SPECIAL ARTICLE

Point-of-Care Ultrasound for the Pediatric Hospitalist's Practice

Akshata Hopkins, MD,[a] Stephanie J. Doniger, MD, RDMS[b]

ABSTRACT Point-of-care ultrasound (POCUS) has the potential to provide real-time valuable information that could alter diagnosis, treatment, and management practices in pediatric hospital medicine. We review the existing pediatric POCUS literature to identify potential clinical applications within the scope of pediatric hospital medicine. Diagnostic point-of-care applications most relevant to the pediatric hospitalist include lung ultrasound for pneumothorax, pleural effusion, pneumonia, and bronchiolitis; cardiac ultrasound for global cardiac function and hydration status; renal or bladder ultrasound for nephrolithiasis, hydronephrosis, and bladder volumes; soft tissue ultrasound for differentiating cellulitis from abscess; and procedural-guidance applications, including line placement, lumbar puncture, and abscess incision and drainage. We discuss POCUS applications with reviews of major pathologic findings, research gaps, the integration of POCUS into practice, and barriers to implementation.

www.hospitalpediatrics.org
DOI:https://doi.org/10.1542/hpeds.2018-0118

Address correspondence to Akshata Hopkins, MD, Office of Medical Education, Johns Hopkins All Children's Hospital, 600 5th St South, Suite 3100, St. Petersburg, FL 33701. E-mail: ahopki16@jhmi.edu

HOSPITAL PEDIATRICS (ISSN Numbers: Print, 2154-1663; Online, 2154-1671).

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

FUNDING: No external funding.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

Dr Hopkins conceptualized and drafted the initial manuscript and revised the final manuscript; Dr Doniger reviewed and revised the manuscript and provided all images; and both authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

[a]Johns Hopkins All Children's Hospital, St. Petersburg, Florida; and [b]St. Christopher's Hospital for Children, Philadelphia, Pennsylvania

Point-of-care ultrasound (POCUS) was first introduced into the practice of emergency medicine (EM) in the 1980s.[1,2] The American College of Emergency Physicians has been instrumental in delineating POCUS applications and training for EM physicians; pediatric-specific POCUS guidelines were published in 2015 and jointly endorsed by the American College of Emergency Physicians, the American Academy of Pediatrics (AAP), the Society for Academic Emergency Medicine, and the World Interactive Network Focused on Critical Ultrasound.[3] The future of POCUS remains to be expanded into other pediatric subspecialties, including pediatric hospital medicine (PHM).[4]

POCUS is distinct from radiology-performed ultrasound, in that the clinician integrates the results with the clinical history and physical examination at the bedside. POCUS has the potential to provide real-time valuable information that could alter diagnosis, treatment, and management practices for pediatric hospitalists. POCUS is cost-effective and efficient while avoiding the use of ionizing radiation, which is particularly important in pediatric populations.[4–7]

The purpose of this article is to describe specific POCUS applications that could be performed in PHM, discuss POCUS' benefits and limitations compared with current practice, and identify research gaps (Table 1).[8–10]

DIAGNOSTIC APPLICATIONS

Lung

In 1995, Lichtenstein first described the use of POCUS for lung pathology (Supplemental Table 2).[11] Lung ultrasound has become a fundamental application for POCUS in many specialties in both pediatric and adult patient populations.[12] Although most initial studies were performed in adults, researchers in more recent studies have applied lung POCUS to pediatric populations and focused on the identification of pneumonias, pneumothorax, and bronchiolitis.[4,13–20]

Pneumothorax

Although relatively uncommon in pediatric patients, the overall incidence of clinically significant spontaneous pneumothoraces has steadily increased since 1997. Current guidelines recommend chest radiographs (CXRs) for the initial diagnosis, follow-up, and/or sudden clinical decompensation.[21]

When evaluating for the presence of a pneumothorax, the 2 most helpful POCUS signs are the absence of lung sliding and the presence of a lung point (Supplemental Table 2).[22–24] In normal lung, the presence of lung sliding can be visualized in real time and confirmed in motion mode (M-mode) by the presence of the "seashore sign" (Supplemental Fig 6). When a pneumothorax is present, there is an absence of lung sliding, creating the M-mode pattern of the "stratosphere sign" (Supplemental Fig 7). The absence of lung sliding has a sensitivity and negative predictive value of 100%, specificity of 91%, and a positive predictive value of 87%.[11] The "lung point" is 66% sensitive and 100% specific for a pneumothorax.[23,25] Compared with CXR, POCUS has been shown to have comparable specificities of 99% (95% confidence interval [CI]: 97.3% to 100%). However, POCUS has a higher sensitivity than CXR (ultrasound: 78.6% [95% CI: 68.1% to 98.1%] versus CXR: 39.8% [95% CI: 29.4% to 50.3%]).[26,27] Although most studies have been conducted with adults, similar findings have been confirmed in pediatric and neonatal literature.[22,28]

Research gaps include the impact on the initial diagnosis in hospitalized patients. In addition, the potential impact on radiation exposure, costs, or hospital length of stay is unknown.

Pneumonia

Pneumonia continues to be a principal admitting diagnosis and a leading cause of mortality worldwide in pediatric patients. Current guidelines recommend a CXR at hospital admission.[29] In practice, CXRs are often repeated with sudden clinical deterioration or inadequate treatment response.[13,29]

With POCUS, pneumonias may be seen as subpleural consolidations or "hepatization" of the lung (Fig 1, Supplemental Table 2).[30] POCUS can help differentiate pneumonias from atelectasis.[12] Although POCUS more readily detects consolidations (~9.4 mm) when compared with CXRs (~26 mm) ($P < .0001$), it may not be able to recognize consolidations that are more centrally located.[14–16,31]

There is a growing body of evidence in the adult literature in which it is reported that lung ultrasound is as accurate as CXR in diagnosing pneumonias.[32] POCUS is actually more sensitive (86%) (95% CI: 71% to 94%) and more specific (89%) (95% CI: 83% to 93%) in diagnosing pneumonias when compared with overall clinical impression (39%) (95% CI: 32% to 57%), auscultation (76%) (95% CI: 68% to 81%), and tachypnea (75%) (95% CI: 68% to 81%); the performance of lung POCUS increases when lung consolidations are >1 cm in size.[16] In a recent systematic review and meta-analysis, it was found that lung POCUS compared with CXR examination or computerized tomography (CT) had a pooled sensitivity and specificity of 94% (95% CI: 92% to 96%) and 96% (95% CI: 94% to 97%), respectively, and a pooled positive and negative LR of 16.8 (7.7–37.0) and 0.07 (0.05–0.10), respectively.[33]

Pediatric studies have confirmed that lung POCUS is highly accurate in diagnosing pneumonias in children when compared with CXR or CT.[16–18,34–36] In a recent meta-analysis, a pooled sensitivity of 96% (95% CI: 94% to 97%), specificity of 93% (95% CI: 90% to 96%), positive likelihood ratio of 15.3 (95% CI: 6.6 to 35.3), and negative likelihood ratio of 0.06 (95% CI: 0.03 to 0.11) were shown.[19] Lung POCUS has a high interrater agreement for normal lung (k = 0.73 [95% CI: 0.70 to 0.74]) and lung consolidation (k = 0.77 [95% CI: 0.75 to 0.78]) compared with the interrater agreement for normal CXRs (k = 0.40 [95% CI: 0.37 to 0.42]) and lung consolidation (k = 0.51 [95% CI: 0.48 to 0.58]).[34] In a recent randomized controlled trial comparing lung ultrasonography with CXR in diagnosing pneumonia, there was a 38.8% (95% CI: 30.0% to 48.9%) reduction in CXRs performed, with no cases of missed diagnoses, adverse events, or subsequent unscheduled health care visits.[35] Although this research seems promising, the impact of lung ultrasound on overdiagnosis, unnecessary antibiotics, CXRs, and hospital

TABLE 1 Current Accepted POCUS Applications for EM or Pediatric EM and Potential POCUS Applications for PHM[8–10]

System	Accepted POCUS Applications for EM/Pediatric EM	Potential POCUS Applications for PHM
Lung	Pneumothorax	Pneumothorax
	Hemothorax	Pneumonia
	Pneumonia	Pleural effusion, empyema
	Pleural effusion, empyema	Bronchiolitis or viral pneumonia
	Bronchiolitis or viral pneumonia	
	Interstitial pathology	
Cardiac	Global cardiac function	Global cardiac function
	Assessment of hydration status	Assessment of hydration status
	Asystole	Asystole
	Pericardial effusions	Pericardial effusions
	Contractility	
Abdominal	Abdominal trauma with hemoperitoneum	Constipation
	Gallbladder (cholecystitis, cholelithiasis)	
	Appendicitis	
	Intussusception	
	Hypertrophic pyloric stenosis	
Renal or bladder	Bladder volume assessment	Bladder volume assessment
	Hydronephrosis	Hydronephrosis
	Nephrolithiasis	Nephrolithiasis
		UTI or pyelonephritis
Skin and soft tissue	Cellulitis or abscess	Cellulitis or abscess
	Foreign bodies	
Procedures	Bladder catheterization	Bladder catheterization
	Vascular access (central, peripheral)	Vascular access (peripheral)
	LP	LP
	Abscess incision and drainage	
	Paracentesis	
	Pericardiocentesis	
	Thoracentesis	
	Nerve blocks	
	Fracture reductions	
	Arthrocentesis	
	Endotracheal tube placement confirmation	
Other	Pelvic ultrasound: obstetrics	
	Pelvic ultrasound: gynecology	
	Scrotal	
	Neck (lymphadenopathy versus abscess versus masses)	
	Sinusitis	
	Optic nerve measurement (intracranial hypertension)	
	Ocular pathology (globe rupture, retinal detachment)	

lengths of stay and clinical outcomes have yet to be studied in the pediatric inpatient hospital setting.

Pleural Effusions

In PHM, pleural effusions are most commonly secondary to complicated pneumonias but can also be due to inflammation, fluid overload, malignancy, chylothorax, or trauma. Although a CT scan is the gold standard for the diagnosis of pleural effusions, radiology-performed ultrasound has shown to have similar sensitivity and diagnostic accuracy.[37] The presence of an effusion replaces the normal mirror-image artifact above the diaphragm (Supplemental Fig 8) and exhibits the "spine sign" (Supplemental Table 2, Fig 2). Complex fluid collections or empyemas can be visualized with floating particles or fibers within the fluid.[30]

In adult patients, lung POCUS is 93% sensitive and 97% specific for qualitatively identifying clinically significant pleural effusions.[31] Serial POCUS examinations can be performed to monitor resolution or identify evolving complications such as septations or empyemas.[38,39] The ability of lung POCUS to identify complex effusions in pediatric patients correlates with both CXRs and chest CT ($k = 1.0$).[19]

It is unknown whether serial lung POCUS would impact morbidity and illness duration because of a change in the rate of procedural interventions.

Bronchiolitis

Bronchiolitis is the most common lower respiratory tract infection that affects infants and children <2 years of age, with a significant increase in admissions for those with high-risk medical conditions (34% increase, $P < .001$).[40] Sonographic findings have been described as subpleural lung consolidations and pleural line abnormalities that are present in several lung scanning regions (Supplemental Fig 9).[20]

Although the AAP does not recommend routine imaging for bronchiolitis, lung POCUS may be helpful in identifying those patients with the potential to have increased disease severity.[41,42] In a recent observational cohort study, it was shown

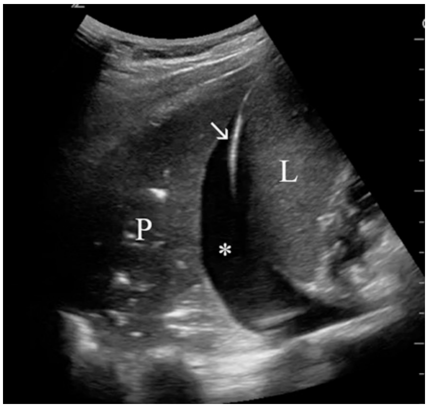

FIGURE 1 Pulmonary consolidation with "hepatization" of the lung. The appearance of the lung, which is typically not seen on ultrasound because it is an aerated structure. With pulmonary consolidation (P), the lung appears sonographically similar to liver (L) tissue. Note, there is also a small anechoic pleural effusion (*) above the diaphragm (arrow).

that lung POCUS was able to identify infants in need of supplemental oxygen with a sensitivity of 96.6% (95% CI: 82.2% to 99.4%), specificity of 98.7% (95% CI: 93% to 99.8%), positive predictive value of 96.6% (95% CI: 82.2% to 99.4%), and a negative predictive value of 98.7% (95% CI: 92.95% to 99.8%).[42] It is unknown how POCUS would compare with radiographs in severe or atypical cases of bronchiolitis. Because bronchiolitis is a clinical diagnosis, the effect on length of stay and cost due to overdiagnosis would be important to monitor. The clinical examination and vital signs may still be the most valuable method to help predict course and severity of illness.

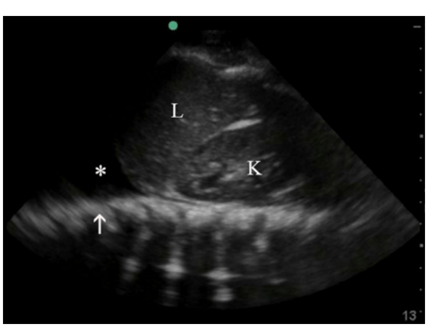

FIGURE 2 Pleural effusion. The presence of an anechoic pleural effusion (*) will obliterate the mirror-image artifact that is seen with normal lung (Supplemental Fig 8). In addition, spine sign (arrow) can be visualized, which occurs when visualization of the spine continues above the diaphragm when fluid is present. K, kidney; L, liver.

Cardiac

The focused cardiac ultrasound (FOCUS) includes the evaluation of the heart and the inferior vena cava (IVC) and can contribute important information about the patient's cardiac function and hydration status that may not be apparent on physical examination.[43–45] FOCUS has long been used in the adult emergency and critical care settings, and its use has been endorsed by several emergency, critical care, and echocardiography societies worldwide.[46] Traditionally, FOCUS is used to diagnose pericardial effusions, assess for asystole, and assess global function and contractility. It is important to note that FOCUS is not meant to identify complex congenital heart disease or replace a comprehensive echocardiogram.

In basic and advanced pediatric life support literature, authors support the use of FOCUS for the evaluation of asystole while limiting interruptions in chest compressions.[46] In community or low-resource settings, FOCUS can be lifesaving in diagnosing asystole and pericardial effusions. Although these applications can be lifesaving, for the majority of pediatric hospitalists, it will not commonly be part of their daily practice.

Dehydration

Clinical dehydration secondary to vomiting and diarrhea is a common indication for pediatric hospital admission. Unfortunately, the history and physical examination findings in children are often unreliable in the diagnosis of dehydration.[47]

In adult patients, POCUS of the IVC has been used to estimate intravascular volume status through absolute measurements, collapsibility index, IVC to aorta ratio, or the "Gestalt" method.[46,48–51] In most studies, authors reported a statistically significant positive correlation between sonographic measurements of the IVC and central venous pressure.[52] Serial average IVC diameters are statistically significantly lower in hypovolemic patients compared with healthy controls ($P = .001$) and increase after fluid resuscitation compared with controls ($P = .001$).[53] POCUS examinations may be repeated with ongoing fluid resuscitation to monitor efficacy of interventions.[46,50,54,55]

In initial pediatric studies, authors suggested that the IVC to aorta ratio may correlate with fluid status,[48,54,56] with the IVC to aorta ratio lower in dehydrated patients.[48] However, the IVC to aorta ratio was found to be only marginally accurate, with a sensitivity of 86% and specificity of 56%.[54] In critically ill children, it has been shown to have poor correlation with central venous pressure monitoring.[55] An alternate approach is to evaluate the IVC through the Gestalt method. With changes in intrathoracic pressure, the IVC exhibits respiratory variation, with $>$50% suggesting dehydration.

Researchers have not yet investigated the accuracy of the Gestalt method or the integration of IVC and cardiac assessment in pediatric patients.

Shock

Pediatric hospitalists and intensivists are developing best practices for the early identification of sepsis, dehydration, myocarditis, and effusions. FOCUS can rapidly assess global cardiac function and can help distinguish between the different types of shock.

The Rapid Ultrasound for Shock and Hypotension (RUSH) protocol was first described for use in adult emergency and critical care patients to distinguish among different types of shock. For adult patients, the RUSH protocol includes cardiac, IVC, focused assessment with sonography for trauma, aorta, deep vein thrombosis, and lung studies. It is an example of a clinically integrated approach to help distinguish between the different types of shock.[57] Although Park et al[58] introduced the idea of applying a modified RUSH protocol (ie, without the aorta and deep vein thrombosis studies) to critically ill pediatric patients in a case series, it has not yet been studied in children.

Tremendous research gaps remain for FOCUS and pediatric patients; it is unknown whether a RUSH protocol modified for pediatric patients could impact the early recognition of pediatric sepsis and clinical outcomes of morbidity and mortality.

Abdominal

The majority of abdominal POCUS applications have traditionally been focused on the "acute abdomen" (appendicitis, intussusception, pyloric stenosis) or trauma in emergency care settings.[59–61] Although these applications continue to be rigorously studied in the acute care setting, their use is beyond the scope of practice for the pediatric hospitalist. However, novel applications, such as the use of POCUS to assess for constipation, would be more applicable to the pediatric hospitalist's practice.

Constipation

Between 1997 and 2009, the number of children hospitalized with constipation rose by 112%. The cost of inpatient care for constipation increased by 221.5% during that same period without a significant change in hospital lengths of stay.[62] Although constipation should be a clinical diagnosis, history and physical examination findings are often unreliable, and abdominal radiographs are frequently obtained to support the diagnosis. Abdominal radiographs have been shown to have wide ranges of sensitivities and specificities of 60% to 80% and 35% to 90%, respectively.[63–65] Despite their poor performance, clinicians frequently obtain abdominal radiographs to evaluate for stool burden (70%), the need for a "clean-out" (35%), fecal impaction (27%), alternate cause for abdominal pain (24%), demonstration of stool burden to families (14%), assessment of response to therapy (13%), or encopresis (10%).[66] POCUS could be a valuable adjunct to the physical examination and has the potential to replace abdominal radiographs.[10]

In one prospective cohort study of pediatric patients ages 4 to 17, researchers evaluated the transrectal diameter (TRD) and its accuracy in diagnosing constipation compared with the ROME III questionnaire (current gold standard). A TRD measurement cutoff of 3.8 cm was found to be diagnostic for constipation, with a sensitivity of 86% (95% CI: 69% to 96%), specificity of 71% (95% CI: 53% to 85%), negative predictive value of 0.87 (95% CI: 0.68 to 0.95), and positive predictive value of 0.70 (95% CI: 0.52 to 0.84).[10] POCUS performed similarly to abdominal radiographs, and therefore 88% of the radiographs could have been eliminated. There is potential that adding additional sonographic views may improve the ability to assess for stool burden. This is a relatively novel application, and therefore large research gaps remain, and more studies are needed.

Renal and Bladder

POCUS can be used as an adjunct to identify pathology of the kidney, collecting system, and bladder. On POCUS, normal kidneys have uniform echogenicity, with structures such as the renal pelvis and pyramids (Supplemental Fig 10). POCUS can help identify hydronephrosis, nephrolithiasis, renal abscesses, and renal cysts. The bladder can also be visualized and assessed for adequate bladder volume before urinary catheterization and to measure postvoid residuals in the hospitalized pediatric patient.[67–69]

Hydronephrosis, Nephrolithiasis

In pediatrics, hydronephrosis can be seen in the setting of urinary tract infections (UTIs) and pyelonephritis, nephrolithiasis, and obstructive congenital anatomic pathologies. The incidence of pediatric nephrolithiasis hospitalizations is increasing.[70,71] Both the American Urologic Association and European Society for Pediatric Radiologists recommend ultrasound as the initial imaging modality of choice.[72] On POCUS, hydronephrosis is identified by the dilatation of the renal pelvis. (Fig 3).[69] False positives for hydronephrosis may be encountered in the setting of rapid oral or intravenous (IV) hydration.[73] POCUS can aid in determining the presence of hydronephrosis secondary to calculi obstruction and occasionally in identifying the stone itself. The ability of POCUS to detect stones is variable depending on the size and location. It is important to note that the absence of hydronephrosis does not rule out nephrolithiasis.[74]

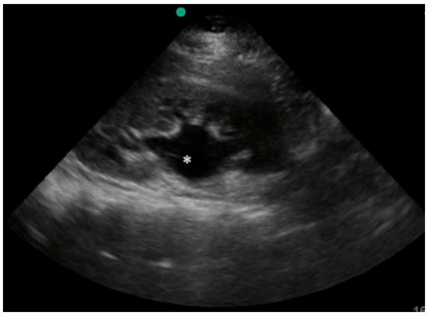

FIGURE 3 Hydronephrosis. With hydronephrosis, there is an anechoic dilatation (*) at the renal pelvis, or central hilum.

In the adult literature, POCUS has primarily focused on evaluating for the presence of hydronephrosis secondary to obstructive nephrolithiasis. In patients presenting with renal colic, sensitivities for detecting hydronephrosis range from 72% to 97% (95% CI: 59% to 99%) and specificities range from from 73% to 83% (95% CI: 52% to 94%), when compared with either CT scan or IV pyelogram.[75–79] In an adult multicenter comparative effectiveness trial, the initial POCUS was associated with a significant decrease in cumulative radiation exposure ($P < .001$) when compared with radiology-performed ultrasound and CT scan. However, there were no significant differences in complications, serious adverse events, pain scores, or hospitalizations when compared with formal radiology ultrasound and CT scan.[80]

In pediatric patients, the cornerstone for the evaluation for hydronephrosis is radiology-performed ultrasound. Guedj et al[81] recently assessed the accuracy of renal POCUS in detecting hydronephrosis in children presenting to the emergency department with complicated UTIs. Renal POCUS performed with a sensitivity of 76.5% (95% CI: 58.1% to 94.6%), specificity of 97.2% (95% CI: 95.2% to 99.2%), positive predictive value of 59.1% (95% CI: 36.4% to 79.3%), and negative predictive value of 98.8% (95% CI: 97.7% to 99.9%) when compared with radiologists' interpretations.[81] As with adult patients with nephrolithiasis, the goal is to evaluate for the presence of hydronephrosis secondary to an obstructing stone. Radiology-performed ultrasound has been shown to be 66.7% sensitive (95% CI: 48.8% to 80.8%) and 97.4 specific (95% CI: 86.8% to 99.9%) for detecting stones, with a false-negative rate of 59%.There is a paucity of pediatric-specific literature in which researchers assessed suspected nephrolithiasis, particularly in comparison with CT.[82,83] Although imaging may not be necessary in the acute setting, POCUS could be a useful screening tool for hospitalized patients who fail to respond to medical management.[81,84]

UTIs and Pyelonephritis

Approximately 4.7% of children with UTIs require inpatient management.[85] For infants <24 months of age, the AAP continues to recommend renal and bladder ultrasound to assess for undiagnosed pathology.[86] POCUS is an attractive screening option because it is noninvasive and does not require contrast or radiation exposure.

In adults, POCUS can identify complications of UTIs, such as renal abscesses. POCUS detected abnormalities suggestive of acute pyelonephritis in 36.9% of adult patients in the emergency department and in 60.9% of complicated cases. One-third of these patients required surgical intervention without a delay in diagnosis.[84]

In pediatrics, although imaging may not be necessary in the acute setting, POCUS can be used to identify renal abscesses or hydronephrosis if a hospitalized patient fails to respond to medical management.[81,84] According to the most recent AAP recommendations, after completion of antibiotic therapy for UTIs, nonurgent renal ultrasound is recommended in all children 2 months to 2 years of age to identify anatomic abnormalities that may lead to recurrent UTIs and renal scarring. Although this may be performed in the outpatient setting, some may be lost to follow-up. Although not traditionally within the scope of POCUS practice, it could potentially be performed before hospital discharge, to ensure appropriate imaging.[86]

This application has been poorly studied in pediatric patients, and therefore there are large research gaps regarding test characteristics and patient outcomes.

Bladder Volume

POCUS can be used to assess the bladder volume (Fig 4), thereby distinguishing between urinary retention (voiding dysfunction) and oliguria.[44,68] It can also be used to determine bladder volume before urinary catheterization, thereby increasing the success of first-attempt catheterizations.[87]

In adults, POCUS has been used to evaluate for urinary retention and postvoid residuals.[88] This has also been applied to pediatric patients, particularly in the age of <24 months. Milling et al[89] measured the bladder index in infants and found that a bladder index of 2.4 cm^2 correlated with 2 to 2.5 mL of urine, the minimum amount required for urinalysis and culture, thereby being considered a successful catheterization.[89] First-attempt urinary catheterization rates were higher when POCUS was first used to ensure adequate bladder volume before catheterization, with a success rate of 96% (95% CI: 93% to 99%) as compared with 72% without ultrasound (95% CI: 66% to 78%).[87] POCUS has shown to more accurately assess postvoid residual volumes compared with bladder scans, particularly in infants <24 months of age.[44,90]

Skin and Soft Tissue

Hospital admissions for skin and soft tissue infections (SSTIs) have nearly doubled between 1997 and 2009.[91] As such, more pediatric hospitalists are increasingly managing soft tissue infections, with soft tissue POCUS having the potential to have an impact on their daily practice.

Cellulitis Versus Abscess

SSTIs represent the spectrum of simple cellulitis to advanced cellulitis to frank abscess. Soft tissue ultrasound can be used to distinguish normal skin (Supplemental Fig 11) from cellulitis (Supplemental Fig 12) and abscesses (Fig 5) and whether a drainable abscess is present.[92] Although POCUS cannot distinguish between inflammatory and infectious fluid, an abscess usually appears as an irregular anechoic or hypoechoic structure (Fig 5). If an incision and drainage is performed, POCUS can help identify and avoid surrounding neurovascular structures.

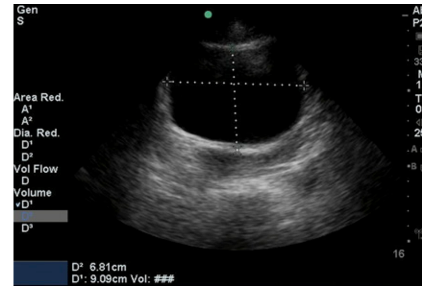

FIGURE 4 Bladder volume calculation. Many modern ultrasound machines have automated calculation software. To perform the volume calculation, the bladder needs to be imaged in the transverse and sagittal planes. In the transverse plane, the depth is measured, followed by the width. Then, the transducer is rotated with the indicator toward the patient's head to obtain the final measurement in the sagittal plane. Measurements are saved and automatically calculated by software, which accounts for the bladder volume correction factor. The vertical dashed line denotes the depth in the transverse view; the horizontal dashed line represents the width in the transverse view.

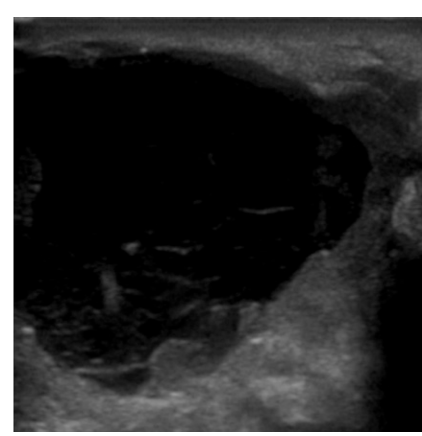

FIGURE 5 Soft tissue ultrasound, abscess. An abscess is a large, irregular fluid collection that may appear anechoic or differing echogenicities.

After incision and drainage is performed, POCUS can be used to ensure the entire abscess is drained without any remaining fluid or loculations.

In adult patients, Squire et al[93] showed that abscess identification by clinical examination had a sensitivity and specificity of 86% (95% CI: 76% to 93%) and 70% (95% CI: 55% to 82%), respectively. When the physical examination is combined with POCUS, the sensitivity and specificity increased to 98% (95% CI: 93% to 100%) and 88% (95% CI: 76% to 96%), respectively.[93] POCUS can be particularly useful when an underlying abscess may not be clinically apparent and can change management in 36% to 48% of cases.[94] Patients with an abscess who had POCUS done on initial presentation failed therapy less often than those who did not have a POCUS performed (4.4% vs 14.6%; $P < .005$).[95]

Similar results have been shown in pediatric studies. Iverson et al[96] showed an increased sensitivity from 78.7% to 97.5% when clinical examination is combined with POCUS; however, the specificities remained the same. In other studies, researchers have shown similar results.[97–100] In a recent systematic review of 800 adult and pediatric patients, POCUS had a pooled sensitivity of 97% (95% CI: 94% to 98%), specificity of 83% (95% CI: 75% to 88%), positive likelihood ratio of 5.5 (95% CI: 3.7 to 8.2), and negative likelihood ratio of 0.04 (95% CI: 0.02 to 0.08) compared with clinical examination alone.[97] Adams et al[98] showed that for every 4 POCUS examinations performed, there was 1 correct change in management decision on the basis of the POCUS results. In these cases, POCUS may improve diagnostic accuracy and expedite management.[101]

Although soft tissue infections have been studied in the acute care setting, few studies have focused on the impact of inpatient measures, such as hospital lengths of stay, treatment outcomes, and cost effectiveness. In addition, the use of POCUS could be expanded to include SSTIs of the neck, including lymphadenitis, masses, and anatomic abnormalities, although this has not yet been studied.

PROCEDURAL GUIDANCE

POCUS has been shown to improve the overall safety and success of a variety of procedures. POCUS may be used to identify structures and mark the skin before performing the procedure (ultrasound assistance) or used in real time during the procedure (ultrasound guidance). Although there are few procedures that pediatric hospitalists routinely perform, line placement and lumbar puncture (LP) are among the most common for the pediatric hospitalist.[102]

Line Placement

Peripheral line placement is the most common procedure performed in pediatric patients of all ages. Failure to obtain vascular access can lead to unnecessary treatment delays, pain, and emotional distress. There are international consensus guidelines regarding the use of POCUS for both central and peripheral line placement.[103] Ultrasound guidance has been shown to be superior to ultrasound assistance.[104] Pediatric hospitalists rarely place central lines, arterial lines, and peripherally inserted central catheters; the discussion will be, therefore, limited to peripheral lines. Of note, POCUS can be a noninvasive method to accurately confirm proper peripherally inserted central catheter line placement.[105]

In a systematic review including adult and pediatric patients, researchers showed increased success rates with ultrasound guidance compared with blind attempts, with a pooled odds ratio of 2.42 (95% CI: 1.26 to 4.68; $P = .008$).[106] In another study, researchers showed that those who used ultrasound guidance made fewer attempts to achieve successful placement.[107]

Limited pediatric studies have suggested an increased overall success rate for ultrasound-guided peripheral IV placement in patients with difficult access. In a randomized controlled trial, Doniger et al[108] compared ultrasound guidance to traditional methods for peripheral IV placement in children with difficult access. No statistical difference in overall success rates (80% ultrasound-guided versus 64% traditional attempts [95% CI: −9% to 38%, $P = .208$]) was shown in the results. However, the ultrasound group required less overall time to placement (6.3 vs 14.4 minutes [95% CI: −12.5 to −3.6], $P = .001$), fewer attempts (median: 1 vs 3, $P = .004$), and fewer needle redirections (median: 2 vs 10, $P < .001$).[108] Recently, there has been concern regarding infection rates and sustainability of ultrasound-guided peripheral IVs. However, Vinograd et al[109] showed that ultrasound-guided peripheral IVs had lower 48-hour failure rates and lower infiltration and phlebitis rates. An overall success rate of 91% within first and second attempts was also shown, in which 55% of the pediatric patients had reported a history of difficult IV access.[109]

Although well studied in adult patients, there are few studies in which researchers investigate POCUS for peripheral lines in the pediatric inpatient setting. Other research gaps include patient outcomes and patient satisfaction.

LP

Pediatric hospitalists routinely perform LPs to evaluate for central nervous system infections (ie, meningitis), autoimmune diseases, and idiopathic intracranial hypertension. POCUS can readily identify interspinous spaces (Supplemental Fig 13), thereby facilitating the performance of LPs.[110,111] Although traditional techniques are largely accurate, when challenges do arise, patients often require fluoroscopic guidance, exposing them to ionizing radiation. Alternatively, radiologists may perform ultrasound-guided LPs; however, this often leads to delay in diagnosis and treatment. With diagnostic delays, a patient may have antibiotic administration delayed or receive antibiotic pretreatment, which ultimately confounds the clinical picture.

In several adult studies, researchers have shown ultrasound-assisted LPs to have high success rates. Even in obese patients, POCUS has been shown to be effective in identifying landmarks for LPs.[112,113] In a randomized control trial, researchers demonstrated that POCUS had a higher success rate (95.8%) than the traditional landmark technique (relative risk: 1.32; 95% CI: 1.01 to 1.72).[114] Mofidi et al[115] showed that ultrasound-assisted LP had decreased overall procedure times, number of attempts, number of traumatic taps, and pain scores; these results were particularly prominent in obese patients. However, the use of ultrasound assistance for LPs is not supported in all literature. Lahham et al[116] showed no significant differences between the ultrasound guidance and the traditional landmark approach, with regard to procedural time, needle redirection, or needle reinsertion.

In one of the first studies of ultrasound for LPs in children, researchers evaluated the interspinous spaces in infants. Surprisingly, they found that the spaces were largest in the seated position rather than the traditional teaching of the lateral recumbent position.[110] In a prospective randomized controlled trial in infants <6 months of age, authors reported that ultrasound assistance improved both first-attempt success rates (absolute risk difference: 27%; 95% CI: 10% to 43%) and overall success rates (absolute risk difference: 31%; 95% CI: 15% to 47%).[117] However, recently, Kessler et al[118] published the largest randomized controlled trial to date. In infants <3 months of age, there were no differences in success rates, rates of traumatic LPs, number of attempts, or duration of LP.[118] It is unclear whether ultrasound assistance would be useful for the pediatric hospitalist, given the inconsistent data supporting its use in acute care settings.

INTEGRATION INTO PRACTICE

Although POCUS has grown exponentially in the last decade, it is still in its infancy in PHM. Although specific training pathways have yet to be described for PHM, well-established guidelines from other specialties may be used as a model for future training and program implementation.[119] The potential value added in using POCUS in the pediatric hospitalist's clinical practice is extrapolated from studies performed largely in EM and pediatric EM. It is important to note that most of these applications have generally low sensitivities; therefore, POCUS should be used as a "rule-in" modality. When there is a high clinical suspicion and the POCUS is negative, alternate imaging should be undertaken. Prospective studies are needed to understand the effects of POCUS on clinical decision-making, including potential for overdiagnosis. Barriers to POCUS implementation have been described throughout several other subspecialties and include insufficient faculty training, high cost of ultrasound equipment, and time required to train physicians.[120]

CONCLUSIONS

POCUS has the potential to improve care for our inpatient pediatric patients. Although there is a paucity of literature for POCUS applications specific to the inpatient pediatric hospital setting, there are well-established applications in other adult and pediatric subspecialties that may be applied in the inpatient pediatric setting. Thus far, as more pediatric hospitalists adopt this technology, there exists a tremendous opportunity to fill the existing research gaps.

REFERENCES

1. Roelandt J, Bom K, Hugenholtz PG. The ultrasound cardioscope: a hand-held scanner for real-time cardiac imaging. *J Clin Ultrasound*. 1980;8(3):221–225
2. Roelandt JR, Sutherland GR. Cardiac imaging in the 1980's: which role for ultrasound. *G Ital Cardiol*. 1988;18(5): 351–354
3. Marin JR, Lewiss RE; American Academy of Pediatrics, Committee on Pediatric Emergency Medicine; Society for Academic Emergency Medicine, Academy of Emergency Ultrasound; American College of Emergency Physicians, Pediatric Emergency Medicine Committee; World Interactive Network Focused on Critical Ultrasound. Point-of-care ultrasonography by pediatric emergency medicine physicians. *Pediatrics*. 2015;135(4). Available at: www.pediatrics.org/cgi/content/full/135/4/e1113
4. Marin JR, Abo AM, Arroyo AC, et al. Pediatric emergency medicine point-of-care ultrasound: summary of the evidence [published correction appears in *Crit Ultrasound J*. 2017;9(1):3]. *Crit Ultrasound J*. 2016;8(1):16
5. Becker DM, Tafoya CA, Becker SL, Kruger GH, Tafoya MJ, Becker TK. The use of portable ultrasound devices in low- and middle-income countries: a systematic review of the literature. *Trop Med Int Health*. 2016;21(3):294–311
6. Gregory S, Kuntz K, Sainfort F, Kharbanda A. Cost-effectiveness of integrating a clinical decision rule and staged imaging protocol for diagnosis of appendicitis. *Value Health*. 2016; 19(1):28–35
7. Mathews JD, Forsythe AV, Brady Z, et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. *BMJ*. 2013;346:f2360
8. Abo A. Physics and "knobology". In: Doniger S, ed. *Pediatric Emergency and Critical Care Ultrasound*. Vol 11. Cambridge, United Kingdom: Cambridge University Press; 2013: 4–20
9. Silva FCR. Pulmonary ultrasound. In: Doniger S, ed. *Pediatric Emergency and Critical Care Ultrasound*. Vol 11. Cambridge, United Kingdom: Cambridge University Press; 2013: 71–85
10. Doniger SJ, Dessie A, Latronica C. Measuring the transrectal diameter on point-of-care ultrasound to diagnose constipation in children. *Pediatr Emerg Care*. 2018;34(3):154–159
11. Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. *Chest*. 1995;108(5):1345–1348
12. Volpicelli G, Elbarbary M, Blaivas M, et al; International Liaison Committee on Lung Ultrasound (ILC-LUS) for International Consensus Conference on Lung Ultrasound (ICC-LUS). International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med*. 2012;38(4):577–591
13. Guerra M, Crichiutti G, Pecile P, et al. Ultrasound detection of pneumonia in febrile children with respiratory distress: a prospective study. *Eur J Pediatr*. 2016;175(2):163–170
14. Claes AS, Clapuyt P, Menten R, Michoux N, Dumitriu D. Performance of chest

ultrasound in pediatric pneumonia. *Eur J Radiol*. 2017;88:82–87

15. Urbankowska E, Krenke K, Drobczyński Ł, et al. Lung ultrasound in the diagnosis and monitoring of community acquired pneumonia in children. *Respir Med*. 2015;109(9): 1207–1212
16. Shah VP, Tunik MG, Tsung JW. Prospective evaluation of point-of-care ultrasonography for the diagnosis of pneumonia in children and young adults. *JAMA Pediatr*. 2013;167(2): 119–125
17. Pereda MA, Chavez MA, Hooper-Miele CC, et al. Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis. *Pediatrics*. 2015;135(4): 714–722
18. Esposito S, Papa SS, Borzani I, et al. Performance of lung ultrasonography in children with community-acquired pneumonia. *Ital J Pediatr*. 2014; 40:37
19. Hajalioghli P, Nemati M, Dinparast Saleh L, Fouladi DF. Can chest computed tomography be replaced by lung ultrasonography with or without plain chest radiography in pediatric pneumonia? *J Thorac Imaging*. 2016; 31(4):247–252
20. Caiulo VA, Gargani L, Caiulo S, et al. Lung ultrasound characteristics of community-acquired pneumonia in hospitalized children. *Pediatr Pulmonol*. 2013;48(3):280–287
21. Baumann MH. Management of spontaneous pneumothorax. *Clin Chest Med*. 2006;27(2):369–381
22. Lichtenstein DA, Mauriat P. Lung ultrasound in the critically ill neonate. *Curr Pediatr Rev*. 2012;8(3):217–223
23. Lichtenstein D, Mezière G, Biderman P, Gepner A. The “lung point”: an ultrasound sign specific to pneumothorax. *Intensive Care Med*. 2000;26(10):1434–1440
24. Lichtenstein D, Hulot JS, Rabiller A, Tostivint I, Mezière G. Feasibility and safety of ultrasound-aided thoracentesis in mechanically ventilated patients. *Intensive Care Med*. 1999;25(9):955–958
25. Lichtenstein D, Mezière G, Biderman P, Gepner A. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. *Intensive Care Med*. 1999;25(4):383–388
26. Kirkpatrick AW, Sirois M, Laupland KB, et al. Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the Extended Focused Assessment with Sonography for Trauma (EFAST). *J Trauma*. 2004;57(2): 288–295
27. Alrajab S, Youssef AM, Akkus NI, Caldito G. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. *Crit Care*. 2013; 17(5):R208
28. Cattarossi L, Copetti R, Brusa G, Pintaldi S. Lung ultrasound diagnostic accuracy in neonatal pneumothorax. *Can Respir J*. 2016;2016:6515069
29. Bradley JS, Byington CL, Shah SS, et al; Pediatric Infectious Diseases Society and the Infectious Diseases Society of America. The management of community-acquired pneumonia in infants and children older than 3 months of age: clinical practice guidelines by the Pediatric Infectious Diseases Society and the Infectious Diseases Society of America. *Clin Infect Dis*. 2011;53(7): e25–e76
30. Silva F, Copetti R. Pulmonary Ultrasound. In: Doniger S, ed. *Pediatric Emergency and Critical Care Ultrasound*. Vol 11. Cambridge, United Kingdom: Cambridge University Press; 2013
31. Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby JJ. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. *Anesthesiology*. 2004;100(1):9–15
32. Nazerian P, Volpicelli G, Vanni S, et al. Accuracy of lung ultrasound for the diagnosis of consolidations when compared to chest computed tomography. *Am J Emerg Med*. 2015; 33(5):620–625
33. Alzahrani SA, Al-Salamah MA, Al-Madani WH, Elbarbary MA. Systematic review and meta-analysis for the use of ultrasound versus radiology in diagnosing of pneumonia. *Crit Ultrasound J*. 2017;9(1):6
34. Ellington LE, Gilman RH, Chavez MA, et al; Lung Ultrasound for Pneumonia Assessment (LUPA) Study Investigators. Lung ultrasound as a diagnostic tool for radiographically-confirmed pneumonia in low resource settings. *Respir Med*. 2017;128:57–64
35. Jones BP, Tay ET, Elikashvili I, et al. Feasibility and safety of substituting lung ultrasonography for chest radiography when diagnosing pneumonia in children: a randomized controlled trial. *Chest*. 2016;150(1): 131–138
36. Copetti R, Cattarossi L. Ultrasound diagnosis of pneumonia in children. *Radiol Med (Torino)*. 2008;113(2): 190–198
37. Xirouchaki N, Magkanas E, Vaporidi K, et al. Lung ultrasound in critically ill patients: comparison with bedside chest radiography. *Intensive Care Med*. 2011;37(9):1488–1493
38. Patel PA, Ernst FR, Gunnarsson CL. Ultrasonography guidance reduces complications and costs associated with thoracentesis procedures. *J Clin Ultrasound*. 2012;40(3): 135–141
39. Trinavarat P, Riccabona M. Potential of ultrasound in the pediatric chest. *Eur J Radiol*. 2014;83(9):1507–1518
40. Hasegawa K, Tsugawa Y, Brown DF, Mansbach JM, Camargo CA Jr. Trends in bronchiolitis hospitalizations in the United States, 2000-2009. *Pediatrics*. 2013;132(1):28–36
41. Ralston SL, Lieberthal AS, Meissner HC, et al; American Academy of Pediatrics. Clinical practice guideline: the diagnosis, management, and prevention of bronchiolitis. *Pediatrics*.

2014;134(5). Available at: www.pediatrics.org/cgi/content/full/134/5/e1474

42. Basile V, Di Mauro A, Scalini E, et al. Lung ultrasound: a useful tool in diagnosis and management of bronchiolitis. *BMC Pediatr*. 2015;15:63
43. Martin LD, Howell EE, Ziegelstein RC, et al. Hand-carried ultrasound performed by hospitalists: does it improve the cardiac physical examination? *Am J Med*. 2009;122(1):35–41
44. Leeson K, Leeson B. Pediatric ultrasound: applications in the emergency department. *Emerg Med Clin North Am*. 2013;31(3):809–829
45. Martin LD, Howell EE, Ziegelstein RC, Martire C, Shapiro EP, Hellmann DB. Hospitalist performance of cardiac hand-carried ultrasound after focused training. *Am J Med*. 2007;120(11):1000–1004
46. Via G, Hussain A, Wells M, et al; International Liaison Committee on Focused Cardiac UltraSound (ILC-FoCUS); International Conference on Focused Cardiac UltraSound (IC-FoCUS). International evidence-based recommendations for focused cardiac ultrasound. *J Am Soc Echocardiogr*. 2014;27(7):683.e1–683.e33
47. Doniger SJ. Bedside emergency cardiac ultrasound in children. *J Emerg Trauma Shock*. 2010;3(3):282–291
48. Chen L, Kim Y, Santucci KA. Use of ultrasound measurement of the inferior vena cava diameter as an objective tool in the assessment of children with clinical dehydration. *Acad Emerg Med*. 2007;14(10):841–845
49. Kosiak W, Swieton D, Piskunowicz M. Sonographic inferior vena cava/aorta diameter index, a new approach to the body fluid status assessment in children and young adults in emergency ultrasound–preliminary study. *Am J Emerg Med*. 2008;26(3):320–325
50. Labovitz AJ, Noble VE, Bierig M, et al. Focused cardiac ultrasound in the emergent setting: a consensus statement of the American Society of Echocardiography and American College of Emergency Physicians. *J Am Soc Echocardiogr*. 2010;23(12):1225–1230
51. Fields JM, Lee PA, Jenq KY, Mark DG, Panebianco NL, Dean AJ. The interrater reliability of inferior vena cava ultrasound by bedside clinician sonographers in emergency department patients. *Acad Emerg Med*. 2011;18(1):98–101
52. Ciozda W, Kedan I, Kehl DW, Zimmer R, Khandwalla R, Kimchi A. The efficacy of sonographic measurement of inferior vena cava diameter as an estimate of central venous pressure. *Cardiovasc Ultrasound*. 2016;14(1):33
53. Zengin S, Al B, Genc S, et al. Role of inferior vena cava and right ventricular diameter in assessment of volume status: a comparative study: ultrasound and hypovolemia. *Am J Emerg Med*. 2013;31(5):763–767
54. Chen L, Hsiao A, Langhan M, Riera A, Santucci KA. Use of bedside ultrasound to assess degree of dehydration in children with gastroenteritis. *Acad Emerg Med*. 2010;17(10):1042–1047
55. Ng L, Khine H, Taragin BH, Avner JR, Ushay M, Nunez D. Does bedside sonographic measurement of the inferior vena cava diameter correlate with central venous pressure in the assessment of intravascular volume in children? *Pediatr Emerg Care*. 2013;29(3):337–341
56. Mea L. This isn't hocus POCUS- point of care ultrasound to diagnose soft tissue neck masses. *Ultrasound Med Biol*. 2015;41(4):S34
57. Perera P, Mailhot T, Riley D, Mandavia D. The RUSH exam: rapid ultrasound in SHock in the evaluation of the critically Ill. *Emerg Med Clin North Am*. 2010;28(1):29–56, vii
58. Park DBPB, Presley BC, Cook T, Hayden GE. Point-of-care ultrasound for pediatric shock. *Pediatr Emerg Care*. 2015;31(8):591–598; quiz 599–601
59. Sivitz AB, Tejani C, Cohen SG. Evaluation of hypertrophic pyloric stenosis by pediatric emergency physician sonography. *Acad Emerg Med*. 2013;20(7):646–651
60. Sivitz AB, Cohen SG, Tejani C. Evaluation of acute appendicitis by pediatric emergency physician sonography. *Ann Emerg Med*. 2014;64(4):358–364.e4
61. Riera A, Hsiao AL, Langhan ML, Goodman TR, Chen L. Diagnosis of intussusception by physician novice sonographers in the emergency department. *Ann Emerg Med*. 2012;60(3):264–268
62. Park R, Mikami S, LeClair J, et al. Inpatient burden of childhood functional GI disorders in the USA: an analysis of national trends in the USA from 1997 to 2009. *Neurogastroenterol Motil*. 2015;27(5):684–692
63. Berger MY, Tabbers MM, Kurver MJ, et al. Value of abdominal radiography, colonic transit time, and rectal ultrasound scanning in the diagnosis of idiopathic constipation in children: a systematic review. *J Pediatr*. 2012;161(1):44–50.e1–e2
64. Freedman SB, Thull-Freedman J, Manson D, et al. Pediatric abdominal radiograph use, constipation, and significant misdiagnoses. *J Pediatr*. 2014;164(1):83–88.e2
65. Pensabene L, Buonomo C, Fishman L, Chitkara D, Nurko S. Lack of utility of abdominal x-rays in the evaluation of children with constipation: comparison of different scoring methods. *J Pediatr Gastroenterol Nutr*. 2010;51(2):155–159
66. Beinvogl B, Sabharwal S, McSweeney M, Nurko S. Are we using abdominal radiographs appropriately in the management of pediatric constipation? *J Pediatr*. 2017;191:179–183
67. Niyyar VD, O'Neill WC. Point-of-care ultrasound in the practice of nephrology. *Kidney Int*. 2018;93(5):1052–1059
68. Kelly CE. Evaluation of voiding dysfunction and measurement of

bladder volume. *Rev Urol*. 2004;6(suppl 1):S32–S37

69. Noble VE, Brown DF. Renal ultrasound. *Emerg Med Clin North Am*. 2004;22(3): 641–659

70. Dwyer ME, Krambeck AE, Bergstralh EJ, Milliner DS, Lieske JC, Rule AD. Temporal trends in incidence of kidney stones among children: a 25-year population based study. *J Urol*. 2012; 188(1):247–252

71. Routh JC, Graham DA, Nelson CP. Epidemiological trends in pediatric urolithiasis at United States freestanding pediatric hospitals. *J Urol*. 2010;184(3):1100–1104

72. Fulgham PF, Assimos DG, Pearle MS, Preminger GM. Clinical effectiveness protocols for imaging in the management of ureteral calculous disease: AUA technology assessment. *J Urol*. 2013;189(4):1203–1213

73. Morse JW, Hill R, Greissinger WP, Patterson JW, Melanson SW, Heller MB. Rapid oral hydration results in hydronephrosis as demonstrated by bedside ultrasound. *Ann Emerg Med*. 1999;34(2):134–140

74. Ulusan S, Koc Z, Tokmak N. Accuracy of sonography for detecting renal stone: comparison with CT. *J Clin Ultrasound*. 2007;35(5):256–261

75. Henderson SO, Hoffner RJ, Aragona JL, Groth DE, Esekogwu VI, Chan D. Bedside emergency department ultrasonography plus radiography of the kidneys, ureters, and bladder vs intravenous pyelography in the evaluation of suspected ureteral colic. *Acad Emerg Med*. 1998;5(7):666–671

76. Rosen CL, Brown DF, Sagarin MJ, Chang Y, McCabe CJ, Wolfe RE. Ultrasonography by emergency physicians in patients with suspected ureteral colic. *J Emerg Med*. 1998;16(6):865–870

77. Gaspari RJ, Horst K. Emergency ultrasound and urinalysis in the evaluation of flank pain. *Acad Emerg Med*. 2005;12(12):1180–1184

78. Watkins S, Bowra J, Sharma P, Holdgate A, Giles A, Campbell L. Validation of emergency physician ultrasound in diagnosing hydronephrosis in ureteric colic. *Emerg Med Australas*. 2007;19(3): 188–195

79. Moak JH, Lyons MS, Lindsell CJ. Bedside renal ultrasound in the evaluation of suspected ureterolithiasis. *Am J Emerg Med*. 2012;30(1):218–221

80. Smith-Bindman R, Aubin C, Bailitz J, et al. Ultrasonography versus computed tomography for suspected nephrolithiasis. *N Engl J Med*. 2014; 371(12):1100–1110

81. Guedj R, Escoda S, Blakime P, Patteau G, Brunelle F, Cheron G. The accuracy of renal point of care ultrasound to detect hydronephrosis in children with a urinary tract infection. *Eur J Emerg Med*. 2015; 22(2):135–138

82. Roberson NP, Dillman JR, O'Hara SM, et al. Comparison of ultrasound versus computed tomography for the detection of kidney stones in the pediatric population: a clinical effectiveness study. *Pediatr Radiol*. 2018;48(7):962–972

83. Palmer JS, Donaher ER, O'Riordan MA, Dell KM. Diagnosis of pediatric urolithiasis: role of ultrasound and computerized tomography. *J Urol*. 2005; 174(4 pt 1):1413–1416

84. Chen KC, Hung SW, Seow VK, et al. The role of emergency ultrasound for evaluating acute pyelonephritis in the ED. *Am J Emerg Med*. 2011;29(7): 721–724

85. Sood A, Penna FJ, Eleswarapu S, et al. Incidence, admission rates, and economic burden of pediatric emergency department visits for urinary tract infection: data from the nationwide emergency department sample, 2006 to 2011. *J Pediatr Urol*. 2015;11(5):246.e1–246.e8

86. Subcommittee on Urinary Tract Infection. Reaffirmation of AAP Clinical Practice Guideline: the diagnosis and management of the initial urinary tract infection in febrile infants and young children 2-24 months of age. *Pediatrics*. 2016;138(6):e20163026

87. 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

88. Selius BA, Subedi R. Urinary retention in adults: diagnosis and initial management. *Am Fam Physician*. 2008; 77(5):643–650

89. Milling TJ, 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

90. Chan H. Noninvasive bladder volume measurement. *J Neurosci Nurs*. 1993; 25(5):309–312

91. Bevan C, Buntsma D, Stock A, Griffiths T, Donath S, Babl FE. Assessing bladder volumes in young children prior to instrumentation: accuracy of an automated ultrasound device compared to real-time ultrasound. *Acad Emerg Med*. 2011;18(8): 816–821

92. Lopez MA, Cruz AT, Kowalkowski MA, Raphael JL. Trends in resource utilization for hospitalized children with skin and soft tissue infections. *Pediatrics*. 2013;131(3). Available at: www.pediatrics.org/cgi/content/full/131/3/e718

93. Ramirez-Schrempp D, Dorfman DH, Baker WE, Liteplo AS. Ultrasound soft-tissue applications in the pediatric emergency department: to drain or not to drain? *Pediatr Emerg Care*. 2009; 25(1):44–48

94. 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

95. 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

96. Gaspari RJ, Sansverino A. Ultrasound-guided drainage for pediatric soft tissue abscesses decreases clinical failure rates compared to drainage without ultrasound: a retrospective study. *J Ultrasound Med*. 2018;37(1): 131–136
97. Iverson K, Haritos D, Thomas R, Kannikeswaran N. The effect of bedside ultrasound on diagnosis and management of soft tissue infections in a pediatric ED. *Am J Emerg Med*. 2012; 30(8):1347–1351
98. Subramaniam S, Bober J, Chao J, Zehtabchi S. Point-of-care ultrasound for diagnosis of abscess in skin and soft tissue infections. *Acad Emerg Med*. 2016;23(11):1298–1306
99. Adams CM, Neuman MI, Levy JA. Point-of-care ultrasonography for the diagnosis of pediatric soft tissue infection. *J Pediatr*. 2016;169: 122–127.e1
100. Marin JR, Alpern ER, Panebianco NL, Dean AJ. Assessment of a training curriculum for emergency ultrasound for pediatric soft tissue infections. *Acad Emerg Med*. 2011;18(2): 174–182
101. Sivitz AB, Lam SH, Ramirez-Schrempp D, Valente JH, Nagdev AD. Effect of bedside ultrasound on management of pediatric soft-tissue infection. *J Emerg Med*. 2010;39(5):637–643
102. Marin JR, Dean AJ, Bilker WB, Panebianco NL, Brown NJ, Alpern ER. Emergency ultrasound-assisted examination of skin and soft tissue infections in the pediatric emergency department. *Acad Emerg Med*. 2013; 20(6):545–553
103. The American Board of Pediatrics. Entrustable professional activities for subspecialties. 2018. Available at: https://www.abp.org/subspecialty-epas#Hospitalist%20Medicine. Accessed June 5, 2019
104. Lamperti M, Bodenham AR, Pittiruti M, et al. International evidence-based recommendations on ultrasound-guided vascular access. *Intensive Care Med*. 2012;38(7):1105–1117
105. Hosokawa K, Shime N, Kato Y, Hashimoto S. A randomized trial of ultrasound image-based skin surface marking versus real-time ultrasound-guided internal jugular vein catheterization in infants. *Anesthesiology*. 2007;107(5):720–724
106. Matsushima K, Frankel HL. Bedside ultrasound can safely eliminate the need for chest radiographs after central venous catheter placement: CVC sono in the surgical ICU (SICU). *J Surg Res*. 2010;163(1):155–161
107. Egan G, Healy D, O'Neill H, Clarke-Moloney M, Grace PA, Walsh SR. Ultrasound guidance for difficult peripheral venous access: systematic review and meta-analysis. *Emerg Med J*. 2013;30(7):521–526
108. Heinrichs J, Fritze Z, Vandermeer B, Klassen T, Curtis S. Ultrasonographically guided peripheral intravenous cannulation of children and adults: a systematic review and meta-analysis. *Ann Emerg Med*. 2013; 61(4):444–454.e1
109. Doniger SJ, Ishimine P, Fox JC, Kanegaye JT. Randomized controlled trial of ultrasound-guided peripheral intravenous catheter placement versus traditional techniques in difficult-access pediatric patients. *Pediatr Emerg Care*. 2009;25(3):154–159
110. Vinograd AM, Zorc JJ, Dean AJ, et al. First-attempt success, longevity, and complication rates of ultrasound-guided peripheral intravenous catheters in children. *Pediatr Emerg Care*. 2018;34(6):376–380
111. Abo A, Chen L, Johnston P, Santucci K. Positioning for lumbar puncture in children evaluated by bedside ultrasound. *Pediatrics*. 2010;125(5). Available at: www.pediatrics.org/cgi/content/full/125/5/e1149
112. Bruccoleri RE, Chen L. Needle-entry angle for lumbar puncture in children as determined by using ultrasonography. *Pediatrics*. 2011; 127(4). Available at: www.pediatrics.org/cgi/content/full/127/4/e921
113. 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
114. Stiffler KA, Jwayyed S, Wilber ST, Robinson A. The use of ultrasound to identify pertinent landmarks for lumbar puncture. *Am J Emerg Med*. 2007;25(3):331–334
115. Nomura JT, Leech SJ, Shenbagamurthi S, et al. A randomized controlled trial of ultrasound-assisted lumbar puncture. *J Ultrasound Med*. 2007;26(10):1341–1348
116. Mofidi M, Mohammadi M, Saidi H, et al. Ultrasound guided lumbar puncture in emergency department: time saving and less complications. *J Res Med Sci*. 2013;18(4):303–307
117. Lahham S, Schmalbach P, Wilson SP, et al. Prospective evaluation of point-of-care ultrasound for pre-procedure identification of landmarks versus traditional palpation for lumbar puncture. *World J Emerg Med*. 2016; 7(3):173–177
118. Neal JT, Kaplan SL, Woodford AL, Desai K, Zorc JJ, Chen AE. The effect of bedside ultrasonographic skin marking on infant lumbar puncture success: A randomized controlled trial. *Ann Emerg Med*. 2017;69(5):610–619.e1
119. Kessler D, Pahalyants V, Kriger J, Behr G, Dayan P. Preprocedural ultrasound for infant lumbar puncture: a randomized clinical trial. *Acad Emerg Med*. 2018;25(9):1027–1034
120. Soni NJ, Schnobrich D, Matthews BK, et al. Point-of-care ultrasound for hospitalists: a position statement of the society of hospital medicine. *J Hosp Med*. 2019;14:E1–E6
121. Gold DL, Marin JR, Haritos D, et al. Pediatric emergency medicine physicians' use of point-of-care ultrasound and barriers to implementation: a regional pilot study. *AEM Educ Train*. 2017;1(4): 325–333