An [illustrative] update on pediatric emergency medicine ultrasound: part 1 – trauma and thoracic applications

Yi Dong¹, Simone Schwarz², Beatrice Hoffmann³, Nasenien Nourkami-Tutdibi⁴, Yun-Lin Huang¹, Sheng Chen¹, Andrius Cekuolis⁵, Rasa Augustiniene⁵, Peter J Snelling⁶, Dagmar Schreiber-Dietrich⁷, Lara Grevelding⁸, Christoph F Dietrich⁹

¹Department of Ultrasound, Xinhua Hospital Affiliated to Shanghai Jiaotong University School of Medicine, Shanghai, China, ²Department of Neonatology and Pediatric Intensive Care Medicine, Sana Kliniken Duisburg GmbH, Duisburg, Germany, ³Harvard Medical School, Department of Emergency Medicine, Beth Israel Deaconess Medical Center, Boston, USA, ⁴Saarland University Medical Center, Hospital of General Pediatrics and Neonatology, Homburg/Saar, Germany, ⁵Ultrasound Section, Department of Pediatric Radiology, Radiology and Nuclear Medicine Centre, Vilnius University Hospital Santaros Klinikos, Lithuania, ⁶Department of Emergency Medicine, Gold Coast University Hospital, Southport, Qld, Australia, ⁷Kliniken Hirslanden, Salem, Bern, Switzerland, ⁸Department of Pediatrics, Division of Pneumology, Allergology, Infectious diseases and Gastroenterology, University Hospital, Frankfurt, Goethe University, Frankfurt, Germany, ⁹Department Allgemeine Innere Medizin, Kliniken Hirslanden, Beau Site, Salem and Permanence, Bern, Switzerland

Abstract

Point-of-care ultrasound (POCUS) plays an essential role in emergency medicine, providing a range of diagnostic and procedural modalities. It does not involve any ionizing radiation and can improve procedural accuracy and safety. The role of POCUS in the care of pediatric patients differs somewhat from that of adult patients, as there are a range of conditions specific to infants and children. The technical background of pediatric POCUS and its current applications for trauma and thoracic scanning are reviewed and illustrated in this first article of this series.

Keywords: emergency ultrasound; point-of-care ultrasound (POCUS); pediatric; trauma; guidelines

Introduction

Emergency ultrasound (EUS) refers to point-of-care ultrasound (POCUS) performed and interpreted at the bedside of a patient by the treating clinician in the emergency department (ED) [1]. Over the last decades, more compact and portable ultrasound machines have been introduced, enabling true bedside ultrasound, called echoscopy, by the European Federation of Ultrasound for Medicine and Biology (EFSUMB) [2-5]. Current POCUS ultrasound machines use sophisticated processors and imaging software, are lightweight and small, and provide high image quality and multiple modes [6,7]. In addition, with the development of ultrasound contrast media, contrast-enhanced ultrasound (CEUS) has been promoted as a novel diagnostic ultrasound mode in emergency medicine POCUS [8,9]. Many scanning methods and relevant clinical applications from adult medicine can be easily transferred to pediatrics. However, the role of POCUS in the care of pediatric patients differs from that of adult patients, and applications specific to Pediatric Emergency Medicine (PEM) are increasingly being described and studied [1,10,11]. Ultrasound is ideal for children because it does not involve any radiation exposure and can improve procedural accuracy and safety [10-
PEM physicians are increasingly using ultrasound in their practice [13], and consensus guidelines for specific ultrasound applications have been published [1,14-16]. Additional benefits of POCUS include decreased patient lengths of stay for various diagnostic examinations and procedural interventions.

This article provides a review of the technical background and illustrations of POCUS in trauma and thoracic applications with a specific emphasis on pediatric patients.

**Trauma applications**

*Focused assessment with sonography for trauma and extended applications*

Focused Assessment with Sonography for Trauma (FAST) is used to detect free fluid in the abdominal and pelvic cavities, as surrogate marker of solid or hollow organ injury, for unstable patients in the setting of trauma. Scanning is performed in three separate regions: the right upper quadrant, left upper quadrant, and pelvis (longitudinal and transverse views) [17]. Hemorrhage in the abdominal cavity can be determined by inspecting the hepatorenal and splenorenal space, inferior liver edge, inferior diaphragmatic recess, and retrovesical space [18].

FAST has been considered as routine practice for injured adults and has been shown to influence patient outcomes and management [19]. However, there is variable evidence for the use of FAST in the pediatric population. A meta-analysis [20] included eight prospective studies encompassing 2,135 pediatric patients with blunt abdominal trauma; and revealed that a positive FAST is helpful for distinguishing intra-abdominal injury, whereas a negative FAST should not be used as a rule-out test and should be interpreted in the clinical context and with caution. These results supported the conclusion of a prior study [17] that physical examination combined with FAST had greater sensitivity (88%) and negative predictive value (NPV) (97%) than either physical examination or FAST alone (sensitivity = 74%, NPV = 95%), and that FAST integrated into routine care can improve diagnostic performance.

The extension to FAST (eFAST) includes cardiac (subxiphoid or parasternal longitudinal views) and thoracic views (parasternal and lateral chest longitudinal views) for rapid exclusion of pericardial tamponade, pneumothorax, and hemothorax [1].

*Pericardial tamponade*

Pericardial tamponade manifests as an anechoic or echoic fluid boundary between the heart and pericardium with restriction of cardiac function (fig 1). The echocardiographic findings are explained in more detail below in the Thoracic Applications section.

**Pneumothorax**

A high-frequency linear or low-frequency curvilinear probe on a lung preset (i.e. enhancements turned off) is used to scan bilateral thoracic cavities through the intercostal spaces and observe pleural sliding at the highest point of the thoracic wall. Pneumothorax is characterized by the absence of pleural sliding, absence of lung pulse, pathognomonic lung point, and a lack of B-lines (vertical reverberation artifacts), and sometimes the non-ventilated or poorly ventilated lung tissue can also be visualized (fig 2).

In traumatic pneumothorax, signs of pulmonary contusion may appear adjacent to the pneumothorax laterally or dorsally as asymmetric or focal B-lines, sometimes in combination with consolidation [18]. Lung ultrasound is highly accurate, particularly in infants [21]. However, lung ultrasound views can be limited by the presence of subcutaneous emphysema.
**Hemothorax**

Hemothorax appears on ultrasound as fluid with variable echogenicity in the pleural space, that compresses the lung parenchyma. This is best observed in the lateral longitudinal sections of the thorax above the diaphragm, just above to the liver on the right and spleen on the left.

**CEUS for solid organ trauma**

CEUS can further improve diagnostic accuracy for solid viscera injury in pediatric low-to-moderate energy blunt abdominal trauma. CEUS can achieve high diagnostic accuracy in detecting parenchymal injury in the pediatric population but is limited by availability, licensing and training [19]. Patients may also have active bleeding after organ transplantation or other procedural intervention, such as kidney biopsies, radial artery catheterization, lumbar puncture and nerve block [8,22-25]. CEUS has been used to detect active bleeding from solid viscera, indicated by contrast agent extravasation [8,9].

**Thoracic applications**

**Focused echocardiography**

Emergency echocardiography does not aim to examine the heart in detail, rather than focusing on the evaluation of cardiac function, presence of pericardial effusion, arrhythmia, and cardiac arrest. The basic emergency point-of-care echocardiography protocol includes the parasternal long axis, parasternal short axis, apical four- and five-chamber, subxiphoid, and inferior vena cava (IVC) views. A prospective study by Longjohn et al [26] included pediatric patients who had fluid-refractory hypotension, newly identified cardiomegaly, or cardiopulmonary arrest, performed focused echocardiography with excellent accuracy for left ventricular function, pericardial effusion and cardiac standstill.

**Cardiac function**

Cardiac function can be estimated from the percentage of left ventricular ejection fraction (LVEF), which can be calculated using ‘eyeballing’, fractional shortening and mitral valve E-Point to Septal Separation (EPSS) [27]. Based on the Teichholz formula, LVEF can be divided into three subclasses of <30% (severe dysfunction), 30-50% (moderate dysfunction), and >50% (normal function).

**Pericardial effusion and pericardial tamponade**

The size of a pericardial effusion can be quantified by the myocardium-epicardium diameter in diastole, with the division into small (<1 cm), medium (1 2 cm) and large (>2 cm). Pleural effusions and anterior pericardial fat pad are the most common mimics of pericardial effusion; however, they are not tracked between the heart and descending thoracic aorta.

A cardiac chamber collapses when the intrapericardial pressure is greater than the intracardiac pressure. Therefore, relevant pericardial effusion leads first to paradox movement of the wall of the right atrium and later of the right ventricle. If a pericardial effusion is identified in a spontaneously breathing patient, pericardial tamponade should be considered when the IVC is plethoric, defined as a decrease in the proximal IVC diameter by <50% during deep inspiration [18].

Pericardiocentesis is a critical and life-saving intervention for cardiac tamponade and is performed on adults in the emergency department, but rarely on children [28]. Evidence-based guidelines recommend that pericardiocentesis under ultrasound-guidance can increase the effectiveness and safety of the procedure [29-31]. The use of ultrasound in the periarrest setting and how to perform during cardiac arrest will be covered in a separate paper.

**Advanced cardiac applications**

**Congenital heart defects**

Neonates presenting with prolonged adaptation after birth, may suffer from different circumstances influencing and compromising their adaptation. Apart from infection, acute respiratory distress, congenital heart disease (CHD) might be the cause for pending cardio-respiratory adaptation. Here prompt diagnosis via POCUS is of utmost importance to start immediate treatment, e.g. application of Alprostadil infusion. Prostaglandin E1 infusion is crucial in newborns born with ductus-dependent congenital heart disease and is accepted as the mainstay therapy for keeping the patient ductus arteriosus until palliative or corrective surgery [32].

Rapid diagnosis of structural congenital heart disease allow for timely intervention [33]. Some POCUS findings may strongly suggest CHD as the cause of hemodynamic compromise. The most common CHD detected during neonatal period after uncomplicated births are coarctation of aorta (CoA). CoA in neonates is a common cause of shock and death. It is the most difficult of all forms of critical CHD to diagnose because the obstruction from the aortic coarctation is not seen to its maximum extent until several days after birth [34]. Apart from the latter, there are various critical CHD that can be easily diagnosed via bedside ultrasound to initiate immediate treatment before a detailed echocardiography will follow to complete examination [33,35]. Transposition of the great arteries (TGA), atresia of the tricuspid valve and hypoplastic heart syndrome (HLHS) are ductus-dependent CHD. Here Prostaglandin E1 infusion and most often Rashkind maneuvers are needed.
Most infants with these conditions become symptomatic after the occlusion of ductus arteriosus, when blood flow in the aorta (Ao) and/or pulmonary artery decreases, leading to rapid clinical deterioration. The clinical presentation of acute decompensation in CHD is similar to that of septic shock. Therefore, congenital heart disease must always be considered in critically ill neonates and infants. In these situations, POCUS can rapidly assess cardiac chamber dilatation, left ventricular systolic function, aorta (including suprasternal views) and ductus arteriosus. In addition, persistent pulmonary hypertension of the neonates (PPNH) can be assessed easily via bedside echocardiography by assessment of blood flow in the ductus arteriosus and measurement of mean arterial pulmonary pressure [36,37].

**Volume assessment**

The diameter of the inferior vena cava (IVC) and its respiratory change reportedly can correlate with the central venous pressure and response to fluid [38]. The change in the diameter of IVC measured by ultrasound during respiration can assist with intravascular volume evaluation and is most accurate at the extremes of collapsibility. It can guide resuscitation interventions or predict the requirement for blood transfusion [39]. IVC measurement is used to evaluate the intravascular volume status of dehydrated patients and patients undergoing resuscitation [40]. Chen et al [41] analyzed the cross-sectional IVC/Ao ratio in pediatric patients with dehydration and found significant differences between dehydrated patients and healthy participants and showed increased IVC/Ao ratios after intravenous fluid administration. Another study showed that IVC/Ao ratios had good test characteristics in the identification of pediatric patients with severe dehydration and showed a sensitivity of 93% and a specificity of 58% [42]. The IVC/Ao ratios may be a more objective feature for volume assessment and dynamic evaluations may change the course of interventions. In cases of volume overload or congestion due to compromised cardiac function, it is useful to examine hepatic vein dilation in addition to IVC undulation, along with duplex sonographic examination of hepatic vein flow.

**Lung ultrasound**

Lung ultrasound relies on artifacts, given that air blocks the transmission of sound waves. A high-frequency linear probe is useful to evaluate the lung surface and pleura and a low-frequency curved probe is useful to evaluate deeper structures [43-46]. Lung ultrasound has been deemed a promising approach aiding the diagnosis of pneumonia and other lung pathologies in children, such as pulmonary edema, pulmonary contusion, acute chest syndrome, and pulmonary embolism (fig 3). More details and examples have been recently published in a separate series of papers on lung ultrasound in pediatric patients [47-50].

**Pneumonia**

Lung ultrasound has a high diagnostic accuracy for pneumonia, particularly when correlated with inflammatory markers [51-53] (fig 4). A pneumonic infiltrate can appear on lung ultrasound as either an area of poorly ventilated lung tissue with the appearance resembling liver (‘hepatization’) or an irregularity of the pleura with a hypoechoic region, often surrounded by B-lines (vertical reverberation artifacts). Bacterial pneumonia is more likely to present as a unilateral consolidation with air or fluid bronchograms. In contrast, viral pneumonia is more likely to show a diffuse distribution pattern of smaller or subpleural consolidations combined with global B-lines. However, lung sonographic findings always have to be interpreted and evaluated in combination with clinical findings [54].

**Thoracentesis**

Thoracentesis and thoracic needle decompression are important and potentially life-saving methods treating pleural effusion and pneumothorax. Although there is no study to evaluate POCUS-assisted thoracocentesis in children, a recent multicenter prospective study for acute decompensated newborns in the neonatal intensive care unit proved the feasibility, efficiency, and safety of using ultrasound to diagnose pneumothorax and perform needle aspiration or chest tube placement before radiological examination [21]. A low-frequency probe is used to identify pleural effusion, underlying lung parenchyma, diaphragm, and subphrenic organs, and to determine the distance from the parietal pleura to the skin. There should be sufficient distance between the visceral pleura and chest wall [55,56]. For ultrasound-guided decom-
pression of a pneumothorax, a high-frequency probe can be used to identify the point where the visceral and parietal pleura separate, the so-called lung point. In the area of the pneumothorax, the pleural line can be identified along with clearly visible A-lines (horizontal reverberation artifacts) without detectable pleural sliding [49]. M-mode ultrasound can also be used, which showed no lung pulse, however, it has limitations such as movements by the patient or examiner. Beyond the pulmonary point, the two pleural sheets are again adjacent, so regular pleural sliding, probably in combination with B-lines or consolidations, can be observed. Because B-lines arise at air-fluid interfaces in lung tissue or alveoli near the visceral pleura, their presence precludes pneumothorax [50,51]. The lung point does not allow conclusions to be drawn about the thickness of the air layer, but it does allow assessment and progression of the extent of pneumothorax.

**Endotracheal tube confirmation**

Endotracheal tube (ETT) insertion is an essential procedure in emergency medicine for children. Inadvertent esophageal intubation is a complication of this procedure, leading to significant morbidity and mortality. Although end tidal CO\(_2\) is the gold standard for ETT placement confirmation morbidity and can be inaccurate in situations of poor cardiac output or from stomach gas. Bedside ultrasound is a useful adjunct for confirmation of ETT placement [57]. In a suprasternal cross-sectional view, the tube within the trachea can be visualized as a double contour, sometimes with artifacts emanating from it (fig 5). Esophageal ETT malposition can be recognized by the double trachea sign, i.e., a representation of the trachea with a neighboring structure of the same size in the esophageal region, which corresponds to the ETT lying in the esophagus [58]. A regular pleural sliding observed parasternal on both sides indicates a correct endotracheal tube position. In special situations, direct visualization of the tube tip with determination of the distance to the tracheal bifurcation is also possible [59].

**Conclusion**

Pediatric emergency ultrasound has revolutionized the clinical management of many conditions. With the increase in training on these pediatric specific clinical applications, physicians could provide timely and precise diagnosis and procedures guided by ultrasound. With respect to trauma and thoracic applications of POCUS in pediatrics, there are a myriad of pathologies and procedures it can assist. In this first part of a the series, we have provided an overview of its use in the detection of intraperitoneal, intrathoracic or pericardial free fluid in the setting of trauma. There is also great promise for solid organ injury detection using contrast enhancement. It also plays a role in the evaluation of cardiac function or congenital heart defects in neonates. It can also guide pericardiocentesis. Various lung pathologies can diagnosed with the assistance of POCUS. It can aid thoracocentesis. Finally, airway POCUS can aid in the confirmation of ETT placement. POCUS has become an essential tool for trauma, lung and cardiac diagnostic and procedural applications.
Conflicts of interest: none

References

32. Akyanat A, Yavuz T, Özalkaya E, Topçuoğlu S, Ovahi F, Karatekin G. Long-Term Prostaglandin E1 Infusion for