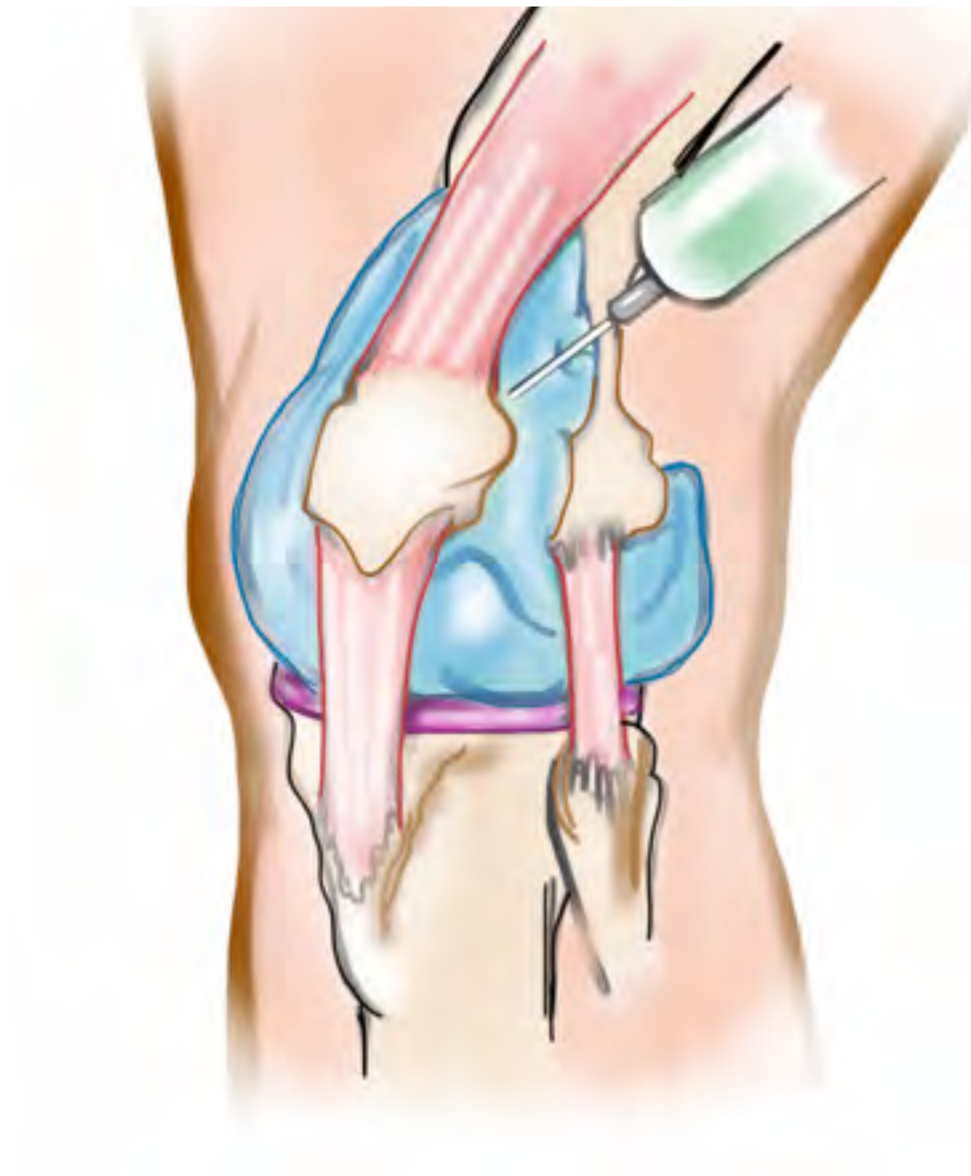
15. Tuite MJ, Turnbull JR, Orwin JF. Anterior versus posterior, and rim-rent rotator cuff tears: Prevalence and MR sensitivity. Skeletal Radiol 1998;27:237-243.

Chapter 26

Joint Injections

SECTION 1

Introduction



SUMMARY:

Ultrasound has been shown to improve the accuracy of common joint injections over landmark based techniques.[1,2] Patient pain scores, the number of attempts, and the amount of time required for joint aspiration were reduced by using ultrasound in the emergency department setting.[3,4] The technique of ultrasound guided joint injection and aspiration are similar and will be discussed together. Prior to planned joint aspiration the physician should consider diagnostic ultrasound to confirm the clinical suspicion of a joint effusion. In one study, the decision to perform arthrocentesis in emergency department patients was changed in 65% of cases by performing pre-procedure ultrasound.[5]

Technique

SUMMARY:

Evaluate the joint with ultrasound and mark prior to injection

Glenohumeral joint injection accuracy improves from 10-42% without ultrasound to 94% with ultrasound

AC joint injection accuracy may increase from 40-45% to close to 100% with ultrasound

Injection of the elbow, hip, knee, ankle, and MTP joints can be performed reliably with ultrasound guidance

TECHNIQUE

Evaluate the joint of interest with ultrasound prior to attempting the procedure. A surgical skin marker can be used to mark the injection site prior to skin cleaning with chlorhexidine, iodine, or surgical prep. Place a wheel of local anesthetic over the injection site. Sterile precautions should be in use before attempting joint aspiration or injection. A sterile probe cover, sterile gel, drape, and sterile gloves should be employed to minimize the risk of infection. The high frequency linear probe is used for the majority of musculoskeletal procedures. (Image 26.1 and 26.2)

IMAGE 26.1

IMAGE 26.2

However, the curvilinear probe may be needed for deeper joints, such as the hip, in patients with larger body habitus. (Image 26.3) A 22-gauge spinal needle can be used for deeper injections while a 22 or 18-gauge needle can be used for more superficial structures.

IMAGE 26.3

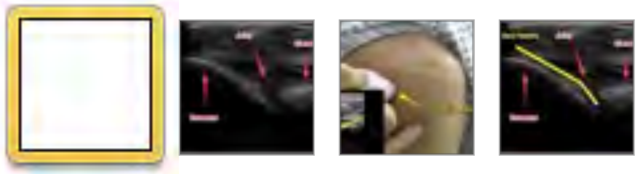
SHOULDER

The accuracy of glenohumeral joint injection using an anterior landmark technique is between 10-42% as compared with 94% with ultrasound guidance.[5-9]

The ultrasound guided aspiration or injection of the glenohumeral joint is performed from a posterior lateral approach. Place the high frequency probe parallel to the infraspinatus, just caudal to the spine of the scapula. (Gallery 26.1) Identify the humerus, glenoid and glenoid labrum. (Gallery 26.1) Adduct the humerus across the thorax, with the patient reaching towards the opposite shoulder. After preparing a sterile field, insert the needle laterally, in plane with the ultrasound probe. (Gallery 26.1) Begin with the needle 1-2 cm lateral to the probe to allow for a shallower angle and better needle visualization. Bending the needle 30 degrees can be helpful in following the curvature of the humeral head and improving placement in the joint.[10] (Gallery 26.1) Visualize the needle tip pass under the glenoid labrum and into the joint capsule or effusion. (Glenohumeral joint injection)

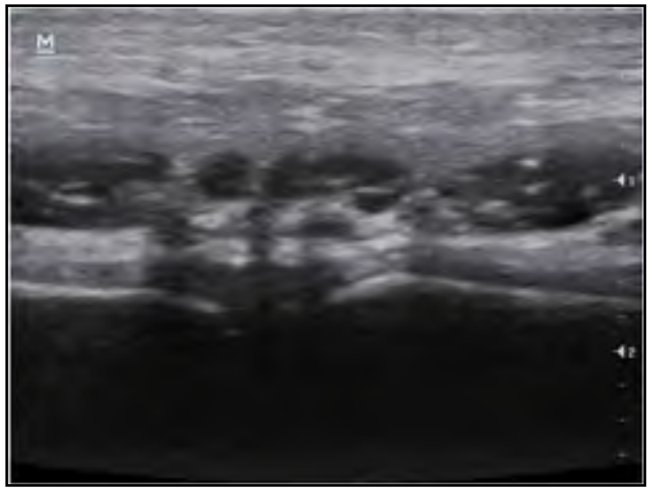
Gallery 26.1

Parallel to the infraspinatus



The acromioclavicular joint, while superficial, can be difficult to accurately inject with a blind technique. Injection accuracy without ultrasound is between 40-45% and increases to 100% with ultrasound in some small studies.[1,11]

Image 26.4



Place the ultrasound probe over the distal clavicle. Follow the clavicle distally to the junction with the acromion. (Image 26.1) The joint is visualized as an interruption of the hyperechoic cortex of both bones with a surrounding thin joint capsule. (Image 26.4) A small effusion may be compressed by over-application of pressure with the ultrasound probe. Position the patient in a seated position with the arm at the side to open the joint space. Due to the superficial location of the acromioclavicular joint, injection is less complicated to perform in short axis, also known as the out of plane approach. (Gallery 26.2) Injection or arthrocentesis can be performed in real time with the ultrasound probe or blindly once the joint has been identified and marked. Avoid passing the needle through the joint as

Gallery 26.2 Short Axis Approach

the supraspinatus tendon lies distally and can be damaged by unintentional injection.

Elbow

The elbow can be injected with ultrasound guidance by a posterior lateral approach.[10,12] Ultrasound is useful to differentiate a joint effusion from bursitis and can improve diagnostic accuracy of an effusion over clinical exam alone.[13] (Elbow effusions)

Position the patient with the elbow bent at 90° and facing away from the physician. (Gallery 26.3) Place the linear probe over the posterior elbow in long axis with the triceps tendon. Identify the olecranon fossa with the olecranon distal and the humerus proximal. (Image 26.5) With the distal transducer on the olecranon, rotate the proximal transducer 30° laterally until the lateral trochlea of the humerus is visualized. (Movies 26.1 and 26.2) After the sterile field is prepared, the needle can be introduced in plane from proximal to distal passing through the triceps muscle and avoiding the triceps tendon.[10] (Image 26.6)

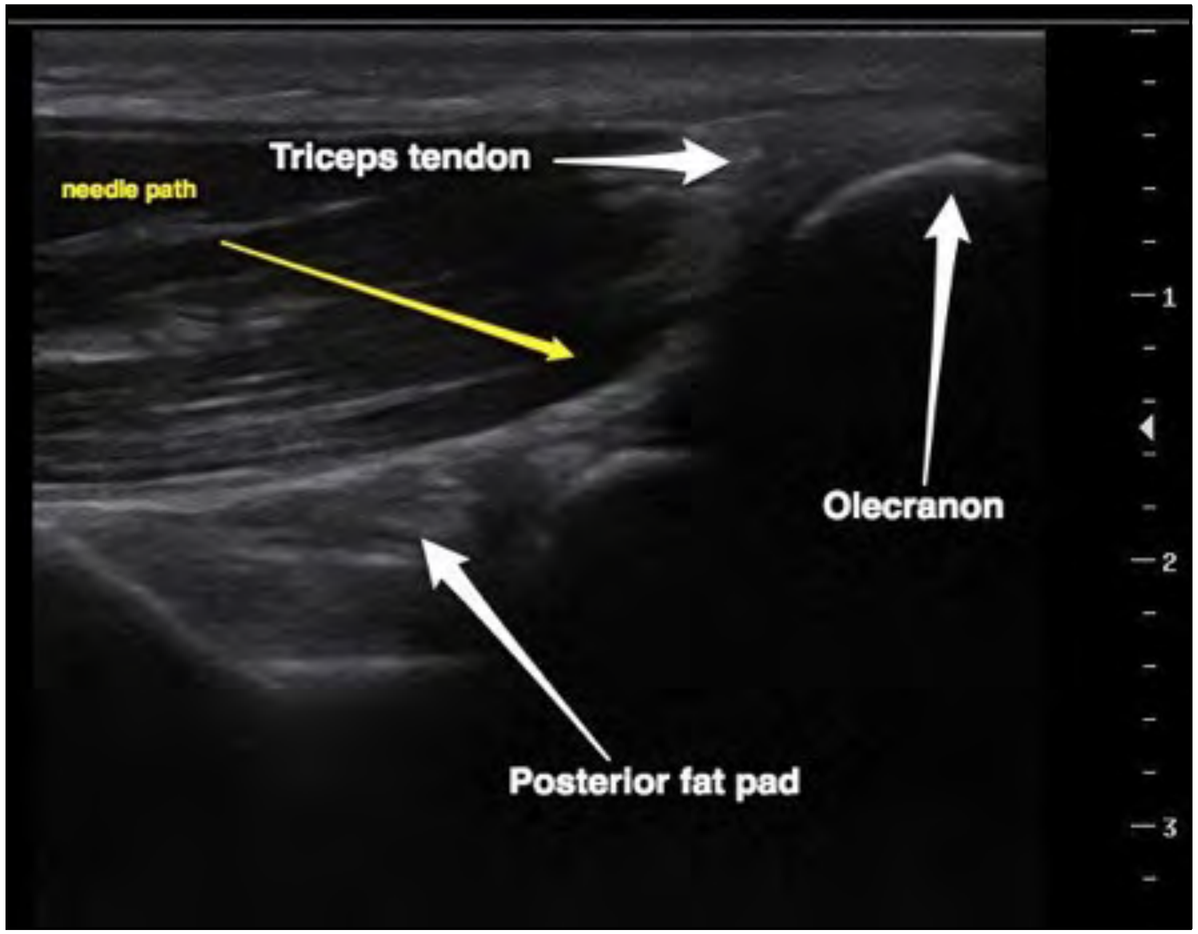
Gallery 26.3 Elbow Positions

Image 26.5

Movie 26.1

Movie 26.2

Image 26.6



Hip

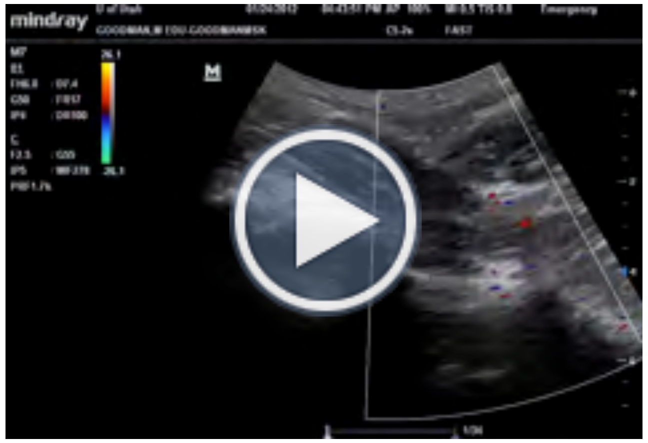
Intra-articular hip injections can provide diagnostic information as well as symptom relief for osteoarthritis of the hip.[14,15] Ultrasound guided aspiration or injection of the hip joint is safe and accurate when compared to fluoroscopy and CT guidance.[16-18] Advantages of ultrasound over fluoroscopy include the ability to visualize soft tissue and vascular structures, portability of the equipment, and a lack of radiation. Ultrasound guided hip aspiration has been described as being performed safely and accurately by emergency physicians in the emergency department setting.[19-22]

Place the patient in the supine position. The femoral neurovascular bundle is located medially and can be easily identified with color flow in cross section. (Gallery 26.4) Begin by identifying the femoral neurovascular bundle and move laterally. Find the junction of the femoral head and neck, which is 30° in a coronal oblique plane off the long axis of the femur. (Gallery 26.4) The normal joint capsule overlies the anterior femoral neck. In the presence of effusion, the anterior joint capsule becomes convex and filled with hypo or hyperechoic fluid. (Case Study) The target for injection or aspiration will be the junction of the femoral head and neck. (Gallery 26.4) Mark the orientation for the probe with a surgical marker and cleanse the site with a surgical prep. Place local anesthetic over the site of needle insertion. Place the probe in line with the femoral neck and visualize the junction between the femoral head and neck. Identify and avoid the circumflex femoral vessels using color Doppler. (Movie 26.3) Insert a 22-gauge spinal needle in plane with the ultrasound probe towards the junction of the femoral head and neck. (Gallery 26.4) Set the angle of the needle to avoid the circumflex vessels. Once the needle contacts bone, withdraw slightly. Begin injecting slowly. There should be minimal injection pressure felt. If there is more than minimal pressure then you are probably not in the joint. Visualize fluid flowing into the joint capsule. (Movie 26.4) (Ultrasound-guided hip injection tutorial)

Gallery 26.4

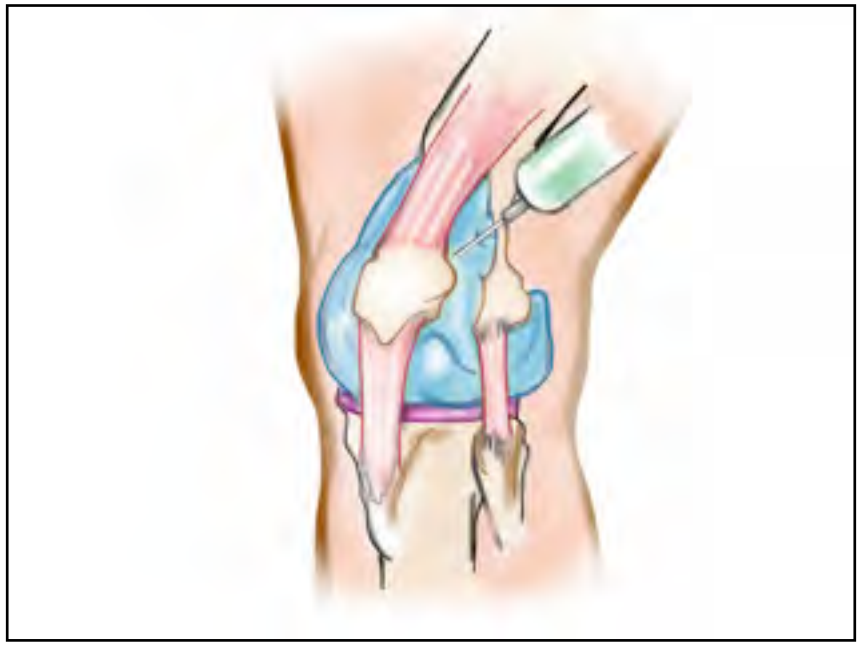
The femoral neurovascular bundle is located medially and can be easily identified with color flow in cross section.

Movie 26.3



Movie 26.4

FIGURE 26.1



KNEE

Ultrasound is useful for injection or aspiration of the knee, especially in patients with difficult anatomy. The use of ultrasound has been shown to improve accuracy of injections over a landmark-based technique.[1, 23] When compared with a blind technique for knee arthrocentesis, ultrasound did not change the amount of fluid obtained, but did decrease patient pain and the time required to perform the procedure. It also made the procedure easier to perform when rated by the provider.[24] Begin by scanning the knee for presence of an effusion.(Figure 26.1) With the knee in full extension, image the suprapatellar recess and lateral pouches. (Image 26.7) A joint effusion is visible in the suprapatellar view deep to the quadriceps tendon.

IMAGE 26.7

(Knee joint effusion) Turn the probe 90° to a transverse view with the probe abutting the proximal edge of the patella. (Gallery 26.5) After sterile preparation, insert the needle from the lateral side of the knee in plane with the ultrasound probe. Insert the needle in the soft spot between the iliotibial band and the vastus lateralis tendon. (Gallery 26.6) The injection should flow easily into the joint space without a fluid collection being visualized in the soft tissues. The anterior lateral or anterior medial approach can also be used with the ultrasound probe bridging between the patella and the femur.[25] (Gallery 26.6) If available, a small footprint high frequency probe should be employed. (Gallery 26.6 and Movie 26.5)
(Ultrasound-guided knee injection tutorial)

GALLERY 26.5

Gallery 26.6

Insert the needle in the soft spot between the iliotibial band and the vastus lateralis tendon.

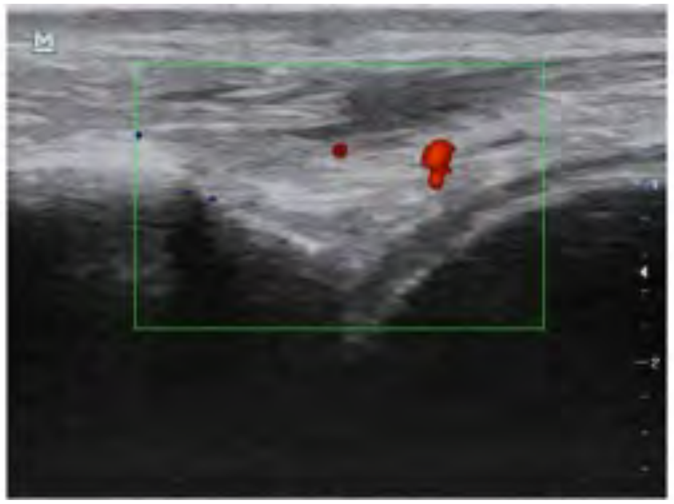
Movie 26.5

Ankle

The use of ultrasound improves accuracy over blind techniques for ankle injections.[26] The procedure is well described in the radiology literature and in case reports from emergency medicine.[25, 27] Ultrasound offers the benefit of being able to detect small effusions that are not visible by radiography.[28]

With the ankle plantar flexed, identify the dorsalis pedis artery using palpation or color Doppler. The deep peroneal nerve sits lateral to the artery. Place the ultrasound probe in a long axis with the tibia, between the lateral malleolus and the extensor digitorum longus. The joint space will be visible between the tibia and the talus. After sterile preparation, insert the needle in plane from distal to proximal. Alternatively, an approach with the needle in short axis with the probe can be used.
(Gallery 26.7)

Gallery 26.7



With the ankle plantar flexed, identify the dorsalis pedis artery using palpation or color Doppler.

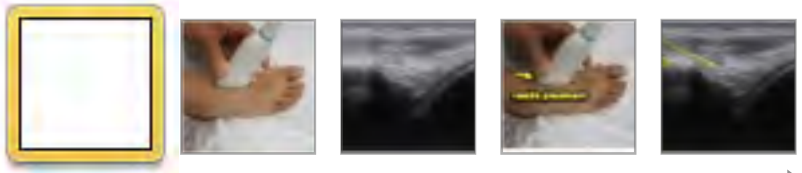
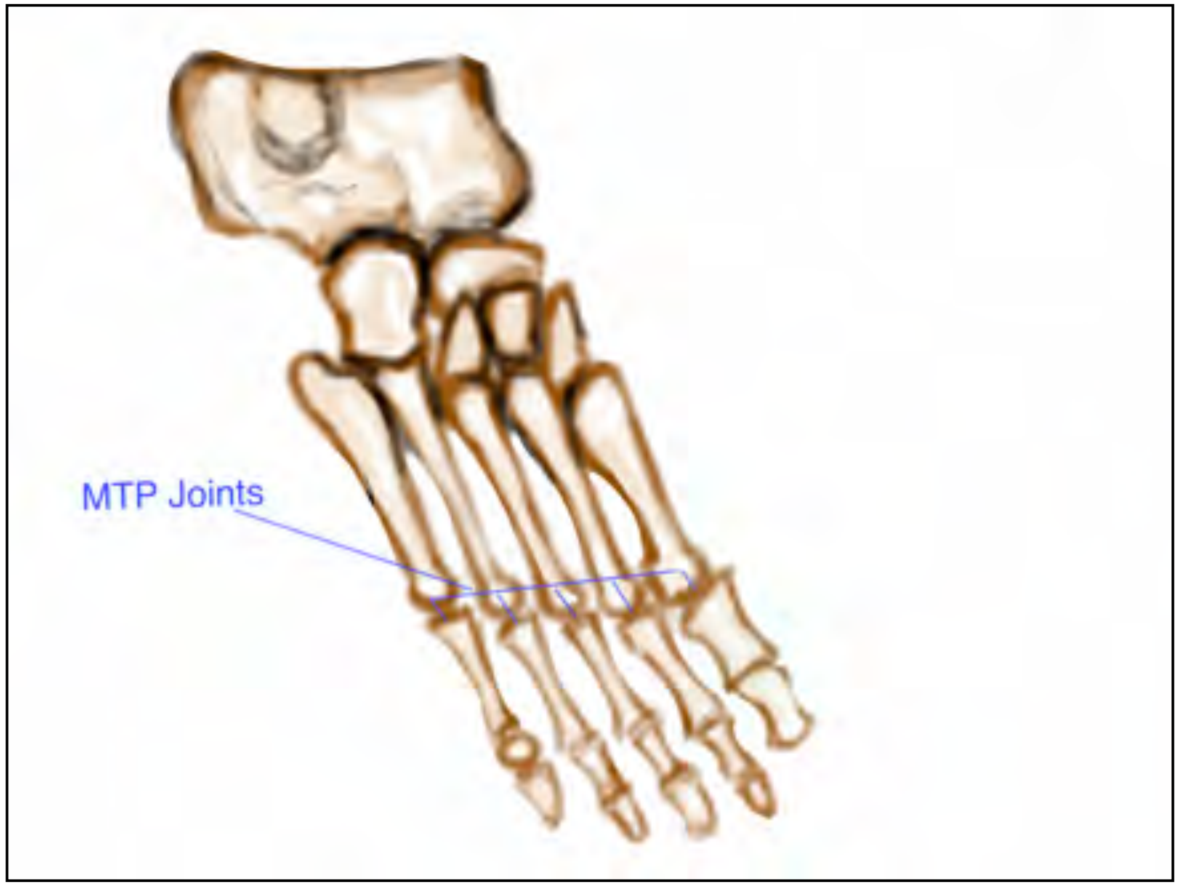


IMAGE 26.8



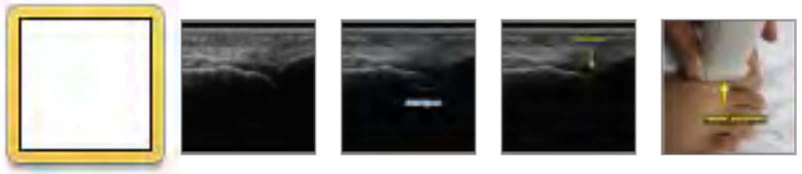
METATARSOPHALANGEAL JOINT

The metatarsophalangeal (MTP) joint is easily evaluated by ultrasound.(Image 26.8) An asymptomatic patient can have an effusion on ultrasound, making clinical correlation with history and exam especially important.

Place the high frequency linear probe over the MTP joint in long axis. (Gallery 26.8) Identify the joint space between the metacarpal and the proximal phalange. Avoid over compression with the ultrasound probe, as that could obscure a small effusion. Mark the joint space and prep the area. Due to the superficial location of the MTP, an out of plane approach with the needle is preferred. With the MTP

GALLERY 26.8

Place the high frequency linear probe over the MTP joint in long axis.



flexed and distracted, center the joint space in the middle of the ultrasound probe and insert the needle from the medial side out of plane with the ultrasound. Insert the needle below the extensor tendon. (Movie 26.6) Alternatively, ultrasound can also be used to identify and mark the joint space to guide a blind injection or

MOVIE 26.6

aspiration.

Conclusion

While ultrasound is not necessary for all injections or aspirations it is a very useful medium indeed. It has been shown to decrease complications, decrease pain, and improve success in multiple studies for multiple joints.

Tell everyone that you finished another chapter!

Contact us:

REFERENCES

1) Daley EL, Bajaj S, Bisson LJ, et al. Improving injection accuracy of the elbow, knee and shoulder: does injection site and imaging make a difference? A systemic review. Am J Sports Med. 2011 Mar;39(3):656-62.
2) Cunnington J, Marshall N, Hide G, et al. A randomized, double-blind, controlled study of ultrasound-guided corticosteroid injection into the joint of patients with inflammatory arthritis. Arthritis Rheum. 2010 Jul;62(7):1862-9.
3) Jackson DW, Evans NA, Thomas BM. Accuracy of needle placement into the intra-articular space of the knee. Bone Joint Surg Am. 2002 Sep;84-A(9):1522-7.
4) Wiler JL, Costantino TG, Filippone L, et al. Comparison of ultrasound-guided and standard landmark techniques for knee arthrocentesis. J Emerg Med. 2010 Jul;39(1):76-82.
5) Adhikari S Blaivas M. Utility of bedside sonography to distinguish soft tissue abnormalities from joint effusions in the emergency department. J Ultrasound Med. 2010 Apr;29(4):519-26.
6) Sethi PM, Kingston S, El Attrache N. Accuracy of anterior intra-articular injection of the glenohumeral joint. Arthroscopy. 2005;21:77-80.
7) Eustace JA, Brophy DP, Gibney RP, et al. Comparison of the accuracy of steroid placement with clinical outcome in patients with shoulder symptoms. Ann Rheum Dis. 1997;56:59-63.
8) Jones A, Regan M, Ledingham J, et al. Importance of placement of intra-articular steroid injections. BMJ. 1993;307(6915):1329-1330.
9) Rutten MJCM, Collins JMP, Maresch BJ, et al. Glenohumeral joint injection: a comparative study of ultrasound and fluoroscopically guided techniques before MR arthrography. Eur Radiol. 2009;19:722-730.
10) Schaefer MP. Ultrasound-guided shoulder joint and bursa injections. In: Narouze SM ed. Atlas of Ultrasound Guided Procedures in Interventional Pain Management., New York (NY): Springer; 2011:293-306.
11) Peck E, Lai JK, Pawlina W, et al. Accuracy of ultrasound-guided versus palpation-guided acromioclavicular joint injections: a cadaveric study. PM R. 2010 Sep;2(9):817-21.
12) Finlay K, Ferri M, Friedman L. Ultrasound of the elbow. Skeletal Radiol. 2004 Feb;33(2):63-79.
13) Luukkainen R, Sanila MT, Saltyshev M, et al. Relationship between clinically detected joint swelling and effusion diagnosed by ultrasonography in elbow joints in patients with rheumatoid arthritis. Clin Rheumatol. 2005 Jun;24(3):228-31.
14) Crawford RW, Gie GA, Ling RS, et al. Diagnostic value of intra-articular anaesthetic in primary osteoarthritis of the hip. J Bone Joint Surg Br. 1998 Mar;80(2):279-81.
15) Kleiner JB, Thorne RP, Curd JG. The value of bupivicaine hip injection in the differentiation of coxarthrosis from lower extremity neuropathy. J Rheumatol. 1991 Mar;18(3):422-7.
16) Smith J, Hurdle MF, Weingarten TN. Accuracy of sonographically guided intra-articular injections in the native adult hip. J Ultrasound Med. 2009 Mar;28(3):329-35

17)Berman L, Fink AM, Wilson D, et al. Technical note: identifying and aspirating hip effusions. Br J Radiol. 1995;68(807):306–10.
18)Pourbagher MA, Ozalay M, Pourbagher A. Accuracy and outcome of sonographically guided intra-articular sodium hyaluronate injections in patients with osteoarthritis of the hip. J Ultrasound Med. 2005 Oct;24(10):1391-5.
19) Smith SW. Emergency physician-performed ultrasonography-guided hip arthrocentesis. Acad Emerg Med. 1999 Jan;6(1):84-6.
20)Minardi JJ, Lander OM. Septic hip arthritis: diagnosis and arthrocentesis using bedside ultrasound [published online ahead of print January 30, 2012]. J Emerg Med. 2012. http://www.jem-journal.com/article/S0736-4679(11)01138-3/abstract. Accessed July 10, 2012.

21)Tsung JW, Blaivas M. Emergency department diagnosis of pediatric hip effusion and guided arthrocentesis using point-of-care ultrasound. J Emerg Med. 2008 Nov;35(4):393-9.
22)Freeman K, Dewitz A, Baker WE. Ultrasound-guided hip arthrocentesis in the ED. Am J Emerg Med. 2007 Jan;25(1):80-6.
23)Im SH, Lee SC, Park YB, et al. Feasibility of sonography for intra-articular injections in the knee through a medial patellar portal. J Ultrasound Med. 2009 Nov;28(11):1465-70.
24)Wiler JL, Costantino TG, Filippone L, et al. Comparison of ultrasound-guided and standard landmark techniques for knee arthrocentesis. J Emerg Med. 2010 Jul;39(1):76-82.
25)Fessell DP, Jacobson JA, Craig J. Using sonography to reveal and aspirate joint effusions. Am J Roentgenol. 2000 May;174(5):1353-62.
26)Wisniewski SJ, Smith J, Patterson DG, et al. Ultrasound-guided versus nonguided tibiotalar joint and sinus tarsi injections: a cadaveric study. PM R. 2010 Apr;2(4):277-81.
27)Roy S, Dewitz A, Paul I. Ultrasound-assisted ankle arthrocentesis. Am J Emerg Med. 1999 May;17(3):300-1.
28)Jacobson JA, Andresen R, Jaovisidha S, et al. Detection of ankle effusions: comparison study in cadavers using radiography, sonography, and MR imaging. Am J Roentgenol. May 1998;170(5):1231-8.
29)Louis LJ. Musculoskeletal ultrasound intervention: principles and advances. Radiol Clin North Am. 2008 May;46(3):515-33, vi.

CHAPTER 27

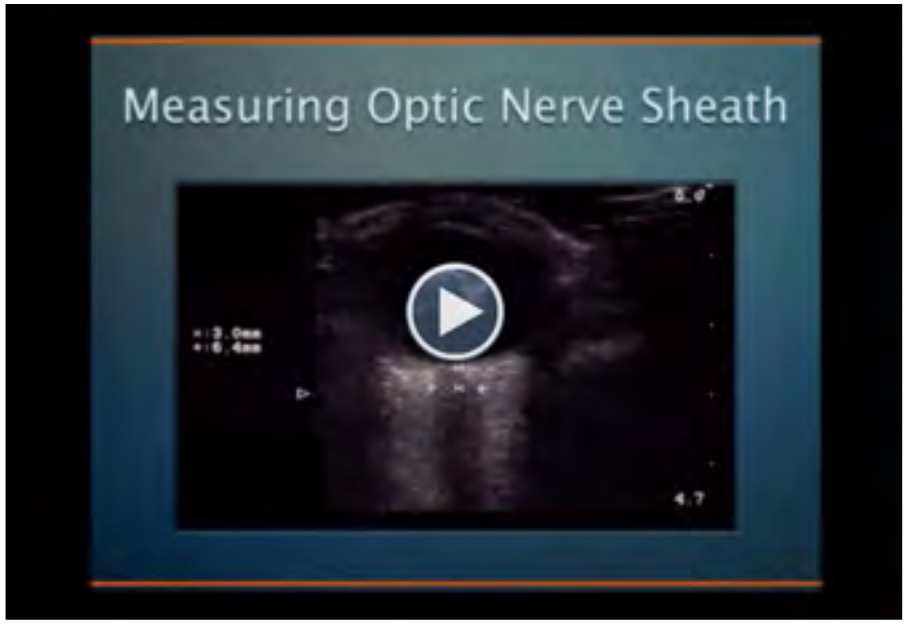
DVT

Click below to watch the Ultrasound Podcast on DVT as well as the One Minute Ultrasound video on DVT

CHAPTER 28

Ocular

While you wait, put your eyes on the Ultrasound Podcast Ocular episode as well as the One Minute Ultrasound ocular video...



Chapter 29

Soft Tissue

Check out the One Minute Ultrasound soft tissue video while you wait...

CHAPTER 30

Pediatrics

Coming Soon...

CHAPTER 31

Administration

Coming Soon...

CHAPTER 32

Medical School Curriculum

Coming Soon...

Chapter 33

Prehospital

Coming Soon...

Chapter 34

Emerging Uses

Coming Soon...

Chapter 35

BONUS!

Coming Soon...