PEDIATRICS®
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Bedside Ultrasound in Pediatric Emergency Medicine

Jason A. Levy and Vicki E. Noble

Pediatrics 2008;121;e1404
DOI: 10.1542/peds.2007-1816

STATE-OF-THE-ART REVIEW ARTICLE

Bedside Ultrasound in Pediatric Emergency Medicine

Jason A. Levy, MD[a], Vicki E. Noble, MD, RDMS[b]

[a]Division of Emergency Medicine, Children's Hospital Boston and Department of Pediatrics, Harvard Medical School, Boston, Massachusetts; [b]Division of Emergency Medicine, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts

The authors have indicated they have no financial relationships relevant to this article to disclose.

ABSTRACT

Bedside emergency ultrasound has been used by emergency physicians for >20 years for a variety of conditions. In adult centers, emergency ultrasound is routinely used in the management of victims of blunt abdominal trauma, in patients with abdominal aortic aneurysm and biliary disease, and in women with first-trimester pregnancy complications. Although its use has grown dramatically in the last decade in adult emergency departments, only recently has this tool been embraced by pediatric emergency physicians. As the modality advances and becomes more available, it will be important for primary care pediatricians to understand its uses and limitations and to ensure that pediatric emergency physicians have access to the proper training, equipment, and experience. This article is meant to review the current literature relating to emergency ultrasound in pediatric emergency medicine, as well as to describe potential pediatric applications.

www.pediatrics.org/cgi/doi/10.1542/peds.2007-1816

doi:10.1542/peds.2007-1816

Key Words
emergency ultrasound, bedside ultrasound, ultrasound, sonography

Abbreviations
EUS— emergency ultrasound
ED— emergency department
EP— emergency physician
FAST—focused assessment with sonography in trauma
CT— computed tomography
DPL— diagnostic peritoneal lavage
CI— confidence interval
IV—intravenous
PEA—pulseless electrical activity
ETT— endotracheal tube

Accepted for publication Nov 8, 2007

Address correspondence to Jason A. Levy, MD, Division of Emergency Medicine, Children's Hospital Boston, 300 Longwood Ave, Boston, MA 02115. E-mail: jason.levy@childrens.harvard.edu

BEDSIDE EMERGENCY ULTRASOUND (EUS) has been used in the emergency department (ED) for >2 decades. Its use has grown rapidly as it has gained widespread acceptance among emergency physicians (EPs), and the range of diagnostic and procedural applications has continued to expand. The American College of Emergency Physicians Section of Emergency Ultrasound now has >500 members. In addition, the American Board of Emergency Medicine, American College of Emergency Physicians, and Society of Academic Emergency Medicine have deemed bedside ultrasound part of the core content for training residents in emergency medicine,[1] and EUS is now a required component of emergency medicine residency training.[2] In recent years, pediatric EPs have increasingly begun to use this modality. One recent study found that 39% of pediatric emergency medicine fellowship directors reported routine use of ultrasound by faculty.[3]

Many of the initial uses for EUS were applicable to disease states found primarily in adult patients, for example, evaluation for abdominal aortic aneurysm or biliary tract disease. However, the increased use of EUS to guide invasive procedures and the ever-broadening range of diagnostic applications reviewed in this article suggest that its use should not be limited to adult patients. As use of this imaging tool in pediatric EDs grows, there will be an increased need for access to training and proper equipment for pediatric emergency medicine physicians. The incorporation of EUS into pediatric emergency practice necessitates that the general pediatrician appreciate current capabilities, limitations, and areas of active research for this promising technology. This review outlines current and potential uses for EUS in the pediatric ED population. We additionally describe recent advances and novel applications of EUS in acutely ill or injured children.

Traditional Uses

Trauma

Emergency bedside sonography for victims of blunt abdominal trauma was one of the first applications for ultrasound in emergency medicine and remains one of the most frequent indications. The most commonly used test is the focused assessment with sonography in trauma (FAST) examination. The guiding principle behind the FAST scan is that the free fluid of hemoperitoneum or hemopericardium will appear anechoic (black) against the more hyperechoic (gray) background of solid organs.

The FAST scan possesses several advantages over other methods used to identify significant intraabdominal injury. Abdominal computed tomography (CT) is currently the study of choice in the evaluation of the stable pediatric patient with suspected traumatic abdominal organ injury. However, abdominal CT exposes the patient to ionizing radiation and necessitates the presence of other specialists to perform and interpret the test. The FAST scan can be performed at the bedside immediately by the treating physician and has no harmful radiation effects. Furthermore, it can be repeated as often as clinically indicated as the patient's condition changes. More importantly, if the patient is not stable, it may be unsafe to transport the patient to the radiology suite, and, thus, bedside FAST scanning offers

a distinct advantage. Although diagnostic peritoneal lavage (DPL) has been the procedure traditionally used to evaluate unstable patients with injuries requiring operative intervention, it is now rarely used in children, because it is invasive and is contraindicated in selected patients. In addition, DPL has such a high sensitivity for intraabdominal bleeding that the rate of nontherapeutic laparotomy is unacceptably high.[4] Like DPL, the FAST scan can be done rapidly at the bedside in critically injured patients but is noninvasive and can better predict the need for laparotomy.[5]

This application of EUS has generated a large body of research. Many EPs and surgeons now consider it a standard part of the trauma evaluation. Because the number of studies assessing the FAST scan is quite large, a review of them here is beyond the scope of this article. However, a brief, critical review is provided.

Results of studies examining the value of FAST in adults have been mixed. In 2005, a Cochrane review of the literature examining the use of EUS in blunt abdominal trauma was published.[6] Only 6 studies were included in the final analysis. The authors concluded that there is insufficient evidence to justify the use of EUS-based pathways in assessing organ injury in victims of blunt abdominal trauma. Subsequent to this report however, Melniker et al[7] published the First Sonography Outcomes Assessment Program Trial, a randomized, controlled clinical investigation. The authors found that use of ultrasound significantly reduced the time from ED presentation to operative care (57 vs 166 minutes). Patients in the ultrasound group were also found to have shorter lengths of stay, fewer complications, and decreased total charges, which the authors hypothesize may have been the result of a more rapid diagnosis in both operative and nonoperative patients, thus facilitating other types of care. With growing evidence regarding its benefit, the FAST examination remains one of the most commonly used and widely accepted applications of ED bedside ultrasound.

The use of the FAST scan as a screening tool specifically in children is more challenging for 2 major reasons. First, children with intraabdominal injuries are more frequently managed nonoperatively and, thus, the need for rapid decision-making regarding operative management, although still crucial, is less common. Second, children have a relatively higher incidence of solid organ injury without free fluid[8–10]; consequently, a negative FAST scan may not obviate the need for an abdominal CT when there is clinical suspicion of significant injury.

Despite these challenges, there is extensive data addressing the use of the FAST scan in children. Comparing results must be done carefully, however, because these investigations have used varying definitions of positive and negative FAST scans, used different scanning personnel, and measured different outcomes. In addition, few studies have addressed the use of FAST in assessing the need for laparotomy in children. Reported sensitivities have ranged from 40% to 93%, with associated specificities of 79% to 100%.[8,9,11–26] One meta-analysis pooled pediatric data from 4 trials encompassing 501 patients.[27] The authors found that a positive FAST examination had a likelihood ratio for organ injury of 17.35 (95% confidence interval [CI]: 8.97–33.53) but that a negative FAST scan did not have a satisfactory negative likelihood ratio (0.32; 95% CI: 0.22–0.45) for ruling out organ injury. Another review concluded that the FAST scan can identify intraabdominal damage but that a negative ultrasound does not rule out important injury.[28]

To account for the reported low sensitivity while using the apparent high specificity of the FAST scan in children, 1 study proposed using FAST in combination with physical examination.[25] In the study protocol, an abdominal CT scan was obtained in the presence of the following: (1) a positive FAST scan, (2) a physical examination suggesting abdominal injury, (3) hypotension, (4) a hematoma or contusion on the torso, or (5) neurologic impairment. Patients were taken to the operating room if they were hypotensive and had a positive FAST scan. FAST scan alone had a sensitivity of 70% and specificity of 100%, but when combined with physical examination the sensitivity rose to 100%. Importantly, 5 children who had positive FAST scans and confirmed solid-organ injury by CT did not have physical examination findings suggesting intraabdominal injury. Of note, 2 children had positive FAST scans for evidence of injury but falsely negative CT scans. Similarly, another study found the accuracy of the FAST examination to be 100% in 13 hypotensive pediatric patients.[18]

Collectively, these data suggest that the FAST examination can be a valuable and reliable diagnostic tool in children with blunt abdominal trauma and hypotension who may be too unstable to be moved from the resuscitation bay. In addition, in the multitrauma patient, FAST may help to prioritize operative management. In the stable patient, the FAST scan should be used not as a screening tool but rather in conjunction with the clinical history and physical examination.

Procedural Applications of Ultrasound

Vascular Access

Although ultrasound-guided vascular access is not a new application, EUS-directed vessel cannulation is an important new procedure for the EP and may soon represent a standard of care for central venous access. In a 2001 Agency for Healthcare Research and Quality report,[29] the US Department of Health and Human Services stated that ultrasound use for central venous catheterization is "a clear [opportunity] for safety improvement." The urgent need to reduce patient injury from the complications of necessary procedures has been one of the most powerful forces driving the placement of ultrasound in the ED.

Ultrasound use for central venous access has been shown to increase success rates and decrease the number of procedural complications.[30–39] Initial investigations were performed largely in the adult population, particularly in the critical care or anesthesia arena. In the pediatric population, Verghese et al[40] demonstrated that use of ultrasound for internal jugular vein cannulation was superior to the use of anatomic landmarks in terms

of overall success rate, speed, and the incidence of inadvertent carotid artery puncture. Likewise, another study reported a 95% success rate on the first attempt when performing ultrasound-guided central venous cannulation in 42 children.[41] A more recent study published in 2007 described using ultrasound for subclavian vein catheter placement in children <10 years of age.[42] In none of these studies, however, was access obtained by an EP.

In the last several years, literature has emerged examining ultrasound-guided vascular access specific to emergency settings. One study showed that, during cardiopulmonary resuscitation, use of EUS by EPs for femoral vein catheterization improved success rates and lowered complications compared with landmark techniques in adults.[32] In 2 separate studies, both Milling et al[38] and Leung et al[43] found that use of EUS improved first-attempt and overall success rates while producing fewer complications than landmark techniques when placing internal jugular vein catheters. Milling et al[38] found that, when comparing dynamic ultrasound to landmark technique, the odds ratio for successful catheter placement using ultrasound was 53 (95% CI: 6.6–440). Further supporting the use of EUS in pediatric patients, research has shown that anatomic landmarks do not always predict femoral vein and artery anatomy; in 1 study, for example, in 12% of children, the femoral artery either completely or partially overlapped the femoral vein.[44] Another investigation found that, after identifying the femoral vascular anatomy with ultrasound, the landmark method located the correct site of the femoral vein in only 9 of 30 attempts.[45]

EUS has also been shown to be useful in peripheral intravenous catheter placement. One study showed that EUS-guided brachial and basilic vein cannulation was safe, rapid, and had a high success rate in adult patients with difficult intravenous access.[46] Costantino et al[47] found that, in adults with difficult access, ultrasonographic-guided peripheral venous access was more successful, required less time, decreased the number of punctures, and was associated with greater satisfaction than traditional methods. A recent pilot study reported that lack of ultrasound visualization of peripheral veins was associated with unsuccessful peripheral intravenous (IV) placement in children <7 years old.[48]

Ultrasound has also been used to confirm intraosseous needle placement in adult cadavers. Stone et al[49] showed that ultrasound correctly identified the location of all of the intraosseous placements, whereas examination of the IV tubing drip chamber for flow had 88% sensitivity and 25% specificity for correct needle position.

The current federal emphasis on patient safety and the abundant available literature both support the notion that EUS should be used when obtaining central venous access in the ED. Whether EUS can improve peripheral IV catheter placement in selected children remains an important area warranting additional investigation.

Identification and Drainage of Abnormal Fluid Collections

Differentiating cellulitis from abscess is a common reason for referral to the pediatric ED. Although abscesses may be clinically obvious in many patients, identification of some presents a diagnostic challenge. Moreover, the best area for incision and drainage may not be clear from physical examination. Of equal significance, there may be structures near the abscess, such as vessels or nerves, posing significant risk to the procedure. EUS plays a critical role both in abscess identification and in the safe performance of incision and drainage.

In 1 study of adult patients, the authors showed that clinicians were able to accurately identify subcutaneous abscesses after only a 30-minute training session and that EUS changed the clinical impression correctly in 17 of 18 cases.[50] Another study found that EUS examination changed physician management in approximately one half of ED patients who presented with cellulitis.[51] As pediatric emergency medicine physicians gain ultrasound skill and experience, this technology should aid in abscess identification and safe incision and drainage.

In a related application, Blaivas et al[52] recently reported use of EUS in the evaluation of 6 patients with suspected peritonsillar abscess. Another study found that ultrasound could reliably identify peritonsillar abscesses and be used for their drainage.[53]

Numerous studies have examined ultrasound for identification and drainage of pleural and pericardial effusions. Although aspiration of these fluids in the ED has traditionally relied on using anatomic landmarks alone, EUS is being increasingly used for these procedures. Research is needed to define how EUS can be used safely and effectively in children requiring aspiration of pleural and pericardial fluid.

Bladder Catheterization and Suprapubic Aspiration

EUS can be used to determine the presence of fluid in the bladder before attempting urine collection. If the bladder appears empty, the clinician may defer the procedure until the child's bladder contains urine. EUS has been shown to increase the success rates in obtaining urine in both bladder catheterization and suprapubic aspiration. One study found that, using a predetermined calculation for bladder size, EUS could identify infants for whom urinary catheterization was likely to be unsuccessful.[54] Two other studies showed that use of EUS significantly improved success rates of bladder catheterization.[55,56] EUS has been shown to increase rates of success in the performance of suprapubic aspirations as well. Both Gochman et al[57] and Munir et al[58] reported that EUS significantly improved the success rate of suprapubic aspirations, limiting the number of failed attempts, whereas another study demonstrated similar success using ultrasound during the procedure.[59]

Foreign Body Identification

Ultrasound has long been used by radiologists to identify subcutaneous foreign bodies and has some advantages over radiography. First, it permits direct, real-time localization for the EP. Second, it has been shown to be more

sensitive than radiograph for certain types of materials.[60–62] Foreign bodies such as wood and plastic (and sometimes glass) are rarely detected radiographically, and EUS may, therefore, be better suited for these materials.

Studies of EUS used by EPs have demonstrated significant accuracy in the identification and localization of certain types of foreign bodies. One study reported a 93% sensitivity for the detection of wood foreign bodies and a 73% sensitivity for plastic when EUS was performed by EPs.[63] Another study found that EPs' ability to detect various foreign bodies did not differ statistically from that of radiologists or ultrasound technicians.[64] In the pediatric population, Friedman et al[65] reported a small case series in which ultrasound was equally sensitive and more specific than radiography for detection of foreign bodies and that combining ultrasound with patient perception resulted in the highest sensitivity. These studies offer early data supporting the use of EUS in the evaluation and management of select soft tissue foreign bodies.

Obstetric and Gynecologic Emergencies

Abdominal pain in the adolescent girl is a common presenting complaint and one that is associated with a range of life-threatening and organ-threatening gynecologic conditions. EUS has been demonstrated in multiple studies to be especially valuable in the evaluation of pregnancy, specifically in ruling in those patients with normal intrauterine pregnancy and, thus, ruling out ectopic pregnancy in those patients with no increased risk of heterotopic pregnancy.

In the pregnant patient with abdominal pain, ectopic pregnancy must be identified and treated rapidly. Ultrasound has been shown to be an effective tool as part of a protocol to diagnose intrauterine and ectopic pregnancy.[66] One prospective study demonstrated 100% sensitivity and 95% specificity for the diagnosis of intrauterine pregnancy and, thus, ruling out ectopic pregnancy by EPs.[67] Another showed that EUS, when performed by EPs, can be used to rule out ectopic pregnancies and make accurate diagnoses in most patients with complicated first-trimester pregnancies.[68] In relation to the time to diagnosis and lengths of stay, several studies have shown that EUS performed in the ED significantly reduced the time to diagnosis and treatment in patients with ruptured ectopic pregnancy when compared with patients who had ultrasound performed in the radiology suite.[69–72] Another investigation reported that pelvic sonography performed by EPs was sensitive, specific, and safe and could shorten ED length of stay in women with early pregnancy.[73] Similar results were demonstrated by Blaivas et al[74] in women found to have intrauterine pregnancies by EUS. These studies imply that ultrasound may have a role in the emergent and urgent evaluation of the pregnant female.

The value of EUS in the nonpregnant female patient with abdominal pain is less clear. Diagnoses such as ovarian torsion, ovarian cyst, and tubo-ovarian abscess require advanced sonographic skill and experience. Further research with EUS in these conditions is needed to determine the range of its use.

Cardiac

Cardiac ultrasound, as part of the FAST examination, was one of the first applications of ED sonography. More focused cardiac examinations have become common in adult EDs and have been reported in pediatric settings as well. The 2 most common indications for EP-performed echocardiography are detection of pericardial effusion and evaluation of cardiac activity in patients with cardiac arrest and pulseless electrical activity (PEA). The uses of cardiac ultrasound in the patient with undifferentiated shock or to assess cardiac function are less established and are discussed later.

One of the earlier studies reporting the use of emergency bedside cardiac ultrasound retrospectively described 156 cases of EP-performed echocardiography. The authors reported that patient care was enhanced in all ($n = 7$) of the positive cases (4 traumatic pericardial effusions, 1 malignant pericardial effusion, 1 pulmonary embolism, and 1 case of PEA).[75] Another study found that ED echocardiography changed decision-making in 37% of patients, changed treatment in 25% of patients, and changed disposition in 11% of patients.[76] In this study, however, scans were not performed by EPs.

The diagnosis of pericardial effusion and tamponade is often difficult to make clinically, and classic physical examination findings such as Beck's triad are unreliable.[77] The use of bedside ultrasound to diagnose pericardial effusions has been shown to be accurate in several different scenarios in the adult literature. In the setting of blunt trauma, EPs have shown the ability to use echocardiography to diagnose cardiac rupture and subsequent pericardial effusions.[78–80] A retrospective review showed that EP-performed echocardiography led to reduced time to diagnosis and disposition to the operating room and to increased survival rates in adults with penetrating chest trauma.[81] Finally, Mandavia et al[82] found that EPs, with limited training, could detect or exclude pericardial effusions with an overall accuracy of 97.5% in patients with a variety of presenting complaints.

The pediatric literature is limited. Milner et al[83] reported 3 cases of children with altered mental status and tachycardia who were subsequently diagnosed with pericardial effusions and tamponade by cardiologist-performed echocardiography. The authors implied that EP-performed cardiac sonography may have led to earlier diagnosis and improved outcome. Another study found that noncardiology-trained critical care physicians diagnosed pericardial effusions correctly in 91% of pediatric patients using a hand-carried ultrasound device.[84] There have been no other published prospective studies using EUS to specifically diagnose pericardial effusions in the pediatric emergency medicine literature.

Bedside cardiac ultrasound has been shown to be useful in adults in cardiac arrest. One study reported that sonographic identification of cardiac activity in pulseless patients undergoing resuscitation was associated with increased survival when compared with those without

cardiac activity by ultrasound.[85] Another study found that, in 169 adults who presented in cardiac arrest, 19% of patients with cardiac activity by echocardiography survived to leave the ED, but none who had cardiac standstill survived.[86] The authors concluded that EUS provided valuable information and may guide resuscitation efforts in patients with cardiac arrest.

There are no published studies that address the use of ultrasound to assess the pediatric patient in cardiac arrest. Because this event is rare in children, a single-institution, prospective, controlled study is not feasible. The results of the adult literature, however, suggest that ultrasound could contribute to the evaluation and management of children presenting in PEA or cardiac arrest by differentiating PEA from asystole and by potentially identifying life-threatening causes of PEA, such as pericardial tamponade.

Novel Uses

Skeletal Fractures

There have been several studies examining the use of EUS in the diagnosis of skeletal fractures in children and adults. In a prospective study of 163 children, Hübner et al[87] were able to diagnose several types of fractures, with a reported sensitivity of 91%. Similarly, another study demonstrated 100% sensitivity and specificity in a small, pilot study using EUS to diagnose greenstick and nondisplaced forearm fractures.[88] Marshburn et al[89] showed that, with limited training, ED physicians were able to diagnose long bone fractures in adult trauma patients with 93% sensitivity. In addition, a case series reported 3 patients with toddler fractures that were not visualized on plain radiographs but were identified by EUS.[90] Another study reported that ultrasound was useful for both guiding fracture reduction and avoiding radiation associated with follow-up films after the reduction of pediatric forearm fractures.[91] Finally, EUS seems to identify sternal and rib fractures with equivalent or greater accuracy than plain radiographs.[92–95] How EUS may be used in the pediatric patient with an occult or Salter Harris 1 fracture or in the reduction of displaced fractures warrants additional investigation.

Hip Effusions

A child who presents with hip pain or limp frequently requires evaluation for the presence of a hip effusion. Purulent effusions signal the diagnosis of septic arthritis, an infection requiring emergent operative intervention. When a significant effusion is identified, hip aspiration is typically required for fluid analysis and culture to distinguish septic arthritis from the more common and benign transient synovitis.

Traditionally, the diagnosis of hip effusion and subsequent hip aspiration occur in the radiology department. However, this protocol often requires transferring the patient out of the ED, which can prolong patient length of stay and necessitate the reallocation of ED staff, who may be needed to administer procedural sedation and provide appropriate monitoring. Smith[96] reported a case in which EUS was used to correctly identify a hip effusion and to guide arthrocentesis successfully after multiple failed attempts using anatomic landmarks alone. Another case series described 5 patients in which ED personnel used EUS, accurately identifying the presence of a hip effusion.[97] These reports imply that hip sonography by the pediatric EP is a desirable and achievable skill that can significantly improve the evaluation and treatment of hip effusion.

Undifferentiated Hypotension

There have been numerous reports describing the use of EUS in the evaluation of undifferentiated hypotension. In the adult literature, studies have shown that EP-performed bedside ultrasound in hypotensive patients leads to shorter, more accurate differential diagnosis lists[98] and allows for a reasonably accurate assessment of cardiac function.[99,100]

There have been several case reports in the pediatric literature on the role of bedside ultrasound in the diagnosis of shock.[101–103] In addition, in a prospective study, Pershad et al[104] showed good agreement between pediatric EPs and experienced pediatric echocardiographers with respect to the estimation of shortening fraction and inferior vena cava volume. The authors concluded that, although there was a statistical difference, pediatric EP sonographers are capable of accurately assessing left ventricular function in pediatric patients. There are no other published studies regarding the accuracy of EP-performed bedside echocardiography to assess cardiac function and evaluate undifferentiated hypotension in the pediatric population. More research is needed to evaluate this potential useful application.

Other Applications and Future Directions

Numerous other applications for EUS have been reported recently and may prove beneficial in the pediatric ED. Studies have evaluated EP- and non-EP-performed bedside ultrasounds for detecting increased intracranial pressure by measuring the optic nerve sheath diameter.[105–109] How this application may apply to pediatric head trauma patients, as well as those presenting to the ED with pseudotumor cerebri or ventriculoperitoneal shunt malfunction, warrants additional investigation, but early research suggests that optic nerve sheath diameter is a sensitive and specific noninvasive way to assess intracranial pressure. Another study revealed that EUS has excellent accuracy in adult patients presenting with an acute scrotum.[110] Two studies have evaluated the use of ultrasound for performing lumbar punctures and found that EPs were able to visualize bony structures[111] and spinal cord anatomy.[112] In addition, Abo et al[113] used ultrasound to find the optimal position for children undergoing lumbar puncture. Several studies have looked at the inferior vena cava diameter as a proxy for patient fluid status,[114–118] and how this application may be used in pediatric patients with dehydration needs additional study. There have been several reports using ultrasound for endotracheal tube (ETT) placement confirmation.[119–122] Weaver et al[122] reported a positive predictive value of 100% for confirming tra-

cheal versus esophageal ETT location and found that this modality had good accuracy, even for right mainstem ETT placement. Finally, considerable literature exists on the use of ultrasound in the diagnosis of pneumothorax,[123–133] and some have suggested that EUS is more sensitive than the supine chest radiograph for detecting traumatic pneumothoraces.[123,132]

The State of the Art

Although EUS has been used in EDs for >20 years, only recently has it been embraced by pediatric EPs. Chen and Santucci[3] reported that 94% of pediatric emergency medicine fellowship directors expressed a desire for pediatric-specific EUS training. Currently, numerous courses and "minifellowships" exist for EPs, ranging from 1 day to 2 weeks. None of these are pediatric specific, however.

Numerous obstacles still exist in the implementation of an ultrasound program in the ED. First, despite abundant literature, many radiology departments still oppose the use of EUS for any indication. Second, establishing a program requires a financial commitment from both hospital and ED administration. Finally, dedicated physicians must be properly trained and gain adequate experience before they can disseminate their skills and work toward the routine application of EUS in the pediatric ED. Despite these barriers, however, establishing a program in EUS is feasible. At our institution, EUS has facilitated patient care and, in some cases, played an integral role in establishing diagnoses and creating management plans. EUS has been used to help diagnose pericardial effusions and traumatic organ injuries. It has become almost routine for the placement of central venous lines and has aided in the incision and drainage of abscesses. Some clinicians are now using EUS for peripheral IV placement in selected patients with difficult venous access.

EUS is a safe technology with numerous applications. Its use in the pediatric ED is likely to increase as new trainees incorporate EUS into their routine practice. As the modality advances and becomes more available, it will be important to ensure that pediatric EPs have access to the proper training, equipment, and experience.

REFERENCES

1. Hockberger RS, Binder LS, Graber MA, et al. The model of the clinical practice of emergency medicine. *Ann Emerg Med.* 2001; 37(6):745–770
2. Heller MB, Mandavia D, Tayal VS, et al. Residency training in emergency ultrasound: fulfilling the mandate. *Acad Emerg Med.* 2002;9(8):835–839
3. Chen L, Santucci A. Probing the availability of emergency ultrasound in pediatrics [Abstract]. *Pediatr Emerg Care.* 2006; 22:688
4. Henneman PL, Marx JA, Moore EE, Cantrill SV, Ammons LA. Diagnostic peritoneal lavage: accuracy in predicting necessary laparotomy following blunt and penetrating trauma. *J Trauma.* 1990;30(11):1345–1355
5. McKenney KL, McKenney MG, Cohn SM, et al. Hemoperitoneum score helps determine need for therapeutic laparotomy. *J Trauma.* 2001;50(4):650–654; discussion 654–656
6. Stengel D, Bauwens K, Sehouli J, et al. Emergency ultrasound-based algorithms for diagnosing blunt abdominal trauma. *Cochrane Database Syst Rev.* 2005;(2):CD004446
7. Melniker LA, Leibner E, McKenney MG, Lopez P, Briggs WM, Mancuso CA. Randomized controlled clinical trial of point-of-care, limited ultrasonography for trauma in the emergency department: the first sonography outcomes assessment program trial. *Ann Emerg Med.* 2006;48(3):227–235
8. Emery KH, McAneney CM, Racadio JM, Johnson ND, Evora DK, Garcia VF. Absent peritoneal fluid on screening trauma ultrasonography in children: a prospective comparison with computed tomography. *J Pediatr Surg.* 2001;36(4):565–569
9. Mutabagani KH, Coley BD, Zumberge N, et al. Preliminary experience with focused abdominal sonography for trauma (FAST) in children: is it useful? *J Pediatr Surg.* 1999;34(1): 48–52; discussion 52–44
10. Taylor GA, Sivit CJ. Posttraumatic peritoneal fluid: is it a reliable indicator of intraabdominal injury in children? *J Pediatr Surg.* 1995;30:1644–1648
11. Katz S, Lazar L, Rathaus V, Erez I. Can ultrasonography replace computed tomography in the initial assessment of children with blunt abdominal trauma? *J Pediatr Surg.* 1996; 31(5):649–651
12. Akgür FM, Tanyel FC, Akhan O, Buyukpamukcu N, Hicsonmez A. The place of ultrasonographic examination in the initial evaluation of children sustaining blunt abdominal trauma. *J Pediatr Surg.* 1993;28(1):78–81
13. Akgür FM, Aktug T, Olguner M, Kovanlikaya A, Hakguder G. Prospective study investigating routine usage of ultrasonography as the initial diagnostic modality for the evaluation of children sustaining blunt abdominal trauma. *J Trauma.* 1997; 42(4):626–628
14. Akgur FM, Olguner M, Aktug T. Investigating the effectiveness of ultrasound as a triage tool to evaluate blunt abdominal trauma in children. *J Trauma.* 1999;47(6):1162–1163
15. Coley BD, Mutabagani KH, Martin LC, et al. Focused abdominal sonography for trauma (FAST) in children with blunt abdominal trauma. *J Trauma.* 2000;48(5):902–906
16. Corbett SW, Andrews HG, Baker EM, Jones WG. ED evaluation of the pediatric trauma patient by ultrasonography. *Am J Emerg Med.* 2000;18(3):244–249
17. Holmes JF, London KL, Brant WE, Kuppermann N. Isolated intraperitoneal fluid on abdominal computed tomography in children with blunt trauma. *Acad Emerg Med.* 2000;7(4): 335–341
18. Holmes JF, Brant WE, Bond WF, Sokolove PE, Kuppermann N. Emergency department ultrasonography in the evaluation of hypotensive and normotensive children with blunt abdominal trauma. *J Pediatr Surg.* 2001;36(7):968–973
19. Krupnick AS, Teitelbaum DH, Geiger JD, et al. Use of abdominal ultrasonography to assess pediatric splenic trauma. Potential pitfalls in the diagnosis. *Ann Surg.* 1997;225(4): 408–414
20. Ong AW, McKenney MG, McKenney KA, et al. Predicting the need for laparotomy in pediatric trauma patients on the basis of the ultrasound score. *J Trauma.* 2003;54(3):503–508
21. Partrick DA, Bensard DD, Moore EE, Terry SJ, Karrer FM. Ultrasound is an effective triage tool to evaluate blunt abdominal trauma in the pediatric population. *J Trauma.* 1998;45(1): 57–63
22. Richards JR, Knopf NA, Wang L, McGahan JP. Blunt abdominal trauma in children: evaluation with emergency US. *Radiology.* 2002;222(3):749–754
23. Soudack M, Epelman M, Maor R, et al. Experience with focused abdominal sonography for trauma (FAST) in 313 pediatric patients. *J Clin Ultrasound.* 2004;32(2):53–61
24. Soundappan SV, Holland AJ, Cass DT, Lam A. Diagnostic accuracy of surgeon-performed focused abdominal sonogra-

phy (FAST) in blunt paediatric trauma. *Injury.* 2005;36(8):970–975
25. Suthers SE, Albrecht R, Foley D, et al. Surgeon-directed ultrasound for trauma is a predictor of intra-abdominal injury in children. *Am Surg.* 2004;70(2):164–167; discussion 167–168
26. Thourani VH, Pettitt BJ, Schmidt JA, Cooper WA, Rozycki GS. Validation of surgeon-performed emergency abdominal ultrasonography in pediatric trauma patients. *J Pediatr Surg.* 1998;33(2):322–328
27. Stengel D, Bauwens K, Sehouli J, et al. Systematic review and meta-analysis of emergency ultrasonography for blunt abdominal trauma. *Br J Surg.* 2001;88(7):901–912
28. Murphy R, Ghosh A. Towards evidence based emergency medicine: best BETs from the Manchester Royal Infirmary. The accuracy of abdominal ultrasound in paediatric trauma. *Emerg Med J.* 2001;18(3):208–209
29. Rothschild J. Ultrasound guidance of central vein catheterization. In: Shojania KG, Duncan BW, McDonald KM, Wachter RM, Markowitz AJ, eds. Evid Rep Technol Assess (Summ), No. 43. *Making Health Care Safer: A Critical Analysis of Patient Safety Practices*. Rockville, MD: Agency for Healthcare Research and Quality; 2001:245–253
30. Denys BG, Uretsky BF, Reddy PS. Ultrasound-assisted cannulation of the internal jugular vein. A prospective comparison to the external landmark-guided technique. *Circulation.* 1993;87(5):1557–1562
31. Farrell J, Gellens M. Ultrasound-guided cannulation versus the landmark-guided technique for acute haemodialysis access. *Nephrol Dial Transplant.* 1997;12(6):1234–1237
32. Hilty WM, Hudson PA, Levitt MA, Hall JB. Real-time ultrasound-guided femoral vein catheterization during cardiopulmonary resuscitation. *Ann Emerg Med.* 1997;29(3):331–336; discussion 337
33. Hind D, Calvert N, McWilliams R, et al. Ultrasonic locating devices for central venous cannulation: meta-analysis. *BMJ.* 2003;327(7411):361
34. Hudson PA, Rose JS. Real-time ultrasound guided internal jugular vein catheterization in the emergency department. *Am J Emerg Med.* 1997;15(1):79–82
35. Legler D, Nugent M. Doppler localization of the internal jugular vein facilitates central venous cannulation. *Anesthesiology.* 1984;60(5):481–482
36. Mallory DL, McGee WT, Shawker TH, et al. Ultrasound guidance improves the success rate of internal jugular vein cannulation. A prospective, randomized trial. *Chest.* 1990;98(1):157–160
37. Miller AH, Roth BA, Mills TJ, Woody JR, Longmoor CE, Foster B. Ultrasound guidance versus the landmark technique for the placement of central venous catheters in the emergency department. *Acad Emerg Med.* 2002;9(8):800–805
38. Milling TJ, Jr, Rose J, Briggs WM, et al. Randomized, controlled clinical trial of point-of-care limited ultrasonography assistance of central venous cannulation: the Third Sonography Outcomes Assessment Program (SOAP-3) Trial. *Crit Care Med.* 2005;33(8):1764–1769
39. Randolph AG, Cook DJ, Gonzales CA, Pribble CG. Ultrasound guidance for placement of central venous catheters: a meta-analysis of the literature. *Crit Care Med.* 1996;24(12):2053–2058
40. Verghese ST, McGill WA, Patel RI, Sell JE, Midgley FM, Ruttimann UE. Ultrasound-guided internal jugular venous cannulation in infants: a prospective comparison with the traditional palpation method. *Anesthesiology.* 1999;91(1):71–77
41. Asheim P, Mostad U, Aadahl P. Ultrasound-guided central venous cannulation in infants and children. *Acta Anaesthesiol Scand.* 2002;46(4):390–392
42. Pirotte T, Veyckemans F. Ultrasound-guided subclavian vein cannulation in infants and children: a novel approach. *Br J Anaesth.* 2007;98(4):509–514
43. Leung J, Duffy M, Finckh A. Real-time ultrasonographically-guided internal jugular vein catheterization in the emergency department increases success rates and reduces complications: a randomized, prospective study. *Ann Emerg Med.* 2006;48(5):540–547
44. Warkentine FH, Kim IK. Ultrasonography to measure femoral vein diameter and depth in pediatric patients [abstract]. *Pediatr Emerg Care.* 2006;22(9):680
45. Woodson J, Tayal V, Pariyadath M, Leathers S, Norton H. Accuracy of the landmark and palpation techniques for pediatric femoral vein identification [abstract]. *Acad Emerg Med.* 2007;14(suppl):S89–S90
46. Keyes LE, Frazee BW, Snoey ER, Simon BC, Christy D. Ultrasound-guided brachial and basilic vein cannulation in emergency department patients with difficult intravenous access. *Ann Emerg Med.* 1999;34(6):711–714
47. Costantino TG, Parikh AK, Satz WA, Fojtik JP. Ultrasonography-guided peripheral intravenous access versus traditional approaches in patients with difficult intravenous access. *Ann Emerg Med.* 2005;46(5):456–461
48. Schnadower D, Lin S, Perera P, Smerling A, Dayan P. A pilot study of ultrasound analysis before pediatric peripheral vein cannulation attempt. *Acad Emerg Med.* 2007;14(5):483–485
49. Stone MB, Teismann NA, Wang R. Ultrasonographic confirmation of intraosseous needle placement in an adult unembalmed cadaver model. *Ann Emerg Med.* 2007;49(4):515–519
50. Squire BT, Fox JC, Anderson C. ABSCESS: applied bedside sonography for convenient evaluation of superficial soft tissue infections. *Acad Emerg Med.* 2005;12(7):601–606
51. Tayal VS, Hasan N, Norton HJ, Tomaszewski CA. The effect of soft-tissue ultrasound on the management of cellulitis in the emergency department. *Acad Emerg Med.* 2006;13(4):384–388
52. Blaivas M, Theodoro D, Duggal S. Ultrasound-guided drainage of peritonsillar abscess by the emergency physician. *Am J Emerg Med.* 2003;21(2):155–158
53. Lyon M, Blaivas M. Intraoral ultrasound in the diagnosis and treatment of suspected peritonsillar abscess in the emergency department. *Acad Emerg Med.* 2005;12(1):85–88
54. Milling TJ, Jr, Van Amerongen R, Melville L, et al. Use of ultrasonography to identify infants for whom urinary catheterization will be unsuccessful because of insufficient urine volume: validation of the urinary bladder index. *Ann Emerg Med.* 2005;45(5):510–513
55. Chen L, Hsiao AL, Moore CL, Dziura JD, Santucci KA. Utility of bedside bladder ultrasound before urethral catheterization in young children. *Pediatrics.* 2005;115(1):108–111
56. Witt M, Baumann BM, McCans K. Bladder ultrasound increases catheterization success in pediatric patients. *Acad Emerg Med.* 2005;12(4):371–374
57. Gochman RF, Karasic RB, Heller MB. Use of portable ultrasound to assist urine collection by suprapubic aspiration. *Ann Emerg Med.* 1991;20(6):631–635
58. Munir V, Barnett P, South M. Does the use of volumetric bladder ultrasound improve the success rate of suprapubic aspiration of urine? *Pediatr Emerg Care.* 2002;18:346–349
59. Chu RW, Wong YC, Luk SH, Wong SN. Comparing suprapubic urine aspiration under real-time ultrasound guidance with conventional blind aspiration. *Acta Paediatr.* 2002;91(5):512–516
60. Fornage BD, Schernberg FL. Sonographic preoperative localization of a foreign body in the hand. *J Ultrasound Med.* 1987;6(4):217–219
61. Manthey DE, Storrow AB, Milbourn JM, Wagner BJ. Ultrasound versus radiography in the detection of soft-tissue foreign bodies. *Ann Emerg Med.* 1996;28(1):7–9

62. Shiels WE 2nd, Babcock DS, Wilson JL, Burch RA. Localization and guided removal of soft-tissue foreign bodies with sonography. *AJR Am J Roentgenol.* 1990;155(6):1277–1281
63. Hill R, Conron R, Greissinger P, Heller M. Ultrasound for the detection of foreign bodies in human tissue. *Ann Emerg Med.* 1997;29(3):353–356
64. Orlinsky M, Knittel P, Feit T, Chan L, Mandavia D. The comparative accuracy of radiolucent foreign body detection using ultrasonography. *Am J Emerg Med.* 2000;18(4):401–403
65. Friedman DI, Forti RJ, Wall SP, Crain EF. The utility of bedside ultrasound and patient perception in detecting soft tissue foreign bodies in children. *Pediatr Emerg Care.* 2005; 21(8):487–492
66. Barnhart K, Mennuti MT, Benjamin I, Jacobson S, Goodman D, Coutifaris C. Prompt diagnosis of ectopic pregnancy in an emergency department setting. *Obstet Gynecol.* 1994;84(6): 1010–1015
67. Mateer JR, Aiman EJ, Brown MH, Olson DW. Ultrasonographic examination by emergency physicians of patients at risk for ectopic pregnancy. *Acad Emerg Med.* 1995;2(10): 867–873
68. Durham B, Lane B, Burbridge L, Balasubramaniam S. Pelvic ultrasound performed by emergency physicians for the detection of ectopic pregnancy in complicated first-trimester pregnancies. *Ann Emerg Med.* 1997;29(3):338–347
69. Burgher SW, Tandy TK, Dawdy MR. Transvaginal ultrasonography by emergency physicians decreases patient time in the emergency department. *Acad Emerg Med.* 1998;5(8):802–807
70. Durston WE, Carl ML, Guerra W, Eaton A, Ackerson LM. Ultrasound availability in the evaluation of ectopic pregnancy in the ED: comparison of quality and cost-effectiveness with different approaches. *Am J Emerg Med.* 2000;18(4):408–417
71. Kaplan BC, Dart RG, Moskos M, et al. Ectopic pregnancy: prospective study with improved diagnostic accuracy. *Ann Emerg Med.* 1996;28(1):10–17
72. Rodgerson JD, Heegaard WG, Plummer D, Hicks J, Clinton J, Sterner S. Emergency department right upper quadrant ultrasound is associated with a reduced time to diagnosis and treatment of ruptured ectopic pregnancies. *Acad Emerg Med.* 2001;8(4):331–336
73. Shih CH. Effect of emergency physician-performed pelvic sonography on length of stay in the emergency department. *Ann Emerg Med.* 1997;29(3):348–351; discussion 352
74. Blaivas M, Sierzenski P, Plecque D, Lambert M. Do emergency physicians save time when locating a live intrauterine pregnancy with bedside ultrasonography? *Acad Emerg Med.* 2000; 7(9):988–993
75. Mayron R, Gaudio FE, Plummer D, Asinger R, Elsperger J. Echocardiography performed by emergency physicians: impact on diagnosis and therapy. *Ann Emerg Med.* 1988;17(2): 150–154
76. Levitt MA, Jan BA. The effect of real time 2-D-echocardiography on medical decision-making in the emergency department. *J Emerg Med.* 2002;22(3):229–233
77. Ameli S, Shah PK. Cardiac tamponade. Pathophysiology, diagnosis, and management. *Cardiol Clin.* 1991;9(4):665–674
78. Schiavone WA, Ghumrawi BK, Catalano DR, et al. The use of echocardiography in the emergency management of nonpenetrating traumatic cardiac rupture. *Ann Emerg Med.* 1991; 20(11):1248–1250
79. Baxa MD. Cardiac rupture secondary to blunt trauma: a rapidly diagnosable entity with two-dimensional echocardiography. *Ann Emerg Med.* 1991;20(8):902–904
80. Ma OJ, Mateer JR, Ogata M, Kefer MP, Wittmann D, Aprahamian C. Prospective analysis of a rapid trauma ultrasound examination performed by emergency physicians. *J Trauma.* 1995;38(6):879–885
81. Plummer D, Brunette D, Asinger R, Ruiz E. Emergency department echocardiography improves outcome in penetrating cardiac injury. *Ann Emerg Med.* 1992;21(6):709–712
82. Mandavia DP, Hoffner RJ, Mahaney K, Henderson SO. Bedside echocardiography by emergency physicians. *Ann Emerg Med.* 2001;38(4):377–382
83. Milner D, Losek JD, Schiff J, Sicoli R. Pediatric pericardial tamponade presenting as altered mental status. *Pediatr Emerg Care.* 2003;19(1):35–37
84. Spurney CF, Sable CA, Berger JT, Martin GR. Use of a hand-carried ultrasound device by critical care physicians for the diagnosis of pericardial effusions, decreased cardiac function, and left ventricular enlargement in pediatric patients. *J Am Soc Echocardiogr.* 2005;18(4):313–319
85. Salen P, O'Connor R, Sierzenski P, et al. Can cardiac sonography and capnography be used independently and in combination to predict resuscitation outcomes? *Acad Emerg Med.* 2001;8(6):610–615
86. Blaivas M, Fox JC. Outcome in cardiac arrest patients found to have cardiac standstill on the bedside emergency department echocardiogram. *Acad Emerg Med.* 2001;8(6):616–621
87. Hübner U, Schlicht W, Outzen S, Barthel M, Halsband H. Ultrasound in the diagnosis of fractures in children. *J Bone Joint Surg Br.* 2000;82(8):1170–1173
88. Williamson D, Watura R, Cobby M. Ultrasound imaging of forearm fractures in children: a viable alternative? *J Accid Emerg Med.* 2000;17(1):22–24
89. Marshburn TH, Legome E, Sargsyan A, et al. Goal-directed ultrasound in the detection of long-bone fractures. *J Trauma.* 2004;57(2):329–332
90. Lewis D, Logan P. Sonographic diagnosis of toddler's fracture in the emergency department. *J Clin Ultrasound.* 2006;34(4): 190–194
91. Durston W, Swartzentruber R. Ultrasound guided reduction of pediatric forearm fractures in the ED. *Am J Emerg Med.* 2000;18(1):72–77
92. Law KL, Rainer TH, Griffith JF, Metreweli C, Cocks RA. Does ultrasound have a role in the clinical diagnosis and management of fractured ribs [abstract]. *Acad Emerg Med.* 1999;6(5): 480
93. Griffith JF, Rainer TH, Ching AS, Law KL, Cocks RA, Metreweli C. Sonography compared with radiography in revealing acute rib fracture. *AJR Am J Roentgenol.* 1999;173(6): 1603–1609
94. Engin G, Yekeler E, Guloglu R, Acunas B, Acunas G. US versus conventional radiography in the diagnosis of sternal fractures. *Acta Radiol.* 2000;41(3):296–299
95. Hurley ME, Keye GD, Hamilton S. Is ultrasound really helpful in the detection of rib fractures? *Injury.* 2004;35(6):562–566
96. Smith SW. Emergency physician-performed ultrasonography-guided hip arthrocentesis. *Acad Emerg Med.* 1999;6(1): 84–86
97. Shavit I, Eidelman M, Galbraith R. Sonography of the hip-joint by the emergency physician: its role in the evaluation of children presenting with acute limp. *Pediatr Emerg Care.* 2006; 22(8):570–573
98. Jones AE, Tayal VS, Sullivan DM, Kline JA. Randomized, controlled trial of immediate versus delayed goal-directed ultrasound to identify the cause of nontraumatic hypotension in emergency department patients. *Crit Care Med.* 2004;32(8): 1703–1708
99. Randazzo MR, Snoey ER, Levitt MA, Binder K. Accuracy of emergency physician assessment of left ventricular ejection fraction and central venous pressure using echocardiography. *Acad Emerg Med.* 2003;10(9):973–977
100. Moore CL, Rose GA, Tayal VS, Sullivan DM, Arrowood JA, Kline JA. Determination of left ventricular function by emer-

gency physician echocardiography of hypotensive patients. *Acad Emerg Med.* 2002;9(3):186–193
101. Pershad J. A 10-year-old girl with shock: role of emergency bedside ultrasound in early diagnosis. *Pediatr Emerg Care.* 2002;18(3):182–184
102. Pershad J, Chin T. Early detection of cardiac disease masquerading as acute bronchospasm: the role of bedside limited echocardiography by the emergency physician. *Pediatr Emerg Care.* 2003;19(2):E1–E3
103. Gilmore B, Noe HN, Chin T, Pershad J. Posterior urethral valves presenting as abdominal distension and undifferentiated shock in a neonate: the role of screening emergency physician-directed bedside ultrasound. *J Emerg Med.* 2004;27(3):265–269
104. Pershad J, Myers S, Plouman C, et al. Bedside limited echocardiography by the emergency physician is accurate during evaluation of the critically ill patient. *Pediatrics.* 2004;114(6). Available at: www.pediatrics.org/cgi/content/full/114/6/e667
105. Blaivas M. Bedside emergency department ultrasonography in the evaluation of ocular pathology. *Acad Emerg Med.* 2000;7(8):947–950
106. Blaivas M, Theodoro D, Sierzenski PR. A study of bedside ocular ultrasonography in the emergency department. *Acad Emerg Med.* 2002;9(8):791–799
107. Malayeri AA, Bavarian S, Mehdizadeh M. Sonographic evaluation of optic nerve diameter in children with raised intracranial pressure. *J Ultrasound Med.* 2005;24(2):143–147
108. Tayal VS, Neulander M, Norton HJ, Foster T, Saunders T, Blaivas M. Emergency department sonographic measurement of optic nerve sheath diameter to detect findings of increased intracranial pressure in adult head injury patients. *Ann Emerg Med.* 2007;49(4):508–514
109. Tsung JW, Blaivas M, Cooper A, Levick NR. A rapid noninvasive method of detecting elevated intracranial pressure using bedside ocular ultrasound: application to 3 cases of head trauma in the pediatric emergency department. *Pediatr Emerg Care.* 2005;21(2):94–98
110. Blaivas M, Sierzenski P, Lambert M. Emergency evaluation of patients presenting with acute scrotum using bedside ultrasonography. *Acad Emerg Med.* 2001;8(1):90–93
111. Peterson MA, Abele J. Bedside ultrasound for difficult lumbar puncture. *J Emerg Med.* 2005;28(2):197–200
112. Ferre RM, Sweeney TW. Emergency physicians can easily obtain ultrasound images of anatomical landmarks relevant to lumbar puncture. *Am J Emerg Med.* 2007;25(3):291–296
113. Abo A, Chen L, Santucci K. Optimal position for lumbar puncture in children, evaluated by ultrasonography [abstract]. *Pediatr Emerg Care.* 2005;21(8):554
114. Krause I, Birk E, Davidovits M, et al. Inferior vena cava diameter: a useful method for estimation of fluid status in children on haemodialysis. *Nephrol Dial Transplant.* 2001;16(6):1203–1206
115. Katzarski KS, Nisell J, Randmaa I, Danielsson A, Freyschuss U, Bergstrom J. A critical evaluation of ultrasound measurement of inferior vena cava diameter in assessing dry weight in normotensive and hypertensive hemodialysis patients. *Am J Kidney Dis.* 1997;30(4):459–465
116. Duvekot JJ, Cheriex EC, Tan WD, Heidendal GA, Peeters LL. Measurement of anterior-posterior diameter of inferior vena cava by ultrasonography: a new non-invasive method to assess acute changes in vascular filling state. *Cardiovasc Res.* 1994;28(8):1269–1272
117. Dietel T, Filler G, Grenda R, Wolfish N. Bioimpedance and inferior vena cava diameter for assessment of dialysis dry weight. *Pediatr Nephrol.* 2000;14(10–11):903–907
118. Cheriex EC, Leunissen KM, Janssen JH, Mooy JM, van Hooff JP. Echography of the inferior vena cava is a simple and reliable tool for estimation of 'dry weight' in haemodialysis patients. *Nephrol Dial Transplant.* 1989;4(6):563–568
119. Chun R, Kirkpatrick AW, Sirois M, et al. Where's the tube? Evaluation of hand-held ultrasound in confirming endotracheal tube placement. *Prehospital Disaster Med.* 2004;19(4):366–369
120. Hsieh KS, Lee CL, Lin CC, Huang TC, Weng KP, Lu WH. Secondary confirmation of endotracheal tube position by ultrasound image. *Crit Care Med.* 2004;32(9 suppl):S374–S377
121. Raphael DT, Conard FU 3rd. Ultrasound confirmation of endotracheal tube placement. *J Clin Ultrasound.* 1987;15(7):459–462
122. Weaver B, Lyon M, Blaivas M. Confirmation of endotracheal tube placement after intubation using the ultrasound sliding lung sign. *Acad Emerg Med.* 2006;13(3):239–244
123. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. *Acad Emerg Med.* 2005;12(9):844–849
124. Dulchavsky SA, Hamilton DR, Diebel LN, Sargsyan AE, Billica RD, Williams DR. Thoracic ultrasound diagnosis of pneumothorax. *J Trauma.* 1999;47(5):970–s971
125. Dulchavsky SA, Schwarz KL, Kirkpatrick AW, et al. Prospective evaluation of thoracic ultrasound in the detection of pneumothorax. *J Trauma.* 2001;50(2):201–s205
126. Kirkpatrick AW, Ng AK, Dulchavsky SA, et al. Sonographic diagnosis of a pneumothorax inapparent on plain radiography: confirmation by computed tomography. *J Trauma.* 2001;50(4):750–752
127. Knudtson JL, Dort JM, Helmer SD, Smith RS. Surgeon-performed ultrasound for pneumothorax in the trauma suite. *J Trauma.* 2004;56(3):527–530
128. Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. *Chest.* 1995;108(5):1345–1348
129. Lichtenstein D, Meziere G, Biderman P, Gepner A. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. *Intensive Care Med.* 1999;25(4):383–388
130. Lichtenstein D, Meziere G, Biderman P, Gepner A. The "lung point": an ultrasound sign specific to pneumothorax. *Intensive Care Med.* 2000;26(10):1434–1440
131. Lichtenstein D, Meziere G. Ultrasound probably has a bright future in the diagnosis of pneumothorax. *J Trauma.* 2002;52(3):607
132. Lichtenstein DA, Meziere G, Lascols N, et al. Ultrasound diagnosis of occult pneumothorax. *Crit Care Med.* 2005;33(6):1231–1238
133. Sargsyan AE, Hamilton DR, Nicolaou S, et al. Ultrasound evaluation of the magnitude of pneumothorax: a new concept. *Am Surg.* 2001;67(3):232–235; discussion 235–236

Bedside Ultrasound in Pediatric Emergency Medicine

Jason A. Levy and Vicki E. Noble

Pediatrics 2008;121;e1404
DOI: 10.1542/peds.2007-1816