REVIEW

# Point-of-care ultrasound in pediatric emergency medicine: Narrative review on current applications, limitations, and future directions

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**ABSTRACT**

Point-of-care ultrasound (POCUS) has emerged as an invaluable tool in pediatric emergency medicine, offering rapid, non-invasive, and radiation-free diagnostic and procedural support directly at the bedside. Its applications span three major domains: resuscitation, diagnostics, and procedures. In resuscitation, protocols such as e-FAST and RUSH facilitate rapid assessment of trauma, shock, and cardiac function, enabling timely intervention. Diagnostic uses encompass a broad spectrum, including soft tissue infections, pulmonary conditions, gastrointestinal emergencies, musculoskeletal injuries, renal pathology, testicular torsion, and ocular abnormalities. Procedurally, POCUS enhances accuracy and safety in endotracheal tube placement, vascular access, lumbar puncture, arthrocentesis, and suprapubic bladder aspiration. Evidence supports that POCUS can improve diagnostic accuracy, reduce time to intervention, and optimize patient management in pediatric emergency settings. However, its effectiveness and safety are dependent on rigorous, competency-based training programs that move beyond minimum scan numbers to include objective assessment and quality assurance, as highlighted in recent international guidelines. Limitations include operator dependence, potential misinterpretation, inability to visualize certain pathologies, and variability in integration into clinical workflows. Future research should focus on standardizing pediatric-specific protocols, defining competency thresholds, and evaluating the cost-effectiveness and patient-centered outcomes of POCUS implementation. Multicenter trials are needed to validate its role in diagnostic algorithms, assess its impact on patient flow, and explore novel applications such as artificial intelligence-assisted interpretation. Given its versatility and growing evidence base, POCUS represents

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a critical adjunct in pediatric emergency medicine, with the potential to reshape diagnostic and procedural strategies while improving safety and efficiency in acute care. (www.actabiomedica.it)

**Key words:** point-of-care ultrasound, pediatric emergency medicine, e-FAST, resuscitation, procedural guidance, diagnostic imaging

## Introduction

Point-of-care ultrasound is a focused ultrasound examination performed by the clinical pediatrician, conducted and interpreted at the patient's bedside, which allows the clinician to supplement the assessments made during the physical examination with images acquired within minutes. Point-of-care ultrasound (POCUS) should be considered a screening examination intended to provide dichotomous yes/no answers to specific questions that arise in the clinical evaluation of the patient in an emergency care setting (1). In recent years, clinician-performed ultrasound has expanded from a trauma screening test to being used by almost every medical specialty for diagnosis, monitoring, and procedural guidance (2). POCUS has also generated debate: some physicians believe they have acquired adequate ultrasound skills but avoid formal image reporting, unlike radiologists; others argue that being highly operator-dependent, POCUS extends beyond the scope of an emergency physician already managing a heavy workload. Importantly, POCUS in emergency settings is best used as a tool to rule in rather than rule out a condition. For example, the inability to visualize an inflamed appendix when clinical suspicion is high should prompt further investigation with alternative imaging modalities (1). The trend of ultrasonography use in pediatric emergency has been documented to increase tremendously from 2006 to 2011, from 57% to 88%, through surveys of emergency pediatric residents (3). Much of this revolution was initiated in tertiary care centers; however, with increasing pressure for expedited diagnosis and efficient use of manpower resources across healthcare, POCUS has been adopted in settings ranging from outpatient clinics to critical care units (4). Given the growing use of POCUS by pediatricians and strong evidence supporting its diagnostic accuracy in pediatric care, the first policy statement on its use by emergency-urgency pediatricians was published in 2015 (1). Multiple studies confirm that POCUS performed by pediatricians in emergency settings can achieve high diagnostic accuracy when preceded by appropriate training (5–7). An important advantage in pediatric care is its safety, as ultrasound does not use ionizing radiation. This is particularly relevant given the well-documented risks of radiation exposure in children, who are more vulnerable due to a higher organ-specific dose, greater tissue radiosensitivity, and longer life expectancy (8). Despite its rapid growth, widespread adoption, and demonstrated benefits, several unmet needs remain. These include variability in operator training and competence, the absence of standardized protocols tailored to pediatric populations, uncertainty regarding its role in complex or equivocal cases, and the challenge of integrating POCUS findings into established diagnostic pathways without delaying care. Importantly, beyond these limitations, there is still no universally accepted framework defining competency benchmarks for the core applications of pediatric POCUS. Although consensus statements and training curricula exist, they vary considerably in scope and rigor, leaving gaps in defining minimum skill levels, required case numbers, and performance metrics for independent practice. Addressing this lack of standardization has become a primary focus of ongoing research and guideline development, with the goal of ensuring reproducibility, safeguarding patient safety, and promoting consistent training outcomes across institutions. Given its rapidity, portability, and absence of ionizing radiation,

POCUS has the potential to transform pediatric emergency care, but its optimal applications, training requirements, and integration into diagnostic and procedural pathways require clarification. This narrative review aims to summarize the current evidence, highlight practical applications, and discuss limitations of POCUS in pediatric emergency settings, with the goal of guiding clinicians in its effective and safe use.

## Methodology

To perform this narrative review, a comprehensive literature search was performed to identify studies addressing the use of point-of-care ultrasound (POCUS) in pediatric emergency room settings. The search strategy included two major electronic databases: PubMed and Google Scholar. The time frame for inclusion was from January 2000 to June 2025, ensuring coverage of both foundational and recent developments in the field, with particular emphasis on studies published within the last 25 years to capture the most up-to-date evidence. The following search terms and Boolean operators were applied in various combinations: "ultrasound" OR "POCUS" AND "pediatrics" OR "children" OR "childhood" OR "adolescent" AND ""emergency" OR "diagnostic" OR "procedures". The reference lists of key articles were manually reviewed to identify additional relevant publications not captured in the initial search. Inclusion criteria were: human studies, age 0-18, studies on POCUS conducted in emergency settings. No language restrictions were initially applied; however, only studies available in English or Italian were ultimately considered for inclusion. Exclusion criteria were studies performed in neonates and in adult populations. Titles and abstracts were screened for relevance, and full texts were retrieved for studies that met the inclusion criteria or where eligibility could not be determined from the abstract alone. Priority was given to articles providing original data, systematic reviews, meta-analyses, clinical guidelines, or consensus statements relevant to POCUS in pediatric emergency care. Since this work is not a systematic review, a PRISMA flowchart has not been made.

## Applications of POCUS in pediatric emergency

In 2013, Vieira and collaborators published consensus educational guidelines for emergency pediatrics residents, proposing a structured framework for the use of POCUS in clinical practice (9). These guidelines organized pediatric emergency ultrasound applications into three main domains: resuscitation, diagnostic, and procedural. Resuscitation-focused POCUS is primarily used to evaluate critically ill patients who may have life-threatening conditions. In this context, the extended focused assessment with sonography for trauma (e-FAST) plays a central role, enabling the rapid identification of intraperitoneal and pericardial fluid as well as thoracic injuries such as pneumothorax and hemothorax. Alongside e-FAST, focused cardiovascular ultrasound is employed to detect pericardial effusion, assess cardiac contractility, evaluate right ventricular strain, and confirm the presence of thoracic complications. These examinations are often performed during trauma evaluation, shock resuscitation, or cardiac arrest, where timely information can decisively influence clinical management. The second domain, diagnostic applications, encompasses a broad range of conditions and organ systems. In soft tissue assessment, POCUS assists in differentiating between cellulitis and abscesses, identifying retained foreign bodies, and guiding drainage procedures. Chest ultrasound can be used to diagnose pleural effusion, pneumothorax, pneumonia, and other parenchymal pathologies. Abdominal-focused ultrasound allows the evaluation of suspected appendicitis, intussusception, and hypertrophic pyloric stenosis, while biliary tract studies can reveal cholecystitis, cholelithiasis, or biliary obstruction. In the musculoskeletal field, ultrasound can detect fractures, joint effusions, and tendon or ligament injuries. Renal and bladder studies enable the identification of hydronephrosis, the assessment of urinary retention, and the estimation of bladder volume. Acute scrotal pain can be evaluated to identify or exclude testicular torsion, and ocular ultrasound can detect retinal detachment, vitreous hemorrhage, or increased optic nerve sheath diameter suggestive of raised intracranial pressure. These diagnostic uses provide real-time information without radiation exposure, potentially accelerating

triage, guiding clinical decisions, and reducing the need for more resource-intensive imaging. Procedural applications represent the third domain of POCUS in pediatric emergency medicine. Ultrasound guidance is increasingly utilized to improve the accuracy and safety of various interventions. Endotracheal tube placement can be confirmed in real time, which is particularly valuable in difficult pediatric airways. Vascular access, whether peripheral, central, or femoral, benefits from ultrasound visualization, especially in patients with challenging anatomy. For lumbar puncture, POCUS helps to identify the optimal intervertebral space, an advantage in infants or those with anatomical variations. In arthrocentesis, ultrasound can localize joint effusions and guide needle placement for aspiration or injection, while in suprapubic bladder aspiration, it ensures adequate bladder distension and safe needle insertion. By integrating resuscitation, diagnostic, and procedural capabilities, POCUS has become a versatile and indispensable tool in pediatric emergency medicine. Its capacity to provide immediate, radiation-free, bedside information has the potential to shorten diagnostic timelines, enhance procedural precision, and improve patient safety, provided its use is supported by adequate operator training and standardized clinical protocols.

## Applications of resuscitation

In pediatric emergency medicine, POCUS plays a pivotal role during resuscitation by providing rapid, real-time imaging that can guide life-saving interventions in critically ill or injured patients. Its ability to assess hemodynamic status, detect life-threatening pathology, and support procedural precision makes it particularly valuable in high-acuity scenarios where every second counts. Unlike in adult care, the use of resuscitation-focused POCUS in children requires careful adaptation to smaller anatomical structures, unique physiological parameters, and the often subtle presentation of critical illness in this age group. Key applications include the Focused Assessment with Sonography for Trauma (FAST) and its extended version (e-FAST) for rapid detection of free fluid and pneumothorax, as well as focused cardiac ultrasound for evaluating cardiac function, pericardial effusion, and shock states. When integrated into structured protocols such as Rapid Ultrasound in Shock (RUSH), POCUS enables clinicians to rapidly differentiate between causes of hemodynamic instability—whether hypovolemic, obstructive, cardiogenic, or distributive—while simultaneously guiding therapeutic interventions. The following sections detail the principal resuscitation applications of POCUS in pediatric emergencies, highlighting their indications, technical considerations, diagnostic performance, and current limitations.

### *e-FAST in Trauma*

The term Focused Assessment with Ultrasound for Trauma (FAST) was formally introduced at the 1997 International Consensus Conference to define a rapid, real-time ultrasound protocol for the initial evaluation of trauma patients. FAST involves scanning four anatomical regions: the pericardial, perihepatic, perisplenic, and pelvic spaces, visualized via right upper quadrant (RUQ), left upper quadrant (LUQ), pelvic, and cardiac windows. The RUQ view typically focuses on Morrison's pouch (between the liver and right kidney), the subhepatic space, and the right pleural recess. The LUQ view examines the splenorenal recess, the subphrenic space above the spleen, the area beneath the left kidney, and the left pleural recess. The pelvic view, essential in pediatric trauma because the pelvis is a common site of free fluid accumulation, uses the bladder as an anatomical landmark to identify hemoperitoneum. The cardiac view, accessed via the subxiphoid window, evaluates for pericardial fluid, which may appear anechoic or echogenic if clotted; effusions are classified by their distribution around the heart. The extended FAST (e-FAST) protocol incorporates thoracic imaging to detect pneumothorax and hemothorax, offering a more complete assessment than traditional FAST (10). Despite advantages such as speed, portability, non-invasiveness, and absence of radiation, pediatric FAST remains less standardized than adult protocols (11). One limitation is its reduced ability to detect solid organ injuries without associated hemoperitoneum; approximately 25% of intra-abdominal injuries in children present without free fluid (12). Consequently, a normal FAST cannot reliably exclude

significant injury. In a meta-analysis, Holmes et al. reported a sensitivity of 80% for detecting hemoperitoneum, dropping to 66% when hemoperitoneum was absent (13). Computed tomography (CT) remains the gold standard for identifying intra-abdominal injuries but carries substantial radiation risks, particularly in children. To minimize unnecessary CT scans, the Pediatric Emergency Care Applied Research Network (PECARN) developed a clinical prediction rule to stratify injury risk (13). In low-risk children, a normal FAST (negative likelihood ratio ≈ 0.2) may reduce the need for CT (13). Evidence suggests that e-FAST can shorten time to intervention and safely decrease CT utilization in appropriately selected pediatric trauma patients (2).

### *e-FAST and the RUSH protocol in shock*

The Rapid Ultrasound in Shock (RUSH) protocol provides a structured approach to identifying the cause of circulatory compromise by evaluating "the pump" (heart), "the reservoir" (inferior vena cava (IVC)), and "the pipes" (major vessels) (14,15). Although pediatric-specific RUSH data are limited, qualitative cardiac, IVC, and abdominal assessments can be adapted from adult practice (16). In pediatric resuscitation, focused cardiac ultrasound (FOCUS) is most commonly used to detect pericardial effusion or tamponade, assess global contractility, evaluate left ventricular function and right ventricular filling, and guide the management of pulseless electrical activity or asystole (15,17,18). Standard cardiac windows include subxiphoid, parasternal long and short axis, and apical four-chamber views (19). Evidence supports the reliability of pediatric emergency physicians in performing FOCUS after training. Longjohn et al. demonstrated sensitivity and specificity of 95% and 83%, respectively, compared with formal echocardiography, with strong interobserver agreement (20). Case reports highlight how timely POCUS can expedite diagnosis of tamponade (21,22), infective endocarditis (23), and pulmonary embolism (24). Assessment of the IVC is another component of RUSH, offering indirect estimation of intravascular volume. In spontaneously breathing children, >50% respiratory variation in IVC diameter with easy collapse suggests hypovolemia, while <50% variation with a distended vessel may indicate hypervolemia or obstructive physiology (25). However, variability in pediatric data means IVC assessment should complement—rather than replace—clinical judgment and other POCUS findings (26,27). This limitation has been confirmed in recent systematic reviews, which demonstrate that IVC dynamics in spontaneously breathing children have only modest accuracy for predicting fluid responsiveness and should not be used in isolation. For example, Orso et al. (26) conducted a large systematic review and meta-analysis showing significant heterogeneity across studies and limited predictive value of IVC collapsibility, reinforcing the recommendation that IVC assessment be interpreted in conjunction with clinical findings and other POCUS parameters. In select cases, RUSH can be expanded to include transfontanellar ultrasound to detect intraventricular hemorrhage in neonates (28). Serial examinations allow monitoring of resuscitation effectiveness, tracking parameters such as left ventricular contractility, IVC dynamics, extravascular lung water, and bladder filling (29,30). In summary, both e-FAST and RUSH enhance pediatric emergency care by providing rapid, bedside information that can guide immediate interventions (Table 1). While limitations remain—particularly in sensitivity for certain injuries and a lack of large pediatric validation studies—these protocols represent valuable adjuncts to the clinical assessment of trauma and shock in children.

## Diagnostic applications of POCUS in pediatric emergency medicine

POCUS has emerged as an indispensable diagnostic adjunct in pediatric emergency medicine, offering rapid, radiation-free, and bedside imaging that complements clinical evaluation and expedites decision-making. Unlike traditional imaging modalities, POCUS enables immediate visualization of a wide range of anatomical structures and pathological processes without requiring patient transfer, sedation, or prolonged waiting times—factors particularly advantageous in pediatric populations, where cooperation may be limited and minimizing distress is essential. Over the past two decades, evidence has accumulated

**Table 1.** Summary of Resuscitation Applications of POCUS in Pediatric Emergency Medicine.

| Protocol | Primary Purpose | Key Anatomical Views | Main Findings Detected | Advantages | Limitations in Pediatrics | Supporting Evidence |
|---|---|---|---|---|---|---|
| **FAST** (Focused Assess-ment with Sonogra-phy for Trauma) | Rapid detection of free fluid in trauma | RUQ (Morrison's pouch, right pleural recess), LUQ (splenorenal recess, subphrenic space), pelvis (bladder view), subxiphoid (heart) | Hemoperitoneum, hemopericardium | Bedside, rapid, non-invasive, no radiation | Lower sensitivity for solid organ injury without hemoperitoneum (~25% cases), non-standardized pediatric protocols | Holmes et al. – Sensitivity 80% for hemoperitoneum, 66% without hemoperitoneum (12) |
| **e-FAST** (Extended FAST) | Adds thoracic assessment to FAST | As above, plus anterior/ lateral chest views | Pneumothorax, hemothorax, pleural effusion | Broader scope than FAST, rapid chest evaluation | Similar limitations to FAST; operator-dependent | Kirkpatrick et al. – Improved pneumothorax detection over chest X-ray (10) |
| **RUSH** (Rapid Ultrasound in Shock) | Identify cause of hemodynamic instability | Cardiac views (subxiphoid, parasternal, apical), IVC (subcostal), abdominal and vascular survey | Pericardial effusion/ tamponade, cardiac dysfunction, hypovolemia, obstructive shock | Integrates multiple systems; real-time resuscitation guidance | Limited pediatric validation; rare obstructive lesions in children | Longjohn et al. – Pediatric EPs match cardiologists for FOCUS (20) |
| **FOCUS** (Focused Cardiac Ultra-sound) – part of RUSH | Focused cardiac function assessment | Subxiphoid, parasternal, apical | LV/RV function, preload estimation, tamponade | High sensitivity/ specificity with training; immediate results | Requires skill; not a replacement for formal echo | Longjohn et al. – Sensitivity 95%, specificity 83% vs. formal echo (20) |
| IVC Assessment – part of RUSH | Estimate intravascular volume | Subcostal IVC | >50% variation = hypovolemia; <50% variation + distension = hypervolemia/ obstructive | Simple to perform, repeatable | Inconsistent predictive value for fluid responsiveness in pediatrics | Mixed evidence (25–27) |
| Extended RUSH (Neonates) | Evaluate CNS in shock | Transfontanellar ultrasound | Intraventricular hemorrhage | Adds CNS assessment in select cases | Limited to neonates; operator-dependent | Huisman et al. (28) |

*Abbreviations:* POCUS: Point-of-Care Ultrasound; FAST: Focused Assessment with Sonography for Trauma; e-FAST: Extended Focused Assessment with Sonography for Trauma; RUSH: Rapid Ultrasound in Shock; FOCUS: Focused Cardiac Ultrasound; RUQ: Right Upper Quadrant; LUQ: Left Upper Quadrant; IVC: Inferior Vena Cava; LV: Left Ventricle; RV: Right Ventricle; EPs: Emergency Physicians.

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demonstrating that pediatric emergency physicians, with appropriate training, can achieve diagnostic accuracy comparable to radiology specialists across multiple clinical scenarios, from differentiating cellulitis from abscesses to diagnosing life-threatening conditions such as pneumothorax, appendicitis, and testicular torsion. Beyond accelerating diagnosis, POCUS often directly alters patient management, reducing the need for additional imaging, guiding procedures, and improving resource utilization in the emergency department. The following subsections present a comprehensive overview of the major diagnostic applications of POCUS in pediatric emergency settings, organized by anatomical system—soft tissues, pulmonary, gastrointestinal, musculoskeletal, genitourinary, and ocular—summarizing key techniques, sonographic findings, clinical relevance, and limitations for each application.

## *Soft tissues*

### Skin and soft tissue infections

POCUS is a valuable adjunct for the rapid assessment of suspected cellulitis, abscesses, or lymphadenitis in pediatric patients presenting with tender, erythematous, and fluctuant lesions (31). The superficial muscle fascia—or tendon/bone in muscle-deficient areas—serves as the key landmark to distinguish superficial from deep infections that may require more complex surgical management. Cellulitis typically appears as "cobblestoning" of subcutaneous fat caused by lobulation and hyperechoic interlobular septa separated by hypoechoic interstitial fluid (31). Abscesses are irregularly shaped, predominantly anechoic fluid collections with posterior acoustic enhancement. Applying gentle downward pressure may reveal swirling movement of pus ("pus swirling" sign). Color Doppler is essential to confirm that the lesion is avascular, thereby excluding lymph nodes or vessels. Lymph nodes appear as well-defined, hypoechoic cortical rims with hyperechoic central hila, and color Doppler typically shows central vascularity and perinodal hyperemia (32,33). Distinguishing cellulitis from abscess clinically is often difficult, particularly in children where procedural drainage may require sedation. In a prospective study of 65 pediatric patients, clinical examination alone had a sensitivity of 78% (95% CI: 71–84%) and specificity of 66% (95% CI: 47–81%) for abscess detection. When POCUS was added, sensitivity rose to 97% (95% CI: 90–99%) without significant change in specificity (34). Other studies have shown that POCUS can alter management decisions in 22% of cases (33), particularly when clinical findings are equivocal. An additional benefit is reduced ED length of stay compared with radiology-performed ultrasound, which helps alleviate ED crowding and may improve patient throughput (35). However, POCUS cannot reliably differentiate between sterile inflammatory and infectious collections, and deep abscesses may be missed, resulting in false negatives (36).

### Soft tissue foreign bodies

POCUS can detect retained foreign bodies in cases of penetrating trauma, non-healing wounds, or recurrent infections (37,38). Both radiopaque (metal, glass) and radiolucent (wood, plastic) materials are usually hyperechoic, often accompanied by posterior acoustic shadowing, comet-tail reverberation artifacts, or a surrounding hypoechoic halo caused by inflammatory reaction (37).

A pediatric study of 131 wounds suspected of containing a foreign body found that ultrasound had comparable diagnostic accuracy to plain radiography, though specificity was lower (76.5% vs. 88%) (39). Limitations include obstruction of the sonographic field by air introduced during injury, difficulty detecting very small or deep foreign bodies, and potential confusion with normal structures such as fascia, fibrous septa, cartilage, or bone—especially in extremities (33).

## Pulmonary POCUS

In pediatric patients, the small thoracic dimensions allow superior visualization of lung parenchyma compared to adults (40). For infants and small children, a high-frequency linear transducer is preferred for its superior resolution, while in older children, a low-frequency curved probe offers better penetration (41). In emergencies, a rapid evaluation typically includes the anterior chest (to detect pneumothorax

**Table 2.** Normal pulmonary ultrasound findings.

| Findings |
|---|
| Pleural line: horizontal hyperechoic line. With the probe in a static position, the line "crawling" back and forth (it represents the normal pleural flow) should be seen. |
| Lines A: horizontal white lines. They are reflexes of the pleural line, in fact they run parallel to it. |
| Tide sign: Pulmonary slipping is a round-trip movement in correspondence pf the pleural line, which spreads downwards. The "M-mode" helps to understand that this movement is related to the surface tissues. |
| Bat wing sign: The association of ribs and pleural line forms a solid point of reference. |

in a supine patient) and the costophrenic angles (to detect fluid accumulation) (41). Awareness of normal anatomic mimics is critical (Table 2)—e.g., the spleen with gastric air may simulate a consolidation, and the thymus can appear as an echogenic lung-like structure but lacks air bronchograms (4).

Main pediatric pulmonary POCUS applications include pleural effusion, pneumothorax, and parenchymal disease (Table 3).

### Pleural effusion

POCUS can detect pleural effusions as small as 5 mL, with near 100% sensitivity for volumes >100 mL (42). It outperforms both physical examination and chest radiography in detection and characterization, and offers diagnostic accuracy comparable to CT (42). In children, Hajalioglu et al. demonstrated that ultrasound—alone or combined with radiography—could replace CT for assessing pleural effusion and empyema without loss of diagnostic accuracy (43). Effusions appear as anechoic or complex fluid between the parietal pleura and collapsed lung, layering according to gravity (44).

### Pneumothorax

While uncommon after blunt pediatric trauma (<4% prevalence on CT) (47), pneumothorax is more typical after penetrating injury. Ultrasound surpasses chest radiography in sensitivity for pneumothorax detection and can identify occult cases missed on X-ray (10,46-50). Classic sonographic signs include: 1) absent lung sliding (no shimmering of the pleural line with respiration); 2) loss of comet-tail/B-line artifacts; 3) lung point—transition zone between normal lung and pneumothorax, 100% specific when present (50). However, comet-tail artifacts are less common in healthy pediatric lungs (49), and single-point anterior scanning (common in adults) is less reliable in pediatric trauma (48).

### Pneumonia

Historically considered secondary to radiography, lung POCUS is now supported as a first-line diagnostic tool in pediatric pneumonia due to portability, absence of ionizing radiation, and high diagnostic accuracy (51,52). A meta-analysis of eight studies (795 children, ages 0.03–5.6 years) found pooled sensitivity of 96% (95% CI: 94–97%) and specificity of 93% (95% CI: 90–96%) (53). Positive likelihood ratio was 15.3 and negative likelihood ratio 0.06, indicating high rule-in and rule-out value. POCUS is especially valuable for detecting subpleural, retrocardiac, or subdiaphragmatic consolidations invisible on plain radiographs (54,55). Its limitations include inability to detect central consolidations not abutting the pleura, particularly in perihilar or paracardiac regions (56).

### Other parenchymal pathologies

Thoracic POCUS findings correlate with severity in bronchiolitis, predicting hospitalization and need for respiratory support (57,58). In pediatric COVID-19, ultrasound features mirror adult cases, including pleural line irregularities, scattered B-lines, and subpleural consolidations, though more pediatric-specific studies are needed (59). Other neonatal and pediatric respiratory conditions assessed include respiratory distress syndrome, meconium aspiration syndrome, and bronchopulmonary dysplasia (60,61).

## *Gastrointestinal emergencies*

### Acute appendicitis

POCUS performed by pediatric emergency physicians yields sensitivity of 85% (95% CI: 75–95%) and

specificity of 94% (95% CI: 88–97%) for diagnosing acute appendicitis (62-65), aligning with the American College of Radiology's recommendation as first-line imaging in children <14 years (66). Diagnostic criteria include a blind-ending, non-compressible tubular structure >6 mm in diameter, wall thickness >1.7 mm, periappendiceal inflammation, and free fluid. In perforated appendicitis, a phlegmon or abscess may be visualized even without the appendix itself (67-69). Limitations include variable visualization rates (22–98%) and false positives from Crohn's disease or inflamed bowel loops.

#### Intussusception

Ileocolic intussusception is the leading cause of intestinal obstruction in young children, yet the classic triad of pain, mass, and bloody stool is present in <50% (70,71). Ultrasound is the gold standard, with POCUS showing 94.9% sensitivity and 99.1% specificity (72,73).

Sonographic signs include the transverse "target" or "donut" and the longitudinal "pseudokidney" sign (74-76). Doppler evaluation can detect ischemia (absent mural blood flow), predicting reduced success of pneumatic or hydrostatic reduction (77-79).

#### Pyloric stenosis

POCUS matches radiology in diagnosing hypertrophic pyloric stenosis (HPS), with some studies reporting 100% sensitivity and specificity (80,81). Criteria include pyloric muscle thickness >3 mm and canal length >15 mm, though thresholds vary, and prolonged observation (5–10 min post-feeding) is recommended to exclude transient pylorospasm (82–84).

#### Biliary tract

Although rare, pediatric gallstone disease is increasing due to obesity and better imaging access (85-87). POCUS diagnosis of cholelithiasis is based on hyperechoic intraluminal foci with posterior acoustic shadowing and mobility (88). For acute cholecystitis, major signs include gallstones, wall thickening, hypervascularity, sonographic Murphy's sign, and pericholecystic fluid. Gas, obesity, and anatomic variations are common limitations.

### *Musculoskeletal*

#### Fractures

In pediatric trauma, POCUS is increasingly used to detect and monitor fractures, particularly of long bones (89,90). It can also confirm alignment following reduction before casting, potentially avoiding repeat radiographs (91–94). High-frequency linear probes allow detection of cortical disruptions as small as 1 mm (95). Distal forearm fractures are the most common pediatric fracture type. In a cross-sectional study of 169 children (4–17 years) with suspected non-angulated distal forearm fractures, POCUS had a sensitivity of 94.7% (95% CI: 89.7–99.8) and specificity of 93.5% (95% CI: 88.6–98.5) (96). Ultrasound-guided fracture reduction is associated with decreased sedation use, reduced pain, fewer repeat radiographs, and higher caregiver satisfaction (97,98). In elbow injuries, POCUS can detect posterior fat pad displacement and lipohemarthrosis as indicators of occult fracture. A prospective study found a sensitivity of 98% (95% CI: 88–100%) for detecting fractures (99). Some injuries—such as sternal and rib fractures—are better visualized with ultrasound than radiography, particularly in detecting associated hematomas or soft tissue injury (100). This is particularly important in suspected child abuse cases, where early identification of occult skeletal injuries is crucial (101). Other fracture sites described in pediatric POCUS literature include scaphoid (102), skull (103), and clavicle (104,105). While POCUS demonstrates high diagnostic accuracy for many pediatric fractures—particularly long bones of the forearm, humerus, tibia, and fibula—its performance can be comparatively lower in certain age groups and anatomical sites. In very young children, unossified epiphyses and wide physes can obscure cortical landmarks and make subtle injuries harder to detect. Conversely, in older children and adolescents, thicker, soft tissues and more complex injury patterns (e.g., transitional fractures) may reduce sonographic conspicuity compared with radiography. Anatomically, accuracy is consistently lower for small, complex

bones of the wrist and hand (e.g., scaphoid/carpals, phalanges) and for subtle, non-displaced metaphyseal injuries; these sites may yield false negatives if scans are not meticulously circumferential and orthogonal. By contrast, ribs and the clavicle—where the cortex is superficial—are well suited to ultrasound, and detection may equal or exceed radiography in experienced hands. Taken together, ultrasound should be used as a first-line tool where evidence is strongest (long bones, clavicle, selected elbow findings), with a low threshold for confirmatory radiographs when clinical suspicion persists at small-bone or subtle-injury sites, or in age groups where anatomic factors limit sonographic windows (104, 105). Maximizing cooperation and image quality in young children hinges on workflow and technique. Practical steps include: (1) early analgesia (oral acetaminophen/ibuprofen; intranasal analgesia when appropriate) before scanning; (2) child-friendly positioning with caregiver involvement (caregiver holding/comforting; limb supported in a comfortable, neutral position); (3) distraction strategies (video, bubbles, toys) and use of warm gel to reduce startle and guarding; (4) selecting a high-frequency linear or small-footprint "hockey-stick" probe for small anatomy, using generous gel, light transducer pressure, and short, focused sweeps; (5) scanning in two orthogonal planes with circumferential cortical interrogation and immediate comparison to the contralateral limb; and (6) marking the point of maximal tenderness to guide targeted, time-efficient views. Applying a removable splint before scanning can reduce pain-related motion for markedly tender injuries. These measures, coupled with pediatric-specific training that emphasizes growth plate anatomy and common mimics, have been associated with higher first-pass diagnostic yield and fewer false negatives in everyday ED practice (104, 105). While fracture diagnosis is relatively well studied, other musculoskeletal applications—such as the use of POCUS for subtle or non-displaced fractures, osteomyelitis, or soft tissue pathology—require further validation in large pediatric cohorts. Integration of musculoskeletal ultrasound into pediatric emergency training curricula, with dedicated emphasis on growth plate anatomy, will be key to safe and reliable adoption. Pain scores during ultrasound are generally similar or lower than with radiography, though cooperation and examination time can be limiting factors (106). Limitations include difficulty distinguishing cartilage growth plates from fractures, mistaking sutures for skull fractures, and the need for circumferential and orthogonal scanning of bones.

## Joints

POCUS is frequently used to assess joint effusions in children with acute pain or limp, particularly the hip joint (107,108). Ultrasound measurement of the anterior synovial recess is considered positive if >5 mm or if there is a >2 mm difference from the contralateral side (109). A prospective study of 28 children with hip pain reported sensitivity of 80% (95% CI: 51–95%) and specificity of 98% (95% CI: 85–99%) when performed by pediatric emergency physicians (110). In suspected radial head subluxation, absence of effusion or lipohemarthrosis on POCUS can support safe reduction without further imaging (111). Limitations include pain-related restriction of probe movement, difficulty ensuring identical positioning for comparison, and the possibility of symptomatic effusions not meeting diagnostic thresholds (112).

## Tendons

Tendon POCUS is indicated for suspected rupture, laceration, or tendinopathy following trauma or overuse (113). Tendons with sheaths (wrist, ankle) and those without (Achilles, patellar) have different sonographic appearances, which must be recognized for accurate assessment. Healthy tendons display fibrillar echotexture with anisotropy, while injury results in fiber disruption, hypoechoic gaps, and loss of normal parallel alignment. Limitations include reduced image quality for deep tendons, the need to scan in multiple planes, and interference from hematoma or edema.

## Kidney evaluation

In suspected renal colic, POCUS offers a radiation-free alternative to CT (111,112). While less sensitive for detecting small (<3 mm) calculi, these are usually clinically insignificant and pass spontaneously (114). POCUS can identify hydronephrosis, renal

pelvic dilatation, and secondary signs of obstruction in urinary tract infection (115). Color Doppler can reveal twinkling artifacts from stones and assess ureteral jets—absent or diminished jets suggest obstruction (116). Limitations include poor visualization in obese patients and operator dependence.

### Testicular ultrasound

POCUS is a first-line tool for acute scrotum evaluation, differentiating emergent conditions such as testicular torsion from inflammatory processes or hydrocele. Sensitivity and specificity for torsion exceed 90% in most series (117).

A pediatric ED study found that POCUS by trained physicians produced diagnoses highly concordant with radiology, expediting surgical decision-making (118). Wing-Chuen Lan et al. demonstrated that Doppler ultrasound reduced unnecessary surgical explorations from 92% to 8% without increasing rates of unsalvaged testes (119). Recent evidence has further strengthened these findings. A 2023 meta-analysis focusing specifically on POCUS for pediatric testicular torsion reported a pooled sensitivity of 97% and specificity of 99%, underscoring its reliability as a frontline diagnostic tool in the acute scrotum. Sonographic findings in torsion include an enlarged, hypoechoic testis with absent intratesticular blood flow on color Doppler. Limitations include false negatives in early torsion and difficulty in small, uncooperative children. Larger pediatric-specific prospective studies are needed to standardize protocols (120).

### Ocular ultrasound

Advances in high-resolution probes have enabled detailed imaging of anterior and posterior ocular segments (121). Structures include the cornea (thin hypoechoic line), anechoic anterior chamber, echogenic lens, vitreous body, and posterior retina-choroid complex. Ocular POCUS is valuable in detecting retinal detachment, vitreous hemorrhage, lens dislocation, and signs of raised intracranial pressure (121). A meta-analysis reported 100% sensitivity and specificity for retinal detachment when performed by highly trained operators (122), although novices may have difficulty distinguishing it from posterior vitreous detachment (123,124). In pediatrics, a case of Coats disease with retinal detachment was successfully diagnosed by POCUS despite clinical examination being limited by poor cooperation (125). Vitreous hemorrhage appears as mobile hyperechoic material within the posterior chamber (126,127), with pooled sensitivity of 90% and specificity of 92% in meta-analysis (128,129). Raised intracranial pressure causes optic nerve sheath dilatation. Measurements >4.5 mm in children >1 year and >4.0 mm in those <1 year are abnormal (130). Studies have shown a correlation with invasive ICP measurements (131), though diagnostic reliability decreases without adequate training (132).

## Procedural applications

POCUS has become an invaluable adjunct for a wide range of pediatric emergency procedures, offering the ability to visualize anatomy in real time, improve procedural accuracy, and reduce complication rates. In children—where small anatomical targets, variable cooperation, and the need to minimize discomfort and risk are constant challenges—ultrasound guidance is particularly advantageous. By enabling direct visualization of vessels, organs, and target structures, POCUS allows clinicians to perform procedures with greater precision and confidence, even in critically ill or anatomically complex patients. Common procedural applications in pediatric emergency medicine include guidance for vascular access, confirmation of endotracheal tube placement, assistance in lumbar puncture, arthrocentesis, and suprapubic bladder aspiration. These techniques not only enhance procedural success rates but also help reduce the need for multiple attempts, limit exposure to ionizing radiation, and improve the overall patient and caregiver experience. The following section reviews the key procedural uses of POCUS in pediatric emergency care, emphasizing technique, benefits, and evidence supporting its clinical impact.

### *Endotracheal tube placement*

POCUS can be a valuable adjunct for confirming tracheal intubation and assessing the size and

**Table 3.** Diagnostic Applications of POCUS in Pediatric Emergency Medicine.

| Area/Condition | Main Indications | Key Ultrasound Findings | Reported Diagnostic Accuracy | Limitations |
|---|---|---|---|---|
| **Soft Tissue Infections** (Cellulitis vs Abscess) | Tender, erythematous, fluctuant lesion; lymphadenitis | Cobblestoning pattern (cellulitis), anechoic/ hypoechoic fluid with posterior enhancement (abscess), pus movement, Doppler for vascularity | Sensitivity ↑ from 78% (clinical exam) to 97% with POCUS; specificity ~69% (34) | Cannot distinguish infectious from sterile fluid; deep abscesses may be missed |
| **Soft Tissue Foreign Bodies** | History of penetrating injury or persistent infection | Hyperechoic object with posterior shadow, comet tail artifact, hypoechoic halo | Specificity 76.5% vs 88% for radiography (39) | Air obscuration; difficulty with small/ deep objects; false positives from normal anatomy |
| **Pleural Effusion** | Respiratory distress, suspected effusion/ empyema | Anechoic fluid between pleura; minimal detection threshold ~5 mL | Sensitivity 100% (>100 mL effusion) (42); equivalent to CT | Overlying structures may mimic consolidation |
| **Pneumothorax** | Blunt/penetrating chest trauma | Absence of lung sliding/ comet tails; lung point pathognomonic (100% specificity) (51) | More sensitive than X-ray (10,46) | Cannot detect all PTX; false positives in fibrosis/ adhesions |
| **Pneumonia** | Fever, respiratory distress | Subpleural consolidation, air bronchograms, B-lines | Meta-analysis: Sens 96%, Spec 93% (53) | Cannot detect deep lesions not reaching pleura |
| **Bronchiolitis & COVID-19** | Bronchiolitis severity assessment; COVID-19 lung changes | B-lines, subpleural consolidation, pleural line irregularity | Correlates with severity (57,58) | Findings non-specific; needs more pediatric data |
| **Appendicitis** | Abdominal pain, suspected AA | Non-compressible tubular structure >6 mm, wall >1.7 mm, periappendiceal fluid | Sens 85%, Spec 94% (62,63) | Appendix not always visualized; false positives with Crohn's/enteritis |
| **Intussusception** | Abdominal pain, bloody stool, palpable mass | Target/donut (transverse), pseudokidney (longitudinal) | Sens 94.9%, Spec 99.1% (72) | Missed if incomplete scan; false positives from stool/masses |
| **Pyloric Stenosis** | Projectile non-bilious vomiting in infant | Pyloric muscle >3 mm, length >15 mm | Sens & Spec 100% in some series (80) | Transient thickening (pylorospasm) may confuse diagnosis |
| **Biliary Tract** | RUQ pain, suspected cholelithiasis/ cholecystitis | Hyperechoic gallstones with shadowing, wall thickening, Murphy sign | Limited pediatric data | Overlying gas; wall thickening in non-biliary disease |
| **Fractures** | Limb trauma, suspected fracture | Cortical disruption on high-frequency probe | Distal forearm: Sens 94.7%, Spec 93.5% (96); elbow: Sens 98% (99) | Need full circumferential scanning; growth plate misinterpretation |
| **Joint Effusion** | Limp, joint pain, suspected septic arthritis | Synovial recess >5 mm or >2 mm asymmetry | Sens 80%, Spec 98% (110) | Pain limits exam; bilateral disease complicates comparison |
| **Tendon Injury** | Trauma, loss of function | Fiber disruption, hypoechoic gap | No large pediatric accuracy studies | Deep tendons harder to image; anisotropy artifacts |

| Area/Condition | Main Indications | Key Ultrasound Findings | Reported Diagnostic Accuracy | Limitations |
|---|---|---|---|---|
| **Kidney/ Urolithiasis** | Flank pain, suspected stone | Hydronephrosis, twinkling artifact, absent ureteral jets | Slightly less sensitive than CT but misses only small (<3 mm) stones (114) | Obesity; gas interference |
| **Testicular Torsion** | Acute scrotal pain | Enlarged hypoechoic testis, absent flow on Doppler | Sens & Spec >90% (117); reduces unnecessary surgery from 92%→98% (119) | Early torsion may have preserved flow |
| **Ocular** | Visual changes, trauma, suspected ICP | Retinal detachment, vitreous hemorrhage, optic nerve sheath diameter | Retinal detachment: Sens/Spec up to 100% (122); VH: Sens 90%, Spec 92% (128) | Needs skill to differentiate vitreous vs retinal detachment; pediatric data limited |

*Abbreviations:* AA: Acute Appendicitis; ACR: American College of Radiology; B-lines: Vertical comet-tail artifacts from pleural line; CI: Confidence Interval; CT: Computed Tomography; ICP: Intracranial Pressure; POCUS: Point-of-Care Ultrasound; PTX: Pneumothorax; RUQ: Right Upper Quadrant; Spec: Specificity; Sens: Sensitivity; VH: Vitreous Hemorrhage.

position of airway devices, helping to avoid excessive tracheal pressure, optimize ventilation, and minimize the number of intubation attempts. This is particularly important in children, where anatomical characteristics—such as a relatively small oral opening, proportionally larger tongue, higher larynx, and more anterior glottic position—can make visualization of the airway challenging and increase the risk of repeated intubation attempts. Multiple attempts not only increase the risk of airway trauma but can also result in rapid arterial desaturation, given the higher oxygen consumption and lower functional residual capacity in pediatric patients (133). Ultrasound provides several rapid, easily recognizable signs to differentiate tracheal from esophageal intubation (9). In the correct tracheal position, real-time imaging at the suprasternal notch typically shows a single, bright air–mucosal interface within the trachea and bilateral symmetric pleural sliding on lung scans. By contrast, esophageal intubation produces a "double tract" sign—two parallel air–mucosal interfaces—indicating the presence of a second gas-filled lumen in addition to the trachea. Absence of pleural sliding or asymmetry on lung ultrasound can further suggest mainstem intubation or malposition. Compared with auscultation and chest radiography, ultrasound confirmation is consistently faster—often within 10–30 seconds of image acquisition—and has shown sensitivities and specificities above 90% in pediatric and neonatal populations (9). Unlike radiography, which requires patient transport and introduces delay, or capnography, which may be unreliable in low-flow states such as cardiac arrest, POCUS offers immediate, bedside confirmation without radiation exposure. Despite these advantages, there are important limitations in specific populations. In very small neonates, narrow anatomical windows, incomplete ossification, and the small size of the airway structures may reduce sonographic resolution and make interpretation more challenging. In critically ill children, especially those requiring rapid resuscitation, the need for probe positioning and image acquisition can introduce brief procedural delays if operators are not highly practiced. Additionally, excessive probe pressure in neonates may risk airway distortion or desaturation. For these reasons, POCUS should be viewed as a complementary tool to standard confirmation strategies, with particular caution in the smallest and most unstable patients. Research into the use of POCUS for airway management in children is expanding. Hasan et al. conducted one of the first major investigations into the role of POCUS for confirming endotracheal tube placement in neonates requiring respiratory support. Misplacement of the tube into the esophagus is one of the most common and dangerous errors during intubation, and

ultrasound has shown promise as a simple, safe, and rapid method for differentiating between tracheal and esophageal placement (134–136). Simulation studies have further demonstrated that POCUS can reduce interpretation time for tube location, potentially enabling faster clinical decision-making during neonatal intubation (137).

### Vascular access

Ultrasound guidance has been shown to facilitate both central and peripheral vascular access in pediatric patients, particularly for femoral, internal jugular, and subclavian vein catheterization. In the femoral region, POCUS can reliably distinguish the femoral vein from the femoral artery, an important consideration given that anatomical variation—including partial overlap of the two vessels—occurs in a significant proportion of children. This makes reliance on external landmarks alone potentially misleading. For peripheral intravenous (IV) access, dynamic ultrasound guidance allows real-time visualization of the needle entering the vessel, whereas static ultrasound can assist in identifying vessel location before cannulation. Although overall success rates for peripheral IV placement may not differ significantly between ultrasound-guided and landmark-based techniques, ultrasound guidance has been shown to reduce procedure time and the number of needle passes—especially in children with difficult venous access (138,139). To optimize safety, vessels should be scanned in both transverse (short-axis) and longitudinal (long-axis) planes to avoid inadvertent puncture of nearby arteries or nerves. Arterial pulsation and color Doppler can aid in differentiating arteries from veins; however, in patients with shock or low cardiac output, these signs may be less reliable. Nerves, which are typically non-compressible and often accompany major vessels, should be identified and avoided during needle advancement.

### Lumbar puncture

POCUS can assist lumbar puncture (LP) by providing real-time visualization of the spinous processes, interspinous spaces, and optimal insertion site. In infants, its utility is enhanced by the cartilaginous composition of the spine, which permits better visualization of the spinal canal and the conus medullaris. Ultrasound can be particularly useful in patients with difficult-to-palpate anatomical landmarks, small interspinous spaces, or obesity, where landmark-based identification of the puncture site may be inaccurate. In such cases, POCUS can improve first-attempt success rates and reduce the need for multiple punctures (4).

### Arthrocentesis

POCUS enables emergency physicians to identify joint effusions—most notably in the hip—and to guide arthrocentesis directly in the emergency department, a role traditionally limited to orthopedic surgeons or radiologists. Ultrasound guidance should be considered in all children presenting with atraumatic hip pain, as it can reduce the need for imaging modalities that expose the patient to ionizing radiation (140,141). In the study by Scheier et al., POCUS was effective in confirming joint effusion, measuring its size, and supporting decision-making on the initiation of antibiotics while avoiding unnecessary radiographs (142). Arthrocentesis under ultrasound guidance allows real-time visualization of needle trajectory, increasing the likelihood of successful aspiration and reducing the risk of injury to adjacent structures. Before needle insertion, it is critical to identify the femoral vessels—using color Doppler when available—and to distinguish hypoechoic or anechoic joint fluid from articular cartilage. Clinicians should note that infection may be present even in the absence of visible effusion, and that small amounts of cartilage may be misinterpreted as fluid.

### Suprapubic bladder aspiration

Suprapubic aspiration (SPA) is performed to obtain a sterile urine specimen in patients unable to void voluntarily or when urethral catheterization fails. POCUS can significantly improve the success rate of this procedure. Static ultrasound can be used to assess bladder size, shape, and position, while dynamic ultrasound allows real-time visualization of the needle entering the bladder. On ultrasound, a well-filled bladder appears as an anechoic structure; conversely, an empty bladder will be collapsed and may not be visible. Continuous visualization of the needle tip during advancement is

essential to avoid injury to adjacent structures such as bowel loops. By confirming adequate bladder filling before needle insertion, POCUS can also help avoid unnecessary attempts (143). To maximize first-pass success, the bladder should be confirmed as adequately distended on ultrasound. Practical thresholds reported in pediatrics include a sagittal (cephalocaudal) diameter >20 mm and an anteroposterior diameter >15 mm—criteria associated with near-100% success—and/or a transverse diameter ≥3.5–4.0 cm, below which unsuccessful aspirations are more likely. When these sonographic cut-offs are not met, deferring SPA and rehydrating/feeding or waiting is recommended. The following is the procedure for keeping the needle tip continuously in view: (i) use a high-frequency linear probe and a shallow, midline approach 1–2 cm above the pubic symphysis; (ii) align the needle in-plane with the ultrasound beam so the entire shaft and echogenic tip are visible throughout advancement; (iii) advance slowly until anterior bladder wall tenting is seen, then enter the lumen with minimal additional pressure; (iv) avoid excessive probe pressure that may collapse a small bladder. If visualization is difficult, slightly adjust the probe to maintain needle–beam alignment rather than advancing blindly. Real-time (dynamic) guidance is preferred over static marking in neonates and small infants. Multiple pediatric studies demonstrate that ultrasound increases SPA yield while reducing needle passes and delays (143). Early work in emergency departments also showed that portable ultrasound improved success and limited non-productive attempts (144). A recent meta-analysis demonstrated that POCUS guidance enhances both first attempt and overall success of SPA also in neonates and infants (145). Notably, studies suggest that dynamic, real-time needle visualization provides the greatest benefit compared to static pre-scan marking (146,147). Table 4 summarizes procedural applications of POCUS in pediatric emergency medicine.

## Strength of evidence across pediatric POCUS applications

Across the pediatric literature, several POCUS applications are now well supported by prospective studies, meta-analyses, or guideline endorsements. These include lung ultrasound for pneumonia, pleural effusion, and pneumothorax (10,45,41,49,52); abdominal applications such as intussusception and pyloric stenosis (70-72,78); appendicitis pathways that prioritize ultrasound-first in children <14 years (61,64,67); soft-tissue infection/abscess evaluation (30,33); fracture detection in common long-bone and elbow injuries (94,97); testicular torsion assessment with high diagnostic accuracy (115–117); and ultrasound guidance for key procedures including vascular access and endotracheal tube confirmation (135,136,131–134). Conversely, several areas remain promising but comparatively under-studied or heterogeneous in children: IVC dynamics for fluid responsiveness (modest and variable predictive value) (25–27); comprehensive hemodynamic protocols (e.g., pediatric adaptations of RUSH/FOCUS) beyond detection of pericardial effusion and gross dysfunction (16,20); bronchiolitis/COVID-19 severity scoring (supportive yet still evolving pediatric datasets) (55–57); biliary tract disease and early/central appendicitis not abutting the pleura (54,83–86); renal colic and ureteral jets/twinkling artifacts (111–114); subtle or small-bone fractures and tendon pathology (110); joint effusion thresholds and standardization across ages (108,110); and ocular metrics such as pediatric ONSD cut-offs for intracranial pressure (127–129).

## Conclusions

Emergency ultrasound is an important skill with the potential to significantly enhance pediatric emergency care. POCUS can be mastered with a relatively rapid learning curve; importantly, the focus is on achieving defined competencies rather than completing a fixed training duration (9). During residency, structured programs on POCUS integrated with supervised practice, might provide sufficient exposure for physicians to acquire fundamental skills. Incorporating pediatric-specific image libraries, case-based simulations, and deliberate practice on high-yield applications (e.g., lung, cardiac, vascular access, and musculoskeletal scans) accelerates learning while ensuring skills remain directly relevant to pediatric

**Table 4.** Procedural Applications of POCUS in Pediatric Emergency Medicine.

| Procedure | Purpose & Main Applications | Key Technical Points | Advantages | Limitations/Challenges |
|---|---|---|---|---|
| **Endotracheal Tube (ETT) Placement** | Confirm tracheal vs. esophageal intubation; assess ETT position and size to optimize ventilation and reduce trauma. | High-frequency linear probe placed transversely over the anterior neck; dynamic assessment during and after intubation. | Rapid, bedside confirmation; avoids delays; reduces risk of unrecognized esophageal intubation. | Requires operator skill; less effective in detecting mainstem intubation; training needed for accurate interpretation. |
| **Vascular Access** (Central & Peripheral) | Guidance for central venous catheterization (femoral, internal jugular, subclavian); assist peripheral IV placement in difficult cases. | Scan vessels in short and long axis; use color Doppler to distinguish arteries from veins; avoid adjacent nerves. | Improves success in difficult access; reduces procedure time; real-time visualization minimizes complications. | Requires training; anatomic variation; arterial pulsation may be unreliable in shock. |
| **Lumbar Puncture (LP)** | Identify optimal puncture site; visualize spinal canal in infants. | Linear probe for superficial scanning; mark insertion site before procedure; in infants, cartilage improves visualization. | Improves first-attempt success; reduces multiple punctures; useful in patients with poor landmarks. | Limited visualization in older children/ adolescents due to ossified spine; requires patient cooperation. |
| **Arthrocentesis** | Identify and quantify joint effusions (esp. hip); guide needle placement for aspiration or injection. | Use linear or curvilinear probe; identify vessels with Doppler; differentiate cartilage from fluid. | Reduces need for radiographs; improves accuracy and safety; enables ED-based procedure. | Effusion not always present in infection; misinterpretation of cartilage as fluid; dependent on patient cooperation. |
| **Suprapubic Bladder Aspiration (SPA)** | Obtain sterile urine specimen when voiding or catheterization is not possible. | Assess bladder filling with static US; dynamic guidance during needle insertion; ensure needle tip visualization. | Increases success rate; avoids unnecessary attempts; reduces complications. | Requires adequate bladder filling; bowel loops may obscure view; operator-dependent. |

*Abbreviations:* ETT: Endotracheal Tube; IV: Intravenous; LP: Lumbar Puncture; SPA: Suprapubic Aspiration; US: Ultrasound.

emergency care. The advantages of POCUS—low cost, ease of execution, non-invasiveness, and ability to yield essential diagnostic information despite limited patient cooperation—make it an attractive tool in emergency settings. Although evidence supporting its full integration into pediatric emergency medicine is still developing, data demonstrating its impact on clinical workflows are growing rapidly. Recent reviews highlight that POCUS use is associated with reduced emergency department length of stay, decreased reliance on CT imaging, and overall improvements in cost-effectiveness. These findings provide a strong argument for its broader adoption, as they underscore not only the clinical but also the economic value of integrating POCUS into routine practice (148). However, its adoption is not without challenges. Misinterpretation

of images, overdiagnosis from incidental findings, and possible procedural delays are recognized pitfalls. While some studies indicate that POCUS can reduce patient length of stay and expedite decision-making, others suggest it may slow patient flow, particularly during the operator's learning phase. Looking forward, future research should focus on establishing standardized protocols and competency benchmarks to ensure reproducibility and inter-operator reliability, while also identifying the specific clinical scenarios where POCUS offers the greatest impact on patient outcomes. Large, multicenter prospective studies are needed to determine its role in high-acuity pediatric care, complemented by economic evaluations assessing cost-effectiveness and workflow implications. Several pediatric emergency and critical care groups have formed networks to standardize curricula, share image repositories, and coordinate multicenter research. International collaborations have also begun to produce consensus statements and guidelines specific to pediatric POCUS. These cooperative efforts are essential to generate the large, diverse data sets needed to refine training standards, validate diagnostic accuracy, and strengthen the evidence base across different health systems. Expanding such partnerships will be key to achieving the multicenter studies we have identified as a priority for the field. Moreover, integrating POCUS into validated clinical decision-making algorithms will be key to reducing unnecessary imaging and radiation exposure. A clear example is the evaluation of suspected appendicitis in children under 14 years of age, where a POCUS-first approach is embedded in the American College of Radiology (ACR) Appropriateness Criteria. Furthermore, artificial intelligence (AI) offers promising avenues to further enhance the accuracy and accessibility of pediatric POCUS. AI-driven image recognition tools could support physicians by highlighting key sonographic landmarks, flagging possible pathologies, and distinguishing normal developmental variants—such as differentiating growth plates from fractures—thereby reducing interpretation errors. Automated quality feedback systems may also help trainees refine probe positioning and image acquisition in real time. Importantly, integration of AI as a supportive, not replacement, tool could lower operator variability, accelerate learning curves, and increase diagnostic confidence, particularly in resource-limited or high-volume emergency settings. Ultimately, strategies for embedding POCUS seamlessly into pediatric emergency workflows must prioritize patient safety, operational efficiency, and equitable access, ensuring that its considerable potential is fully realized in routine clinical practice.

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## References

1. Marin JR, Lewiss RE. Point-of-care ultrasonography by pediatric emergency medicine physicians. Pediatrics. 2015; 135(4):e1113-22. doi: 10.1542/peds.2015-0343
2. Moore CL, Copel JA. Point-of-care ultrasonography. N Engl J Med. 2011;364(8):749-57. doi: 10.1056/NEJMra0909487
3. Marin JR, Zuckerbraun NS, Kahn JM. Use of emergency ultrasound in United States pediatric emergency medicine fellowship programs in 2011. J Ultrasound Med. 2012;31(9): 1357-63. doi: 10.7863/jum.2012.31.9.1357
4. Marin JR, Abo AM, Arroyo AC, et al. Pediatric emergency medicine point-of-care ultrasound: summary of the evidence. Crit Ultrasound J. 2016;8(1):16. doi: 10.1186/s13089 -016-0049-5
5. Levy JA, Noble VE. Bedside ultrasound in pediatric emergency medicine. Pediatrics. 2008;121(5):e1404-12. doi: 10.1542 /peds.2007-1816

6. Fox JC, Boysen M, Gharahbaghian L, et al. Test characteristics of focused assessment of sonography for trauma for clinically significant abdominal free fluid in pediatric blunt abdominal trauma. Acad Emerg Med. 2011;18(5):477-82. doi: 10.1111/j.1553-2712.2011.01071.x
7. 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):264-8. doi: 10.1016/j.annemergmed.2012.02.007
8. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet. 2012;380(9840):499-505. doi: 10.1016/S0140-6736(12)60815-0
9. Vieira RL, Hsu D, Nagler J, et al. Pediatric emergency medicine fellow training in ultrasound: consensus educational guidelines. Acad Emerg Med. 2013;20(3):300-6. doi: 10.1111/acem.12087
10. 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):288-95. doi: 10.1097/01.ta.0000133565.88871.e4
11. Scaife ER, Fenton SJ, Hansen KW, Metzger RR. Use of focused abdominal sonography for trauma at pediatric and adult trauma centers: a survey. J Pediatr Surg. 2009;44(9):1746-9. doi: 10.1016/j.jpedsurg.2009.01.018
12. Holmes JF, Lillis K, Monroe D, et al. Identifying children at very low risk of clinically important blunt abdominal injuries. Ann Emerg Med. 2013;62(2):107-16.e2. doi: 10.1016/j.annemergmed.2012.11.009
13. Holmes JF, Gladman A, Chang CH. Performance of abdominal ultrasonography in pediatric blunt trauma patients: a meta-analysis. J Pediatr Surg. 2007;42(9):1588-94. doi: 10.1016/j.jpedsurg.2007.04.023
14. 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):1225-30. doi: 10.1016/j.echo.2010.10.005
15. 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. doi: 10.1016/j.emc.2009.09.010
16. McLario DJ, Sivitz AB. Point-of-care ultrasound in pediatric clinical care. JAMA Pediatr. 2015;169(6):594-600. doi: 10.1001/jamapediatrics.2015.22
17. Pershad J, Myers S, Plouman C, et al. Bedside limited echocardiography by the emergency physician is accurate during evaluation of the critically ill patient. Pediatrics. 2004;114(6):e667-71. doi: 10.1542/peds.2004-0881
18. Leeson K, Leeson B. Pediatric ultrasound: applications in the emergency department. Emerg Med Clin North Am. 2013;31(3):809-29. doi: 10.1016/j.emc.2013.05.005
19. Via G, Hussain A, Wells M, et al. International evidence-based recommendations for focused cardiac ultrasound. J Am Soc Echocardiogr. 2014;27(7):683.e1-33. doi: 10.1016/j.echo.2014.05.001
20. Longjohn M, Wan J, Joshi V, Pershad J. Point-of-care echocardiography by pediatric emergency physicians. Pediatr Emerg Care. 2011;27(8):693-6. doi: 10.1097/PEC.0b013e318226c7c7
21. Milner D, Losek JD, Schiff J, Sicoli R. Paediatrics pericardial tamponade presenting as altered mental status. Pediatr Emerg Care. 2003;19(1):35-7. doi: 10.1097/00006565-200302000-00010
22. Smith AT, Watnick C, Ferre RM. Cardiac tamponade diagnosed by point-of-care ultrasound. Pediatr Emerg Care. 2017;33(2):132-4. doi: 10.1097/PEC.0000000000001024
23. Cheng AB, Levine DA, Tsung JW, Phoon CK. Emergency physician diagnosis of pediatric infective endocarditis by point-of-care echocardiography. Am J Emerg Med. 2012;30(2):386.e1-3. doi: 10.1016/j.ajem.2010.12.006
24. Presley BC, Park DB, Sterner SE, et al. Pulmonary embolism in the pediatric emergency department: a case demonstrating the application of point-of-care cardiac ultrasound in a pediatric patient with pulmonary embolism. Pediatr Emerg Care. 2014;30(11):839-44. doi: 10.1097/PEC.0000000000000274
25. De Backer D, Fagnoul D. Intensive care ultrasound: VI. Fluid responsiveness and shock assessment. Ann Am Thorac Soc. 2014;11(1):129-36. doi: 10.1513/AnnalsATS.201309-320OT
26. Orso D, Paoli I, Piani T, et al. Accuracy of ultrasonographic measurements of inferior vena cava to determine fluid responsiveness: a systematic review and metaanalysis. J Intensive Care Med. 2020;35(4):354-63. doi: 10.1177/0885066617752308
27. Long E, Duke T, Oakley E, et al. Does respiratory variation of inferior vena cava diameter predict fluid responsiveness in spontaneously ventilating children with sepsis. Emerg Med Australas. 2018;30(4):556-63. doi: 10.1111/1742-6723.12948
28. Huisman TA. Intracranial hemorrhage: ultrasound, CT and MRI findings. Eur Radiol. 2005;15(3):434-40. doi: 10.1007/s00330-004-2615-7
29. Funk DJ, Jacobsohn E, Kumar A. The role of venous return in critical illness and shock-part I: physiology. Crit Care Med. 2013;41(1):255-62. doi: 10.1097/CCM.0b013e3182772ab6
30. Kathuria N, Ng L, Saul T, Lewiss RE. The baseline diameter of the inferior vena cava measured by sonography increases with age in normovolemic children. J Ultrasound Med. 2015;34(6):1091-6. doi: 10.7863/ultra.34.6.1091
31. Squire BT, Fox JC, Anderson C. ABSCESS: applied bedside sonography for convenient evaluation of superficial soft tissue infections. Acad Emerg Med. 2005;12(7):601-6. doi: 10.1197/j.aem.2005.01.016
32. Marin JR, Dean AJ, Bilker WB, et al. Emergency ultrasound-assisted examination of skin and soft tissue infections in the pediatric emergency department. Acad Emerg Med. 2013;20(6):545-53. doi: 10.1111/acem.12148
33. Sivitz AB, Lam SH, Ramirez-Schrempp D, et al. Effect of bedside ultrasound on management of pediatric soft-tissue

infection. J Emerg Med. 2010;39(5):637-43. doi: 10.1016/j.jemermed.2009.05.013
34. 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):1347-51. doi: 10.1016/j.ajem.2011.09.020
35. Kocher KE, Meurer WJ, Desmond JS, Nallamothu BK. Effect of testing and treatment on emergency department length of stay using a national database. Acad Emerg Med. 2012;19(5):525-34. doi: 10.1111/j.1553-2712.2012.01353.x
36. Ma O, Mateer JR, Blaivas M. Emergency ultrasound. 2nd ed. New York: McGraw-Hill; 2008.
37. Marin JR, Bilker W, Lautenbach E, Alpern ER. Reliability of clinical examinations for pediatric skin and soft-tissue infections. Pediatrics. 2010;126(5):925-30. doi: 10.1542/peds.2010-1039
38. Giovanni JE, Dowd MD, Kennedy C, Michael JG. Inter-examiner agreement in physical examination for children with suspected soft tissue abscesses. Pediatr Emerg Care. 2011;27(6):475-8. doi: 10.1097/PEC.0b013e31821d8545
39. Friedman DI, Forti RJ, Wall SP, Crain EF. The utility of bedside ultrasound and patient perception in detecting soft tissue foreign bodies in children. Pediatr Emerg Care. 2005;21(8):487-92. doi: 10.1097/01.pec.0000173344.30401.8e
40. Costa F, Titolo A, Ferrocino M, et al. Lung ultrasound in neonatal respiratory distress syndrome: a narrative review of the last 10 years. Diagnostics (Basel). 2024;14(24):2793. doi: 10.3390/diagnostics14242793
41. Ord HL, Griksaitis MJ. Fifteen-minute consultation: using point of care ultrasound to assess children with respiratory failure. Arch Dis Child Educ Pract Ed. 2019;104(1):2-10. doi: 10.1136/archdischild-2017-313795
42. Soni NJ, Franco R, Velez MI, et al. Ultrasound in the diagnosis and management of pleural effusions. J Hosp Med. 2015;10(12):811-6. doi: 10.1002/jhm.2434
43. 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):247-52. doi: 10.1097/RTI.0000000000000209
44. Kurepa D, Zaghloul N, Watkins L, Liu J. Neonatal lung ultrasound exam guidelines. J Perinatol. 2018;38(1):11-22. doi: 10.1038/jp.2017.140
45. Holmes JF, Brant WE, Bogren HG, London KL, Kuppermann N. Prevalence and importance of pneumothoraces visualized on abdominal computed tomographic scan in children with blunt trauma. J Trauma. 2001;50(3):516-20. doi: 10.1097/00005373-200103000-00017
46. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. Acad Emerg Med. 2005;12(9):844-9. doi: 10.1197/j.aem.2005.05.005
47. Zhang M, Liu ZH, Yang JX, et al. Rapid detection of pneumothorax by ultrasonography in patients with multiple trauma. Crit Care. 2006;10(4):R112. doi: 10.1186/cc5004
48. Vasquez DG, Berg GM, Srour SG, Ali K. Lung ultrasound for detecting pneumothorax in injured children: preliminary experience at a community-based level II pediatric trauma center. Pediatr Radiol. 2020;50(3):329-37. doi: 10.1007/s00247-019-04509-y
49. Calder BW, Vogel AM, Zhang J, et al. Focused assessment with sonography for trauma in children after blunt abdominal trauma: a multi-institutional analysis. J Trauma Acute Care Surg. 2017;83(2):218-24. doi: 10.1097/TA.0000000000001546
50. Lichtenstein D, Mezière G, Biderman P, Gepner A. The "lung point": an ultrasound sign specific to pneumothorax. Intensive Care Med. 2000;26(10):1434-40. doi: 10.1007/s001340000627
51. Harris M, Clark J, Coote N, et al. British Thoracic Society guidelines for the management of community acquired pneumonia in children: update 2011. Thorax. 2011;66(Suppl 2):ii1-23. doi: 10.1136/thoraxjnl-2011-200598
52. Stadler JAM, Andronikou S, Zar HJ. Lung ultrasound for the diagnosis of community-acquired pneumonia in children. Pediatr Radiol. 2017;47(11):1412-9. doi: 10.1007/s00247-017-3910-1
53. 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):714-22. doi: 10.1542/peds.2014-2833
54. 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):163-70. doi: 10.1007/s00431-015-2611-8
55. 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):119-25. doi: 10.1001/2013.jamapediatrics.107
56. Ianniello S, Piccolo CL, Buquicchio GL, Trinci M, Miele V. First-line diagnosis of paediatric pneumonia in emergency: lung ultrasound (LUS) in addition to chest-X-ray (CXR) and its role in follow-up. Br J Radiol. 2016;89(1061):20150998. doi: 10.1259/bjr.20150998
57. San Sebastian Ruiz N, Rodríguez Albarrán I, Gorostiza I, et al. Point-of-care lung ultrasound in children with bronchiolitis in a pediatric emergency department. Arch Pediatr. 2021;28(1):64-8. doi: 10.1016/j.arcped.2020.10.003
58. Supino MC, Buonsenso D, Scateni S, et al. Point-of-care lung ultrasound in infants with bronchiolitis in the pediatric emergency department: a prospective study. Eur J Pediatr. 2019;178(5):623-32. doi: 10.1007/s00431-019-03335-6
59. Kennedy TM, Malia L, Dessie A, et al. Lung point-of-care ultrasound in pediatric COVID-19: a case series. Pediatr Emerg Care. 2020;36(11):544-8. doi: 10.1097/PEC.0000000000002254
60. Potter SK, Griksaitis MJ. The role of point-of-care ultrasound in pediatric acute respiratory distress syndrome: emerging evidence for its use. Ann Transl Med. 2019;7(19):507. doi: 10.21037/atm.2019.07.76

61. Liu J, Chen SW, Liu F, et al. BPD, not BPD, or iatrogenic BPD: findings of lung ultrasound examinations. Medicine (Baltimore). 2014;93(23):e133. doi: 10.1097/MD.0000000000000133
62. Sivitz AB, Cohen SG, Tejani C. Evaluation of acute appendicitis by pediatric emergency physician sonography. Ann Emerg Med. 2014;64(4):358-64.e4. doi: 10.1016/j.annemergmed.2014.03.028
63. Elikashvili I, Tay ET, Tsung JW. The effect of point-of-care ultrasonography on emergency department length of stay and computed tomography utilization in children with suspected appendicitis. Acad Emerg Med. 2014;21(2):163-70. doi: 10.1111/acem.12319
64. Halm BM, Eakin PJ, Franke AA. Diagnosis of appendicitis by a pediatric emergency medicine attending using point-of-care ultrasound: a case report. Hawaii Med J. 2010;69(9):208-11.
65. Ravichandran Y, Harrison P, Garrow E, Chao JH. Size matters: point-of-care ultrasound in pediatric appendicitis. Pediatr Emerg Care. 2016;32(11):815-6. doi: 10.1097/PEC.0000000000000690
66. Rosen MP, Ding A, Blake MA, et al. ACR appropriateness criteria® right lower quadrant pain--suspected appendicitis. J Am Coll Radiol. 2011;8(11):749-55. doi: 10.1016/j.jacr.2011.07.010
67. Doniger SJ, Kornblith A. Point-of-care ultrasound integrated into a staged diagnostic algorithm for pediatric appendicitis. Pediatr Emerg Care. 2018;34(2):109-15. doi: 10.1097/PEC.0000000000000773
68. Benabbas R, Hanna M, Shah J, Sinert R. Diagnostic accuracy of history, physical examination, laboratory tests, and point-of-care ultrasound for pediatric acute appendicitis in the emergency department: a systematic review and meta-analysis. Acad Emerg Med. 2017;24(5):523-51. doi: 10.1111/acem.13181
69. Goldin AB, Khanna P, Thapa M, et al. Revised ultrasound criteria for appendicitis in children improve diagnostic accuracy. Pediatr Radiol. 2011;41(8):993-9. doi: 10.1007/s00247-011-2018-2
70. Waseem M, Rosenberg HK. Intussusception. Pediatr Emerg Care. 2008;24(11):793-800. doi: 10.1097/PEC.0b013e31818c2a3e
71. Edwards EA, Pigg N, Courtier J, et al. Intussusception: past, present and future. Pediatr Radiol. 2017;47(9):1101-8. doi: 10.1007/s00247-017-3878-x
72. Lin-Martore M, Kornblith AE, Kohn MA, Gottlieb M. Diagnostic accuracy of point-of-care ultrasound for intussusception in children presenting to the emergency department: a systematic review and meta-analysis. West J Emerg Med. 2020;21(4):1008-16. doi: 10.5811/westjem.2020.4.46241
73. Hsiao HJ, Wang CJ, Lee CC, et al. Point-of-care ultrasound may reduce misdiagnosis of pediatric intussusception. Front Pediatr. 2021;9:601492. doi: 10.3389/fped.2021.601492
74. Li XZ, Wang H, Song J, et al. Ultrasonographic diagnosis of intussusception in children: a systematic review and meta-analysis. J Ultrasound Med. 2021;40(6):1077-84. doi: 10.1002/jum.15504
75. del-Pozo G, González-Spinola J, Gómez-Ansón B, et al. Intussusception: trapped peritoneal fluid detected with US--relationship to reducibility and ischemia. Radiology. 1996;201(2):379-83. doi: 10.1148/radiology.201.2.8888227
76. Hryhorczuk AL, Strouse PJ. Validation of US as a firstline diagnostic test for assessment of pediatric ileocolic intussusception. Pediatr Radiol. 2009;39(10):1075-9. doi: 10.1007/s00247-009-1353-z
77. Kong MS, Wong HF, Lin SL, Chung JL, Lin JN. Factors related to detection of blood flow by color Doppler ultrasonography in intussusception. J Ultrasound Med. 1997;16(2):141-4. doi: 10.7863/jum.1997.16.2.141
78. Weihmiller SN, Buonomo C, Bachur R. Risk stratification of children being evaluated for intussusception. Pediatrics. 2011;127(2):e296-303. doi: 10.1542/peds.2010-2432
79. Kuppermann N, O'Dea T, Pinckney L, Hoecker C. Predictors of intussusception in young children. Arch Pediatr Adolesc Med. 2000;154(3):250-5. doi: 10.1001/archpedi.154.3.250
80. Sivitz AB, Tejani C, Cohen SG. Evaluation of hypertrophic pyloric stenosis by pediatric emergency physician sonography. Acad Emerg Med. 2013;20(7):646-51. doi: 10.1111/acem.12163
81. Park JS, Byun YH, Choi SJ, et al. Feasibility of point-of-care ultrasound for diagnosing hypertrophic pyloric stenosis in the emergency department. Pediatr Emerg Care. 2021;37(11):550-4. doi: 10.1097/PEC.0000000000002532
82. Leaphart CL, Borland K, Kane TD, Hackam DJ. Hypertrophic pyloric stenosis in newborns younger than 21 days: remodeling the path of surgical intervention. J Pediatr Surg. 2008;43(6):998-1001. doi: 10.1016/j.jpedsurg.2008.02.022
83. Hernanz-Schulman M. Infantile hypertrophic pyloric stenosis. Radiology. 2003;227(2):319-31. doi: 10.1148/radiol.2272011329
84. Demian M, Nguyen S, Emil S. Early pyloric stenosis: a case control study. Pediatr Surg Int. 2009;25(12):1053-7. doi: 10.1007/s00383-009-2463-2
85. Bailey PV, Connors RH, Tracy TF Jr, Sotelo-Avila C, Lewis JE, Weber TR. Changing spectrum of cholelithiasis and cholecystitis in infants and children. Am J Surg. 1989;158(6):585-8. doi: 10.1016/0002-9610(89)90199-2
86. van Rijn RR, Nievelstein RA. Paediatric ultrasonography of the liver, hepatobiliary tract and pancreas. Eur J Radiol. 2014;83(9):1570-81. doi: 10.1016/j.ejrad.2014.03.025
87. Tsung JW, Raio CC, Ramirez-Schrempp D, Blaivas M. Point-of-care ultrasound diagnosis of pediatric cholecystitis in the ED. Am J Emerg Med. 2010;28(3):338-42. doi: 10.1016/j.ajem.2008.12.003
88. Della Corte C, Falchetti D, Nebbia G, et al. Management of cholelithiasis in Italian children: a national multicenter study. World J Gastroenterol. 2008;14(9):1383-8. doi: 10.3748/wjg.14.1383

89. Weinberg ER, Tunik MG, Tsung JW. Accuracy of clinician-performed point-of-care ultrasound for the diagnosis of fractures in children and young adults. Injury. 2010; 41(8):862-8. doi: 10.1016/j.injury.2010.04.020
90. Barata I, Spencer R, Suppiah A, Raio C, Ward MF, Sama A. Emergency ultrasound in the detection of pediatric long-bone fractures. Pediatr Emerg Care. 2012;28(11):1154-7. doi: 10.1097/PEC.0b013e3182716fb7
91. Patel DD, Blumberg SM, Crain EF. The utility of bedside ultrasonography in identifying fractures and guiding fracture reduction in children. Pediatr Emerg Care. 2009;25(4):221-5. doi: 10.1097/PEC.0b013e31819e34f7
92. Chen L, Kim Y, Moore CL. Diagnosis and guided reduction of forearm fractures in children using bedside ultrasound. Pediatr Emerg Care. 2007;23(8):528-31. doi: 10.1097/PEC.0b013e318128f85d
93. Dubrovsky AS, Kempinska A, Bank I, Mok E. Accuracy of ultrasonography for determining successful realignment of pediatric forearm fractures. Ann Emerg Med. 2015;65(3): 260-5. doi: 10.1016/j.annemergmed.2014.08.043
94. Hübner U, Schlicht W, Outzen S, Barthel M, Halsband H. Ultrasound in the diagnosis of fractures in children. J Bone Joint Surg Br. 2000;82(8):1170-3. doi: 10.1302/0301-620X.82B8.10087
95. Neri E, Barbi E, Rabach I, et al. Diagnostic accuracy of ultrasonography for hand bony fractures in paediatric patients. Arch Dis Child. 2014;99(12):1087-90. doi: 10.1136/archdischild-2013-305678
96. Poonai N, Myslik F, Joubert G, et al. Point-of-care ultrasound for nonangulated distal forearm fractures in children: test performance characteristics and patientcentered outcomes. Acad Emerg Med. 2017;24(5):607-16. doi: 10.1111 /acem.13146
97. Chaar-Alvarez FM, Warkentine F, Cross K, Herr S, Paul RI. Bedside ultrasound diagnosis of nonangulated distal forearm fractures in the pediatric emergency department. Pediatr Emerg Care. 2011;27(11):1027-32. doi: 10.1097 /PEC.0b013e318235e228
98. Williamson D, Watura R, Cobby M. Ultrasound imaging of forearm fractures in children: a viable alternative? J Accid Emerg Med. 2000;17(1):22-4. doi: 10.1136/emj.17.1.22
99. Rabiner JE, Khine H, Avner JR, et al. Accuracy of point-of-care ultrasonography for diagnosis of elbow fractures in children. Ann Emerg Med. 2013;61(1):9-17. doi: 10.1016 /j.annemergmed.2012.07.112
100. Ekşioğlu F, Altinok D, Uslu MM, Güdemez E. Ultrasonographic findings in pediatric fractures. Turk J Pediatr. 2003;45(2):136-40.
101. Warkentine FH, Horowitz R, Pierce MC. The use of ultrasound to detect occult or unsuspected fractures in child abuse. Pediatr Emerg Care. 2014;30(1):43-6. doi: 10.1097 /PEC.0000000000000064
102. Tessaro MO, McGovern TR, Dickman E, Haines LE. Point-of-care ultrasound detection of acute scaphoid fracture. Pediatr Emerg Care. 2015;31(3):222-4. doi: 10.1097 /PEC.0000000000000385
103. Ramirez-Schrempp D, Vinci RJ, Liteplo AS. Bedside ultrasound in the diagnosis of skull fractures in the pediatric emergency department. Pediatr Emerg Care. 2011; 27(4):312-4. doi: 10.1097/PEC.0b013e3182131579
104. Cross KP, Warkentine FH, Kim IK, Gracely E, Paul RI. Bedside ultrasound diagnosis of clavicle fractures in the pediatric emergency department. Acad Emerg Med. 2010;17(7): 687-93. doi: 10.1111/j.1553-2712.2010.00788.x
105. Chien M, Bulloch B, Garcia-Filion P, Youssfi M, Shrader MW, Segal LS. Bedside ultrasound in the diagnosis of pediatric clavicle fractures. Pediatr Emerg Care. 2011;27(11): 1038-41. doi: 10.1097/PEC.0b013e318235e965
106. Snelling PJ, Keijzers G, Byrnes J, et al. Bedside ultrasound conducted in kids with distal upper limb fractures in the emergency department (BUCKLED): a protocol for an open-label non-inferiority diagnostic randomised controlled trial. Trials. 2021;22(1):282. doi: 10.1186/s13063-021-05239-z
107. Garrison J, Nguyen M, Marin JR. Emergency department point-of-care hip ultrasound and its role in the diagnosis of septic hip arthritis: a case report. Pediatr Emerg Care. 2016;32(8):555-7. doi: 10.1097/PEC.0000000000000874
108. Deanehan J, Gallagher R, Vieira R, Levy J. Bedside hip ultrasonography in the pediatric emergency department: a tool to guide management in patients presenting with limp. Pediatr Emerg Care. 2014;30(4):285-7. doi: 10.1097 /PEC.0000000000000113
109. Hashimoto BE, Kramer DJ, Wiitala L. Application of musculoskeletal sonography. J Clin Ultrasound. 1999;27(6): 293-318. doi: 10.1002/(SICI)1097-0096(199907/08)27: 6<293::AID-JCU1>3.0.CO;2-C
110. Vieira RL, Levy JA. Bedside ultrasonography to identify hip effusions in pediatric patients. Ann Emerg Med. 2010;55(3):284-9.doi:10.1016/j.annemergmed.2009.06.527
111. Rabiner JE, Khine H, Avner JR, Tsung JW. Ultrasound findings of the elbow posterior fat pad in children with radial head subluxation. Pediatr Emerg Care. 2015;31(5):327-30. doi: 10.1097/PEC.0000000000000420
112. Yabunaka K, Ohue M, Morimoto N, et al. Sonographic measurement of transient synovitis in children: diagnostic value of joint effusion. Radiol Phys Technol. 2012;5(1): 15-9. doi: 10.1007/s12194-011-0128-z
113. Ng C, Tsung JW. Avoiding computed tomography scans by using point-of-care ultrasound when evaluating suspected pediatric renal colic. J Emerg Med. 2015;49(2):165-71. doi: 10.1016/j.jemermed.2015.01.017
114. Smith-Bindman R, Aubin C, Bailitz J, et al. Ultrasonography versus computed tomography for suspected nephrolithiasis. N Engl J Med. 2014;371(12):1100-10. doi: 10.1056 /NEJMoa1404446
115. 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):135-8. doi: 10.1097 /MEJ.0000000000000158
116. Vallone G, Napolitano G, Fonio P, et al. US detection of renal and ureteral calculi in patients with suspected

renal colic. Crit Ultrasound J. 2013;5(Suppl 1):S3. doi: 10.1186/2036-7902-5-S1-S3
117. Kalfa N, Veyrac C, Lopez M, et al. Multicenter assessment of ultrasound of the spermatic cord in children with acute scrotum. J Urol. 2007;177(1):297-301. doi: 10.1016/j.juro.2006.08.128
118. Friedman N, Pancer Z, Savic R, et al. Accuracy of point-of-care ultrasound by pediatric emergency physicians for testicular torsion. J Pediatr Urol. 2019;15(6):608.e1-6. doi: 10.1016/j.jpurol.2019.07.003
119. Lam WW, Yap TL, Jacobsen AS, Teo HJ. Colour Doppler ultrasonography replacing surgical exploration for acute scrotum: myth or reality? Pediatr Radiol. 2005;35(6):597-600. doi: 10.1007/s00247-005-1411-0
120. Mori T, Ihara T, Nomura O. Diagnostic accuracy of point-of-care ultrasound for paediatric testicular torsion: a systematic review and meta-analysis. Emerg Med J. 2023;40(2):140-6. doi: 10.1136/emermed-2021-212281
121. Blaivas M. Bedside emergency department ultrasonography in the evaluation of ocular pathology. Acad Emerg Med. 2000;7(8):947-50. doi: 10.1111/j.1553-2712.2000.tb02080.x
122. Vrablik ME, Snead GR, Minnigan HJ, et al. The diagnostic accuracy of bedside ocular ultrasonography for the diagnosis of retinal detachment: a systematic review and meta-analysis. Ann Emerg Med. 2015;65(2):199-203.e1. doi: 10.1016/j.annemergmed.2014.02.020
123. Shinar Z, Chan L, Orlinsky M. Use of ocular ultrasound for the evaluation of retinal detachment. J Emerg Med. 2011;40(1):53-7. doi: 10.1016/j.jemermed.2009.06.001
124. Yoonessi R, Hussain A, Jang TB. Bedside ocular ultrasound for the detection of retinal detachment in the emergency department. Acad Emerg Med. 2010;17(9):913-7. doi: 10.1111/j.1553-2712.2010.00809.x
125. Buzzard AK, Linklater DR. Pediatric retinal detachment due to Coats' disease diagnosed with bedside emergency department ultrasound. J Emerg Med. 2009;37(4):390-2. doi: 10.1016/j.jemermed.2007.09.027
126. Lahham S, Shniter I, Thompson M, et al. Point-of-care ultrasonography in the diagnosis of retinal detachment, vitreous hemorrhage, and vitreous detachment in the emergency department. JAMA Netw Open. 2019;2(4):e192162. doi: 10.1001/jamanetworkopen.2019.2162
127. Bates A, Goett HJ. Ocular ultrasound. In: StatPearls (Internet). Treasure Island (FL): StatPearls Publishing; 2022.
128. Propst SL, Kirschner JM, Strachan CC, et al. Ocular point-of-care ultrasonography to diagnose posterior chamber abnormalities: a systematic review and metaanalysis. JAMA Netw Open. 2020;3(2):e1921460. doi: 10.1001/jamanetworkopen.2019.21460
129. Körber F, Scharf M, Moritz J, Dralle D, Alzen G. Sonography of the optic nerve: experience in 483 children [German]. Rofo. 2005;177(2):229-35.
130. Newman WD, Hollman AS, Dutton GN, Carachi R. Measurement of optic nerve sheath diameter by ultrasound: a means of detecting acute raised intracranial pressure in hydrocephalus. Br J Ophthalmol. 2002;86(10):1109-13. doi: 10.1136/bjo.86.10.1109
131. Driessen C, Bannink N, Lequin M, et al. Are ultrasonography measurements of optic nerve sheath diameter an alternative to funduscopy in children with syndromic craniosynostosis? J Neurosurg Pediatr. 2011;8(3):329-34. doi: 10.3171/2011.6.PEDS10547
132. Le A, Hoehn ME, Smith ME, et al. Bedside sonographic measurement of optic nerve sheath diameter as a predictor of increased intracranial pressure in children. Ann Emerg Med. 2009;53(6):785-91. doi: 10.1016/j.annemergmed.2008.11.025
133. Kars MS, Gomez Morad A, Haskins SC, et al. Point-of-care ultrasound for the pediatric regional anesthesiologist and pain specialist: a technique review. Reg Anesth Pain Med. 2020;45(12):985-92. doi: 10.1136/rapm-2020-101341
134. Merali HS, Tessaro MO, Ali KQ, et al. A novel training simulator for portable ultrasound identification of incorrect newborn endotracheal tube placement – observational diagnostic accuracy study protocol. BMC Pediatr. 2019;19(1):434. doi: 10.1186/s12887-019-1717-y
135. O'Shea JE, Loganathan P, Thio M, et al. Analysis of unsuccessful intubations in neonates using videolaryngoscopy recordings. Arch Dis Child Fetal Neonatal Ed. 2018;103(5):F408-12. doi: 10.1136/archdischild-2017-313628
136. Sharma D, Tabatabaii SA, Farahbakhsh N. Role of ultrasound in confirmation of endotracheal tube in neonates: a review. J Matern Fetal Neonatal Med. 2019;32(8):1359-67. doi: 10.1080/14767058.2017.1403581
137. Ali KQ, Soofi SB, Hussain AS, et al. Simulator-based ultrasound training for identification of endotracheal tube placement in a neonatal intensive care unit using point of care ultrasound. BMC Med Educ. 2020;20(1):409. doi: 10.1186/s12909-020-02338-4
138. Acar Y, Tezel O, Salman N, et al. 12th WINFOCUS world congress on ultrasound in emergency and critical care. Crit Ultrasound J. 2016;8(Suppl 1):12.
139. 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):154-9. doi: 10.1097/PEC.0b013e31819a8946
140. Boniface K, Pyle M, Jaleesah N, Shokoohi H. Point-of-care ultrasound for the detection of hip effusion and septic arthritis in adult patients with hip pain and negative initial imaging. J Emerg Med. 2020;58(4):627-31. doi: 10.1016/j.jemermed.2019.11.036
141. Tsung JW, Blaivas M. Emergency department diagnosis of pediatric hip effusion and guided arthrocentesis using point-of-care ultrasound. J Emerg Med. 2008;35(4):393-9. doi: 10.1016/j.jemermed.2007.10.054
142. Scheier E, Levick N, Ujirauli N, Raviv O, Balla U. Point-of-care ultrasound-guided drainage of joint effusions in

the pediatric emergency setting: a case series. J Ultrasound Med. 2022;41(5):1285-93. doi: 10.1002/jum.15795
143. Mahdipour S, Saadat SNS, Badeli H, Rad AH. Strengthening the success rate of suprapubic aspiration in infants by integrating point-of-care ultrasonography guidance: a parallel-randomized clinical trial. PLoS One. 2021; 16(7):e0254703. doi: 10.1371/journal.pone.0254703
144. Gochman RF, Karasic RB, Heller MB. Use of portable ultrasonography to assist urine collection by suprapubic aspiration. Ann Emerg Med. 1991;20(6):631-5. doi: 10.1016 /s0196-0644(05)81605-7
145. Abosamak MF, Shaban EE, Elkandow A, et al. Point-of-care ultrasonography for suprapubic bladder aspiration in pediatric patients: a systematic review and meta-analysis. Arab J Urol. 2025;24(2):138-48. doi: 10.1080 /20905998.2025.2557135
146. Kumar M, Sreenivas V, Singh P. Point-of-care ultrasonography-guided suprapubic aspiration for urine collection in neonates: a randomized controlled trial. Arch Dis Child Fetal Neonatal Ed. 2020;105(3):254-8. doi: 10.1136/archdischild-2019-316993
147. Kim DJ, Theoret J, Liao MM, Kendall JL. Experience, training, and confidence in point-of-care ultrasound: a cross-sectional survey of emergency physicians in Canada. J Emerg Med. 2020;59(6):880-7. doi: 10.1016 /j.jemermed.2020.09.045
148. Lentz B, Fong T, Rhyne R, Risko N. A systematic review of the cost-effectiveness of ultrasound in emergency care settings. Ultrasound J. 2021;13(1):16. doi: 10.1186 /s13089-021-00216-8