Translating Guidelines into Practical Practice

Point-of-Care Ultrasound for Pediatric Critical Care Clinicians

Mark D. Weber, RN, CPNP-AC, FCCM[a,*], Joel K.B. Lim, MBBS, MRCPCH[b], Sarah Ginsburg, MD[c], Thomas Conlon, MD[a], Akira Nishisaki, MD, MSCE[a]

KEYWORDS

• Pediatric critical care • Ultrasound • POCUS • Guidelines

KEY POINTS

- Point-of-care ultrasound (POCUS) is an emerging technology that can provide immediate answers to clinical questions at the bedside.
- Expert guidelines are now available to direct the application of POCUS for the critical care provider.
- Recognizing the limitations of the current guidelines and formalizing the next steps in POCUS development will further increase the utility of this valuable tool.

INTRODUCTION

During the 1990s, the broad use of point-of-care ultrasound (POCUS) by nonradiologists within the emergency department was met with misgivings.[1] Since that time, clinicians have realized measurable benefits of POCUS, resulting in American College of Emergency Physicians guidelines published in 2001.[2] Adult and pediatric critical care providers now also use POCUS applications for procedural and diagnostic applications frequently encountered in their respective care settings.[3–5] With the rapid growth in critical care POCUS, there is a need for a more structured approach to education, credentialing, and its application at the bedside.

[a] Division of Critical Care Medicine, Department of Anesthesiology and Critical Care Medicine, Children's Hospital of Philadelphia, University of Pennsylvania, Philadelphia, PA 19104, USA; [b] Children's Intensive Care Unit, Department of Pediatric Subspecialties, KK Women's and Children's Hospital, Singapore; [c] Division of Critical Care Medicine, Department of Pediatrics, University of Texas Southwestern Medical Center, Dallas, TX, USA
* Corresponding author. Wood 6025, 3401 Civic Center Boulevard, Philadelphia, PA 19104.
E-mail address: weberm@chop.edu

Crit Care Clin 39 (2023) 385–406
https://doi.org/10.1016/j.ccc.2022.09.012 criticalcare.theclinics.com

In 2015 and 2016, the Society of Critical Care Medicine (SCCM) published both procedural and diagnostic evidence-based guidelines for POCUS applications in adult critical care with pediatric considerations included.[6,7] In 2020, the European Society of Pediatric and Neonatal Intensive Care (ESPNIC) published guidelines specific to pediatric and neonatal populations, including 41 statements on the use of POCUS[8] (Supplemental Table 1). Although both SCCM and ESPNIC guidelines provide an important beginning toward incorporating relevant POCUS applications in clinical practice, they are not meant to deliver a comprehensive POCUS education curriculum for pediatric critical care practitioners. The authors review SCCM and ESPNIC guidelines within cores of applications (ie, procedural, cardiac, thoracic, abdominal, and neurologic), discuss strengths and limitations of statements, explore unanswered questions, and suggest important considerations when translating POCUS education to the care of critically ill children.

PROCEDURAL ULTRASOUND

The dawn of ultrasound for vascular access procedures was heralded by the use of doppler to localize the internal jugular vein (IJV) in the late 1970s.[9,10] Several years later, ultrasound was used for direct visualization of the IJV and subclavian veins (SCVs).[11] POCUS to both visualize vessels and guide cannulation became accepted practice for frequently accessed central vessels, including IJVs,[12] femoral veins,[13] and SCVs.[14] With the progression of its adoption for central venous access, there has been a parallel acceptance of the use of POCUS as an adjunct for securing both peripheral venous and arterial access.[15,16]

Both SCCM and ESPNIC guidelines presented strong expert agreement for the use of POCUS for IJV and femoral venous access (**Table 1**). The data demonstrate a decrease in insertion attempts, decrease in arterial punctures, and increased success rates.[17–20] Although the SCCM guidelines cited strong evidence in the adult population, they reported a paucity of data in support of POCUS for IJV placement in children, citing a meta-analysis with equivocal support for POCUS use versus the landmark technique in infants and children.[21] The ESPNIC group subsequently found strong pediatric evidence, grade A, to support the use of POCUS for pediatric IJV line placement. Notably, the meta-analysis cited by SCCM guidelines was in pediatric cardiac populations, and increased benefits of POCUS were noted when POCUS was used by novice providers in the operating room. This may reflect the challenges of training experienced providers new techniques.

POCUS for the use of SCV and axillary vein cannulation had strong agreement in ESPNIC guidelines but conditional agreement in SCCM guidelines.[6–8] Data in the pediatric and adult population demonstrate safe cannulation of the subclavian and brachiocephalic veins using POCUS for guidance.[22–25] These benefits translate even to neonates weighing less than 1500 g.[26]

Arterial access may also benefit from the use of POCUS. The strength of data is not as robust, leading to both ESPNIC and SCCM giving agreement and conditional support, respectively.[6–8] Literature suggests integration of POCUS results in shorter time to arterial cannulation with fewer attempts compared with palpation technique.[15,27,28] These benefits are also found in the neonatal population.[29] Despite growing literature supporting use of POCUS in peripheral vascular access to improve provider performance and patient outcomes in both children and neonates, neither guidelines commented on this important application.

Technically, a short-axis out-of-plane (SA-OOP) approach is most commonly used for POCUS-guided vascular access.[11] The SA-OOP approach is recommended by the

Table 1
Vascular access procedural statements achieving strong agreement in European Society of Pediatric and Neonatal Intensive Care guidelines with corresponding Society of Critical Care Medicine statement

Summary of POCUS Application Statement	ESPNIC Level of Evidence	SCCM Strength of Recommendation	SCCM Pediatric Discussion	SCCM Pediatric-Specific	SCCM Level of Evidence
Internal jugular line placement	A	1	Yes	No	A
Subclavian line placement	B	2	No	No	C
Femoral line placement	B	1	Yes	No	A
Verification of catheter tip position	C	2	No	No	B

Table 1 summarizes the point-of-care ultrasound application within ESPNIC statements with strong agreement among experts. Corresponding level of evidence within the ESPNIC guidelines is defined using GRADE criteria with A as “high,” B as “moderate,” C as “low,” and D as “very low.” SCCM guidelines were reviewed to evaluate whether a statement was made corresponding to the ESPNIC statement achieving strong agreement. Strength of recommendation within SCCM guidelines is defined as 1, “strong recommendation”; 2, “weak/conditional recommendation”; and 3, “not reaching agreement.” The table also indicates whether pediatric data are included in the discussion of the statement or the statement is pediatric-specific.

SCCM guidelines,[6] as it is an easier skill to acquire over the long-axis in-plane (LA-IP) approach, with early studies showing increased success of SA-OOP over the LA-IP approach.[30–32] Over time, more data have been published on the benefits of an LA-IP approach, with reports of reduced arterial punctures, increased first attempt success, and decreased catheter misplacements.[25,26,33,34] In studies using gel-based phantoms, fewer posterior wall punctures were noted when using the LA-IP approach as opposed to the SA-OOP approach.[35] Although it may be a more challenging technique to master, the above benefits of the LA-IP approach may allow for safer access of the vessel over the SA-OOP approach.

Numerous publications exist regarding the approach to POCUS training for procedural applications. Both manikins and more advanced dynamic haptic trainers provide educational benefits to trainees in IJV placement, including a decrease in procedural time.[36] Another potential training modality includes a real-time 3-dimensional mixed reality simulator. This training approach has led to improved provider confidence with more technically challenging approaches, such as landmark approaches in the supraclavicular subclavian catheter placement.[37] The use of newer needle navigation technology has had mixed reviews with trainees. A study of anesthesia residents within an adult intensive care unit (ICU) revealed that needle navigation technology led to lower satisfaction scores and longer procedure times among experienced providers.[38] On the other hand, a study wherein the technology was implemented with radiology residents found it to be beneficial. It may be that the radiology residents are more comfortable with newer technologies that require complex spatial relations.[39]

In addition, there have been novel approaches to the didactic component of POCUS education. Didactic educational formats have been successfully implemented using an online approach. This online approach could be applied to geographic areas where POCUS educators are limited and is particularly relevant in the era of the SARS-CoV-2 pandemic when large gatherings are avoided. When an online approach is used, follow-up hands-on simulation sessions to solidify a learner's psychomotor skill are essential.[40] As with any education experience, POCUS trainees with the highest level of motivation will benefit most from online training, leading to greater confidence and independence.[41,42]

Following the implementation of hands-on and didactic training, it is imperative to follow the procedural competency of trainees to ensure their skills are progressing as expected. Tools capable of measuring procedural competency are essential to develop and may identify areas of weakness for targeted education.[43–45] Such tools should measure not only psychomotor technique but also essential aspects of preprocedural planning, patient safety considerations, communication skills, and teamwork.[44] Educators can use cumulative sum (CUSUM) analysis charts to track individual skill acquisition over time. CUSUM charts have been used in ultrasound-guided peripheral intravenous cannulation skill acquisition among anesthesiology trainees to determine competency.[45] The investigators noted that with the CUSUM charts it was possible to detect an individual's deterioration in competency before their averages of failed attempts identify issues. With this approach, remediation in training can be implemented early before poor techniques become engrained into practice.

CARDIAC ULTRASOUND

Cardiac ultrasonography has become a valuable tool in assessing critically ill patients, including patients with shock,[46] dyspnea,[47] and cardiac arrest.[48] Although acknowledging the extensive utility of this application, it is important to distinguish the scope of cardiac POCUS compared with traditional echocardiography performed by cardiologists. Singh and colleagues[49] define cardiac POCUS as a tool for intensivists to "answer a defined clinical question" that informs patient management, often in a time-sensitive manner (**Table 2**). These scans can help providers decide on therapies, further evaluation, and when to involve advanced consultants.

Globally, the scope of cardiac POCUS addresses basic questions of qualitative ventricular function, ventricular size relationships, gross estimates of right ventricular (RV) pressure, preload and fluid responsive conditions, and the presence of pericardial effusion. Further training in cardiac POCUS can allow for "semiquantitative" measurements of function and pressure by intensivists at the bedside.[8] However, comprehensive evaluation of cardiac structure and function falls into the realm of formal cardiology-performed echocardiography. As such, the ESPNIC guidelines state with strong agreement that ultrasound should not be used for screening or evaluation of congenital heart disease without advanced cardiology training. The SCCM guidelines support this conclusion, although on lower strength of evidence. Similarly, the guidelines do not support evaluation for acquired defects, such as acquired valvular disease, per SCCM, or endocarditis, per ESPNIC.

One caveat to the statements on structural evaluation involves the assessment of patent ductus arteriosus (PDA) in neonates. Once a formal echocardiogram has excluded ductal-dependent structural heart disease, serial POCUS can be used to assess and trend PDA patency over time or to assess hypotensive patients without congenital heart disease. With advanced training, bedside providers may be able to delineate PDA characteristics, such as diameter, flow direction, velocity, and hemodynamic significance of the shunt.[50,51] ESPNIC supports POCUS PDA assessment with strong agreement, whereas SCCM cites good consensus although low quality of evidence (2C) and indicates that the scans should be performed specifically by providers with advanced training.

The assessment of patients' fluid status and volume responsiveness is an essential part of critical care, yet remains complicated by the lack a gold-standard method for measurement.[52,53] On the topic of fluid status, the ESPNIC guidelines suggest, with strong agreement, POCUS "may be helpful" for determining volume status and preload responsiveness, although cites grade D (very low) evidence. In comparison, SCCM guidelines support similar recommendations for pediatrics with very good consensus and grade 1B evidence. Evaluation of the inferior vena cava (IVC) dimension and respiratory variation is the most easily accessible parameter for assessing preload conditions via POCUS. However, although studies in intubated adults demonstrated an association between IVC distensibility and volume status[54] as well as fluid responsiveness,[55] a similar study of pediatric patients intubated for surgery did not find that IVC respiratory variation accurately predicted fluid responsiveness.[56] In spontaneously breathing patients, an IVC collapsibility index greater than 50% has been considered highly predictive for fluid responsiveness.[57] However, meta-analyses in both adult[58] and pediatric settings[59] failed to show a consistent association between IVC variation and fluid responsiveness. This may be explained by the complex interactions between variables that impact on IVC dimensions, such as volume status, venous capacitance, tricuspid regurgitation (TR), cardiac compliance and function, respiratory effort, and intrathoracic and intra-abdominal pressures. In an attempt to standardize conditions for IVC assessment, adult studies often cite a goal of 8 mL/kg of tidal volume in a sedated patient without spontaneous respiratory effort.

The respiratory variation of both the peak aortic blood flow velocity and the velocity-time integral (VTI) measured across the left ventricular (LV) outflow tract has been

Table 2
Cardiac statements achieving strong agreement in European Society of Pediatric and Neonatal Intensive Care guidelines with corresponding Society of Critical Care Medicine statement

Summary of POCUS Application Statement	Advanced Training Recommended	ESPNIC Level of Evidence	SCCM Strength of Recommendation	SCCM Level of Evidence	SCCM Pediatric-specific
Screening for congenital heart defects	Yes	A	2	C	Yes
Assessment of preload	No	D	1	B	Yes
Assessment of fluid responsiveness	No	D	1	B	Yes
Qualitative assessment of function	No	D	1	C	Yes
Assessment of pulmonary artery pressure	Yes	B	1	B	Yes
Semiquantitative assessment of PAH	No	B	1	B	Yes
Assessment of pericardial effusion	No	B	1	C	No
Guide pericardiocentesis	No	B	1	C	No
Assess patency of ductus arteriosus	Yes	A	2	C	Yes

Table 2 summarizes the POCUS application within ESPNIC statements with strong agreement among experts. Corresponding level of evidence within the ESPNIC guidelines is defined using GRADE criteria with A as "high," B as "moderate," C as "low," and D as "very low." SCCM guidelines were reviewed to evaluate whether a statement was made corresponding to the ESPNIC statement achieving strong agreement. Strength of recommendation within SCCM guidelines is defined as 1, "strong recommendation"; 2, "weak/conditional recommendation"; and 3, "not reaching agreement." The table also indicates whether pediatric data are included in the discussion of the statement or the statement is pediatric-specific.

Abbreviations: N/A, statements were not applicable and without recommendations due to lack of agreement; PAH, pulmonary artery hypertension.

demonstrated to accurately predict fluid responsiveness in both adults and children.[59–65] Using VTI, stroke volume and cardiac output can be calculated and trended over time in critically ill patients. Measuring VTI requires an appropriately oriented apical 5-chamber view and the ability to capture pulse-wave doppler, making it a higher-level skill compared with IVC measurement.

For ventricular function, basic cardiac POCUS uses a qualitative approach to “eyeball” systolic function. Studies have shown such assessments are accurate when compared with formal echocardiographic measurements, particularly for LV systolic function.[66–69] The ESPNIC guidelines state with strong agreement that POCUS “may be helpful” for qualitative assessment, although citing grade D evidence. Quantitative assessments of systolic function, including shortening fraction and ejection fraction for the LV and tricuspid annular plane systolic excursion for the RV, are noted as “helpful” by ESPNIC with grade C evidence. Such calculations require more advanced POCUS skills and should be learned under expert guidance.[70,71]

Cardiac POCUS should be used as a part of holistic clinical hemodynamic assessment of critically ill patients.[46,72,73] As such, the SCCM guidelines do not comment on specific types of functional evaluation but rather applications to shock states. In suspected pediatric cardiogenic shock, the guidelines suggest using cardiac POCUS with an overall recommendation grade of 2C with good consensus. Because of lack of data, the guidelines do not make a recommendation on using cardiac POCUS to evaluate function in pediatric septic shock, although there is growing literature that POCUS can guide resuscitation in pediatric septic shock.[74,75]

Citing similar lack of evidence, the SCCM guidelines do not make a recommendation on the use of cardiac POCUS to specifically evaluate RV function in pediatric patients. In comparison, ESPNIC, with strong agreement, supports the use of cardiac POCUS to evaluate for pulmonary hypertension in neonates and children on grade B evidence (moderate quality evidence). With basic cardiac views, the shape of the interventricular septum in the parasternal short-axis view can indicate RV hypertension when the septum is flattened or bowing. More advanced studies include measurement of the TR velocity, when a TR jet is present, to calculate pulmonary artery systolic pressure using the Bernoulli equation.[71,76] Because of transitional physiology and risk of persistent pulmonary hypertension in neonates, bedside assessment of TR is part of the recommended evaluation for POCUS performed by the neonatologist.[51]

Last, the ESPNIC guidelines recommend that cardiac POCUS is helpful with assessment and drainage of pericardial effusions with strong agreement and grade B evidence. Pericardial effusions can be seen in multiple basic cardiac views, with the subcostal view being the first choice.[77] Evaluation for hemodynamically significant pericardial effusion is an essential part of the ultrasound assessment of an acutely decompensating patient.[78,79] When pericardiocentesis is required for an effusion, the procedure should be done under ultrasound guidance rather than a blind approach.[80,81] Although the SCCM guidelines do not make specific recommendations on pericardial effusion evaluation, they do recommend that cardiac POCUS be used to evaluate for reversible causes of pediatric cardiac arrest and specifically mention evaluation for cardiac tamponade as part of this process with very good consensus (Supplemental Table 3.2).[48]

LUNG ULTRASOUND

Initially, the lung was deemed unsuitable for interrogation via ultrasound. The inability of ultrasound waves to penetrate air and the surrounding thoracic cage was thought to prevent an adequate sonographic assessment.[82] Subsequently, the recognition of ultrasound artifacts generated at the interface between normal and abnormal lung tissues formed the basis for sonographic evaluation of the lung.[83,84] This has been followed by progressive interest and growth in the use of POCUS for the assessment of respiratory failure in the emergency department and ICU, in both adult and pediatric settings.[84–86]

In 2015, guidelines published by SCCM, predominantly focused on applications of POCUS for critically ill adults, included 4 recommendations for the use of lung ultrasound (LUS).[6] In comparison, guidelines from ESPNIC included 11 recommendations for the use of LUS in critically ill neonates and children (**Table 3**).[8] This reflected a rapid expansion of LUS use in emergency departments and ICUs around the world, accompanied by a significant growth of evidence for LUS in neonates and children over several years[83–85,87,88] (Supplemental Table 4.2).

In general, recommendations from the SCCM and ESPNIC guidelines regarding LUS assessment of pleural disorders are well aligned with each other. As the role of LUS in this context is well established, both guidelines have put forth strong recommendations (or strong agreement) in the following: (1) detecting pleural effusions; (2) providing ultrasound guidance for thoracocentesis or drainage of pleural effusions; and (3) detecting a pneumothorax.[83,84,89–91] In addition, the ESPNIC guidelines proposed "strong agreement" that LUS is useful for guiding chest tube insertion or needle aspiration in neonatal tension pneumothorax. Because of limited pediatric evidence, this recommendation is extrapolated from adult studies reporting reduced complications and improved success rates. This was also based on the rationale that LUS may be used to identify margins of the lung, diaphragm, and subdiaphragmatic organs throughout the respiratory cycle so as to safely avoid them during needle or chest tube insertion.[92]

Regarding the assessment of lung parenchyma, the SCCM guidelines make a conditional recommendation that a systematic approach with LUS may be used as a

Table 3
Pulmonary statements achieving strong agreement in European Society of Pediatric and Neonatal Intensive Care guidelines with corresponding Society of Critical Care Medicine statement

Summary of POCUS Application Statement	ESPNIC Level of Evidence	SCCM Strength of Recommendation	SCCM Level of Evidence	SCCM Pediatric-specific
Describe viral bronchiolitis	A	N/A	N/A	N/A
Detect pneumothorax	B	1	A	No
Evacuation of pneumothorax	B	N/A	N/A	N/A
Detect pleural effusions	B	1	A	No
Guided thoracentesis	B	1	B	No

Table 3 summarizes the POCUS application within ESPNIC statements with strong agreement among experts. Corresponding level of evidence within the ESPNIC guidelines is defined using GRADE criteria with A as "high," B as "moderate," C as "low," and D as "very low." SCCM guidelines were reviewed to evaluate whether a statement was made corresponding to the ESPNIC statement achieving strong agreement. Strength of recommendation within SCCM guidelines is defined as 1, "strong recommendation"; 2, "weak/conditional recommendation"; and 3, "not reaching agreement." The table also indicates whether pediatric data are included in the discussion of the statement or the statement is pediatric-specific.

Abbreviation: N/A, not available as a statement within guidelines.

primary diagnostic modality for assessing interstitial and parenchymal lung pathologic condition in critically ill patients with respiratory failure. This recommendation is based on evidence that LUS (complemented by venous analysis where relevant) has a diagnostic accuracy of more than 90% in identifying common causes of acute respiratory failure in adults, including cardiogenic pulmonary edema, pneumonia, decompensated chronic obstructive pulmonary disease, acute asthma, pneumothorax, and pulmonary embolism.[82,93]

In contrast, the ESPNIC guidelines have crafted their recommendations for the role of LUS in assessing interstitial and parenchymal lung disease into 7 separate statements, with several specific to neonates and children. Of the 7 recommendations, the role of LUS in describing features of viral bronchiolitis was the only one assigned “strong agreement.” This is supported by reports that LUS is superior to chest radiography in detecting lung abnormalities, with LUS features of bronchiolitis correlating well with clinical severity, facilitating timely identification of patients who may require escalating respiratory support.[94–98] The remaining 6 recommendations were assigned “agreement” and include the utility of LUS in the following: (1) distinguishing between neonatal respiratory distress syndrome and transient tachypnea of the neonate[99–108]; (2) detecting pneumonia in neonates and children[109–112]; (3) recognizing meconium aspiration syndrome[113,114]; (4) evaluating lung edema in neonates and children[115,116]; (5) detecting anesthesia-induced atelectasis in neonates and children[117]; and (6) semi-quantitatively evaluating lung aeration and guiding management of respiratory interventions in acute respiratory distress syndrome (ARDS) in neonates and children.[118,119]

These guidelines are undeniably a welcome step in the evolution of POCUS in the ICU, providing evidence-based recommendations for LUS in critically ill neonates and children. There is little doubt that compared with chest radiography or computed tomography (CT), LUS provides an economical, timely, nonirradiative, and easily repeatable bedside assessment with immediate results, without having to move a critically ill patient. LUS should be used in the appropriate context to answer specific clinical questions, bearing its limitations in mind: (1) LUS is limited in its ability to reliably determine the size of pneumothorax, necessitating clinical considerations or chest radiography to decide between conservative or surgical management; (2) LUS is unable to evaluate the extent of lung hyperinflation; (3) LUS is unable to assess the central areas of the thorax for hilar or mediastinal disorders, such as pneumomediastinum, pneumopericardium, or interstitial emphysema; (4) LUS cannot visualize areas beneath the scapulae, and patients with obesity, subcutaneous emphysema, wounds, or dressings may pose additional challenges with acquiring adequate images; and (5) radiographs are still considered the gold standard for determining the exact position of tubes and lines.

The publication of these recommendations has set the stage for future studies to determine if LUS improves clinical outcomes, particularly for applications related to parenchymal disease. Although it is generally accepted that LUS improves outcomes in the management of pleural disorders, there remains a paucity of evidence for the benefit of LUS in parenchymal disease, such as LUS-guided interventions to mitigate atelectasis via chest physiotherapy or lung recruitment maneuvers and ventilator titration during mechanical ventilation.[120,121] There is a need for consensus on the optimal LUS scoring system that incorporates the spectrum of LUS findings, to accurately reflect the severity of lung parenchymal disease in pediatric ARDS, the impact of clinical interventions, and correlates with outcomes. In the future, such advances in LUS may guide titration of mechanical ventilation at the bedside and lay the foundation for crafting a standardized curriculum for LUS and its applications in the ICU.

ABDOMINAL ULTRASOUND

The Focused Assessment with Sonography in Trauma (FAST) examination arose alongside the development of Emergency Medicine as a distinct clinical practice. Ultrasound now not only found itself in the hands of nonradiology and noncardiology providers, but data suggested POCUS use resulted in better clinical performance and patient outcomes in acute clinical care.[122–126] The historical growth and accumulated evidence are most apparent in abdominal applications of POCUS.

SCCM guidelines recommend the use of ultrasound for paracentesis (1A) and to exclude mechanical causes of renal failure (2C) with no mention of the pediatric population.[6] ESPNIC guidelines (**Table 4**) include the identification of free fluid and paracentesis guidance (strong agreement) as well as solid organ assessment, identifying obstructive uropathy, visualizing bowel peristalsis, and diagnosing necrotizing enterocolitis (agreement).[8] The traditional purpose for abdominal POCUS was to provide definitive, often dichotomous, answers to a focused question. For example, direct ultrasound visualization of "normal versus abnormal" and "present versus absent" (abdominal fluid, renal calyx dilation, peristalsis) provides additional data points for diagnostic considerations. Abdominal POCUS now includes the assessment pathophysiologic evolution resulting in less definitive and more nuanced diagnostic capabilities relevant to care and outcomes. For example, in assessing necrotizing enterocolitis, there are multiple ultrasonographic findings characterizing the varied stages of disease, including the presence of pneumatosis, portal venous air, large/complex ascites, aperistaltic bowel, and an evolution of bowel hyperemia to overt ischemia.[127] Individually these findings may be nonspecific but together improve the accuracy in diagnosis and clearly depict the progression of pathophysiology. Some diagnoses will have pathognomonic image findings (eg, pyloric stenosis), whereas others may require a constellation of findings similar to necrotizing enterocolitis (eg, appendicitis). Guidelines can hardly capture the complex interplay between ultrasound findings and clinical diagnostics specifically in the assessment of abdominal pathophysiologic processes in the pediatric patient.

The "signs and symptoms" traditionally obtained from clinical examination (eg, palpation, percussion) and history now require consideration of real-time ultrasound imaging data. However, the question of *what to do* with the data remains the same,

Table 4
Abdominal statements achieving strong agreement in European Society of Pediatric and Neonatal Intensive Care guidelines with corresponding Society of Critical Care Medicine statement

Summary of POCUS Application Statement	ESPNIC Level of Evidence	SCCM Strength of Recommendation	SCCM Level of Evidence	SCCM Pediatric-specific
Detect intra-abdominal free fluid	C	1	B	No
Guide drainage of peritoneal fluid	D	1	B	No

Table 4 summarizes the POCUS application within ESPNIC statements with strong agreement among experts. Corresponding level of evidence within the ESPNIC guidelines is defined using GRADE criteria with A as "high," B as "moderate," C as "low," and D as "very low." SCCM guidelines were reviewed to evaluate whether a statement was made corresponding to the ESPNIC statement achieving strong agreement. Strength of recommendation within SCCM guidelines is defined as 1, "strong recommendation"; 2, "weak/conditional recommendation"; and 3, "not reaching agreement." The table also indicates whether pediatric data are included in the discussion of the statement or the statement is pediatric-specific.

and one that ultrasound alone cannot answer. Take, for example, the FAST examination in children. Whereas randomized trials demonstrate decreased abdominal CT use, hospital lengths of stay, complications, and hospital charges when ultrasound is used in adult assessment,[128,129] a randomized trial including 925 hemodynamically stable children with blunt abdominal trauma found no outcome differences when FAST was integrated in management decisions.[130] Furthermore, there was only moderate agreement (k = 0.45) between FAST performer and expert reviewer, suggesting needs for improved training and potential risks of misdiagnosis at the bedside.

Although both psychomotor and interpretative skill development is of paramount importance, just because we *can* use ultrasound does not mean we *should* use it when a clinical benefit is in doubt. Thus, as demonstrated by controversies in performing the pediatric FAST examination, we need to move beyond a simple argument related to diagnostic accuracy to better understand how ultrasound is best used within a clinical context. Despite the expert consensus agreement, are longitudinal ultrasound evaluations of abdominal solid organ injuries really in the scope of the acute care provider in a tertiary care institution with radiology services? These are questions that guidelines cannot directly address but should be asked when reaching for a probe.

NEUROLOGIC ULTRASOUND

One of the earliest translations of ultrasound technology to clinical practice was in attempts to identify brain anatomy and pathophysiology as theorized by Dr Karl Dussik[131] in the 1940s. Nonradiology specialty learners in both adult and pediatric clinical practice have only recently explored training in neurosonographic clinical applications. SCCM guidelines did not provide guidance regarding any ultrasound applications related to the evaluation of the nervous system. ESPNIC guidelines did suggest a role for ultrasound use by acute care providers with strong agreement regarding the evaluation of intraventricular hemorrhage in neonates and agreement with its integration in evaluating both changes to and absence of cerebral blood flow in varied clinical settings. Furthermore, ESPNIC guidelines endorsed the evaluation of the optic nerve for assessing elevated intracranial pressure (ICP) (**Table 5**).[8]

Neurosonographic imaging uses both what is seen and what is not seen. Direct visualization of the neonatal brain and an understanding of normal anatomy and corresponding symmetry allow for improved interpretation of gross abnormalities by

Table 5
Neurosonography statements achieving strong agreement in European Society of Pediatric and Neonatal Intensive Care guidelines with corresponding Society of Critical Care Medicine statement

Summary of POCUS Application Statement	ESPNIC Level of Evidence	SCCM Strength of Recommendation	SCCM Level of Evidence	SCCM Pediatric-Specific
Detect intraventricular hemorrhage	A	N/A	N/A	N/A

Table 5 summarizes the POCUS application within ESPNIC statements with strong agreement among experts. Corresponding level of evidence within the ESPNIC guidelines is defined using GRADE criteria with A as "high," B as "moderate," C as "low," and D as "very low." SCCM guidelines were reviewed to evaluate whether a statement was made corresponding to the ESPNIC statement achieving strong agreement. Strength of recommendation within SCCM guidelines is defined as 1, "strong recommendation"; 2, "weak/conditional recommendation"; and 3, "not reaching agreement." The table also indicates whether pediatric data are included in the discussion of the statement or the statement is pediatric-specific.

neonatology providers following brief training.[132] Although ESPNIC guidelines support the evaluation of neonatal intraventricular hemorrhage with grade A level of evidence, there is no cited literature regarding image acquisition and interpretation performed in the clinical setting by neonatology, emergency medicine, or critical care subspecialists.

Direct imaging of the optic nerve sheath diameter (ONSD) may provide important information regarding increased ICP. Meta-analysis of adult data suggests that an increased ONSD measured using ultrasound is accurate for assessing ICP[133–135]; however, a recently published systematic review of pediatric literature suggests ONSD strong sensitivity with only moderate specificity (ie, overdiagnosing increased ICP).[136] Of the 11 studies evaluated for the pediatric systematic review, the investigators found heterogeneity in assessment techniques, including use of different probes for evaluation as well as different standards for measurements. Pediatric caveats, such as the presence of an open fontanelle as well as whether elevated ICP is a chronic or acute clinical change, need to also be considered in ONSD measurements.

Transcranial doppler (TCD) is increasingly used in pediatric acute care settings. TCD provides important information regarding cerebral blood flow in select pediatric populations, most prominently in children with sickle cell disease.[137] A recent Expert Consensus Statement for use of TCD in critically ill children resulted in the development of standardized methods of assessing and reporting TCD findings.[138] TCD can be categorized as imaging and nonimaging. Imaging TCD combines pulsed-wave doppler with 2-dimensional assessment of corresponding anatomy to decipher not only flow patterns but also potential structural abnormalities.[139] Nonimaging TCD is "blind" and uses knowledge of normal anatomy to assess blood flow integrating the spectral display and sound acquired by imaging within a cranial window. ESPNIC guidelines do not specify preferred methods of TCD, and the quality of evidence is C for the limited scope of identified TCD applications.[8] Although TCD is increasingly used in pediatric critical care settings, the vast majority of studies are performed in institutions with dedicated neurocritical care centers, and they are currently interpreted by vascular sonography specialists.[140]

MOVING FORWARD

Considerable time and effort by experts in the POCUS field resulted in SCCM and ESPNIC guidelines providing important guideposts for the integration of ultrasound technology in the pediatric critical care practice setting. Although guidelines are important first steps toward developing curricular platforms, the critical care community must now focus on POCUS clinical practice *guidance*. There appear to be some notable common considerations relevant to translating and expanding all core guidelines in clinical care.

First, we need to understand the educational needs within each core of applications and define implementation strategies that coincide with those educational needs. Common educational domains include knowledge and affective and psychomotor skill development.[141] The authors suggest that an additional domain, interpretative skill, be considered within ultrasound education. This domain necessarily incorporates knowledge and psychomotor skills and also requires contextual understanding of ultrasound data within the scope of the clinical setting. The interpretative domain must teach what ultrasound both *can* and *cannot* tell us at time of performance, as well as during longitudinal incorporation in care. Acquiring mastery skill level within educational domains is vital to the quality of POCUS image acquisition, interpretation, and integration in quality care.

Second, we need to clarify the purpose of each POCUS study and identify whether ultrasound is a simple tool to provide a definitive answer versus an advanced diagnostic tool to provide constellation of findings and/or stage of the disease. The former will have questions that will be easier to answer and therefore easier to master. The latter will require more advanced training with detailed practice parameters. Defining the purpose of POCUS will allow the images gathered to be translated into clinically meaningful outcomes. As more clinical evidence accumulates, we may shift the type of POCUS study from those we *can* perform to those we *should* perform.

Third, it is necessary to tailor the use of POCUS to meet the needs of specific patients, providers, and clinical practice contexts. Should we create practice guidance that meets the needs of both beginner and advanced POCUS providers? Should we account for clinical resources, that is, resource-rich versus resource-limited settings? Local resource availability may likely require tailored curricular design and methods of delivery.

Fourth, education delivery should target measurable clinical competency development by learners. The American College of Graduate Medical Education now emphasizes use of Entrustable Professional Activities to monitor educational growth and ensure competency in clinical practice.[142] Defining thresholds for translation of education to independent bedside performance within cores of applications is an important step to help identify relevant methods of measurement.

Finally, clinical practice guidance may require programmatic support mechanisms. These are present within the current emergency medicine guidelines[143] and suggested within adult critical care literature.[144] These support mechanisms may be difficult to build in pediatric critical care at a unit level and require community support, whether through the institution or external mechanisms.[145] Multicenter database built with common elements can provide longitudinal educational and clinical outcome measures to monitor implementation and translational effectiveness at local, regional, national, and international levels.

SUMMARY

The development of SCCM and ESPNIC guidelines was an important first step to assessing existing evidence and providing support for the use of POCUS in core clinical applications. POCUS is an important adjunct to a systematic clinical assessment in many clinical contexts. Thus, there is a need to develop clinical practice guidance to facilitate the translation of these guidelines into meaningful curriculum that will support the needs of our pediatric critical care community and those it serves.

DISCLOSURE

The authors have nothing to disclose.

CLINICS CARE POINTS

- The use of POCUS for vascular access procedures decreases insertion attempts, time to cannulation and procedural complications.
- Cardiac POCUS can provide rapid answers to defined clinical questions thereby informing management in critically ill children, particularly those with hemodynamic instability.
- Lung US can rapidly diagnose a pneumothorax but cannot accurately quantify its size, requiring clinical considerations or chest radiography to decide between conservative or invasive management.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at https://doi.org/10.1016/j.ccc.2022.09.012.

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