
Current Neonatal Applications of Point-of-Care Ultrasound

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Abstract

Point-of-care ultrasound (POCUS) is an imaging modality that continues to gain acceptance in pediatric and neonatal medicine. In neonatology throughout many areas of the world, functional echocardiography performed by neonatologists has been at the forefront in the growth of POCUS compared to non-cardiac POCUS, the latter which potentially carries more opportunities for use. Despite the early adoption in obstetrics and maternal-fetal medicine, the actual bedside implementation in neonatology has unfortunately been much slower. Examples in neonatology where POCUS may continue to expand include central line placement, endotracheal tube localization, diagnosis of pneumothoraces, cardiac function assessment, and bowel viability assessment just to name a few. This chapter will be a practical synopsis of the most active uses and opportunities for POCUS in neonatology. Expanded training for neonatologists and trainees is required before widespread adoption occurs.

Keywords: ultrasound, point of care, newborn, preterm, central catheter, pneumothorax, necrotizing enterocolitis

1. Introduction

Point-of-care ultrasound (POCUS) is an imaging modality that continues to gain acceptance in pediatric and neonatal medicine. While ultrasound initially served as a clinical tool with a consultative model with radiology and cardiology disciplines, the value of POCUS in assessment of the heart and other organs is slowly being recognized. In neonatology throughout many areas of the world, functional echocardiography performed by neonatologists has been at the forefront in the growth of POCUS compared to non-cardiac POCUS. Technological

advances have pushed ultrasound (US) to have improved image quality and mobility while reducing cost and size of devices increasing the availability of ultrasound as a point-of-care bedside tool in several areas such as emergency medicine, obstetrics, and intensive care. Despite the early adoption in obstetrics and maternal-fetal medicine, the actual bedside implementation in neonatology has unfortunately been much slower. Examples in neonatology where POCUS may continue to expand include central line placement, endotracheal tube localization, diagnosis of pneumothoraces, cardiac function assessment, and bowel viability assessment just to name a few. What follows is a practical synopsis of the most active uses and opportunities for POCUS in neonatology.

2. Head

The newborn brain is readily accessible for sonographic imaging by the open soft tissue windows of the anterior fontanelle and the open sutures found between the unfused cranial bones. Neonatologists are quite familiar with viewing and interpreting cranial ultrasound images as these are routinely reviewed daily on clinical rounds. The primary views are coronal (front to back), sagittal (left to right) and axial views for posterior fossa [1]. POCUS can provide excellent views of the general architecture of the brain especially the two ventricles, evaluation of hemorrhage or calcifications and early evidence of ischemic changes. The use of POCUS for brain imaging is particularly useful when suspect hemorrhage may be responsible for deterioration or hemodynamic instability, at times when sonographic support is not readily available. The detection of increased pressure, cerebral edema or stroke is not sensitive with HUS and other imaging modalities such as CT or MRI are recommended. It is important to remember that these evaluations are limited in evaluating this triangulated view of the brain and can miss events or lesions outside of this window in the parietal regions. Head ultrasound is one of the easier techniques to learn for neonatologists since the views are already very familiar to them. The imaging techniques hinge upon establishing stable upright views of the two hemispheres and axial views of the posterior fossa structures. Neonatal providers have ample experience in reviewing and interpreting head ultrasounds for common pathology such as periventricular leukomalacia, intraventricular and intracranial hemorrhages and so most of the skills are focused on imaging.

3. Central catheters

Central vascular catheters such as umbilical arterial catheters (UAC), umbilical venous catheters (UVC), and peripherally inserted central catheters (PICC) are the most common central catheters placed in the sick neonate. Any neonate born at less than 32 weeks gestation will have at least a UVC and/or a PICC during their admission for nutrition and/or medications. In most units all of these lines are placed blind and confirmed with a single radiograph. UVC tip localization by standard radiography is imprecise. In one study approximately 30% of the radiographs were read as normal but actually had the UVC tip in the right atrium when checked with US [2]. Radiographic localization of UVC on anterior-posterior (AP) is difficult

to place in ideal position because of the doming of the diaphragm. The lateral chest radiograph is better than the AP view of the chest but this view is not as convenient with the infant typically secured down for the procedure.

Ultrasound more accurately confirms the position of the catheter tip than radiographs and reduces the exposure of ionizing radiation. Ultrasound guidance results in faster placement and fewer manipulations and radiographs for both umbilical catheters and PICC as compared with conventional placement [3, 4]. POCUS can be very useful in localizing the tip of central catheters either during placement or after a catheter has been placed to follow any migration. Umbilical catheters can frequently migrate after placement in the first few days after insertion. This may be due to drying and shrinkage of a longer umbilical cord. POCUS allows for the direct visualization of the umbilical and PICC catheters and their tips and indirect visualization of the UVC in the hepatic portion of the catheter pathway where it is localized by the shadow cast by the catheter [4]. Ultrasound may be able to help guide the catheter and thereby reduce complications during UVC, UAC, or PICC insertion. Doppler ultrasound is also useful to examine the aorta and renal vessels when placing or evaluating a UAC (**Figure 1**).

Use of POCUS for vascular access for PICCs has been limited due to the greater skillset required to accessing these small veins compared to older children. Setting up dedicated PICC teams can help develop this expertise to promote this aspect of central catheter POCUS.

With US, the UVC can be placed just beyond the IVC-RA junction. This permits good visualization and eliminates any risk of extravasation of the catheter in the liver. The UAC is readily placed just behind the heart which approximates the T7-8 position. The recognition of PICC movement in the large vessels makes it particularly challenging to manage the best position to place these catheters. Movement of the arm or leg to identify the deepest position of the PICC will ensure that the catheter does not inadvertently migrate deeper after placement and cause more risk of complications. For upper PICCs the arm position in a 45 degree flexed position at the shoulder and elbow usually represents the deepest point for a PICC while the knees bent close to the chest represent the deepest point for lower PICCs. The upper PICC can be placed at least 1 cm before the SVC-RA junction while the lower PICC is placed at 1–2 cm below the IVC-RA junction (**Figure 2**).

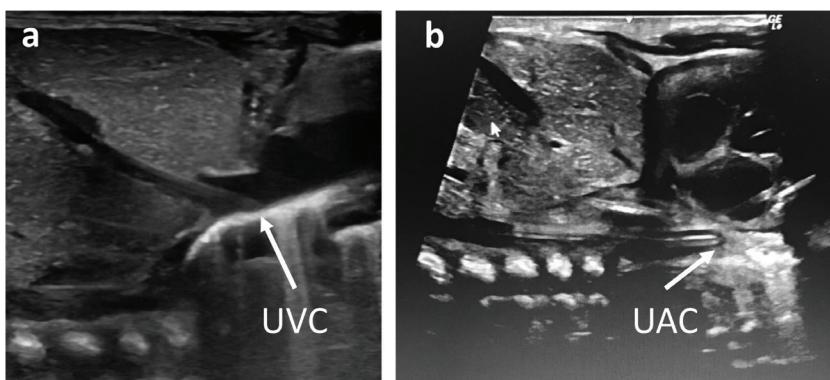


Figure 1. Umbilical catheter placement (a) UVC-umbilical venous catheter, (b) UAC-umbilical arterial catheter.

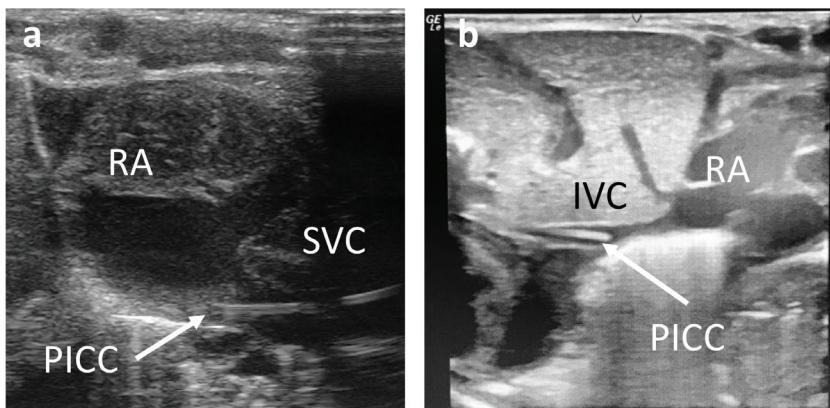


Figure 2. PICC localization (a) upper PICC, (b) lower PICC, PICC-peripherally inserted central catheter, RA-right atrium, SVC-superior vena cava, IVC-inferior vena cava.

Other areas of benefit from POCUS in the NICU are arterial line placement where localization of the vessel and flow identification by Doppler ultrasound can be performed. A modified Allen test with Doppler ultrasound evaluation of collateral flow is useful prior to the procedure. Real-time ultrasound can result in fewer attempts and less chance of a hematoma as compared with palpation.

4. Cardiac

The use of echocardiography has aided the evaluation of cardiac anatomy and function of the unborn fetus and the newborn. Ordering an assessment of the heart by ultrasound is a routine practice in the NICU. There has been a need to supplement the clinical assessment and current hemodynamic monitoring as they do not provide a comprehensive picture of cardiac output and organ perfusion states. The need for serial measurements is another unmet need with routine cardiac echocardiograms since transitional physiology after birth and during illness often require repeated measurements. Bedside POCUS for cardiac assessment is still an emerging practice as training to evaluate the heart is one of the hardest POCUS skills. Despite its difficulty there are probably more neonatologists worldwide with training to assess the heart through limited functional assessments than there are for non-cardiac POCUS. Cardiac POCUS is not intended to replace a cardiology assessment or structural echocardiogram. It is intended to be limited and dynamic assessment of hemodynamic of the heart to help with clinical decision making. Cardiac assessment in neonates is unique due to the dynamic changes that occur in the first few weeks of life making it challenging to order frequent dynamic assessments. The ability to help determine rapid determination of hemodynamics with serial functional assessments makes it increasingly attractive to work it into the daily workflow [5]. The focus of neonatal cardiac POCUS is to concentrate on a limited set of assessments that are helpful in determining the real-time hemodynamics. These include assessment of the patent ductus arteriosus (PDA), ventricular function, filling of the heart and volume assessment.

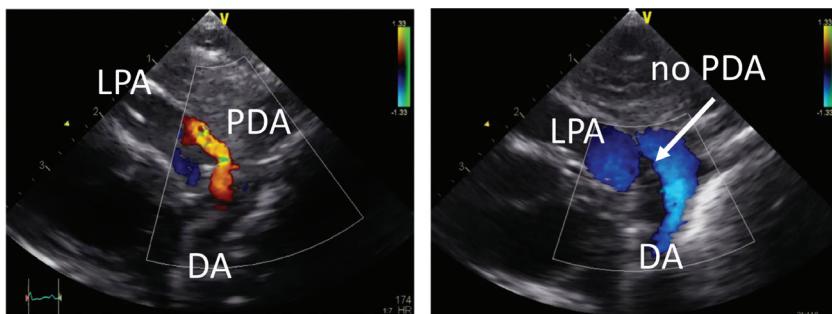


Figure 3. PDA (a) large PDA, (b) no PDA, LPA-left pulmonary artery, DA-descending aorta.

To start, cardiac POCUS can provide a rapid qualitative assessment of contractility: normal, hyperactive, reduced contractility (mild, moderate, or severe). Fractional shortening measurements are relatively easy to obtain and provide quantitative information. Cardiac filling as a measure of volume assessment can also be determined quickly. The PDA represents an important shunt to assess to facilitate clinical management to determine if the PDA is contributing to cardiorespiratory compromise or systemic hypoperfusion. The PDA can be determined to be open or closed (**Figure 3**). The presence of a patent ductus arteriosus can lead to an overestimate of cardiac output using usual left ventricular output measurements. An alternative measure of cardiac output using superior vena caval flow (SVC) measurements as a surrogate measure has been proposed [6–9]. Unfortunately, SVC flow has not become widely used as it has proven to be difficult to minimize inter-operator variability in this measurement. While several examples of benefit of neonatal cardiac POCUS have been published, there remains a paucity of neonatal clinical studies to validate each of the functional assessments and their ability to improve diagnostic or management of the sick neonate [10, 11]. As more neonatologists become comfortable with the skillset of cardiac echocardiography, there is a need for improved standardization and quality assurance [12, 13]. There have been some attempt to standardize the practice but many feel that the standards set are excessive and restrict early adoption [14, 15]. The anatomic assessment of the heart for the most part should be left to the cardiologist but it is equally important to recognize patterns of normal structure to know when there is suspicion of a congenital heart lesion.

Nevertheless, despite a number of hurdles, there remains tremendous promise that neonatal cardiac POCUS can provide a focused assessment to provide hemodynamic information to the bedside clinician.

5. Lung

The evaluation of lung by POCUS in neonates is increasingly practiced as the imaging technique is relatively simple and the lung is readily accessible for interrogation through the chest wall. Several recent articles have noted lung ultrasound to be as good if not better than X-ray as a diagnostic modality. Reduction in cost of image acquisition and exposure to ionizing

radiation improves quality of care as well as patient safety [16]. Neonatal lung POCUS is similar to pediatric lung POCUS except that the neonate has very thin soft tissue in the chest with thin ribs and a cartilaginous sternum that enables larger windows of viewing. From a technical perspective, we need a high frequency transducer like a 7–15 MHz hockey stick or equivalent linear array transducer. The detection of common respiratory conditions has been documented making it potentially possible to define the parenchymal lung disease by characteristic patterns to the common respiratory conditions such as pneumonia (PNA), transient tachypnea of the newborn (TTN) and respiratory distress syndrome (RDS). The ability to make an urgent diagnosis is where the greatest utility of lung POCUS may lie as acute respiratory compromise often requires rapid diagnostics. The presence of air or fluid such as blood, transudate or exudate in the pleural space is readily discernable by US.

The complication of spontaneous pneumothorax (PTX) at birth is one such condition that may be aided by lung POCUS. PTX will display several differing US patterns compared to normal lung. The characteristic findings on US of PTX in neonates are similar to adults and children (**Figure 4**). Normal lung appears homogeneous in texture with the occasional presence of hyperechoic linear A (horizontal) and B (vertical) lines. Movement of the parietal and visceral pleura against each other during respiration creates a “shimmering effect” or an “ants marching effect” which is termed lung sliding. The presence of the sliding lung sign rules out a pneumothorax on B mode [17]. Further confirmation of a PTX can be achieved with M mode which displays the data from a single line in an image mapped against time on the x-axis. The appearance of moving lung tissue results in a granular appearance similar to a sandy “seashore” with the “waves” at the top representing the static soft tissue above the lungs. Some data suggests that US may not be as sensitive for PTX in neonates [18].

The underlying changes in RDS involve loss of the smallest airspaces (alveoli or saccules). This generates denser tissue that gives the appearance of “white lung” using lung POCUS. Some have proposed a scoring system to categorize lung disease in RDS to assist in increasing specificity for diagnosing RDS [19]. This score can reliably predict the need for surfactant treatment in preterm babies less than 34 weeks gestation treated with nasal CPAP from birth. Several

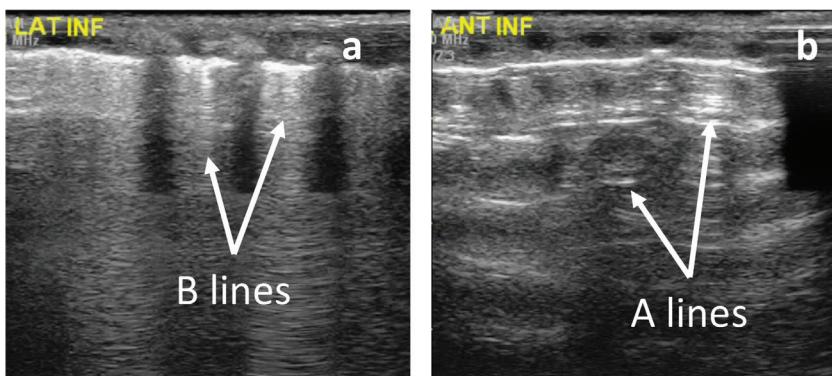


Figure 4. Pneumothorax (a) normal lung, (b) pneumothorax.

studies have validated the ability to distinguish between RDS and transient tachypnea of the newborn (TTN) [20, 21]. In TTN ultrasound changes include abnormalities of pleural lines, absence of A-lines, and interstitial syndrome or pulmonary edema. Pneumonia has been described to have A-lines, interstitial syndrome and possible lung consolidation. Lung POCUS has been able to differentiate meconium aspiration syndrome from other respiratory conditions since it is also associated with absent A-lines, lung consolidation, and interstitial syndrome.

The role of lung ultrasound may not replace chest radiographs but may offer more time sensitive information and reduce the total number of radiographs taken. The evaluation of lung by POCUS in neonates is increasingly being studied and practiced. The most promising application may be during resuscitation where early detection and management of conditions like pneumothoraces and pleural effusions are life-saving.

6. Endotracheal tube

Neonatal intubation remains a difficult high level skill. Although there are much less intubations taking place compared to a decade ago, the need to establish a secure airway remains ever important. This is particularly true for resuscitation of neonates <28 weeks gestation. The current standard of practice to confirm the placement of the endotracheal tube (ETT) is with chest x-ray (CXR). The passage of the ETT into the trachea or esophagus can be discerned readily using a transverse probe position in adults and pediatric subjects [22–25]. POCUS can be used to rapidly and accurately visualize the anatomic position of the ETT position in preterm and term infants [26] (**Figure 5**). Unlike in pediatric or adult patients, evaluating the ETT in the newborn

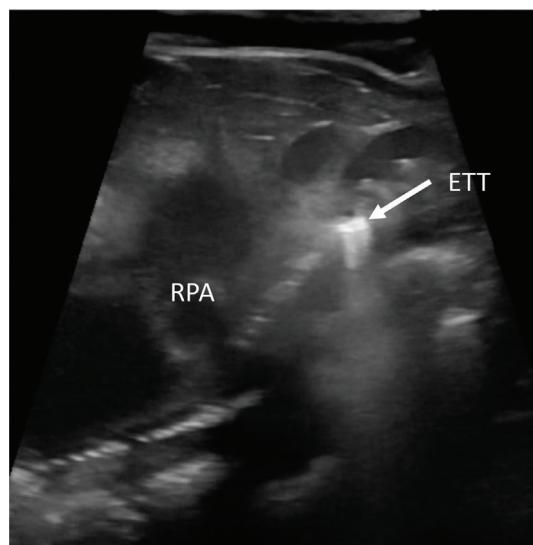


Figure 5. Endotracheal tube placement ETT-endotracheal tube, RPA-right pulmonary artery.

through the chest is possible due to the cartilaginous sternum. Although there is air inside and around the ETT and the entry is at a steep angle to the ultrasound probe, the tip of the probe can be identified with a white or hyperechoic line. The ideal location for the tip of the ETT is midway between the thoracic inlet and the carina. Identifying the distance of the tip of the ETT from the carina can be accurately measured. In a recent publication of an extensive database literature search on studies relating to US use for ETT position confirmation found nine studies which collectively reported a > 80% visualization of the ETT tip by US [22]. Also, US interpretation of the ETT position correlated with the XR position in 73–100% of cases. US appears comparable to XR determining ETT position in this population. As US is more easily available and is safer than CXR, it may be a better modality for confirming proper placement of ETT in neonates when time is critical. There are no current data yet on identifying tip location during placement of the ETT and so more clinical data may be required before widespread adoption.

7. Bowel

The assessment of bowel by POCUS in neonates remains an emerging practice despite the availability of clinical data in neonates for more than a decade. POCUS can show dynamic intestinal peristalsis as well as characterize the physical nature and perfusion of bowel that can be used to assess bowel integrity and viability. The newborn can be affected by a variety of congenital and acquired bowel conditions that may lead to significant bowel dysfunction or even death. Early recognition of the signs of impending bowel injury or the progression of bowel damage is essential. Intestinal peristalsis can be quantified by counting cumulative motility events over time to give an objective assessment of bowel movement [27]. Identifying peristalsis can assist in the routine management of neonatal feeding or bowel assessment but more studies are required to validate its utility for clinical outcomes (**Figure 6**). Some other studies have demonstrated that gastroesophageal reflux can be evaluated by POCUS both identifying anatomic risk factors as well as visualizing the bolus but this has not gained traction in clinical practice yet [28, 29].

Recent data suggest that dedicated abdominal ultrasound examination may be of utility in the diagnosis and management of infants with necrotizing enterocolitis (NEC). Advantages of ultrasound include assessment of peristalsis, vascular perfusion, bowel-wall thickening, and abdominal fluid. Absence of ionizing radiation is an added benefit. A recent meta-analysis showed that bowel ultrasound is increasingly being recognized as an important imaging tool for evaluating NEC that provides additional detail over plain abdominal radiographs [30]. There are still only few studies with small case series and heterogeneous gestational age population that have investigated the comparison between plain radiographs and abdominal ultrasound in predicting the outcomes of patients with NEC.

NEC is one of the most severe gastrointestinal conditions affecting neonates. The risk increases with degree of prematurity and in those with low birth weight [31–35]. Although risk factors have been identified, the etiology is still not well recognized. Despite significant advances in neonatal care, mortality in NEC remains high (between 20 and 60% in a group of most immature neonates) and maintained at the same level. Therefore, in cases of clinically suspected

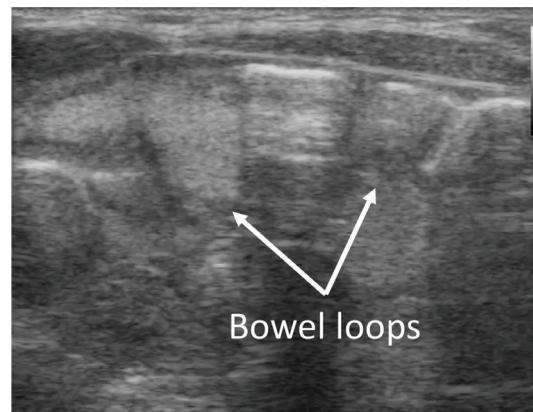


Figure 6. Normal bowel appearance.

NEC quick diagnostics and implementation of appropriate treatment are crucial [34–36]. Diagnosis is based on clinical presentation, laboratory testing and imaging. Traditionally, the gold standard for imaging evaluation of the neonatal intestine is the intestinal gas pattern on plain abdominal radiographs; however interpretation can be challenging with intestinal gas pattern being nonspecific [37–39], and significant overlap between radiographic signs of NEC and other intestinal pathology [40].

The usefulness of abdominal ultrasound in the diagnosis of NEC has been known since 1984 as evidenced in a number of studies [41–43]. Studies have looked at ultrasound being an adjunct to diagnose and manage infants with NEC. It allows for an earlier detection of typical signs of NEC, with more rapid disease management. When compared with abdominal radiographs in predicting NEC, studies showed that they can depict bowel distension, to some extent bowel-wall thickness, pneumatosis intestinalis, portal venous air and free abdominal air which ultrasound could easily depict as well. More importantly, abdominal ultrasound provides important additional information regarding viability of bowel wall viability and free fluid, which might aid in diagnosis and management of NEC [44, 45]. With color Doppler specific suspicious loops of bowel can be interrogated to reveal if they are perfused or not which enables the identification of non-viable bowel with a high degree of certainty. The gradual progression of NEC can be identified by POCUS from the initial hyperemia and swelling of bowel wall to the dilatation with increased disease and then thinning of bowel wall with loss of perfusion or blood flow. Therefore, nonviable bowel will no longer have any blood flow present (**Figure 7 Epelman diagram**). The detection of portal venous gas is much easier by POCUS than by radiographs [46].

7.1. Procedure and features

For performing bowel ultrasound a linear probe of 8–15 MHz probe (higher frequency for higher resolution and lower depth targeting superficial structures). Features that are key include: (a) bowel wall thickening >2.6 mm, (b) increase in bowel wall echogenicity, (c) portal venous air, (d) pneumatosis Intestinalis and free air and (e) intra-abdominal fluid.

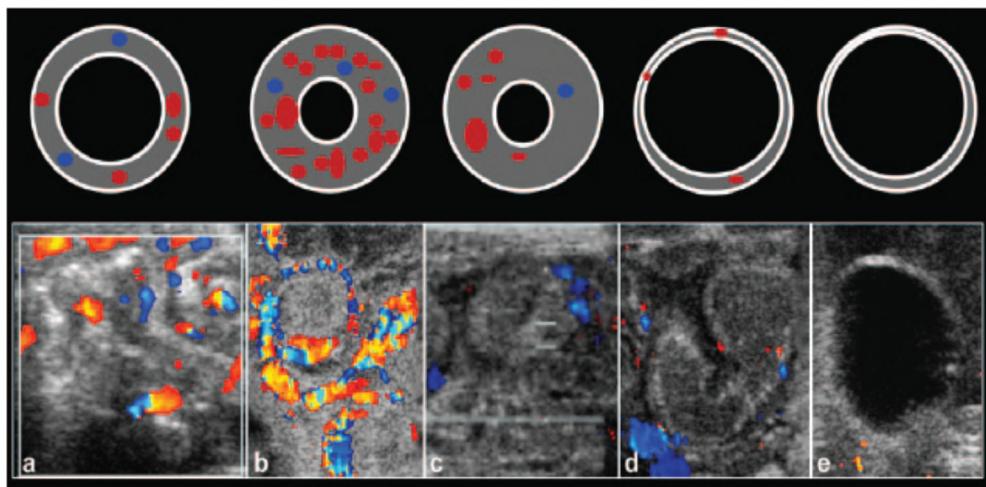


Figure 7. Sonographic appearance of NEC progression (figure from Epelman et al. 38 need permission).

Some limitations of ultrasound include that it is operator or skill dependent and this is a real time diagnosis which might create an obstacle for radiologists to evaluate the ultrasounds retrospectively and in turn underlines the need for neonatologists to be more familiar with this tool. Currently most of the available literature are single center trials, retrospective observational cohorts. We still need more prospective studies doing head to head trials with abdominal radiograph to understand the true value and usefulness of abdominal US. More studies are required to fully validate these assessments in clinical care. Training of radiologist and their sonographers as well as other providers such as neonatologists and surgeons is required before broad adoption of bowel POCUS occurs.

8. Bladder

Bladder aspiration through suprapubic urine collection is ideal to perform under ultrasound guidance over landmark techniques. Ultrasound of the bladder can help determine the size and location of the bladder and the volume of urine in the bladder. Portable ultrasound can significantly improve the diagnostic yield; a minimum volume on ultrasound of 10 mL is associated with a 90% successful bladder aspiration. If the cephalocaudal diameter of the bladder (sagittal view) is >20 mm and the anteroposterior diameter is >15 mm, the success rate approaches 100%.

9. Lumbar puncture

Lumbar puncture (LP) is a relatively common procedure performed in emergency department and the NICU as part of a complete sepsis evaluation. The LP is typically performed using the “blind” surface landmark guidance. Anecdotally, this technique is reported to be have a high percentage of success. However successful identification of landmarks has been

shown to be accurate only 30% of the time [47]. Traumatic or unsuccessful LPs in this group have been documented in the pediatric literature in 30–50% of patients [48, 49]. This translates to increased difficulty in obtaining CSF and higher rate of complications such as local/subdural/epidural hematoma, bloody tap and incomplete sepsis evaluation to name a few. Fluoroscopy guided LP is an alternative but challenges include limited availability, radiation exposure, need to transport critical patients for the procedure.

Use of POCUS for identification of key landmarks is a safe and easy alternative to the blind method [50–52]. In adults, using ultrasound for LP has been associated with a reduction in the number of attempts and interspaces accessed [51–55]. In neonates, the incompletely ossified spinous processes, minimal fat aids in interrogation of the space by ultrasound compared to older kids and adults. The good resolution of image, lack of ionizing radiation and potential for real time guidance makes ultrasound a valuable tool for performing LP in neonates [48, 56].

LP can be performed in the neonate without general anesthesia or sedation, using oral sucrose and local anesthesia. Patient can be in lateral decubitus position or sitting up. Using ultrasound to measure the interspinous space at L3-L4 and L4-L5 in varying positions, the lumbar spine is found to be maximally positioned in both neonates and children in the seated position with flexed hips versus the lateral decubitus position [57, 58]. The probe used is the 7–15 MHz hockey stick or equivalent linear array transducer. There is still very limited knowledge on ultrasound guided LP in neonates. There are two techniques described in literature, the transverse approach and longitudinal approach based on how the probe is held.

The first skill is to define the landmarks for the LP procedure. Using a surgical marker or pen one can delineate the location of midline and the position of the conus, the point where the spinal cord ends. There are no studies validating the guidance of the needle into the inter-space and so this will require more studies before guidance by US is a routine procedure.

10. Summary

Existing and emerging POCUS applications are numerous and promising but more validation for clinical value is required in addition to larger scale training of individuals to learn and become competent in these techniques. Emphasis should be on training all incoming and existing fellows to learn POCUS.

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