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Cardiology/CT Surgery (K Gist, Section Editor)

Point-of-Care Ultrasound-Guided Procedures in the Pediatric Cardiac Intensive Care Unit

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Abstract

Purpose of Review This publication will review the numerous uses for procedural point-of-care ultrasound (POCUS), and its supporting literature, specifically for pediatric patients admitted to the cardiac intensive care unit.
Recent Findings Procedural POCUS can be applied broadly to critically ill children with congenital and acquired heart disease and there is longstanding, supporting evidence for procedures such as central venous catheter placement and thoracentesis. Recently, studies have demonstrated the success of innovative POCUS-guided procedures, including transpyloric enteric tube placement and endotracheal intubation, which are frequently performed in this high-risk population.
Summary POCUS, a non-invasive, bedside imaging modality, can be used to guide high-risk procedures in vulnerable populations, such as critically ill children with

congenital and acquired heart disease. The use of POCUS guidance for procedures in the pediatric cardiac intensive care unit is associated with increased procedural success and fewer complications, thereby enhancing patient safety and, ultimately, outcomes.

Introduction

Point-of-care ultrasound (POCUS) is an important diagnostic and procedural tool for critical care providers. POCUS guidance for invasive procedures, such as obtaining vascular access, is well studied in both adult and pediatric patients [1, 2••]. In fact, for many procedures, utilization of POCUS is now considered standard of care in critical care and emergency medicine settings [3].

The benefits of POCUS include the lack of ionizing radiation, bedside/portable nature, and, most-importantly, real-time interpretation by the operator. There are few disadvantages to using POCUS, specifically the one-time cost of the machine and the training required to skillfully perform and interpret the ultrasound findings.

Procedural guidance with POCUS is a crucial instrument when caring for critically ill patients as it augments patient safety and enhances procedural success, leading to faster therapeutic intervention [4••]. This review will emphasize the procedural application of POCUS as it relates to critically ill children with congenital and acquired heart disease, focusing on the evaluation and therapeutic implications of utilizing POCUS. The diagnostic utility of POCUS in this specific patient population was recently reviewed so will not be discussed in this review [5].

Vascular

Evaluation

POCUS guidance for vascular access, specifically for cannulation with arterial and central venous catheters, is a standard of care in both pediatric and adult medicine. We will review the supportive literature in this section, highlighting pediatric specific data. Additionally, the importance of ultrasound guidance for peripheral intravenous catheters (PIV) will be discussed as there has been an increased use of this tool in pediatrics, particularly in children with difficult vascular access.

For vascular imaging, in general, a high-frequency, linear ultrasound transducer is recommended [6]. Short-axis (transverse) and long-axis (longitudinal) views can both be utilized together to enhance vessel and catheter visualization (Fig. 1) [6].

Therapeutic implications

Central venous catheter placement is a high-risk procedure in critically ill children with congenital and acquired heart disease. These patients are commonly hemodynamically unstable and may require sedation given the painful nature of the procedure, both increasing the risk for complications and adverse outcomes. Additionally, the procedure itself can be

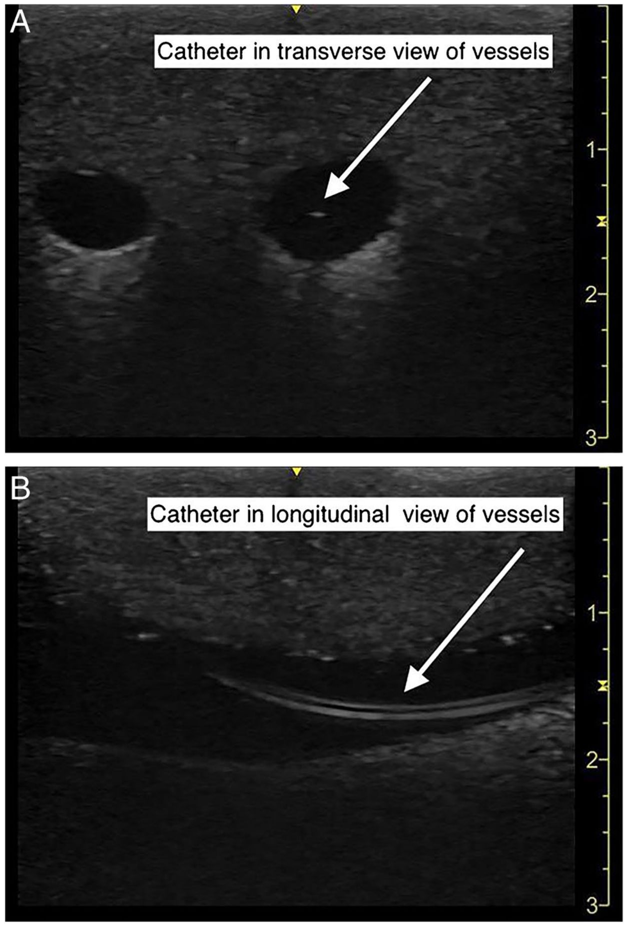

Fig. 1 Vascular catheters by ultrasound. A Transverse view of blood vessel with catheter seen in vessel on the right; B longitudinal view of blood vessel with catheter seen

technically challenging given the small vessel size and vascular anomalies that may be present in infants and children with congenital heart disease.

POCUS guidance during central venous catheter placement is associated with higher rates of successful placement with fewer complications (such as pneumothorax, hematoma, and unintentional arterial puncture) in pediatric patients as compared to the traditional technique of using landmarks [7–9]. Oulego-Erroz et al. highlighted the number of puncture attempts as the main risk factor for line placement complications and that ultrasound use during central venous catheter placement leads to fewer skin punctures and higher rates of first-attempt success [10]. POCUS guidance for central line placement not only reduces the number of attempts but also leads to faster time to central venous access, which can minimize pain and expedite delivery of care [11]. As a result, the utilization of POCUS guidance during line placement is now standard of care in both pediatric and adult populations [1, 12]. Notably, a study in the UK demonstrated that POCUS utilization during central venous catheter placement is more cost-effective than not using POCUS, even when taking into account the cost of the ultrasound machine, as it lessens procedural time and reduces the cost of managing complications [13]. As an added benefit, POCUS can also confirm central catheter tip position similar to chest radiography, thereby minimizing the need for additional radiography [14]. Additionally, with specific training, POCUS can be used prior to line placement to measure the vein diameter, thereby minimizing thrombosis risk by ensuring optimal catheter size selection [15, 16]. Important to note, it is prudent to maintain sterile technique during central venous catheter placement as POCUS guidance has not been shown to reduce infection risk [17].

Similarly, POCUS guidance for peripherally inserted central catheter (PICC) placement is the standard for both pediatric and adult patients [18]. Procedural utilization of POCUS for PICC placement allows for real-time assessment of PICC tip location as well as real-time manipulation of the line to optimize position. POCUS can accurately localize the PICC line when compared to radiography [19, 20]. In neonates, the use of POCUS for PICC line placement prevents repeated adjustments of the PICC line, thereby reducing this risk of infection, complication, and need for repeated radiographs [20, 21].

Alternatively, Galen et al. demonstrated that, in adults, the use of invasive venous access (PICCs and midline catheters) can be reduced by training nurses to perform ultrasound-guided peripheral intravenous line (PIV) placement [22]. Hand motion analysis can be utilized to objectively assess nurse competence in ultrasound-guided PIV placement [23]. Use of ultrasound-guided PIV placement has been shown to improve first-attempt success and increase PIV longevity in critically ill children and children with difficult vascular access, when compared to standard PIV placement [24–26]. Ultrasound use for PIV placement also has positive implications in the peri-operative period, specifically by decreasing procedural time of PIV placement and, as a result, reducing delays in procedures [27, 28].

Strong evidence also exists in the support of POCUS use for peripheral arterial catheter insertion. The use of ultrasound for arterial cannulation improves first-attempt success, leading to fewer attempts and reducing the overall procedural time [29–31]. Importantly, there are fewer cannulation complications when ultrasound guidance is utilized for arterial line placement in critically ill children [32]. Additionally, in infants, the overall success rate of arterial line placement is higher when POCUS is used than when traditional palpation is performed [33]. Meta-analysis by Huang et al. confirmed the benefits of ultrasound use for arterial line placement and, based on the evidence, reiterates that ultrasound guidance be the standard of practice in pediatric care [34•].

Pulmonary

Evaluation

Pleural chest tube drainage is a mainstay of post-operative management in infants and children following cardiac surgery. Additionally, thoracentesis and thoracostomy tube placement are common diagnostic and therapeutic procedures performed in pediatric cardiac intensive care units, as patients can develop pleural effusions from post-operative bleeding, fluid overload, heart failure, infection, and chylothorax or pneumothoraces from surgical chest tube removal or air leak syndrome. In critically ill adults, POCUS guidance for thoracentesis and chest tube placement is the standard of care [35, 36]. Several studies recommend the use of POCUS for thoracentesis and chest tube placement in infants and children [4••, 37•, 38].

A high-frequency, linear probe should be used to perform lung POCUS [37•, 38]. For diagnosis, the probe can be placed on the anterior chest or along the mid-axillary line to evaluate for and diagnose pleural effusions and pneumothoraces. For thoracentesis and chest tube placement, the probe should be placed along the posterior axillary line to identify the optimal location for the chest tube and, subsequently, guide needle insertion [38].

Therapeutic implications

For neonatal pneumothoraces, diagnosis and thoracentesis using lung ultrasound is recommended by an International Expert Consensus from Liu et al. [37•]. Similarly, in infants and children, Marin et al. recommend the use of lung POCUS for diagnosis and thoracentesis [38]. The use of ultrasound for thoracentesis and chest tube placement leads to fewer complications and increased procedural success [37•, 38, 39]. Complications following thoracentesis, such as pneumothorax, are associated with longer hospitalizations and overall increased hospital costs [39, 40]. Therefore, reducing complications by utilizing POCUS to guide the procedure has both medical and financial implications. Also, the use of procedural POCUS in these scenarios is associated with quicker procedural time, which may minimize pain—an important factor when providing pediatric care [37•]. Lastly, an additional benefit of using lung POCUS during tube thoracostomy is that it allows for immediate visualization of lung re-expansion and decrease in effusion size [41].

Cardiac

Evaluation

Post-operative cardiac tamponade is a feared, life-threatening complication in the pediatric cardiac intensive care unit. Timely diagnosis and intervention are critical to maintaining patient safety. For nearly half a century, ultrasound guidance for pericardiocentesis has been utilized and recommended [42–44].

The use of a phased-array transducer is recommended for evaluation of pericardial effusions and guidance of drainage. Typical cardiac views, including subxiphoid, parasternal long-axis, and apical windows, are ideal for localizing the effusion [38]. For ultrasound-guided pericardiocentesis, the subxiphoid window is traditionally recommended [38, 45•].

Therapeutic implications

In pediatric patients, ultrasound-guided pericardiocentesis is associated with fewer complications than by blindly performing the procedure [42]. Importantly, the use of ultrasound guidance allows for successful, non-traditional approaches to pericardiocentesis. Myers et al. described shorter procedure times with similar complications rates when non-subxiphoid views were used to guide pericardiocentesis [45•].

Airway

Evaluation

Endotracheal intubation is another common, yet high-risk, procedure in the pediatric cardiac intensive care unit. Endotracheal tube (ETT) malposition can lead to hypoxemia, acidosis, lung collapse, and pneumothorax; all of which, if not quickly resolved, can be life-threatening. ETT placement is typically confirmed with end-tidal carbon dioxide monitoring, auscultation to confirm bilateral breath sounds, and chest radiography. Over the past several years, POCUS has gained traction as a quick and accurate method in confirming ETT placement in critically ill infants and children.

To evaluate ETT position, a high-frequency, linear ultrasound probe is recommended. Views are obtained with the probe in a transverse (short-axis) and sagittal (long-axis) orientation over the anterior neck, at the level of the sternal notch (Fig. 2) [46, 47•]. The sagittal (long axis) view is particularly helpful in localizing the tip of the ETT in neonates [47•].

Therapeutic implications

In neonates, the ETT tip can be visualized via POCUS [48, 49]. There is a high positive and negative predictive value for confirmation of ETT position in neonates, ranging from 75 to 98% [47•, 50]. Similar positive results have been shown in studies evaluating the use of POCUS to confirm ETT position in critically ill infants and children [51, 52]. Supplementary windows, including transverse subcostal and/or sagittal, mid-axillary views, can assess for diaphragm movement and lung sliding, further supporting appropriate ETT position [52, 53].

Interestingly, a study by Tessaro et al. demonstrated that POCUS can accurately confirm ETT depth in children when the ETT cuff is filled with saline, which is echogenic, instead of air [54]. When filling the ETT cuff with saline, the authors noted utilizing a manometer to ensure no more than 35 cm H2O of pressure. For critically ill patients in the pediatric cardiac intensive care unit, we would recommend subsequently replacing the saline with 20 to 30 cm H2O of air pressure, per standard practice. POCUS can also play a role is determining ETT size. Altun et al. suggest that tracheal diameter, as measured by POCUS, can estimate ETT size better than age or heights standards [55].

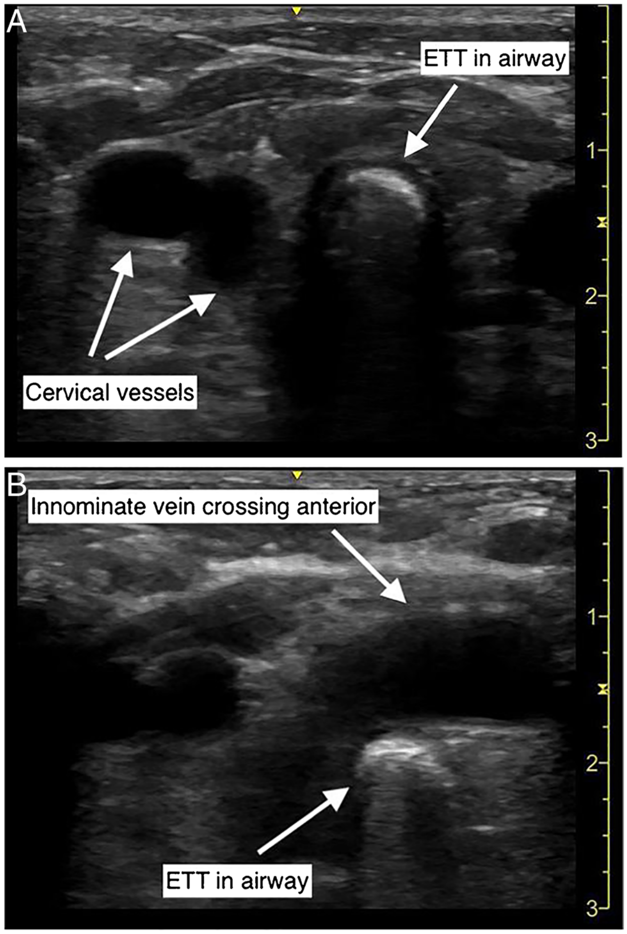

Fig. 2 Endotracheal tube visualization by POCUS. **A** Transverse view with ETT in airway on the right and head and neck vessels on the left; **B** transverse view with ETT in airway on the right, under the anterior crossing innominate vein

Importantly, confirmation of ETT position via POCUS is much faster than standard radiography in both neonates and children [47•, 52]. Utilization of POCUS during intubation can improve patient safety and outcomes by allowing for quick and repetitive evaluation of ETT position.

Gastrointestinal

Evaluation

Oral feeding difficulties, poor somatic growth, and feeding intolerance are prevalent comorbidities in the pediatric cardiac intensive care unit, especially in the neonatal and infant populations. As a result, enteral feeding tubes are commonplace. After placement of these enteric tubes, specifically transpyloric tubes, radiographs are required to confirm proper location prior to use. This need for radiographs delays initiation of enteral nutrition and medication administration. In addition, POCUS allows for real-time visualization of mispositioned enteric tubes (and, therefore, real-time repositioning), whereas standard radiography requires repeated images upon repositioning of the mispositioned tube. POCUS guidance of feeding tube insertion can expedite placement and location confirmation. Certainly, transpyloric enteric tubes can be placed under fluoroscopy but at the expense of time, cost, and exposure to ionizing radiation.

To perform ultrasound of the stomach and post-pylorus region, a linear or curvilinear probe is recommended [56]. The probe can be placed transversely in the epigastric region with angling toward the left subcostal area [56]. Longitudinal views can also be obtained over the left epigastric area. If needed, injection of a small amount of saline and air mixture can create echogenic bubbles to help visualize the tip of the enteric tube [56].

Therapeutic implications

Numerous studies support the use of POCUS guidance for nasogastric tube placement in pediatric patients, including neonates [57–59]. Importantly, as POCUS can confirm nasogastric tube position, the need for abdominal radiographs can be reduced [59, 60].

In 1993, Greenberg et al. established the ability to confirm transpyloric tube location with ultrasonography in pediatric patients [61]. In more recent years, Hamadah et al. corroborated these findings, describing successful POCUS-guided insertion of transpyloric feeding tubes in infants in the cardiac intensive care unit [62]. Similar positive findings of POCUS guidance for transpyloric feeding tube insertion have been demonstrated in critically ill adults [63–65].

Neurologic

Evaluation

Lumbar puncture (LP) is a routine procedure in pediatrics. Analysis of cerebral spinal fluid (CSF) allows for the diagnosis of infection, autoimmune, and metabolic disorders. Despite the common nature of this procedure, the failure rate is high, ranging from 15 to 50% [4••, 66]. In recent years, the application of POCUS to guide lumbar puncture has gained popularity and credibility. In adults, a randomized-control trial comparing POCUS-guided LP to traditional landmark method found that the POCUS-guided LPs were more likely to be successful [67]. Importantly, in obese patients, POCUS-guided LPs led to fewer failed attempts [67]. Similar benefits of POCUS-guided LPs in pediatric patients have been reported.

A high-frequency, linear ultrasound probe is recommended for POCUS-guided LP. The transducer is placed on the lumbar spine and sagittal (long-axis) or transverse (short-axis) views can then be obtained to identify the optimal lumbar level for LP and guide needle insertion [4••, 68].

Therapeutic implications

In pediatric patients, the use of POCUS guidance to perform lumbar punctures is associated with increased procedural success than the traditional landmark method [4••, 68, 69, 70•]. Additionally, the use of POCUS during LP decreases the rate of traumatic and/or failed puncture [68, 69, 70•]. Olowoyeye et al. conferred the same findings of increased success and fewer traumatic punctures when POCUS is used in neonatal and infant lumbar puncture [70•].

Conclusion

POCUS is a versatile, non-invasive tool for pediatric cardiac intensivists. POCUS can be used to guide a wide range of high-risk procedures in critically ill children, ranging from PIV placement to endotracheal intubation and pericardiocentesis. Importantly, the use of POCUS guidance for procedures has been shown to reduce complications and improve success rates, optimizing both patient safety and outcomes.

Compliance with Ethical Standards

Conflict of Interest

Jessica N. Persson declares that she has no conflict of interest. Ryan J. Good declares that he has no conflict of interest. Sarah A. Gitomer declares that she has no conflict of interest. John S. Kim declares that he has no conflict of interest.

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

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