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REVIEW

Point-of-care abdominal ultrasound in pediatric and neonatal intensive care units

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Abstract
A spectrum of critical abdominal pathological conditions that might occur in neonates and children warrants real-time point-of-care abdominal ultrasound (abdominal POCUS) assessment. Abdominal radiographs have limited value with low sensitivity and specificity in many cases and have no value in assessing abdominal organ perfusion and microcirculation (Rehan et al. in Clin Pediatr (Phila) 38(11):637–643, 1999). The advantages of abdominal POCUS include that it is non-invasive, easily available, can provide information in real-time, and can guide therapeutic intervention (such as paracentesis and urinary bladder catheterization), making it a crucial tool for use in pediatric and neonatal abdominal emergencies (Martínez Biarge et al. in J Perinat Med 32(2):190–194, 2004) and (Alexander et al. in Arch Dis Child Fetal Neonatal Ed 106(1):F96–103, 2021).

Conclusion: Abdominal POCUS is a dynamic assessment with many ultrasound markers of gut injury by two dimensions (2-D) and color Doppler (CD) compared to the abdominal X-ray; the current evidence supports the superiority of abdominal POCUS over an abdominal X-ray in emergency situations. However, it should still be considered an adjunct rather than replacing abdominal X-rays due to its limitations and operator constraints (Alexander et al. in Arch Dis Child Fetal Neonatal Ed 106(1):F96–103, 2021).

What is Known:
- *Ultrasound is an important modality for the assessment of abdominal pathologies.*

What is New:
- *The evidence supports the superiority of abdominal POCUS over an abdominal X-ray in emergency abdominal situations in the neonatal and pediatric intensive care units.*

Keywords Abdominal POCUS · Neonatal intensive care · Pediatric intensive care · Point-of-care ultrasound

Assessment of the upper abdomen (liver, spleen, and stomach)

The upper abdomen can be divided into the right and left sides, with the right upper abdomen containing the right lobe of the liver, pylorus, and duodenum. The left side contains the left lobe of the liver and the body of the stomach. The right posterior is the liver's right lobe, and the left posterior is the spleen. Fig. 1 demonstrates the organs in the upper abdomen and plans for ultrasound assessment.

Liver

The recommended probe is the curved linear arrays (and sector transducers), which can be used for positioning supine and lateral decubitus.

The liver can be assessed from the ventral and lateral; the posterior approach is sometimes helpful. Start with a sweep through the entire liver in sagittal and axial sections. Follow the course of major blood vessels (portal vein, hepatic veins), assess gall bladder, and eventually add Doppler if indicated.

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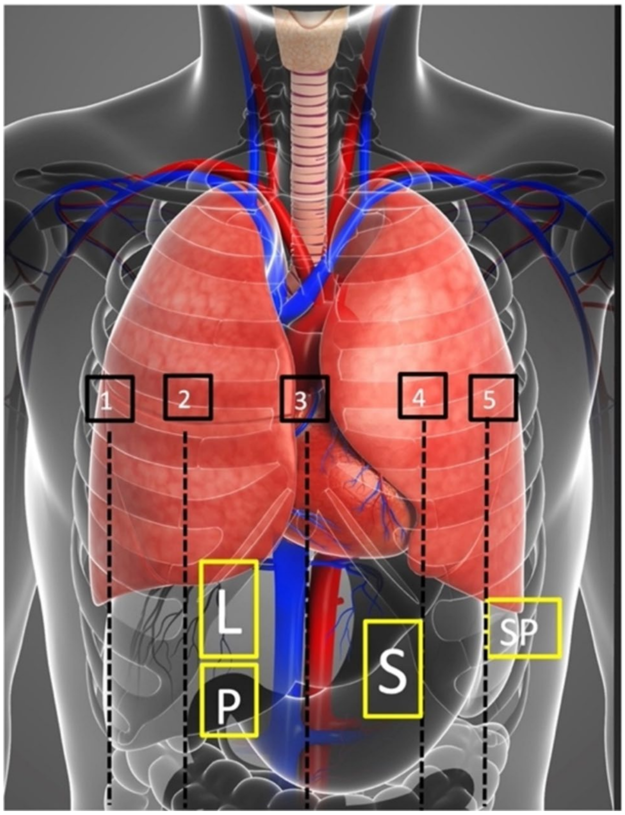

Fig. 1 The organs of the upper abdomen can be assessed by ultrasound, and the transparency of the organs can reflect the anteroposterior arrangement of the organs. L: liver, S: stomach, P: pylorus, SP: spleen; the US plans from right to left: 1: right anterior axillary line, 2: right midclavicular line, 3: midline, 4: left midclavicular line, 5: left anterior axillary line

Standard liver plans

Anterior upper right abdomen assessment in 2 plans (sagittal and axial), anterior axillary, and midclavicular lines – posterior right in posterior axillary line. Upper left abdomen assessment in the midclavicular line and posterior left assessment in the posterior axillary line, perform sagittal and axial sections in all plans as 2D ultrasound and add color Doppler (CD) or pulse wave Doppler (PWD) whenever necessary.

The following are the common hepatic pathological conditions.

- Liver congestion

  It occurs in conditions with increased right atrial pressure (secondary to congenital heart diseases or pulmonary hypertension) and may also occur in conditions with hypervolemia [5].

  Ultrasound findings

  - An enlarged liver initially reduced echogenicity, but in a chronic state, it shows increased echogenicity. Smooth surface, rounded lower margin, dilated HV that can be followed into the liver periphery, and it shows reduced or lack of size modulation dilated IVC and connected HV, making a sign of moose head.
  - Ascites, splenomegaly, omental thickening, and congested bowel wall edematous thickening. Figure 2 demonstrates an ultrasound image of liver congestion.

- Liver hematoma

  Simple hematoma or subcapsular hemorrhage is usually less threatening but may become more serious if the liver capsule is ruptured and significant free peritoneal fluid is seen (potentially with sedimentation, depending on the time of investigation). Free peritoneal fluid/blood appearing like complicated ascites can be found anywhere in the abdomen and does not necessarily correlate with the site of injury [6].

  Ultrasound findings

  Initially, the same echogenicity as liver parenchyma and potential disruption of other structures such as vessels or outer contour can help diagnosis; the subcapsular hemorrhage appears as a hypoechoic fluid-like collection surrounding the liver. Figure 3 shows subcapsular hemorrhage [6].

- Liver contusion

  More difficult to diagnose, often triangular, located in subcapsular regions. Initially difficult to see, echogenicity changes from hyperechoic to hypoechoic, as in Fig. 4. CD may improve the detection of contusions by focal disruption of normal vascular architecture with regional disruption of vessel color signals.

- Portal venous gasses

  Gas bubbles, commonly within the PV system, derive from some conditions in the GI tract (e.g., necrotizing

Fig. 2 Liver congestion with dilated IVC and hepatic veins, making a sign of moose head

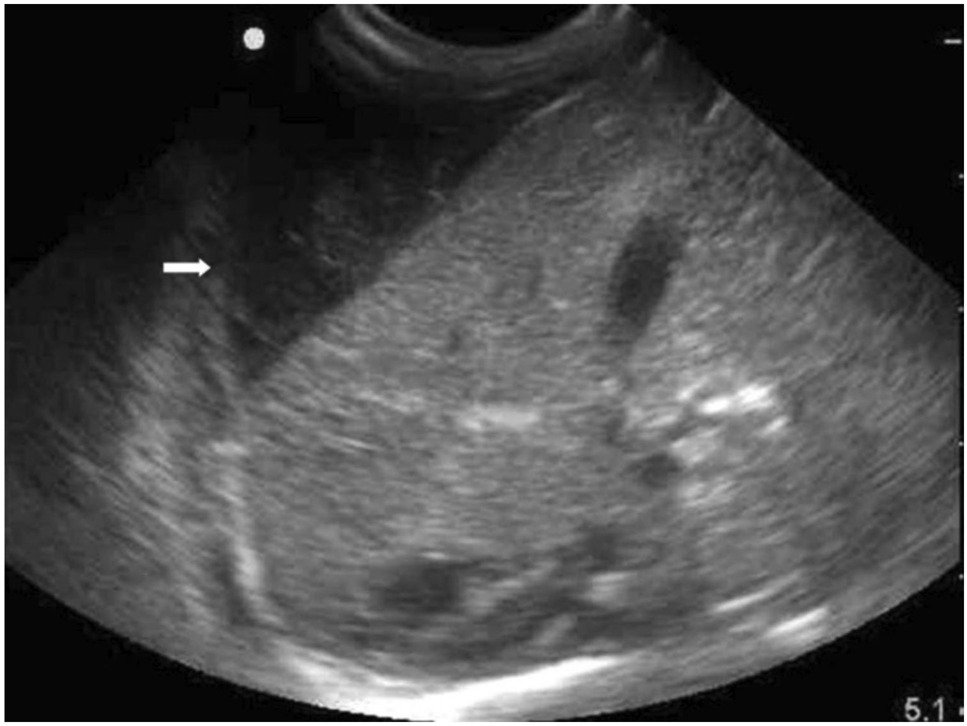

Fig. 3 Subcapsular hemorrhage with the hypoechoic subcapsular collection of fluid (the arrow)

enterocolitis, food protein-induced enterocolitis); they may also be from the central venous lines [7, 8]. Most commonly, gas gathers in dependent areas (highest parts of the liver, upper areas in the supine position) (Fig. 5). Seen as moving tiny echogenic foci (with comet-tail-like reverberation echoes), sometimes floating echogenic foci visualized in central PV [9].

Spleen

Recommended probe: curved linear arrays (and sector transducers) used. For detailed analysis, linear transducers are recommended: positioning supine, prone, and lateral decubitus [4].

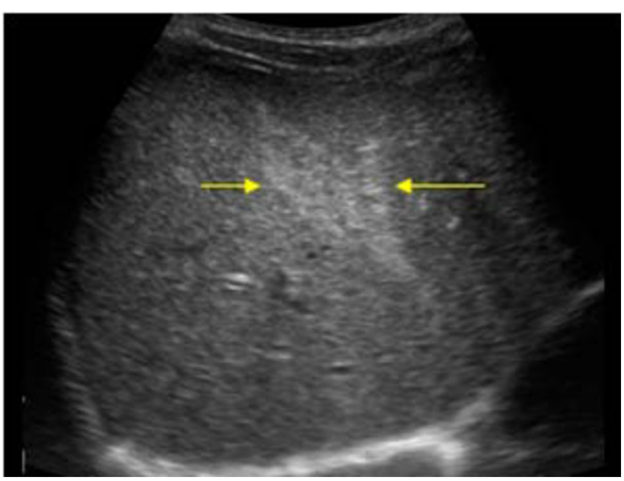

Fig. 4 Liver contusion, still hyperechoic (the arrows)

Indications

- Splenomegaly

  Enlargement of the spleen is the most common indication for abdominal POCUS in some areas. Enlargement can be secondary to portal hypertension and focal lesions (abscess, fungus, lymphoma, or leukemia).
- Splenic injury

  Spleen injury, common in blunt abdominal trauma in children or rarely birth trauma, may lead to acute hemorrhage. Children often compensate for even severe hemorrhage for a significant time to eventually deteriorate suddenly, making a thorough abdominal POCUS investigation particularly valuable [4].

  Ultrasound findings

  Potentially increased size due to subcapsular hematoma, which in the early post-traumatic phase sometimes cannot be discriminated from normal spleen tissue, but peri splenic fluid or later phases with sedimentation of erythrocytes and complex fluid-like appearance of hematoma enables visualization. Contusions without hemorrhage often only exhibit regionally heterogeneous structures without demarcation of hematoma. In laceration, contour-disrupted paren-

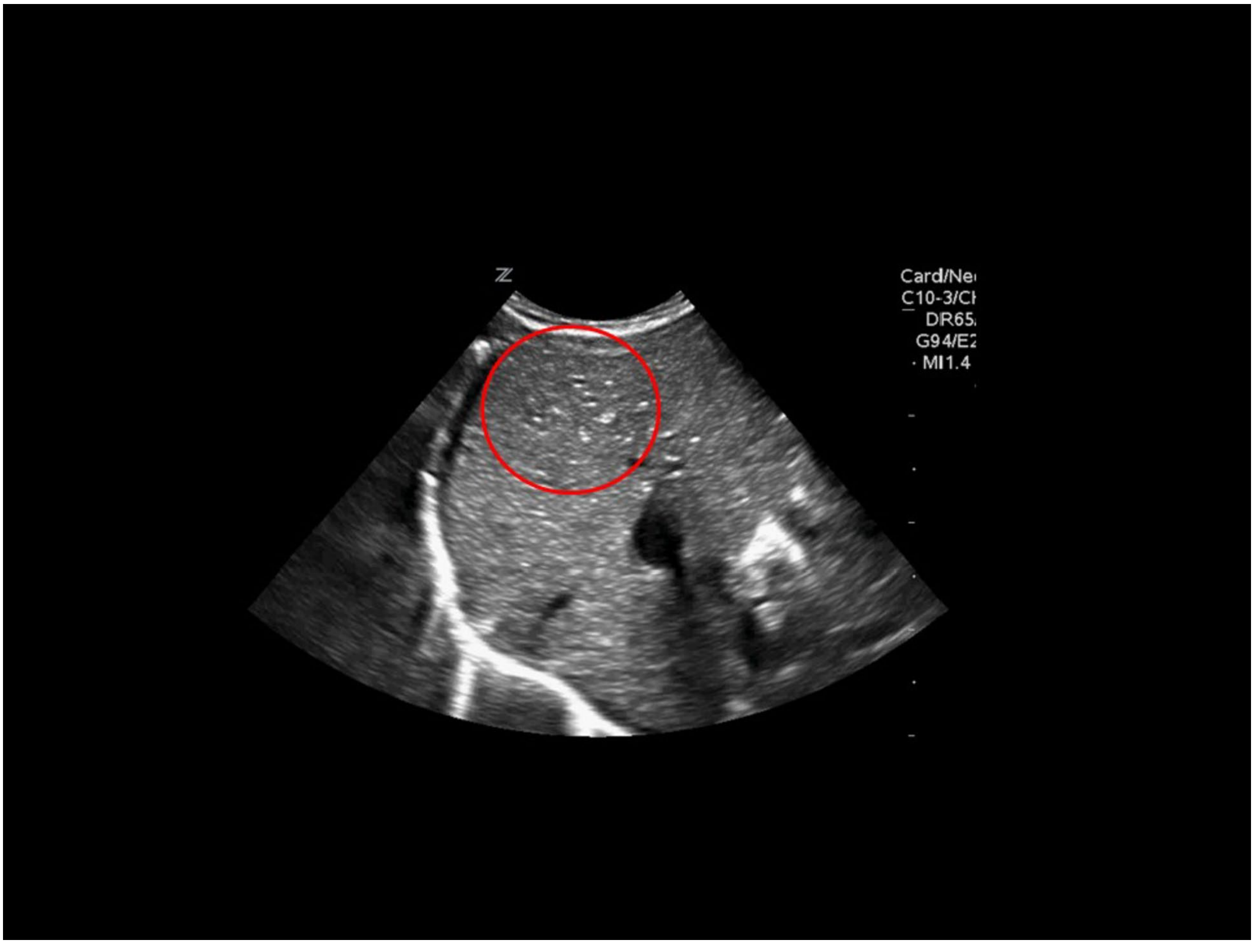

Fig. 5 Liver image with portal venous gasses, more inside the red circle

chyma and reduced diaphragmatic motion are indirect signs, and close follow-up is recommended.

Stomach

Patient preparation is important to reduce the amount of air: optimal initially fasting – if appropriate, feeding during assessment. Commonly starts in a supine position, positioning maneuvers helpful (changing to right/left/lateral decubitus); sometimes posterior access may improve assessment, particularly of dorsal parts or if gas impairs access. Preferred high-frequency transducer (pylorus, ventral wall) with high-resolution linear (or curved array) [11].

Indications are mostly vomiting (non-bilious) and bloody gastric aspirate, which are also included in the upper abdomen abdominal POCUS assessment.

Ultrasound protocol

Access the subxiphoid, median, or upper left abdomen; for the pylorus, access the upper right quadrant. Use the left liver lobe as a window. Try to localize either the entrance or outlet in the axial section; follow in the axial section before turning into the longitudinal plane for the outlet (pylorus) or inlet (gastroesophageal junction). Assess for reflux or intermittent herniation toward the thoracic space. Assess pylorus and its function with the transition of stomach contents into the duodenal bulb.

Common pathological conditions

1. Gastroesophageal reflux (GER)

   Reflux of stomach contents to the esophagus and small amounts of intermittent regurgitation are physiologic in the first 6 months of life. Provocation by drinking formula or water test in older children left decubitus position with slight pressure on the abdomen with the transducer, similar to fluoroscopy.

<u>Ultrasound findings</u>

Regurgitation of fluid as echogenic fluid air interface from the stomach into the esophagus with variable dilation of the gastric inlet. Assess the number and duration of reflux episodes, esophageal clearance, and wall thickness. Assess any potential herniation of gastric parts to the thoracic cavity [12].

2. Hypertrophic pyloric stenosis

The ultrasound best diagnoses it; cramps usually present with propulsive non-bilious vomiting. It typically occurs more in boys aged 2–12 weeks. Treatment is usually by surgery, although medical conservative treatment may be an option in early and mild diseases with high surgical risk [11, 13] (Fig. 6).

- Enlargement of pylorus, particularly pylorus muscle, length > 15 mm, muscle > 3 mm, axial diameter ≥ 12 mm, and wall lumen ratio > 2:1.
- Change in wall thickness from stomach to pylorus with typical shoulder-like contour at the pyloric entrance.
- Often displacement of the pylorus, gastric enlargement with residual volume in fasted children.

Lower abdomen (bowel, peritoneal cavity, and abdominal blood vessels):

Preparation

Preparation is optional in emergency situations. Visualization of the bowel is easier after feeding and with less air content; the best assessment time is after birth when there is not much air and the bowel is full of fluid and meconium. Saline enema helps visualization of the colon and can be used therapeutically in the meconium ileus [14, 15]. Common indications are suspected bowel obstruction with twisted bowel with compromised blood flow: intussusception or volvulus, blood stools or bleeding per rectum, crashing infant or suspected bowel ischemia, bloody diarrhea, inflammatory bowel diseases, and acute abdomen (e.g., after trauma).

Ultrasound protocol

Positioning

Usually, supine, relaxed abdominal wall musculature is helpful (can be achieved by support to knees). Transducers linear transducers with the highest achievable frequency for optimal resolution are helpful. Curved linear arrays allow better overview or extended view techniques. Frequency depends on the patient's age and position of the targeted bowel segment, but generally, a higher frequency is better for bowel assessment (e.g., neonates: 14–20 MHz; children: 8–10 MHz). The lower abdomen is divided into 4 quadrants: upper and lower right, upper and lower left quadrants. Each quadrant should be assessed by 2D and CD in sagittal and axial sections; sweep is preferred in both sagittal and axial Sects. [3, 10, 16, 17].

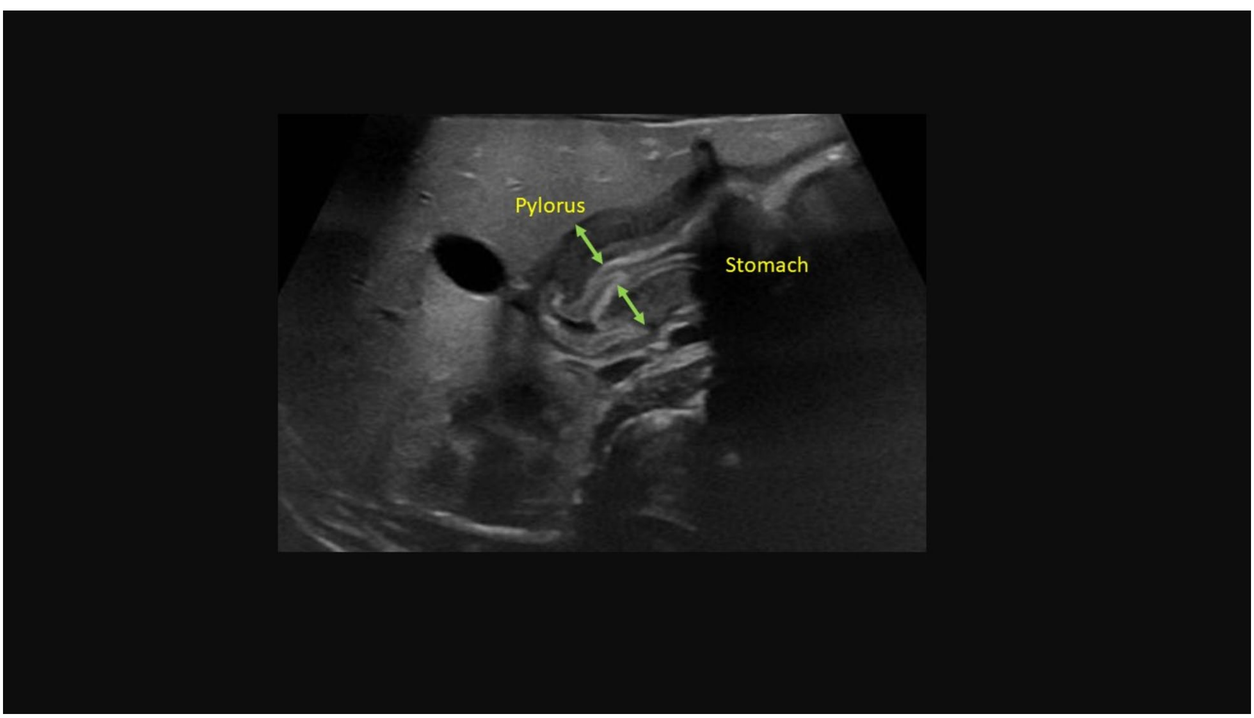

Fig. 6 The thickening of the muscular layer in hypertrophic pyloric stenosis (the green arrows)

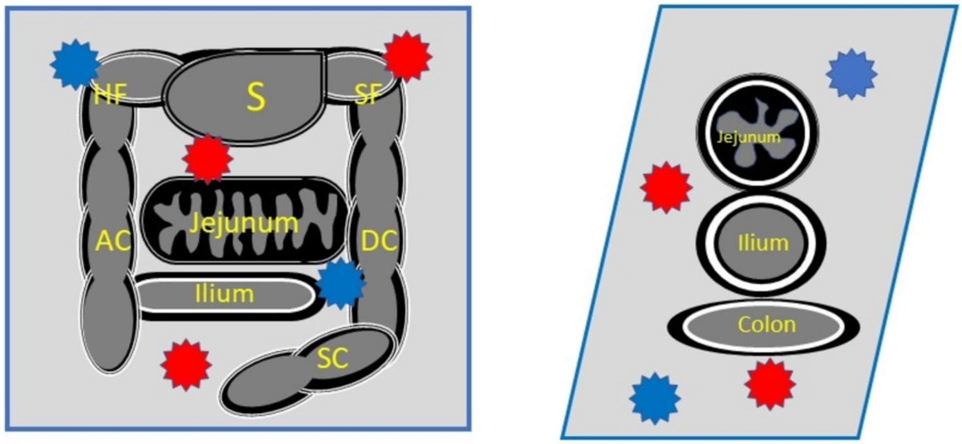

Fig. 7 Cartoon simulating the normal ultrasound images of bowel structures in the sagittal section (left image) and axial section (right image). In the left image, S: stomach, which may overlap the transverse colon, HF: hepatic flexure, SF: splenic flexure, AC: ascending colon, DC: descending colon, SC: sigmoid colon. The jejunum represents the upper left part of the lower abdomen; it has a thick wall and mucosal folds, and the ilium is the lower right part; it has a thin, smooth wall. The colonic wall is also smooth and thin but also has a haustra design, and the color Doppler appears as small speckles, 3–9 speckles in each 2×2 color box. Right image, the axial section of the jejunum has a thicker wall than the ilium and colon, and the wall in all views has multiple layers, giving the normal wall signature

Identifying bowel structure

The first step is to identify well-defined structures (e.g., pylorus, gastro-esophageal junction, cecum, and rectum). Follow respective loops continuously from distal to proximal or the opposite direction. The jejunum occupies the upper part of the bowel, mainly the left side of the abdomen, while the ileum occupies the lower, mainly right side. The jejunal wall is thickened, and the mucosa is reached in luminal folds called plicae circularis, while the ileum wall is thinner and smoother from the inside. The colonic wall is characterized by incomplete balls or domes from the outside called colonic haustra, which can also be identified from the inside. The colonic wall is generally smooth and thin. Figure 7 is a cartoon simulating an ultrasound view of different bowel structures [16]. Assess bowel wall (thickness, structure), size (any stenotic part?), peristalsis, direction, and compressibility. Assess lumen and content. Assess longitudinal sections for documentation of inner contour (folds) to differentiate jejunum (proximal)from ilium (distal) and assessment of stenotic segments.

Adding CD for assessing bowel wall vasculature; in some applications (e.g., NEC), assessment of mesenteric artery/

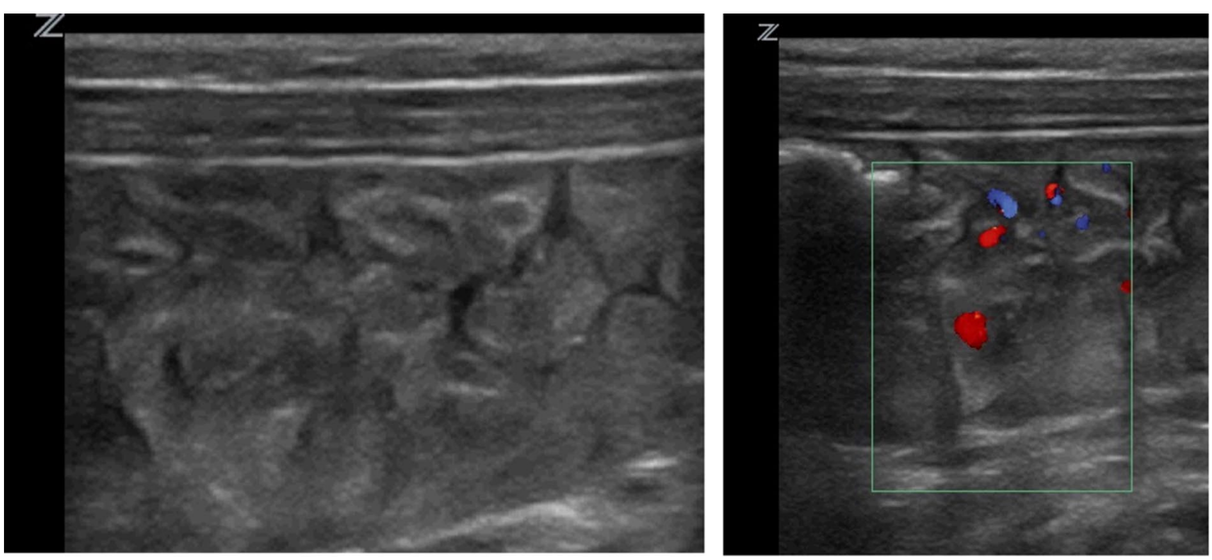

Fig. 8 The right image is a normal gray or hypoechoic looking of bowels; they appear crowded, with no peritoneal fluids, and with active peristalsis in the live clip; the white arrow represents the thickness of the bowel, and the left image is a normal-looking color Doppler

vein and coeliac trunk is helpful in assessing malrotation. Normal abdominal POCUS findings typically stratified bowel wall (Fig. 8) [17–19].

The following are the main identifiable sonographic features in intestinal assessment and detection of gut injury:

1. Free intraperitoneal gas can be identified by the presence of linear or punctuated echogenic foci outside of the bowel with multiple A-lines artifacts (Supplementary Fig. 1) or air over the liver surface.
2. Focal fluid collections can be identified as focal locules of fluid with complex echoes or septations within the fluid collections.
3. Bowel wall thickening is present when the bowel wall thickness is 2.6 mm or greater.
4. Bowel wall thinning is considered when the bowel wall thickness is 1.0 mm or less.
5. Bowel wall hyper-echogenicity is present when there is a loss of the hypoechogenic muscle layer "bowel wall signature," with an overall increase in mural echogenicity (Supplementary Fig. 2).
6. Pneumatosis intestinalis is defined by the presence of punctate echogenic foci within the bowel wall in the absence of artifact shadows or punctate artifacts.
7. Portal venous gas (PVG) is identified by punctate or linear moving echogenic foci within the portal vessels.
8. Increased perfusion was determined from a review of the color Doppler images; this can be detected by abnormal color Doppler pattern signifies hyperemia (zebra, Y shaped, circular); the normal color pattern is small, scattered speckles (3–9 in one color box).
9. Absent bowel perfusion can be recognized when no flow is seen within a loop of the bowel on color Doppler imaging.
10. Absent peristalsis is defined as the absence of peristalsis on a recorded clip.
11. A dilated bowel with anechoic contents is defined by the presence of anechoic fluid within the bowel whose diameter was equal to or greater than two vertebral body heights (as seen on radiography; this can be used as a convenient internal control for size) [16, 20].

Supplementary Table 1 demonstrates the different ultrasound markers of NEC and other types of gut injury.

Ultrasound protocol of suspected gut injury

Assess liver echotexture by sweeping both right and left lobes in sagittal and axial sections; this is important to detect PVG as moving echogenic dots within the portal vein branches, any clots in the hepatic or portal veins, and check gall bladder for any abnormality. Then, assess the bowel for the abdominal POCUS markers in 4 main abdominal quadrants as above. The colon is best assessed in the subhepatic area and lateral flanks; the colon can be identified by colonic haustra (looks like side-by-side balls from inside and outside). All images should be recorded as clips for offline detailed assessment. Color Doppler should assess all quadrants. Supplementary Fig. 3 shows the 4 abdominal quadrants that should be assessed by ultrasound; the right upper quadrant contains part of the right lobe of the liver, right hepatic flexure of the colon, gall bladder, pylorus, duodenum, and part of the jejunum. The right lower quadrant contains the ascending colon, but you need to slide the probe more posteriorly, cecum, ilium, and appendix. Left upper quadrant: splenic flexure, descending colon, but you need to slide the probe more posteriorly and jejunum. Left lower quadrant: mix of jejunum and ilium, descending colon, and sigmoid colon [9, 16, 20–22].

Triggers and phenotypes of gut injury

1. *Necrotizing enterocolitis*: This disease category has been used inaccurately in describing most cases with gut injury. NEC is a multifactorial and multi-triggered disease in preterm infants, with a peak incidence around corrected gestational age of 29–32 weeks; it can be triggered by delayed feeding or periods of nil per os (NPO), prolonged use of antibiotics, but prematurity is still the most significant association; the diagnosis is a combination of ultrasound markers, roentgenography, laboratory, and clinical markers. A minimum of 3 sonographic markers are necessary to differentiate NEC from other types of gut injury.
2. *Food protein-induced enterocolitis (FPIE):* It is poorly described in the neonatal population and commonly misdiagnosed and treated as NEC. Abdominal POCUS can differentiate both conditions, which is crucial as the management is different. FPIE is non-IgE-induced gut injury due to sensitivity to food protein, and it occurs more frequently with artificial formula but might occur with breast milk. Ultrasound in FPIE can be routine or with localized sonographic features, 1–2 markers commonly mild PVG, localized pneumatosis intestinalis, and hyperemia.
3. *Ischemic or hypoxic injury of the gut:* ischemic injury might be associated with severe hypoxic-ischemic encephalopathy (HIE) or associated with compromised oxygen delivery due to severe anemia, shock, congenital heart diseases with compromised systemic blood flow or severe hypoxemia, any of the 11 sonographic markers can be present, commonly bowel wall thinking, bowel wall echogenicity, bowel hyperemia or ischemia by CD.
4. *Compromised blood flow secondary to an anatomical twist of the gut*: it is familiar with malrotation, volvulus,

or intussusception; this type of injury needs urgent surgical intervention [23, 24].

Ultrasound findings

The 11 described ultrasound markers should be checked in each quadrant separately; localized NEC, restricted to 1–2 quadrants considered mild to moderate, can be recognized versus the generalized distribution of abnormal markers in 3–4 quadrants. It has been reported that the odds ratio for eventual need for surgery or death was highly significant in the presence of generalized thickening or thinning of bowel walls, generalized absent peristalsis, and generalized ischemia and was less significant in the presence of generalized hyperemia or generalized dilated loops. Bowel wall echogenicity has been reported in early-stage NEC before portal venous gas or perforation [8, 25–27]. Loss of peristalsis or hyperemia suggests bowel dysfunction, while mural thinning and absent perfusion suggest nonviable bowel; these ultrasound findings have been well correlated with pathological changes of the bowel in NEC [28].

1. Henoch–Schönlein Purpura
   Systemic vasculopathy may affect the bowels, kidneys, and other organs. Ultrasound is nonspecific but could be echogenic and cause a thickened bowel wall (particularly mucosa). Lumen may have echogenic content due to hemorrhage hyperemia [6, 29].
2. Bowel atresia
   Congenital occlusion of the bowel lumen. Abdominal POCUS findings are proximal fluid-filled distended bowel loops, sudden change in diameter at obstruction, and collapsed loops in distal parts. In high atresia (duodenum, jejunum), meconium may be present in distal parts. In distal atresia, the bowel is without meconium and is a narrow "empty bowel." Supplementary Fig. 4 is an ultrasound image at the RUQ with a microcolony secondary to the ileal atresia [30, 31].
3. Malrotation
   Atypical rotation or abnormal fixation of the gut, potentially with intermittent obstructive symptoms. Based on the incomplete fetal rotation of the foregut. Abdominal POCUS findings relate to mesenteric vessels at the mesenteric root, typically the mesenteric vein to the right of the superior mesenteric artery (in front of the aorta). The duodenum normally crosses retroperitoneally (behind mesenteric vessels).

<u>Ultrasound findings</u>

   The atypical position of mesenteric vessels is not diagnostic, as rotation anomalies may coexist with normal upper vessel position, and normal rotation may be present despite inverse vessel relation. The diagnosis is confirmed by demonstrating the abnormal position of duodenum-jejunal flexure (after filling stomach/duodenum) by the US or fluoroscopy [32–34].

4. Volvulus
   Twisted torsion of the upper small bowel around the mesenteric root, leading to vascular compromise and bowel ischemia with hemorrhagic infarction. It commonly presents as a surgical emergency in the first few weeks of life [32, 35].

<u>Ultrasound findings</u>

   Dilated, fluid-filled duodenum with abrupt disruption by a dilated structure, formed by a clockwise twisted dilated superior mesenteric vein curling around a more centrally positioned superior mesenteric artery; this is known as whirlpool sign (Supplementary Fig. 5). The 2-D image of the bowel depends on severity and duration: peritoneal fluid, thickened echogenic bowel wall with hemorrhage, and edema. The twisted bowel might be donut-shaped (Supplementary Fig. 6). The US is reliable; time is critical for surgical intervention once the whirlpool sign is seen. Emergency fluoroscopy should be performed in equivocal situations to establish the diagnosis [32].

5. Hirschsprung disease
   Neuronal intestinal dysplasia is due to a lack of colonic ganglion innervation and, consequently, a lack of peristalsis, leading to constipation and dilatation [35, 36]. They are presented on abdominal POCUS as impressive dilatation of stool-filled colon (megacolon). Diagnosis confirmed by biopsy and histology.
6. Meconium ileus
   Obstruction by inspissated meconium is commonly seen in preterm infants, after dehydration, or secondary to cystic fibrosis [35]. They are presented on abdominal POCUS as dilated small bowel loops with very echogenic content, typical for meconium.
7. Bowel adhesions and strictures:
   Usually, NEC complications present with recurrent vomiting and abdominal distension with progressing feeding. Presented on abdominal POCUS as dilated small bowel with sudden luminal change from dilated to very narrow bowel, bidirectional peristalsis (Supplementary Fig. 7).
8. Intussusception
   Telescopic invagination of a proximal bowel (intussuscepted) into a more distal loop (intussusceptions). Small bowel intussusception: it commonly happens in many conditions in the jejunum/ileum (gastroenteritis or hyperperistalsis) [2, 37]. Reliable for diagnosis, the invaginated loop can be assessed as a double-walled loop in both sagittal and axial sections with disrupted blood flow by CD (Supplementary Fig. 8).

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9. Appendicitis

   Inflammation of the appendix with risk of perforation, abscess, peritonitis, and fistulae [6, 38]. It is presented on abdominal POCUS focusing on the right lower quadrant; it can commonly be found when carefully searching around the cecal pole and looking at the lower margin of the liver. The appendix typically appears as a blind-ending tubular structure with a typical gut wall appearance, commonly without content, compressible and painless on probe palpation, and with a diameter of 3–6 mm in children. In inflammation, it appears to have an enlarged, enhanced wall structure (Supplementary Fig. 9).
10. Abdominal bleeding

   Ultrasound has higher sensitivity in assessing and localizing abdominal bleeding; abdominal ultrasound can be performed in any infant suspected of having anemic shock due to traumatic abdominal bleeding [6, 14, 39]. Clinical correction is essential for anechoic fluid collection around bowel loops or in the hepatorenal angle, as ultrasound does not differentiate hemorrhagic ascites from other fluids [6].

Renal and bladder ultrasound

Renal and bladder ultrasound (RBUS) is particularly valuable in the initial investigation of a child or neonate with oliguria/anuria.

Renal ultrasound

A low-frequency curvilinear probe is preferred for interrogating both the kidneys and the urinary bladder. However, a linear probe may be sufficient in infants and neonates, given the superficial positioning of the organs. The probe is placed in the right and left upper quadrants and a sagittal plane in the posterior axillary line, with the probe marker oriented cranially for right and left kidney evaluation [40]. The kidneys are retroperitoneal and require the probe to be directed posteriorly compared to the interrogation of the liver and spleen. The left kidney is usually higher and more posterior than the right kidney. The gain is adjusted to ensure the renal calyx appears anechoic (black). The kidney is divided into an outer cortex with an outer rim of tissue and columns of cortical tissue (hyperechoic) descending in between the medullary pyramids (anechoic) [41]. Urinary tract dilatation (UTD) can be seen with or without obstructive pathology of the urinary tract and is helpful in acute care settings to delineate pathology in patients presenting with oliguria/anuria and flank pain. A few examples of its clinical utility are described as follows [42].

1. UTD in an infant with oliguria/anuria, elevated creatinine, and blood urea nitrogen (BUN) with or without growth abnormalities should trigger a comprehensive radiological evaluation for congenital anomalies of the kidney and urinary tract (CAUKT).
2. UTD in a patient with anuria and a dilated urinary bladder may indicate lower urinary tract obstruction and requires bladder decompression with further interrogation for the causes of obstruction.
3. UTD in a patient with a neurogenic bladder and a previously normal RBUS indicates the need for more frequent bladder catheterizations to avoid urinary retention. Pre- and post-void bladder volume estimation can demonstrate incomplete bladder emptying.
4. UTD in a neonate/infant with a large urinary bladder should trigger consideration for a posterior urethral valve. The probe is placed in the suprapubic area, in a transverse plane, with the probe marker oriented toward the patient's right. It is then rotated 90 degrees into a longitudinal plane with a probe marker oriented cranially.

Urinary bladder

The probe is tilted anterior–posterior and side to side to image the bladder. Posterior acoustic enhancement through the bladder impedes visualization of free fluid behind the bladder and should be corrected by reducing the far field gain. The depth is adjusted to ensure the bladder is centered on the screen [43]. The bladder volume is calculated by measuring bladder length and width in the transverse plane and height in the longitudinal plane. One formula commonly used for assessing bladder volume in pediatric patients is length $\times$ width $\times$ height $\times$ 0.53 (correction factor for the shape of a pediatric bladder). Many ultrasound machines allow automated bladder–volume estimation. Ultrasound can visualize urinary catheters within the bladder (Supplementary Fig. 10) when a urinary catheter is in place. Still, the bladder is distended with fluid; either the catheter is obstructed or mispositioned—the presence of free fluid around the bladder in a patient with blunt abdominal trauma [44].

Conclusion

Point-of-care abdominal ultrasound is essential for diagnosing critical abdominal conditions in the NICU and PICU. Many abdominal ultrasound applications are relevant to assessing pathophysiological processes and guiding diagnostics for children. Targeted abdominal POCUS can be categorized into upper abdomens assessment, focusing on the liver, spleen, and stomach; lower abdomen assessment, focusing on gut assessment; and the third category, kidney and bladder assessment. As with all POCUS applications, the benefit of the technology depends on the context of its use. First, defining abdominal ultrasound applications relevant to practice depends on patient populations and the frequency of clinical presentations. Then, the technology requires provider skill development to a competency level.

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Authors' contributions YE and HS conceptualized the article. YE and HS conducted the background literature search. YE devised the manuscript, and both authors agreed to the formatting and contents.

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Code availability N/A.

Declarations

Ethical approval This article contains no studies with human participants or animals performed by authors.

Consent to participate N/A.

Consent for publication Yes.

Competing interests The authors declare no competing interests.

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