

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

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## 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.

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Point-of-care ultrasound (POCUS) was first introduced into the practice of emergency medicine (EM) in the 1980s.<sup>1,2</sup> 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.<sup>3</sup> The future of POCUS remains to be expanded into other pediatric subspecialties, including pediatric hospital medicine (PHM).<sup>4</sup>

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.<sup>4-7</sup>

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).<sup>8-10</sup>

## DIAGNOSTIC APPLICATIONS

### Lung

In 1995, Lichtenstein first described the use of POCUS for lung pathology (Supplemental Table 2).<sup>11</sup> Lung ultrasound has become a fundamental application for POCUS in many specialties in both pediatric and adult patient populations.<sup>12</sup> 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.<sup>4,13-20</sup>

### 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 (CXR) for the initial diagnosis, follow-up, and/or sudden clinical decompensation.<sup>21</sup>

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).<sup>22-24</sup> 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%.<sup>11</sup> The "lung point" is 66% sensitive and 100% specific for a pneumothorax.<sup>23,25</sup> 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%]).<sup>26,27</sup> Although most studies have been conducted with adults, similar findings have been confirmed in pediatric and neonatal literature.<sup>22,28</sup>

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.<sup>29</sup> In practice, CXRs are often repeated with sudden clinical deterioration or inadequate treatment response.<sup>13,29</sup>

With POCUS, pneumonias may be seen as subpleural consolidations or "hepatization" of the lung (Fig 1, Supplemental Table 2).<sup>30</sup> POCUS can help differentiate pneumonias from atelectasis.<sup>12</sup> 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.<sup>14-16,31</sup>

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.<sup>32</sup> 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.<sup>16</sup> 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.<sup>33</sup>

Pediatric studies have confirmed that lung POCUS is highly accurate in diagnosing pneumonias in children when compared with CXR or CT.<sup>16-18,34-36</sup> 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.<sup>19</sup> 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]).<sup>34</sup> 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.<sup>35</sup> 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<sup>8-10</sup>

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.<sup>37</sup> 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.<sup>30</sup>

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

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

### *Bronchiolitis*

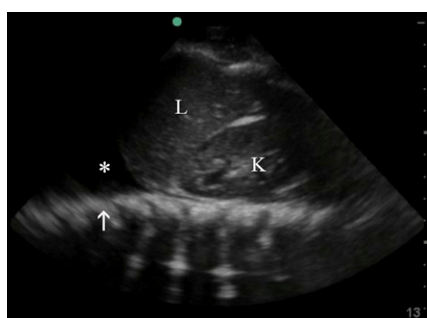
Bronchiolitis is the most common lower respiratory tract infection that affects infants and children <2 years of age, with a significant increase in admissions for those with high-risk medical conditions (34% increase,  $P < .001$ ).<sup>40</sup> Sonographic findings have been described as subpleural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

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.<sup>41,42</sup> 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%).<sup>42</sup> It is unknown how POCUS would compare with



**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 when visualization of the spine continues above the diaphragm when fluid is present. K, kidney; L, liver.

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.

### 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.<sup>43–45</sup> 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.<sup>46</sup> 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.<sup>46</sup> 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.<sup>47</sup>

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.<sup>46,48–51</sup> In most studies, authors reported a statistically significant positive correlation between sonographic

measurements of the IVC and central venous pressure.<sup>52</sup> 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 ( $P = .001$ ).<sup>53</sup> POCUS examinations may be repeated with ongoing fluid resuscitation to monitor efficacy of interventions.<sup>46,50,54,55</sup>

In initial pediatric studies, authors suggested that the IVC to aorta ratio may correlate with fluid status,<sup>48,54,56</sup> with the IVC to aorta ratio lower in dehydrated patients.<sup>48</sup> However, the IVC to aorta ratio was found to be only marginally accurate, with a sensitivity of 86% and specificity of 56%.<sup>54</sup> In critically ill children, it has been shown to have poor correlation with central venous pressure monitoring.<sup>55</sup> 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.<sup>57</sup> Although Park et al<sup>58</sup> 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.<sup>59–61</sup> 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.<sup>62</sup> 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.<sup>63–65</sup> 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%).<sup>66</sup> POCUS could be a valuable adjunct to the physical examination and has the potential to replace abdominal radiographs.<sup>10</sup>

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

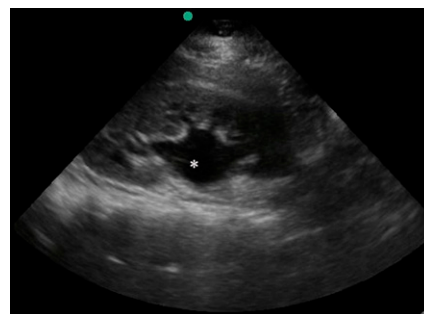
(current gold standard). A TRD measurement cutoff of 3.8 cm was found to be diagnostic for constipation, with a sensitivity of 86% (95% CI: 69% to 96%), specificity of 71% (95% CI: 53% to 85%), negative predictive value of 0.87 (95% CI: 0.68 to 0.95), and positive predictive value of 0.70 (95% CI: 0.52 to 0.84).<sup>10</sup> 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.<sup>67–69</sup>

## 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.<sup>70,71</sup> Both the American Urologic Association and European Society for Pediatric Radiologists recommend ultrasound as the initial imaging modality of choice.<sup>72</sup> On POCUS, hydronephrosis is identified by the dilatation of the renal pelvis. (Fig 3).<sup>69</sup> False positives for hydronephrosis may be encountered in the setting of rapid oral or intravenous (IV) hydration.<sup>73</sup> 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



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

important to note that the absence of hydronephrosis does not rule out nephrolithiasis.<sup>74</sup>

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 73% to 83% (95% CI: 52% to 94%), when compared with either CT scan or IV pyelogram.<sup>75–79</sup> 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.<sup>80</sup>

In pediatric patients, the cornerstone for the evaluation for hydronephrosis is radiology-performed ultrasound. Guedj et al<sup>81</sup> 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.<sup>81</sup> 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.<sup>82,83</sup> 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.<sup>81,84</sup>

### UTIs and Pyelonephritis

Approximately 4.7% of children with UTIs require inpatient management.<sup>85</sup> For infants <24 months of age, the AAP continues to recommend renal and bladder ultrasound to assess for undiagnosed pathology.<sup>86</sup> 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.<sup>84</sup>

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.<sup>81,84</sup> 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.<sup>86</sup>

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.<sup>44,68</sup> It can also be used to determine bladder volume before urinary catheterization, thereby increasing the success of first-attempt catheterizations.<sup>87</sup>

In adults, POCUS has been used to evaluate for urinary retention and postvoid residuals.<sup>88</sup> This has also been applied to pediatric patients, particularly in the age of <24 months. Milling et al<sup>89</sup> measured the bladder index in infants and found that a bladder index of 2.4 cm<sup>2</sup> correlated with 2 to 2.5 mL of urine, the minimum amount required for urinalysis and culture, thereby being considered a successful catheterization.<sup>89</sup> 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%).<sup>87</sup> POCUS has shown to more accurately assess postvoid residual volumes compared with bladder scans, particularly in infants <24 months of age.<sup>44,90</sup>

### Skin and Soft Tissue

Hospital admissions for skin and soft tissue infections (SSTIs) have nearly doubled between 1997 and 2009.<sup>91</sup> 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.

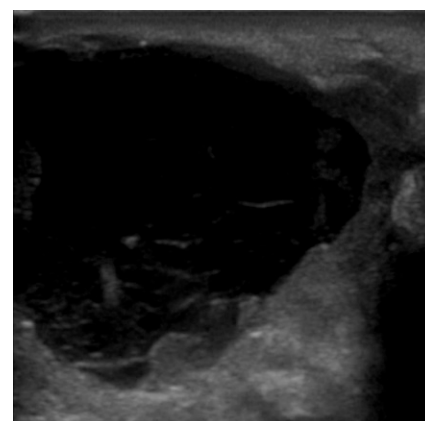
### Cellulitis Versus Abscess

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.<sup>92</sup> Although POCUS cannot distinguish between inflammatory and infectious fluid, an



**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.

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 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<sup>93</sup> 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.<sup>93</sup> POCUS can be particularly useful when an underlying abscess may not be clinically apparent and can change management in 36% to 48% of cases.<sup>94</sup> 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%;  $P < .005$ ).<sup>95</sup>

Similar results have been shown in pediatric studies. Iverson et al<sup>96</sup> 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.<sup>97–100</sup> 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.<sup>97</sup> Adams et al<sup>98</sup> 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.<sup>101</sup>

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.<sup>102</sup>

### 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.<sup>103</sup> Ultrasound guidance has been shown to be superior to ultrasound assistance.<sup>104</sup> 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.<sup>105</sup>

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;  $P = .008$ ).<sup>106</sup> In another study, researchers showed that those who used ultrasound guidance made fewer attempts to achieve successful placement.<sup>107</sup>

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<sup>108</sup> 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,  $P < .001$ ).<sup>108</sup> Recently, there has been concern regarding infection rates and sustainability of ultrasound-guided peripheral IVs. However, Vinograd et al<sup>109</sup> 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.<sup>109</sup>

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.<sup>110,111</sup> 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.<sup>112,113</sup> 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).<sup>114</sup> Mofidi et al<sup>115</sup> 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<sup>116</sup> 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.<sup>110</sup> 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%).<sup>117</sup> However, recently, Kessler et al<sup>118</sup> 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.<sup>118</sup> 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.<sup>119</sup> 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.<sup>120</sup>

## 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.

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