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REVIEW ARTICLE

Point-of-care ultrasound in paediatric emergency medicine

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Point-of-care ultrasound (POC US) is an adjunct to clinical paediatric emergency medicine practice that is rapidly evolving, improving the outcomes of procedural techniques such as vascular access, nerve blocks and fluid aspiration and showing the potential to fast-track diagnostic streaming in a range of presenting complaints and conditions, from shock and respiratory distress to skeletal trauma. This article reviews the procedural and diagnostic uses, both established and emerging, and provides an overview of the necessary components of quality assurance during this introductory phase.

Key words: point-of-care ultrasound; emergency medicine; paediatric; PEM; POCUS; bedside.

Introduction

Over 20 years since the focused assessment with sonography in trauma scan was introduced into the emergency management of adult trauma patients,[1] there has been a dramatic increase in the uses of and indications for point-of-care ultrasound (POC US) in emergency medicine, initially in the adult emergency medicine domain, and more recently, with paediatric emergency medicine (PEM). POC US provides the clinician with real-time, radiation free, anatomical, physiological and pathological information that guides clinical care. The recent establishment of dedicated paediatric emergency ultrasound fellowships[2] with research and teaching agendas has enabled not only an extension of adult-based POC US uses, but also the development of specific uses in PEM. This article provides an overview of established and emerging uses of POC US in PEM, and the implications for training, clinical practice and patient care.

Key points

- Ultrasound guidance increases the effectiveness and safety of invasive procedures.
- POC US can improve diagnostic accuracy and streamline management of the acutely unwell patient.
- The establishment of POC US in paediatric emergency medicine should include robust training, credentialing, auditing and clinical research components.

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The American Academy of Pediatrics has recently released a policy statement on ultrasound in PEM stating 'PEM physicians should be familiar with the definition and application of point-of-care ultrasonography and the utility for patients in the ED' and advising on various aspects of training, research and credentialing.[3] Within the Australian context, the landmark 1999 Australasian College for Emergency Medicine Policy P21 encourages 'all emergency physicians to be competent in the "core" areas of emergency ultrasound, being abdominal aortic aneurysm, EFAST (extended focussed assessment with sonography in trauma), procedural guidance and echo in life support', and expecting that 'all emergency medicine training programmes will have processes in place that allow trainees to gain instruction and experience in bedside ultrasound imaging'.[4]

The premise of a POC US examination is a focused examination in answer to a specific clinical question. For example, is an intestinal intussusception able to be visualised in this patient's abdomen, or what is the global cardiac contractility in this shocked patient? Hospital-based radiology departments offer a different service – comprehensive ultrasound examinations (systematic regional surveys) performed by highly experienced ultrasonographers with a deep and broad understanding of the principles underlying image production and interpreted by specialist radiologists. The American Academy of Pediatrics policy statement cautions that 'clinicians should be aware that point-of-care ultrasonography is better used as a "rule in" and not a "rule out" diagnostic modality'.[3] Systematic regional surveys will remain an essential tool in the PEM investigative repertoire, particularly where false negatives need to be minimized. However, POC US examination by an experienced clinician, holding the nuances of physical examination and differential diagnoses in their mind, can allow rapid streaming of probabilities and can be repeated serially to map an evolving clinical picture.

The uses of ultrasound in PEM can be broadly divided into procedural and diagnostic. An overview of these uses can be seen in Table 1.

Procedural Ultrasound

Procedural guidance is the most immediately quantifiable benefit of ultrasound in PEM. A range of PEM procedures, including femoral nerve blockade and central line insertion, have been shown to have greater first-attempt success and fewer complications when guided by ultrasound.[5,6] Real-time ultrasound procedural guidance requires the acquisition of fine motor skills[7] and the recognition of anatomical structures, all of which can be learnt with theoretical education, utilisation of anatomical models and real-time scanning. Emergency medicine procedures can be categorised into three groups:

1 Vascular access

Once the technique of ultrasound-guided peripheral vascular access has been mastered, its use in daily practice will increase the rate of successful cannulation, particularly in those children with difficult veins[8] with an improvement in parental satisfaction.[9] Given the likelihood of movement of the paediatric patient during peripheral venous access, an out-of-plane approach with the vessel in short axis is most appropriate.[10] In contrast, central venous access can be achieved with an in-plane approach with the vessel viewed in its long axis so that the needle tip can be observed at all times, making penetration of important deeper structures less likely. The position of an intraosseous needle can be assessed with Doppler ultrasound of the medulla of the bone while injecting an isotonic fluid flush.[11]

2 Analgesia

In the setting of trauma, ultrasound-guided femoral nerve blockade reduces the need for sedating analgesic agents in paediatric patients,[12] and ultrasound guidance has been shown to decrease volumes required and increase efficacy compared with traditional methods of blockade.[13] Other nerve blocks useful in PEM include ulnar nerve blocks for metacarpal fracture reductions and posterior tibial nerve blocks for procedures involving the sole of the foot.

3 Aspiration

Diagnostic or therapeutic aspiration of fluid without ultrasound can be difficult and has the potential to injure important structures. Aspiration of urine, joints, abscesses, cerebrospinal fluid, pleural and pericardial effusions and peritoneal fluid are all more effectively and safely accomplished with ultrasound guidance.[14]

Diagnostic Ultrasound

There are many possible diagnostic uses of POC US in PEM ranging from long-bone fracture identification or confirmation to hydronephrosis in a neonate with a urinary tract infection. Immediate acquisition of such specific clinical information with POC US might be sufficient to guide initial clinical management. Alternatively, further imaging including serial POC ultrasounds, a comprehensive ultrasound assessment or computed tomography (CT) delineation, may be arranged as required. Recent studies of POC US in adult emergency patients[15,16] demonstrate that early use of focused POC US as part of an integrated clinical evaluation leads to earlier diagnostic streaming and initiation of appropriate therapies.

Such integrated clinical evaluation must incorporate the clinician's awareness of their own sonographic experience, the

Table 1 Procedural and diagnostic uses for point-of-care ultrasound in paediatric emergency medicine

Procedural		Diagnostic	
Vascular access†	Peripheral, central	Respiratory distress	Pneumothorax†
Analgesia†	Peripheral, regional		Pneumonia‡
Lumbar puncture§	Location, depth		Pleural effusion†
Bladder†	Pre-catheterisation volume; suprapubic localisation	Hypotension	Global cardiac function§
Abscess‡	Localisation and liquefaction staging		Cardiac tamponade‡
Foreign body‡	Localisation and efficacy of removal		Hypertrophic obstructive cardiomyopathy (HOCM)‡
Fracture manipulation§	Real-time reduction		Fluid status§ (aorta/IVC/lungs/bladder)
Endotracheal intubation§	Endotracheal versus oesophageal; efficacy (bilateral lung sliding)		Other congenital heart disease§
Pericardiocentesis§	Optimal siting	Trauma	EFAST§
Joint aspiration‡	Optimal siting		Skull fracture‡
Pleurocentesis†	Localisation		Neonatal intracranial evaluation‡
Paracentesis†	Optimal fluid pocket localisation	Musculoskeletal	Fracture§
Intraosseous placement§	Confirm correct placement by flow		Foreign body removal‡
			Abscess drainage‡
			Joint effusion (e.g. hip)‡
		Abdominal	Intussusception†
			Appendicitis§
			Cholecystitis†
			Hydronephrosis‡
			Pyloric stenosis†
			Constipation; rectal loading§

Value of ultrasound. †Useful with supporting literature. ‡Probably useful (hypertrophic obstructive cardiomyopathy). §Possibly useful with emerging evidence. EFAST, extended focussed assessment with sonography in trauma; IVC, inferior vena cava.

unique patient characteristics such as haemodynamic stability, differential diagnoses and the pre-test probability for a given diagnosis, suitability for serial review and knowledge of the sensitivity of POC US for the sought condition. While this may appear to be a major mental balancing act, it is exactly the real-time mental sifting and re-calibrating required by the emergency physician in all clinical practice and in response to any new clinical information.

Resuscitation

The following describes the utility of ultrasound in effectively, efficiently and safely managing the severely ill or injured child who requires resuscitation.

1 Airway

Real-time ultrasonography can immediately confirm correct positioning of an endotracheal tube or, conversely, inadvertent oesophageal intubation.[17]

2 Breathing

Once the trachea has been successfully intubated, a main bronchus intubation can be quickly excluded by examining each anterior hemithorax for lung sliding. Alternatively, the presence of a lung pulse, indicating an inflated but non-ventilating lung, implies that the contralateral main bronchus has been intubated.[18] Carefully withdrawing the tube until lung sliding is seen on both sides will optimise endotracheal tube position and ventilation.

3 Circulation

The haemodynamically unstable child may have a contributory cardiac cause identified with basic echocardiographic views. Possibilities include a thickened myocardium in the syncopal adolescent with undiagnosed hypertrophic cardiomyopathy, a pericardial effusion with tamponade pathophysiology or a poorly functioning left ventricle in a child with viral myocarditis.

The haemodynamic status and prediction of fluid responsiveness in the shocked child can be evaluated by assessing[19–21]:

i. The contractility of the left ventricle of the heart;
ii. The size of the inferior vena cava (IVC) and its collapsibility during inspiration[22];
iii. The presence or absence of interstitial fluid within the lungs; and
iv. The amount of urine in the bladder at serial intervals.

A hyperdynamic heart, a relatively small IVC with more than 50% collapse during inspiration, 'dry' lungs and an empty bladder suggest a hypovolaemic cause of shock and that a fluid bolus is appropriate. Conversely, a patient with poor cardiac contractility, a full IVC and pulmonary interstitial fluid might be best managed with early inotropes (Fig. 1). Alternatively, a full IVC with little inspiratory collapse may be present in obstructive causes of shock including a tension pneumothorax, pulmonary embolism or cardiac tamponade. Importantly, the IVC in children will vary in size depending on their age. As a guide, it should be similar in size to the adjacent aorta.[23]

The Australasian College for Emergency Medicine (ACEM) Policy P22 states 'Basic echocardiography should be rapidly available in the setting of a patient in cardiac arrest or haemodynamic compromise'.[24] The potential for POC US to answer critical questions and guide early therapy in children in shock is so great that it is now being incorporated into algorithms for the management of pulseless electrical activity cardiac arrest in North America.[25]

A more advanced method of using ultrasound to predict fluid responsiveness in the shocked child is to measure the stroke volume before and after a fluid bolus. If there is no change in stroke volume following a fluid bolus, it is likely that inotropes or vasopressors would be more useful than additional fluids.[26]

In the event of an arrested patient, a 10-s cardiac assessment during a routine pulse check can establish:

i. Whether there is a reversible cause of the cardiac arrest such as cardiac tamponade or tension pneumothorax; and
ii. The presence or absence of ventricular wall motion. Its absence is associated with a very low chance of successfully achieving a return of spontaneous circulation. This information may contribute to the decision to continue or cease resuscitation.[27]
iii. Disability

Head trauma, or a suspected primary neurological problem, may lead to elevated intracranial pressure. Measuring the optic nerve sheath diameter can indirectly assess this. If it is greater than 5 mm, it is likely that there is raised intracranial pressure (ICP). However, current paediatric research findings are mixed, meaning that the interpretation of this finding should be cautious.[28]

Open fontanelles in the infant make it possible for the brain to be directly visualised for the presence of sinus thrombosis, increase in extra-axial space (suggesting possible subdural hematoma), hydrocephalus or major midline shift.[29] Furthermore, skull fractures may be readily detected by ultrasound.[30]

1 Trauma

2 Extended focused assessment with sonography in trauma

In the child who has sustained blunt or penetrating abdominal trauma, the EFAST scan can be performed following the primary survey[31] to identify free fluid in the peritoneal space, thorax and pericardium and a pneumothorax. The paediatric EFAST performs poorly when compared with its use in adults, having a sensitivity of about 50% in detecting clinically significant intraperitoneal blood, equating to approximately 250 mL.[32,33] Therefore, the absence of intraperitoneal free fluid does not exclude significant intra-abdominal injury in children, nor does it replace the need for CT scan. When compared with adults, paediatric patients are more likely to sustain contained solid organ injuries, and blood tends to accumulate in the pelvis where it can be more difficult to detect because of overlying air-filled bowel loops. Likewise, organ injuries are more difficult to detect than free intraperitoneal fluid for the novice sonographer; furthermore, examination for organ injuries does not form a part of the routine EFAST examination. Interestingly, European imaging departments are using contrast-enhanced ultrasound to monitor solid organ injuries found on initial CT scans, thereby decreasing exposure to radiation.[34]

In the trauma patient, a pneumothorax can be rapidly excluded with significantly higher sensitivity than a supine chest X-ray.[35] Sternal and rib fractures are more sensitively diagnosed with ultrasound, and importantly, underlying pulmonary contusions can be detected by the presence of hypoechoic (dark) areas of the lung immediately deep to the sonographic pleural line.[36]

ii. Secondary survey

The secondary survey, performed once the airway, breathing and circulation are stabilised, is a systematic examination of the

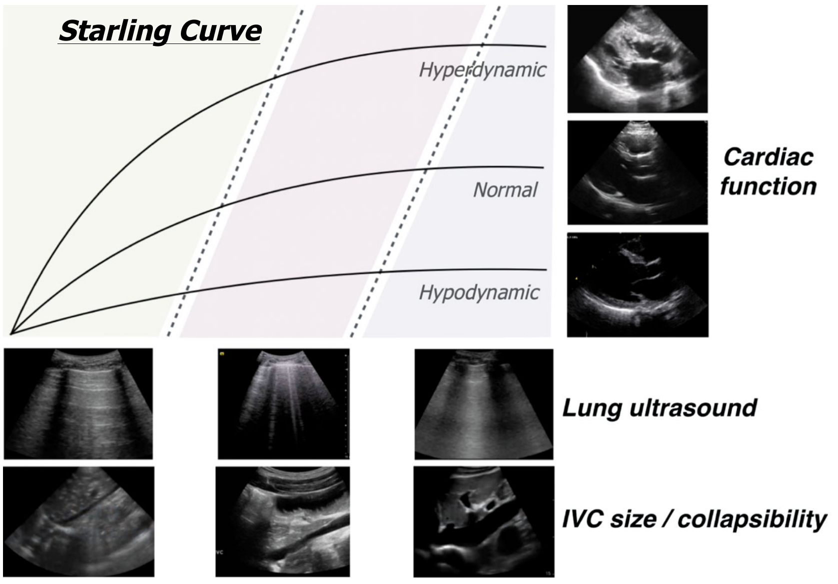

Fig. 1 Predicting fluid responsiveness in the septic patient. 1. The Starling curve slope is firstly estimated by assessing the global cardiac function (hyperdynamic, normal and hypodynamic). 2. The patient's physiological position on the curve can then be estimated by examining for:-Interstitial fluid with lung sonography (horizontal 'A lines' on left indicate normal lungs and coalescing vertical 'B lines' on right indicate a significant amount of interstitial fluid); and-The dimension and collapsibility of the inferior vena cava during the respiratory phase.

child to detect non-life threatening injuries. Ultrasound can be used to improve the detection of orbital[37] and skeletal injuries including long-bone fractures and pelvic diastasis.[38]

2 Respiratory presentations

The child who presents in respiratory distress causes diagnostic and management uncertainties on a daily basis in PEM. POC lung ultrasound can rapidly and reliably diagnose consolidation, pneumothoraces, simple or complex pleural effusions, pulmonary congestion or normal lung fields with sensitivities of over 90%.[39–41] This has the potential to guide clinicians' resuscitative interventions, after which other investigative modalities can be performed.

Viral pneumonitis has been differentiated from bacterial consolidation with lung sonography.[42] Viral infections cause small subpleural consolidations unlike bacterial infections, which are larger and contain sonographic air bronchograms. Furthermore, lung sonography may have a role in the stratification of bronchiolitis severity.[43]

3 Abdominal presentations

Abdominal pain is a common paediatric emergency department presentation, and both POC and comprehensive ultrasound play a role in its evaluation. After assessing the child with acute abdominal pain, a clinician has a provisional and alternative differential diagnoses with varying pre-ultrasound likelihoods. POC US may then confirm a provisional surgical diagnosis such as intussusception or appendicitis and expedite definitive treatment. However, because of the limited sensitivity and significant experiential variability, a negative POC US finding should rarely be used to *exclude* clinical diagnoses, particularly surgical diagnoses.[3]

Intussusception has typical appearances, which emergency physicians can learn after focused tuition and subsequently scan with a sensitivity approaching 85%.[44] With experience, small-bowel intussusceptions can be differentiated from ileo-colic intussusceptions, the former tending to be self-resolving and therefore less problematic.[45]

Paediatric appendicitis is a common PEM presentation requiring surgery. Several studies analysing the utility of PEM POC US in its diagnosis have had variable findings, ranging from a 31% incidence of being unable to identify an inflamed appendix,[46] to sensitivities and specificities of greater than 90% when used in combination with clinical scoring systems.[47] A blind ending, dilated, non-compressible structure that has no peristalsis is very suggestive of appendicitis.

In the neonatal presentation, the diagnosis of pyloric stenosis with ultrasound is highly sensitive and specific in the hands of an experienced ultrasonographer. One study has indicated that paediatric emergency physicians might also be able to learn the technique and diagnose it with a high level of accuracy, and thereby expediting appropriate referral.[48]

Constipation, one of the leading causes of abdominal pain in paediatrics, is associated with sonographic rectal distension of more than 3 cm.[49] While the utility of sonographic bowel and rectal assessments in the emergency department has not been clearly established, this measurement and the real-time visualisation of bowel motility may add extra clinical information in this common presentation. Other abdominal diagnoses, where POC US has been shown to be diagnostically useful include bowel obstruction,[50] inflammatory bowel disease, perforated bowel,[51] hernias, renal and ureteric obstruction.[52] Testicular torsion may be diagnosed with POC US. However, caution must be used in interpreting a 'normal' scan as the torsion may have resolved, or be incomplete or intermittent.[53]

4 Musculoskeletal/soft tissue presentations

Soft tissue and joints can be examined with high-resolution ultrasound to provide useful clinical information. In the toddler who presents with limping, localisation of the cause can be difficult. The detection of a hip effusion can localise the cause of the limp, but the nature of the effusion, septic versus reactive, cannot be differentiated with ultrasound.[54] Fractured bones can be readily diagnosed with ultrasound, with successful reduction, then being guided with ultrasound.[55] The ability of ultrasound to identify subperiosteal hematoma may make it particularly valuable in the early recognition of possible abusive skeletal injury.[56]

Most foreign bodies are seen as bright (hyperechoic) structures with posterior shadowing. Careful use of ultrasound can detect glass, wood or plastic foreign bodies, guide their removal and confirm complete removal.[57]

Ultrasound findings of skin infections range from the non-specific finding of interstitial fluid ('cobblestone' appearance) to collections of fluid that may be infected collections. These collections should have no blood flow within them and be compressible and measurable.[58] The larger the volume of the collection, the more likely will be the need for surgical drainage.

Ultrasound Safety

1 Training

The Australasian Society for Ultrasound in Medicine was formed in 1970 and has played the major role in providing education and setting standards of practice in this continually developing area. Obtaining the Diploma of Diagnostic Ultrasound or Certificate in Clinician Performed Ultrasound through the Australasian Society for Ultrasound in Medicine, or equivalent, are minimum standards recommended for clinicians supervising PEM POC US training and credentialing.[24,59,60] The Australasian College for Emergency Medicine has published minimum standards for ultrasound training workshops.[61] The American College of Emergency Physicians[62] states that training should involve the following three phases to develop optimal ultrasound skills:

i. Image acquisition – eye-hand coordination and technical proficiency follow supervised practice with anatomical models, normal models and supervised educational ultrasound 'rounds' within the department. Modern POC US machines are supremely optimised for image quality in highly specific examination settings. An understanding of ultrasound physics is important to ensure the basis for these is understood.
ii. Image interpretation – the training doctor must build up an understanding of sonographic anatomy, image artefacts, the limitations of image acquisition and the range of normal and abnormal appearances in relation to the clinical question being addressed.
iii. Image integration into clinical practice – this is the most advanced clinical skill to learn in POC US. It requires a thorough understanding of the significance of pre-test probabilities, the performance of ultrasound in their hands and for the system being examined and the weighting of other findings. Without this ability, adverse patient outcomes may ensue from incorrect conclusions about the examination.

2 Credentialing

Credentialing for PEM POC US, as in other disciplines, should be specific to a given study type[63] and should require experience with both normal and abnormal findings. Credentialing is ultimately the responsibility of the health service. The Australasian College for Emergency Medicine has provided a description of the phases needed for a successful ultrasound credentialing programme[24,60]:

i. An introductory teaching phase covering both theoretical and practical aspects.
ii. A period of gaining experience with a minimum number of scans, including both normal and abnormal findings, in patients with relevant clinical indications.
iii. The candidate being directly observed performing the examination, completing adequate documentation and integrating the findings into clinical practice.

3 Quality assurance

A PEM POC US program must regularly audit images to the following:

i. Ensure maintenance of practice standards;
ii. Monitor use of ultrasound in the department;
iii. Enable verified maintenance of credentials for individual practitioners; and
iv. Provide a mentored review of scans that include 'perceived concerns' identified during routine or educational scans.

For a quality assurance system to function effectively, scans must be annotated and saved with practitioner and patient details, including the practitioner's interpretation of the scan and any action that was taken.[64]

Depending on the number and experience of proficient POC sonographers in a PEM department, auditing can be led from within this pool or involve internal or external sonographers or radiologists. A supportive relationship with a hospital-based imaging department can be a great asset.

4 Collaboration and research

The Australasian College for Emergency Medicine has policies acknowledging the advantages of POC US for patient care and safety.[4] It also advocates for training and research in this field.

Over recent decades, research efforts have focused on establishing the diagnostic advantages of POC US in specific conditions, ranging from pneumothoraces to intussusception. More recently, the focus of adult ultrasound research has shifted to the impact of POC US on patient outcomes, including earlier diagnostic accuracy followed by more directed management[15,16] and reducing ionising radiation in those with renal colic.[65] There is a need for further research, which uses patient-focused outcomes into the impact of POC US on PEM patients, examples being reduction of radiation exposure and time to treatment.

Conclusions

The art of diagnostic medicine has always involved rapid shifting of multiple probabilities in an evolving clinical setting. Just as no physician would be without their stethoscope despite its limited sensitivity and specificity in isolation, so too the use of focused POC US is becoming a natural extension of the clinical examination across a wide range of clinical scenarios. Despite its limitations, the use of POC US is leading to more rapid diagnostic focusing and commencement of treatment, and overall higher diagnostic success both in cardiorespiratory and abdominal emergencies in the adult setting. Given some of the diagnostic advantages of lung ultrasound, and the high sensitivity of ultrasound for intussusception and skull fractures, it is likely that there will be research-based development of clinical pathways incorporating focused POC US into the management of paediatric cardiorespiratory, abdominal and head injury emergencies.

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