Diagnostic Emergency Ultrasound: Assessment Techniques In The Pediatric Patient

Abstract

Emergency ultrasound is performed at the point of care to answer focused clinical questions in a rapid manner. Over the last 20 years, the use of this technique has grown rapidly, and it has become a core requirement in many emergency medicine residencies and in some pediatric emergency medicine fellowships. The use of emergency ultrasound in the pediatric setting is increasing due to the lack of ionizing radiation with these studies, as compared to computed tomography. Utilizing diagnostic ultrasound in the emergency department may allow clinicians to arrive at a diagnosis at the bedside rather than sending the patient out of the department for another study. This issue focuses on common indications for diagnostic ultrasound, as found in the pediatric literature or extrapolated from adult literature where pediatric evidence is scarce. Limitations, current trends, controversies, and future directions of diagnostic ultrasound in the emergency department are also discussed.
Case Presentations

You are working in a small community ED on an overnight shift. It is 2:00 AM, and an 8-year-old boy with no significant past medical history arrives with his parents after 2 days of abdominal pain and vomiting that has worsened over the past 24 hours. They deny fever or a change in his bowel movements. His triage vital signs are normal, other than a temperature of 37.8°C. He is lying on the stretcher, reluctant to move. His head and neck, cardiac, respiratory, and skin examinations are all normal. His abdominal examination reveals a soft abdomen, with tenderness at McBurney point and a positive Rovsing sign. You believe your patient has appendicitis. Your practice is to send the patient for an ultrasound as the first diagnostic test; however, ultrasound is not available overnight at your hospital. You want to avoid radiation exposure for this child, but you also want to quickly disposition the patient to the operating room if appendicitis is confirmed. You order basic laboratory work, a urinalysis, intravenous morphine, ondansetron, and normal saline to relieve the patient’s symptoms. You consider performing a bedside emergency ultrasound…

While discussing the plan for an ultrasound to assess for appendicitis in your patient, you are called overhead to the resuscitation room. On arrival, visibly concerned EMTs are placing a 3-year-old girl on a stretcher. She is in extreme respiratory distress. Her parents say that she had a “cold” for 10 days. Over the last several days, she developed progressively increasing difficulty breathing. For the last 2 days, she has been crying more than usual and today had a sudden increase in respiratory distress as well as increasing lethargy. Her parents called the ambulance when they found her difficult to arouse. On your initial assessment, you note that she only moans in response to stimulation, and she has markedly increased work of breathing, with intercostal retractions and nasal flaring, despite being on a nonrebreather mask. Her peripheral pulses are weak and thready, and her capillary refill is 5 seconds. She is placed on a cardiac monitor, and has the following vital signs: temperature, 37.3°C; blood pressure, 50/20 mm Hg; heart rate, 170 beats/min; respiratory rate, 50 breaths/min; and oxygen saturation, 98% on nonrebreather mask. The nurses place 2 intravenous lines and draw laboratory tests. The physical examination reveals clear lungs. You cannot appreciate heart sounds, but note jugular venous distention and hepatomegaly. You order a portable chest x-ray, ECG, and a 20-cc/kg bolus of normal saline. You consider cardiac tamponade as your most likely diagnosis and would like an echocardiogram performed as soon as possible to confirm the diagnosis. However, you also believe the patient may be too unstable to wait for the on-call cardiologist to arrive. While the fluid bolus is being administered and you are awaiting the other studies, you consider an emergency ultrasound for immediate diagnosis.

Introduction

Over the last 2 decades, the use of ultrasound by emergency clinicians, as well as other specialists at the point of care, has become increasingly common. Emergency ultrasound can be used as a diagnostic test and also to visualize anatomy for procedural guidance. It allows the emergency clinician to rapidly rule in or rule out disease processes and guide ongoing investigation and management of patients in the emergency department (ED). It is a skill required by the Accreditation Council for Graduate Medical Education for emergency medicine residency training, and it is supported by many organizations, including the American Medical Association, the American Academy of Pediatrics, the American College of Emergency Physicians (ACEP), the American Board of Emergency Medicine, and the American Institute for Ultrasound in Medicine.

Pediatric emergency ultrasound has been slower to progress than adult emergency ultrasound. Of the 95 emergency ultrasound fellowships currently listed on the Emergency Ultrasound Fellowships website (www.eusfellowships.com), only 5 are pediatric-specific. However, the pediatric patient is arguably more suited for emergency ultrasound than the adult patient. Children generally have a smaller body habitus than adults and, therefore, less tissue for the ultrasound beams to penetrate. This often leads to clearer images of the different organ systems, which should yield better diagnostic accuracy. There are sparse data to support this, however, due to a lack of comparative studies of the populations. The largest meta-analyses pool together adult and pediatric patients without assessing the diagnostic accuracy of this testing separately in adults and children, even for the most basic emergency ultrasound technique, the focused assessment with sonography in trauma (FAST) examination.

Children are an ideal target population in which to increase the use of emergency ultrasound. Exposure to ionizing radiation from computed tomography (CT) scans may lead to an increased incidence of cancer. Pediatric cells divide at a faster rate than adult cells, and, therefore, pediatric patients have a greater risk of harm from ionizing radiation as compared to adults. The number of CT scans performed overall has increased 5-fold over the last 20 years, and it is widely believed that we will see an increased incidence of cancer directly linked to medical imaging. One large retrospective epidemiological study found a small, but significant, increase in cancer related to CT scanning in the first decade of life. The study predicted that there would be 2 cases of excess cancer (cancer that would not have occurred without the CT scans) per 10,000 CT scans in the decade following the first CT scan in patients aged < 10 years. With an estimated 4 mil-
Ultrasound has been shown to have a high diagnostic accuracy for many pathologies, without the associated risks of ionizing radiation. Diagnostic ultrasound in pediatric patients has been traditionally in the domain of pediatric radiologists and technicians who are skilled in the interpretation of ultrasound for pediatric-specific pathologies. Many centers do not have access to pediatric radiologists or do not have access to pediatric ultrasound during evening and night hours. These centers generally transfer pediatric patients who need medical and surgical care to tertiary care centers with pediatricians and pediatric surgeons. If the emergency clinician can make or rule out a diagnosis at the bedside, transfer to the appropriate facility can be expedited and unnecessary transfers avoided.

Critical Appraisal Of The Literature

A literature search was performed in PubMed to identify relevant articles pertaining to each of the modalities discussed, utilizing combinations of the following search terms: diagnostic emergency ultrasound, pediatric, cardiac, pericardial effusion, tamponade, cardiac arrest, ejection fraction, focused assessment with sonography in trauma, FAST, pelvic trauma, extended focused assessment sonography in trauma, E-FAST, skull, lung, abdominal, appendicitis, intussusception, pyloric stenosis, cholecystitis, testicular torsion, and pregnancy. Original research, systematic reviews, and meta-analyses were the primary literature reviewed. If there was a lack of original research, case reports and case series were evaluated and presented. Additionally, previous reviews were used to identify relevant literature. Critical appraisal for specific indications will be discussed the relevant sections.

Before pediatric data became available, most of the evidence for the utility of pediatric emergency ultrasound was derived from adult literature and applied to the pediatric patient. However, there are important differences in the efficacy of pediatric emergency ultrasound compared to adult emergency ultrasound. While the FAST examination is the most widely used and accepted emergency ultrasound modality in adults, its diagnostic accuracy in children has been shown to be poor.2,14 There are also pediatric-specific applications, such as hypertrophic pyloric stenosis and intussusception, that require pediatric data. Therefore, pediatric-specific data are crucial for the growth of emergency ultrasound in the pediatric setting. Such data are needed before emergency ultrasound modalities that may be standard in the adult population can be safely recommended for children. Fortunately, the emergency ultrasound field is growing very rapidly, and more emergency ultrasound research is being explored than ever before. It is, therefore, expected that more pediatric emergency ultrasound data will be available in the near future. This issue will focus on the pediatric-specific emergency ultrasound literature. Where there is a paucity of pediatric data in the emergency setting, adult emergency ultrasound data or pediatric radiology data will be presented.

Prehospital Care

Ultrasound has been investigated for use in the prehospital setting. It is more widely used in Europe,15 but is only rarely used in this setting in North America.16 In a recent survey of emergency medical services (EMS) directors in the United States and Canada, the most common reasons for not implementing prehospital ultrasound were equipment and training costs, as well as a lack of evidence that it improves patient morbidity and mortality.16 Two systematic reviews, 1 for trauma and 1 for nontrauma, concluded that there was insufficient evidence that prehospital ultrasound improves patient outcomes.17,18 There are no randomized controlled trials in this area, and there are no studies in the pediatric setting in particular. Most of the studies are from the trauma setting and assessed patients of all ages, while some excluded pediatric patients.

Despite the lack of evidence on patient outcomes, there is evidence that ultrasound is feasible and accurate in the prehospital setting when performed by either physicians or nonphysician clinicians, especially in the context of trauma.18 Studies evaluating the feasibility of ultrasound included adult patients, and, therefore, may not reflect feasibility in pediatric patients. A prospective multicenter British study looked at FAST performed by EMS personnel and physicians on adults and children with suspected blunt or penetrating abdominal trauma. For the 202 patients completing the protocol, they found a sensitivity of 93% and a specificity of 99% as compared to hospital ultrasound or CT. Furthermore, prehospital management was altered in 30% of cases and the choice of admitting to hospital changed in 22% of cases.19 Of note, because FAST has been shown to be less accurate in pediatric patients as compared to adults and because the results of this study were not separated between pediatric patients and adult patients, the accuracy of FAST in this study cannot be extrapolated to the pediatric population. In a Korean study, FAST performed by EMS personnel was found to have a similar diagnostic accuracy compared to FAST performed by physicians.20 Lyon et al randomized a cadaver to tracheal or esophageal intubations to assess prehospital critical care clinician accuracy in the diagnosis of lung sliding on ultrasound. After a 9-month period without additional teaching, the prehospital clinicians maintained a sensitivity and specificity of 100%.21

Retrospective studies and case series have looked
at the use of prehospital ultrasound in the mass casualty setting, both for earthquakes and war zones. These reports use ultrasound as an adjunct to the Simple Triage And Rapid Treatment protocol in the prehospital setting and as an adjunct to clinical care in the hospital setting.\textsuperscript{22-26} In a report on an earthquake in China, patient statuses were successfully upgraded from yellow to red based on the FAST.\textsuperscript{25} However, whether or not ultrasound changes outcomes in this setting requires further study.

As noted earlier, there are fewer studies in the nontrauma setting and, again, none of the studies included pediatric patients. Breitkreutz et al performed a prospective study of emergency clinicians in Germany who performed focused cardiac ultrasound on 204 patients in cardiac arrest or in a severe shock state, to look for a reversible cause. They found ultrasound changed management in 78\% of cases.\textsuperscript{27} In Slovenia, Prosen et al performed a prospective study on 16 patients in a state of pulseless electrical activity (PEA) to differentiate patients with cardiac contractility on ultrasound (pseudo-PEA) from patients without cardiac activity on ultrasound (PEA). Vasopressor administration was given based on the results of their ultrasound.\textsuperscript{28} The authors found a significant improvement in return of spontaneous circulation and good neurological outcome as compared to a historical control. Prehospital lung ultrasound has been described as a diagnostic tool and for confirmation of tracheal intubation.\textsuperscript{29,30} However, a recent meta-analysis concluded that the studies were too heterogeneous to make firm conclusions on the utility of prehospital medical ultrasound on patient outcomes.\textsuperscript{17}

Emergency Department Evaluation With Ultrasound

Cardiac Ultrasound

Echocardiography has long been used to improve the care of patients with cardiac pathologies as well as to monitor and manage hemodynamically unstable patients.\textsuperscript{31-33} Focused echocardiography is used by emergency clinicians and intensive care physicians to guide therapy. The 2014 International Conference on Focused Cardiac UltraSound by the International Liaison Committee on Focused Cardiac UltraSound strongly recommended that focused cardiac ultrasound should be used in pediatric patients in cardiac arrest as well as in the evaluation of cardiac function, pericardial effusion, relative chamber sizes, valvular dysfunction, and volume status. They determined the evidence to be of moderate quality.\textsuperscript{34}

Most of the data regarding the usefulness of point-of-care echocardiography in the pediatric setting are derived from case reports and case series.\textsuperscript{35} The studies involving focused echocardiography with noncardiologists performing the ultrasound are limited to the comparison between findings by emergency physicians or intensive care unit (ICU) physicians in comparison to an echocardiogram performed by a cardiologist. These studies showed that trained noncardiologists have excellent diagnostic accuracy when compared to cardiologists.\textsuperscript{36-39} Since echocardiograms performed by cardiologists change the management of pediatric patients with suspected and known cardiac disease or critical illness, trained noncardiologists may similarly perform focused echocardiograms to change the management of their patients.

Technique

Cardiac ultrasound is unique in that there are various imaging techniques that are specialty-specific. Pediatric patients being diagnosed with congenital heart disease for the first time are evaluated and managed differently from adults with known congenital heart disease. Adult cardiologists, pediatric cardiologists, and emergency clinicians have different conventions for probe positioning and orientation. The pediatric convention is “inverted” compared to the standard adult convention in some views. This orientation places the cardiac structures on the ultrasound screen in a more anatomically intuitive way, allowing for more precise definition of congenital cardiac abnormalities.\textsuperscript{34,40} Whichever technique is used to perform the examination, it should be internally consistent within the ED, so colleagues can adequately interpret the ED studies at any point and compare cardiac ultrasound assessments. The International Liaison Committee on Focused Cardiac UltraSound, therefore, recommends that pediatric emergency clinicians perform studies in the convention of pediatric cardiology, but emergency clinicians who care for both adult and pediatric patients may use the adult convention, for ease of use and learning.\textsuperscript{34} Use of the pediatric view does not necessitate changing the screen orientation. The ultrasound machine can have a preset pediatric cardiac ultrasound view, limiting the number of additional buttons that need to be pressed to obtain the appropriate screen orientation.

In pediatric-specific cardiac ultrasound, the views are complementary and at least 2 views in orthogonal planes should be obtained. While some clinical questions (such as left ventricular ejection fraction [LVEF]) may be adequately assessed in all views, not all clinical questions can be adequately assessed in all views. The specific views chosen should be the ones that answer the focused clinical question at hand. In some patients, not all views can be obtained. For example, in patients with a distended colon, air may interfere with the subxiphoid view. In cases where a specific view cannot be obtained, other views should be used to answer the clinical questions, such as assessment for pericardial effusion and left ventricular systolic dysfunction.
Subxiphoid View
The subxiphoid view is performed by placing the transducer just inferior to the xiphoid process and aiming the beam cephalad and anteriorly, with the probe marker to the patient’s left side. The image on the screen should be inverted compared to the adult views, such that the apex of the image should be at the bottom of the screen. (See Figure 1.) This view can be used to assess LVEF and right ventricle (RV)-to-left ventricle (LV) ratios in the assessment of pulmonary embolism. While this view is useful in ruling out pericardial effusion, a pleural effusion may be mistaken for a pericardial effusion in this view, and any evidence of a pericardial effusion should be confirmed using another view. This view is ideal for a patient in cardiac arrest, as no gel is left on the chest to interfere with chest compressions.

Apical 4-Chamber View
The apical 4-chamber view is also “inverted” as compared to the adult orientation. The probe is placed at the cardiac apex, typically where the point of maximal impulse is felt, and pointed toward the base of the heart. The probe marker should be facing the left side of the patient. The probe might need to be adjusted slightly, such that the interventricular septum and the interatrial septum are oriented as a vertical line on the screen. (See Figure 2.) This view is best to assess for RV-to-LV ratios, but can be used to address any of the...
basic clinical questions, such as assessment for pericar-
dial effusion and left ventricular systolic dysfunction.

Parasternal Long-Axis View
The parasternal long-axis view is performed in the
same manner in children as it is in adults. The probe
is placed on the third or fourth intercostal space. In
the traditional emergency medicine orientation, the
screen marker is on the left side of the screen and the
probe marker is pointed to the patient’s left hip. If
the screen marker is on the right (in the traditional
cardiology orientation) the probe marker is pointed
toward the right shoulder. (See Figure 3.) This view is
best for assessment of a pericardial effusion. Because
pericardial fluid moves posteriorly in the supine

Parasternal Short-Axis View
The parasternal short-axis view is best obtained by first
obtaining a parasternal long-axis view and rotating the probe 90°
clockwise, such that the probe marker is facing the patient’s right hip (in the
emergency medicine orientation) or the left shoulder
(in the cardiology orientation). (See Figure 4.) The
parasternal short axis can be viewed at 4 cardiac

Figure 3. Cardiac Ultrasound In The
Parasternal Long-Axis View

Image is in the traditional cardiology orientation.
Abbreviations: Ao, aortic outflow tract; LA, left atrium; LV, left ventricle;
RV, right ventricle.
Photo used with permission from Bret Nelson, MD.

Figure 4. Cardiac Ultrasound In The
Parasternal Short-Axis View, Mitral Valve
Level, In The Cardiology Orientation

Image is in the traditional cardiology orientation.
Abbreviations: LV, left ventricle; RA, right atrium; RV, right ventricle.
Photo used with permission from Bret Nelson, MD.
levels: the aortic valve level, the mitral valve level, the papillary muscle level, and the apex. The mitral valve and papillary muscle levels are the most commonly obtained, and either may be used in answering all of the basic clinical indications.

**Other Cardiac Views**
Other cardiac views (such as the right parasternal view and the suprasternal view) are not typically used in the focused cardiac ultrasound, but may be helpful when looking for congenital cardiac anomalies.  

**Indications For Cardiac Ultrasound**

**Pericardial Effusion And Tamponade**
The assessment of pericardial effusion is historically one of the first indications for emergency cardiac ultrasound. A pericardial effusion is diagnosed when an anechoic or hypoechoic layer is seen between the pericardium and myocardium on any cardiac view. (See Figure 5.)

The parasternal long-axis view is considered to be the most accurate in the diagnosis of pericardial effusion, as it can differentiate between pleural and pericardial fluid. If the fluid is anterior to the thoracic aorta, it is pericardial fluid. (See Figure 6.)

A study of 384 patients showed that concordance was excellent between focused cardiac ultrasound performed by pediatric emergency clinicians or by pediatric intensivists and echocardiographers after the emergency clinicians and intensivists had each performed 24 ultrasound studies. There were several cases of missed pericardial effusions; however, these were all deemed small and not clinically relevant.  

Furthermore, multiple studies have shown that noncardiologists as well as novice learners can identify pericardial effusions with a diagnostic accuracy comparable to echocardiographers.  

In the largest study on emergency physicians performing bedside cardiac ultrasounds, sensitivity and specificity were 96% and 98%, respectively.  

The most recent study looking at the performance of cardiac ultrasound by novice sonographers found a sensitivity and a specificity of 100% and 99%, respectively.  

Of note, there are studies in the literature showing poorer sensitivities, of approximately 60%; the missed pericardial effusions were all small and would likely not have changed clinical management in the emergent setting.  

The diagnosis of cardiac tamponade with cardiac ultrasound is more difficult. The ability of general emergency clinicians to accurately detect ultrasound evidence of tamponade has never been formally studied, but the protocol has been described.  

The diagnosis of cardiac tamponade is typically made with an emergency ultrasound showing a pericardial effusion in the context of a hemodynamically unstable patient. Indeed, cardiac tamponade still remains a clinical diagnosis and not an echocardiographic one. It is important to emphasize that the size of the pericardial effusion does not necessarily correlate with tamponade. For example, in a patient
with penetrating chest trauma, tamponade may be seen with a small pericardial effusion, as the rapid accumulation of hemopericardium does not allow the pericardium to expand to accommodate the extra fluid. Conversely, a large pericardial effusion that has accumulated slowly may not cause tamponade.

**Assessment Of Left Ventricular Ejection Fraction**

LVEF is an important consideration when evaluating a patient who is short of breath, especially in the context of known congestive heart failure or congenital heart disease, and in the hemodynamically unstable patient. Although congestive heart failure is rare in the pediatric patient, sepsis is also known to cause myocardial depression. Cardiac dysfunction can be a contributing factor in the hemodynamic instability of patients in septic shock. If cardiac dysfunction is identified, an inotropic may be added to target therapy to a potential cause of the hemodynamic compromise and possibly improve patient outcomes. A small retrospective study evaluated children with septic shock in the pediatric intensive care unit (PICU) using point-of-care ultrasound. They found that ultrasound changed management and that shock resolved more readily in patients with cardiac dysfunction in whom inotropic therapy was added. Bedside assessment of LVEF in children is strongly recommended in the focused cardiac ultrasound international consensus guidelines.

LVEF can be assessed in a visual, qualitative manner, as well as a quantitative manner. The qualitative method involves assessing the LV during systole for: (1) relative motion of the endocardium, (2) thickening of the myocardium, and (3) approximation of the anterior leaflet of the mitral valve toward the interventricular septum. There are numerous quantitative methods that are complex and require a cardiac calculation package to be installed on the ultrasound machine. These methods, described in most echocardiography texts, are beyond the scope of this review.

Results obtained from the 2 methods correlate closely to each other. The qualitative method is generally thought to be easier and faster to perform; however, both methods are considered valid. Small differences in ejection fraction that are important when following a patient over the long term are less important in the acute setting. In contrast, broad functional categories such as normal, hyperdynamic, moderately hypodynamic, and severely hypodynamic are more important in assessing whether or not the LVEF is contributing to the patient’s clinical presentation. Echocardiography by both pediatric and general emergency clinicians has been shown to be accurate when compared to standard echocardiography for assessing broad categories of LVEF. Multiple studies have shown substantial agreement with cardiologists. This applies both for the novice and the more experienced sonographer.

**Cardiac Arrest**

The use of cardiac ultrasound intra-arrest has become a mainstay in the evaluation of the adult cardiac arrest patient. It can readily identify reversible causes, such as cardiac tamponade, massive pulmonary embolism, and severe hypovolemia. In adult patients with PEA, ultrasound can differentiate between patients with pseudo-PEA and patients with PEA. This can both direct treatment and, as shown in a meta-analysis, be a predictor of return of spontaneous circulation and survival.

In pediatrics, there are little data on ultrasound in cardiac arrest, and its use is extrapolated from adult studies. It can potentially be used to rule in or rule out reversible causes. It can also be used to confirm cardiac standstill, as palpation of pediatric pulses is unreliable, with an accuracy of only 78%. The cardiac ultrasound should not be definitively relied on in the prognosis of children in cardiac arrest. Though sonographic cardiac standstill may suggest a poor prognosis, there are no data to support this, and it should not be used as the sole reason to terminate resuscitation efforts.

**Future Applications**

The identification of certain common congenital abnormalities (such as coarctation of the aorta and patent ductus arteriosus) is feasible and can potentially be used to rule in congenital cardiac disease when the emergency clinician is evaluating a patient in a setting without access to pediatric cardiology. Furthermore, if emergency clinicians can obtain the appropriate views, telemedicine could potentially connect emergency clinicians with pediatric cardiologists remotely. This could assist in managing patients in whom a cardiac ultrasound is key to appropriate diagnosis and management, such as in the cyanotic neonate.

Cardiac ultrasound could also be used more consistently in cases of cardiac arrest in pediatric patients. A large multicenter retrospective study could shed light on the intra-arrest applicability as well as the prognosis of patients with and without cardiac activity on ultrasound. Perhaps intra-arrest ultrasound will play a critical role in pediatrics in the future as it now does in adults.

**Link To Cardiac Ultrasound Video**

To view a video on cardiac ultrasound, scan the QR code with a smartphone or go to [https://www.youtube.com/watch?v=x8XUST-iNJM](https://www.youtube.com/watch?v=x8XUST-iNJM)
Trauma
Historically, the first application of portable emergency ultrasound was to assess blunt abdominal trauma. The success of this led to further applications of emergency ultrasound, especially in the context of trauma. The FAST examination has since become the extended FAST, or E-FAST, and includes lung windows in the ultrasonographic assessment of the trauma patient.

FAST
The FAST examination is performed in patients with abdominal or chest trauma. It includes 3 abdominal windows and 1 cardiac window. The 3 abdominal views include views of the Morison pouch, the perisplenic space, and the pelvis. (See Figures 7 and 8, and Figure 9, page 10.) The result of the FAST examination is either positive or negative. A FAST examination is positive when free fluid (which is anechoic on ultrasound) is seen on any of the aforementioned views. The FAST examination is negative when no free fluid is seen.

The cardiac view was traditionally a subxiphoid view using the same low-frequency curvilinear probe as the abdominal views. (See Figure 10, page 10.) However, the subxiphoid view can be substituted with any of the other cardiac views previously described, as the other views will also identify cardiac changes.

There are robust data on the diagnostic accuracy of the FAST examination in pediatric patients that indicate that it is not as sensitive as in adults. A 2007 meta-analysis including 25 prospective and retrospective studies evaluating almost 4000 patients determined a sensitivity of 66%, a specificity of 95%,
Due to its poor sensitivity, studies have looked at uses for the FAST examination in combination with either other predictors or as a step in a diagnostic pathway. Sola et al performed a retrospective chart review of 3171 cases of blunt abdominal trauma and found that by combining FAST with liver function tests, sensitivity improved to 88%. Van Schuppen et al recently performed a retrospective chart review of a single Dutch hospital’s protocol in evaluating patients with blunt abdominal trauma. The protocol had all trauma patients receive a FAST examination. If no free fluid was found and they were hemodynamically stable, they were either observed or discharged without further testing. If free fluid was found, patients underwent a CT scan or surgery, depending on hemodynamic status. Therefore, it has been recommended that FAST should not be used as the sole test in excluding intraperitoneal injury in the evaluation of blunt abdominal trauma in children. However, given its high specificity, a positive FAST examination can guide emergency clinicians to send hemodynamically compromised children who are refractory to fluid and blood administration directly to the operating room after consultation with a surgical specialist.

Figure 9. Pelvic View In The FAST Examination

Abbreviation: FAST, focused assessment with sonography in trauma. Photo used with permission from Bret Nelson, MD.

Figure 10. Subxiphoid Cardiac View In The FAST Examination

Abbreviations: FAST, focused assessment with sonography in trauma; LV, left ventricle; RV, right ventricle. Photo used with permission from Bret Nelson, MD.
patients who were studied, the authors found a sensitivity of 83%, and 54% of patients were discharged. Only 1 patient failed the protocol. This patient was initially observed and deteriorated in hospital, requiring intervention. The authors, unfortunately, did not mention the change in CT scan use from before and after the protocol was implemented, as this could have solidified their argument that CT use can be decreased when patients are first evaluated with the FAST examination. Though the sensitivities in these studies were better, the data are not robust enough nor are the sensitivities high enough to apply these protocols more broadly.

Due to concerns about ionizing radiation, researchers continue to find support for methods to decrease the number of CT scans performed on pediatric patients. Recently, Menaker et al performed a secondary analysis of patients with blunt abdominal trauma in the Pediatric Emergency Care Applied Research Network (PECARN). They found that, in low-risk patients, a negative FAST examination decreased the likelihood that pediatric surgeons would order a CT scan. In a prospective study by Scaife et al looking at a similar population, the investigators asked surgeons, after performing a history and physical examination but prior to performing a FAST examination, if they would order a CT scan. After the FAST examination, they were asked if they would, theoretically, cancel the CT scan. In 48% of cases, the surgeons indicated that they would cancel the CT scan. Though these studies did not assess any particular protocol or intervention, it did show that surgeons are influenced by the results of the FAST examination.

The future of the FAST examination may be in using intravenous contrast to enhance its ability to detect organ injuries. Contrast-enhanced ultrasound has grown in popularity over the last 10 years, and has been performed in adult and pediatric settings. Several studies have compared contrast-enhanced ultrasound to conventional ultrasound and CT scan. Results from these studies show that contrast-enhanced ultrasound detects more injuries than conventional ultrasound. One study showed a sensitivity of 91% and a specificity of 100% compared to CT scan. These ultrasounds were all performed by radiologists. Whether the emergency clinician or the trauma surgeon would perform these examinations with similar accuracy is unknown.

The diagnostic accuracy of FAST examinations has been sufficiently evaluated. Large prospective studies are now needed to assess a diagnostic protocol incorporating the FAST examination as part of a clinical pathway in an effort to decrease CT use without missing any clinically significant injuries. Until that time, emergency ultrasound should be used for its specificity, but not its sensitivity. For additional information on the management of blunt abdominal trauma in children and the use of the FAST examination, see the October 2014 issue of Pediatric Emergency Medicine Practice, titled “Pediatric Blunt Abdominal Trauma In The Emergency Department: Evidence-Based Management Techniques,” available at: www.ebmedicine.net/pedsabdominaltrauma.

E-FAST

The E-FAST examination, as initially described, included the addition of anterior thoracic views to assess for pneumothorax, and has been extended further to include an assessment for hemothorax.

E-FAST To Detect Pneumothorax

To assess for pneumothorax, a high-frequency linear probe will give the best images; however, the low-frequency curvilinear probe may also be used for convenience, to avoid switching probes during the examination. If adequate images cannot be obtained using the curvilinear probe, then it is advised to switch to the linear probe. In the supine trauma patient, the probe is placed in the sagittal plane along the anterior chest, at approximately the third or fourth intercostal space at the midclavicular line on the right and left sides of the chest. An image showing 2 ribs and the pleural line just posterior is sought. (See Figure 11.)

The pleurae are then assessed for lung sliding (seen as shimmering) or movement of the visceral and parietal pleurae, as well as comet tail artifacts (short thin vertical lines emanating from the pleura). (See Figure 11.) The presence of these signs is normal,
whereas in a pneumothorax, these signs will be absent. Additionally, a lung point can be sought, which is found when there is a segment of pleura that has only partial lung sliding. This is the point where the visceral and parietal pleurae separate, and this finding can rule in pneumothorax. False-positive findings can occur in certain conditions when lung sliding will not be seen, despite the absence of a pneumothorax. These include main stem intubation, pulmonary contusion, acute respiratory distress syndrome, pleuritis, severe pulmonary fibrosis, phrenic nerve palsy, apnea, and bullous chronic obstructive pulmonary disease.

However, in an otherwise healthy trauma patient, especially one who is in severe respiratory distress and is hemodynamically unstable, the absence of lung sliding may be relied upon to diagnose pneumothorax.

There are, unfortunately, no pediatric data on the use of E-FAST in the assessment of pneumothorax; all data presented here are for adult patients. Diagnostic accuracy was best shown in a 2011 meta-analysis by Ding et al who pooled prospective and retrospective studies of lung ultrasounds and chest x-ray (CXR) for pneumothorax, and compared them to a gold standard of CT. The patient type was either traumatic, critically ill, or post biopsy. The data showed a pooled sensitivity of 88% and a pooled specificity of 99% for lung ultrasound, whereas CXR had a pooled sensitivity of 52% and a pooled specificity of 100%. The studies also found that accuracy increased with operator training, as more experienced sonographers demonstrated sensitivities consistently > 90%.

Two subsequent studies found similar diagnostic accuracy. They found that any missed pneumothoraces on emergency ultrasound were absent on CXR and were not immediately life-threatening.

E-FAST To Detect Hemothorax
Detection of hemothorax by E-FAST is completed with the same probe as the FAST examination. The scan is easily added on to the standard FAST examination, as the probe is held in the same manner for the right and left upper quadrant views. However, the probe is slid superiorly so that the clinician can assess the area above the diaphragm (the pleural space) for the presence of free fluid. Ultrasound can detect as little as 20 mL of pleural fluid, whereas CXR requires at least 175 mL for detection.

There are no pediatric-specific studies on the diagnostic accuracy of E-FAST for hemothorax. One study specifically mentioned including children, and included patients as young as 1 year old. Other studies either had no mention of age criteria or used only adult patients. The sensitivities ranged from 92% to 97.5%, with specificities ranging from 98.4% to 100%. The gold standard was tube thoracostomy results, clinical course, or CT scan. Of note, there was an outlying study that had a sensitivity of 12.5%. In this study, all included patients had a CT scan and all false-negative findings were in patients with very small hemothoraces that were not intervened upon or considered clinically relevant.

What is clear from all studies is that the sensitivity of ultrasound is superior to CXR, with similar specificity. The advantages of ultrasound over CXR include rapid, if not immediate, availability of results, a lack of radiation, and no need to have the treating team leave the patient’s side so that the CXR may be performed. Therefore, in adult patients, many emergency clinicians have abandoned CXR in the trauma bay and are, instead, using ultrasound. It is not yet known whether this practice may be safely used in pediatric patients.

Skull Fracture
Ultrasound can be used in the evaluation of children with blunt head trauma to assess for skull fractures. (See Figure 12, page 13.) The presence of a skull fracture increases the risk of traumatic intracranial hemorrhage 4- to 6-fold.

While the absence of a skull fracture does not rule out the presence of intracranial injury, assessment for skull fracture has been used by emergency clinicians to risk stratify patients with blunt head trauma. In a meta-analysis published in 2000, skull x-rays had a sensitivity of 38% and a specificity of 95% when interpreted by radiologists. Given this poor sensitivity, skull x-rays have been falling out of favor for assessment of skull fracture. However, there has been a renewed interest in skull ultrasound as perhaps a better tool to assess for skull fracture and to risk stratify patients.

Technique
Skull ultrasound is performed with a high-frequency linear array probe. The probe should be placed on the area of the skull with maximal tenderness, hematoma, or other sign of possible fracture. It should be scanned in 2 planes, looking for disruptions in the cortex. Sutures can be differentiated from fractures by following the cortical break to a fontanelle and by

Link To Video Of Trauma Ultrasound Of The Peritoneum

To view a video on ultrasound assessment of the peritoneum for free fluid, scan the QR code with a smartphone or go to:

https://www.youtube.com/watch?v=Ov2TiQJMpZ8
Lung Ultrasound

Given its ability to rapidly differentiate causes requiring different treatments, lung ultrasound has been increasingly utilized in adult patients with severe respiratory distress. The previous section described assessment of pneumothorax and hemothorax as part of a trauma assessment, and the same techniques can be employed in nontrauma patients as well. This section will focus on other applications of thoracic ultrasound in pediatric patients.

Technique

There are several assessment techniques used in lung ultrasound. One commonly used technique was described by Lichtenstein and Meziere as the Bedside Lung Ultrasound in Emergency (BLUE) protocol. It involves dividing each hemithorax into 3 sections: the anterior chest, lateral chest, and posterolateral chest. Each of these sections is divided into superior and inferior sections, giving 6 lung zones per hemithorax. A detailed description of the complete lung ultrasound is beyond the scope of this review; however, in brief, the pleural line in each of the lung zones is interrogated. In the normal lung, the pleural line is smooth and A lines are seen posterior (deep) to it. A lines are artifactual horizontal lines that appear below the pleura at depth intervals that are the same as the pleural depth itself, as these denote reflections of the pleura from the skin surface. B lines are vertical lines that begin at the pleural line and reach the bottom of the ultrasound screen. These artifactual lines denote interstitial lung fluid. Having 1 or 2 B lines may be normal, but a greater number is pathologic and carries with it a differential diagnosis. B lines seen acutely may be due to pneumonia, pulmonary edema, pulmonary contusion, or acute respiratory distress syndrome. B lines may be seen chronically in patients with pulmonary fibrosis.

Daniel Lichtenstein, the French intensivist who described these lung ultrasound findings, observed that neonates had similar ultrasound findings to adults. He based this on 3 years of observation of lung ultrasound applied in the neonatal ICU. In lung ultrasound studies, the gold standard is the CT scan, which is not often performed on many neonates. He therefore conceded that there is no hard proof for these similarities, but he did note that, in cases where CT scans were performed, CT findings correlated with lung ultrasound results, and he recommended using the bedside lung ultrasound in emergency protocols in the critically ill neonate.

Future Applications

The current trend in the evaluation and risk stratification of pediatric head trauma is the incorporation of clinical decision rules, with the PECARN rule being the most sensitive and most commonly used in the United States. An area of future research is the incorporation of skull ultrasound in conjunction with a clinical decision rule to better risk stratify patients and possibly further decrease the number of CT scans being performed.

Figure 12. Skull Fracture On Ultrasound

Used with permission from Mount Sinai Hospital, New York, NY.
Esposito et al studied Italian pediatric residents performing lung ultrasound for pneumonia. They enrolled 103 children and confirmed pneumonia in 48, with a sensitivity of 98% and a specificity of 94.5% in diagnosing pneumonia, with CXR being the reference standard (CXR had a sensitivity of 82% and a specificity of 94%). Reali et al enrolled patients admitted to the hospital with suspected pneumonia. The ultrasonographers were a pulmonologist and 2 residents experienced with lung ultrasound. This study was unique for nonradiologist assessments because it used a gold standard of a final clinical diagnosis of pneumonia made by an independent committee, whereas the other studies compared the results to CXR.

Though the size and number of studies in children is less than that of adults, preliminary studies suggest that lung ultrasound is noninferior to CXR. In most studies, ultrasound is less sensitive but more specific than CXR in the diagnosis of pneumonia. This is because ultrasound cannot evaluate deep to the pleural line, and, therefore, it will miss pneumonias...
Future Applications

Further research is required in this area. Most specifically, the clinical significance of a pneumonia found on ultrasound but not on CXR has not been evaluated. It is possible that pneumonias found only on ultrasound do not require antibiotics or that there is a certain characterization of a consolidation on ultrasound that is considered clinically significant and should therefore be treated. It is also possible that if only lung ultrasound is used, the decreased use of CXR will be matched by an increased use of antibiotics. Based on the data to date, it is reasonable to perform an ultrasound only if the pretest probability for pneumonia is already high, if CXR is not available, or if CXR is refused by a patient or parent, with the caveats mentioned previously.

Intravascular Volume Assessment

In adult patients, the collapsibility of the inferior vena cava (IVC) as well as the caval index are used in the assessment of volume status. Both qualitative and quantitative assessment of the IVC has been shown to correlate with central venous pressure (CVP) and can be used as a predictor of fluid status. On the extremes, a flat IVC or an IVC with respiratory collapse tends to predict hypovolemia and fluid responsiveness, whereas a distended, noncollapsing IVC often indicates a patient who will not be responsive to fluids.

The ability of IVC ultrasound to assess dehydration in pediatric patients is less well known. A study of 15 pediatric patients on hemodialysis, where a known quantity of fluid was removed, showed that IVC ultrasound is accurate in the assessment of volume status. Chen et al created a novel technique of measuring the IVC-to-aorta ratio in the assessment of fluid status in children. Their rationale was that since IVC and aorta size vary by age and since the aorta size remains constant in the setting of dehydration, then the IVC-to-aorta ratio may determine fluid status. In a subsequent study of 71 children presenting with gastroenteritis, they found that an IVC-to-aorta ratio of 0.8 had a sensitivity of 86% and a specificity of 54% for the assessment for severe dehydration. The gold standard was the change in weight when the patient was ill and in follow-up when symptoms had resolved. Levine et al assessed Rwandan children admitted with dehydration. They measured the aorta-to-IVC ratio upon admission to the hospital. Their gold standard for dehydration was an increase in weight of 10% from admission to discharge. They found that the aorta-to-IVC ratio had a sensitivity of 93% and a specificity of 59%. IVC collapse had a similar sensitivity, but a specificity of 35%. These were both better than the World Health Organization dehydration scale, which had a sensitivity of 73% and a specificity of 43%. Limits to the use of an IVC-to-aorta ratio is that it may vary with age in normal patients, and accurate normal values for specific age groups are not yet available.

Ng et al evaluated the IVC-to-aorta ratio as compared to CVP in patients in the pediatric ICU, the majority of whom were intubated (67%). They found a poor correlation between IVC-to-aorta ratio and CVP. This study is limited as compared to other IVC ultrasound studies, as the included patients were mechanically ventilated and had a high incidence of congenital cardiac disease. Furthermore, the gold standard used was CVP as opposed to clinical dehydration status. Therefore, the applicability to ED patients is questionable.

The IVC may also be dilated in patients who are dehydrated. Patients with chronic lung disease, pulmonary hypertension, or right ventricular pathology may have dilated IVCs even while dehydrated. In these patients, a very small, collapsed IVC can be a helpful data point in the overall assessment, but a dilated IVC cannot be interpreted to mean that the patient does not require rehydration.

Technique

The IVC is measured in the subcostal view, using the liver as an acoustic window. Measurements are taken at the point where the hepatic vein can be seen entering the IVC, or 2 cm distal to the cavoatrial junction. The IVC can be measured in the transverse or longitudinal plane. (See Figures 15 and 16, page 16.)

When performing an ultrasound to determine IVC-to-aorta ratio, measurements must be taken at the maximal diameter of the structures, as the diameter can vary with respiratory (IVC) or cardiac (aorta) cycles. This is facilitated by freezing the image and scrolling back through the previous frames (known as cine-loops).

The data are limited on the use of ultrasound in the assessment of volume status. While the IVC-to-aorta ratio is the most promising, there are limited studies in the standard pediatric ED patient. With the current data, IVC ultrasound cannot be recommended as the sole assessment for hydration status in children. Future studies should assess the use of IVC-to-aorta ratio to determine a cutoff for when intravenous hydration is determined to be unnecessary. An objective measurement of hydration status would benefit the emergency clinician who is con-
Consider whether to pursue intravenous hydration, a relatively invasive procedure in children.

**Abdominal Ultrasound**

Ultrasound is the first-line imaging test used by radiologists to evaluate for several common conditions associated with abdominal pain in children. Pediatric patients generally have little body fat and abdominal musculature and, therefore, have better acoustic windows.

**Indications For Abdominal Ultrasound**

**Appendicitis**

Ultrasound is recommended by the 2014 American College of Radiology guidelines as the most appropriate initial test in the evaluation of appendicitis in children. It was recommended by ACEP in 2010 as a modality to confirm, but not exclude appendicitis. Doria et al performed the most recent meta-analysis that separated pediatric and adult patients. They found that for pediatric patients, ultrasound performed by pediatric radiologists had a sensitivity of 88% and a specificity of 94% for appendicitis when compared to surgical findings and clinical outcome. The same meta-analysis found a CT scan to have a sensitivity of 94% and a specificity of 95%.

Given that ultrasound does miss some cases of appendicitis, some studies have looked at clinical and imaging pathways that utilize ultrasound as a first-line step in evaluation of pediatric patients. Krishnamoorthi et al performed a retrospective chart review on their hospital protocol that uses ultrasound as the initial imaging modality. In the protocol, only patients with an equivocal ultrasound underwent CT scan. In the 1228 patients on whom the protocol was applied, they found a sensitivity of 98.6% and a specificity of 90.6%. Notably, CT scan was avoided in 53% of patients with use of the protocol.

Saucier et al recently performed a prospective study at a single academic center. In their protocol, patients were initially evaluated using the pediatric appendicitis score, a clinical score used in the risk stratification of patients with possible appendicitis. Patients with a moderate risk were evaluated using ultrasound performed by pediatric radiologists. Ultrasound was assessed in a binary fashion, and ultrasounds could not be deemed equivocal. If the appendix was not visualized, then secondary signs were used to determine whether the ultrasound was positive or negative. CT was used only at the discretion of the pediatric surgeon. The results from their study showed a sensitivity of 92.3% and a specificity of 94.7% for the protocol. Most notably, the rate of CT use was 6.6%, with a negative laparotomy rate of 4.4%; negative laparotomy rates are normally reported to be between 15% and 25%. Several subsequent retrospective studies similarly found that if the clinical score was low or if clinical suspicion was low and an ultrasound that was performed by the radiologist did not show any signs of appendicitis (whether the appendix was visualized or not), then the utility of CT was low. These studies suggest that CT should be used if ultrasound is equivocal and clinical suspicion is moderate to high.

Two studies have looked specifically at pediatric emergency clinicians evaluating pediatric patients. Sivitz et al prospectively evaluated the diagnostic accuracy of 1 pediatric emergency physician and 12 pediatric emergency fellows in the emergency ultra-

**Figure 15. Inferior Vena Cava In The Long Axis**

Abbreviations: IVC, inferior vena cava; RA, right atrium.

Used with permission from Mount Sinai Hospital, New York, NY.

**Figure 16. Inferior Vena Cava And Aorta In The Short Axis**

Abbreviation: IVC, inferior vena cava.

Used with permission from Mount Sinai Hospital, New York, NY.
Using Doppler to assess for signs of periappendiceal inflammation may assist in the diagnosis. This involves using color Doppler on the appendix to determine if there is a large amount of color flow surrounding the appendix. This is known as the “ring of fire” sign. An appendicolith, a hyperechoic structure with posterior shadowing, may also be seen. (See Figure 18.)

Though studies are limited, emergency ultrasound seems to be specific for the diagnosis of appendicitis, with diagnostic accuracy increasing with operator experience. Future studies should assess the diagnostic accuracy in a larger population with a larger number of operators, as well as using a clinical pathway combining clinical score with emergency ultrasound to assess patient outcomes. Emergency ultrasound for appendicitis has strong potential to decrease ED length of stay, as well as to allow emergency clinicians who do not have access to radiology ultrasound to diagnose appendicitis and proceed with appropriate transfer and management.

Intussusception

While contrast or air enema have traditionally been used as the gold standard, ultrasound has become a first-line imaging modality to evaluate children with suspected ileocolic intussusception, as it is less invasive than an enema. Multiple studies have shown an excellent diagnostic accuracy in radiology ultrasound with sensitivities of ≥ 98%, thereby

Figure 18. Appendicitis With An Appendicolith On Ultrasound

Used with permission from Mount Sinai Hospital, New York, NY.

Technique

While there are several methods used for finding the appendix, a common method is to start at the area of maximal tenderness. If the appendix is not visualized, then graded compression of the right lower quadrant is used to look for the appendix. Graded compression involves evaluating the right lower quadrant by starting at the area of maximal tenderness, and then compressing slowly. The probe is then moved and the abdomen is compressed again. This is completed in 2 planes, but in no particular order. Appendicitis is diagnosed when a tender, noncompressible, blind-ended, tubular structure is found that is > 6 mm in diameter. (See Figure 17.)

Figure 17. Appendicitis On Ultrasound

Used with permission from Mount Sinai Hospital, New York, NY.
Risk Management Pitfalls In The Use Of Diagnostic Ultrasound To Evaluate Pediatric Patients In The Emergency Department

1. “While caring for a child with possible intussusception, I couldn't obtain a good view of the abdomen on my emergency ultrasound, so I assumed it was not intussusception, and I discharged the patient.”

   Emergency ultrasound is meant to answer yes or no questions. If your examination is technically inadequate or if you are unsure that you adequately answered your clinical question based on the images, then order a radiology-performed ultrasound or another available imaging study.

2. “I did not see any abnormalities on my emergency ultrasound, so I told the patient’s parents everything was normal, and that she could be discharged home.”

   Emergency ultrasound is meant to be a limited study to answer focused clinical questions. It is not meant to be a comprehensive organ system assessment. Patients and caregivers should understand the limited nature of the bedside ultrasound.

3. “The patient had a pericardial effusion and was tachycardic. However, I saw no signs of cardiac tamponade on my emergency ultrasound, so I did not consult cardiology or cardiac surgery.”

   Cardiac tamponade is a clinical diagnosis. If the patient has a pericardial effusion and is unstable, then cardiac tamponade should be considered, despite the lack of ultrasound findings of tamponade.

4. “The FAST examination was negative, so I ruled out serious abdominal trauma and discharged the patient.”

   The FAST examination is a poorly sensitive test and cannot be used to rule out intra-abdominal injuries. Children often have organ injury without evidence of free intraperitoneal fluid.

5. “The appendix appeared normal on ultrasound, so I told the patient’s parents that it was not appendicitis and discharged him.”

   While ultrasound is quite specific for appendicitis, it is not sensitive enough to rule out this high-risk condition. Also, visualization of the normal appendix challenges even experienced sonographers and radiologists, so misdiagnosis remains a possibility. While clinical pathways combining risk scoring and ultrasound are being developed, this has yet to be repeated in multiple populations and cannot be relied upon. However, one can use ultrasound to rule in appendicitis.

6. “In a pediatric patient with cardiac arrest, there was no evidence of cardiac activity on ultrasound, so I recommended discontinuation of resuscitation efforts.”

   While there are data in adults that ultrasound can be used as a prognostic indicator in cardiac arrest, there are insufficient data in children for it be used alone to prognosticate outcomes in pediatric cardiac arrest.

7. “The child presented with fever, cough, and mild tachypnea for 5 days. My emergency ultrasound did not reveal pneumonia, so I sent the patient home without antibiotics.”

   While ultrasound is more specific than CXR, it is not as sensitive as CXR, as it can only evaluate pneumonias that reach the pleural line. If only lung ultrasound is employed, patients and clinicians should be aware of the sensitivity of that testing and ensure close follow-up.

8. “In my patient with gastroenteritis, the IVC ultrasound was normal, so I decided not to give intravenous fluids.”

   There are insufficient data to rely only on the IVC ultrasound for volume assessment. Patients may have a dilated IVC due to other diseases (such as pulmonary hypertension) and still require intravenous fluids for treatment of dehydration. Rather, the ultrasound can be used as a data point, combined with other clinical elements in the evaluation of the possibly dehydrated child.

9. “While evaluating a child with right upper quadrant pain, I performed an emergency ultrasound that did not reveal any gallbladder pathology, so I told the parent it could not be cholecystitis, and I discharged the patient.”

   The minimal data we have suggest that ultrasound is poorly sensitive for biliary tract disease in children, even when performed by radiologists. If highly suspected, other testing or consultation should be pursued.

10. “Despite significant testicular pain and swelling, the testicular ultrasound was normal, so I discharged the patient.”

    Intermittent testicular torsion may present with a normal ultrasound, whether the radiologist or the emergency clinician performs the ultrasound. High clinical suspicion should prompt urology consultation in the ED, even if the ultrasound does not show testicular torsion.
avoiding the use of an enema should the ultrasound be negative.\textsuperscript{116-120} Ultrasound does not perform as well for ileocolic intussusception, identifying only 76\% of cases and, therefore, other imaging modalities may be required for diagnosis.\textsuperscript{121} Though there are several case reports on emergency ultrasound for intussusception, there is only 1 prospective study.\textsuperscript{122,123} Riera et al performed a prospective study on pediatric emergency physicians with no prior experience in bowel ultrasound.\textsuperscript{124} The physicians underwent a 1-hour training session. Patients were enrolled if a radiology ultrasound was ordered, and the emergency ultrasound result was compared to the radiology ultrasound as the gold standard. They found a sensitivity of 85\% and a specificity of 97\% for emergency ultrasound in this group.

**Technique**
The ultrasound examination for ileocolic intussusception is generally performed with a high-frequency linear array probe. The examination begins with identification of the colon in the right lower quadrant in the transverse plane. The probe is then moved in the same plane superiorly to the right upper quadrant, where the intussusceptum is usually found. The intussusceptum is a large, round structure, with multiple layers of hyperechoic and hypoechoic bowel wall, commonly referred to as a "target" or "bull's eye" sign.\textsuperscript{125} (See Figure 19.) If the intussusceptum is still not found, then the remaining colon (transverse and descending colon) are scanned in a transverse plane.

Currently, there are not enough data to support the routine use of emergency ultrasound in the evaluation of intussusception. However, the limited data suggest that emergency ultrasound may potentially be used as a rule-in test, allowing more expedited transfer or management should radiology ultrasound not be available. Further study should continue to assess the diagnostic accuracy, as well as the impact of emergency ultrasound on length of stay and time to definitive management.

**Pyloric Stenosis**
For almost 40 years, the imaging modality of choice in pyloric stenosis has been ultrasound.\textsuperscript{126,127} With the recent increase in the use of emergency ultrasound, researchers are now beginning to study the diagnostic accuracy of ultrasound performed by emergency clinicians for pyloric stenosis. A prospective trial conducted over 3 years by Sivitz et al assessed pediatric emergency physicians with only basic knowledge of emergency ultrasound. They received 45 minutes of lecture and a hands-on session.\textsuperscript{128} The authors of the study defined pyloric stenosis as a muscle width of > 3 mm and a channel length of > 17 mm, with a preference for the width in conflicting measurements. (See Figure 20.) They also considered the visualization of gastric contents moving through a relaxed pylorus to be a negative study. The emergency ultrasound was compared to the radiology ultrasound. Among 67 patients, they found a sensitivity and a specificity of 100\%. This study was limited in that there was a small sample size with few positive studies, which led to a wide confidence interval. The authors also did not record the time it took to perform the ultrasound. They do describe an ultrasound that took 20 minutes of scanning to determine it to be positive. This may limit generalizability to the emer-

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**Figure 19. Intussusception On Ultrasound**

Abbreviation: Int, intussusception.

Used with permission from Mount Sinai Hospital, New York, NY.

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**Figure 20. Normal Pylorus On Ultrasound**

Used with permission from Mount Sinai Hospital, New York, NY.
Ultrasound is an excellent bedside test for the emergency clinician in a busy ED. While certainly promising, more studies are needed prior to implementing emergency ultrasound for diagnosis of pyloric stenosis in the ED. Specifically, more data on diagnostic accuracy as well as feasibility are needed.

**Cholecystitis**

While biliary tract disease is rare in the pediatric population, the rates of incidence have been increasing. The emergency ultrasound assessment of cholelithiasis and cholecystitis in adults is highly accurate when compared to radiology assessment and is considered by ACEP to be a core application of emergency ultrasound. In pediatrics, however, recent data suggest that ultrasound is not as robust a modality as in adults. Tsai et al performed a retrospective analysis of 223 pediatric patients undergoing cholecystectomy at a single center. The results of the study indicate that ultrasound had poor sensitivity for detecting cholecystitis. The highest sensitivity of any individual sign was the presence of gallstones (66%). They also found that having any 1 ultrasonographic sign had a sensitivity of 82%. The most specific signs were pericholecystic fluid (93%), enlarged gallbladder (88%), sonographic Murphy sign (88%), and gallbladder wall thickening (86%). The postulated reasons for this discrepancy are that children more often present with chronic cholecystitis and most likely had multiple low-grade or subclinical episodes prior to diagnosis. Adults present most commonly with acute cholecystitis, which has a more dramatic course and is more easily diagnosed on ultrasound. Furthermore, as opposed to adults, whose stones are primarily cholesterol-based, children with cholecystitis are more likely to have sludge associated with total parenteral nutrition, or pigment stones due to hemolytic disease.

In emergency ultrasound, there is only a single case series evaluating pediatric cholecystitis. Tsung et al collected a case series of 13 children and adolescents evaluated by an emergency physician skilled in emergency ultrasound where biliary tract disease or cholecystitis was detected and found that the ultrasound results assisted in preventing misdiagnosis or delays to diagnosis.

Ultrasound has good specificity but poor sensitivity in the detection of cholecystitis. If clinical suspicion is high, further testing should be obtained. Whether the general emergency clinician can obtain a similar diagnostic accuracy to a radiologist is yet unknown.

**Testicular Torsion**

The clinical diagnosis of testicular torsion is difficult, as historical features and the physical examination are deemed to be inadequate at ruling out this high-risk diagnosis. If the patient is not deemed at high enough risk for direct surgical exploration without imaging, then an ultrasound is considered the first-line test.

There are little data on the performance of testicular ultrasound by emergency clinicians. Data are limited to case series and a small retrospective study, all performed by the same group of researchers. Without further data, it would be unwise for an emergency clinician to rule out testicular torsion based on the emergency ultrasound. However, testicular ultrasound may still have a role in the ED. If torsion is suspected, an ED ultrasound can be performed while waiting for the radiology ultrasound. If testicular torsion is found, this may be used to expedite urology consultation and decrease time to surgical management.

**Technique**

When performing the ultrasound, comparison to the unaffected testicle is essential. Features on B-mode imaging suggestive of torsion are a heterogeneous appearance of the testicle, testicular wall thickening, testicular enlargement, and a hydrocele. Doppler imaging should be performed. Complete torsion will show lack of flow to the affected testes, whereas incomplete torsion will show decreased flow. Advanced users should use spectral Doppler to assess for arterial and venous waveforms, as partial torsion can show one without the other.

**Pregnancy In The First Trimester**

The evaluation of pregnant patients is one of the most common uses of emergency ultrasound. Numerous studies have shown that emergency ultrasound is not only highly accurate, but reduces length of time to operative management.

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**Time- And Cost-Effective Strategies**

- Ultrasound is an excellent bedside test for the detection of pneumothorax. In the supine patient, it is more sensitive than a CXR and can be performed without delay.
- Ultrasound, whether performed by the emergency physician or radiology, should be the initial test of choice in patients with suspected appendicitis. This saves both cost and radiation to the patient and is often diagnostic. CT should be reserved for circumstances where the ultrasound is equivocal.
- In patients for which you have a moderate to high suspicion for testicular torsion, consider performing the ultrasound at the bedside, even if you have ordered a radiology study. A positive study may prompt the urology consultants to take the patient to the operating room directly, thus decreasing time to operative management.

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of stay and time to definitive care. Clinicians can utilize the same views as the FAST examination; however, right upper quadrant and pelvic views are most helpful. In a patient with a low risk of heterotopic pregnancy, the presence of an intrauterine pregnancy allows patients to be safely discharged home, without increased time in the ED or increased cost of an ultrasound performed in the radiology or the obstetric department. Further, the presence of a significant amount of free fluid in the abdomen or pelvis in a patient with concern for ruptured ectopic pregnancy can expedite obstetrical consultation and operative management.

An intrauterine pregnancy is diagnosed when a gestational sac is seen within the uterus, with either a yolk sac or fetal pole located in the gestational sac. (See Figure 21.) The myometrial mantle, which is the distance from the gestational sac to the edge of the uterus, must be > 8 mm, or an interstitial ectopic pregnancy may be present.

**Controversies And Cutting Edge**

To a certain extent, many of the emergency ultrasound indications discussed in this issue may be considered controversial and cutting edge. While data may be very robust in adults, there is still a dire need for more data for most of the emergency ultrasound applications in the pediatric population. While diagnostic accuracy studies are still needed, studies should be conducted that focus on patient-oriented outcomes, such as length of stay, cost, and time to definitive management.

**Figure 21. Intrauterine Pregnancy On Ultrasound**

Arrows point to the gestational sac (solid arrows) and fetal pole (open arrow). Y indicates the yolk sac.

Used with permission from Mount Sinai Hospital, New York, NY.

**Summary**

Emergency ultrasound has revolutionized the practice of emergency medicine. Ultrasound is an ideal imaging modality in children as it does not subject them to ionizing radiation, and because most pediatric patients have a small body habitus. Emergency ultrasound is applicable across the field of pediatric emergency medicine, from trauma to critical care, and it increases the diagnostic ability of pediatric emergency clinicians beyond the traditional history and physical examination. However, pediatric emergency medicine still lags behind general emergency medicine in training, experience, and research in the field of ultrasound. More pediatric emergency medicine studies on patient outcomes are needed and more training for pediatric emergency clinicians and fellows is needed in order for emergency ultrasound to reach its full potential in the pediatric setting.

**Case Conclusions**

Your 8-year-old patient’s pain and nausea significantly improved with the medications. You then performed an ultrasound to evaluate for appendicitis. The imaging revealed a 9-mm tubular, blind-ended structure that was not compressible. Even though the blood tests were still pending, you called the on-call surgeon with your findings. When the surgeon arrived, you showed her your images. She agreed with your findings and took the patient to the operating room, where appendicitis was confirmed.

You performed a bedside cardiac ultrasound on the 3-year-old girl in respiratory distress and found a large pericardial effusion with diastolic collapse of the right ventricle. You diagnosed cardiac tamponade and immediately called the cardiothoracic surgeon on call and prepared for an emergency pericardiocentesis. The patient’s blood pressure stabilized after 2 20-mL/kg boluses of intravenous fluid. The cardiothoracic surgeon arrived and took the patient to the operating room where she underwent a successful pericardial window.

**Associated Resources**

To view additional ultrasound resources, scan the QR codes with a smartphone or go to: [https://m.youtube.com/user/SinaiEMultrasound](https://m.youtube.com/user/SinaiEMultrasound) and [https://m.youtube.com/channel/UCnFSdFUBEgjI-Zcn0xHNSMq](https://m.youtube.com/channel/UCnFSdFUBEgjI-Zcn0xHNSMq)
Acknowledgement

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References

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study will be included in bold type following the references, where available. The most informative references cited in this paper, as determined by the author, will be noted by an asterisk (*) next to the number of the reference.


43. Jones AE, Tayal VS, Kline JA. Focused training of emergency medicine residents in goal-directed echocardiography: a prospective study. Acad Emerg Med. 2003;10(10):1054-1058. (Prospective observational educational study; 21 participants)


5. Which of the following cannot be used to differentiate skull fractures from sutures?
   a. Comparison to the contralateral side
   b. Fractures are more displaced from the skull than sutures.
   c. Fractures have a ragged edge, while sutures have a smooth edge.
   d. Following the cortical break back to a fontanelle

6. How are A lines and B lines differentiated on lung ultrasound?
   a. A lines are vertical and shadow to the bottom of the screen
   b. B lines are horizontal and are reflections of the pleura
   c. By evaluating for lung sliding
   d. A lines are horizontal lines and reflections of the pleura, while B lines are vertical and reflect to the bottom of the ultrasound screen.

7. Which of the following is a sign of a normal appendix as seen on ultrasound?
   a. Tenderness during appendiceal compression
   b. Compressible tubular structure
   c. Size > 6 mm
   d. Increased periappendiceal Doppler flow

8. Regarding ultrasound for intussusception, which of the following is TRUE?
   a. Emergency ultrasound can be used to rule out intussusception, but not to rule it in.
   b. Intussusception is associated with a “bull’s eye” sign on emergency ultrasound.
   c. Magnetic resonance imaging is the gold standard for intussusception.
   d. The search for intussusception on ultrasound begins in the left lower quadrant and proceeds to scanning the entire colon.

9. Which of the following is a sign of testicular torsion as seen on ultrasound?
   a. Lack of Doppler flow to the affected testis
   b. Homogenous-appearing testis
   c. Increased color Doppler flow to the affected testis
   d. Increased color Doppler flow to the epididymis

10. Which of the following results on emergency ultrasound would require close follow-up to confirm the presence of an intrauterine pregnancy?
    a. Visualization of a yolk sac within a gestational sac inside the uterus
    b. Visualization of a fetal pole without cardiac activity in the gestational sac inside the uterus
    c. Visualization of a fetal pole inside the gestational sac inside the uterus, where fetal cardiac activity is present
    d. Visualization of only a gestational sac inside the uterus