Appendix The Core Content of Clinical Ultrasonography Fellowship Training

The following document details the resident level (Topics 1-18) and fellow level (Topics A1-A22) curriculum for Clinical Ultrasonography education. Each application description will include a scanning protocol, normal anatomy and pathology to be mastered and how to integrate into the clinical care of the patient.

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Resident Level

Fellow Level

TOPIC I. FOCUSED ASSESSMENT WITH SONOGRAPHY IN TRAUMA

SCANNING PROTOCOL

Transducer and System Settings

The Focused Assessment with Sonography in Trauma or the FAST examination can be performed with a curvilinear or curved array transducer, using either the standard or small footprint curve format. A phased array probe can also be utilized. Pediatric or smaller patients should be imaged with a small curved array or a phased array due to the smaller probe footprint. Ultrasound systems should be set to general abdominal imaging, even if a phased array probe is used. Lower frequency settings or a lower frequency broadband transducer can be used for obese patients.

The pulmonary component for evaluation of pneumothorax can be performed with a high frequency linear array probe for greater resolution. However, this portion of the examination can be adequately performed with either the curved or phased array probe that was utilized for the other portions of the examination.

Patient Positioning

The FAST examination is frequently performed as part of the primary or secondary survey in the evaluation of the trauma patient. It has also been utilized in the assessment of hemodynamically unstable patients with an unknown etiology. Due to the commonly critical nature of these two groups, the FAST examination is generally performed with the patient in the supine position.

Image Acquisition

The FAST examination differs from some other ultrasound studies since it is a problem focused examination rather than an anatomically derived evaluation. It also includes the evaluation of several potential spaces in additional to abdominal and thoracic organs. There are several anatomic locations that are interrogated for completion of the study.

The cardiac views are obtained from the subxiphoid approach in a coronal plane. The abdominal orientation (machine setting) is preferred since the study is performed most commonly in an abdominal preset. The probe can be moved to the patient's right, lateral to midline, and angled towards the heart to avoid gastric and colonic gas, using the liver as a sonographic window. Alternatively, a parasternal long axis view of the heart can be obtained to avoid abdominal gas. Cardiac evaluation should occur over several cardiac cycles to ensure adequate visualization.

The right upper quadrant (RUQ) view is obtained in a coronal plane through the upper right quadrant of the abdomen and the lower right postero-lateral thorax. The probe is initially placed in the mid-axillary line at roughly the 10th to 12th intercostal space. Fanning the transducer from this position will allow for imaging supra-diaphragmatically through both the inferior pole of the liver and the inferior pole of the kidney to identify the appropriate anatomic structures and interfaces. The primary area of interest is "Morison's Pouch", the interface between the kidney and the liver. Attention to the area superior to the diaphragm provides information on fluid within the right thoracic cavity.

The left upper quadrant (LUQ) view is obtained in a coronal plane through the upper left quadrant of the abdomen and the lower left postero-lateral thorax. The probe is initially placed in the posterior axillary line at roughly the 9^{th} to 12^{th} intercostal space. Fanning the transducer from this position will allow for imaging from the sub-diaphragmatic space and perisplenic region to the inferior pole of kidney to identify the appropriate anatomic structures and interfaces. Attention to the area superior to the diaphragm provides information on fluid within the left thoracic cavity.

The pelvis area is imaged in both sagittal and transverse planes at the level of the bladder and retrovesical organs (uterus or prostate and rectum). Sagittal images of the pelvis are obtained between the lateral edges the bladder. Transverse images are obtained from the inferior to the superior border of the bladder.

The pleural interface is imaged for evaluation of pneumothorax; this is separate from the evaluation of the lower thorax for the presence of fluid. At a minimum bilateral anterior rib spaces in the upper thorax should be evaluated.

NORMAL ANATOMY

Pericardial

The pericardial space is a potential space and in non-pathologic conditions, the pericardium and epicardial surface is a contiguous image. Anterior to the pericardial space a pericardial fat pad can sometimes be visualized, characterized by a focal hypoechoic structure that is contiguous and moves with the adjacent epicardium.

Abdominal/Pelvic

The hepatorenal and splenorenal spaces are potential spaces and normally should be devoid of any fluid. The renal and solid organ capsule should be opposed and form a contiguous signal. A normal variant includes hypoechoic retroperitoneal fat between the liver or spleen and the renal capsule, causing a separation of the renal capsule and the hepatic or splenic capsule. The sub-diaphragmatic space between the diaphragm and the liver or spleen is also a potential space where fluid can accumulate in a pathologic condition; generally the diaphragm and superior organ border form a continuous echo signal.

The normal slightly filled bladder has a triangular appearance in the sagittal plane and a square shape in the transverse plane. The retrovesical space, anterior cul-de-sac, and posterior cul-de-sac are potential spaces and should not contain a significant amount of fluid. Other non-pathologic conditions such as ovulation can result in trace amounts of fluid in the pelvis.

Thoracic

The supra-diaphragmatic region of the thorax evaluated from the RUQ and LUQ views can show a mirroring artifact of the liver or spleen. The thoracic cavity and contents including the thoracic spine should not be visible in the non-pathologic state. In the absence of thoracic pathology, anterior superior thorax evaluations should show the pleural line with visible lung sliding.

PATHOLOGY

Pericardial

The anechocic separation of the epicardial surface and the pericardium connotes the presence of a pericardial effusion. Pericardial blood appears variably as anechoic in acute bleeding to a tissue-like pattern in the context of clotted blood. Cardiac function can be evaluated for the presence or absence of cardiac activity, but since abdominal preset imaging favors spatial resolution over temporal resolution only gross evaluation of cardiac function can be made (see section on cardiac imaging).

Abdominal/Pelvic

When the abdominal potential spaces contain fluid they will appear as anechoic wedges with sharp edges. This can occur at the sub-diaphragmatic space between the diaphragm and the liver or spleen, the hepato-renal space, the spleno-renal space, and at the inferior edges of the liver, spleen, or kidneys. Fluid can also appear as anechoic sharp-edged interfaces posterior to the bladder in the males and in the posterior and anterior cul-de-sac in females. Fluid in the posterior cul-de-sac in female patients can be physiologic depending on the menstrual cycle, but anterior cul-de-sac fluid should be considered pathologic.

Thoracic

Fluid in the inferior thorax can be seen by the loss of mirroring artifact, visualization of the supra-diaphragmatic spine, and the presence of an anechoic wedge superior to the diaphragm. Presence of only one or two of these elements should raise the suspicion for atelectasis or artifact. Loss of lung sliding and the presence of a lung point in the anterior thorax denote the presence of a pneumothorax (see section on thoracic imaging).

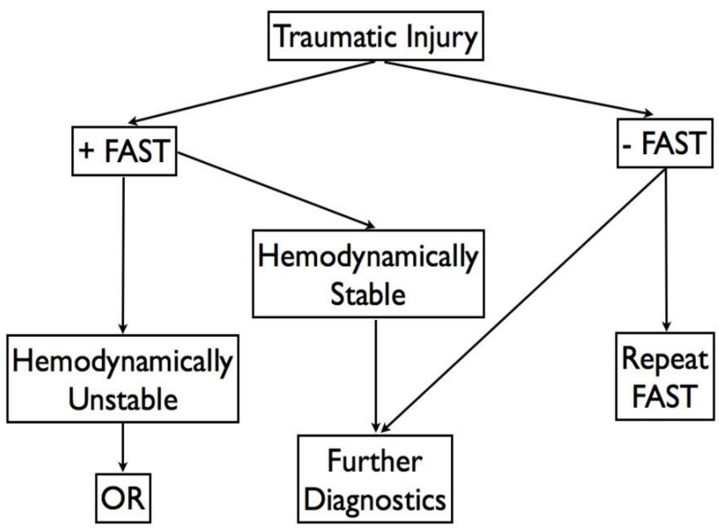
CLINICAL INTEGRATION

Trauma

The most common use of the FAST examination is to evaluate the traumatically injured patient as a part of the primary or secondary survey. In the hemodynamically unstable patient the presence of abdominal fluid on the FAST examination can be utilized to prioritize patients for operative therapy and/or help identify life-saving procedures such as emergent pericardiocentesis. Hemothorax or pneumothorax diagnosed by FAST can prioritize the placement of a tube thoracostomy. A FAST positive for free fluid can be used to prioritize patients for operative therapy or further diagnostic studies to form a treatment plan in the hemodynamically stable patient.

A negative FAST does not exclude the presence of injury, especially to the solid organs. The FAST examination can be repeated over time to evaluate for slow accumulation of fluid. A negative FAST does not exclude the need for additional diagnostic studies based upon the clinical situation.

Even in patients who have experienced chest or abdominal trauma, the presence of fluid on the FAST examination does not necessarily mean that there is a traumatic injury. Alternative possibilities such as pre-existing pleural effusions, pericardial effusions, ascites, and lung disorders unrelated to the traumatic event should be considered.



SEMINAL STUDIES

The FAST examination has been one the longest and most studied uses of clinical ultrasonography. As such there is a large amount of data for the performance, use, and integration of the FAST examination for experienced users. It shows good performance for the evaluation of injury in the traumatic patient.(1) There is also wide spread support from several societies and guidelines. (2,3) Consensus has been reached on the use, terminology, and implications of thoracic ultrasound that is incorporated into the FAST.(4) Data synthesis from multiple studies also support the use and interpretation of inferior vena cava (IVC) measurements in preload assessment (see Topic 10).(5)

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TOPIC 2. FOCUSED CARDIAC ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

A transthoracic bedside echocardiogram (TTE) is typically performed with the patient supine and the sonographer positioned on the patient's right side (consistent with other bedside ultrasound examinations). Alternatively, the TTE can be done from the patient's left side using the sonographer's left hand if they are comfortable imaging this way. When possible, particularly for the apical and parasternal views, having the patient turn to a left lateral decubitus position may enhance visualization.

Transducer and System Settings

Scanning is best performed using a phased array probe with tissue harmonic imaging and an optimized cardiac preset. Understanding probe-to-screen orientation is particularly important in TTE, as the orientation convention used in cardiology is reversed from that used in other ultrasound ex

aminations. Most emergency sonographers use the standard screen-to-probe orientation (probe indicator corresponds to left of screen as it is viewed), although a cardiology convention may be used. Differences in conventions and indicator positioning for different views need to be understood to appreciate anatomy and adequately recognize pathology.

Image Acquisition

Three windows and six major views comprise the focused point-of-care TTE examination:

Parasternal long axis (PSLA): The probe is placed to the left of the sternum with the plane of the ultrasound directed from the right shoulder to left hip. The view includes right ventricle (RV) anteriorly; left atrium (LA), mitral valve (MV), and left ventricle (LV) posteriorly; aortic valve (AoV) and left ventricular outflow tract (LVOT) centrally. The descending aorta should be appreciated in cross section in the far field of the screen. The PSLA window may be angled inferiorly to obtain an RV view and to interrogate the tricuspid valve (TV). The parasternal short axis (PSSA) is obtained by rotating the transducer 90 degrees clockwise from the PSLA. It is used primarily for evaluation of the LV, the PSSA ultrasound plane should be scanned systematically through the four levels: apex, papillary muscles, MV ("fish mouth"), and AoV ("Mercedes Benz sign").

Apical: The probe is placed at the point of maximal impulse, angled towards the patient's right scapula or shoulder. The ventricular septum should be seen vertically on the screen. In the apical four chamber view (A4C) all four chambers (LV, RV, LA, RA) and two valves (TV, MV) should be seen. This view is optimal for comparing RV to LV and interrogating the TV and MV. The A4C includes the lateral and septal LV walls. The apical two-chamber view (A2C) is obtained by rotating the probe 90 degrees to visualize the anterior and inferior LV walls.

Subcostal (or subxiphoid): The probe is placed in the subxiphoid area and is directed towards the patient's left shoulder. The view includes the RA, RV, LA, and LV. The hepatic veins may be followed into the inferior vena cava (IVC) and RA. The subcostal short axis is obtained by rotating the probe so that the indicator is directed towards the patient's head and the IVC is seen in long axis emptying into the RA, allowing assessment of IVC diameter and collapsibility.

NORMAL ANATOMY

Interrogation of normal anatomy for basic cardiac ultrasound includes visualizing the pericardium, four chambers (LV, RV, RA, LA), the aortic root, descending aorta, and IVC.

- A normal pericardial fat pad may appear as a hypoechoic area (particularly on the anterior part of the PSLA view) with some internal echoes that move with the heart and are less evident in diastole.
- The LV cavity should not exceed a largest diameter of 5.2cm in diastole and should contract symmetrically with normal ejection fraction (>50%) and normal wall thickness (<1.2cm in diastole).
- The RV should contract symmetrically and well, with an RV:LV size ratio (best measured in an A4C view) of about 0.6:1.
- Atria are typically less than 4.0cm in largest diameter.
- The thoracic aortic root and descending thoracic aorta should be 4.0cm or less.
- The IVC should be <2.5cm maximum diameter and should exhibit ~50% collapse with quiet inspiration in a normally hydrated patient.

PATHOLOGY

Pericardial Effusion.

The anechocic separation of the epicardial surface and the pericardium connotes the presence of a pericardial effusion. The size may be graded as small (<1cm), moderate (1-2cm), and large (>2cm), measured at the largest point in diastole. It is important to note that blood clot and loculated effusions can appear with variable echogenicity that may appear tissue-like.

Pericardial Tamponade.

Tamponade is largely a clinical diagnosis (evidence of hemodynamic compromise in a patient with an effusion). However, there are some basic echocardiographic signs of tamponade and they include RA systolic and RV diastolic inversion, a plethoric

IVC and decreased RV filling during diastole. More detailed descriptions are found in the advanced cardiac section (Topic A3).

Evaluation of Global Cardiac Function.

Global assessment of cardiac function is usually done by visually estimating the squeeze of the LV and estimating whether the cavity chamber size decreases by more than 50% (normal), only by 30-50% (decreased) or less than 30% (severely decreased).

Evaluation of RV function.

An RV:LV ratio >0.6:1 in the A4C view is considered indicative of RV enlargement but a RV:LV ratio of 1 or greater is more specific for RV enlargement. Other signs of RV strain or pressure overload include RV hypokinesis, paradoxical septal motion and septal flattening ("D-shaped septum") and McConnell's sign (RV hypokinesis with apical sparing, specific for pulmonary embolism). RV overload may indicate acute pulmonary embolism. RV overload may also be chronic, typically resulting in RV hypertrophy (RV free wall 5mm or greater in diastole).

CLINICAL INTEGRATION

Clinical cardiac ultrasonography is very useful in patients with undifferentiated hypotension, chest pain or dyspnea where the exact etiology of the symptoms is unknown. The TTE examination may be done in isolation but is frequently combined with other examinations of the chest, abdomen and vasculature depending on the clinical scenario. TTE may be indicated in the patient with: shortness of breath, hypotension, hypoxia, tachycardia, syncope, chest pain, an abnormal EKG, cardiomegaly on chest radiography, trauma, altered mental status, or sepsis.

In addition, there is equal value in assessing global cardiac function in an arrest, peri-arrest or resuscitation scenario. Evaluation with TTE for cardiac contractility has been shown to identify patients with "pseudo-PEA" or cardiac contractility on ultrasound without a palpable pulse. Multiple studies have shown that TTE can identify patients with contractility in the resuscitation scenario and that they tend to have better outcomes. Moreover, multiple causes of PEA arrest can be identified by ultrasound and thus more expeditiously treated (e.g. pneumothorax, pericardial effusion, hypovolemia).

SEMINAL STUDIES

Policy Statements

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Pericardial Effusion/Tamponade

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

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2. Jones AE, Tayal VS, Kline JA. Focused training of emergency medicine residents in goal-directed echocardiography: a prospective study. *Acad Emerg Med*. 2003;10:1054-8.

RV Strain/PE

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2. Dresden S, Mitchell P, Rahimi L, et al. Right Ventricular Dilatation on Bedside Echocardiography Performed by Emergency Physicians Aids in the Diagnosis of Pulmonary Embolism. *Ann Emerg Med*. 2014; 63:16-24.

IVC

1. Kircher BJ, Himelman RB, Schiller NB. Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. *Am J Cardiol.* 2005;66:493-6.
2. Gunst M, Ghaemmaghami V, Sperry J, et al. Accuracy of cardiac function and volume status estimates using the bedside echocardiographic assessment in trauma/critical care. *Trauma*. 2008; 65(3):509-16

Cardiac Arrest

1. Salen P, Melniker L, Chooljian C, et al. Does the presence or absence of sonographically identified cardiac activity predict resuscitation outcomes of cardiac arrest patients? *Am J Emerg Med*. 2005;23:459-62.
2. Blaivas M, Fox J. Outcomes in cardiac arrest patients found to have cardiac standstill on the bedside emergency department echocardiogram. *Acad Emerg Med*. 2001;8:616-621.

Cardiac US-guided resuscitation

1. Rose JS, Bair AE, Mandavia D, et al. The UHP protocol: a novel ultrasound approach to the empiric evaluation of the undifferentiated hypotensive patient. *Am J Emerg Med*. 2001;19:299-302.
2. Tayal VS, Kline JA. Emergency echocardiography to detect pericardial effusion in patients in PEA and near-PEA states. *Resuscitation*. 2003;59:315-18.
3. 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;32:1703-8.
4. Breitkreutz R, Walcher F, Seeger FH. Focused echocardiographic evaluation in resuscitation management: concept of an advanced life support-conformed algorithm. *Crit Care Med*. 2007;15(Suppl 5):S150-61.

TOPIC 3. BASIC THORACIC ULTRASOUND

Pneumothorax and Pleural Effusion Evaluation

SCANNING PROTOCOL

Patient Positioning

For either application, the patient can be scanned upright or in the supine position. In the supine position, air should layer anteriorly while fluid will layer in the posterior thoracic cavity. In the upright position, air should rise to the apices, while fluid will collect superior to the diaphragm.

Transducer and System Settings

A high frequency linear probe is usually used to interrogate the pleura although a low frequency probe can be used as long as the depth is adjusted to bring the pleural line to the center of the screen. A low frequency curvilinear or phased array probe is typically used to evaluate for effusions.

Image Acquisition

When evaluating the pleura for a pneumothorax, the linear transducer should be placed in a sagittal plane at the 3^{rd} to 4^{th} intercostal space at the most anterior point on the chest wall. If the patient is upright then the probe should be placed in the mid-clavicular line at the apex of the chest. Using B-mode, first identify two ribs and their shadows with the pleura situated between the ribs. *The more rib spaces that are interrogated the more sensitive the examination will be.*

When evaluating the chest cavity for fluid, the transducer is placed in the mid-axillary line with the indicator to the patient's head in the right or left upper quadrant, and using the liver or spleen as an acoustic window, the diaphragm and the hemithoraces should be identified.

NORMAL ANATOMY

Pleura

Horizontal to-and-fro movement of the visceral and parietal pleura should be visualized at the pleural line, which is termed "lung sliding." This indicates that the two pleural surfaces are in contact and there is no pneumothorax. In M-mode a granular pattern should be seen below the pleural line ("seashore sign"), again ruling out a pneumothorax. Power Doppler can also be used to identify movement at the pleural line.

Pleural Fluid

The diaphragm will appear as a bright echogenic line superior to the liver or spleen. The mirror image artifact should be seen above the diaphragm when there is no pleural fluid in the thoracic cavity and the vertebral column shadows should not extend superior to the diaphragm.

PATHOLOGY

Pneumothorax

Absence of lung sliding suggests that the patient has a pneumothorax. M-mode can be used to confirm the lack of motion, which is represented by parallel lines below the pleural line ("stratosphere sign" or "barcode sign"). Using B-mode, a lung point may also be identified. This finding, demonstrated by an alternating pattern of seashore and stratosphere signs, is highly specific for a pneumothorax. The lung point represents the location along the chest wall at the edge of the pneumothorax where there is a transition from normal pleural opposition to separation.

Pleural Fluid

Pleural fluid appears as an anechoic wedge-shaped collection superior to the diaphragm and the vertebral column shadow will extend above the diaphragm when pleural fluid is present. If the pleural effusion is large, the lung can be seen floating within the effusion. The superior aspect of the transducer may need to be angled posteriorly to minimize rib shadows.

CLINICAL INTEGRATION

Early detection of a pneumothorax or hemothorax is crucial, especially in an unstable patient. Thoracic ultrasound can be used in both trauma and medical patients and help to decrease the time to diagnosis. Multiple studies have shown an improved sensitivity and specificity of ultrasound when compared to chest radiographs for both pneumothorax and pleural effusion assessment.

It is important to remember that lack of lung sliding is suggestive of a pneumothorax in the right clinical setting. However, lung sliding may also be absent in other conditions, including severe chronic obstructive pulmonary disease, acute respiratory distress syndrome, mainstem bronchus intubation, previous lung surgery/pleurodesis, or in intubated patients with high PEEP settings. While lung sliding is very sensitive when a thorough examination is performed and can be very helpful in ruling out a pneumothorax, lack of lung sliding is less specific and must be correlated clinically.

SEMINAL STUDIES

1. Lichtenstein DA, Meziere G, Lascols N, et al. Ultrasound diagnosis of occult pneumothorax. *Crit Care Med*. 2005, 33:1231-8.
2. 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, 57:288-95.
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5. 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.

TOPIC 4. AORTA ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

The supine position is preferred, although if patients cannot lie flat, the examination can be completed with the patient in a semi-recumbent position. The examination is easiest if the abdominal wall is relaxed.

Transducer and System Settings

Choose a low frequency (2-5 MHz) curvilinear or phased array transducer with the ultrasound machine set to a general abdominal or aorta preset.

Image Acquisition

Begin in the epigastrium in a transverse orientation (indicator at 9 o'clock), using the liver as an acoustic window when possible. Adjust the focal depth so that the aorta is imaged optimally in the midfield. Gently move down the abdomen to visualize the entire length of the aorta, down to and including the bifurcation into the common iliac arteries. Repeat the scan in a longitudinal orientation (indicator at 12 o'clock), being sure to observe the major branches of the aorta (celiac axis, superior mesenteric artery, renal arteries). Rock the transducer side-to-side to be sure that the scan continues in the long axis of the aorta; a tortuous aorta may require adjustments in scan position for accurate measurements. In the nonfasting patient, bowel gas commonly obscures the aorta. Gentle pressure can displace the bowel gas; altering the transducer orientation to an oblique approach, or moving the patient to a lateral decubitus position may offer alternative techniques to fully visualize the aorta in its entirety. Measure the diameter of the aorta in two planes. A normal abdominal aorta should be ≤3 cm at the epigastrium, then gently taper as it courses caudad. The normal diameter of the common iliacs is ≤1.5 cm.

NORMAL ANATOMY

The abdominal aorta enters the abdomen through the diaphragm and courses in the long axis of the body. It lies just anterior to the vertebral column, in the midline or just to the right of midline. In the epigastrium it first gives rise to the celiac trunk (that branches into the common hepatic, left gastric and splenic arteries), then the superior mesenteric artery, the renal arteries, and the inferior mesenteric artery (though the latter is not typically visualized). It terminates at the level of the 4^{th} lumbar vertebra as it divides into the common iliac arteries. The ultrasound appearance of the aorta is a thick-walled structure in the pre-vertebral space. Atherosclerotic changes tend to cause the wall of the aorta to be somewhat irregular in appearance. Plaque and calcium may generate shadowing.

It is important to distinguish between the IVC and the aorta; both structures are in the long axis of the body and may appear similar in ultrasound appearance. In the transverse orientation, both will be seen in short axis; the IVC will lie more to the right and tends to drape over the vertebral body. The IVC tends to have thinner appearing walls (sometimes even difficult to visualize the actual wall) that lack the atherosclerotic changes and muscular wall typical of aorta. Outside the liver, the IVC lacks the characteristic branching of the aorta: identification of the major branches of the aorta will confirm the identity.

PATHOLOGY

The most common concern with respect to the abdominal aorta is the detection of dilatation. An aneurysm will appear as a dilated aorta of variable length. Diseased aortas may have thrombus that will appear as gray or mixed echogenicity within the lumen. Measurements of diseased aortas should include surrounding thrombus; failure to measure thrombus can lead to false or misleading measurements.

Aortic dissections that extend into the abdominal aorta may be detected; they appear as an echogenic flap that moves in real-time with the pulsations of the aorta. Care should be taken to not confuse thrombus with an intimal flap. A dissection flap should be visualized in two planes to confirm.

CLINICAL INTEGRATION

Rupture of an abdominal aortic aneurysm (AAA) is typically a catastrophic event but may be portended by vague abdominal or back pain. Sudden collapse with hypotension is a common late presentation. Evaluation for an aortic aneurysm is typically emergent, and clinical ultrasonography is ideally suited for the rapid evaluation of the aorta. The presence of an AAA in the face of pain, syncope, or hypotension is sufficient for an emergent vascular consultation with a surgeon. Ruptures tend to occur in the retroperitoneum; free intraperitoneal fluid is unusual and a negative FAST examination should not give false reassurance. A retroperitoneal rupture may at times be seen by ultrasound, but typically is not. In the clinically symptomatic aneurysm, the aneurysm may be tender. In the high-risk unstable patient, surgical consultation should take priority over attempts at further imaging. In the stable patient, additional studies (e.g. CT) should be expedited to prevent delays and potential for deterioration.

SEMINAL STUDIES

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2. Constantino TG, Bruno EC, Handly N, et al. Accuracy of emergency ultrasound in the evaluation of abdominal aortic aneurysm. *J Emerg Med*. 2005;29(4):455-60.
3. Knaut AL, Kendall JL, Patten R, et al. Ultrasonographic measurement of aortic diameter by emergency physicians approximates results obtained by computed tomography. *J Emerg Med*. 2005;28(2):119-26.
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):219-23.

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TOPIC 5. BILIARY ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

Imaging may begin with the patient supine, ideally with the head supported, arms relaxed at the patient's sides and slight flexion to the hips and knees. Analgesia may also be beneficial. Placing the patient more upright or in reverse Trendelenburg may help in more difficult scans. The left lateral decubitus position is usually helpful and some prefer to begin scanning with the patient in this position.

Transducer and System Settings

Choose a low frequency (2-5 MHz) curvilinear or phased array transducer with the ultrasound machine set to a general abdominal, gallbladder, or biliary preset.

Image Acquisition

Imaging may begin with the subcostal sagittal view with the transducer placed just under the right costal margin in the midclavicular line and the indicator directed cephalad. Instructing the patient to inhale deeply will usually result in more complete visualization of the anatomy of the liver and gallbladder. An intercostal view may be necessary. This view can be obtained in multiple locations depending on the patient's anatomy. A common location is with the transducer 1-2 rib spaces above the right costal margin in the midclavicular line with the indicator initially directed cephalad. Slight rotation of the probe may be required to obtain a true long axis view of the gallbladder. Once the gallbladder is identified, the transducer may be rotated to obtain transverse and oblique views. Coronal views may be obtained with the transducer placed in the midaxillary line at approximately the level of the xiphoid and the indicator directed cephalad. Transverse or oblique views may be obtained from this position as well.

If difficulty is encountered, imaging may be optimized with respiration, changes in patient position and utilizing multiple transducer positions.

A complete scan should document still images, or preferably cine-loops of the entire gallbladder to include the fundus, body, and special attention to the gallbladder neck in both long and transverse planes. Images or clips through the portal triad, including the common bile duct should be included. If the gallbladder wall appears abnormal, the wall thickness should be measured anteriorly to avoid posterior artifacts related to bowel gas or posterior acoustic enhancement. The normal thickness of the gallbladder wall should be <4 mm. The inner diameter of the common bile duct should be measured if it appears abnormal, with normal diameter (on average) being <6 mm. A number of factors, however, can increase the diameter of the duct including increasing age and interventions such as cholecystectomy and sphincterotomy.

NORMAL ANATOMY

The normal gallbladder is a sac filled with hypoechoic or anechoic bile that is surrounded by a thin, hyperechoic wall. It is often surrounded by hepatic parenchyma with a rounded fundus, tapering toward the gallbladder neck. The gallbladder can have many different orientations in the right upper quadrant but generally the long axis of the gallbladder from the fundus to the neck is oriented toward the portal triad. The gallbaldder may contain thin echogenic folds and typically, posterior acoustic enhancement is seen. The contracted gallbladder may be more difficult to image, but can usually be identified by its proximity to other sonographic landmarks, the main lobar fissure and the portal vein. The contracted gallbladder may appear to have a thickened wall, but will usually measure <4 mm. The common bile duct has echogenic walls and usually runs parallel with the portal vein to complete the portal triad. In transverse the portal triad typically forms three circles in cross section with the portal vein flanked by the hepatic artery and the common bile duct.

PATHOLOGY

The primary pathology of interest is gallstones. Gallstones generally appear hyperechoic and are typically found in dependent areas. They interrupt the smooth curvature of the posterior gallbladder wall and cast acoustic shadows. The acoustic shadows of gallstones typically appear hypoechoic with sharp margins or "clean", compared to the more diffuse, echogenic or "dirty" shadows seen due to intestinal air.

Gallbladder sludge may also be seen which is usually echogenic and may appear heterogeneous. Sludge is usually dependent, but does not cast acoustic shadows.

Gallbladder wall thickening is very specific in the diagnosis of cholecystitis. The wall should be measured anteriorly and the texture and echogenicity should be noted. A diseased gallbladder will often have a more hypoechoic and heterogeneous appearing wall. Fluid, gas or hyperechoic deposits in the gallbladder wall should be noted.

Pericholecystic fluid is typically hypoechoic and present in small amounts layering along the gallbladder wall and even in Morison's pouch. It is highly specific in the diagnosis of cholecystitis.

Pathologic air, which appears hyperechoic with "dirty" shadows and rises to the highest possible point, may be seen in the gallbladder lumen, within the gallbladder wall or external to the gallbladder in cases of emphysematous cholecystitis. Air within the gallbladder lumen may also occur following some procedures such as endoscopy.

The sonographic Murphy's sign is localized tenderness that is elicited with the transducer directly over the gallbladder. When eliciting this sign, it is important to compare the gallbladder tenderness to tenderness over the remainder of the abdomen.

The common bile duct should be examined for dilation which may imply a distal obstruction. Focal dilatation occurs in other conditions such as choledochal cysts. Stones or air in the common bile duct may also be seen in biliary tract pathology.

CLINICAL INTEGRATION

Acute cholecystitis is largely a clinical diagnosis that is significantly aided by clinical ultrasonography. Diagnoses range from normal gallbladder, asymptomatic or incidental abnormal findings such as stones or sludge, to symptomatic subacute gallbladder disease or lastly acute cholecystitis. Differentiating among these conditions requires history, physical examination, and often laboratory studies. The presence of gallbladder wall thickening and pericholecystic fluid are highly specific for acute cholecystitis, but may rarely be seen in other nonurgent conditions. Symptomatic gallbladder dysfunction may occur in the absence of sonographic findings and the clinical picture should dictate whether further diagnostic evaluation is pursued.

SEMINAL STUDIES

Several studies have examined the accuracy and benefits of gallbladder ultrasound performed by emergency physicians at the bedside. In a 2001 study, Kendall and Shimp compared, in a blinded fashion, emergency physician performed biliary ultrasound studies to radiology studies and showed that emergency physicians could detect gallstones with a 96% sensitivity and the examination could be completed in <10 minutes. Similarly, in 2006 Miller et al. and Scruggs et al. in 2008 showed high correlation between bedside and radiology ultrasound in the detection of gallstones. In 2010, Summers et al. showed in a prospective study that emergency physicians' diagnostic accuracy for cholecystitis was comparable to radiologists. All of these studies demonstrate that appropriately trained emergency physicians can accurately and efficiently diagnose biliary pathology at the bedside. Additionally, Blaivas et al. showed in 1999 that patient length of stay could be significantly reduced by emergency physician performed biliary ultrasound when compared to radiology studies, implying a significant savings in healthcare resources.

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TOPIC 6. RENAL ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

Both kidneys and the bladder can usually be imaged with the patient in the supine position, but it may be necessary to turn the patient into the lateral decubitus or prone position to obtain better visualization.

Transducer and System Settings

Choose a low frequency (2-5 MHz) curvilinear or phased array transducer with the ultrasound machine set to a general abdomen or renal examination preset. A smaller curvilinear transducer may also be used if rib shadows obscure important detail.

Image Acquisition

Kidney: The kidney should be scanned in both long and short axis. To obtain a long axis view of the right kidney, the transducer is placed over the right lower intercostal spaces in the mid-axillary line with the transducer aimed posteriorly and indicator directed cephalad. The kidneys lie obliquely and it may be necessary to rotate the transducer slightly to obtain the longitudinal axis of the kidney. The transducer is swept anteriorly to posteriorly and cephalad to caudad in order to image the entire kidney. To obtain a long axis view of the left kidney, a more posterior approach is required to avoid stomach or intestinal air interference. The transducer is placed in the posterior axillary line over the left lower intercostal spaces but more cephalad than when imaging the right kidney. The left kidney should be scanned in the long axis using the same technique as the right kidney. For the short axis view of the both kidneys, the transducer is rotated 90 degrees from the long axis with indicator pointing down towards the floor. If difficulty is encountered, changes in patient position (from supine to lateral decubitus or prone) or respiration (asking the patient to inhale then exhale) can improve imaging of the kidney.

Bladder: The probe is placed in the suprapubic area, in the midline with the indicator aimed cephalad. The probe can then be angled slightly downward toward the pelvis until the bladder is visualized. The entire bladder should be evaluated by "fanning" the probe laterally until the largest dimensions of the bladder are found. The image should then be frozen and using calipers measurements of the depth (anterior to posterior) and the length (cephalad to caudad). The probe should then be rotated counterclockwise until the probe indicator is pointing to the patient's right to obtain a transverse view. Once again the entire structure should be evaluated. When the largest dimension is visualized, the image should be frozen and the third dimension, width (lateral to lateral) should be obtained. These measurements (depth, length, and width) should be collected and will be used to calculate the bladder volume. The calculation of bladder volume is as follows:

[Depth (mm) x Length (mm) x Width (mm)] x 0.7 = Bladder Volume (mL)

NORMAL ANATOMY

Kidney: The normal kidney will be surrounded by an echogenic capsule consisting of perinephric fat and Gerota's fascia. The renal cortex and the medullary pyramid make up the parenchyma of the kidney. The renal cortex appears less echogenic than the liver and the medullary pyramids filled with urine appear less echogenic than the renal cortex. The renal sinus, consisting of the renal pelvis, calyces and sinus fat, and renal vasculature as a whole appears very echogenic. Normal ureters are usually not visualized with ultrasound, however dilated ureters may be appreciated.

Bladder: A normal bladder should have smooth walls and should contain anechoic fluid. The bladder appears as a fluid filled structure in the pelvis. Using color or power Doppler, ureteral jets may be appreciated intermittently near the trigone area of the bladder in patients without ureteral obstruction. A normal empty bladder may contain little or no anechoic fluid.

Identification of a catheter balloon in the lumen of the bladder is a normal finding for an adult patient with an indwelling bladder catheter.

PATHOLOGY

Kidney: The most common reason for a clinical ultrasonography renal examination is to evaluate for obstructive uropathy. Hydronephrosis is the most commonly seen sonographic abnormality in patients presenting with obstructive uropathy. Hydronephrosis appears as anechoic areas within the normally echogenic renal sinus. The degree of hydronephrosis is based solely on visual diagnosis and is graded as mild, moderate or severe. Doppler imaging of the renal sinus can sometimes be useful as prominent renal vasculature can be mistaken for mild hydronephrosis.

Renal stones may occasionally be visualized within the kidney and appear as hyperechoic structures producing shadows. Placing color Doppler on a suspected stone and identifying the "twinkling" artifact can help to identify larger stones. A dilated hydroureter may also be appreciated however ureteral stones are rarely seen using ultrasound. Bilateral hydronephrosis or a distended bladder may indicate bladder outlet obstruction.

Renal cysts are a common finding and must meet the following criteria to be considered benign: 1) smooth, rough, or oval-shaped, 2) lack internal echoes or solid elements, 3) well-defined interface between cyst and adjacent renal parenchyma, and 4) posterior acoustic enhancement posterior to the cyst. If a cyst does not meet the aforementioned criteria, the patient should be referred for further evaluation. Polycystic kidney disease produces kidneys with multiple cysts, which can be visualized as a collection of large simple cysts with no discernible renal structure.

Bladder: A full bladder can be normal or the sign of pathology. A full bladder should prompt further evaluation with a post-void residual. Post-void, the bladder volume should be measured and recalculated. A post-void residual of greater than 50 mL is abnormal and should prompt further evaluation.

CLINICAL INTEGRATION

Kidney: The following questions should be answered when evaluating a patient with hydronephrosis:

1. Is there hydronephrosis? If yes then:
    a. Is the hydronephrosis bilateral or unilateral?
    b. What is the degree (mild, moderate, severe) of hydronephrosis?
2. Is a stone visualized in the calyces or bladder?
3. Is the bladder distended?

If the patient has unilateral hydronephrosis and nephrolithiasis is suspected, then renal calculus it is the most likely diagnosis. If the patient has severe hydronephrosis, there is likely severe obstruction and evaluation of the stone size with CT should be obtained; this will help determine the likelihood of the patient passing the stone independently. If the patient has intractable pain, severe hydronephrosis, fever, or abnormal labs, it is generally prudent to evaluate the patient further for other pathology.

If bilateral hydronephrosis is present in a nonpregnant patient, bladder dysfunction or bladder outlet obstruction should be considered.

Bladder: In adults, evaluation of bladder volume and post-void residual is a useful adjunct to the clinical history and physical examination. A severely distended bladder on initial evaluation or a large post-void residual should prompt further evaluation.

In children and adults, assessment of bladder volume is a useful tool when there is need for urinalysis obtained by catheterization. Low bladder volume is sometimes the cause of failed catheterization. Assessment for urine within the bladder prior to catheterization results in increased success of sample collection and decreased risk of infection due to multiple catheterizations.

SEMINAL STUDIES

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Topic 7. FIRST TRIMESTER PREGNANCY ULTRASOUND

SCANNING PROTOCOL

Ultrasound imaging to diagnose an intra-uterine pregnancy (IUP) includes initial trans-abdominal sonography (TAS), although transvaginal imaging of the uterus may be required to fully and accurately visualize the contents of the uterus. In the second and third trimester, transvaginal sonography (TVS) is rarely necessary.

Transabdominal

Patient Positioning

Imaging may begin with the patient supine, ideally with the head supported, arms relaxed at the patient's sides and slight flexion to the hips and knees. Ideally the bladder will be full, but visualization of the pelvic structures is still possible without the sonographic window of the distended bladder.

Transducer and System Settings

Choose a low frequency (2-5 MHz) curvilinear or phased array transducer with the ultrasound machine set to a general abdomen or obstetrics examination preset.

Image Acquisition

Starting in midline longitudinal orientation (transducer indicator oriented cephalad) above the pubic symphysis with the transducer angled inferiorly toward the coccyx, identify the bladder (near field) and the uterus (far field). Image completely through the uterus in longitudinal orientation, noting any pelvic or intrauterine fluid collections and their location relative to the body of the uterus. Carefully visualize the margin of the uterus, looking primarily for the sharp angles of hypoechoic fluid collections. Next, obtain transverse views, again imaging completely through the uterus, especially noting a generally midline location for any intrauterine structures and the minimum thickness of the myometrium surrounding any gestational sac. Pay special attention to the lateral margins of the uterus where fluid is most likely to collect. Attention should also be paid to the contents of the uterus (if visible) to determine if they meet criteria for a live IUP.

The uterus can be variably located and sometimes extremely retroverted. This can allow bowel gas to interpose and make the uterus difficult to image. The anatomy may require transvaginal imaging for adequate visualization.

Transvaginal

Patient Positioning

Prior to commencing the examination, it is helpful to have the patient void and then undress from the waist down. The lithotomy or a reclined butterfly position with the hips elevated are the most common patient positions for transvaginal scanning.

Transducer and System Settings

Use a mid-frequency (5-8 MHz) endocavitary transducer, with the ultrasound machine set to an ob

stetrics or gynecology preset. Place standard scanning gel on the probe for coupling, followed by a non-latex transducer cover and then bacteriostatic gel for lubrication.

Image Acquisition

Begin in longitudinal orientation (transducer indicator oriented anteriorly) and focus attention on identifying the bladder after entering the introitus and advancing the endovaginal probe closer to the vaginal vault. Once the bladder is identified, systematically search the posterior region to identify the uterus. Image completely through the uterus in longitudinal orientation, noting any pelvic or intrauterine fluid collections and their location relative to the body of the uterus. Note any free fluid in either the posterior and/or anterior cul-de-sacs. Obtain coronal views (transducer indicator oriented to the patient's right), again imaging completely through the uterus, especially noting a generally midline location for any intrauterine structures and the minimum thickness of the myometrium. In the coronal view, look for fluid primarily in the postero-lateral corners.

Although not the focus of a first trimester ultrasound, imaging the adnexa provides valuable clinical information. Occasionally, alternative pathology can be visualized directly in the adnexae (i.e. ectopic pregnancy, cysts, corpus luteum).

If imaging the adnexal region fails to identify the ovary or fallopian tube, gentle pressure on the anterior abdomen can displace the ovary toward the transducer and improve the imaging.

NORMAL ANATOMY

The bladder is a thick-walled structure with a variable amount of fluid that is generally identifiable even when decompressed. The uterus is a pear-shaped, generally homogenous structure located directly posterior to the bladder. The standard uterine position is midline, anteflexed (uterine body relative to cervix) and anteverted (axis of cervix relative to vagina), but may be deviated laterally. The endometrial stripe defines the axis of the uterus. With a standard anteverted uterus, the fundus will curve over the bladder, especially when the bladder is decompressed. The midline hyperechoic endometrial stripe is more pronounced just prior to menses and in pregnancy.

A blastocyst will normally implant adjacent to the endometrial stripe and generally appears contiguous with the stripe but not necessarily centered. Structures appear in a fairly consistent time progression: first a gestational sac (GS) (4.5-5 weeks menstrual age), then a double decidual sign (concentric hyperechoic rings adjacent to the fluid collection, one the chorion, one an endometrial reaction), then a yolk sac (a thin walled round structure usually about 4-5 mm diameter), a fetal pole, and finally a fetal heart beat (>80 bpm for crown rump length<5mm, >100 for crown rump length >5mm). The earliest sonographic definition of an IUP is an anechoic fluid collection with a thickened, hyperechoic ring containing a yolk sac. This complex should be contiguous with the endometrial stripe and within the upper uterine segment. Once the yolk sac involutes, the GS may contain only a fetal pole. Fluid noted in the posterior cul-de-sac (Pouch of Douglas, recto-uterine space) is considered within physiologic limits unless extends more than halfway up the posterior wall of the uterus. Note the location of the implantation as an eccentric location could indicate an interstitial, a corneal or a cervical ectopic pregnancy. An endo-myometrial mantle less than 8mm is concerning. In later pregnancy, important characteristics to note are fetal presentation, placental position, and fetal heart rate determination.

PATHOLOGY

A common finding is the absence of a gestational sac in a patient with a positive pregnancy test. This may represent an early pregnancy, an early spontaneous abortion or an ectopic pregnancy, so clinical correlation is required to guide subsequent management. Pelvic fluid may also be considered pathologic if it tracks more than halfway up the uterus in the posterior cul-de-sac (Pouch of Douglas, recto-uterine space) or if is present in the anterior cul-de-sac (vesico-uterine space).

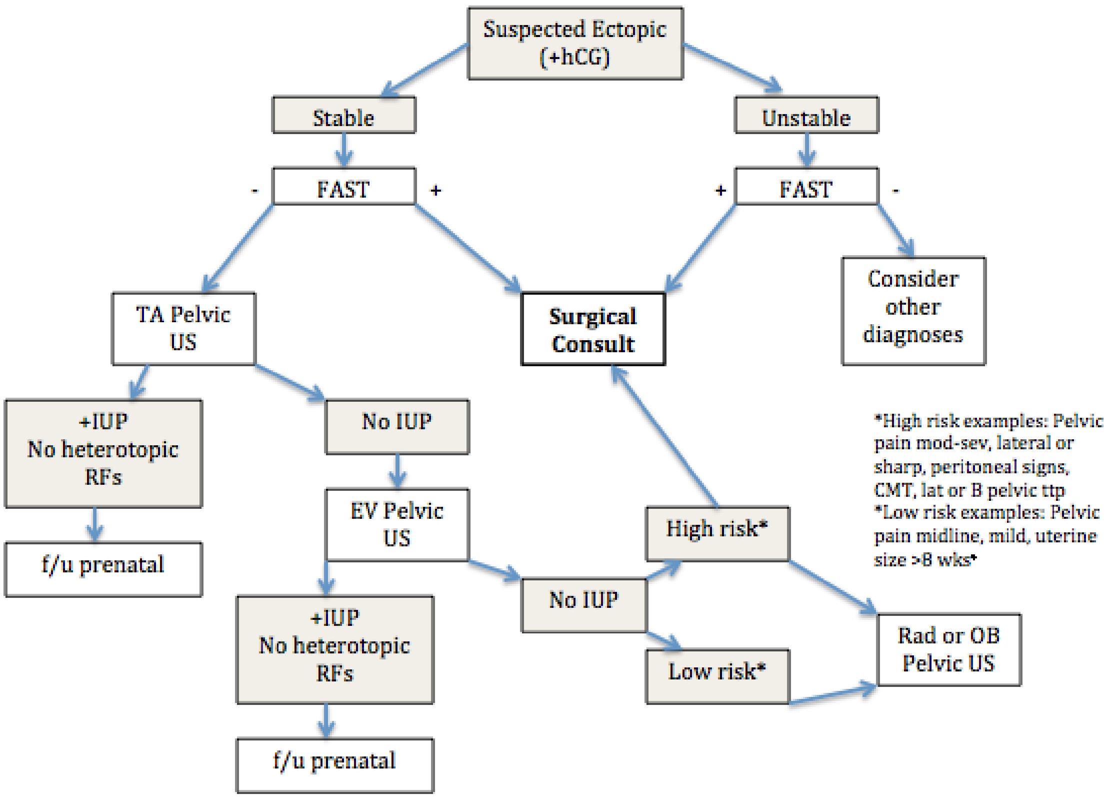
An abnormal gestational sac may also be encountered, which can be predictive of pregnancy failure. Current recommendations suggest that a mean sac diameter (MSD) of >=25mm with no embryo indicates pregnancy failure. Additionally, the presence of an amnion seen adjacent to a yolk sac, a yolk sac greater than 7 mm, and a small gestational sac in relation to the embryo (MSD-CRL < 5mm) are all suspicious, but not diagnostic, for pregnancy failure.

Occasionally it is possible to identify an ectopic pregnancy. Ectopic gestations can be found in an intrauterine (cornual, intramural, cervical) or extrauterine (tubal, ovarian, abdominal, etc) location. They may have complex appearances with characteristics including cystic structures, complex masses, and/or peri-adnexal free fluid. Sometimes live ectopic pregnancies may be identified. The most common finding for an ectopic pregnancy is an adnexal mass (65-84% of cases), while the most specific finding is a live ectopic fetus (3-26% of cases).

One pathologic variant that can be mistaken for an early gestational sac is a pseudogestational sac. Instead of a blastocyst cavity with amniotic space, the pseudogestational sac is a fluid collection in the endometrial cavity, which forms in response to the hormones of a pregnancy that exists outside the uterine cavity (i.e. an ectopic).

CLINICAL INTEGRATION

The clinical pathway in a patient with a known positive β-hcg starts with an initial transabdominal examination. If an IUP is seen (i.e. yolk sac, fetal pole or fetal heart beat within the uterus) in a patient with no known heterotopic risk factors then the patient has effectively been ruled out for an ectopic. If no IUP or only a gestational sac is seen, a transvaginal ultrasound should be performed. If a definitive IUP is not visualized, depending on the clinical picture, a gynecology consult may be warranted to discuss ectopic treatment options. Hemodynamically stable and reliable patients may go home with ectopic precautions and return in 48 hours for another ultrasound and serum β-hcg, or the patient may be observed in the ED.



SEMINAL STUDIES

Studies examining the use of emergency physician-performed ultrasound for evaluation of 1st trimester pregnancy have consistently demonstrated improved time to definitive diagnosis and improved throughput without an increased risk of missed ectopics. Durham et al enrolled 136 patients in a prospective study examining pelvic ultrasound performed by emergency physicians for detection of ectopic and found a NPV of 100%, concluding that emergency physicians-performed pelvic ultrasound can be used to rule out ectopic pregnancy. A recent systematic review examining point of care TVS demonstrated sensitivities >90% and specificities >98%. Also noted was evidence for reduced frequency of missed ectopic, decreased time for definitive care in ectopic pregnancy, shorter length of stay for normal pregnancy, and possible increased cost-effectiveness associated with emergency physician-performed TVS.

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TOPIC 8. 2ND/3RD TRIMESTER PREGNANCY ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

The patient is supine on a stretcher with the sonographer at the side of the bed facing the ultrasound machine/screen.

Transducer and System Settings

A curvilinear or phased array low frequency 2-5 MHz transducer is used for late trimester ultrasound.

Many ultrasound systems feature a general setting for obstetric examinations. This changes contrast slightly, and makes certain measurements, calculationss and labels available.

Image Acquisition

The fetus may lie at irregular angles relative to maternal body planes. Start by locating the fetal spine; its size provides a characterisitc landmark that indicates the longitudinal axis and orientation of the fetal body. Follow the spine toward the head to measure head circumference or bipareital dimeter or caudally to identify the pelvis and then the femur in order to measure femur length. Most often the fetus will be oriented in the vertex position with the head in the maternal pelvis. Once the fetal orientation is identified any one of several methods can be used to estimate the gestationdal age of the fetus. For greater accuracy, use multiple methods and average the values or discard an outlying value.

NORMAL ANATOMY

Biparietal Diameter: Obtain an axial view of the fetal head. Identify the following landmarks when possible: 1) the midline falx cerebri 2) the hypoechoic central thalami 3) the septum pellucida anterior to the thalamus, and/or 4) the hyperechoic bilateral kidney-shaped choroid plexuses seen on either side of the falx. One measuring caliper is placed at the outer skull table and the other on the opposite inner skull table.

Head Circumference: The level and landmarks are the same as described above, or alternatively identify the plane of greatest anterior-posterior cranial length. Measuring calipers should be placed on the outer skull anterior and posterior adjusting the resultant circle to best circumscribe the skull. Avoid including the skin overlying the skull.

Femur Length - Care must be taken to align the transducer exactly along the long axis of the femur. Only the diaphysis, or shaft, of the femur is measured from the greater trochanter to the distal femoral diaphysis. The epiphyses are excluded, and only osseus bone is measured, not cartilage.

Abdominal Circumference - Abdominal circumference is obtained in an axial plane at the level of the liver. Other landmarks that may be visible at this level are the fetal stomach, gallbladder, and ductus venosus. The plane should be perpendicular with the spine and ribs should be seen symmetrically enclosing the area. Similar to head circumference, a measuring circle is arranged along the outer perimeter of this axial section.

PATHOLOGY

Developmental Abormalities – Though it is beyond the scope of most bedside ultrasound examinations, there are numerous abnormailies of the fetal gut, head development, and skeletal dysplasias that will distort an individual dating technique. For this reason, multiple techniques are typically performed and averaged to increase accuracy. This process is termed fetal biometry. However, in the emergency department (ED) setting, the relatively small gain in accuracy from multiple measurements is rarely necessary, and generally one technique will provide a sufficiently accurate measurement.

CLINICAL INTEGRATION

Gestational dating in the second and third trimester is rarely an emergently indicated application, however, there are situations in which it may prove beneficial. Patients may present to the ED with little, if any, prenatal care and symptoms of labor soley or in addition to concommitent issues, such as trauma. If obstetric resources are unavailable or delayed, then it would be important for an emergency physician to asses the gestational age and viability, as well as fetal orientation, etc. to plan the order and urgency of subsequent resource utilization such as consults, radiology, or transfer, as well as to aid in anticipating subsequent complicaitons. Additionally, the rare, but critical, scenario in which an emergent or perimortem cesarian section is a consideration may hinge on a rapid estimation of gestiational age and viability.

SEMINAL STUDIES

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TOPIC 9. DEEP VENOUS THROMBOSIS

SCANNING PROTOCOL

Patient Positioning

To facilitate the identification of the veins and test for compression, they need to be distended. If they are not visible with the patient in a supine position, placing the lower extremities in a position of dependency such as reverse Trendelenberg or inclining the patient in a semi-seated position will facilitate distension.

Transducer and System Settings

A high frequency linear probe is usually used to interrogate the deep veins, however, for obese or edematous patients, a lower frequency or even curvilinear probe may be needed to provide adequate tissue penetration.

Image Acquisition

For the lower extremity, an abbreviated approach is undertaken with segmental assessments focusing on the common femoral vein, proximal greater saphenous, superficial femoral, and popliteal veins. The deep femoral vein is not considered a unique source of emboli and thus is not included in the imaging protocol. Although the entire lower extremity can be imaged, ultrasound interrogation is commonly limited to two anatomical regions of the leg, the upper leg segment and the popliteal region.

The scan is initiated with the highest view obtainable at the inguinal ligament, with the vein and artery located in cross-section. Angling superiorly, a short section of the distal common iliac vessels may be imaged. Moving sequentially, the common femoral is then imaged distally, visualizing its junction with the proximal greater saphenous vein, until 2 cm beyond the bifurcation of the superficial and deep femoral vein branches.

The popliteal vein is accessed in the popliteal fossa as it exits from the adductor canal. It is then traced down to its trifurcation in the proximal calf. Duplication of the popliteal vein or artery can occur, and in these cases all vessels are investigated.

The sonographic evaluation is performed by compressing the vein directly under the transducer while watching for complete apposition of the anterior and posterior walls. If complete compression is not attained with sufficient pressure to cause arterial deformation, obstructing thrombus is assumed to be present.

Many practitioners have ultrasound equipment with color and pulse wave Doppler capabilities, which may prove especially helpful in discerning vascular structures in technically limited studies.

The contralateral leg, if asymptomatic, is not routinely imaged, however, in equivocal cases its interrogation may be a helpful reference.

NORMAL ANATOMY

The deep veins of the lower extremity include the popliteal, deep femoral, superficial femoral, and common femoral veins. It is worth noting that despite its name, the superficial femoral vein is in fact part of the deep system, not the superficial system. To avoid confusion, it is sometimes simply referred to as the femoral vein. The popliteal vein is formed by the merger of the anterior and posterior tibial veins with the peroneal vein. Continuing proximally, the popliteal vein becomes the superficial femoral vein in the distal thigh. The superficial femoral vein joins the deep femoral vein to form the common femoral vein, which becomes the external iliac vein at the level of the inguinal ligament. At the level of the inguinal ligament, the great saphenous vein (a superficial vein) merges with the common femoral vein. In relation to the companion arteries, the popliteal vein is usually superficial to the artery. The common femoral vein lies medial to the artery only in the region immediately surrounding the inguinal ligament. The vein abruptly runs posterior to the artery distal to the inguinal region.

PATHOLOGY

Noncompression is the inability to completely compress the vessel with proper pressure (enough to slightly deform the artery) after ensuring good position. Only complete compression of the vessel rules out deep venous thrombosis (DVT), and only the lack of total compression is a hard finding for DVT. Obviously findings such as direct visualization of clot may suggest a DVT, but compression findings stand alone as rule-out/rule-in criteria. Other sonographic findings such as vein distention or decreased Doppler signal can support the finding of a DVT. If an echogenic clot is visualized it is not necessary to perform compression. Clot may appear echogenic or completely hypoechoic depending on its age. Likewise, an echogenic lumen is not always clot; gain artifact or sludging blood may mimic this appearance so it is important to image in different planes. Thrombus that is clearly free floating and not attached to the wall should be appreciated for its high chance of embolization and compression should be avoided. Other associated causes of extremity pain such as cellulitis, abscess, muscle hematoma, lymphadenopathy, and Baker's cyst of the lower extremity may also be diagnosed at the time of examination. However, this examination is not designed to identify all abnormalities of the extremity and should always be interpreted with reference to the entire clinical picture. Note a negative study does not rule out pulmonary embolism (PE).

CLINICAL INTEGRATION

In many cases an emergency ultrasound can guide disposition and treatment decisions. When the veins are adequately visualized but lack compressibility, the diagnosis of DVT is established and treatment is indicated. If the vessels are visualized and compressible, the patient's disposition depends upon the pretest probability guided by e.g. Wells criteria. Low-risk patients with normal ultrasounds can be discharged home. If patients have a moderate to high probability of a DVT, two options are available. Either an alternative test can be performed (e.g. CT, MRI, or venogram), or arrangements can made for a follow-up ultrasound in three to five days. Alternative testing will be necessary in cases of an indeterminate examination.

SEMINAL STUDIES

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TOPIC 10. INFERIOR VENA CAVA ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

The patient is supine on a stretcher with the sonographer on the patient's ride side facing the ultrasound machine/screen.

Transducer and System Settings

A low frequency 3-5 MHz curvilinear probe or 2-5 MHz phased array probe can be used for inferior vena cava (IVC) ultrasound.

Image Acquisition

Long axis view: start with the probe in the sagittal position just inferior to the xiphoid process with the marker pointing cephalad. Scan 1-2 cm to the patient's right to identify the IVC and angle the probe under the costal margin to follow the IVC into the right atrium.

Short axis view: start with the probe in the transverse position at midline just inferior to the xiphoid process with the marker pointing to the patient's right. Identify the IVC and the aorta anterior to the vertebral body. Scan caudally until the left renal vein is seen entering the IVC.

Images needed for complete scan: For adults-saggital view of the IVC entering the right atrium with hepatic veins draining into the IVC. For pediatrics-transverse view of the IVC next to the aorta at the level of the left renal vein.

NORMAL ANATOMY

The following evaluation is necessary for a normal anatomy scan: the liver, hepatic veins, IVC, aorta and right atrium. Distinguish IVC from aorta by its thinner wall, its course through the liver, its respiratory variation and its confluences (hepatic veins drain into IVC and IVC drains into right atrium). Other structures that may mimic the IVC include the portal vein, biliary ducts and gallbladder.

Measure the maximal anterior-posterior diameter of the IVC 1cm from the hepatic vein inlet. Alternatively, the IVC diameter can be measured 2cm from the IVC-right atrial junction if the hepatic vein inlet is not visualized. Measurements may be facilitated by using M-mode with the cursor placed at the appropriate measuring point. IVC measurements may be inaccurate if the patient has been pre-treated with vasodialtors and diuetics or with excessive external compression with the probe.

Respiratory variation of the IVC can also be assessed using ultrasound:

Normal inspiration and expiration – The IVC diameter is dynamic over time due to variances in intrathoracic pressure during spontaneous respirations. During inspiration, negative intrathoracic pressure increases venous return to the right atrium causing the IVC to collapse. Conversely, during expiration, positive intrathoracic pressure decreases venous return causing the IVC to expand. The maximal (expiration) and minimal (inspiration) diameters can be used to calculate the percentage of IVC collapse, also known as the caval index: [(IVC expiratory diameter – IVC inspiratory diameter)/IVC expieratory diameter] x 100%. A caval index greater than or equal to 50% predicts intravascular depletion and likely response to volume resuscitation.

Positive pressure ventilation – During positive pressure ventilation, positive intrathoracic pressure is generated during inspiration and realxation of the thoracic cage during passive expiration returns the intrathoracic pressure to 0. Therefore, the mechanics of IVC dilation and collapse are reversed. To calculate the percentage of IVC distention or the distensibility index: [(IVC inspiratory diameter – IVC expiratory diameter)/IVC expiratory diameter] x 100%. A distensibility index greater than or equal to 16% predicts response to volume resuscitation.

Pediatric patients – There are no published reference values for pediatric IVC diameter. Obtain the short axis view of the IVC and aorta at the level of the left renal vein and measure the anterior-posterior diameter of each vessel.

PATHOLOGY

Fluid responsiveness: IVC diameter with > 50% collapse of IVC diameter during sponatenous inspiration suggests intravascular volume depletion. In pediatrics, an IVC-to-aorta ratio < 0.8 may suggest intravascular volume depletion and potential response to fluid resuscitaiton.

Fluid non-responsiveness: IVC diameter with minimal collapse of diameter during inspiration suggests elevated intravascular volume or increased right atrial pressures.

CLINICAL INTEGRATION

IVC ultrasound provides a real time and noninvasive means to monitor a patient's hemodynamic status. It can guide the management of undifferentiated hypotension, assess responsiveness to volume resuscitation and differentiate between causes of dyspnea.

If IVC ultrasound in a hemodynamically unstable patient suggests volume depletion (e.g. hypovolemic and distributive shock) then the patient may respond to fluid resuscitation. In these patients, the IVC can be assessed serially with therapy to assess response to fluids and may guide the clinician to continue fluids or switch to another therapy (e.g. vasopressors).

If IVC ultrasound suggests volume overload, then fluids may (e.g. cardiac tamponade) or may not (e.g. cardiogenic shock) be beneficial and further investigations are required to identify and treat the underlying cause. Similarly dyspnea in patients with a plethoric non-collapsible IVC could be suggestive of mechanical obstruction with increasaed right atrial pressures (e.g. pulmonary embolism, cardiac tamponade, tension pneumothorax) or decompensated heart failure with pulmonary edema and an ultrasound evaluation of the heart and lungs should be performed.

SEMINAL STUDIES

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7. Nagdev AD, Merchant RC, Tirado-Gonzalez A, et al. Emergency department bedside ultrasonographic measurement of the caval index for noninvasive determinate of low central venous pressure. *Ann Emerg Med*. 2010;55(3):290-5.
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TOPIC 11. SOFT TISSUE ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

Patient positioning is used to optimize image acquisition. For example, extremities may be rotated and supported by pillows to allow the area of interest to be easily accessible.

Transducer and System Settings

Imaging is usually accomplished using a high frequency, linear array transducer but occasionally the location of the area of interest requires the use of a high frequency endocavitary transducer. Deeper abscesses may require the use of a lower frequency transducer.

Image Acquisition

Soft tissue ultrasound imaging involves obtaining orthogonal images of the area of interest for complaints of the soft tissue. Long axis and transverse axis imaging of the area of interest is obtained in reference to either the axis of the patient or the axis of the area of interest (i.e. hand, foot, axilla…). Imaging of surrounding anatomy can be useful to demonstrate additional anatomic landmarks or nearby vascular structures. Compression views can sometimes provide additional information such as mobility of the abscess contents. In addition, images of the normal contra-lateral should be obtained (if available). Optional images include Doppler imaging of the area of interest, either color- or power-Doppler.

NORMAL ANATOMY

The anatomy visible during soft tissue imaging depends on the location of the area of interest. Specific landmarks include the skin surface, subcutaneous layer of the skin, underlying muscle or bone and any arteries, veins or tendons located near the area of interest. The minimal views required for a soft tissue ultrasound is a long axis and short axis view of the area of interest.

PATHOLOGY

Pathology encountered during soft tissue ultrasound includes abscess, cellulitis, reactive lymph nodes and foreign bodies.

Soft tissue infections such as cellulitis result in a more echogenic appearance of the soft tissue with a "cobblestoning" appearance due to increased local edema. Comparison with surrounding tissue deemed normal on physical examination is useful in identifying this finding and its extent.

Soft tissue abscesses are characterized by a well-demarcated area of mixed echogenicity. The cavity may be entirely filled with slightly echoic fluid exhibiting posterior enhancement or it may contain a mixture of anechoic fluid and significantly echogenic debris.

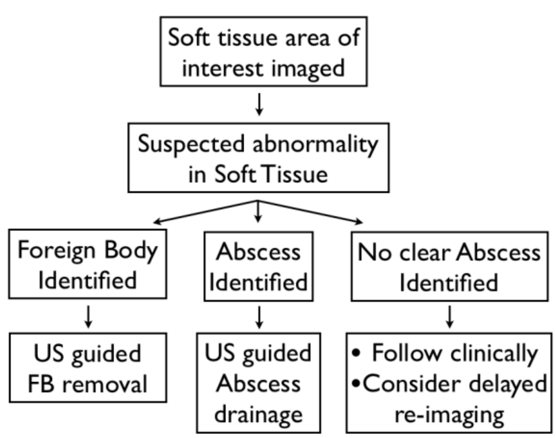
Reactive lymph nodes tend to have an oval shape with an isoechoic cortex and a hyperechoic hilum.

The most common soft-tissue foreign bodies are glass, wood, and metal. All foreign bodies appear hyperechoic and, depending on their composition and proximity to certain anatomic structures, will display variable degrees of acoustic shadowing or reverberation artifacts. Gravel and wood cast a characteristic acoustic shadow similar to that of a gallstone. A large wood fragment with its brightly echogenic anterior surface can easily be mistaken for bone but because of its immunogenic properties often the object will have a surrounding anechoic rim of reactive edema. Metallic objects frequently display a "comet tail," or a reverberation artifact in which bright, regularly spaced parallel lines are seen distal to the foreign body. Foreign bodies retained for longer than 24-48 hours are frequently surrounded by an echolucent halo, resulting from reactive hyperemia, edema, abscess, or granulation tissue, which may aid in their identification.

Necrotizing fasciitis is an uncommon infection that is difficult to diagnose clinically, despite having high rates of mortality and morbidity. Unlike simple cellulitis, which is limited to the superficial epidermis and dermis, ultrasound findings of necrotizing fasciitis include anechoic fluid in the deep fascial planes. The imaging protocol is similar to the imaging technique for differentiating abscess and cellulitis, but the clinician should evaluate the deep fascial planes. Delineating the margins of the edema and the width (>4mm) may aid in diagnosis the presence of a deeper space fascial infection. As with all soft tissue examinations, evaluation of the contralateral/unaffected extremity can help in determining normal sonographic anatomy.

The presence of gas in the soft tissue is a worrisome finding that may represent infection with gas forming organisms or destruction of tissue i.e. necrotizing fasciitis.

CLINICAL INTEGRATION



Necrotizing fasciitis cannot be ruled out with clinical ultrasonography. Detection of deep fascial edema in a patient with a concerning soft tissue infection can aid the clinician in continuing the process of consultation and imaging.

SEMINAL STUDIES

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TOPIC 12. OCULAR ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

The patient is supine on a stretcher with the sonographer at the head of the bed facing the ultrasound machine/screen.

Transducer and System Settings

A linear high frequency 7.5-10 MHz probe is used for ocular ultrasound.

Alternative transducers include small footprint high frequency probes such as a small footprint phased array or even an endocavity probe. Many ultrasound systems feature an ophthalmology setting.

Image Acquisition

Apply a tegaderm patch over the closed eyelid and then a generous amount of gel to the closed eyelid. By slowly fanning through the motionless eye in both transverse and sagittal planes, the anterior and posterior chambers of the eye can be visualized. Take care to apply little pressure on the eye during imaging, especially to the traumatic eye.

Applying a tegaderm patch will prevent gel from getting on the eyelid and allow for easy gel removal once the tegaderm is removed to maximize patient comfort.

Images needed for complete scan: transverse and sagittal views of the entire orbit including visualization of the inner orbital anatomy, optic nerve sheath, and its adjacent soft tissue.

NORMAL ANATOMY

The following evaluation is necessary for a normal anatomy scan, from superficial to deep: the eyelid will be thin and homogeneously echogenic with the deeper anterior chamber of the orbit, filled with vitreous fluid, providing an excellent acoustic window for deeper structures. When visualized through the visual axis the orbit containing the anterior and posterior chamber should appear circular separated by the linear ciliary muscles and oval shaped lens with anechoic center located midline just deep to the iris. The iris and ciliary body are echogenic and can be visualized well. The vitreous fluid will appear anechoic (black) without echogenic debris. The retina will be seen as a hyperechoic line adherent to the posterior chamber of the eye. Deep to the orbit will be the optic nerve sheath, a hypoechoic linear structure that is most times visualized in the posterior orbit. There is some research to support measurements posterior to the eye as a proxy for intracranial pressure assessments. Conventional measurements include the optic nerve sheath diameter measured at 3 mm deep to the retina. The optic nerve sheath diameter should measure no more than 5mm in adult patients.

Ocular function can also be tested using ultrasound:

Pupillary constriction - placing the transducer in transverse view, have the patient look downward. Decrease your depth in order to focus on the longitudinal view of the ciliary musculature and pupil. Once the ciliary muscles are seen as two thick linear echogenic structures, shine a light on the contralateral eye. The ciliary muscles will be seen extending to constrict the pupil. Another way to perform this is to place the linear transducer on the lower eyelid to attempt a coronal view of the eye. The pupil will be seen as a circular image and constrict when light is shined on the eye.

Extraocular movement - with the linear transducer in transverse view, have the patient look left and right; with the linear transducer in sagittal view, have the patient look up and down. The amount of movement to each side should be symmetric.

Subcutaneaous air may limit the resolution and patients unable to cooperate fully with this examination can introduce limitations.

PATHOLOGY

Retinal detachment: The retina appears posteriorly as a hyperechoic linear membrane, which when detached, is seen as a ribbon, but always anchored near the optic disk. Having the patient look at different planes of sight and fanning through each area of the retina will increase your sensitivity of picking up this pathology.

Vitreous detachment: A vitreous detachment appears as a wispy hyperechoic linear line through the posterior chamber of the eye that is generally mobile with eye movements. In constrast to a retinal detachment, a vitreous detachment is less commonly seen unless the gain settings are increased as it is less echogenic. In addition, a vitreous detachment will cross the posterior chamber and is not tethered to the optic disc.

Vitreous hemorrhage: Vitreous hemorrhage typically appears as echogenic debris of foci within the normally anechoic posterior chamber. Increase the gain and have the patient move their eye for the highest sensitivity of visualizing vitreous hemorrhage: movement of granular or linear echogenic material in the posterior chamber

Lens dislocation: The typical central location of the oval shaped lens should be evaluated, and if not where expected, it has been dislocated.

Retrobulbar hematoma: Posterior to the eye there is soft tissue that is echogenic and adjacent to the optic nerve sheath. If a hematoma has developed, an anechoic area may be seen there but these can be difficult to visualize without optimizing the transducer settings for the soft tissue posterior to the eye.

Foreign body localization: The foreign body can be seen as an echogenic structure in the soft tissue around the orbit or within the posterior or anterior chamber of the eye.

Globe rupture: Decrease in the size of the eye, loss of the normal circular structure of the eye, scleral buckling, and anterior chamber collapse are signs of globe rupture.

Papilledema : Papilledema can be visualized as increased height of the optic disc relative to the posterior curve of the retina and posterior wall of the eye.

CLINICAL INTEGRATION

Symptoms consistent with acute vision loss are the most common reason to image the eye with ultrasound. Differentiating retinal detachment (ocular emergency) from vitreous detachment (ocular urgency) can help effectively arrange appropriate follow up. Even with the above distinguishing sonographic features, in some cases it may be difficult to make a definitive diagnosis based on sonography alone. Therefore, should the emergency physician note any hyperechoic material within the vitreous chamber of the eye, an emergent ophthalmology consultation should be obtained.

Careful imaging of the eye following trauma can help with cases where a ruptured globe is not suspected or is less likely. Patients with significant swelling after facial trauma can have valuable information identified with ultrasound that is not available any other way.

An opthamologist should be consulted for any of the above pathologic findings in the setting of vision loss or trauma . In addition if there is a clinical suspicion for iritis, retinitis, acute closed angle glaucoma, and central retinal arterial or venous occlusion appropriate referrals should be made as none of these diagnoses are made with ultrasound.

SEMINAL STUDIES

1. Blaivas, M. Bedside emergency department ultrasonography in the evaluation of ocular pathology. *Acad Emerg Med.* 2000;7(8):947-50.
2. Roque PJ, Wu TS, Barth L, et al.Optic nerve ultrasound for the detection of elevated intracranial pressure in the hypertensive patient. *Am J Emerg Med*. 2012;30(8):1357-63.
3. Harries A, Shah S, Teismann N, et al. Ultrasound assessment of extraocular movements and pupillary light reflex in ocular trauma. *Am J Emerg Med*. 2010;28 (8): 956-9.
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TOPIC 13. ULTRASOUND-GUIDED CENTRAL VENOUS ACCESS

SCANNING PROTOCOL

Patient Positioning

The patient should be placed so that all equipment is easily within reach of the person performing the procedure. In addition, when using ultrasound to guide procedures including venous access the ultrasound should be directly in front of the person performing the procedure so that it is easy to look between the screen and the needle without turning. In circumstances where two individuals are involved in the procedure, the machine should be directly in front of the individual "guiding" the procedure, not the individual inserting the needle.

Transducer and System Settings

Except where otherwise indicated or not available a high frequency linear array probe is recommended. When possible the probe should be held at a 90-degree angle to the vessel to maximize resolution. When performing central line placement, sterile technique using a sterile probe cover should always be implemented.

Image Acquisition

Internal Jugular Vein

Anatomy: The internal jugular vein runs adjacent to the carotid artery typically in the triangle formed between the two heads of the sternocleidomastoid and the clavicle.

Scanning Protocol: The patient is positioned supine preferably in Trendelenburg position to increase venous pooling. The anterolateral neck is imaged cephalad to caudad. The internal jugular vein and common carotid artery should be identified with the internal jugular lateral and superficial. In addition the vein is thinner walled and more compressible than the artery.

Axillary/Subclavian Vein

Anatomy: The axillary vein begins at the confluence of the brachial and basilic veins and courses beneath the clavicle until it becomes the subclavian at the lateral border of the first rib.

Scanning Protocol: The patient is placed in supine position. A linear transducer is placed on the chest wall near the axilla where the axillary vein and artery can be identified and traced until they disappears beneath the clavicle.

Femoral Vein

Anatomy: The femoral vein begins in the adductor hiatus as the continuation of the popliteal vein and becomes the external iliac at the inguinal ligament. Distally it travels behind the femoral artery and becomes medial and more superficial as it nears the inguinal ligament.
Scanning Protocol: The patient is placed in reverse Trendelenburg position with the leg slightly abducted and externally rotated in semi frog leg position. The medial mid thigh is scanned cephalad to the inguinal ligament to identifying the femoral vein medial to the femoral artery. The femoral vein is typically punctured 1cm below the inguinal ligament. Anomalous femoral venous anatomy can occur reinforcing the use of ultrasound for localization.

CANNULATION

The target central vein should be cannulated under real-time ultrasound guidance with constant visualization and awareness of the needle tip avoiding adjacent structures such as arteries or nerves. The transducer may be oriented in either the longitudinal or transverse plane relative to the vein. The longitudinal plane allows constant visualization of the needle, needle tip, and the target vessel, however requires the sonographer to maintain all three structures in line with the beam of the transducer. This may be difficult in patients that are moving or in respiratory distress. Alternatively, the transverse plane allows for easier simultaneous visualization of the needle and vessel, however the transducer must be translocated as the needle tip is advanced to maintain constant needle tip visualization. Loss of needle tip visualization can result in the needle traveling deeper than expected which may result in penetration of the posterior vein wall, artery, or lung (in the case of the internal jugular or subclavian vein cannulation).

When the procedure is complete, a comprehensive note is documented in the medical record including the use of ultrasound guidance.

SEMINAL STUDIES

1. Denys B, Uretsky B, Reddy P. Ultrasound-assisted cannulation of the internal jugular vein. A prospective comparison to the external landmark-guided technique. *Circulation.* 1993;87(5):1557-62.
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3. Miller AH, Roth BA, Mills TJ, et al. Ultrasound guidance versus the landmark technique for the placement of central venous catheters in the emergency department. *Acad Emerg Med.* 2002;9(8):800-5.
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rates and reduces complications: a randomized, prospective Study. *Ann Emerg Med*. 2006;48(5):540-7.

TOPIC 14. ULTRASOUND-GUIDED PERIPHERAL VENOUS ACCESS

SCANNING PROTOCOL

Patient Positioning

The patient should be placed so that all equipment is easily within reach of the person performing the procedure. In addition, when using ultrasound to guide procedures including venous access the ultrasound should be directly in front of the person performing the procedure so that it is easy to look between the screen and the needle without turning.

Transducer and System Settings

Except where otherwise indicated or not available a high frequency linear array probe is recommended. When possible the transducer should be held at a 90-degree angle to the vessel to maximize resolution.

Image Acquisition

For both children and adults, the upper extremity is the preferred location. However in young children, the greater saphenous may preferable than the upper arm given its relative size compared to upper extremity veins.

For the upper extremity, the patient is placed in a supine position with their arm extended. A high-frequency linear-array transducer is used to search the arm and forearm for a peripheral vessel that is suitable for cannulation. A quick systematic search of all four named vessels is helpful to find the most appropriate vessel. Vessels with an internal diameter > 5mm and less than 1.6 cm deep have a greater likelihood of success.

NORMAL ANATOMY

There are four named veins in the upper extremity that are commonly used for peripheral venous access: cephalic, basilic, brachial and antecubital. All of these veins eventually coalesce to form the axillary vein. In the lower extremity, the greater saphenous vein is amenable to peripheral venous access. Other peripheral veins can also be cannulated as long as their internal diameter is large enough and they run in a relatively straight course, so as not to cause kinking of the catheter once it is inserted into the vessel.

It is important to ensure the vein is patent before attempting cannulation - this can be done simply by compressing the vein and demonstrating that the walls of the vein collapse completely. This will also ensure that a small artery is not accidentally cannulated.

CANNULATION

Catheters used for ultrasound guided peripheral venous access, in adults, can range from 48 mm up to 15 cm in length. A peripheral catheter that is greater than 7.5 cm long is considered a midline catheter and should be inserted using standard sterile procedures, including a sterile probe cover and gel. A peripheral catheter less than 7.5 cm can be placed using standard aseptic peripheral cannulation procedures with a non-sterile probe covering and bacteriostatic gel.

A real-time ultrasound-guided technique should be employed where the tip of the needle is guided into the vessel lumen. Once the skin and probe are prepared and the vessel is located, a peripheral catheter can be inserted using either a short- or long-axis technique.

When procedure is complete, a comprehensive note is documented in the medical record including the use of ultrasound guidance.

SEMINAL STUDIES

1. Panebianco NL, Fredette JM, Szyld D, et al. What you see (sonographically) is what you get: vein and patient characteristics associated with successful ultrasound-guided peripheral intravenous placement in patients with difficult access. *Acad Emerg Med*. 2009;16(12):1298-303.
2. Adhikari S, Blaivas M, Morrison D, et al. Comparison of infection rates among ultrasound-guided versus traditionally placed peripheral intravenous lines. *J Ultrasound Med*. 2010;29(5):741-7.

TOPIC 15. ULTRASOUND-GUIDED PERICARDIOCENTESIS

SCANNING PROTOCOL

Patient Positioning

With the traditional blind approach, a semi-recumbent position with the head of the bed at 30-45 degrees is often used to bring the heart forward in the chest and to better allow pooling of fluid in the inferior and anterior portions of the pericardium. However, with ultrasound guidance, the pericardial space may be approached more readily from an intercostal approach, and a left lateral decubitus position will bring the effusion forward and towards the apex. Alternatively, the supine position is acceptable, especially in critically ill patients.

Transducer and System Settings

A 2.5-5MHz phased array transducer is ideal as its relatively smaller footprint allows it to scan more easily between ribs. However, a curvilinear transducer can also be used with attention to angling the transducer axis between the ribs as needed.

Image Acquisition

Using the standard echocardiography subxiphoid, parasternal long or apical views, the size of the effusion can be determined and it's most superficial aspect should be localized. The transducer is then positioned directly over the area of effusion that is closest to the skin and in an area without vital structures such as liver or lung in between. This is often found at a point between the apical and parasternal long axis views. *It is important to note that the internal mammary artery runs cephalocaudad down the anterior chest about 4cm lateral to the sternum and that neurovascular bundles traverse along the inferior border of each rib. These structures should be avoided.* If a subxiphoid approach is chosen and time permits, an NG tube can be passed to decompress the stomach.

Once the optimal location for aspiration has been established, sterile precautions should be taken as time allows, including patient draping and sterile transducer cover. The pericardiocentesis needle is then advanced under real-time ultrasound guidance, with the needle piercing the skin just lateral to the probe and visualized advancing in the long axis of the transducer until the needle tip is observed within the pericardial fluid collection. Fluid should be aspirated and if a pericardiocentesis kit is being used, the sheath is then advanced and the needle withdrawn.

Further visual confirmation of placement can be obtained by injecting 1-2cc of agitated saline (created by energetically injecting the fluid between two connected syringes) into the catheter, and observing the hyperechoic microbubbles appear on ultrasound within the pericardial space only.

PATHOLOGY

A pericardial effusion will be seen as an anechoic fluid collection around the heart and within the pericardium. If blood is present, a clot may form in the pericardial space and can be visualized as a heterogenous echodensity within the pericardial sac. Small effusions will be seen only on one side, usually the inferior aspect of the heart, moderate effusions extend to the apex and large effusions encircle the entire heart with fluid. In the presence of large effusions, the heart may be seen to swing or oscillate within the fluid collection as it beats, a motion that can be represented on EKG by electrical alternans. Tamponade physiology is evidenced by the presence of collapse or near collapse of the right ventricle or atrium during diastole and is an indication to proceed with pericardiocentesis.

CLINICAL INTEGRATION

Ultrasound is the diagnostic modality of choice for identifying pericardial effusion and confirming the presence of tamponade physiology. When used to guide pericardiocentesis, ultrasonography can reduce complications and allows for real-time confirmation of needle placement within the pericardial space. In addition, it facilitates immediate assessment of the success of aspiration on the cardiac physiology.

SEMINAL STUDIES

Experience with ultrasound guidance for pericardiocentesis can be found in the literature dating back to the 1970's and has been used routinely by some institutions as early as the 1980's. However, it is only within the last 15 years that it has become more widely used for its improved safety profile and the increasing prevalence of bedside ultrasound accessibility and trained providers.

1. Callahan JA, Seward JB, Tajik AJ. Two-dimensional echocardiographically guided pericardiocentesis: experience in 117 consecutive patients. *Am J Cardiol*. 1985; 55:476-9.
2. Salem K, Mulji A, Lonn E, Echocardiographically guided pericardiocentesis- the gold standard for the management of pericardial effusion and cardiac tamponade. *Can J Cardiol.* 1999;15(11):1251-5.
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4. Tsang TSM, Enriquez-Sarano M, Freeman WK, et al. Consecutive 1127 Therapeutic Echocardiographically Guided Pericardiocenteses: Clinical Profile, Practice Patterns and Outcomes Spanning 21 Years. *Mayo Clinic Proc.* 2002;77: 429-36.

TOPIC 16. ULTRASOUND-GUIDED THORACENTESIS

SCANNING PROTOCOL

Patient Positioning

The preferred position is with the patient sitting up but in the critically ill patient, the lateral decubitus position can be used with the affected side dependent.

Transducer and System Settings

A 3-5 MHz curvilinear transducer is used for localization and definition of the extent of the effusion. A phased array transducer may also be successfully used depending on the patient's body habitus.

Image Acquisition

The affected hemithorax is imaged in the longitudinal plane to demonstrate the borders of the effusion. If transverse images are taken, the transducer is parallel to the rib. It is especially important to evaluate the diaphragm during a full normal respiratory cycle to know how high the diaphragm rises during respirations and to ensure the puncture site is above that rib space.

Once orthogonal scanning has demonstrated the extent of the effusion, the point for aspiration should be marked. The depth to the effusion can also be measured to provide additional guidance so that it is clear how deep the needle can go before penetrating the pleura.

Following determination of the extent of the effusion and optimal location for aspiration, the chest is then prepped and draped. The patient should maintain the same position as when they were scanned when a blind aspiration is used. If active or dynamic scanning is desired, a sterile probe cover is used to provide guidance until the needle is within the effusion and aspiration begun. This can be helpful to note that as fluid is drained and the lung re-expands, the pleura should expand as well and could come out toward the needle. Monitoring this in real time could avoid an unintended puncture.

When procedure is complete, a comprehensive note is documented in the medical record including the use of ultrasound guidance.

PATHOLOGY

A simple effusion will appear as an anechoic collection disrupting the normal anatomy. More complex effusions may demonstrate loculations and septations. Collapsed lung may exhibit hepatization.

CLINICAL INTEGRATION

Ultrasound reduces the time of the procedure, prevents failed attempts and reduces complications. Challenges may include patient body habitus, uncooperative patients, and adhesions but this is where ultrasound is most helpful. In addition, ultrasound can rule out a pneumothorax immediately post-procedure by evaluating the pleura just deep to the needle puncture avoiding chest radiography.

SEMINAL STUDIES

Studies since the 1980's have demonstrated that the use of ultrasound localization for identification and drainage of pleural effusions is clinically beneficial. It has been shown to reduce complications such as pneumothorax and increase success rate. A recent review of over 19,000 thoracentesis procedures demonstrated both a reduction in complications and a cost savings.

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TOPIC 17. ULTRASOUND-GUIDED PARACENTESIS

SCANNING PROTOCOL

Patient Positioning

The preferred position for imaging a patient with suspected ascites is with the patient supine. If a small amount of fluid is expected, the patient may be positioned with support to either help the fluid flow to one side or with reverse Trendelenberg to help the fluid pool caudally.

Transducer and System Settings

A 3-5 MHz curvilinear probe or phased array probe may be used for localization and definition of the extent peritoneal fluid.

Image Acquisition

Images are obtained in the longitudinal plane in all four quadrants with special attention to the left lower quadrant: the traditional area of blind paracentesis. Once the area of largest fluid collection is identified, orthogonal images are obtained of the desired fluid pocket with a measurement of depth from the skin to the ascetic fluid.

The abdomen is imaged in the longitudinal plane to demonstrate the location and size of the intraperitoneal fluid. Pre-procedure voiding may decrease the risk of bladder misidentification as ascites. *Note should be made of abdominal wall vascular structures to avoid hemorrhagic complications as well as solid organs and bowel loops.* Images should be labeled clearly with relevant normal anatomy and pathology.

Following determination of the extent of the ascites and marking of the skin at the location for needle insertion, the site is then prepped and draped. Before needle puncture or insertion it is important to use color Doppler to ensure there are no vessels (inferior epigastric artery or vein or distended abdominal veins) beneath the skin surface superficial to the peritoneum. This is especially important if using non-traditional sites for access to the peritoneal cavity. If active/dynamic scanning is desired, a sterile probe cover is used until the needle is within the ascites and aspiration begun.

When procedure is complete, a comprehensive note is documented in the medical record including the use of ultrasound guidance.

NORMAL ANATOMY

In the normal patient, small amounts of physiologic free fluid are usually not visible on transabdominal ultrasound imaging.

PATHOLOGY

Ascites is generally anechoic though it may occasionally exhibit echogenic characteristics or visible debris. Hemoperitoneum may be anechoic initially or hypoechoic if clotting has occurred.

CLINICAL INTEGRATION

Ultrasound reduces the time of the procedure, prevents failed attempts and reduces complications. Challenges may include patient body habitus, uncooperative patients, and adhesions but this is where ultrasound is most helpful.

SEMINAL STUDIES

Abdominal paracentesis is commonly performed by emergency physicians for diagnostic purposes. The use of ultrasound guidance in one study demonstrated a success rate of 95% versus 61% in the traditional (blind) technique. Also in this study, 25% of patients randomized to US-guided paracentesis did not receive the procedure due to identification of insufficient fluid.

Original studies using A-mode ultrasound in the 1970's were able to both identify and ascites estimate volume. Early studies also demonstrated that ultrasound can easily identify loops of bowel in the chosen area of needle placement. A more recent study demonstrated correlation between pre-procedure ultrasound measurement of fluid depth at the site of paracentesis and the total volume of ascites drained in the procedure. In general, ultrasound guidance for abdominal paracentesis increases the rate of success and increases patient safety through prospective identification of anatomy and pathology.

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TOPIC 18. ABSCESS IDENTIFICATION AND DRAINAGE

SCANNING PROTOCOL

Patient Positioning

Patient positioning is used to optimize image acquisition but depends on the area of interest. In general patients are positioned so that the area of interest is easily accessible.

Transducer and System Settings

A high-frequency linear-array transducer is used in most cases for skin and soft tissue infections. The intracavitary transducer can be used for imaging the tonsillar fossa.

Image Acquisition

Orthogonal views of the area under evaluation should be obtained and may include video clips or static images demonstrating the border between normal and abnormal tissue.

The use of a standoff pad or a water bath may be helpful for very superficial anatomy to provide improved resolution. Once an abscess cavity is identified, the skin may be marked in this area to guide incision and drainage. It is prudent to use color doppler prior to incision to ensure there are no vessels nearby and to ensure that the anechoic cavity being imaged is not a vascular structure. This is especially true for abscesses in the groin and axilla where atypical lymph nodes may appear as hypoechoic fluid collections.

When procedure is complete, a comprehensive note is documented in the medical record including the use of ultrasound guidance.

NORMAL ANATOMY

The exact anatomy and relative thickness of the dermis and subcutaneous tissue varies by anatomic location. The normal appearance of the skin and soft tissue area is generally mildly echogenic and homogeneous. Peripheral blood vessels are sometimes visualized in the superficial subcutaneous tissue. It is often quite easy to see the distinct layers of the epidermis (hyperechoic), dermis (more anechoic with septations), muscle (striations) and bone (hyperechoic and reflective).

PATHOLOGY

Soft tissue infections such as cellulitis result in a more echogenic appearance of the soft tissue with a “cobblestoning” appearance due to increased local edema. Comparison with the contralateral side or with surrounding tissue deemed normal on physical examination is useful in identifying this finding.

The appearance of superficial abscesses varies from anechoic to hypoechoic or even isoechoic. Superficial abscesses are rarely hyperechoic. The typical soft tissue abscess is characterized by a well-demarcated area of mixed echogenicity but many image patterns exist, some with clearly defined borders and others that are poorly visualized. The abscess cavity may be entirely filled with slightly echoic fluid exhibiting posterior enhancement or contain a mixture of anechoic fluid and significantly echogenic debris. Additional sonographic findings of an abscess cavity include "swirling" or movement of the purulence with axial compression. Inflammation surrounding an abscess cavity is visualized as a loss of the normal horizontal tissue planes.

Gas forming infections can produce abscess cavities with hyperechoic gas within the cavity and "dirty" posterior shadowing.

CLINICAL INTEGRATION

Ultrasound reduces the time of the procedure, prevents failed attempts and reduces complications. Challenges may include patient body habitus, uncooperative patients, and adhesions but this is where ultrasound is most helpful. Ultrasound guidance for incision and drainage of smaller and deeper abscesses improves the success rate following the procedure.

SEMINAL STUDIES

The ability of ultrasound to tell the difference between cellulitis and soft tissue abscess is excellent and has been demonstrated to alter management in over 50% of cases. In contrast, the ability of the physical examination to determine a soft tissue abscess lacks sufficient precision as demonstrated in a recent pediatric study in which inter-examiner agreement of whether a lesion required incision and drainage was just under 50%. A study in the pediatric population noted that US changed management in 25% of patients by detecting subclinical abscesses and in 14% by diagnosing cellulitis and avoiding incision and drainage. The use of bedside US to diagnose and localize soft tissue abscesses increases diagnostic precision and reduces unnecessary invasive procedures.

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TOPIC A1. AIRWAY ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

Patients will typically be intubated or in the process of being intubated, so the supine position is preferable.

Transducer and System Settings

A high frequency linear array probe is most commonly utilized for airway assessment. Users may prefer to use a non-vascular setting for tracheal evaluation and a vascular setting for increased frame rate in thoracic evaluation of lung sliding.

Image Acquisition

There are generally two components of the ultrasound airway evaluation. First the trachea is imaged for the presence of an endotracheal tube (ETT). Second, the bilateral pleural interfaces are evaluated for lung sliding during ventilation.

For the first component, a linear high frequency transducer is placed in transverse orientation just inferior to the laryngeal prominence of the anterior neck. Imaging at the level of the thyroid isthmus is easily obtainable and a good starting point. From this point, scan inferiorly past the initial tracheal rings to the level of the suprasternal notch. This can be performed during intubation in a 'dynamic' examination, or post-intubation in a 'static' examination. Note that the dynamic examination may render cricoid pressure difficult to perform, and that it requires an assistant to both hold probe position as well as help with ultrasound interpretation.

Once tracheal imaging is obtained, proceed with the assessment pleural sliding during ventilation. The transducer should be placed along the midclavicular line, at the 2nd intercostal space, with the indicator pointed cephalad. Visualization should focus on identification of the visceral-parietal pleural interface of each hemi-thorax.

NORMAL ANATOMY

Trachea

The thyroid isthmus lies about 1 cm caudal to the laryngeal prominence. At this level, the trachea appears as a circular air-filled structure demonstrating reverberation artifact just posterior to the neck soft tissue. Trachea rings are hyperechoic on ultrasound and exhibit posterior shadowing. In roughly 70% of patients, the esophagus appears to the left of the trachea as a flat muscular structure.

Presence of ETT in the trachea

An ETT may be detected in the trachea by demonstration of comet tail or lung rocket artifact that extends to the far field of the image. Dynamic assessment on endotracheal intubation has high sensitivity and specificity (>95%), whereas static assessment has as low as 50% sensitivity. The absence of a double lumen that is seen with esophageal intubation may be a more reliable indicator of endotracheal intubation. However, there are no studies that specifically compare these two signs.

Pleural Interface

The initial layers of soft tissue for thoracic ultrasound include skin, subcutaneous tissue, pectoral muscles, and ribs separated by intercostal muscles. The parietal and visceral pleura directly posterior to the ribs and are tightly apposed in the normal thorax. Correct placement of the ETT 2-4 cm above the carina will result in both lungs equally ventilated. Therefore, with each tidal volume-induced expansion of the lungs, pleural or lung sliding should be evident in each hemithorax.

PATHOLOGY

Suspected esophageal intubation

Esophageal intubation can be seen on the tracheal examination as the presence of an additional air-filled lumen next to the trachea. This is the esophagus that has now been stented open by the ETT.

On pleural examination, there may be no lung sliding on either hemithorax, or paradoxical motion towards the head due to a tidal volume delivered to the GI tract. In addition, a "lung pulse" may be seen in synchrony with cardiac motion.

Suspected mainstem bronchus intubation

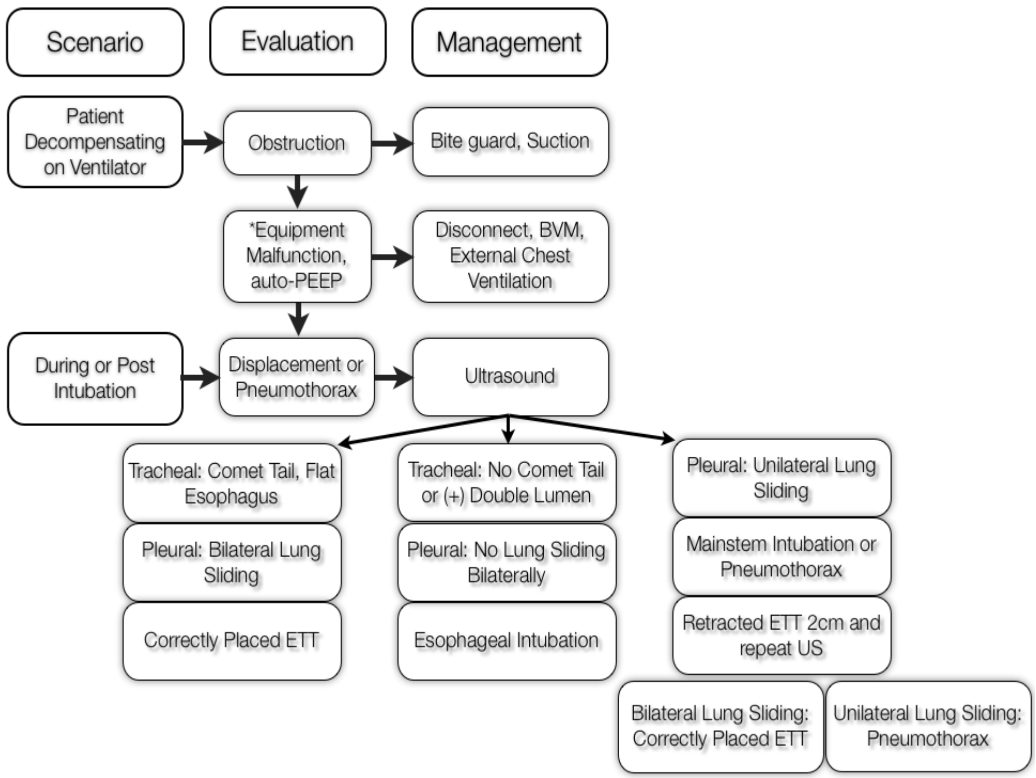
Mainstem bronchus intubations will have tracheal examinations that indicate correct placement of the ETT in the trachea. However, the lung contralateral to the mainstem intubation will exhibit no lung sliding on pleural examination. In most cases, this will be a right mainstem bronchus intubation that shows lung sliding on the right but absent lung sliding on the left.

CLINICAL INTEGRATION

Ultrasound is an integral component for evaluating the decompensating patient on mechanical ventilation or in confirming endotracheal intubation. The DOPES mnemonic is commonly used to assist clinicians in recognizing common problems associated with mechanically ventilated patients. D is for displacement of the ETT tube, either out of the trachea or in a mainstem intubation. O is for obstruction of the large airways, such as in mucous plugging or when patients bite on the ETT. P is for pneumothorax, specifically tension pneumothorax. E is for equipment or ventilator failure. S is for "stacked breaths" or auto-PEEPing, which is typically seen in patients with exacerbation of asthma or COPD.

Initial assessment and management of obstruction, equipment failure, and auto-PEEPing may be performed by suction of the ETT, placing a bite block, and disconnection from the ventilator. Should the patient's clinical status not improve with these measures, evaluation of ETT displacement or tension pneumothorax may be performed with ultrasound.

It may be difficult to differentiate between pneumothorax and mainstem intubation by ultrasound. If this is suspected, pull the ETT back about 2 cm, and repeat the pleural ultrasound. If the ETT length is 20-22 cm at the mouth after pulling the ETT 2 cm, and there is still absence of lung sliding unilaterally, this likely indicates a pneumothorax.



SEMINAL STUDIES

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TOPIC A2. ADVANCED THORACIC ULTRASOUND

Interstitial Fluid and Consolidation

SCANNING PROTOCOL

Patient Positioning

The patient is usually evaluated in a supine position although if dyspnea prevents the patient from being evaluated supine, the evaluation can take place in a position of comfort or more upright position.

Transducer and System Settings

A high frequency linear probe is usually used to interrogate the pleura although a low frequency probe may be preferable when evaluating for interstitial fluid or consolidation.

It is important to disable advanced acoustic filters, particularly harmonics, to allow for visualization of the pathologic artifacts (the generation of B-lines). These artifacts also tend to be more evident with "persistence" minimized and a high-contrast grayscale map.

Image Acquisition

Interstitial Fluid

In the diagnosis of undifferentiated dyspnea two locations on the anterior/superior chest wall may be enough for the diagnosis of cardiogenic pulmonary edema, in a protocol based on up to six locations. An eight-region scan provides a semi-quantitative estimate of the degree of pulmonary congestion: four quadrants at each side, scoring from zero to eight. A quadrant is considered positive if three or more B-lines are seen in one single screenshot of an intercostal space. If a detailed quantification of the interstitial fluid is desired a 28-points scan can be performed as detailed by Gargani, providing a score between 0 and 28.

The depth of field should be set to at least 18 cm to ensure accurate interpretation of the B-line artifact.

Consolidation

When clinical or alternative imaging data suggest a suspect region (pleuritic chest pain, auscultation, previous imaging) a focal examination can be enough to diagnose a consolidation. Otherwise, a 10 region protocol can be performed with excellent sensitivity in the emergency department setting.

NORMAL ANATOMY

The normal well aerated lung should produce artifacts known as A-lines. These are horizontal reverberation artifacts that repeat distal to the pleural line and should recur at the skin to pleura distance. In addition, the lung sliding of the pleural line should be readily visible (described in basic thoracic ultrasound section). A few scattered hyperechoic vertical lines (less than three per rib interspace) can be seen in normal lung physiology - especially in posterior lateral fields.

PATHOLOGY

Interstitial Fluid

The presence of increased interstitial fluid (as well as any interstitial thickening, fibrotic or inflammatory, and incomplete alveolar flooding of any source) is sonographically defined by the presence of multiple B-lines. B-lines are vertical artifacts that originate at the pleural line, move with the pleural line and travel the full distance of the ultrasound field of few (at least 18cm deep). More than 3 B-lines per rib interspace is considered pathologic. However, there appears to be a linear relationship between B-lines and interstitial fluid: the more B-lines that are present, the greater the amount of interstitial fluid.

Consolidation

Consolidations are seen as a subpleural soft-tissue like image with irregular margins, generated by the inflammatory debris completely flooding alveoli and small airways (hepatization). B-lines can be seen surrounding the consolidation, representing the transition between aerated and non-aerated parenchyma. Air bronchograms can usually be seen within the consolidation as irregular hyperehoic linear structures. When movement of secretions are seen inside an air bronchogram, they are known as dynamic air bronchograms, highly specific for pneumonia. The bronchograms seen in atelectasis are static, meaning without detectable movement of secretions. Also in atelectasis, the bronchograms tend to be parallel to each other, reflecting the loss of volume during the process of de-aeration, whereas a normal branching structure is seen in pneumonia, where there is no loss of parenchymal volume. Fluid bronchograms are seen in obstructive pneumonias, representing fluid-filled airways. These can be differentiated from blood vessels by their hyperechoic walls and absence of Doppler signal.

CLINICAL INTEGRATION

Interstitial Fluid

Thoracic ultrasound should be used very early in the approach of the critical patient, given its high sensitivity and high accuracy in the differential diagnosis of dyspnea. There is literature to support this recommendation and specific protocols have been suggested for how to differentiate between different etiologies of dyspnea using clinical ultrasound alone. Literature also supports the recommendation for thoracic ultrasound to monitor interstitial fluid as thoracic ultrasound seems to respond in real time to fluid shifts. Other clinical scenarios where lung ultrasound is useful are 1) during fluid replacement therapy in elderly patients with cardiomyopathy, as well as 2) to monitor resolution of acute pulmonary edema after treatment for CHF.

Consolidation

Although research is still developing, thoracic ultrasound has been shown to be more sensitive and specific than plain radiography in the diagnosis and in monitoring the resolution of lung consolidation. Changes on ultrasound seem to follow resolution of clinical symptoms more closely than with plain radiographs.

SEMINAL STUDIES

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TOPIC A3. ADVANCED CARDIAC ULTRASOUND

SCANNING PROTOCOL

The patient positioning, transducer and system settings and image acquisition techniques are the same for focused and advanced cardiac ultrasound. The basic cardiac windows (parasternal long, parasternal short, apical 4 and subxiphoid) are also the same. However, for advanced cardiac ultrasound, if thoracic aortic pathology is suspected, a suprasternal notch view should be attempted, following the carotid arteries inferiorly in order to visualize the thoracic aortic arch for aneurysm or dissection.

NORMAL ANATOMY

In advanced cardiac ultrasound, more attention is paid to the flow across valves and so it is important to obtain the basic cardiac windows with particular emphasis on getting valve images in the proper plane.

The mitral valve (MV) should move vigorously in a patient with normal LV function, with e-point septal separation of 6mm or less.

Flow across the MV should demonstrate a normal filling pattern with an early ("E" wave) filling that has higher peak velocity than the late atrial ("A" wave) using pulsed wave spectral Doppler at the tips of the MV. Tissue Doppler of the septal annulus of the MV should demonstrate similar E' and A' waves with the E'>10cm/s.

Normal patients may demonstrate trivial tricuspid regurgitation (TR), with peak velocity <2m/s.

The thoracic aortic root and descending thoracic aorta should be 4cm or less.

PATHOLOGY

Pericardial Effusion/Tamponade

In addition to reliably identifying pericardial effusions, the size may be graded as small (<1cm), moderate (1-2cm), and large (>2cm), measured at largest point in diastole. Echocardiographic evidence of tamponade includes RV diastolic and/or RA systolic inversion, plethora of the IVC, and exaggerated (>25%) respiratory variation of mitral inflow velocity using pulsed wave spectral Doppler at the tips of the MV.

Left ventricular systolic assessment and cardiac output

In addition to global LV assessment, focal wall motion abnormalities may be appreciated when marked or severe; these may be acute from ischemia or chronic from scar, and should be differentiated from cardiac conduction delays. Cardiac output may be determined by calculating stroke volume and multiplying by heart rate. Stroke volume may be calculated by subtracting systolic from diastolic volume using measurements in the apical four and two chamber views, or may be estimated by multiplying the velocity time integral (VTI) of continuous wave (CW) Doppler across the aortic valve by the left ventricular outflow tract area, calculated from diameter measured on the PSLA view.

Left ventricular diastolic and hypertrophy assessment

Diastolic function may be assessed using pulsed wave Doppler of the mitral inflow. E (early) to A (atrial) wave reversal may indicate impaired relaxation, though pseudonormalization may occur. Tissue Doppler imaging of the mitral annulus may reliably indicate diastolic dysfunction when the E' wave is less than 10cm/s. Left ventricular hypertrophy may be present if the LV free wall or septum exceeds 1.2cm in thickness at end diastole. Asymmetric hypertrophy of the LV septum should be appreciated.

Valve interrogations

2-dimensional echo may demonstrate calcifications, vegetations, or reduced valvular motion (from stenosis or reduced cardiac function). The motion of the MV and measurement of e-point septal separation (>12mm=low EF) may help determine LV function. Color flow Doppler may demonstrate stenotic or regurgitant patterns. As noted above, CW Doppler may be used to measure the amount of flow across the AV and used to determine stroke volume and cardiac output. For situations where there is concern for increased RV pressure (i.e. acute PE), CW Doppler may be used to estimated RV systolic pressure (i.e. acute PE) by measuring the peak velocity of the TR jet using CW Doppler and the modified Bernoulli equation: $\Delta P = 4 \times velocity^2$. A TR velocity greater than 2.7m/s (corresponding to pressure gradient of 29mmHg) is abnormal. Velocities of 4m/s or higher indicate severely elevated RV pressures that are likely to be chronic.

Thoracic aorta

Measurements of the thoracic aorta on bedside echocardiogram have been shown to correlate well with CT. A measurement of over 4.0cm of the aortic root at the sinuses of Valsalva using the leading edge method is concerning for a dilated thoracic aorta, with increased risk of dissection. Dilation or dissection of the arch may be visualized using a suprasternal notch view, and the portions of the descending aorta may be seen on the parasternal and apical views.

CLINICAL INTEGRATION

Clinical cardiac ultrasound is most useful in undifferentiated presentations that may involve the heart or lungs. The cardiac ultrasound examination may be performed in isolation but is frequently combined with other examinations of the chest, abdomen and vasculature depending on the clinical scenario. Clinical cardiac ultrasound may be indicated in the patient with: shortness of breath, hypotension, hypoxia, tachycardia, syncope, chest pain, abnormal EKG, cardiomegaly on CXR, trauma, altered mental status, or sepsis.

Clinical cardiac ultrasound may help delineate causes of dyspnea and/or hypotension and may help guide intravenous fluid and vasopressor therapy to optimize cardiac output by looking at LV function, IVC parameters, and cardiac output. The presence of focal wall motion abnormalities indicates cardiac ischemia, although old cardiac ischemia (scar) may not be distinguishable from acute ischemia without a prior echo.

While not sufficiently sensitive to exclude thoracic aortic pathology, thoracic aortic dilatation may guide further dilatation and visualization of an aortic flap is specific for dissection. In addition, while not routinely ruled out in bedside echocardiography, significant valvular abnormalities and intracardiac masses or clots may be discovered on point-of-care echo, helping to diagnose and/or expedite appropriate care.

SEMINAL STUDIES

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TOPIC A4. ADVANCED OCULAR ULTRASOUND

Optic Nerve Sheath Diameter and Intracranial Pressure Assessment

SCANNING PROTOCOL

Patient Positioning

The patient is supine on a stretcher with the sonographer at the head of the bed facing the ultrasound machine/screen.

Transducer and System Settings

When examination the optic nerve during a trauma survey for evidence of elevated intracranial pressure (ICP), a high frequency linear array transducer (7-12 MHz) should be used. Alternate transducers include small footprint transducers such as pediatric phased array or intracavitary transducers.

Image Acquisition

The most common method of performing the examination is carried out with the trauma patient in the supine position; a thin sonolucent dressing such as Tegaderm® may be placed over the closed lid to improve patient comfort and prevent conjunctival contamination, then the preorbital space is filled with a liberal amount of ultrasound coupling gel. The transducer is positioned with care taken to limit contact with the lid; no pressure should be placed on the globe unless globe rupture has been ruled out. Ocular ultrasound is contraindicated when there is suspicion for globe rupture or in any other instance where the examination could result in further injury. Additionally, pressure on the globe may elicit the vagal oculocardiac reflex, which can result in decreased heart rate and syncope, especially in pediatric patients.

Transverse and sagittal images are obtained when performing a complete examination to ensure that optic nerve sheath measurements correlate in both axes. Since the optic nerve enters the orbit at an angle, slight movement of the transducer toward the lateral aspect of the orbit may be necessary to visualize the nerve. Still images should be obtained so that measurements of the optic nerve sheath diameter (ONSD) can be made.

NORMAL ANATOMY

The structure of interest when evaluating the trauma patient for increased ICP is the optic nerve sheath, which lies posterior to the prominent anechoic, vitreous-filled globe. Standard ONSD is measured 3mm posterior to the retina since the optic nerve sheath is theoretically most susceptible to changes in diameter due to transmitted pressures at this location, and there is a clear distinction between the optic nerve sheath and surrounding tissue at this level. Normal ONSD measurements are less than 5mm regardless of age.

PATHOLOGY

There have been a number of studies performed which have tried to define the level at which ONSD becomes pathologic. Most have found that elevated ICP is present when the ONSD is greater than 5mm. ONSD measurements tend to level off at a maximum of about 7.5mm regardless of ICP.

CLINICAL INTEGRATION

The clinical utility of this technique is still being defined; however, there are potential benefits of sonography as an objective non-invasive indicator of elevated ICP. The use of an intracranial catheter remains the standard method for diagnosing elevated ICP due to severe traumatic brain injury (TBI), however, catheter placement is not always feasible due to lack of neurosurgical capabilities or clinical contraindications. Additionally, ONSD measurements in the evaluation of the multi-trauma patient may serve as a tool that initially alerts the trauma team to the presence of elevated ICP when there is concern for severe TBI and the patient is too unstable to undergo other imaging.

SEMINAL STUDIES

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TOPIC A5. ENT ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

Most authors recommend the patient should be examined with the neck extended and head extended in sniffing position.

Transducer and System Settings

A high-frequency, small footprint intracavitary microconvex array probe should be used to visualize the peritonsillar region. A high-frequency linear transducer should be used to image the upper airway and neck.

Image Acquisition

The peritonsillar area is visualized by placing a sheathed intracavitary probe near the tonsils in the pharynx and soft palate. The tonsils should be evaluated bilaterally in transverse and longitudinal orientation. The cervical lymph node chain is visible bilaterally in the anterior neck and is best visualized using a high-frequency linear array transducer. The floor of the mouth can be imaged in transverse and longitudinal planes beneath the mandible in the sub-mental fossa. From this location, the base of the tongue and hyoid bone are visualized anteriorly in the midline of the neck. Deep to the hyoid cartilage, the vocal cords can be seen. Below the hyoid bone the thyroid cartilage can be visualized. The thyroid is followed inferiorly by the criciothyroid membrane, then cricoid cartilage, then tracheal cartilage rings.

NORMAL ANATOMY

The palatine tonsils are readily visible sonographically as homogeneous oval structures. The carotid artery is generally found posterolateral to each tonsil.

Normal lymph nodes are ovoid and hypoechoic with respect to adjacent muscles, with an echogenic hilum.

Although the upper airway is comprised largely of air-filled structures such as the oral cavity, pharynx, larynx, and trachea, visualization of these structures superficially is possible with ultrasound. The floor of the oral cavity is visible, as is the base of the tongue. Salivary glands may be visualized in the superficial soft tissue. Lateral to the base of the tongue on either side the valleculae are visible. The larynx and hyoid bone are visible anteriorly, and the tracheal rings below that. The epiglottis can be found deep to the thyrohyoid membrane, seen as a hyperechoic curvilinear area.

The vocal cords can be viewed behind the hyoid cartilage. They form a triangle around the shadow of the trachea. The hyperechoic vocal ligaments are visible medially.

PATHOLOGY

Peritonsillar abscess: Enlarged tonsils with associated hypoechoic material are the hallmark of pertonsillar abscess. Posterior acoustic enhancement is consistently seen as well.

Lymphadenopathy: Local cervical lymphadenopathy may be associated with a nearby cellulitis or other focal infection. Bilateral lymphadopathy may represent viral illness. Reactive lymph nodes often appear enlarged and hypervascular.

Difficult intubation assessment: Measurement of pretracheal soft tissue at the level of the vocal cords is a good predictor of difficult laryngoscopy in obese patients. Greater than 28mm of pretracheal soft tissue and neck circumference greater than 50cm predict difficult laryngoscopy.

Neck mass: Another common presentation is a patient with a neck mass. Cystic structures such as brachial cysts or thyroglossal duct cysts are readily visible by ultrasound. Neck masses such as lymph nodes, thyroid masses or salivary gland masses are also readily visible with ultrasound.

CLINICAL INTEGRATION

Pharyngitis: Ultrasound can be helpful in differentiating peritonsillar cellulitis from abscess.

Neck masses: Inflammatory conditions of the upper airway such as epiglottitis or the presence of mucosal swelling can be assessed with ultrasound. In addition, the presence of lymphadenopathy or abscess can be assessed in the cervical chain.

Vocal cords: Although clinical scores to predict difficult direct laryngoscopy exist, ultrasound may be of benefit in patients where difficult laryngoscopy is a possibility. In addition to providing data on the anatomy, ultrasound can be used to investigate backup airway management options such as the location of the cricothyroid membrane, or the optimal endotracheal tube size in children.

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TOPIC A6. ADNEXAL ULTRASOUND

SCANNING PROTOCOL

Transabdominal

Patient Positioning

Imaging may begin with the patient supine, with the head supported, arms relaxed at the patient's sides and slight flexion to the hips and knees. Ideally the bladder will be full but visualization of the pelvic structures is still possible without the sonographic window of the distended bladder.

Transducer and System Settings

Choose a low frequency (2-5 MHz) curvilinear or phased array transducer with the ultrasound machine set to an obstetrics, gynecology or general abdomen examination preset.

Image Acquisition

Starting in midline longitudinal orientation (transducer indicator oriented cephalad) above the pubic symphysis with the transducer angled inferiorly toward the coccyx, identify the bladder (near field or anterior) and the uterus (far field or posterior to the bladder). Image completely through the uterus in longitudinal orientation, fanning the probe right to left, noting any pelvic or intrauterine fluid collections and their location relative to the body of the uterus. Carefully examine the margin of the uterus, looking primarily for the sharp angles of hypoechoic fluid collections outside the uterus that are characteristic of free fluid. In particular note the potential space of the rectouterine pouch (pouch of Douglas). Next, obtain transverse views (transducer indicator oriented to the patient's right), again imaging completely through the uterus by fanning cephalad and caudad, especially noting a generally midline location for any intrauterine structures and the minimum thickness of the myometrium surrounding any gestational sac. Pay special attention to the lateral margins of the uterus where fluid is most likely to collect. The focus of the examination will be to examine the adnexa. However, a complete examination includes visualization of the entire uterus from fundus to cervix with identification of the endometrial stripe (hyperechoic line) and vaginal stripe (thin echogenic, curved stripe posterior to the bladder) in the longitudinal view. Imaging the uterus provides contextual information that aids in locating the ovaries as the ovaries are best seen posterior and lateral to the uterus in the transverse plane. In the transabdominal approach, the fallopian tubes are normally not visualized unless surrounded by or containing fluid but occasionally the ovaries can be seen anterolateral to the transverse uterus as isoechoic structures with anechoic follicles.

Transvaginal

Patient Positioning

Prior to commencing the examination, it is helpful to have the patient void and then undress from the waist down. The lithotomy or reclined butterfly position with the hips elevated are the most common patient positions for transvaginal scanning.

Transducer and System Settings

Use a mid-frequency (5-8 MHz) endocavitary transducer, with the ultrasound machine set to an obstetrics or gynecology preset. Place standard scanning gel on the probe for coupling followed by a transducer cover. Ensure that all air is expelled between the probe head and the transducer cover. Next, place bacteriostatic gel over the cover for lubrication.

Power or spectral Doppler is critical for ovarian torsion. Doppler parameters should be optimized to detect low flow velocities in the ovary and surrounding tissue. Doppler gain should be increased to a level slightly below excessive flash artifact. A low wall filter and low pulse repetition frequency should be utilized. Use the asymptomatic side to set these parameters.

Image Acquisition

Starting in the longitudinal orientation with the transducer indicator oriented anteriorly, insert the endocavitary transducer into the vaginal vault and identify the bladder, located anteriorly, and uterus, located posterior to the bladder. Fanning the transducer left and right, completely image the uterus and adnexa in the longitudinal (sagittal) plane. Note any fluid collections in the anterior and/or posterior cul-de-sac (rectrovesicular pouch). Next, orient the transducer indicator to the patient's right to obtain complete transverse (coronal) views of the uterus by fanning superiorly and inferiorly. In this view, the bilateral ovaries are best visualized on either side of the uterus anterior and medial to the internal iliac vessels. The size and appearance of both ovaries should be recorded and presence or absence of arterial and venous flow should be evaluated with color Doppler. The fallopian tubes may not be visualized unless pathology that renders them more prominent is present such as fluid within or surrounding the tube, masses, or cystic structures.

NORMAL ANATOMY

Using the uterus as a point of reference, the ovaries, bilateral structures suspended on either side of the uterus by the broad ligament and suspensory ligament, can be identified. The ovaries should measure less than 3.5x2x1.5cm in premenopausal females and 1.5x0.7x0.5cm in postmenopausal females. Multiple follicles may be visualized within the ovaries in the premenopausal patient. Normal follicles measure less than 3cm, and are simple, thin walled, anechoic, fluid filled cysts without blood flow. In postmenopausal females, the ovaries typically appear small and homogenous. A corpus luteum cyst is a normal finding in pregnancy. A corpus luteum cyst is a thick walled cystic mass, measuring less than 3cm, with peripheral blood flow ('ring of fire') that may exhibit internal echoes. An attempt should be made to visualize the fallopian tubes but they are often not visualized on transvaginal or transabdominal ultrasound unless outlined or filled with fluid. This occurs in several pathologic states as discussed below.

PATHOLOGY

When examining the adnexa with ultrasound, any mass should be measured and characterized. Location, size and presence of solid or cystic components should be noted along with secondary findings such as free fluid and lymphadenopathy.

Ovarian Cysts

Simple ovarian cysts are unilocular, thin walled and without septations or solid components. Examples include corpus luteum cysts and follicular cysts. Complex cysts may be multilocular, septated, contain solid components or internal echoes, or have irregular, thickened walls. Findings concerning for malignancy include solid components, thick septations (>2-3mm), blood flow in solid components/septae and ascites.

Ovarian Torsion

Unilateral pelvic or lower abdominal pain that is sudden in onset and accompanied by nausea and vomiting is suggestive of ovarian torsion. The most common ultrasonographic finding suggesting torsion is a unilaterally enlarged ovary with multiple cortical follicles. Absent/abnormal blood flow (loss of arterial waveform) is highly suggestive of torsion but the presence of arterial and venous flow within the ovary does not exclude ovarian torsion due to the dual blood supply to the ovary.

Pelvic Inflammatory Disease

Pelvic inflammatory disease (PID) encompasses a spectrum of disease and ultrasound is the modality of choice for evaluation of the adnexa for signs of PID and its sequelae. Ultrasonographic signs of PID may include hydrosalpinx, pyosalpinx, and tubo-ovarian abscess (TOA). Hydrosalpinx, anechoic fluid around or within the fallopian tube, is also associated with ectopic pregnancy. In pyosalpinx, low-level echoes are seen in fluid within the tube. Care should be taken to distinguish a fluid-filled fallopian tube (lack of peristalsis) from bowel. Thickened fallopian tube walls (>5 mm) are associated with acute PID. TOA appears as a complex multiloculated mass where ovary and fallopian tube are complexed together due to infection; a TOA will be hyperemic with color/power Doppler.

CLINICAL INTEGRATION

Sonographers with the proper training can use adnexal ultrasound to assess patients with pelvic pain. Ultrasonographic findings can help correlate with a clinical examination consistent with PID, ovarian torsion, ruptured and non-ruptured ovarian cysts. It is not unusual to find a slight amount of free fluid in the posterior cul-de-sac. However more concerning would be a large amount of fluid in the posterior cul-de-sac or fluid in the anterior cul-de-sac. Finding this abnormality should immediately be followed by a FAST examination to quantify the amount of intra-abdominal free fluid. A large amount could clinically correlate with a rupture ectopic pregnancy or other vascular emergency leading to hemodynamic instability and death.

Ob-Gyn should be consulted emergently for any findings concerning for ovarian torsion.

TOPIC A7. UTERINE ULTRASOUND

SCANNING PROTOCOL

Transabdominal

Patient Positioning

Place the patient in the supine position with a full bladder and the abdomen exposed. Slight flexion of the hips and knees helps to relax the abdominal muscles. A full bladder is best for imagining of pelvic structures but visualization is still possible without the sonographic window of the distended bladder.

Transducer and System Settings

Use a low frequency (2-5 MHz) curvilinear or phased array transducer, with the ultrasound machine set to an obstetrics or general abdominal preset. Ample scanning gel is helpful.

Image Acquisition

Starting in midline longitudinal orientation (transducer indicator oriented cephalad) above the pubic symphysis with the transducer angled inferiorly toward the coccyx, identify the bladder (near field) and the uterus (far field). Image completely through the uterus in longitudinal orientation, noting any pelvic or intrauterine fluid (hypoechoic) collections and their location relative to the body of the uterus. Carefully examine the margin of the uterus, looking primarily for the sharp angles of fluid collections. In particular note the potential space of the rectouterine pouch (Pouch of Douglas). Next, obtain transverse views, again imaging completely through the uterus. Pay special attention to the lateral margins of the uterus where fluid is most likely to collect. Attention should also be paid to the homogeneity of the uterus as well as the endometrial stripe thickness in post-menopausal women.

Transvaginal

Patient Positioning

Have the patient empty her bladder and undress from the waist down with a drape or sheet to place over her lower body. Place the patient in a lithotomy position or a reclined butterfly with the hips elevated.

Transducer and System Settings

Use a mid-frequency (5-8 MHz) endocavitary transducer, with the ultrasound machine set to an obstetrics or gynecology preset. Place standard scanning gel on the probe for coupling followed by a transducer cover. Ensure that all air is expelled between the probe head and the transducer cover. Next, place bacteriostatic gel over the cover for lubrication.

Image Acquisition

Begin in longitudinal orientation (transducer indicator oriented anteriorly) and focus attention on identifying the bladder after entering the introitus and advancing the endovaginal probe closer to the vaginal vault. Once the bladder is identified, systematically search the posterior region to identify the uterus. Image completely through the uterus in longitudinal orientation, noting any pelvic or intrauterine fluid (hypoechoic) collections and their location relative to the body of the uterus. Note any free fluid in either the posterior and/or anterior cul-de-sacs. Obtain coronal views (transducer indicator oriented to the patient's right), again imaging completely through the uterus, especially noting a generally midline location for any intrauterine structures. In the transverse view, look for fluid primarily in the postero-lateral corners.

NORMAL ANATOMY

The bladder is a thick-walled structure with a variable amount of fluid that is generally identifiable even when decompressed. The uterus is a pear-shaped, generally homogenous structure located directly posterior to the bladder. The average size of the uterus is 7x4cm in nulliparous and 8.5x5.5cm in multiparous women. The standard uterine position is midline, anteflexed (uterine body relative to cervix) and anteverted (axis of cervix relative to vagina), but may be deviated laterally. The endometrial stripe defines the axis of the uterus. With a standard anteverted uterus, the fundus will curve over the bladder, especially when the bladder is decompressed.

The midline hyperechoic endometrial stripe is more pronounced just prior to menses and in pregnancy. The endometrial stripe does become thinner during the post-menopausal period. In the pregnant female, it is important to locate the position of the placenta and ensure that it does not cover the cervical os. The placenta appears as a homogenous mass within the uterus that is hyperechoic to the myometrium, indenting the gestational sac. As the pregnancy progresses to the third trimester, the placenta will appear more heterogeneous because of the presence of calcifications and vascular lakes. When situated on the front wall of the uterus, the placenta is referred to as anterior, the back wall is a posterior placenta, the top as fundal and the side walls are referred to as left or right lateral. The position of the placenta can change during the pregnancy and a low-lying placenta should be reevaluated with ultrasound in the 3rd trimester of pregnancy.

PATHOLOGY

Fibroids (leiomyomas) are benign tumors of the uterus that have a variable appearance on ultrasound. Fibroids may be hyper- or hypoechoic and can have a wide variety of sizes and shapes but often the striated abnormal muscle can be seen to swirl and it may have a hyperechoic rim s. They may also be located in the uterus as well as the cervix.

The endometrium is the inner lining of the uterus and is normally less than 5mm in thickness in post-menopausal women. There is concern for endometrial cancer when the endometrial lining is over 5mm in post-menopausal women with vaginal bleeding and when over 11mm in post-menopausal women without vaginal bleeding. An increase in endometrial thickness would warrant an endometrial biopsy with gynecology consultation.

The placenta can have a variety of locations throughout the pregnancy. When evaluating for placental previa, where the placenta is partially or completely covering the cervical os, it is important to evaluate the placenta between weeks 20-23 of pregnancy.

CLINICAL INTEGRATION

Sonographers with the proper training can use uterine ultrasound to assess patients with pelvic pain. Ultrasonographic findings can help to clinically correlate history and physical examination findings, the most important of which would be to rule-in an ectopic pregnancy. A slight amount of free fluid in the posterior cul-de-sac is not abnormal, however a large amount or the finding of free fluid in the anterior cul-de-sac should be followed up with a FAST examination to quantify the amount of intraabdominal free fluid. A patient with a positive pregnancy test and intra-abdominal or pelvic free fluid is extremely concerning for a ruptured ectopic pregnancy or other vascular emergency leading to hemodynamic instability and death. This topic is covered in detail in the section, 1st Trimester Pregnancy. Most other uterine pathologies while needing gynecologic follow-up, are by themselves non-emergent, and not immediately life threatening diseases unless of course there is bright red vaginal bleeding in a second or third trimester pregnancy and placenta previa is suspected.

SEMINAL STUDIES

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TOPIC A8. TESTICULAR ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

The patient is supine on a stretcher and made as comfortable as possible. A towel is placed between the patient's thighs and under the scrotum in order to immobilize and elevate the scrotum. The penis is positioned or held by the patient to the side or cephalad and covered with a towel. The sonographer stands to the patient's right, facing the ultrasound machine and screen.

Transducer and System Settings

A linear high frequency 6-14 MHz probe, capable of color, power and spectral Doppler, is used for testicular ultrasound. Occasionally, a curvilinear abdominal probe may be necessary in the setting of large fluid collections, scrotal edema or acute swelling in order to provide adequate depth of imaging.

Power or spectral Doppler is critical for testicular ultrasound. Doppler parameters should be optimized to detect low flow velocities in the testicle and surrounding tissue. Doppler gain should be increased to a level slightly below excessive flash artifact. A low wall filter and low pulse repetition frequency should be utilized. Use the asymptomatic side to set these parameters.

Image Acquisition

Apply a large amount of warm gel across both testicles. Start by scanning the unaffected testicle. Begin in the longitudinal axis of the testicle, with the probe marker towards the patient's head. Thoroughly scan through the testicle taking care to note texture of the testicle and abnormalities. Rotate the probe 90 degrees counter-clockwise, so that the probe marker is towards the patient's right, and again scan through the testicle. Repeat on the affected side. Be sure to interrogate the epididymis.

After a thorough examination of both testicles has been performed in gray scale, color or power Doppler is used to assess vascular integrity. Begin with the unaffected side. Start with the probe in the transverse plane near the mediastinum testis. After intratesticular blood vessels have been identified with color or power Doppler, spectral Doppler is utilized to identify arterial and venous flow. Repeat on the affected side.

It is helpful to obtain a transverse view across both testicles, in order to compare gray scale anatomy and blood flow.

Images needed for a complete scan: transverse and sagittal views of both testicles in B mode, assessing testicle and epididymis architecture, as well as color or power Doppler and spectral Doppler images assessing venous and arterial blood flow.

NORMAL ANATOMY

Scrotal wall thickness ranges from 2-8 mm, depending on cremasteric muscle contraction. The scrotum is divided by the median raphe. Testes are oval in shape, measuring 5x3x2 cm in size. They are homogenous in echogenicity, and their texture has been compared to that of the liver. The mediastinum testis is tissue that runs along the longitudinal axis of the testicle and supports testicular vessels and ducts. This is usually seen as a thin echogenic band. The epididymis runs superior and posterior to the testis. It is divided into the head, body and tail. The head is readily identifiable, and is located superiorly, usually measuring 1 to 1.2 cm in diameter. It has a similar echogenicity to the testicle. The appendix testis is small and oval, and is normally hidden by the epididymal head.

The testicular artery supplies the testes. It runs posteriorly to the testicle and branches into capsular arteries that are found beneath the tunica albuginea. These in turn become centripetal arteries that flow towards the mediastinum testis. Testicular veins flow from the mediastinum testis into the pampiniform plexus, found in the spermatic cord.

PATHOLOGY

Testicular torsion: Acutely the testicle will appear similar to the non-affected side in gray scale imaging. After 4 hours edema will increase testicle size and it will be hypoechoic in comparison to the affected side. A difference in flow between the affected and un-affected testicle is key to this diagnosis. In complete torsion no blood flow will be identified by color or power Doppler. A reactive hydrocele frequently develops. Intact arterial flow but compromised venous flow, as identified by spectral Doppler, is indicative of incomplete torsion.

Epididymitis and orchitis: Epididymitis is identified sonographically by enlargement and thickening of the epididymis, most frequently involving the epididymal head. An enlarged heterogeneous testis characterizes orchitis. Both are associated with increased color or power Doppler flow when compared to the non-affected side. A reactive hydrocele is common.

Testicular trauma: Disruption of the tunica albigunea and extrusion of testicular contents into the scrotal sac defines a testicular rupture. By ultrasound this is identified as loss of normal contour of the testis, presence of a testicular hematocele and heterogeneity of the testicular parenchyma. Acute hematoceles are echogenic.

Hydrocele: Hydroceles are typically anechoic and are most commonly seen in the anterolateral scrotum. They are associated with acute or chronic pathology. They may contain loculations or irregular septations, reflecting hemorrhage or infection.

Scrotal hernia: Bowel in the scrotal sac will have peristalsis, air artifact or fluid. Color or power Doppler can help identify flow, indicating continued perfusion. Presence of peristalsis also decreases the likelihood of bowel incarceration. A significant increase in flow by color or power Doppler is suggestive of early strangulation. An akinetic, dilated loop of bowel is highly suggestive of bowel strangulation.

CLINICAL INTEGRATION

Testicle or scrotal pain is frequently the presenting complaint for traumatic, infectious or vascular causes of testicular injury. Physical examination findings for these etiologies overlap. Patients with testicular or scrotal pain can also be difficult to examine, due to guarding and lack of cooperation. If the diagnosis of testicular torsion or rupture is missed, the testicle can be lost and fertility of the patient compromised. Ultrasound helps facilitate triage and management of patients presenting with this high-risk chief complaint. Careful imaging of both testicles, with attention paid to color or power Doppler, as well as spectral Doppler, allows identification of these surgical emergencies from other causes of testicular pain.

Urology should be consulted emergently for any findings concerning for testicular torsion or rupture. A surgeon should be consulted for incarcerated or strangulated hernias.

SEMINAL STUDIES

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TOPIC A9. ADVANCED ABDOMINAL ORGAN ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

The patient should be comfortably placed in a supine position, and if possible, should be fasting, for best views.

Transducer and System Settings

The curved 2-5 MHz abdominal or phased array probe should be used. Using a transducer with a small scanning footprint, it is easier to view the liver between the ribs.

Image Acquisition

Liver: Sagittal, transverse, coronal, and subcostal oblique views are required for a complete survey including all lobes of the liver and portal triad.

Pancreas: Using gentle compression technique may displace bowel gas and intra-abdominal fat for better imaging. Consider alteration of the patient's position to include erect and supine views, to displace bowel gas. Transverse scans in the midline below the xyphoid may prove to be a valuable starting point in identification of nearby anatomy; sagittal and oblique views are also required for a complete survey. Consider using the left kidney as an acoustic window for the tail of the pancreas. Fanning the probe (side-tilting) may provide better visualization than sliding laterally away from midline to visualize the entire gland.

Spleen: If patients are able to follow commands, instructing them to take deep breaths to move the spleen inferiorly and allow for better visualization. An initial starting point for the scan is the coronal view, from the mid axillary line, and the probe may be fanned anteriorly and posteriorly to visualize the entire parenchyma of the spleen

NORMAL ANATOMY

Liver: The normal liver is the largest solid intra-abdominal organ, and is generally located in the right upper quadrant. Goals of the liver examination include:

- Identify the liver and its relation to the adjacent kidney, inferior vena cava, and right hemidiaphragm
- Identify the three lobes of the liver (Right, Left, Caudate) and their segments including (R anterior and posterior, L medial and lateral)
- Identify the right and left intersegmental fissures which subdivide the right and left lobes into their segments

- Identify the main lobar fissure (MLF) which divides the right from the left lobe of the liver, and passes through the gallbladder fossa
- Become familiar with the vascular anatomy of the liver, including identification of the hepatic and portal venous systems including Right, Middle and Left hepatic veins, and main, right and left portal veins.
- Know the normal flow pattern and diameter of the portal vein
- Understand Couinaud's anatomy and the functional portal segment system of dividing the liver
- Identify ligaments of interest including Glisson's capsule, hepatoduodenal ligament, falciform ligament.
- Normal liver size and normal echogenecity/homogeneity of liver tissue on ultrasound

Pancreas: The pancreas is one of the more difficult organs to visualize by ultrasound because of its location deep to many gas filled loops of bowel and colon. Evaluation of the pancreas includes normal anatomical structures and relationships as outlined below.

a. Identify the pancreas and its relation to the adjacent aorta, stomach, transverse colon, liver, inferior vena cava and duodenum

b. Identify the head, uncinate process, neck, body and tail of the pancreas

c. Attempt to identify surrounding arteries including superior mesenteric vessels, abdominal aorta with celiac axis, common hepatic artery, and superior mesenteric artery.

d. Identify surrounding venous structures including inferior vena cava, splenic vein, and superior mesenteric vein

e. When possible, identify the pancreatic duct

f. Know the normal size and echotexture of the pancreas which is usually homogenous and often hyperechoic compared with the liver

Spleen: The spleen ultrasound examination is invaluable in the evaluation of causes for palpable splenomegaly and due to the relative homogeneity of splenic tissue, focal lesions and abnormalities are relatively easy to identify using ultrasound. Evaluation of the spleen includes normal anatomical structures and relationships as outlined below.

a. Identify the spleen and its relation to the adjacent stomach (which may contain gas or fluid), left hemidiaphragm, tail of the pancreas (close to the hilum) and left kidney (inferior /posterior and medial to the spleen)

b. Identify the superomedial component and the inferolateral component, and their junction at the hilum

c. Attempt to identify surrounding vasculature splenic artery and splenic vein. Normal diameter of the splenic vein should be noted, such that signs of portal hypertension including splenic vein dilation would be noticed on routine examination.

d. Normal size (averages 12 cm length, and does not surpass the kidney inferiorly) and echotexture of the spleen should be assessed. The spleen is usually uniform, homogenous and often mid-low level of echogenecity.

PATHOLOGY

Liver: A list of important findings to be familiar with is below:

- Liver cysts including the differences between simple cysts and septated cysts more suggestive of parasitic infection
- Liver abscess (often heterogeneous, occasionally with gas /speckling artifact inside)
- Adult Polycystic Liver disease
- Fatty Liver
- Cirrhosis- macro and micro nodular cirrhosis
- Portal Hypertension
- Portal Vein thrombosis
- Liver Mass characterization and qualities of primary tumors vs. metastatic lesions
- Hepatic Trauma

Pancreas: A list of important findings to be familiar with is below:

- Acute pancreatitis including appearance of a hypoechogenic and enlarged gland, with edema in surrounding tissues and possibly foci of air within the pancreas
- Neoplasms including cystic neoplasms and solid tumor differentiation
- Chronic pancreatitis findings including calcifications

Spleen: The most common splenic pathology to assess in the non-trauma patient by clinical sonography is splenomegaly. Causes to consider for homogenous splenomegaly include tropical splenomegaly from chronic malaria, portal hypertension, AIDS, leukemia , lymphoma, and myelofibrosis. If the spleen is enlarged, notation should be made whether the appearance is hetero- or homogenous. A list of important findings to be familiar with is below:

- Cysts including from echinococcus, post-trauma, congenital, or intrasplenic pancreatic pseudocysts.
- Splenic abscess may be difficult to distinguish from cystic disease, however gas within an abscess cavity or ring down artifact may suggest infectious causes in the right clinical picture
- Solid masses including from TB, Sarcoid, and histoplasmosis or malignancy
- Splenic infarct often appears as a focal, wedge shaped hypoechoic lesion in the periphery of the parenchyma usually in a patient with pain. However, these lesions may change in appearance with time.
- Splenic fungal disease including candidiasis may have the appearance of several nodules within the spleen with a "wheels within wheels" appearance.
- Miliary TB may appear as multiple tiny echogenic foci within the parenchyma
- Splenic trauma including fracture and hemoperitoneum
- Congenital abnormalities including accessory spleen tissue

CLINICAL INTEGRATION

Liver: Ultrasound examination of the liver is clinically indicated when there is suspected ascites, liver disease, unexplained jaundice or RUQ pain with or without palpable hepatomegaly. The bedside sonographer should be comfortable identifying the normal anatomy of the liver, and if an abnormality of tissue structure or vasculature is found, accurately describing the location and type of abnormality and getting further imaging when appropriate. If cysts, abscesses or other infectious entities are suspected, appropriate antimicrobial therapy should begin based on the ultrasound findings. Similarly, if trauma and hemoperitoneum are identified, appropriate trauma care should be provided.

Pancreas: Ultrasound examination of the pancreas is often difficult but may be indicated in patients presenting with painless jaundice, or signs/symptoms concerning for acute or chronic pancreatitis. Familiarity with pancreatic mass lesions and pseudocysts is important so they are not mistaken for abdominal aortic aneurysms in emergent focused examinations. The bedside sonographer should be comfortable identifying the pancreas and recognizing normal appearance vs abnormal appearance. If abnormalities are visualized, including signs of acute pancreatitis, consider focused assessment of the RUQ for choledocholithiasis as a potential cause. If masses or lesions are seen within the pancreas, further imaging with CT/MRI or consultative sonography would be indicated.

Spleen: Bedside sonography of the spleen is clinically indicated in patients presenting with palpable splenomegaly, trauma, or concerns for left upper quadrant abdominal pain that may be due to infarcts or lesions within the spleen. It can also be useful following mononucleosis and for evaluation for splenomegaly in this instance. The bedside sonographer should be comfortable identifying the spleen and recognizing normal appearance vs. abnormal appearance. If abnormalities are visualized, including signs of acute trauma or infectious causes, appropriate clinical care should be initiated immediately. If masses or lesions are seen within the spleen, further imaging with CT/MRI or consultative sonography, and a work up for systemic causes such as malignancy, would be indicated prior to biopsy.

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TOPIC A10. BOWEL ULTRASOUND

SCANNING PROTOCOL

Patient Positioning

The patient is usually supine and may require analgesia as graded compression is occasionally used to assess whether the hernia is reducible.

Transducer and System Settings

Hernia: Imaging may be accomplished using a high frequency, linear array probe in thin patients or when evaluating the scrotal sac, but often the use of a lower frequency, curvilinear probe is necessary in patients with a larger body habitus.

Bowel obstruction: Imaging may be accomplished using a high frequency, linear array probe in thin patients or children, but often the use of a lower frequency, curvilinear probe is necessary in patients with a larger body habitus.

Image Acquisition

Hernia: Sonography for hernia assessment involves obtaining orthogonal images of the area of interest, most commonly the inguinal canal but also including other areas such as the abdominal wall and umbilicus. Sonography should focus on (i) luminal diameter of the bowel, (ii) the appearance and thickness of the bowel wall, and (iii) bowel peristalsis and kinesis. Compression views can sometimes provide additional information and may help in determining if the hernia is incarcerated or reducible.

Bowel obstruction: Sonography for bowel obstruction and ileus involves sweeping across the abdomen using the "lawnmower approach" to assess the (i) bowel contents (eg, aearated vs. fluid filled), (ii) luminal diameter of the bowel, (iii) the appearance and thickness of the bowel wall, and (iv) bowel peristalsis and kinesis. If abnormal bowel is encountered, it should be followed until normal bowel is visualized. This would allow for identification of a transition point and other obstructive causes such as intussusception or compressing masses. Compression views can sometimes provide additional information.

Pneumoperitoneum: While pneumperitoneum can be detected at any position where the intraperitoneal space can be visualized, the most readily available interface is anteriorly where the liver abuts the anterior abdominal wall. Placement of a curvilinear transducer in a sagittal plane at the midclavicular line slightly inferior to the right costal margin is the most appropriate imaging plane.

NORMAL ANATOMY

Hernia: The anatomy visible during hernia imaging depends on the location of the images. In general, you would be expected to identify the skin surface, subcutaneous adipose, and specific deep structures. In the case of the abdominal wall, you would expect to see musculature and then nondilated, peristaltic bowel.

Oftentimes you can see the multiple layers of the bowel wall and this helps to distinguish it from a cyst. In the case of the scrotum, you would expect to see normal scrotal contents without the presence of bowel.

Bowel obstruction: The anatomy visible during bowel imaging depends on the location of the images. In general, you would be expected to identify the skin surface, subcutaneous adipose, and specific deep structures. You would expect to see musculature and then nondilated, peristaltic bowel, which should be easily compressible. In the subxiphoid region you would expect to see the aorta and IVC deep to the bowel. In the suprapubic area, you should also see the bladder. In the pericolic gutters, you should be able to visualize the kidneys deep to the bowel.

PATHOLOGY

Hernia: The primary pathology that is encountered during hernia imaging is the presence of bowel within a hernia sac. When reducible, the bowel should have normal peristalsis and caliber with easy compression. When strangulated, the bowel will be dyskinetic, most often dilated, and likely possess thickened, edematous walls while being noncompressible. If color flow is used on the bowel wall a lack of perfusion would indicate potential strangulation while hyperemia would indicate incarceration but not strangulation.

Other pathology that can be encountered depending on anatomical location include cysts, abscesses, vascular aneurysms, and herniated adipose.

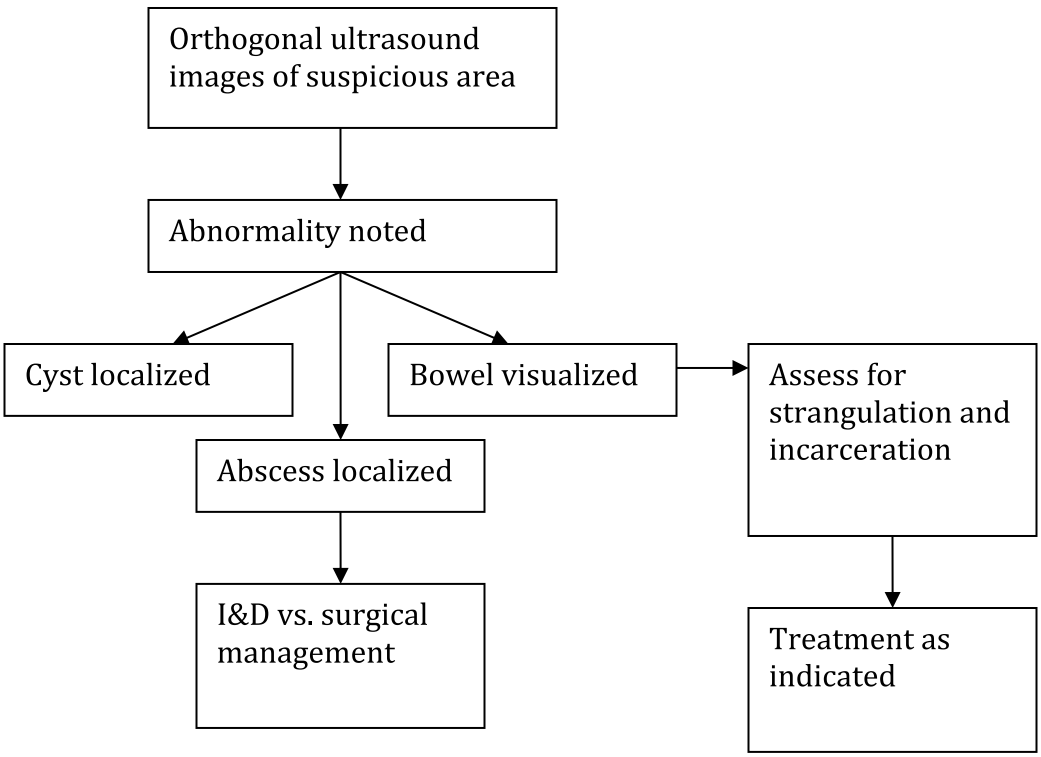
Bowel obstruction: Several key pathologic findings are important to note:

a. Dilated, fluid-filled small bowel with a diameter greater than 25mm or large bowel greater than 50 mm. This suggests either an akinetic process such as an ileus versus an obstructive process.
b. Thickening and edema of the bowel wall. This suggests either a chronic process or strangulation, but may also occur with some infectious or inflammatory causes, such as diverticulitis.
c. Decreased peristalsis or aperistalsis. This suggests either a complicated or complete obstruction. Increased persistalsis would be expected in the case of an early or partial obstruction. When an ileus is suspected, the gallbladder should be evaluated for gall stones.
d. Non-compressible bowel. This suggests a complete obstruction with increased intraluminal pressure, raising concern for strangulation.

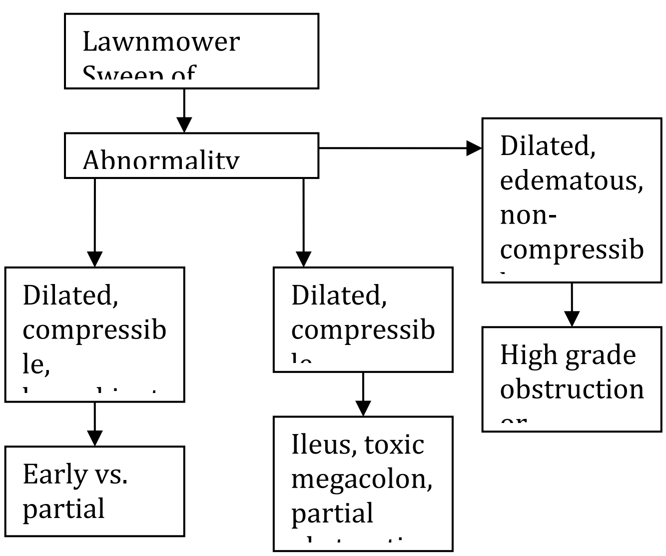
Pneumoperitoneum: Air within the peritoneal cavity will create scatter and thus will prevent visualization of deeper structures, such as the liver, spleen, or bowel. Often a reverberation artifact may be observed. In many instances, the air will be confined to a particular area. For instance, in the upright patient, air will migrate to the upper quadrants. This phenomenon has led to a description of a specific sign, termed the “scissors sign”. It is seen when the transducer is placed at the anterior costal margin and the liver is initially not visualized due to pneumoperitoneum. Downward transducer pressure displaces the air, facilitating visualization of the liver, thus the name “scissors sign”.

CLINICAL INTEGRATION

Hernia:



Bowel obstruction:



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TOPIC A11. APPENDICITIS

SCANNING PROTOCOL

Patient Positioning

The patient should be placed in the supine position. Adequate analgesia is key to performing the technique of "graded compression", as pain and guarding of the patient during scanning may limit the examiner's ability to perform the study.

Transducer and System Settings

Either a linear or curvilinear transducer may be used for the evaluation of appendicitis. Transducer selection primarily depends on patient body habitus; in pediatric or thin adult patients the high frequency linear transducer is preferable, as it provides a higher resolution image. In patients with a higher body mass index, the curvilinear transducer may be used if necessary to allow for greater tissue penetration.

Image Acquisition

During scanning the probe is placed on the anterior abdominal wall, with the goal of scanning the right lower quadrant of the abdomen in a systematic fashion. Graded gentle compression helps move bowel gas out of the way of the visual field, as well as decreasing the distance between the probe and the structure of interest.

Landmarks include the iliac vessels and the psoas muscle, which are usually found posterior to the appendix. If the ascending colon can be identified, this can be followed towards the cecum to the origin of the appendix.

Alternatively, imaging at the point of maximal tenderness is often a useful strategy.

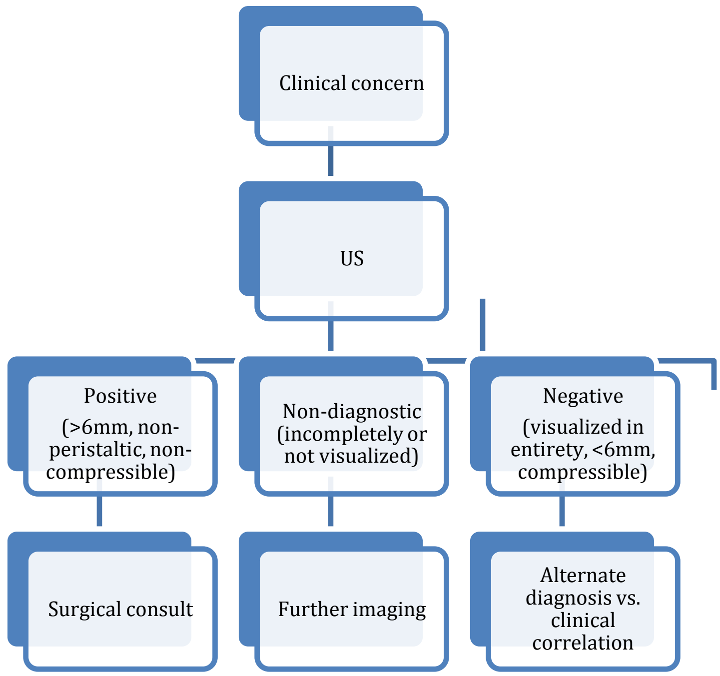
NORMAL ANATOMY

The appendix is a tubular blind-ended structure. It should be imaged in its entirety in the longitudinal and transverse planes to be called normal, as early stages of inflammation may be limited to the distal tip of the appendix. Multiple views may be required due to its curvature. Visualization of a normal appendix may be difficult and is not often successful. As such, sonography for appendicitis must be approached with caution: while a positive scan may rule in the condition, a non-diagnostic study that does not fully visualize the appendix cannot rule it out. In this instance further imaging should be pursued as clinically indicated.

PATHOLOGY

Diagnostic criteria for appendicitis include a tubular, blind-ended structure that is non-peristaltic and non-compressible, with an outer wall to outer wall diameter of greater than 6mm. In the transverse plane it will often have the appearance of a target sign, with a hypoechoic center surrounded by concentric hyperechoic and hypoechoic rings. Wall asymmetry or thickening may be noted and occasionally a fecalith with posterior shadowing can be visualized in the lumen. Adjacent enlarged lymph nodes, as well as periappendiceal fluid due to surrounding edema may be seen, while the inflammatory process frequently results in hyperemia evident on color Doppler imaging.

CLINICAL INTEGRATION



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TOPIC A12. INTUSSUSCEPTION

SCANNING PROTOCOL

Patient Positioning

Patients should be placed in the supine position.

Transducer and System Settings

A high frequency linear transducer is the preferred probe for imaging the shallow pediatric abdomen.

Image Acquisition

While most intussusceptions occur in the right upper quadrant, just inferior to the liver, they can also occur at any point along the length of the colon so it is prudent to scan along the length of the colon in a methodological, 'picture frame,' manner with the graded-compression technique. For most pediatric patients, the optimal depth to visualize an intussusception is 3 to 5 cm from the skin. The transducer should be placed initially in the transverse plane in the right lower quadrant at the level of the psoas muscle and then swept supralaterally towards the right upper quadrant. The transducer should then be rotated clockwise 90 degrees towards the longitudinal plane, and then swept across the epigastrium towards the left upper quadrant. At the left upper quadrant, the transducer should be rotated counterclockwise 90 degrees back to the transverse plane and swept inferiorly towards the left lower quadrant. Views of all four quadrants should be recorded.

NORMAL ANATOMY

The healthy, normal colon should have active peristalsis that can be visualized sonographically without evidence of inflammation, masses or free fluid.

PATHOLOGY

When scanning in a 'picture frame' manner around the abdomen, attention should be focused on identifying a solid-looking segment of bowel that does not peristalse. The intussusception will have alternating hyperechoic layers of compressed mucosa with hypoechoic layers of muscle, which have been described as a target, doughnut or hamburger in cross section, as a pseudo-kidney in the oblique view, or as layers of invaginated bowel in the longitudinal section. The diameter of the intussuscepted bowel normally exceeds 3 cm in maximal diameter in the transverse view. Dilated loops of bowel may be noted proximal to the site of intussusception. A lead point can occasionally be visualized as a mass in the center of the intussusception.

Pearls and pitfalls:

- Intussusceptions are intermittent and can self-reduce, highlighting the importance of repeat clinical ultrasounds when there is a high clinical suspicion for intussusception.

- Limiting the ultrasound to just the right upper or lower abdomen without doing a complete abdominal scan can miss intussusceptions that are on the left side.

- If the visual depth is not optimized on the transducer (either too shallow or too deep or a low frequency transducer), then the full intussusception may not be visualized.

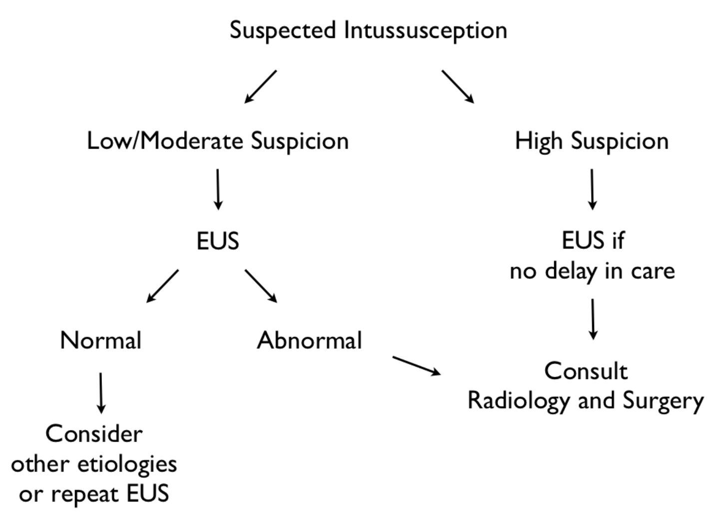
- Misidentifying the normal kidney for a pseudo-kidney sign. If a pseudo-kidney is visualized, an orthogonal image should be obtained which should look like the cross section of the intussusception rather than a transverse view of the kidney. A normal kidney is usually a deeper abdominal structure that can be identified inferior to the liver.

- False-positive signs for intussusception include enlarged lymph nodes, the psoas muscle, stool in the colon and the normal colon. Enlarged lymph nodes, such as in mesenteric adenitis, are generally small (approximately 10 mm) and more superficial than an intussusception. The psoas muscle is a semicircular structure with striations, just lateral to the iliac vessels.

- The doughnut and pseudo kidney signs are not pathognomonic for intussusception, as they can also be visualized in necrotizing enterocolitis or volvulus.

CLINICAL INTEGRATION

The role of Clinical Ultrasonography in the diagnosis of intussusception is still a relatively new application. Suspicious findings for intussusception found at the bedside should be shared with surgical consultants who may request a repeat ultrasound by the Department of Radiology. Clinical integration with surgical consultants should be tailored to each institution's protocol.



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TOPIC A13. PYLORIC STENOSIS

SCANNING PROTOCOL

Patient Positioning

Patients should be kept NPO prior to their sonogram so that they will be hungry and eager to drink clear fluids during the study. Fluid intake during a sonogram to evaluate for pyloric stenosis serves two functions: 1) to fill an empty stomach thereby providing a sonographic window into the pylorus, and 2) to assess for passage of contents through the pylorus into the duodenum. Patients should be placed in the supine position or right lateral recumbent position with a roll placed behind them for support to bring the stomach more anteriorly, displace bowel gas, and allow for gravitational filling of fluid into the antrum.

Transducer and System Settings

A high frequency linear transducer is the preferred probe for imaging the shallow pediatric abdomen.

Image Acquisition

Once the patient is in position, the probe should be placed in the transverse position just lateral to the midline. Once the gallbladder is identified, the infant should be fed a clear liquid as the probe is swept medially towards the pylorus at the level of the antrum, which can be identified when fluid is visualized passing through the antrum into the duodenum. As with any imaging, visualizing the organ of interest in two orthogonal planes is ideal.

NORMAL ANATOMY

The probe should follow the walls of the gastric antrum until it empties into the pylorus.

Fluid should be visualized passing from the antrum through the pylorus into the duodenum with associated normal peristaltic activity. In the transverse view, the pylorus looks like a 'doughnut' or 'target' sign, while in the longitudinal view, the pylorus has an elongated appearance with a double mucosal channel.

If the stomach is over distended, the antrum and pylorus may be pushed too posteriorly, making them difficult to visualize on ultrasound. Similarly, bowel gas superficial to the antrum and pylorus limit visualization of these structures on ultrasound. In this scenario, graded compression as well as repositioning the patient in the right lateral recumbent position with a roll placed behind them for support may displace some of the bowel gas and bring the structures of interest more anterior.

PATHOLOGY

If there is an absence or delay of fluid passing through the pylorus, the index of suspicion for hypertrophic pyloric stenosis should be raised. Once the pylorus is visualized, the pyloric channel length and wall thickness should be measured. In the transverse view, the hypertrophied pylorus looks like a 'doughnut' or 'target' sign with a thickened hypoechoic muscular layer, while in the longitudinal view, the pyloric channel has a thickened, elongated, hyperechoic appearance between the hypoechoic mucosal walls. The hypertrophic pyloric channel may also prolapse into the antrum, with the characteristic 'antral nipple sign' that is sometimes seen on ultrasound.

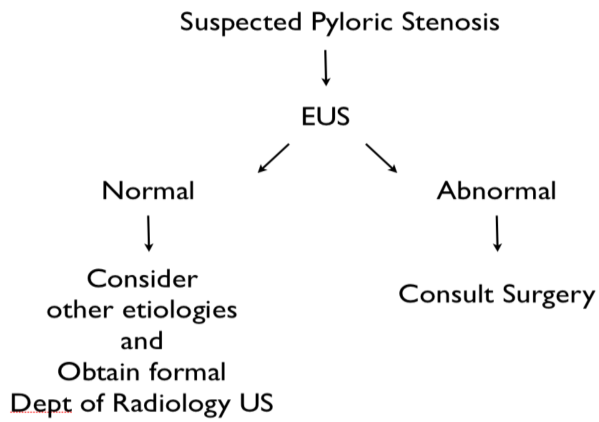
While there is no consensus regarding normal measurements in infants, the current accepted criteria are a muscle thickness of > 3 mm and a channel length of > 15 mm to support a diagnosis of hypertrophic pyloric stenosis.

Pearls and pitfalls:

- An oblique view of the pylorus may lead to over-estimation of pyloric channel length in a normal pylorus.
- If the patient is overfed, pylorospasm may occur which can falsely elevate the pyloric wall thickness measurements. As a result, it is important to visualize the pylorus for a period of time to differentiate severe pylorospasm from pyloric stenosis. Pylorospasm is characterized by antral narrowing, delayed gastric emptying and normal measurements of the pyloric channel and wall.
- On the other hand, if the patient's stomach is empty or the patient has just vomited, then gastric decompression makes the pyloric wall appear falsely thickened.
- Premature infants may have pyloric stenosis in the presence of measurements that are less than those quoted above.
- Mimics of pyloric stenosis include gastric duplication, antral webs, focal alveolar hyperplasia (as a result of prostaglandin therapy in patients who require a patent ductus arteriosus in ductal dependent congenital cardiac lesions).

CLINICAL INTEGRATION

The role of Clinical Ultrasonography in the diagnosis of pyloric stenosis is still a relatively new application. Suspicious findings for pyloric stenosis found on bedside ultrasound should be shared with surgical consultants who may request a repeat ultrasound by the Department of Radiology. Clinical integration with surgical consultants should be tailored to each institution's protocol.



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While ultrasound has long been the preferred diagnostic modality for pyloric stenosis,there have only been a couple of case reports that have delineated its role within pediatric emergency medicine and Clinical Ultrasonography.

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TOPIC A14. FRACTURE ASSESSMENT

SCANNING PROTOCOL

Patient Positioning

If the trauma patient is able to cooperate, they may be able to localize area of interest by pointing to the region of greatest pain. Sufficient analgesia should be provided prior to the ultrasound examination.

Transducer and System Settings

When evaluating for bony fractures during a trauma survey, a high frequency linear array transducer (7-12 MHz) typically provides the best images. Bony structures of interest are usually superficial making a higher-frequency transducer optimal for better resolution. In the case of deeper structures, such as a femur in a large thigh, a lower-frequency curvilinear probe (3-5 MHz) may provide better penetration.

Image Acquisition

Long axis and transverse axis imaging of the injured extremity should be obtained. The depth should be adjusted so the bony cortex appears in the middle of the screen, and the focus should be adjusted to the level of the cortex. Imaging of very superficial structures may be aided by the use of a standoff pad or water bath; the liberal use of ultrasound gel, a standoff pad or water bath may also alleviate some of the pain that may otherwise be produced by placing an ultrasound transducer directly over the fracture site.

Imaging of bony fractures should be performed in at least two orthogonal planes. The ultrasound examination should be performed along the entire length of the bony structure of interest from proximal to distal articulation. Cortical disruption may be most obvious with the transducer oriented along the longitudinal axis of a long bone, however, the transverse view often provides additional information regarding the degree of displacement or angulation.

NORMAL ANATOMY

Bone is visualized on ultrasound as a thin, brightly echogenic cortex with a prominent posterior shadow. The shape of the cortex will reflect the contour of the bone in the plane it is being scanned. A long bone will appear as a bright curved line in cross-sectional profile and as a straight line in a longitudinal profile. Although ribs are smaller and follow a curved path around the thorax, they have a similar appearance. A normal scan will demonstrate no cortical disruption along the entire length of the bone of interest.

PATHOLOGY

A fracture is visualized as a disruption in the smooth echogenic cortex of the bone. If a fracture is not readily apparent, but the patient has significant point tenderness, gentle pressure over the area with the transducer may result in a widening of the cortex and visualization of a disruption that may not be seen on x-ray. Fractures are often associated with an anechoic region nearby representing blood or edema. Ultrasound has been shown to be helpful in guiding cortical alignment of long bone fractures and may be used as an imaging adjunct during reduction.

Bony fractures are best visualized in long bones as even small cortical disruptions down to 1mm can easily be seen along the straight surfaces when the transducer is oriented perpendicular to the fracture line. Ultrasound is less reliable in detecting small avulsion fractures, fractures near joints or in the small bones of the hands and feet, non-displaced epiphyseal fractures among children (Salter-Harris type 1), or fractures with cortical disruptions less than 1mm.

CLINICAL INTEGRATION

In trauma management, plain radiography and other advanced imaging modalities other than ultrasound are frequently employed to detect fractures as well as other injuries. The use of point of care ultrasound for the evaluation of bony fractures can has been used to improve trauma care in the following situations:

- When other imaging may be delayed - ultrasound may provide clinical information that allows reduction, traction or improved analgesia in a more time efficient manner.
- When serial examinations are necessary – ultrasound examinations can be performed serially when performing reductions to save time and reduce radiation exposure.
- When performing a hematoma block – ultrasound guidance can be used to direct the placement of local anesthesia prior to fracture reduction.
- When detection of a fracture would change clinical management - ultrasound is more sensitive than plain radiography for detecting certain fractures, such as sternal and rib fractures, and should be utilized if decisions regarding admission, follow-up or management of the injury would change if the examination was positive.
- When working in an austere environment – due to their relatively small size and light weight, portable ultrasound machines have been used at sporting events, on humanitarian missions, by the military in forward operating environments, in aircraft, space and in other austere environments where additional imaging equipment cannot be carried. The ability to detect fractures and other injuries in these environments allows for improved evacuation planning as well as management of the injury itself.

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TOPIC A15. ULTRASOUND OF TENDON AND MUSCLE

SCANNING PROTOCOL

Patient Positioning

The patient is placed in a position of comfort with care not to place an extremity so that there is pressure or compression on vulnerable surfaces (nerves, bony prominence).

Transducer and System Settings

Select a high frequency (5-17MHz) linear transducer to adequately image musculoskeletal (MSK) structures up to about 4-5 cm beneath the skin. Less often, the low frequency (3-5MHz) curvilinear transducer is needed when the structure of interest is deeper, such as in the case of hip evaluation. On the machine itself, begin by utilizing the appropriate preprogrammed settings, such as the Small Parts or MSK presets, to optimize machine set up and image quality.

Image Acquisition

For all applications including MSK, visualize relevant structures in both the long and short axis. For tendon and muscle evaluation, dynamic imaging in flexion and extension or contraction and relaxation must be performed to assess function.

- The superficial location and contour of relevant MSK structures often makes visualization difficult. These inherent challenges are often readily overcome by utilizing a liberal amount of ultrasound gel. For particularly superficial of painful areas, a water bath immersion or a stand off pad may be useful and often improves visualization and reduces patient discomfort.
- Due to the complexity of MSK imaging, always begin by scanning similar areas of normal anatomy first, such as the unaffected extremity or areas away from the site of suspected pathology. This re-establishes in the sonographers mind the appearance of normal anatomy, making the subsequent comparison and recognition of pathology much more straightforward.
- Next identify the patient’s point of maximal tenderness or swelling or concern. Move the probe directly over the suspected area with the proximal aspect on the left of the image and the distal aspect on the right of the image.

NORMAL ANATOMY

Tendon

Tendons appear as echogenic structures with a fibrillar architecture of parallel collagen fibers best visualized in the long axis. Intact tendons appear continuous without disruption.

Assessment of tendon/ligament integrity is one of the best applications of musculoskeletal ultrasound. Use the contralateral tendon/ligament (if available) to determine normal anatomy. Place the probe longitudinal to the tendon/ligament and obtain a normal fibrillar pattern. Slight adjustments in angle will produce changes in the echogenicity of the structure (termed anisotropy). The sonographer should fan the probe to ensure that a 90-degreee angle of incidence is obtained and a clear image of the tendon/ligament is obtained. After evaluating the tendon/ligament in a longitudinal manner, rotate the probe and evaluate the in a transverse manner.

Muscle

Skeletal muscle appears as groups of hypoechoic fibers separated by hyperechoic septae. In the long axis, these units are representative of perimysium encasing parallel muscle fascicles. In the short axis, these muscle fibers appear as distinct circular groups. Individual muscles are encased by a thicker layer of fascia that appears hyperechoic in both the long and short axis.

PATHOLOGY

Partial and Complete Tendon Tears

Tendon injury appears as focal areas of partial or complete disruption of the normal fibrillar pattern with thinning, edema, or hematoma. Acute edema results in an enlarged, and either hyper or hypoechoic tendon in comparison to the unaffected contralateral tendon. Complete tendon tears may no longer be located in the normal anatomic position. Instead, opposite ends of the torn tendon are now often separated by an anechoic area of acute hematoma formation.

Full thickness tears of tendons and ligaments will be represented by a large anechoic defect in the normal fibrillar structure. Hematoma over the location of the tear may act as an ultrasound window, which aides in the visualization of the torn ends. Dynamic evaluation (either passive or active range of motion) aides in the evaluation of tendon/ligament tears. Evaluate the tendon/ligament in both a longitudinal and transverse manner, looking for irregularities.

Partial thickness tears are often more difficult to image with ultrasound. Small anechoic defects are often not apparent to the novice musculoskeletal sonographer. Also, when scanning in the longitudinal plane, it is easy to mistake abnormal echoes for tears. If small areas of irregularities are noted, the sonographer should fan the probe and perform the scan in two distinct planes (transverse and longitudinal).

Tendinosis (rather than tendinitis) can also be noted in the hands of an experienced sonographer. In the correct clinical setting, anechoic fluid in the tendon sheath can be useful confirmatory tool for the clinician.

Partial or Complete Muscle Tears

The optimal time to image the affected muscle is 2 to 48 hours after injury. Prior to 2 hours, the early diffuse hematoma is not adequately visualized. Between 2 and 48 hours, the tear will appear as a hypoechoic area within the muscle. After 48 hours the hematoma will again become diffuse as resolution begins. The extent of the injury also determines the sonographic appearance. Small muscle tears may be difficult to detect at any time. More significant tears appear as hypoechoic areas within the muscle. In contrast, complete tears often appear as hyperechoic edematous muscle seen floating within surrounding hematoma.

Tendinitis

Acute tendinitis, as seen in tendons lacking a sheath, will appear thickened in comparison to the contralateral tendon with hypoechoic areas due to acute edema. Tendons encased in a sheath will also appear thickened but may appear either hypoechoic or hyperechoic. The inflamed tendon will have poorly defined margins and increased vascularity on Doppler imaging. Additionally, the nearby point of insertion may appear calcified or nodular.

Tenosynovitis

In cases of tenosynovitis, the tendon sheath becomes distended due to fluid accumulation between the tendon and the sheath. Tenosynovitis may result from a number of disorders including infection, inflammation, and traumatic injury. In the appropriate clinical context, any amount of fluid within the sheath confirms the diagnosis. Complex fluid collections are suggestive of an infectious process.

Acute Myositis

Acute myositis is signified by an ultrasound image that becomes the reverse of the normal. Specifically, the muscle becomes edematous while the septae are hypoechoic. The resultant sonographic architecture is no longer distinct. Evaluation of the contralateral muscle again becomes important, as the degree of muscle enlargement may not be obvious without comparison views.

CLINICAL INTEGRATION

The integration of MSK ultrasound into the patient care will vary considerably based on the extent of the disorder, practice environment, and skill set of the physician sonographer.

Sensitivity and specificity of the clinical examination of tendons and ligaments can be improved with bedside ultrasound. As with all imaging modalities, pretest evaluation with a clear imaging study can aide in the diagnosis of tendon/ligament tears and inflammation. Sonographers should always use the unaffected extremity and image passive range of motion when possible, and recognize the limits of their experience with musculoskeletal ultrasound. In cases when clear imaging is not possible, emergency physicians should be aware that the sensitivity of ultrasound is not 100% for tendon/ligament injuries.

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TOPIC A16. ULTRASOUND OF JOINTS

Ultrasound evaluation of joints can be useful for the emergency physician. Often differentiating a more superficial cellulitis versus an underlying joint infection can be challenging. Both often present with pain with movement, fever and erythema. Bedside evaluation can aide the clinician in determining the presence of a joint effusion and guide arthrocentesis. Joints that can be scanned include the hip, knee, ankle and shoulder. Once the clinician becomes more proficient with ultrasound of joint spaces, any joint can be evaluated to determine the presence of an effusion.

SCANNING PROTOCOL

Patient Positioning

Positioning is used to optimize obtaining proper images.

Transducer and System Settings

We recommend a high frequency linear transducer (>7MHz) for superficial joints under 4-6 cm in depth. Large amounts of coupling gel will be needed when examining very shallow joint spaces. For the hip joint (and other similar deeper joints spaces) we recommend the curvilinear, low frequency transducer (unless being done in the pediatric patient - see following section).

Image Acquisition

Long axis and transverse axis imaging of the joint of interest are obtained. Additional images of surrounding anatomy can be useful to demonstrate additional anatomic landmarks or nearby vascular structures. Compression views can sometimes provide additional information such as mobility of fluid within the joint space. In addition, images of the normal contra-lateral should be obtained (if available).

NORMAL ANATOMY

The clinician must be aware of the relevant bony landmarks that define the joint space for each individual joint space evaluated. Scanning in both a longitudinal and transverse plane will allow for a complete view of the overlying soft tissue structures as well as the joint space. Superficial skin and muscle should appear as very organized structures on ultrasound. Dynamic evaluation by slowly ranging the joint can help the clinician in locate bony landmarks as well and ensure a lack of effusion. Often the joint will not be visualized in non-pathologic states.

PATHOLOGY

Evaluation of the contralateral unaffected extremity is always recommended. In cases of superficial cellulitis, anechoic fluid or edema will be noted in the superficial epidermis interspersed between fat. An abscess will appear as a disorganized collection of tissue that will contain both anechoic and hyperechoic shadows. The clinician should delineate the margin of both the cellulitis and abscess when performing a bedside ultrasound examination.

Joint effusions are generally deeper than soft-tissue infections, and located in spaces delineated by either bony or ligamentous landmarks. Knowledge of specific bony and ligamentous landmarks will allow for an accurate evaluation of the joint space. For the ankle, the space between the tibia and talus must be imaged and the clinician must be able to locate the specific sonographic landmarks for each joint space to ensure the presence or lack of an effusion. Dynamic evaluation of the joint (if possible) can aide in confirming the presence of an effusion.

Ultrasound-guided Joint Aspiration

There are no clinical studies that indicate the efficacy of ultrasound for joint aspiration in the ED. Extrapolating studies looking at intraarticular injections performed by non-ED clinicians may indicate the benefit of ultrasound guidance for accurately entering the joint space when attempting to perform joint aspiration.

The clinician who plans to use ultrasound to guide joint aspiration must be comfortable with relevant anatomy and use ultrasound to detect anechoic fluid located between the bony landmarks that define the joint space. For example, in the ankle, the tibia and talus must be identified before guiding the needle into the joint space. The shoulder, knee, hip, elbow and wrist are joints that can benefit from ultrasound guidance when performing aspiration. Standard sterile draping, including a sterile probe cover, will be required. Depending on the joint, in-plane or out-of-plane needle guidance will be required and the provider should be comfortable with both techniques.

CLINICAL INTEGRATION

The clinician should use data from the clinical examination as well as the ultrasound to determine the presence of a joint effusion. The lack of a joint effusion does not rule out the possibility of a joint infection, and the clinician should have a very low threshold to obtain consultation in patients with a high clinical pretest suspicion. In cases of a suspected septic joint, we recommend using ultrasound to guide needle aspiration.

SEMINAL STUDIES

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TOPIC A17. ULTRASOUND OF THE PEDIATRIC HIP

SCANNING PROTOCOL

Patient Positioning

The patient should be positioned supine with the hip slightly flexed and externally rotated.

Transducer and System Settings

We recommend a high frequency linear transducer (>7MHz).

Image Acquisition

With the patient lying supine, the linear probe is positioned parallel to the femoral neck in the longitudinal plane. The probe marker should be pointing roughly towards the patient's umbilicus, which will give a standardized image on the screen regardless of sidedness. Thus, it is important to mark the laterality of the hip when saving images, as right and left hips will appear the same when this approach is used.

NORMAL ANATOMY

The hip joint is a ball-and-socket joint comprised of the femoral head (ball) sitting in the acetabulum of the pelvis (socket), surrounded by a thick ligamentous joint capsule. Inside this capsule, the synovial membrane provides protection and nourishment to the surrounding structures. A small amount of synovial fluid is present in the normal hip joint around the femoral head. Abnormal fluid, due to trauma, infection, or inflammation, collects within the capsule between the femoral head and neck and the surrounding soft tissues.

The first structure often identified is the round, hyperechoic (bright) femoral head. In growing children a notch can be seen in the femoral head, which represents the physis and around the femoral head will be a small amount of fluid and cartilage, both of which are anechoic. The femoral neck is the curvilinear hyperechoic structure extending distally from the femoral head. Superficial to the femoral neck, the muscle fibers and tendon of the iliopsoas muscle can be seen. Once the capsule is identified, the distance between the anterior surface of the femoral neck and the posterior surface of the iliopsoas muscle is measured for each hip.

PATHOLOGY

According to most texts, a measurement of greater than or equal to 5 mm or a measurement of greater than 2 mm difference from the contralateral hip is considered positive for an effusion.

The most common pitfall involves measuring the hip capsule. A normal hip will often have no appreciable fluid or a very thin anechoic strip of fluid. At times, the inexperienced practitioner will measure the muscle belly of the iliopsoas muscle, thinking that it is an effusion. If there is an effusion and the fluid is especially thick or purulent, it may not appear completely anechoic and may be mistaken for soft tissue rather than fluid. Finally, there is usually a small amount of fluid around the femoral head. This fluid, along with normal cartilage (which appears anechoic) may be mistaken for a pathologic effusion. Consequently, fluid around the femoral head should not be measured or considered pathologic.

CLINICAL INTEGRATION

Limp, leg pain, and refusal to bear weight are common pediatric complaints encountered in the ED. In many of these patients, the etiology of the pain or limp can be difficult to discern, while other patients are found to have pain that localizes to the hip. The differential diagnosis of limp or hip pain in children is broad, and the identification of a hip effusion narrows the differential diagnosis and may raise the suspicion for septic arthritis, a surgical emergency. In general, we recommend a hip ultrasound for any patient that complains of upper leg pain, discomfort or limp that either cannot be localized or localizes specifically to the hip. If an effusion is identified, the clinician should effectively rule out a septic joint, which can be done either clinically or with the aid of further diagnostic studies. If a septic joint is suspected, an arthrocentesis should be performed and orthopedics consulted. If a hip effusion is present and septic joint is not suspected, other entities should be considered, including but not limited to transient synovitis, lyme arthritis (in endemic areas), osteomyelitis with reactive effusion, and reactive arthritis. If an effusion is not identified, further diagnostic studies should be considered contingent on the individual patient presentation.

HIP ARTHROCENTESIS

The decision to perform hip arthrocentesis in children should be driven by historical factors, physical examination findings, and laboratory parameters (if obtained) related to the evaluation for septic arthritis. Although numerous studies have attempted to differentiate septic versus aseptic arthritis, there is considerable overlap in clinical and laboratory characteristics and no widely accepted guidelines exist. Important specific clinical and laboratory features to consider are ability to bear weight, presence of fever, range of motion, and inflammatory markers such as white blood cell count, erythrocyte sedimentation rate and c-reactive protein.

Hip aspiration should be performed under real-time ultrasound guidance using aseptic technique. With younger children, procedural sedation is often required. With the patient supine, the hip should be positioned in a neutral or slightly internally rotated position to allow joint fluid to collect along the anterior recess above the femoral neck (although this position may be limited by pain). The effusion should be located sonographically as described above and local anesthesia given subcutaneously at the site of aspiration. Once the skin is anesthetized, a 22-guage spinal needle should be inserted at the caudal end of the transducer directed cephalad towards the effusion. The needle should be visualized longitudinally along its entire length as it penetrates the joint capsule. Once synovial fluid is obtained (usually 2-5 mL), samples should be sent for gram stain, culture and cell count. If the sample is grossly bloody, an EDTA tube may be used for the cell count to prevent clotting. If possible, placing 1-3 mL of synovial fluid in a blood culture bottle may improve sensitivity of culture results. After aspiration, the joint capsule may be re-visualized with ultrasound to determine the presence of any remaining joint effusion.

SEMINAL STUDIES

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2. Shavit I, Eidelman M, Galbraith R. Sonography of the hip-joint by the emergency physician: its role in the evaluation of children presenting with acute limp. *Pediatr Emerg Care*. 2006;22(8):570-3.
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TOPIC A18. ADVANCED VASCULAR ASSESSMENT

SCANNING PROTOCOL

Patient Positioning

The patient is supine on a stretcher with the sonographer on the patient's right side facing the ultrasound machine/screen.

For the arterial assessment, the area of concern should be exposed to enable the sonographer to scan both proximal and distal to the area of concern.

For upper extremity evaluations the patient is usually positioned supine and in slight reverse-Trendelenburg to enhance venous engorgement.

Transducer and System Settings

A linear array vascular probe with a frequency of 6-10 MHz and a width of 6-8 cm is often ideal for these applications. However, for obese or edematous patients, a lower frequency or even curvilinear probe may be needed to provide adequate tissue penetration of deep venous structures.

Image Acquisition

Arterial Assessment: Bedside sonography of the peripheral arteries, carotids, and upper extremity vessels should first focus on the location of the signs and symptoms. Suspected disruption of normal blood flow due to thromboembolism or trauma warrants imaging of the affected extremity. Neurologic deficits may be ipsilateral or contralateral to the affected carotid artery. Arterial imaging should be obtained proximal to, directly at, and distal to the traumatic injury or to the area demonstrating signs of decreased perfusion such as pain, skin color change, and sensation change. The contralateral artery is imaged to provide baseline comparison if unilateral peripheral arterial insufficiency is suspected. In the case of ischemic cerebral stroke where carotid thromboembolism is suspected, both carotid arteries should be imaged.

All ultrasounds should be performed in both a transverse and longitudinal orientation.

Mode and Angles. The following 3 modes should be used to obtain images while paying particular attention to the angle of the sound beam.

1. B Mode. The artery should be perpendicular (90 degrees) to the ultrasound beam.
2. Color Doppler Mode. The angle of insonation should be 60 degrees or less. In addition, Power (or Angio) Doppler is often useful for imaging low flow states in peripheral arteries, as this modality provides greater

sensitivity in low-flow states when compared to Color Doppler. The angle of insonation should be 60 degrees or less.

3. Spectral Doppler Mode. The angle of insonation should be 60 degrees or less.

Upper Extremity Venous Assessment: The superior internal jugular vein is located lateral to the carotid artery and is scanned proximally with compression every centimeter when possible until its junction with the subclavian vein, forming the brachiocephalic vein. The subclavian vein is then traced back using direct visualization, not compressible at this site, with the optional application of color or power Doppler to confirm flow, over its visible extent to the axillary vein. The proximal axillary vein cannot be visualized due to bone, so inspection begins again in the axilla with the brachial vein being identified and directly compressed every centimeter all the way to the antecubital fossa. At the antecubital fossa, the radial and ulnar veins should be identified and separately interrogated a short distance into the forearm.

NORMAL ANATOMY

B Mode

First, identify the vessel of interest by scanning transversely to identify the anechoic vasculature with characteristic thicker arterial walls, along with other surrounding anatomical landmarks such as nerves, bones, and the thinner walled veins. Gentle compression can be applied to show the pulsatile movement of the artery whereas the vein will appear to be more collapsible with compression. Next, rotate the transducer 90 degrees in order to obtain a longitudinal view. The normal arterial lumen should be anechoic. At times, the arterial wall can be hyperechoic with posterior shadowing, suggesting calcification. This finding should be correlated with the patient's age and clinical presentation. Carotid intimal-media wall thickness can also be measured in this mode, with normal thickness ranging from 0.5mm to 1.2mm based on age.

Color Mode

Using this mode, an artery shows rhythmic color signals that match the pulses felt by palpation. A vein would show a color signal that is more continuous. On the transverse view, a patent artery should demonstrate a color signal occupying the entire lumen. On the longitudinal view, color signal should occupy the entire course of the artery.

Spectral Doppler Mode

There are two normal arterial waveforms as detected by Spectral (Pulsed Wave) Doppler. In general, end organ arteries (e.g. testicular artery, ovarian artery, splenic artery) demonstrate a biphasic low resistance velocity waveform, whereas other arteries show a high resistance arterial velocity waveform that is triphasic . A normal low resistance biphasic waveform begins with a sharp upstroke and a gradual downstroke with continuous forward flow throughout diastole to perfuse end organs continuously. The high resistance triphasic waveform begins with a sharp upstroke during systole, and results in peak systolic velocity (PSV) measurements typically less than 125 cm/s at the abdominal aorta to 70cm/s at the tibial artery. The second phase is a sharp downstroke, due to early diastolic flow reversal, followed by the third phase which demonstrates an upstroke during late diastole.

PATHOLOGY

Thromboembolism

The aim is to identify evidence of arterial occlusion and decreased flow. In B mode, an echogenic clot may be seen within the vessel, which may be better appreciated when color Doppler is added. There is an absence of color signal within the entire vessel lumen in a complete occlusion, or a partial absence of color signal with color signal adjacent to the clot in a partial occlusion. Spectral Doppler is a better mode to detect decreased flow. The Doppler waveform of peripheral arterial insufficiency transitions from the normal triphasic pattern to a biphasic or even monophasic pattern. In addition, the normal waveform width should be narrow, demonstrating a brisk systolic flow, and is pathologic if widened. PSV at the site of occlusion is increased, and typically greater than 125 cm/s in a peripheral occlusion. When compared to a normal segment in the proximal or contralateral limb, an occluded PSV could be several times higher, with doubling of the PSV indicating a >50% occlusion and quadrupling indicating a >75% occlusion.

Trauma

Typical arterial injuries include arterial lacerations, dissections, and pseudoaneurysms. Using B mode, signs of arterial injury can be seen grossly, such as the loss of vessel wall circumference in transverse view, discontinuity of the vessel in longitudinal view, presence of an intimal flap, and free fluid outside of the vessel. Color Doppler mode can be further utilized to assess turbulence or disruption of flow, as well as highlight the presence of an intimal flap or extravasation. The addition of color may help to identify the neck of a pseudoaneurysm and to localize the vessel of origin. Color Doppler focused at the neck of a pseudoaneurysm demonstrates a to-and-fro bidirectional pattern (ying-yang sign) and attempts should be made to document this flow abnormality. Distal to the site of an arterial injury, spectral Doppler can show loss of the narrow triphasic waveform and a decrease in PSV.

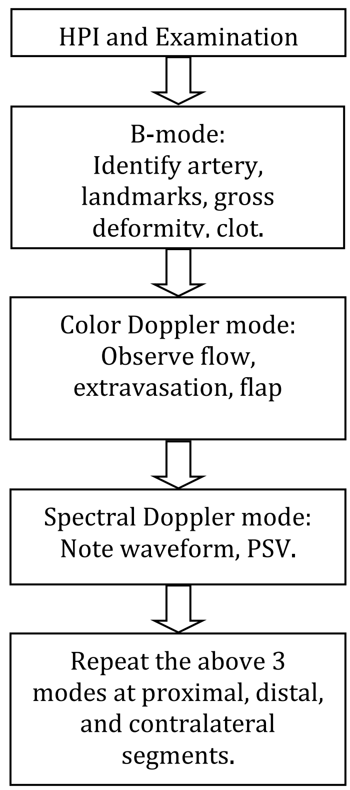
Risk of Cardiovascular Disease

The thickness of the carotid intima and media can be measured in B mode to assess risk of diseases such as myocardial infarction or stroke. Obtain an optimal longitudinal view to show the near and far walls of the carotid and measure the distance between the edge of the hypoechoic lumen and the hyperechoic mediaadventitia interface on both the near and far walls. Abnormal values are typically above 0.5mm to 1.0mm based on age of the patient.

Upper Extremity Venous Thrombosis

The upper extremity venous evaluation is more dependent on indirect confirmation of patency, given the subclavian and axillary veins are not accessible to compression.

CLINICAL INTEGRATION



SEMINAL STUDIES

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TOPIC A19. ULTRASOUND-GUIDED NERVE BLOCKS

SCANNING PROTOCOL

Patient Positioning

Traditionally the patient is in the position of comfort. Care should be taken to make sure that the limb being blocked is well supported so that during the duration of the motor blockade no compression injury or pressure ulcers develop.

Transducer and System Settings

Choose a high frequency (8-12 MHz) linear transducer with the ultrasound machine set to a nerve block or small parts preset.

Image Acquisition

Femoral Nerve Blocks

Indications

Anesthesia to the hip and proximal thigh for pain relief due to hip, femur and patella fractures, and repair of complex lacerations to the anteromedial thigh.

Patient Positioning

The patient is positioned supine with the leg neutral. The skin and high-frequency linear transducer are sterilely prepared, and the transducer placed in the inguinal crease with the directional indicator commonly oriented to the patient's right. The femoral nerve is identified lateral to the femoral artery and deep to the fascia iliaca. Anesthetic injection can be performed using an in-plane or out-of-plane technique.

Block Specific Concerns

Femoral nerve blocks are considered a basic block, but failure to inject deep to the fascia iliaca is a common reason for block failure. Given the proximity to the femoral vessels, cardiac monitoring and familiarity with the management of local anesthetic systemic toxicity (LAST) are mandatory.

Tibial Nerve Blocks

Indications

Anesthesia to the majority of the plantar surface of the foot for laceration repair, foreign body removal, and relief of pain due to calcaneal fractures.

Patient Positioning

The patient is positioned supine, with the lower extremity elevated by a blanket and the leg externally rotated (though prone or lateral decubitus position are also acceptable). The skin and the high-frequency linear transducer are sterilely prepared, and the transducer is placed transversely just posterior to the medial malleolus. Scanning begins with identification of the cortex of the distal tibia, the posterior tibial artery, and finally the tibial nerve, usually just posterolateral to the posterior tibial artery. Anesthetic injection is usually performed with an out-of-plane technique, though in-plane is acceptable.

Block Specific Concerns

None.

Forearm Nerve Blocks

Indications

Anesthesia to the hand for repair of lacerations, removal of foreign bodies, or pain relief from metacarpal fractures.

Patient Positioning

The patient's volar forearm is exposed. The skin and high-frequency linear transducer are sterilely prepared, and the transducer placed in the mid-forearm with the directional indicator commonly oriented to the provider's left. The median nerve is identified in the mid-forearm, lying on the fascia separating the flexor compartments. The ulnar nerve is located in the mid-forearm, just ulnar to the ulnar artery. As the transducer is moved proximally, the ulnar nerve and artery separate in the proximal forearm, facilitating access to the ulnar nerve. The radial nerve is located radial to the radial artery in the mid-forearm. Anesthetic injection can be performed using an in-plane or out-of-plane technique.

Block Specific Concerns

Forearm nerve blocks result in anesthesia to the hand and are not sufficient to provide anesthesia for distal radial or ulnar fractures.

Interscalene Brachial Plexus Nerve Blocks

Indications

Anesthesia to the shoulder and proximal arm for reduction and splinting of humerus fractures, incision and drainage of deltoid abscesses, and reduction of glenohumeral dislocations.

The patient is positioned supine or semi-recumbent with the head turned 45 degrees to the contralateral side. The skin and the high-frequency linear transducer are sterilely prepared, and the directional indicator is commonly oriented to the midline (medially). The interscalene groove and roots of the brachial plexus can be located by 1) identifying the great vessels at the level of the cricoid cartilage and moving the transducer laterally or 2) identifying the brachial plexus lateral to the subclavian artery in the supraclavicular fossa and then moving the transducer cranially, following the brachial plexus into the interscalene groove. Anesthetic injection can be performed using an in-plane or out-of-plane technique.

Block Specific Concerns

Interscalene brachial plexus nerve blocks near invariably result in blockade of the phrenic nerve, and should never be performed bilaterally, or unilaterally in patients with underlying respiratory compromise. Temporary Horner's syndrome and hoarseness due to recurrent laryngeal nerve involvement have been reported. Cardiac monitoring and familiarity with the management of local anesthetic systemic toxicity (LAST) are mandatory.

Popliteal Sciatic Nerve Blocks

Indications

Anesthesia to the lower leg for reduction and splinting of ankle and foot fractures and dislocations.

The patient is positioned prone or, if supine, with the lower extremity elevated by blankets (though lateral decubitus position is also acceptable). The skin and the high-frequency linear transducer are sterilely prepared, and the transducer is placed transversely in the popliteal fossa.. Scanning begins with identification of the tibial nerve, just superficial (posterior) to the popliteal vessels. The transducer is moved cranially following the tibial nerve until the common peroneal nerve is identified laterally, and visualized as it joins the tibial nerve (representing the distal sciatic nerve). Anesthetic injection can be performed using an in-plane or out-of-plane technique.

Block Specific Concerns

Due to its orientation in the distal thigh, the sciatic nerve is often best visualized by angling the ultrasound transducer towards the patient's feet. Intermittent dorsiflexion and plantarflexion of the ankle, if possible, can also assist in identifying the nerve (the "seesaw sign"). Cardiac monitoring and familiarity with the management of local anesthetic systemic toxicity (LAST) are mandatory.

NORMAL ANATOMY

The femoral nerve, a major branch of the lumbar plexus, is located lateral to the femoral artery and deep to the fascia iliaca.

The tibial nerve is a terminal branch of the sciatic nerve, and courses posterior to the medial malleolus, usually posterior to the posterior tibial artery.

The median nerve lies on the fascial plane separating flexor digitorum superficialis and profundis muscles. The superficial radial nerve is located just radial to the radial artery. The ulnar nerve is located just ulnar to the ulnar artery.

The roots of the brachial plexus are located within the interscalene groove, between the anterior and middle scalene muscles at the level of the cricoid cartilage (corresponding to C6). The interscalene groove is deep to the sternocleidomastoid muscle and lateral to the great vessels of the neck and the anterior scalene, and medial to the middle scalene.

The sciatic nerve courses along the posterior thigh and branches into the common peroneal nerve and tibial nerve proximal to the popliteal fossa. It is bounded medially by the semimembranosus and semitendinosus muscles, and laterally by the biceps femoris muscle.

SEMINAL STUDIES

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TOPIC A20. ULTRASOUND-ASSISTED LUMBAR PUNCTURE

The goals of ultrasound in lumbar puncture guidance include: 1) assessment of the midline as determined by the spinous processes; 2) assessment of the L4-L5 and L3-L4 interspaces; 3) estimation of the distance between the skin and the subarachnoid space; and 4) estimation of the angle for needle advancement. In addition, ultrasound may be used to detect possible barriers to successful lumbar puncture, such as the presence of calcifications to the supraspinous and interspinous ligaments that would necessitate a paramedian approach.

SCANNING PROTOCOL

Patient Positioning

The patient should be placed so that all equipment is easily within reach of the person performing the procedure. In addition, when using ultrasound to guide procedures the ultrasound should be directly in front of the person performing the procedure so that it is easy to look between the screen and the needle without turning. The patient should be positioned as for a non-ultrasound guided lumbar puncture and ultrasound identification of landmarks will take place prior to sterile prep.

Transducer and System Settings

A high-frequency linear transducer on a non-vascular setting should be used in most cases, unless significant body habitus necessitates a curvilinear probe for better tissue penetration. An indelible skin marker should be available for skin markings.

Image Acquisition

First, place the probe in a transverse orientation with indicator pointed to the patient's left, starting at Tuffier's line. This is the imaginary line between the superior aspects of the iliac crests, and corresponds to about the L4-L5 interspace. In morbidly obese patients, placing the probe at the origin of the gluteal folds is an alternative to palpation of the iliac crests. Translate the probe cephalad until the L5 spinous process is seen, and center the probe so that the spinous process is in the middle of the screen. Mark the location of the spinous process with a dot or hash-mark. Repeat for both the L4 and L3 spinous processes, which will help to determine the true midline, and whether the patient's trunk is malrotated.

Next, return the indicator to Tuffier's line with the probe in a sagittal orientation, with the indicator pointed towards the patient's head. The probe should be anchored on the midline, and translated cephalad until two spinous processes are located on the screen. This should correspond to the L4-L5 interspace, but may be the L3-L4 interspace. If the probe is off-midline, the paraspinal muscles are usually imaged in longitudinal view, with a classic linear, fibrillar pattern. Once the probe is in the midline and between an interspace, mark a hash on both sides of the center notch of the probe. Upon removing the probe, the intersection of the four hash marks will indicate the point for needle entry. It may be more efficient to mark two interspaces in this manner before a sterile preparation so that there is an alternative needle entry point should the initial point fail.

Place the probe again on this intersection in a sagittal orientation to verify localization of the interspace. Next, adjust the depth to about 6-8 cm to visualize the ligamentum flavum, which appears as a horizontal line deep to the interspace. The posterior dura lies just anterior, but may not be well visualized, especially with a curvilinear probe. In addition, the orientation of the bony cortices of the spinous processes will allow for an estimation of the angle of needle entry. Demonstration of less than 5mm of interspace at the depth of the ligamentum flavum may prompt the clinician to reposition the patient in order to widen this opening.

Some operators prefer to use the curvilinear probe at this point to obtain a paramedian sagittal or transverse view. This probe does afford better depth penetration and visualization of the anterior and posterior dural sac, the laminae, as well as the vertebral bodies. However, this requires a reorientation of the probe to an oblique axis, which may complicate estimation of needle depth. In addition, either the posterior and anterior dural wall may be mistaken for the ligamentum flavum, which is less echogenic.

NORMAL ANATOMY

Users should at minimum be able to visualize the midline, at least one lumbar interspace below L2, the posterior dura or ligamentum flavum for depth estimation, and estimation of angle of needle approach.

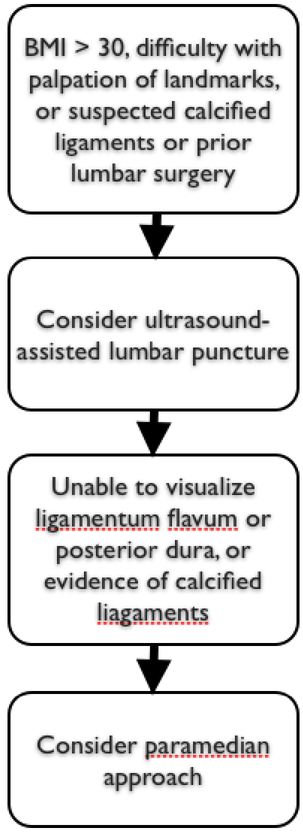
PATHOLOGY

Pathology may be seen as calcified interspinous or supraspinous ligaments, or if the patient has had lumbar fusion, brightly echogenic hardware may be visualized.

CLINICAL INTEGRATION

If the patient's bony landmarks are not readily apparent, perform an ultrasound for the landmarks described above. If the supraspinous or interspinous ligaments appear to be calcified or the landmarks are not readily appreciated with a linear transducer, either attempt a paramedian view or switch to the curvilinear probe. If the landmarks are still not well visualized, attempt a different interspace.

Once the interspaces are marked, and the needle depth and angle of approach are ascertained, begin sterile prep and drape for lumbar puncture. It is recommended that a sterile cover be placed on the probe, in order to verify landmarks should the patient need to be repositioned during the lumbar puncture.



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TOPIC A21. ULTRASOUND-GUIDED ARTERIAL LINE PLACEMENT

SCANNING PROTOCOL

Patient Positioning

The radial artery is the preferred site for arterial cannulation, given its superficial location and low rate of complications. The patient should be positioned supine with the arm in an abducted position. All equipment should easily be within reach of the person doing the procedure. The ultrasound machine should be placed directly in front of the person doing the procedure to minimize extraneous head movements between the ultrasound screen and the procedural field.

Transducer and System Settings

The ideal transducer is a high-frequency linear probe (7-12 MHz). The probe should ideally be positioned at a 90-degree angle to the vessel to maximize resolution.

Image Acquisition

The target artery must be distinguished from any adjacent veins. On ultrasound, arteries appear pulsatile, are not compressible, and have a characteristic appearance on pulse-wave Doppler that is different from veins.

For radial artery cannulation, the patient's arm should be placed in abduction. A high-frequency linear probe is used to identify the radial artery anywhere from the wrist to the mid-forearm level. For femoral artery cannulation, the patient's leg should be placed in abduction and external rotation.

NORMAL ANATOMY

Potential locations for arterial catheterization include the radial, femoral, axillary, brachial, and dorsalis pedis arteries.

The radial artery is located superficially between the flexor carpi radialis tendon and the radius. The dimensions of the radial artery are unaltered when the wrist is extended up to 45 degrees, but wrist extension beyond 60 degrees decreases radial artery height and may make cannulation more difficult.

The femoral artery runs laterally to the femoral vein. However, the inguinal crease is an unreliable landmark for vascular anatomy, as up to 65% of patients may have a portion of the common femoral artery overlap the common femoral vein in an anteroposterior plane.

The axillary artery is located superior to the subscapularis and teres major muscles. It runs with the axillary vein and can be accessed via the axillary fossa or by a transpectoral approach through the chest wall.

The brachial artery runs 5-10 cm distal to the antecubital fossa, medial to the biceps tendon.

The dorsalis pedis artery lies between the extensor hallicus longus and extensor digitorum tendons, distal to the navicular bone. Catheterization of the dorsalis pedis artery is less successful than at other arteries due to the smaller size of this vessel.

CANNULATION

The use of ultrasound guidance for radial artery cannulation is associated with a significantly increased likelihood of first-attempt success, compared to the traditional palpation technique. A 20-gauge catheter should be used in the radial artery, while a 16- to 18-gauge catheter should be used for the femoral artery. Small children and infants require a smaller 22- to 24-gauge catheter. Arterial catheter sets are currently available with an attachable, catheter-contained, wire stylet that permits a modified Seldinger technique for cannulation. Other catheter sets contain a separate wire, needle, and catheter and are inserted using a Seldinger technique.

Arterial catheters should be inserted using standard sterile technique. Once a suitable artery is identified, the skin is prepared with antiseptic cleaning solution. A sterile cover should be applied over the ultrasound probe with ultrasound gel inside the cover. Sterile gel should be used on the surface of the cleaned skin. The ultrasound probe should be held with the non-dominant hand while the dominant hand directs the arterial catheter and needle to the artery in real-time. Either a short- or long-axis technique may be used. Once the artery is accessed, the catheter is inserted into the vessel using either a direct over-the-needle cannulation technique or a modified or proper Seldinger technique. The needle and wire should then be removed, and the catheter attached to a transducing line. Once completed, the procedure should be documented in the medical record, making note of the use of ultrasound guidance.

SEMINAL STUDIES

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TOPIC A22. GASTROSTOMY/JEJENOSTOMY AND SUPRAPUBIC TUBE PLACEMENT

Confirmation of proper placement via traditional methods is time consuming, may expose patients to ionizing radiation, and in the case of aspiration of contents can be misleading. Ultrasound can expedite placement and can ensure that the tube is correctly placed.

SCANNING PROTOCOL

Patient Positioning

The patient should be placed so that all equipment is easily within reach of the person performing the procedure. In addition, when using ultrasound to guide procedures the ultrasound should be directly in front of the person performing the procedure so that it is easy to look between the screen and the needle without turning.

Transducer and System Settings

Except where otherwise indicated or not available a high frequency linear array probe is recommended.

Image Acquisition

Gastrostomy/Jejunostomy Tube Placement

Anatomy
The stomach lies in the left upper abdominal quadrant inferior to the fascia. The liver and splenic borders should be visualized. In the NPO patient the gastric antrum mural layers will be located behind the liver and directly in front of the pancreas. For J-tube replacement the loop of jejunum will often be visualized against the abdominal wall adjacent to the previously created tract.

Scanning protocol

The patient should be in the supine position. Visualization of the stomach/ jejunum, fascia and surrounding structures should be performed prior to the procedure. A curvilinear transducer (3-6 MHz) is typically utilized. The stomach/jejunum should be scanned in the longitudinal plane to visualize tube entry under dynamic ultrasound guidance as the tube is passed through the patent stoma. If any resistance is felt, or if deflection of the peritoneum is seen on ultrasound, the procedure should be stopped and a tube one size smaller should be chosen. After passage, color Doppler may be employed at the tube tip with manual oscillations to confirm proper placement. Alternatively a 10cc sterile saline flush may be pushed to directly visualize fluid entry at the correct location through the tube.

Suprapubic/Cystostomy Tube Placement

Anatomy

The full bladder is an anechoic cystic structure lying midline in the pelvis, posterior to the abdominal rectus musculature and, in females, anterior to the uterus. The bladder tends to descend lower into the pelvis with advancing age, and may be shifted off the midline by external pressure from abdomino-pelvic masses. The normal bladder classically appears as a rounded rectangle in transverse imaging, shaped more like a triangle in sagittal scanning. The prostate in males, and vaginal stripe in females are seen posterior to the bladder.

Scanning Protocol

The patient should be in the supine position. The skin and probe should be prepared in a sterile fashion. A curvilinear transducer (3-6 MHz) is generally used to adequately image the bladder, with the indicator directed cranially or to the patient's right side to obtain sagittal and transverse views of the bladder respectively. Prior to performing the procedure the clinician should calculate the bladder volume utilizing the formula for an ellipsoid length X width X height X 0.7. The bladder should be scanned fully in both planes to delineate the bladder boundaries, lower abdominal contents, and localize the bladder mid-point where catheterization should be attempted. Scanning the bladder in 2 planes will also eliminate any confusion in confirming bladder identification versus other fluid-filled structures (distended loop of bowel, ovarian cyst). Careful attention should be paid to the depth to bladder lumen measured on the right side of the ultrasound screen. The wall and lumen of the urinary bladder can only be adequately examined when the bladder is full. Distended bladder wall thickness is normally <4mm.

CANNULATION

Upon identification of the distended bladder and absence of obstructing anatomical structures anesthetic can be locally administered. If bowel is visualized anterior to the bladder, graded compression or modification of patient positioning can be performed to move the obscuring bowel loops. Direct visualization of the needle tip entering the bladder should occur under dynamic ultrasound guidance using either the short or long axis (preferred) approach. Tenting of the bladder wall is often seen as the needle enters the bladder lumen, and the catheter also will appear as a hyperechoic linear structure within the bladder after placement. The Seldinger technique is typically used for catheterization.

Upon completion of the procedure, repeat scanning in the longitudinal and transverse planes should be performed to confirm bladder decompression.

CLINICAL INTEGRATION

Ultrasound reduces the time of the procedure, prevents failed attempts at cannulating an empty bladder, and reduces complications. Challenges may include patient body habitus, uncooperative patients, and adhesions. The most serious complication of suprapubic cystostomy catheter placement is bowel perforation, with the most common complication being self-limiting microhematuria. Other complications include hemorrhage with hematoma formation, penetration into the uterus, vagina, and rectum, infection, and tube displacement.

SEMINAL STUDIES

1. Wu, TS, Leech SJ, Rosenberg M, etal. Ultrasound can accurately guide gastrostomy tube replacement and confirm proper tube placement at the bedside. *J Emerg Med*. 2009;36:280-4.
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