Non-cardiac Ultrasound Signs in Shock

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Learning Objectives

- Review the utility of ultrasonography for detection of bleeding in the trauma and non-trauma patient.
- Review the utility of ultrasonography for identification of source of infection in septic shock.

19.1 Introduction

The intensivist uses echocardiography at the bedside of the patient to identify imminently life-threatening causes of shock, to categorize its cause, and to guide management. While echocardiography is preeminent for the evaluation of hemodynamic failure, other aspects of critical care ultrasonography are productively combined with it using a whole-body ultrasonography (WBU) approach [1]. The WBU consists of thoracic (lung and pleura) and screening abdominal examinations as well as a vascular diagnostic ultrasonography for the detection of deep venous thrombosis. This combined approach is useful for rendering the cause of the shock state with early and accurate diagnosis leading to therapeutic interventions [2–4]. While recognizing the importance of echocardiography, this chapter will focus on the utility of other aspects of ultrasonography as they pertain to the diagnosis and management of shock. The authors will use a case-based approach that includes narrated video material that can be accessed from the online library.

Severe reduction in intravascular volume results in shock. The history and physical examination are key aspects of the evaluation. In some cases, the diagnosis is obvious. Massive gastrointestinal hemorrhage with hematemesis and/or melenic stool does not require ultrasonography nor does a patient presenting with obvious whole-body hypovolemia due to major body fluid loss from cholera or an environmental exposure without access to fluid repletion. Ultrasonography becomes helpful in situations where there is clinical suspicion for hypovolemic shock without apparent explanation for the critical loss of effective circulation volume, such as in the patient who has major internal bleeding that is not evident by history or physical examination.

Clinical Case 1

This 39-year-old male patient presents to the emergency department following a motor vehicle accident that involved a high-speed deceleration event. He is hypotensive with cutaneous abdominal and chest wall injury suggestive of a steering column impact. The critical care team performs an immediate extended FAST (focused assessment with sonography in trauma) exam, while the trauma team manages other key aspects of resuscitation.

Rapid evaluation for life-threatening internal bleeding with ultrasonography is widely used by trauma teams. The FAST exam was originally described as a limited examination of the abdominal compartment in the trauma victim [5]. If fluid is present on FAST exam within the abdominal compartment, it is taken as evidence that the fluid is blood. This indicates that there is a high probability of significant injury to an intraabdominal organ. This technique has replaced peritoneal lavage for the detection of intraabdominal bleeding. It is safe, rapid and has similar predictive value to detect blood accumulation within the peritoneal compartment when compared to peritoneal lavage [6, 7]. When free fluid is identified in a normotensive blunt trauma patient on FAST exam, this method has a sensitivity and specificity of 75.8% and 97.4%, respectively [8]. Larger amounts of blood accumulate in the prehepatic, perisplenic, subphrenic, and pelvic spaces. But even a small fluid collection within the hepatorenal or splenorenal space is considered a positive result, and as little as 120–150 cc of fluid can be detected by ultrasonography [9].

A commonly applied algorithm holds that if the FAST exam for intraabdominal fluid is positive in a patient who is hemodynamically unstable, the patient is taken to the operating theater without the need for additional imaging. Delay in operating on patients with positive FAST exams is associated with both early and late in-hospital mortality [10, 11]. If the initial examination is negative for fluid, it can be performed in a serial fashion, and further imaging such as computerized tomography or serial FAST examinations may be indicated.

To perform a FAST exam, the operator, using a low-frequency (2.0–5.0 MHz) phased array or curvilinear probe, images the hepatorenal and splenorenal spaces in the coronal axis. Ascites appears as a hypoechoic collection within the space. Blood accumulates in these spaces as they are dependent in position when the patient is supine. The operator then images the pelvic area by placing the probe above the pubic bone in transverse scanning axis. The tomographic plane is angled into the pelvis to check for pelvic fluid collection.

Case 1 ▪ Video 19.1 shows fluid collection in the hepatorenal recess of the Case 1 patient. There was no detectable pelvic fluid.

▪ Video 19.2 shows an example of absence of fluid in the hepatorenal space.

▪ Video 19.3 shows an example of pelvic fluid collection.

▪ Video 19.4 shows an example of prehepatic fluid collection.

▪ Video 19.5 shows an example of fluid collection in splenorenal and presplenic spaces.

In the trauma patient, all of these examples except for ▪ Video 19.2 would be considered a positive FAST exam.

As a standard approach to thoracic trauma, the critical care team extended the ultrasonography examination to include the thorax. The extended FAST (eFAST) exam includes evaluation for pneumothorax, intrapleural blood, and hemopericardium. It can be performed rapidly with the patient in supine position [12]. If any component of the examination is positive, the team may need to take immediate action (e.g., chest tube insertion, emergency thoracotomy). If the initial examination is negative, further imaging, such as computerized tomography or serial FAST examinations, may be indicated.

In the supine trauma patient, ultrasonography evaluation for pneumothorax can be performed rapidly and is superior to standard chest radiography when chest computerized tomography (CT) scan is used as the "gold standard" [13]. Ultrasonography has similar operating characteristics as chest CT for this application with the added advantage of speed and bedside utility with no need to transport the critically ill patient to the CT scanner. In the context of thoracic trauma, this finding of absent lung sliding is an indication for insertion of a pleural drainage device, particularly if there is clinical concern for a tension pneumothorax.

There are several characteristics of a pneumothorax that can be identified via US. The presence of lung sliding indicates that there is no pneumothorax with 100% negative predictive value at the site of the probe at the chest wall. The presence of B lines, lung consolidation, or pleural effusion rules out the pneumothorax at the site of the probe at the chest wall. The absence of lung sliding is consistent but not diagnostic for a pneumothorax [14]. With ultrasonography, multiple interspaces can be examined in a short period of time. In the case of thoracic trauma, absence of lung sliding, barring alterative explanation is strong evidence for a pneumothorax. The presence of a lung point is diagnostic of a pneumothorax. This finding may be difficult to detect; so, while 100% specific for pneumothorax, its absence does not rule out pneumothorax [15].

Following evaluation for pneumothorax, the operator then examines the posterolateral thorax for blood. The presence of a pleural effusion in a patient with thoracic trauma is assumed to be a hemothorax. Intervention is predicated on the clinical condition of the patient. A large pleural effusion with internal echogenicity is consistent with acute hemorrhage and may warrant urgent thoracotomy for source control.

The extended FAST exam concludes with a subcostal long axis view of the heart to rule out hemopericardium. This comes under the definition of echocardiographic evaluation of shock and will not be reviewed in this chapter.

Case 1 ▪ Video 19.6 shows the presence of lung sliding which was present bilaterally thereby ruling out pneumothorax in this Case 1 patient.

▪ Videos 19.7 and 19.8 show an example of absent lung sliding and the presence of lung point, respectively, the former being consistent with pneumothorax and the latter being diagnostic of pneumothorax.

Case 1 Video 19.9 shows a large left-sided pleural effusion which has a swirling echogenic pattern ("hematocrit sign") characteristic of an acute hemothorax in the Case 1 patient. The descending aorta has a dissection and perforation which explains the acute hemothorax.

In this Case 1 patient, based upon the results of the ultrasonography examination, the trauma team performed an immediate left-sided thoracotomy and was able to cross-clamp the aorta with immediate source control followed by successful repair of the aortic injury. Based upon the identification of intraabdominal fluid, the patient also underwent exploratory laparotomy, which identified bowel injury with successful repair.

Case 1 provides an example of the utility of ultrasonography to detect an imminently life-threatening cause for shock in the form of internal bleeding that was not readily detected by physical examination.

Clinical Case 2

This is a 54-year-old male patient, who presents with massive recurrent ascites due to hepatic cirrhosis complicated by portal hypertension. Several hours following a routine high-volume paracentesis, he develops hypotension. The critical care team performs immediate abdominal ultrasonography.

Severe bleeding from injury due to an aberrantly positioned vascular structure or inadvertent injury of a normally positioned vessel is an occasional complication of paracentesis.

Case 2 Video 19.10 shows ascites with a sedimentation effect in the Case 2 patient. Typical of peritoneal bleeding is that the red cells by gravitational effect sediment in dependent fashion. If the patient remains inactive, the sedimentation effect yields a linear interface between the echoic red cell collection and the anechoic plasma component of blood. This has operational consequence. A diagnostic paracentesis will show a paucity of red cells if the fluid is sampled from the anechoic area (i.e., plasma), thereby confusing the clinical team. To avoid a false-negative result, the paracentesis is performed when the patient has been moved sufficiently to assure uniform distribution of red cells within the fluid.

Sekiguchi et al. [16] described a case of lethal peritoneal bleeding following laceration of an inferior gastric vein after a paracentesis in which ultrasonography was not used to guide the procedure. They propose a measure to improve the safety of paracentesis. Ultrasonography, using a low-frequency phased-array or curvilinear probe, identifies a safe site, angle, and depth for needle insertion. The site is then scanned with a high-frequency linear vascular probe with doppler to detect any blood vessels that would contraindicate needle insertion. The color doppler examination is straightforward and adds little time to the procedure.

In the Case 2 patient, an urgent interventional radiology procedure was able to stop the bleeding with embolization of an aberrant peritoneal vessel.

Clinical Case 3

A 45-year-old female patient presents with a recurrent pleural effusion due to breast cancer. Several hours following a routine therapeutic thoracentesis, the patient develops dyspnea and hypotension. The critical care team performs immediate thoracic ultrasonography exam.

As with paracenteses, thoracenteses can be complicated by severe bleeding from an aberrantly positioned vascular structure or inadvertent injury of a normally positioned vessel. This can be detected with characteristic findings on ultrasonography. Unlike trauma, where blood loss can be rapid, bleeding from a peritoneal or intercostal vessel presents in a delayed fashion – often hours after the procedure. Ultrasonography allows for immediate identification of this form of internal blood loss.

Severe bleeding from injury to an intercostal vessel is an occasional complication of thoracentesis. The intercostal vessels are usually located along the inferior aspect of the ribs. However, these vessels may be tortuous, and collaterals can cross the proposed thoracentesis site especially in elderly patients. Several studies have examined the position of intercostal vessels with patients and human cadavers. There is significant variability of vessel position in the posterior medial thorax, so the operator avoids needle insertion within 10 cm of the posterior midline [17–19].

Kanai and Sekiguchi [20] described severe pleural bleeding after injury to an intercostal artery during a seemingly uncomplicated thoracentesis. As with paracentesis, they proposed the use of color doppler to identify aberrantly positioned intercostal vessels. Ultrasonography is used to identify a safe site, angle, and depth for needle insertion. The site is then scanned with a high-frequency linear vascular probe using color doppler to detect any vascular structure that would contraindicate needle insertion. If an aberrant vessel is identified, then the insertion site can be adjusted accordingly.

Case 3 ◘ Video 19.11 shows a discrete, mobile, homogeneous, and hypoechoic structure that has the typical appearance of an intrapleural thrombus. Because of the delayed presentation, the blood had sufficient time to clot with the resultant thrombus. The examination included evaluation for pneumothorax in order to rule out delayed presentation of a tension pneumothorax. In the Case 3 patient, lung sliding was present at multiple sites on the thorax, thereby ruling out pneumothorax. An urgent interventional radiology procedure was able to stop the bleeding with embolism of an intercostal vessel.

In Case 3, the cause of the shock state was from blood loss into the pleural space. Without bleeding, large pleural effusions have been implicated as a cause for shock, the presumed mechanism being due to cardiac chamber compression with tamponade physiology [21, 22].

Clinical Case 4

This 57-year-old male patient presents with hypotension and an acute reduction in hemoglobin level following initiation of low molecular weight heparin for pulmonary embolism. In association with treatment, the critical care team performed an immediate ultrasonography exam.

When the cause for bleeding is not readily apparent from history and physical examination, the operator uses ultrasonography to examine for cryptic sources. Potential sites include retroperitoneal, gastric, or bladder bleeding.

To examine for retroperitoneal bleeding, the operator examines the posterior flank area bilaterally using the low-frequency phased-array or curvilinear probe with the tomographic plane oriented in longitudinal scanning axis. The tomographic plane is adjusted to achieve a coronal axis view of the retroperitoneum, which is posterior to the peritoneal compartment, containing the intestinal structures. Patient-specific factors such as body habitus, dressings, and difficulty with positioning the probe may degrade image quality. In these cases, abdominal CT is superior to ultrasonography for detection of a retroperitoneal bleed.

Case 4 ◘ Video 19.12 shows a fluid collection within the retroperitoneum with a sedimentation effect that is characteristic of blood collection.

In the Case 4 patient, an urgent interventional radiologic procedure was able to stop the bleeding with embolism of a culprit vessel.

The following videos show other situations of unexplained hemorrhagic shock. ◘ Video 19.13 shows an example of gastric blood collection. ◘ Video 19.14 shows an example of blood collection in the bladder.

Clinical Case 5

This 82-year-old female patient presents with hypotension and abdominal pain. Six months before admission, the patient had an aortic abdominal repair with insertion of a graft.

Vascular injury with internal bleeding may occur acutely from an aortic aneurysm leak or as a late complication of vascular surgery. Aorto-duodenal fistula is a well-described though rare delayed complication of aortic aneurysm repair [23]. Graft failure with bleeding from the site is also a possibility.

Case 5 ▶ Video 19.15, taken with a phased-array probe placed in the abdominal midline using a transverse scanning plane, shows an aortic aneurysm with a double-lumen graft within it. Case 5 ▶ Video 19.16 using color doppler shows blood flow within the graft and through the wall of the graft into a periaortic collection.

In Case 5, the patient required emergent surgical repair of the leaking graft. There was a large aortic pseudoaneurysm.

Ultrasonography has utility for identification of the source of infection in the patient with septic shock. As with standard chest radiographs and CT scans, ultrasonography findings are integrated into the results of the history, physical examination, and laboratory values thereby allowing the clinician to establish a diagnosis.

Clinical Case 6

This 29-year-old male patient presented with hypotension, fever, and tachycardia. The presentation was consistent with septic shock. Following the early use of appropriate antibiotics and hemodynamic management, the critical care team performed a whole-body ultrasonography examination.

Thoracic (pleural and lung), abdominal, and soft tissue ultrasonography may identify the source for sepsis. This information may be used to refine antibiotic selection, obtain diagnostic material, and achieve source control.

Ultrasonography is superior to standard chest radiography for identification of lung consolidation and parapneumonic effusion and is similar to chest CT scan for these applications [24, 25]. It is also useful for identification of a variety of intraabdominal infections such as liver abscess, cholecystitis, ascending cholangitis, complex ascitic collections, and pyelonephritis. Soft tissue abscess is readily found with ultrasonography as are fluid collections within joint spaces. In addition to identification of the source, ultrasonography is used to guide aspiration of diagnostic material and intervention for source control.

Case 6 ▶ Video 19.17 shows a liver abscess in the Case 6 patient. The study was performed using a phased-array probe to examine the right upper quadrant. The abscess is identified as a round structure in the liver with heterogeneous echogenicity pattern including hyperechoic foci representing air within the abscess cavity.

In the Case 6 patient, the patient had a drainage catheter inserted, which guided final antibiotic selection based upon culture results and was a key component of successful resolution of the sepsis.

▶ Videos 19.18, 19.19, 19.20, and 19.21 are examples of lung consolidation, infected septated pleural effusion, emphysematous pyelonephritis, and a soft tissue abscess, respectively. These findings had impact on the management of septic shock in terms of antibiotic choice, diagnostic material, and source control.

Practical Implications

While echocardiography is a key component for the diagnosis and management of shock, other aspects of ultrasonography have utility for identification of the cause of hemodynamic failure. By utilizing a methodical ultrasonography exam (e.g., WBU and FAST exams), the examiner can evaluate for source of hemorrhage or source of septic shock.

Clinical Protocol
When the critical care clinician evaluates the patient with shock, ultrasonography may be useful in identifying a source for shock that is independent of the echocardiography evaluation. The components of WBU approach include a search for occult blood loss within intraabdominal, intrathoracic, bladder, retroperitoneal, intraperitoneal spaces and for site of infection as the source of septic shock.

Conclusions

Echocardiography is the primary method for evaluating the patient with shock. It is useful to supplement echocardiography assessment with other aspects of ultrasonography. These include detection of occult hemorrhage and source of sepsis.

Take-Home Messages

- Ultrasonography examination is useful in assessing the trauma patient for bleeding into the abdomen or pleural space. The use of ultrasonography in trauma has been codified into the FAST and extended FAST exam that is in widespread use by trauma teams.
- Ultrasonography examination is useful in assessing for internal bleeding that results in hemorrhagic shock in the non-trauma patient. Blood can be detected in the peritoneal and pleural spaces as a complication of paracentesis or thoracentesis. Blood loss into the retroperitoneum, bladder, and stomach and as a result of vascular injury can be detected with ultrasonography. Identification of bleeding source may lead to lifesaving interventions.
- Ultrasonography is useful in the detection of a source of infection in the patient with septic shock. Identification of the source for infection allows for appropriate antibiotic selection, sampling for accurate bacteriologic analysis, and intervention for source control.

Conflicts of Interest Becky Lou MD and Paul H. Mayo MD have no conflicts of interest regarding the content of this chapter.

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