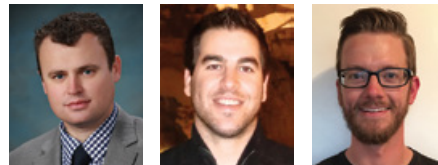# Shock Waves

Ultrasonographic Assessment of Shock

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and **Scott Lotz, MD**

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Reviewed by **Joshua S. Broder, MD, FACEP**

OBJECTIVES

On completion of this lesson, you should be able to:

1. Explain the importance of shock identification and differentiation.
2. Describe the pathological conditions that can be identified on bedside ultrasound in patients with shock.
3. Demonstrate the techniques utilized to evaluate shock with bedside ultrasound.
4. Describe strategies for ultrasound-guided resuscitation in cases of shock.
5. Identify pearls and pitfalls of bedside ultrasonography in the differentiation of shock in the emergency department.

FROM THE EM MODEL

19.0   Procedures and Skills Integral to the Practice of Emergency Medicine

      19.5   Other Diagnostic and Therapeutic Procedures

            19.5.3   Ultrasound

CRITICAL DECISIONS

- How can bedside ultrasound help differentiate types of shock in the emergency department?
- How can bedside ultrasound be used to evaluate the heart and IVC of a patient in shock?
- How can bedside ultrasound be used to evaluate the abdomen in cases of shock?
- How can bedside ultrasound be used to assess the lungs and pleura in cases of shock?
- How can bedside ultrasound help guide resuscitation in patients with shock?

Shock, a multifactorial condition characterized by insufficient tissue perfusion, represents a true medical emergency that accounts for significant morbidity and mortality worldwide.[1] Septic shock alone is a leading cause of hospital mortality in the United States, with an annual incidence of 18.6 cases per 1,000 hospitalizations, a mortality rate of approximately 50.7%, a cost of $20.3 billion dollars (2011), and a projected 1.5% increase in the number of annual cases.[2-4]

CASE PRESENTATIONS

■ CASE ONE

A 65-year-old woman arrives via ambulance with altered mental status. Her family called 911 when the patient awoke from a nap confused and disoriented. En route, her vital signs were blood pressure 74/50, heart rate 125, respiratory rate 25, temperature 37°C (98.6°F), and oxygen saturation 94% on room air. EMS reports a Glasgow Coma Scale score of 12 and a finger-stick blood glucose level of 112 mg/dL. The patient was provided supplemental oxygen via nonrebreather mask at 15 L/minute, a 1-liter normal saline bolus, and intravenous naloxone (0.4 mg) without improvement.

Upon arrival, the patient's mental status and vital signs have not improved and the patient is unable to provide any further history. A physical examination reveals an intact airway, spontaneous respirations, and pulses that are diminished diffusely with mild peripheral cyanosis. Pertinent positives include bilateral 2+ peripheral edema and distended neck veins with 2+ jugular venous distension. Breath sounds are diminished in the bases, and distant heart sounds without murmur are appreciated. The left upper extremity is notable for a pulsatile arteriovenous fistula with palpable thrill.

Two large-bore intravenous (IV) catheters are placed and resuscitation is continued with intravenous fluids. An electrocardiogram (ECG) reveals a sinus rhythm with a rate of 115 beats per minute, low voltage in the limb and precordial leads, and nonspecific ST-T-wave changes. A portable chest x-ray demonstrates cardiomegaly without focal infiltrates or pneumothorax. A broad set of blood work is drawn and sent to the laboratory. As the assessment continues, the patient's blood pressure begins to trend down.

■ CASE TWO

A 54-year-old woman presents with chest pain and shortness of breath. She has a history of coronary artery disease status post stenting of the left anterior descending artery 6 years ago, and is well known to the cardiology service. The patient says her symptoms began earlier today and have been steadily worsening. Upon arrival, her vital signs are blood pressure 90/52, heart rate 122, and respiratory rate 22. She is mildly hypoxic at 89% on room air, but returns to 96% when placed on 4 L/minute nasal cannula. She is afebrile but appears in moderate distress and is speaking in short sentences. She denies a history of congestive heart failure, chronic obstructive pulmonary disease, deep venous thrombosis/pulmonary embolism, or home oxygen use. She takes metoprolol, lisinopril, and aspirin daily.

The patient is placed on a cardiac monitor and an initial ECG demonstrates a right bundle branch block, which is consistent with previous ECGs. Her examination reveals symmetrical breath sounds and tachycardia without murmurs, rubs, or gallops. She has mild non-pitting edema of the bilateral lower extremities. Equal pulses are noted in both upper and lower extremities, and her abdominal examination is normal.

Initially, the patient appears to stabilize on the nasal cannula, but her blood pressure soon plummets to 65/43 and she becomes obtunded. At the bedside, her heart rate increases to 148 and oxygen saturation drops to 87% on 4 L nasal cannula.

While the condition may arise from a variety of etiologies (eg, infection, hypovolemia, and cardiac dysfunction), the resultant sequelae, including inadequate oxygen delivery, organ dysfunction, and cell death, often is the same. Successful shock management is incumbent upon early recognition and differentiation. Furthermore, delays in timely intervention and resuscitation repeatedly have been shown to worsen outcomes.[5]

Bedside ultrasound has been demonstrated to narrow the differential diagnosis of shock rapidly and accurately and can be used to help identify additional pathologies, prompt treatment strategies, and improve physician confidence.[6-8]

CRITICAL DECISION

How can bedside ultrasound help differentiate types of shock in the emergency department?

Shock etiologies most commonly are divided into four distinct categories: *cardiogenic, obstructive, distributive*, and *hypovolemic*. The sonographic evaluation of undifferentiated hypotension and shock is performed through a sequential visual assessment of multiple organ systems in conjunction with the physical examination. While numerous approaches are described in the literature, the three most commonly recommended include evaluation of the heart with inferior vena cava, the abdomen, and the lungs (*Figure 1*).

The heart and inferior vena cava (IVC) frequently are grouped and evaluated simultaneously. In the emergency department, the cardiac examination should follow the traditional limited approach for identifying pericardial effusion or tamponade, global cardiac systolic function, and right ventricular dilatation or strain. The inferior vena cava also should be assessed for evidence of hypovolemia or, conversely, signs of dilatation seen with cardiac tamponade or pulmonary embolism.

The abdomen should be examined for intraabdominal free fluid and abdominal aortic aneurysm. Classically, the focused assessment with sonography in trauma (FAST) examination is used to identify abdominal, thoracic, or pericardial hemorrhage in cases of trauma. In patients with undifferentiated hypotension and shock, the abdominal FAST and aorta assessments are utilized not only to identify traumatic injury, but also alternative nontraumatic etiologies such as ruptured ectopic pregnancy or a leaking aortic aneurysm.
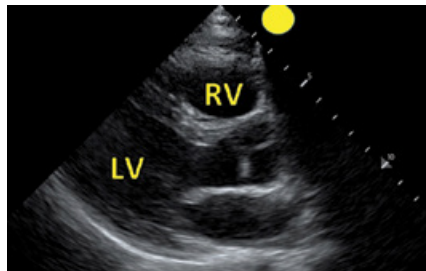
A thoracic examination should be performed to identify pneumothoraces, pulmonary interstitial fluid (seen with edema

FIGURE 1. Undifferentiated Shock and Resuscitation Ultrasound Protocol
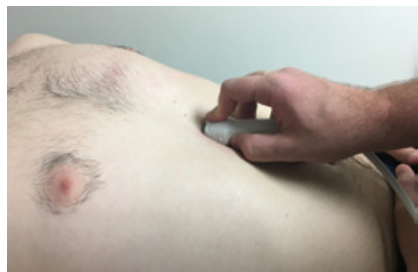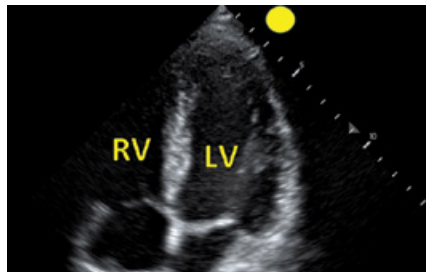### Step 1. Limited Cardiac Windows

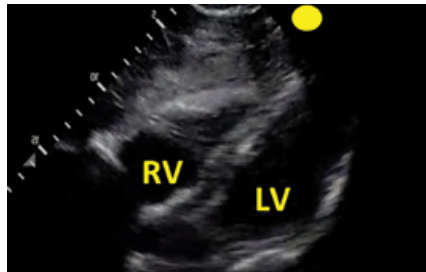

Parasternal Long Axis

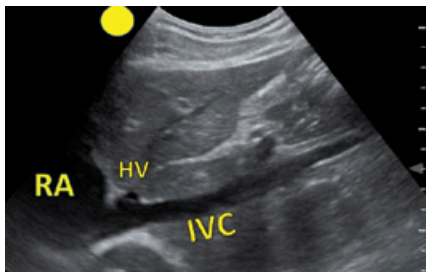Parasternal Short Axis

Apical

Subxiphoid

Inferior Vena Cava

RV=Right ventricle   LV= Left ventricle   RA= Right atrium   HV=Hepatic vein
IVC= Inferior vena cava   L= Liver   SP= Spleen   K= Kidney
A= Aorta   R= Rib   ➔ = Diaphragm

or consolidation), and pleural effusion or hemothorax. The invaluable information gained through this rapid assessment makes bedside ultrasound an essential tool for the real-time differentiation of hypotension and shock.

CRITICAL DECISION

How can bedside ultrasound be used to evaluate the heart and IVC of a patient in shock?

Cardiac ultrasound is best performed with a phased-array transducer; its smaller footprint enables improved intercostal views of the heart. Image acquisition traditionally includes four windows: the parasternal long- and short-axis views, the subxiphoid view, and the apical 4-chamber view (*Figure 1-Step 1*). Each window allows the clinician to visualize a distinct portion or function of the heart. Images commonly are obtained in B- (brightness) mode as two-dimensional grayscale structural images. Alternatively, M- (motion) mode, which demonstrates sequential B-mode images over time, may be required in certain circumstances.

To acquire parasternal views of the heart, the patient should be placed in a supine or left lateral decubitus position, with the ultrasound probe to the left of the sternum in the third or fourth intercostal space. The probe indicator traditionally is directed (with the indicator on the right side of the ultrasound monitor screen) toward the patient's right shoulder in the long axis, or rotated clockwise 90-degrees to the left shoulder in the short axis.

The subxiphoid view can be obtained with the probe placed below the tip of the sternum with the indicator directed toward the patient's left side. Finally, the apical view is best obtained by placing the probe just below the left nipple line at the point of maximal impulse, with the indicator directed toward the left axilla.

Pericardial Effusion and Tamponade

In cases of undifferentiated shock, focused echocardiography can be utilized to identify the presence of pericardial effusion or tamponade. Effusions increase the pressure within
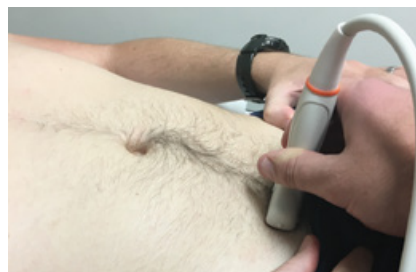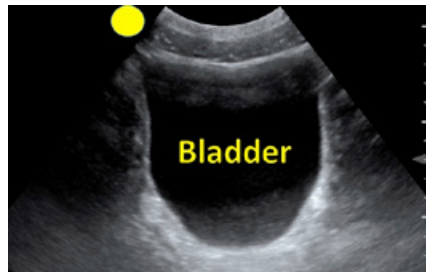
Step 2. Limited Abdominal Windows

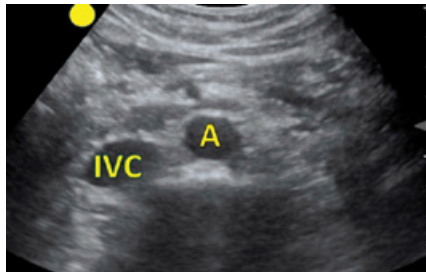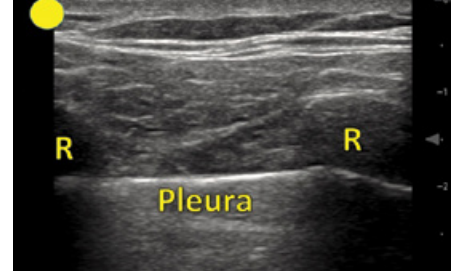Right Upper Quadrants

Left Upper Quadrant
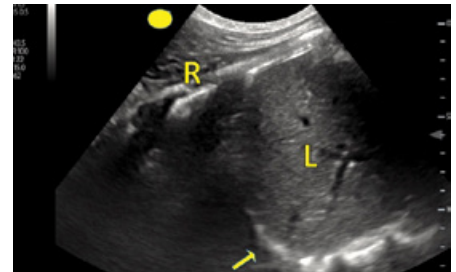

Suprapubic

Aorta

Step 3. Limited Thoracic Windows

Anterior Chest Wall

Diaphragm

the pericardial sac, compressing the heart and reducing cardiac filling and output. When evaluating for pericardial effusion, the heart should be visualized as described above; attention should be paid to the pericardium, which normally appears as an echogenic (ie, bright) line immediately surrounding the myocardium.

Pericardial fluid often appears as a dark or anechoic stripe within the pericardial space, separating the pericardium and myocardium. Smaller effusions initially will present as thin stripes, while larger effusions can envelop the heart circumferentially. Fluid may appear dark, while clotted blood can have a "speckled" or echogenic appearance.

If a pericardial effusion is identified, the heart should be further evaluated for signs of impaired filling or tamponade (*Figure 2a*). The right side of the heart, as compared to the left, is a low-pressure system. Increased pericardial pressures will limit the right heart from fully expanding during diastole, ultimately resulting in reduced cardiac filling. Both the right atrium and ventricle should be analyzed for diastolic collapse, which will appear as collapse of the free wall during filling. As pericardial pressures increase and tamponade worsens, the right-sided chambers will collapse to a greater degree and the interventricular septum may bow into the left side of the heart.

Left Ventricular Assessment

Any sonographic evaluation of undifferentiated shock should include an assessment of the patient's left ventricular systolic function. For clinical purposes, ventricular function (ie, ejection fraction) generally can be divided into four categories: *severely reduced* (<30%), *mildly reduced* (30%-55%), normal (55%-65%), and *hyperdynamic* (>65%). A cardiac function evaluation can help the emergency physician identify the hyperdynamic contractions associated with hypovolemic shock (including hemorrhagic shock) or distributive shock (including septic shock), or the dilated left ventricle and globally reduced contraction seen in cardiogenic shock. Furthermore, assessments of left ventricular contraction can reveal the strength of the "pump" as well as the patient's ability to tolerate fluid during resuscitation.

The cardiac function evaluation commonly involves both a general visual assessment of the contractile motion of the left ventricle during systole and a measurement of the mitral valve inflow excursion, described below. A ventricle with normal or hyperdynamic function will demonstrate a large contraction percentage during cardiac cycles. Alternatively, a poorly contracting heart will have minimal contractions during systole and may have a dilated cross-sectional diameter. A simple visual analysis of the heart during the cardiac cycle can help identify the contractile function of the left ventricle accurately.[9]

Next, the inflow excursion of the anterior leaflet of the mitral valve can be used as an additional measurement of left ventricular function, referred to as E-point septal separation (EPSS) (*Figure 2c*). The movement of the mitral valve anterior leaflet can be visually assessed in the parasternal long view as it moves towards the septum during ventricular filling. With a normal ejection fraction, the anterior leaflet will move significantly during ventricular filling, nearly touching the septum. Reduced or minimal movement of the mitral valve (>7 mm from the inter-ventricular septum during diastole) is consistent with reduced systolic function.

Right Ventricular Assessment

A focused evaluation of the right heart can be utilized to identify signs of increased pressures or strain. Right heart strain is best identified with the parasternal long axis, parasternal short axis, and apical views. In a normal heart, the right:left ventricle diameter ratio is less than 1:1. In patients with obstructive conditions (eg, pulmonary embolism) right-sided pressures can increase, resulting in dilatation of the right ventricle to equal or greater than the left. This elevation can be assessed through a cross-sectional diameter comparison of the right and left ventricles (*Figure 2b*). As right-sided pressures increase, flattening of the interventricular septum may be noted as a "D-shaped" left ventricle on the parasternal short axis view.

IVC Assessment

In addition to identifying potential shock etiologies, a sonographic inferior vena cava assessment can help guide resuscitation in hypotension and shock by providing noninvasive estimates of intravascular volume status and right heart pressure. To visualize the IVC, the patient should be placed in a supine position with the transducer in the subxiphoid location (*Figure 1-Step 1*). A low-frequency (3.5-5 MHz) probe (eg, phased array or curvilinear) should be selected in B-mode.

Once an appropriate subxiphoid view of the heart has been obtained, the probe is rotated 90 degrees until the marker is pointed toward the patient's

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FIGURE 2. Cardiac Ultrasound in Undifferentiated Shock
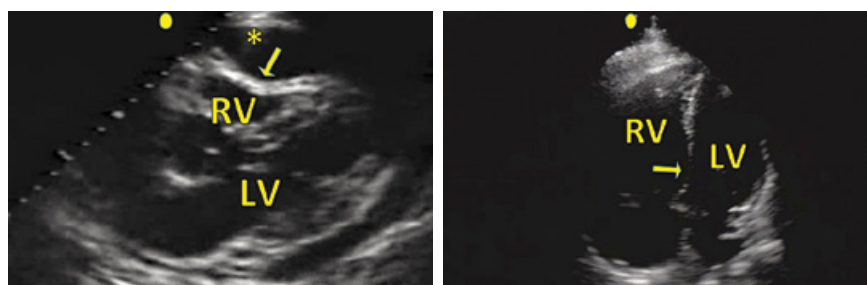
A. Pericardial fluid (*) and scalloped right ventricle free wall during diastole consistent with tamponade *(arrow)*.

B. Right heart strain pattern with increased right ventricle diameter (>left ventricle) and bowing of the septum *(arrow)*.
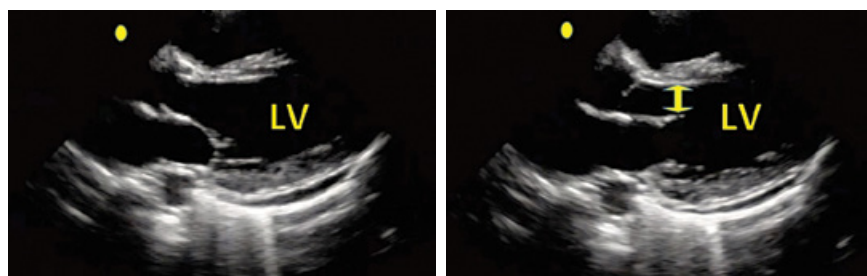
C. Left ventricle during systole demonstrates reduced ejection fraction, ventricular dilation *(left)*, and increased E-point septal separation *(right, arrow)*.
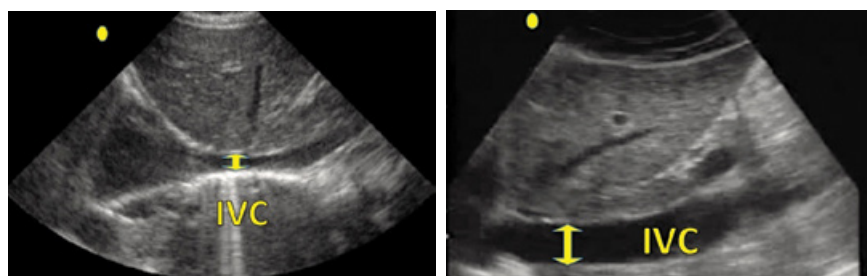
D. Inferior vena cava collapse *(left)* and dilation *(right)*.

RV=Right ventricle   LV=Left ventricle   *=Free fluid

A. Right upper quadrant *(left)* and left upper quadrant *(right)* peritoneal free fluid.

B. Abdominal aortic aneurysm *(arrow)* with intraluminal hematoma.

L= Liver
K= Kidney
*=Free Fluid

SP= Spleen
A= Aorta

head. At this point, the IVC should be visualized in the longitudinal plane as it enters the right atrium. The IVC should be followed inferiorly, while 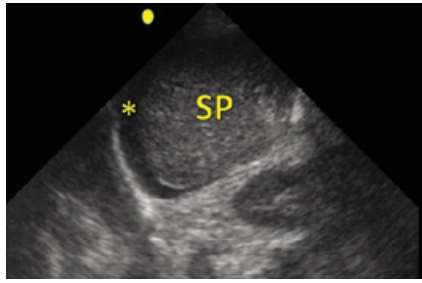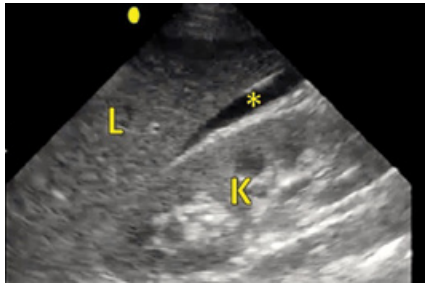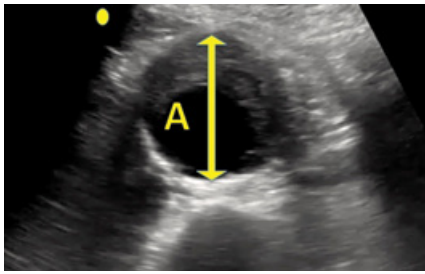looking for the confluence of the hepatic veins, and measured 2 cm caudal to the right atrium. M-mode sonography should be avoided, as it potentially introduces inaccuracy due to the displacement of the IVC relative to the probe during inspiration.

An assessment of the IVC in patients with hypotension and shock should include an anterior-posterior diameter measurement and respiratory variation evaluation *(Figure 2d)*. A distended (ie, full) IVC with minimal respiratory variation may be seen in patients with cardiogenic failure or obstructive causes of shock such as cardiac tamponade, pulmonary embolism, and tension pneumothorax. Alternatively, a flat (ie, collapsing) IVC more commonly is associated with relatively decreased volume states, including hypovolemic or septic shock.

CRITICAL DECISION

How can bedside ultrasound be used to evaluate the abdomen in cases of shock?

When clinically indicated, the sonographic evaluation of undifferentiated shock and hypotension should include

an abdominal assessment to identify potential etiologies such as intraabdominal hemorrhage and aortic aneurysm.

Peritoneal Free Fluid

The peritoneal cavity can be assessed for the presence of abnormal fluid collections using the FAST examination. When using this approach, the patient should be placed in either a supine or Trendelenburg position (head down) and ideally evaluated with the curvilinear transducer. Abdominal views include the right and left upper abdominal quadrants and pelvis *(Figure 1– Step 2)*.

First, the transducer should be fanned across the lateral intercostal spaces of the right and left upper quadrants with the indicator angled toward the patient's head. Next, the transducer should be

placed over the suprapubic region, with the indicator toward the patient's right side (for a transverse view of the pelvis), followed by a 90-degree rotation toward the patient's head to obtain a longitudinal view. With these views, the hepatorenal space in the right upper quadrant, the perisplenic space in the left upper quadrant, and the rectovesicular space in the pelvis can be evaluated for signs of free fluid or clot. Fluid in these dependent areas of the abdomen typically will appear as a dark (ie, anechoic) stripe or area *(Figure 3a)*.

When hemorrhagic shock is clinically suspected in a patient with trauma, the FAST examination can be used to quickly assess for the presence of hemoperitoneum. Fluid collections of approximately 200 mL can be rapidly and reliably identified with high sensitivity and specificity, leading to a timely diagnosis and intervention.[10] Similarly, in nontraumatic etiologies such as ruptured ectopic pregnancy, spontaneous splenic rupture, gastric or bowel perforation, and leaking abdominal aortic aneurysm, the sonographic identification of intraabdominal free fluid may identify diagnoses in patients otherwise too unstable for alternative imaging modalities such as CT or MRI.

Abdominal Aorta

In the sonographic evaluation of the abdominal aorta, the transducer should be placed in a midline position over the patient's epigastrium; the indicator should be pointed toward the patient's right side to visualize the aorta in an anterior-posterior orientation

Pearls

- Emergency physicians can perform bedside ultrasound in real-time to efficiently differentiate critically ill patients.
- Cardiac function can be evaluated through visual global assessments and specific measurements such as E-point septal separation (EPSS).
- As little as ~200 mL of abdominal free fluid can be detected on the FAST examination and commonly will appear as a dark (ie, anechoic) stripe.
- A sonographic evaluation of the heart and inferior vena cava can guide volume resuscitation reliably.

(*Figure 1-Step 2)*. A short axis view of the abdominal aorta at the level of the celiac artery can be identified as an anechoic circular vessel, anterior to the vertebral body and to the patient's left of the inferior vena cava.

With constant, steady pressure, the transducer then can be moved caudally toward the umbilicus to enable visualization of the entire length of the abdominal aorta through the iliac bifurcation, which appears approximately at the level of the umbilicus.

Finally, the indicator should be rotated toward the patient's head for a longitudinal evaluation. Aortic measurements can be obtained in the short axis, at the maximal diameter, from anterior outer wall to posterior outer wall to identify aneurysmal dilation. An aortic measurement of 3 cm or more is considered aneurysmal, with rupture more commonly seen in aneurysms greater than 5 cm (*Figure 3b)*. An inner wall to inner wall measurement may underestimate aortic diameter or fail to identify thrombus in the vessel lumen.

The differential of possible diagnoses in patients presenting to the emergency department with abdominal pain is notoriously broad. Among the possible etiologies is an unstable aortic aneurysm, which represents an abdominal catastrophe and can be difficult to identify on physical examination alone. If missed, this diagnosis will result in almost certain death, sometimes within minutes of clinical presentation. However, emergency physicians have demonstrated the ability to recognize this pathology on bedside ultrasound with excellent sensitivity (100%) and specificity (98%), as compared to CT imaging.[11]

CRITICAL DECISION

How can bedside ultrasound be used to assess the lungs and pleura in cases of shock?

Focused ultrasound of the lungs and pleura is an invaluable tool for the evaluation of patients in respiratory distress or with undifferentiated hypotension. In the critically ill patient, a chest x-ray can be of poor quality and considerably limited in illuminating early manifestations of pathology. Ultrasonography can be utilized for the real-time identification of a number of diagnoses, including pneumothorax, pulmonary edema, pneumonia, and pleural effusions.
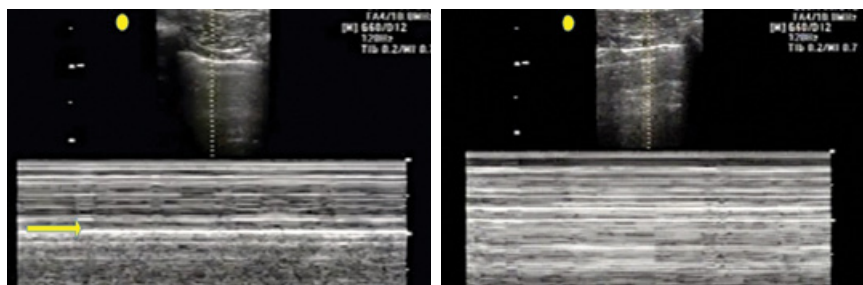
Thoracic Evaluation

In thoracic and pleural evaluations, a low-frequency (for deeper thoracic structures) or high-frequency (for superficial pleural evaluation) transducer should be selected. The transducer can be placed on the anterior chest wall between the third and fourth intercostal space at the midclavicular line, with the indicator directed cephalad in a longitudinal plane (*Figure 1 – Step 3)*. The transducer then can be adjusted to visualize the echogenic, reflective pleural line between two adjacent ribs.

The presence or absence of pleural sliding, identified as the shimmering movement of the pleura, can be visualized in both B- and M-modes. Sequential, bilateral intercostal spaces can be evaluated by moving the transducer inferiorly and posteriorly along the chest wall. "A-lines" also can be seen with this view as equidistant, horizontal, echogenic lines below the pleural surface.

A low-frequency probe (3.5-5 MHz) such as a phased array or curvilinear probe should be used to evaluate for B-lines, with the depth adjusted to at least 18 cm. These artifacts should extend as "comet-tail" reverberations to the bottom of the screen. Each hemithorax should be divided into anterior, lateral, and posterior zones, demarcated by the anterior and posterior axillary line. A complete examination consists of imaging multiple regions on each side of the chest wall.

Finally, a pleural effusion is best evaluated by using a low-frequency probe with the indicator directed cephalad in the posterior axillary line between the 9th and 11th ribs. This view may be obtained with patient in a sitting or supine position. It is important to be mindful of the probe orientation when differentiating thoracic and peritoneal fluid collections. A thoracic fluid collection will be visualized superior to the reflective, hyperechoic diaphragmatic line, which moves with respiration. Once identified, ultrasound can be used to assess the size of the

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FIGURE 4. Thoracic Ultrasound in Undifferentiated Shock

A. M-mode *(motion)* evaluation of pneumothorax with normal "seashore" sign *(left)* and abnormal "barcode" sign indicative of pneumothorax *(right)*.
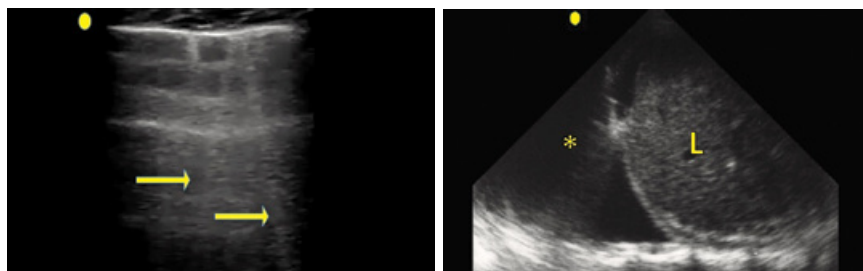
B. Pathological "B-lines" *(arrows)* seen in interstitial lung syndromes such as pulmonary edema.

C. Large pleural effusion

L=Liver   **=Free Fluid*

effusion and choose an appropriate location for thoracentesis if necessary.

Pneumothorax Identification

In normal lung, respiration is associated with physiological sliding of the visceral and parietal pleura, which can be visualized with ultrasound. In a 2005 study of 200 ICU patients who underwent CT scanning, the absence of lung sliding on ultrasound was noted with 100% sensitivity in those with pneumothoraces.[12] Lung sliding can be visualized — either directly on B-mode, or over time on M-mode — as either the physiological "seashore" or pathological "barcode" sign (*Figure 4a*).

A-lines represent the horizontal reverberation artifact generated by the parietal pleura in normal lung. In the previous study, this finding in combination with absent lung sliding was diagnostic for pneumothorax with a specificity of 94%.[12] Finally, "lung point," the junction between normal lung sliding and an absence of lung sliding on the same ultrasound image, was pathognomonic for pneumothorax with a specificity of 100%.[12]

Interstitial Lung Syndrome

In critically ill patients with acute respiratory distress, lung ultrasound can assist in differentiating causes of dyspnea and shock. B-lines represent a "comet-tail" reverberation artifact that arises from interstitial pulmonary fluid. These hyperechoic lines originate at the pleural line and traverse the entire ultrasound screen vertically to at least 18 cm (*Figure 4b*). While these can be seen in normal lung, more than three B-lines per rib space is considered pathological.

A predominance of bilateral B-lines often can be visualized in cases of cardiogenic pulmonary edema, but also can be seen in other pulmonary interstitial disease processes such as pneumonia, hemorrhage, and acute respiratory distress syndrome. Causes of unilateral B-lines can include pneumonia, unilateral edema, and pulmonary contusion. A 2014 systematic review found these artifacts to be 94.1% sensitive and 92.4% specific for the detection of pulmonary edema.[13]

FIGURE 5. Stroke Volume Assessment
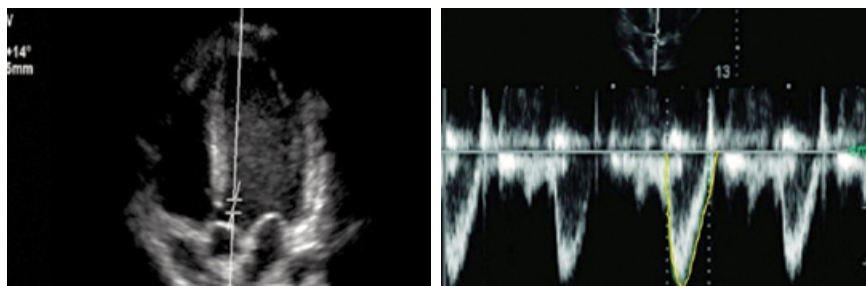
Pulsed-wave Doppler gate through the left ventricular outflow track in an apical 5-chamber view (*left*) obtained from a traditional apical 4-chamber view with slight transducer angulation toward the chest wall (*tail down*). Velocity-time integral measurement obtained with wave tracing (*right*).

Pleural Fluid Assessment

In addition, lung ultrasonography can be utilized for the detection of pleural fluid. Delineated by the pleural line, an anechoic thoracic fluid collection often represents a transudative effusion, whereas heterogeneous fluid collections may be more exudative (*Figure 4c*). Compressed, atelectatic lung "floating" also may be identified within large pleural effusions. Ultrasound has been shown to be superior to chest x-ray in the detection of these abnormalities with a sensitivity and specificity of 92% and 93%, respectively. In addition, lung ultrasonography is better able to differentiate effusion from consolidation when an opacification is seen on a supine chest radiograph.[14]

CRITICAL DECISION

How can bedside ultrasound help guide resuscitation in patients with shock?

Clinical signs of shock may be delayed and can be misleading, thus limiting a traditional physical examination; in contrast, ultrasound allows for real-time resuscitation guidance and end-point identification.

Resuscitation strategies are based on the concept of empiric volume expansion with the goal of optimizing cardiac preload, maximizing cardiac output, and improving tissue perfusion. Volume responsiveness is defined as an increase in cardiac output by more than 10% to 15% following the administration of a 500-mL fluid bolus over 10 minutes.[15]

Volume loading in a responsive patient results in a rightward shift along the Starling curve and an increase in cardiac output until the patient is preload optimized.

Unfortunately, as many as 50% of patients with severe sepsis may not be fluid responsive. In such cases, empiric fluid challenges are unlikely to increase cardiac output and may lead to increased cardiac dysfunction, pulmonary edema and hypoxemia, prolonged mechanical ventilation, increased length of hospitalization, and mortality.[16] Conversely, inadequate fluid loading can result in persistently inadequate tissue perfusion and shock. Strategies for determining the patient's cardiac function, volume status, and responsiveness are essential to successful shock resuscitation.

IVC Assessment

The dynamic relationship between venous return, the function of the right ventricle, and its interaction with lung mechanics are key determinants for estimating intravascular volume status and response to fluid resuscitation. Bedside ultrasound is a useful tool for gauging volume responsiveness by evaluating the collapse or distention of the IVC during respiration. The IVC collapsibility index, also known as the caval index, is defined as the difference between the maximal and minimal IVC diameters divided by the maximal diameter, multiplied by 100. This technique is based upon the variation of intrathoracic pressure gradients during respiration.

In spontaneously breathing patients, the diaphragm expands during inspiration, creating a transient but significant negative intrathoracic pressure change. This decrease in intrathoracic pressure results in an increase in venous return to the heart via the IVC. This relationship is reversed with positive pressure ventilation, in which positive intrathoracic pressure accompanies inspiration. As a very compliant blood vessel, the IVC is affected by these changes in flow and will collapse to various degrees under negative pressures (inspiration during spontaneous breathing, expiration under mechanical ventilation) and expand under positive pressures (expiration during spontaneous breathing, inspiration under mechanical ventilation) (*Figure 2d*).

The extent of respirophasic variability is a function of volume status and venous return. In a small study of spontaneously breathing patients, an IVC collapse of greater than 40% with inspiration was more consistent with fluid responsiveness.[17] In two small studies of mechanically ventilated patients, an increase of 12% to 18% during inspiration similarly indicated responsiveness.[18,19] In a recent prospective study, the bedside sonographic evaluation of cardiac contractility and IVC collapsibility in patients with suspected sepsis was shown to increase physician certainty and alter more than 50% of treatment plans.[6]

IVC assessment for volume responsiveness is potentially limited in patients with valvular disease, cardiac tamponade, pulmonary hypertension, right heart dysfunction, elevated intraabdominal pressures, and dysrhythmia.

Stroke Volume Assessment and Velocity-Time Integral

Unlike the respirophasic changes of the IVC, which are affected by right atrial pressures, an assessment of stroke volume (SV) can reliably predict volume responsiveness. Furthermore, as volume responsiveness is defined as an increase in stroke volume in response to a fluid challenge, the direct measurement of stroke volume can be critically important in managing patients in shock.

Velocity-Time Integral

Stroke volume calculations are obtained by assessing the velocity-time integral (VTI) of the left ventricular outflow tract (LVOT). An LVOT VTI assessment should be performed using an apical 5-chamber view. To obtain this, first begin with an apical 4-chamber view followed by a slight anterior angulation of the transducer toward the chest wall (tail down). The LVOT VTI can be measured by placing a pulsed-wave (PW) Doppler cursor in the LVOT as close to the aortic valve as possible without including it. To acquire the PW trace (which will appear as a shark fin), choose LVOT VTI from the calculation menu and manually trace the PWD waveform (*Figure 5*). The machine will calculate the area under the curve and represent it as a VTI in centimeters. A normal VTI in a healthy patient is 18 to 22 cm with a heart rate between 55 and 95 beats per minute.[20]

Stroke Volume and Responsiveness

If one thinks of the LVOT as a cylinder, the VTI is the distance that blood travels in the cylinder's area. As the area of the LVOT essentially is constant, any change in LVOT VTI can be attributed to shifts in the stroke volume.[20] Therefore, an increase in VTI of more than 15% with a fluid challenge or passive leg raise would be consistent with volume responsiveness.[21] A 2015 study advocated changes in VTI in the rapid ultrasound in shock (RUSH) examination in critically ill shock patients to guide response to therapy.[20]

A 2012 study showed that emergency department physicians could accurately measure VTI using standard bedside ultrasound in 78.4% of 97 patients.[22] LVOT VTI measurements may be limited as a surrogate of stroke volume in cases of moderate to severe aortic regurgitation or dynamic LVOT obstruction.

Summary

Undifferentiated shock represents a complex diagnostic dilemma that requires timely recognition and differentiation. When performed by the emergency clinician at the bedside, an ultrasound evaluation can aid in the identification of critical pathologies and guide the implementation of lifesaving treatments. The sonographic evaluation of undifferentiated shock includes assessments of the heart, IVC, abdomen, and lungs to identify potential etiologies such as pericardial effusion and tamponade, cardiac dysfunction, right heart strain, reduced volume status, peritoneal free fluid, abdominal aortic aneurysm, and pneumothorax.

Finally, bedside ultrasound can provide critical resuscitation guidance through IVC and stroke volume assessments. It is incumbent upon emergency physicians to familiarize themselves with the sonographic techniques required to manage the undifferentiated patient in shock.

Pitfalls

- Using bedside ultrasound in isolation. Diagnostic imaging should be done in conjunction with each portion of the patient's evaluation and treatment.
- Failing to measure the diameter of the abdominal aorta from outer wall to outer wall, potentially missing aneurysmal dilatation.
- Relying on an M-mode evaluation of the inferior vena cava. This approach should be avoided, as it potentially introduces inaccuracy due to respiratory variations.
- Neglecting to include serial examinations when performing ultrasound-guided resuscitation.

CASE RESOLUTIONS

■ CASE ONE

An ultrasound machine quickly was brought to the bedside of the woman with altered mental status. A limited cardiac evaluation revealed a moderate circumferential pericardial effusion on the parasternal long view. Right-sided diastolic ventricular collapse with interventricular septal bowing was identified, and the inferior vena cava appeared distended with minimal respiratory variation – findings that were concerning for cardiac tamponade.

An ultrasound-guided pericardiocentesis was performed using a subxiphoid approach. The catheter was identified on ultrasound within the pericardial sac, and the fluid was removed slowly. The patient's blood pressure quickly improved to 135/72 and her mental status returned to baseline. Cardiothoracic surgery was consulted and the patient was admitted to the operating room for a pericardial window.

■ CASE TWO

The patient with chest pain received an emergent bedside echocardiogram, including evaluations of the IVC and thorax. The parasternal long view demonstrated a normal left ventricle contraction without focal wall-motion abnormalities or pericardial effusion. However, the parasternal short view revealed a flattened interventricular septum and a left ventricle that resembled a "D." The apical 4-chamber view also revealed the right ventricle to be much larger than the left. The inferior vena cava was noted to be plethoric without significant respiratory variation. Finally, the lung evaluation was negative for B-lines or signs of pneumothorax or consolidation.

Using the information obtained on bedside ultrasound, the emergency physician suspected a massive pulmonary embolism. The patient received IV fluids and was placed on a nonrebreather mask, which improved his oxygen saturation. Intravenous thrombolytic therapy with alteplase was administered to manage his persistent hypotension. Once his vital signs stabilized, a CT angiogram of the chest was ordered, which revealed a large, nonobstructive embolus. The patient was admitted to the medical intensive care unit.

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