



A new stethoscope for pediatric intensivists: Point-of-care ultrasound

Çocuk yoğun bakım uzmanları için yeni bir stetoskop: Yatak başı ultrasonografi

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Abstract

In recent years, the use of point-of-care ultrasound by non-radiologist physicians has become widespread. Especially for clinicians working in pediatric emergency departments and pediatric intensive care units, point-of-care ultrasound has almost become a part of physical examinations due to the rapid responses it offers to the problems of critically ill patients. Numerous studies revealed the important clinical benefits of point-of-care ultrasound use by pediatric intensive care providers. In this review, we aimed to give detailed information about different types of point-of-care ultrasound applications in pediatric intensive care units and wanted to draw attention to the increased use and clinical benefits of this noninvasive and radiation free technique.

Keywords: Noninvasive, pediatric intensive care, point-of-care ultrasound

Öz

Son yıllarda radyoloji uzmanı olmayan klinisyenler tarafından yatak başı ultrasonografi kullanımı yaygınlaşmıştır. Özellikle pediatrik acil servislerde ve çocuk yoğun bakım birimlerinde çalışan uzmanlar için yatak başı ultrasonografi, kritik hastaların sorunlarına sunduğu hızlı yanıtlar nedeniyle neredeyse fizik muayenelerin bir parçası haline gelmiştir. Çok sayıda çalışma, pediatrik yoğun bakım uzmanları tarafından yatak başı ultrason kullanımının klinik faydalarını ortaya koymuştur. Bu derlemede biz çocuk yoğun bakım birimlerindeki farklı yatak başı ultrasonografi uygulamaları hakkında detaylı bilgi vermeyi ve bu girişimsel olmayan ve radyasyon içermeyen tekniğin artan kullanımına ve klinik faydalarına dikkat çekmeyi istedik.

Anahtar sözcükler: Çocuk yoğun bakım, noninvaziv, yatak başı ultrasonografi

Introduction

Point-of-care ultrasound (POCUS) is a bedside ultrasonographic assessment and is applied to patients by the clinician in charge (1). It provides rapid and real time answers about the clinical problems of patients. Especially in recent years, use of POCUS by non-radiologist clinicians in emergency and intensive care departments is becoming common (2). In the world the frequency of POCUS training courses intended for pediatric intensive care and emergency care specialists are increasing. In fact, POCUS has become a part of the physical examination of critically ill children in pediatric intensive care

units (PICU) (2, 3). Patients in PICU frequently have critical and urgent problems and need quick assessments due to their hemodynamical instability. Through POCUS results, clinicians can manage treatment approaches. The most important advantages of this technique are that it is easy to use, repeatable, noninvasive, cheap, painless and radiation-free (4).

The purpose of this review is thus to provide an overview of the raising applications of POCUS in PICUs. Here we aimed to give information about different usage fields of POCUS and want to draw attention of significance of POCUS in the management of critically ill pediatric patients.

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Figure 1. View of LVOT in the parasternal long axis

Application fields of POCUS

Critical-care echocardiography

Echocardiography is becoming a standard of critical care in many intensive care units, and more clinicians are learning how to perform bedside critical-care echocardiography techniques as more pediatric intensivists are becoming familiar with POCUS in PICUs. The echocardiography type referred to as critical-care echocardiography has become a part of the routine evaluation of patients in most PICUs by pediatric intensivists (5). Critical-care echocardiography is currently considered a key tool for the hemodynamic assessment in intensive care units. This noninvasive technique allows the intensivist to measure left ventricular (LV) systolic function, cardiac output and cardiac index and to assess pericardial effusion and becomes a guide for the management of treatment and ensuring the hemodynamic stability of critically ill patients (6). Besides, you can easily detect and manage pericardial tamponade which an emergency cause of obstructive shock if you able to use critical-care echocardiography. Critical-care echocardiography plays an important role in guiding pericardiocentesis.

Especially in last years, LV systolic function measurement seems as a part of hemodynamical monitorization of critically ill patients. Ranjit et al. (7) suggested how the echocardiographic analysis of LV systolic function may be part of a multimodal hemodynamic assessment in association with physical examination and invasive blood pressure monitoring for pediatric patients with septic shock.

The importance of cardiac index in guiding fluid and inotropic management in septic shock was emphasized in the recent clinical practice parameters published in 2017, which highlighted the significance of cardiac index measurement in the PICU (8). For detecting cardiac output,

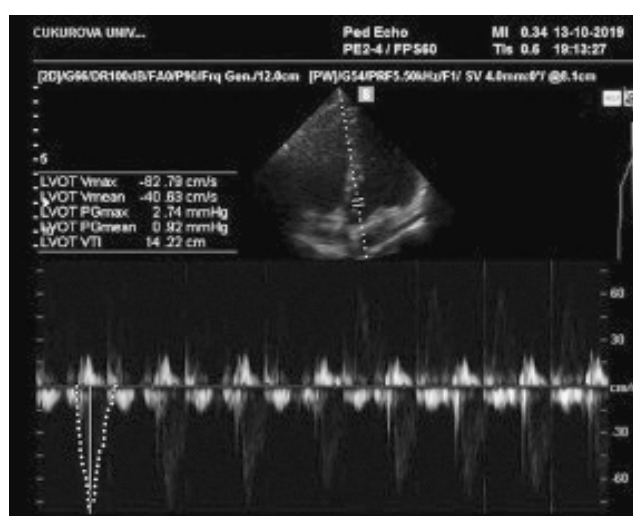


Figure 2. LVOT-VTI measurement using Doppler ultrasound

first the distance of left ventricle outflow tract (LVOT) in parasternal longer axis was measured (Fig. 1). In the apical 4 chamber image, LVOT-Velocity Time Integral (LVOT-VTI) measurement is performed by pulsed-wave Doppler on the aortic valve (Fig. 2). Stroke volume is calculated using these two measurements. Cardiac output is calculated by stroke volume and heart rate multiplication $[CO = (Heart\ rate \times LVOT-VTI \times LVOT2 \times 3.14) / 4]$ (9). Cardiac index is computed by dividing the CO by the square meter of the patient. The targeted cardiac index in children with septic shock suggested by Surviving Sepsis Campaign is between 3.5 and 5.5 L/min/m² (10).

There are different methods for evaluating cardiac index in critically ill pediatric patients. One of them is Pulse index Contour Cardiac Output (PiCCO) device. However, PiCCO is an invasive and expensive device. In a study from one of tertiary PICUs in Turkey, the authors compared cardiac index values measured by PiCCO and measured by critical-care echocardiography and they noticed a statistically significant correlation between these measurements. And they suggested that echocardiographic cardiac index measurements performed by an experienced pediatric intensive care specialist may be as valuable as invasive PiCCO monitoring measurements in the planning of the vasopressor-inotrope and fluid treatment of critically ill pediatric patients (11).

Pediatric patients in the PICUs are at higher risk for hemodynamic instability. Therefore, detecting preload and planning appropriate parenteral fluid therapy is vitally important in this patient population. Fluid resuscitation is part of the initial management of shock. Another useful aspect of critical-care echocardiography is providing information about fluid responsiveness (12). There is two option to determine fluid status and responsiveness by

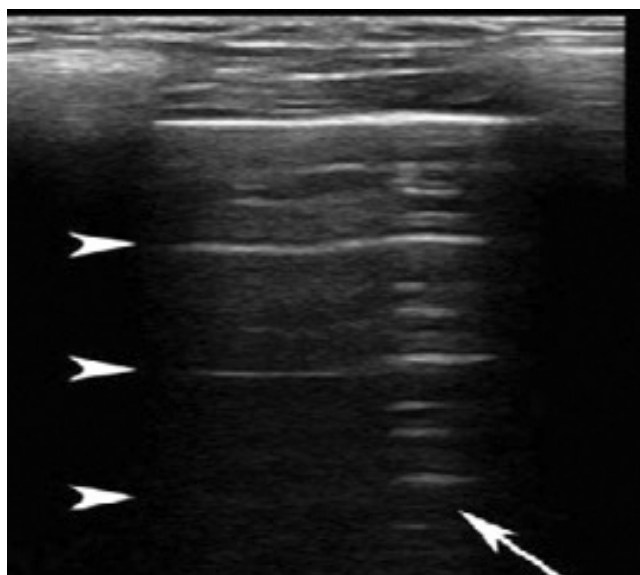


Figure 3. A lines as a sign of normal lung parenchyma in lung ultrasound

critical-care echocardiography. The first way is analyzing inferior vena cava (IVC) diameters. We will give detailed information about in IVC collapsibility and IVC distensibility indices in separate sections. Another way of assessing fluid responsiveness using critical-care echocardiography is analyzing the respiratory change of the aortic peak flow velocity on Doppler during inspiration and expiration in patients under mechanical ventilation (13).

Lung ultrasound

Community-acquired and ventilator-associated pneumonia are common and important problems in PICUs. In addition, chest X-ray is still a widespread tool for the diagnosis of pneumonia. In the last years, most studies have shown that bedside lung ultrasound performed by pediatric critical care providers was highly accurate for the diagnosis of pediatric pneumonia (14). Lung ultrasound has proven useful for detecting lung abnormalities in adults, and recent studies have reported the usefulness of lung ultrasound in children with pneumonia and bronchiolitis (15). Lung ultrasound as a noninvasive and radiation-free technique can be beneficial for evaluating children with respiratory failure that are admitted to PICUs and can contribute to applying appropriate therapy for children. The most important advantage of lung ultrasound is that it is a radiation-free technique (1).

There are important marks in a lung ultrasonographic assessment. A-lines are horizontal, hyperechoic lines under the pleural line (Fig. 3). The presence of A-lines and lung-sliding in an area of lung ensures the absence of pathology in that area. The B-lines are vertical, hyperechoic lines that start perpendicularly from the pleural line (15).

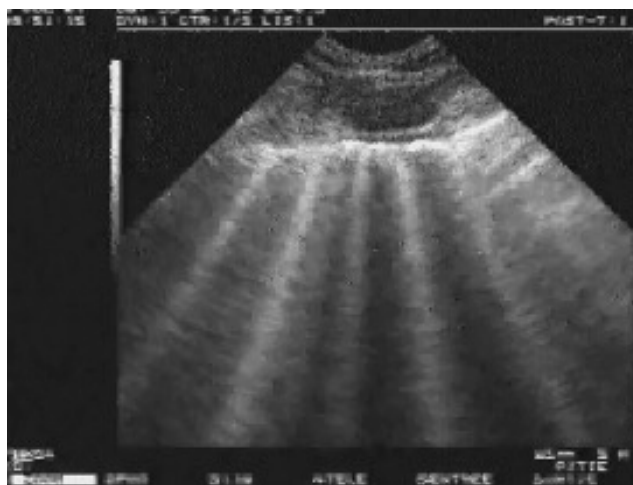


Figure 4. B lines in lung ultrasound

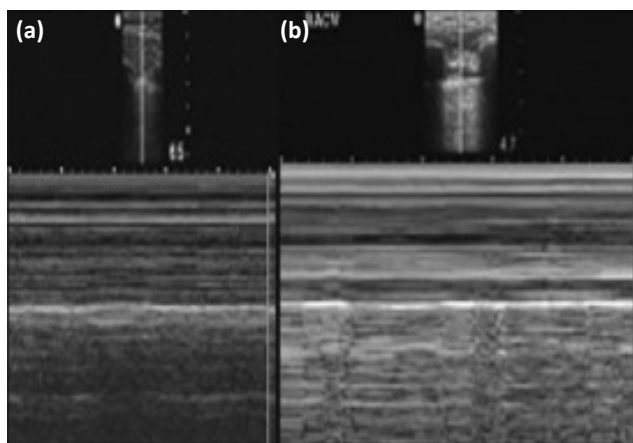


Figure 5. (a) Sea-shore sign for normal lung parenchyma at M-mode. (b) Barcode sign for pneumothorax at M-mode

These lines erase the images that go through their way, including the A-lines. B-lines are become visible when the lung congestion increases (Fig. 4). Presence of B lines is associated to the expansion of the interlobular septae and the aggregation of fluid in the lung. The B-lines are nonspecific marks for to differentiate pulmonary diseases (15). Fewer than 3 B lines between two ribs in the lung fields is normal in healthy lung. B-lines are considered significant when ≥ 3 B-lines are detected in a scan.

The normal view of lung on M-mode called 'sea-shore' sign. In terms of pneumothorax, in contrast to the normal 'sea-shore' sign seen in M-mode (Fig. 5a), absent pleural sliding will cause a 'barcode' or 'stratosphere' view. 'Barcode' sign represents the lack of pleural movement (16, 17). The 'barcode' sign has a sensitivity and specificity greater than 90% with negative predictive value of 100% (18) (Fig. 5b). The 'lung point' is where the transition between the normal lung and pneumothorax occurs. It represents the

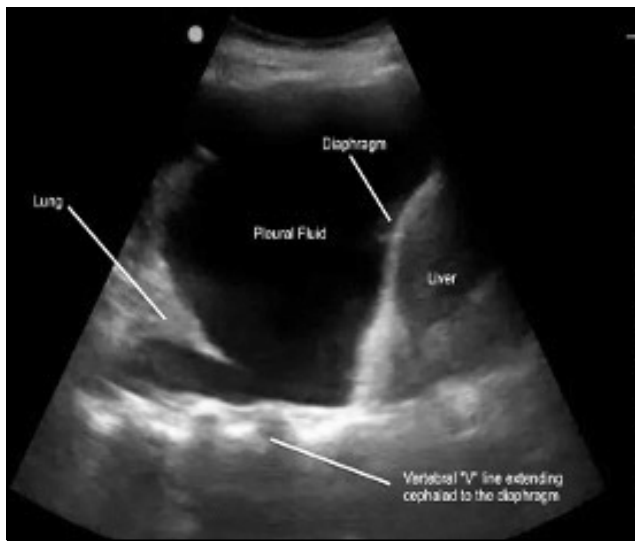


Figure 6. Pleural effusion in lung ultrasound

point at which the visceral and parietal pleural start to separate. You can evaluate and detect lung point on M-mode. This is the most specific sign, and the only sign which rules in pneumothorax. The presence of B-lines rules out pneumothorax (100% negative predictive value) (19).

Besides, lung ultrasound allows the evaluation and drainage of pleural effusion, which is another useful aspect of lung ultrasound (Fig. 6). Clinicians can manage pleural effusion drainage with less complication and greater success with POCUS guidance. POCUS is helpful to decide the optimal place to perform a thoracentesis (20). POCUS can detect effusions smaller than 10 mL. Cortés et al. (21) reported POCUS use rates in Spanish PICUs for pleural effusion, pneumothorax and other lung diseases such as pneumonia as 73.3%, 50% and 46.7%, respectively.

Central venous catheter insertion

In pediatric emergency and intensive care departments, central venous catheter placement may be required in life-threatening conditions where fluid and drug resuscitation are needed or in complex patients with poor vascular access. Risks during central venous catheter insertion include iatrogenic pneumothorax and catheter malposition during internal jugular vein and subclavian vein insertions (22). Central venous catheter malposition may be associated with inaccuracies in hemodynamic measurements, venous thrombosis, and delays in treatment (23). In addition, pneumothorax often requires emergency procedural interventions because of being one of the obstructive shock reasons. Ultrasound-guided pediatric central venous catheterization has been shown to be superior to traditional landmark and palpation techniques (23). POCUS improves procedural success and safety during central venous catheter placement.

Arterial catheter insertion

Arterial catheterization, commonly used in infants and small children in intensive care units and operating rooms, can be technically challenging. Nevertheless, the ultrasound-guided technique improves the first-attempt success rate in both adults and children (24).

Peripheral venous catheter insertion

The use of POCUS decreases the risk of complication and the number of attempts in some procedures such as central-peripheral venous catheterization and arterial catheterization. It has been reported that the use of US guidance significantly improves the rate of successful peripheral intravenous access, especially in patients who are difficult to access and decreases the amount of time to perform the procedure, the number of percutaneous punctures and needle redirections compared to traditional approaches such as palpation and landmark guidance (25). Pediatric critical care nurses had training for ultrasound use for peripheral venous catheter insertion only in one of our participating units.

Vena cava inferior collapsibility index

One of the most important parts of POCUS for noninvasive and rapid assessment of fluid status in critically ill children is the measurements of IVC diameters (12). Inferior vena cava is a vessel that is highly sensitive to fluid changes, and the collapsible vessel varies in size with respiratory changes in intra-thoracic pressure. Ultrasonographic measurements of IVC are performed while the patient was in the supine position. Images were acquired in the sagittal section. Images of IVC, draining into the right atrium, were obtained while the probe was in the subxiphoid area and the liver was taken the acoustic window. The minimum IVC diameter on inspiration and the maximum IVC diameter on expiration were recorded using M-mode just beyond the point, where the hepatic veins drain into IVC (Fig. 7). The maximum IVC diameter on inspiration and the minimum IVC diameter on expiration were measured using the same ultrasonographic method. IVC collapsibility index is calculated by the following formula: $\text{IVC collapsibility index} = \left[\frac{\text{the maximum diameter on expiration} - \text{the minimum diameter on inspiration}}{\text{the maximum diameter on expiration}} \right]$ (26).

Natori et al. (27) were the first to describe the correlation between the IVC diameter and the right atrial pressure in 1979. Several adult studies are available in the literature, demonstrating that the IVC collapsibility index, which is calculated using the maximum and minimum diameters of IVC, correlates well with CVP (28). However, the reference values defined for the IVC collapsibility index and the maximum and minimum diameters of IVC belong to

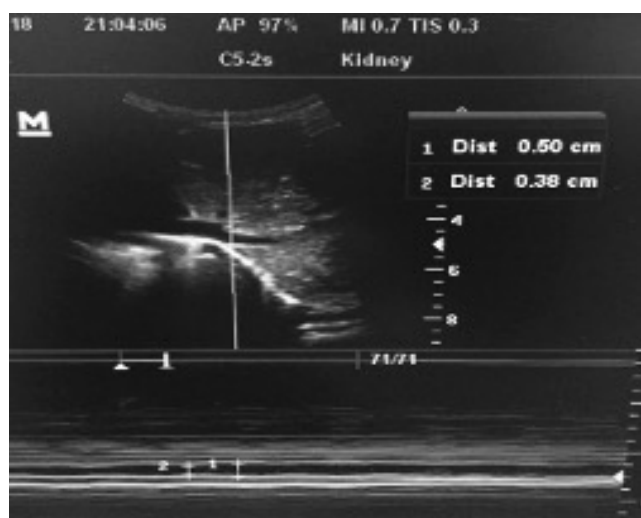


Figure 7. M-mode measurement of the maximum and minimum IVC diameters in the sagittal section

the adult population. Pediatric data about these reference values are limited. In adults, an IVC collapsibility index of >50% is associated with a reduced right atrial pressure and severe dehydration, leading to the interpretation that the patient needs fluid therapy (29). A study by Babaie et al. (26) about the prediction of fluid status in pediatric patients evaluated 70 children in the age range from 1 month to 12 years. A negative correlation between CVP and IVC collapsibility index was reported, and the mean IVC collapsibility index was found to be $35 \pm 16\%$. In another study, Mugloo et al. (30) evaluated fifty newborns and reported that the IVC collapsibility index and CVP were negatively correlated.

Vena cava inferior distensibility index

Positive-pressure ventilation elevates the pleural and right atrial pressure values and reduces the venous that return to the heart by increasing the intrathoracic pressure during inspiration. These factors act on the diameter and the distensibility of IVC. Finally, the IVC diameter dilates during inspiration and becomes smaller during expiration in an intubated patient unlike spontaneously breathing patients (31). In mechanically ventilated patients, ultrasonographic measurements of IVC are performed with the same technique. And the IVC distensibility index is calculated by using the following formula: $\text{IVC distensibility index} = \frac{(\text{the maximum diameter on inspiration} - \text{the minimum diameter on expiration})}{\text{the minimum diameter on expiration}}$ (32).

Therefore, it is recommended that the IVC distensibility index should be used instead of IVC collapsibility index in patients undergoing positive-pressure mechanical ventilation. A study on mechanically ventilated adult patients in septic shock demonstrated that the IVC distensibility

index values of >18% were in favor of fluid deficit (33). Previous studies were conducted about the effectiveness of the use of the IVC distensibility index in predicting fluid responsiveness in critically ill children. Although the results are contradictory, recent studies have shown that the IVC distensibility index is a reliable measure of predicting fluid responsiveness in mechanically ventilated children (34). However, both Babaie et al. (26) and Mugloo et al. (30) used the IVC collapsibility index measurements in their studies on intubated patients.

Optic nerve sheath diameter (ONSD)

Ophthalmic ultrasound is also an important one of these uses in intensive care units and emergency departments. Bedside sonographic ophthalmic ultrasound measurement of ONSD is an easy, cheap, noninvasive and repeatable technique to define increased ICP and has been used in adults and children in practice. The most important advantage of these technique is to be a radiation free technique (35). The optic nerve sheath is an anatomical extension of the dura mater, and the subarachnoid space around the optic nerve is continuous with the subarachnoid space. Changes in ONSD show the changes in ICP because of the direct communication between subarachnoid space and optic nerve in central nervous system. When ICP is increased, the ONSD increases initially even before papilledema occurs. It is not easy to take computed tomography or magnetic resonance images in a hemodynamically unstable patient. Ultrasound technology allows to take repeated and radiation-free images of the optic nerve sheath in patients with increased intracranial pressure at the bedside. For ONSD measurements the patients are placed in the supine position by raising their heads by 20–30 degrees. The ultrasound probe is placed on the eyelid and the ONSD measurement is performed in B mode, 3 mm behind the optic disc (Fig. 8).

Previous studies have reported safety and accuracy of ONSD for diagnosing increased ICP in various clinical conditions. In previous studies; for children below 10 years >4 mm ONSD and for children older than 10 years age >5 mm ONSD were considered as a sign of raised ICP (36). The sensitivity and specificity of ONSD in detecting an elevated ICP varies widely in the literature from 36% to 100% and from 38% to 100%, respectively (37). Transorbital ultrasound measurement of the OSND is a reliable technique, demonstrating a good relationship with ICP and high diagnostic accuracy for detecting raised ICP. In one pediatric study, Rehman Siddiqui et al. (38) reported the threshold of ultrasonographic ONSD values of >4.0 mm in infants, >4.71 mm in children of 1–10 yrs, and >5.43 mm in adolescents older than 10 years old to identify the raised ICP with sensitivity and specificity values of 100%



Figure 8. Ultrasonographic optic nerve sheath diameter measurement method

and 60–66.7%, respectively. Yapicioglu et al. (39) evaluated the largest serie in the literature with 554 newborn babies without cranial pathologies and they have given the detailed normal values of ONSD for different gestational ages both preterm and term babies.

Ophthalmic artery Doppler ultrasound

In recent years, the Doppler ultrasound assessment of ophthalmic arteries is one of the options for evaluating patients with increased ICP. The anatomy of the central retinal vessels is well-suited for Doppler sonography because the ultrasound probe is easily positioned parallel to the axis of the blood flow in the anterior portion of the optic nerve. After visualizing the arteries, the peak systolic velocity and end-diastolic velocity can be measured with the color Doppler imaging (Fig. 9). Then, the ultrasonography machine calculates an resistive index value automatically. It should be noted that the effect of elevated ICP on the ophthalmic vessel parameters has not been established yet because of the conflicting reports in the current literature (40). Ebraheim et al. (41) performed color Doppler ophthalmic ultrasound in 24 adult patients with pseudotumor cerebri syndrome. However, they did not detect any significant differences in the parameters between the patient and healthy control groups. Furthermore, the observed changes in the patient group at the follow-up were insignificant. In contrast, Karami et al. (42) demonstrated significant elevations in the transorbital Doppler parameters in pseudotumor cerebri syndrome patients.

Transcranial Doppler ultrasonography

Transcranial Doppler ultrasonography allows to rapid, recurrent and noninvasive assessment of serebrovascular physiology and serebral hemodynamics at the bedside (43). In recent years Transcranial Doppler ultraso-

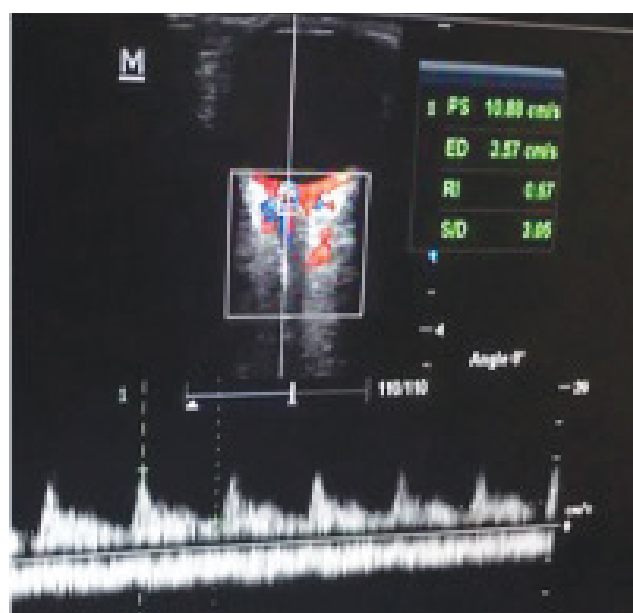


Figure 9. Doppler ultrasonographic assessment of the central retinal artery and ophthalmic artery

nography has been used in PICUs. The working principle of this technique based on measurement of flow patterns at middle cerebral artery. In a review about transcranial Doppler ultrasonography useage after pediatric traumatic brain injury, the authors have noticed that transcranial Doppler ultrasound is a benefical tool for evaluating otoregulation, vasospasm andintracranial pressure after traumatic brain injury. This technique provides an opportunity to prevent seconder brain damage by detection of decreased cerebral blood flow and applying required vasopressor support in early stages (43). A review about transcranial Doppler ultrasonography using in PICU, Tolga Fikri Koroglu has reported that, this type of POCUS will become a common procedure in a near future because of it's advices for diagnosis and management of neurological conditions (44).

Cardiopulmonary resuscitation

Ultrasonography can identify potentially reversible causes of cardiac arrest, particularly pericardial tamponade and pulmonary embolism. The current cardiopulmonary resuscitation guidelines recommend performing POCUS when a reversible cause of cardiopulmonary arrest is suspected, although it is stated that improvement of outcomes with the use of POCUS in cardiopulmonary arrest has not been yet demonstrated. POCUS is helpful in cardiopulmonary resuscitation in diagnosing reversible causes of cardiac arrest (45). In contrast an adult study results which evaluated 23 adults with cardiac arrest at emergency department has shown POCUS use during cardiopulmonary resuscitation associated with prolonged pulse check times and delayed high quality chest com-



Figure 10. Confirmation of endotracheal tube placement in trachea

pressions (46). Long et al. (47) noticed POCUS usage has not been shown to improve survival in cardiac arrest and they did not recommend that transthoracic ultrasonography be used routinely in cardiac arrest particularly for shockable rhythms. According to current literature recommendations it could be said, ultrasonography may guide management especially in nonshockable cardiac arrest rhythms which are due to obstructive processes.

Nasogastric tube insertion

The placement of a nasogastric tube (NGT) is a common bedside procedure in PICUs. There is potential risk for NGT misplacement with each insertion. A misplaced NGT causes increased risk for serious and even fatal complications. Radiography is the recommended gold standard method for confirmation of NGT placement (48). Point-of-care ultrasound has been reported as a diagnostic tool for the confirmation of nasogastric tube placement for neonates and adults in the literature. A study from our country, which evaluated POCUS effects for confirmation of NGT placement in 51 neonates, showed POCUS is a promising device for determining NGT location in neonates. The results of this study showed a decreased need for abdominal radiography and decreased risk for radiation exposure during NGT placement (48).

Airway management

Ultrasound assessment of the airway provide the clinician important information about the patient's airway static and dynamic anatomy. Ultrasound can help identify vocal cord pathologies, assess airway size, predict the appropriate diameter of endotracheal and tracheostomy tubes, rule out esophageal intubation, localize the cri-

cothyroid membrane for emergency airway access and identify tracheal rings for possible tracheostomy. POCUS is highly accurate for confirming ETT placement in adult and pediatric patients. ETT depth can be assessed by visualizing the ETT cuff in the trachea (Fig. 10). Despite it is not standard yet, there is a raising potential for the integration of ultrasound technology into the routine care of the airway (49).

Diaphragm ultrasound

Detection of ventilator induced diaphragm dysfunction using POCUS has been well described in adult patients requiring acute mechanically ventilating in the intensive care setting. The prevalence of diaphragmatic dysfunction in critical care patients requiring intubation has been reported to exceed 60% and be as high as 80% in patients requiring prolonged mechanically ventilation. In a recent study, 400 healthy infants and children between 1 month and 16 years were studied to determine normal reference values for diaphragmatic excursion with M-mode ultrasound using a subcostal view. Compared to age, body surface area, body length, chest circumference, and other anthropometric data, stepwise regression analysis showed that body weight was the only dependent predictor of diaphragmatic excursion, and percentile curves were plotted for diaphragmatic excursion against body weight (50).

In conclusion, POCUS is an important technology frequently used in most PICUs. Numerous studies revealed the most important clinical benefits of POCUS use by pediatric intensive care providers. In the light of increased and valuable literature about POCUS usage by pediatric intensive care specialists, according to us, POCUS can define as the new stethoscope of critical care physicians. If you have POCUS and have an experienced team, you can perform fast, noninvasive and repeatable assessments with clinical changes of patients without the need for an external consultant. The studies confirm the widespread use and most important clinical benefits of POCUS in PICUs.

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