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Terminal Ileum and Mesenteric Vessels; Two Fundamental Gateways for Ultrasound Examination in Children with Acute Abdomen: A Review

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Abstract

Acute abdomen is a major cause of pediatric hospitalization that can represent a variety of conditions, some of which carrying a high risk of complications. Ultrasonography is usually the primary diagnostic method and provides quick aid in decision-making for the surgeons. It is cardinally important to follow a logical and comprehensive approach in ultrasound examination of children with acute abdomen, to reduce the chance of diagnostic pitfalls and prevent unnecessary delays in surgical interventions. However, there is still controversy regarding the best starting point and the optimal sequence of ultrasonography. In this review, we have summarized the most relevant literature regarding the ultrasonography of acute abdomen in the pediatric population by reviewing the most common causes of acute abdomen that require intervention and lead to complications in this age group. We conclude that ultrasound examination through a systematic approach focusing on terminal ileum and mesenteric vessels can aid timely diagnosis of the most important etiologies and expedite the management of critically ill patients.

Key Words: Acute Abdomen, Ileum, Mesenteric, Pediatric, Technique, Ultrasound.

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1- INTRODUCTION

Acute abdomen is a medical emergency characterized by a sudden onset of severe abdominal pain, which may or may not be accompanied by symptoms and/or signs of an abdominal organ involvement. Acute abdominal pain is a common pediatric complaint and accounts for around one in every ten visits to the emergency departments. Manifold conditions can cause acute abdomen among children depending on their age and sex; while most of them are mild and self-limiting in nature, some can be life-threatening and need urgent surgical intervention (1, 2).

Early and accurate diagnosis is vital for appropriate clinical decision-making and management of children with acute abdomen, in order to minimize the risk of morbidity. Imaging modalities, such as ultrasound and computed tomography (CT) are frequently used to diagnose patients with acute abdomen. Ultrasound is currently considered the primary imaging modality for acute abdomen in children by many clinicians, due to its low cost, fast and easy accessibility, and favorable safety profile (3, 4). Children are non-cooperative and their clinical findings are almost ambiguous (5).

In addition, ultrasonography assessment of entire abdomen is time consuming and mostly unnecessary. Thus, a logical and comprehensive approach to performing the diagnostic ultrasound exam in pediatric patients with acute abdominal pain is essential in order to visualize all the possible foci that can cause the pain (6-10). Herein, we review various causes of acute abdomen in children with special focus on anatomic locations, pathologic changes in each condition, and the technical points to find the respective ultrasound features. We aimed to provide useful insights into proper techniques for performing ultrasonography of acute abdomen in children to make an accurate and timely diagnosis.

2- MATERIALS AND METHODS

In this review, two independent researchers carried out an electronic search in online databases including Web of Science, Medline, Scopus, and EMBASE for the available literature published between January 2005 and February 2021. No language limits were applied. Different combinations of the following keywords and/or their alternatives were used: "acute abdomen", "ultrasound", "children", and "technique". The references of the retrieved records were hand-searched to identify additional relevant articles. Overall, 147 records were identified originally based on the initial search. Then, the title and abstract of all the retrieved articles were screened by two independent pediatric radiologists and 96 irrelevant studies were excluded. The remaining 51 studies underwent full-text review and those not complying with our criteria were excluded. Eventually, the screened records were checked by a third reviewer to reduce the chance of bias.

3- RESULTS

Finally, 33 studies on sonography in pediatric patients with acute abdomen were included in our review. The summarized findings of the included studies are categorized with respect to the pain location, the involved organ, and condition in the following paragraphs (**Table.1**).

Table-1: Sonographically detected causes of acute abdomen in children and most common location.

RLQ	Epigastria	Other area
Mesenteric adenitis	Mal-rotation	Constipation
Appendicitis	Volvulus (mid-gut)	Neurogenic bladder
Intussusception	Hypertrophic Pyloric Stenosis	Urinary tract infection
Meckel's diverticulitis	Pylorospasm	Nephrolithiasis
Henoch Schönlein purpura	Pancreatitis	Mittelschmerz
Omental infarct	Pancreas injury	Ovarian torsion
Typhlitis	Henoch Schönlein purpura	Hematocolpos
Crohn's disease	Duodenal hematoma	Colorectal polyp
Enterocolitis	Choledochal cyst	Spleen infarct
Cystic fibrosis	smallbowel obstruction	Testicular torsion
Necrotizing entero-colitis	Gastroenteritis	Testicular appendix torsion
GI tuberculosis	Peptic ulcer	Inguinal hernia
GI lymphoma	Intussusception (transverse colon)	Peritonitis
Ovarian torsion	Hepatitis	Sepsis
GI duplication cyst	Cholecystitis	--
Meconium ileus	Portal vein thrombosis	--
Small bowel obstruction	Cholelithiasis	--
Bezoar	Gallbladder Hydrops	--
Adhesion	Gastro-esophageal reflux	--
Mesenteric cyst	Diaphragmatic hernia	--
Psoas hematoma	--	--
Spiegel hernia	--	--

RLQ: Right lower quadrant.

3-1. Acute Right Lower Quadrant (RLQ) Abdominal Pain

Please see **Figures 1 and 2**.

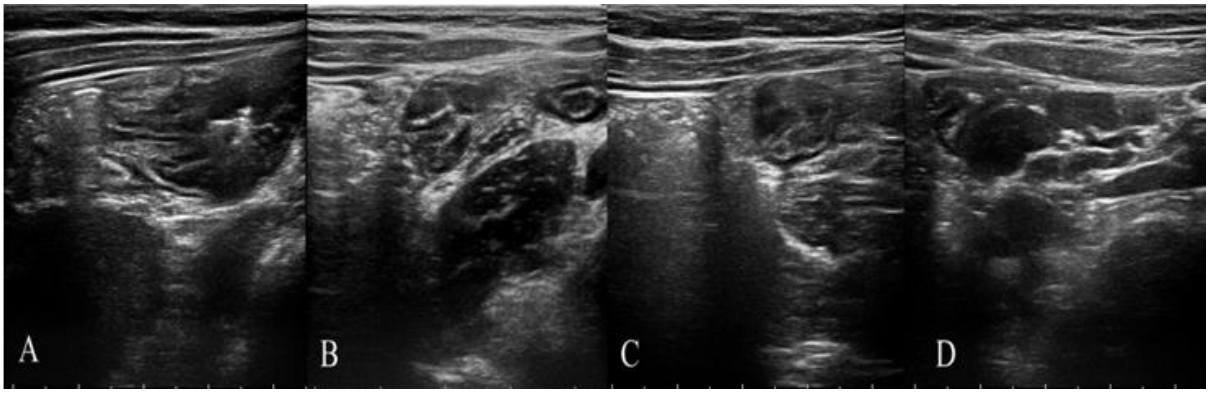

Fig.1: The sonographic feature of terminal ileum: **A)** Visibility of ileocecal valves and Peyer's patches as confluent hypoechoic nodules, **B)** Visibility of appendix in posterior-inferior aspect of terminal ileum, **C)** Specific appearance of terminal ileum between other bowels, and **D)** Terminal ileum and mesenteric lymphadenitis.

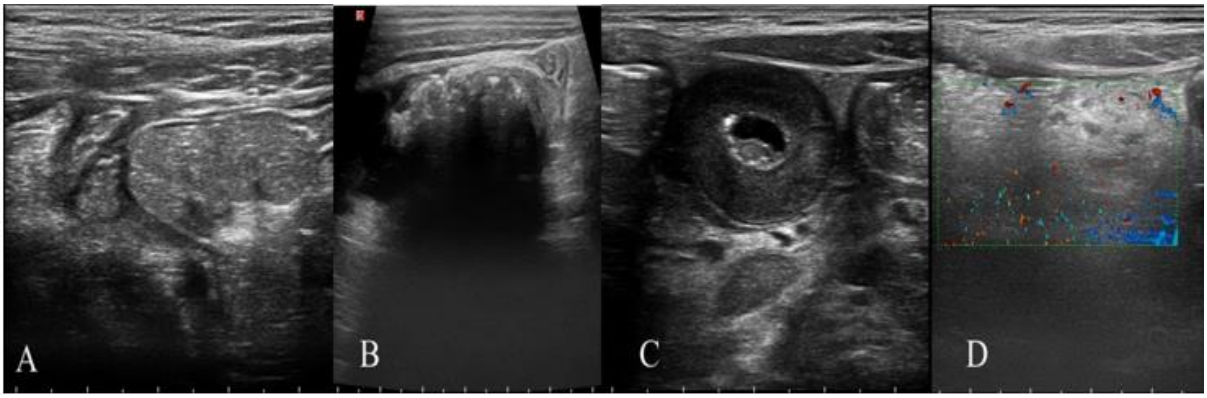

Fig.2: The sonographic appearance of some pathologies in RLQ area: **A)** Post-operative adhesion band, **B)** Bezoar in terminal ileum, **C)** Meckel's diverticulum, and **D)** Omental torsion.

3-1-1. Appendix

Appendicitis is the most common cause of acute abdomen requiring immediate surgical intervention. Diagnostic criteria are diameter of >6 mm, non-compressibility, wall thickness of >2 mm , hyperemia, and fluid-filled state of the appendix, as well as increased echogenicity of peri-appendicular fat and bowel adhesion (11). The appendix can be found at the infero-posterior border of the terminal ileum, medial to the ascending colon (12).

3-1-2. Mesentery

Mesenteric adenitis is often secondary to viral gastroenteritis and commonly mimics acute appendicitis. In ultrasonography, tender enlarged lymph nodes are observed with axis diameter of >6 mm. Presence of >4 lymph nodes in an ultrasound image (with any size) of RLQ or a >8 mm thickness of terminal ileum may indicate mesenteric adenitis (13). If massively enlarged or abnormal lymph nodes with no hilum are observed, other conditions such as tuberculosis and lymphoma should be considered.

Mesenteric cysts are observed as fluid-filled cystic structures with thin septa, most commonly located in the ileal mesentery (14).

Adhesion most commonly occurs in the ileum, causing obstruction (70.0%). Fibrotic bands are formed between bowel loops, mesentery, and omentum. These bands can be hypo- or hyper-echoic depending on their nature (15).

3-1-3. Omentum

Omental infarction, a rare condition in children that mimics acute appendicitis, is classified into two types of with and without torsion. If accompanied by torsion, it may be primarily caused by obesity or anatomical abnormalities or secondarily due to omental cysts, adhesion or tumors. Omental infarction without torsion is usually secondary to hypercoagulopathy, vasculitis, or pancreatitis (16). It appears as a hyperechoic, incompressible oval mass between the abdominal wall and bowels on ultrasound scan. Color Doppler scan shows hyper-vascularity proximal to the omentum, due to vascular cut-off in the infarcted omental mass (17, 18).

3-1-4. Cecum

Cecum is commonly involved in ***enterocolitis*** and ***intussusception***. ***Typhlitis*** is a necrotizing inflammation of the cecum and ascending colon, often in patients with malignancy or acquired immunodeficiency. It causes severe thickening and hyper-vascularity in the wall of cecum and right colon. In 40% of

patients, transverse and descending colon may also be involved. Thickness of the sub-mucosal layer leads to hyperechogenicity of the wall on ultrasound scan (11).

3-1-5. Ileum

Intussusception, caused by the invagination of an intestinal loop into the adjacent loop, is ileocolic in 80-95% of cases. Ultrasound scan commonly shows alternating echogenic and hypoechoic rings of intestinal wall, resembling a "target" or "doughnut". In longitudinal views, it has a pseudo-kidney appearance. The shortest diameter of ileocolic intussusception is often >20 mm. If intussusception occurs in children older than 2 years, we should think of a lead point. Ultrasonography is the modality of choice for etiological diagnosis, hydrostatic reduction, and follow-up of intussusception. Ileo-ileal or jejuno-jejunal intussusceptions are transient with short axis diameter of <20 mm and do not require special treatment (1, 11).

Meckel's diverticulitis stems from incomplete closure of omphalomesenteric duct and should be suspected in children with inflammatory signs in RLQ whose ultrasound scan shows normal appendix with a lesion attached to terminal ileum. The cause of inflammation in Meckel's diverticulum may be ectopic gastric mucous or foreign bodies. A thick-wall loop attached to the small bowel, with or without intra-luminal fluid and/or surrounding mesenteric inflammatory changes can be seen on ultrasound scan. Identification of normal appendix confirms the diagnosis (19).

The most common extra-nodal site of ***lymphoma*** is small intestine. Non-Hodgkin lymphoma, especially Burkitt's, mainly affects mesenteric lymph nodes of ileocecal region. Sonography shows focal asymmetrical wall thickening with low echogenicity with or without preserved layers (20).

Duplication cysts can occur anywhere from the esophagus to the rectum, but most are located in terminal ileum. In ultrasonography, they appear as fluid-filled cysts with gut signature sign (echogenic inner mucosal layer and hypoechoic muscular layer), which differentiates them from other intraperitoneal cysts (3, 6, 7, 21).

Abdominal tuberculosis (TB) is usually misdiagnosed because of non-specific symptoms such as fever, abdominal distention, and vomiting. Intestinal TB is a rare condition presented with bowel wall thickening, especially in the ileum and is associated with hepatosplenomegaly, ascites, mesenteric lymphadenopathy, and omental thickening (22).

Inflammatory bowel disease (IBD) is a common chronic gastrointestinal disease in children. Terminal ileum is involved first in Crohn's disease (CD), but all parts of the gastrointestinal tract may be involved. In early stages of CD, intestinal wall layers are preserved but the submucosa is thickened and hyperechoic. In advanced stages, wall layer stratification disappears due to ulcer formation. The thickened wall appears hypoechoic. It is fixed and aperistaltic because of fibro-fatty infiltration in adjacent mesentery. Color Doppler reveals increased vascularity in the inflamed segment (23, 24).

Necrotizing enterocolitis (NEC) commonly causes morbidity and mortality in premature infants due to intestinal necrosis and perforation. Abdominal X-ray can diagnose NEC only in presence of pneumatosis intestinalis and pneumoperitoneum. However, ultrasonography has advantages over X-ray in early stages and can detect bowel wall thickening with reduction of normal layering, bowel fixation, increased bowel wall vascularity, air in thickened walls

(pneumatosis intestinalis), portal venous pneumatosis, and abnormal presence of fluid in peritoneal cavity (25).

Small bowel obstruction (SBO) on ultrasound presents with sausage-shaped dilated fluid-filled loops, mucosal stack of coins appearance, and abnormal peristalsis ("to-and-fro" peristalsis in early stages, progressing to absent peristalsis) (26).

Meconium ileus, caused by obstruction of bowel with inspissated meconium, is usually observed in patients with cystic fibrosis.

Cystic fibrosis causes ileum distention with hyperechoic content and bowel wall thickening in children. In ultrasonography, the inspissated meconium pellets are observed in the lumen as uniform hypo- to hyper-echoic material with tubular or beaded shape, in ileocolic or recto-sigmoid regions. In patients with ***meconium peritonitis***, inspissated meconium pellets are observed in RLQ and free peritoneal fluid with debris is observed within a well-circumscribed wall (27).

Bezoar*s* mostly involve the stomach and ileum. The typical pattern of bezoar on ultrasound is hypoechoic intraluminal feces-like oval mass with marked acoustic shadows, surrounded by hyperechoic linear surfaces (28).

Gastroenteritis (GE) is a leading cause of morbidity and mortality in children with rotavirus being the most common cause. On ultrasound, GE commonly presents with dilation and wall-thickening of intestine, especially jejunum, with increased fluid content (29).

In bacterial ***enterocolitis***, ultrasound examination shows symmetrical bowel wall thickening and hyperemia, usually in terminal ileum and cecum. Enlarged mesenteric lymph nodes and echogenic fat may be seen. If the bowel wall layers are preserved, thickening in terminal ileum indicates infectious ileitis, enterocolitis, or early CD, while thickening in colon indicates infectious colitis with *Salmonella*, *Shigella*, or *E. coli*. If the layers are not preserved, thickening in terminal ileum indicates Henoch-Schonlein purpura, advanced CD, or TB ileitis, while thickening in colon indicates pseudo-membranous colitis and typhlitis (30).

3-1-6. Ovaries

Ovarian torsion is more common on the right side. In ultrasonography, the most important finding is unilateral increase in ovarian size. Color Doppler ultrasound may reveal peripheral follicular cysts and reduced blood flow. It rarely occurs in ovaries smaller than 5 cm in diameter (31).

3-1-7. Psoas muscles

Psoas hematoma occurs in children with coagulopathies, especially hemophilia (32). In acute phase, intramuscular collections are detected and in chronic phase, solid mass appearance with septa or calcification (33).

3-1-8. Abdominal wall

Spigelian hernia is an omental or bowel herniation lateral to rectus muscle. Inferior epigastric vessels should be identified and followed proximally up to where they pierce the deep rectus fascia. A defective Spigelian fascia at the Douglas' arcade level, can indicate the hernia, which can be better visualized using Valsalva maneuver (34).

3-2. Epigastric area

Please see **Figures 3 and 4**.

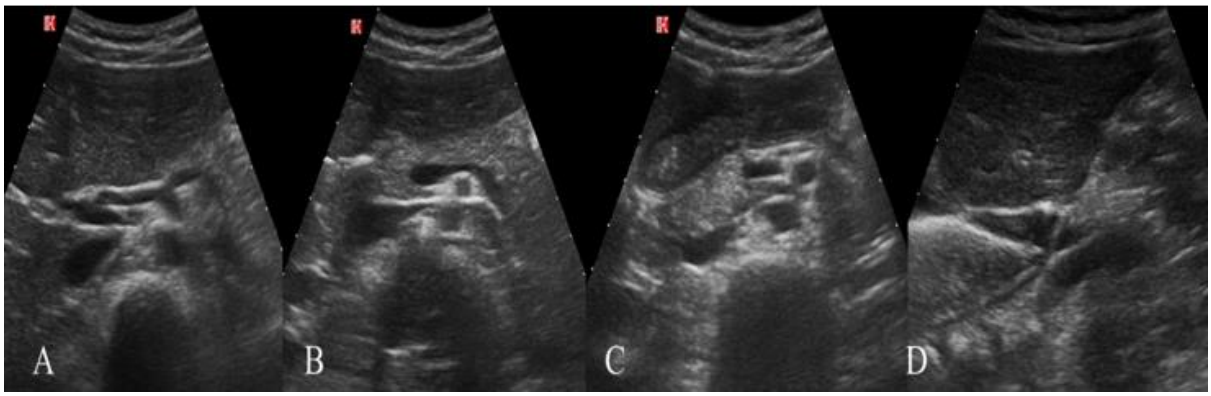

Fig.3: The sonographic appearance of epigastric area: **A)** Above of pancreas (celiac trunk and porta hepatis), **B)** Level of pancreas, **C)** Below of pancreas, and **D)** Sagittal view of gastro-esophageal junction.

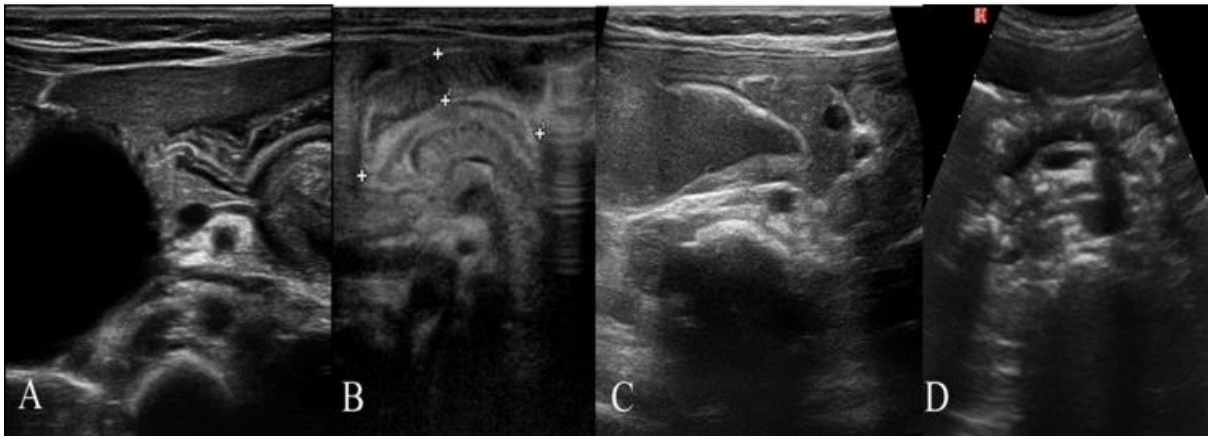

Fig.4: The sonographic appearance of some pathologies in epigastric area and their relations with mesenteric vessels: **A)** Cholodocal cyst, **B)** Hypertrophic pyloric stenosis, **C)** Duodenal obstruction, and **D)** chronic pancreatitis.

3-2-1. Mesenteric vessels

Malrotation is a congenital anatomical anomaly that may cause complications such as mid-gut volvulus or bowel obstruction. Early diagnosis is vital to save the patient from bowel necrosis and mortality. The main sonographic feature is inversion of superior mesenteric artery (SMA) and vein (SMV), in which SMV is oriented anterior or left of SMA. The sensitivity and specificity of ultrasound is 82.5% and 54.5% in this regard. Twirling of SMV with mesentery and duodenum around the SMA (whirlpool sign) is a reliable indicator for ***mid-gut volvulus***. Abnormal mesenteric pathway is seen in bowel obstruction, diaphragmatic hernia, abdominal masses, and malrotation (35).

Acute portal vein thrombosis is seen as hyperechoic shadows in venous system. In late stages, it is followed by portal hypertension, portal vein cavernoma, and peri-pancreatic varices (36).

3-2-2. Stomach

Hypertrophic pyloric stenosis (HPS) is characterized by thickening of the pyloric muscular layer >3 mm, abnormal elongation of pyloric canal >17 mm, and failure of relaxation in pyloric sphincter. It should be differentiated from ***pylorospasm***, in which thickening of muscular layer is transient and does not exceed >3 mm in diameter. To find the

pyloric canal, ultrasonography should be done after feeding, when the baby is comfortably lying supine and the transducer is on the epigastric region in transverse plane with minimal rotation. If the stomach is full of gas, the baby can be turned obliquely to the right downwards to fill the antrum with milk. If the stomach is much dilated with fluids, turning the baby obliquely to the left downwards helps to find the pylorus (37).

To assess ***gastroesophageal reflux***, ultrasonography is performed after usual feeding with the probe being in sub-xiphoid area, slightly angled to the left to visualize the distal esophagus and detect bright echoes from stomach to esophagus. Mucosal thickening >1.8 mm or esophageal wall thickness >3.5 mm in sonography is considered as esophagitis. Continuous gastroesophageal reflux suggests an associated hiatal hernia. ***Congenital diaphragmatic hernia*** presents with abnormal deviation of mesenteric vessels and visualization of intestine in the thorax (38).

3-2-3. Pancreas

Pancreatitis, defined as inflammation of the pancreas, is uncommon in children. Acute pancreatitis presents with pancreatic bulging, decreased echogenicity, ill-defined edges, and peri-pancreatic fluid on ultrasound scans. Chronic pancreatitis is rarer and associated with congenital disorders. In sonography, dilated pancreatic duct (30%), calcification (10%), or pseudocyst (10%) may appear (39).

Pancreatic injury due to rupture of pancreatic body is common during traffic accidents in children. It presents with partial rupture of pancreas or focal enlargement of pancreas and adjacent pseudocyst on ultrasound (39).

Pancreatic tumors are mostly secondary to other origins such as non-Hodgkin lymphoma. Neuro-endocrine tumors, mainly insulinoma, are the most common primary pancreatic tumors in children (39).

3-2-4. Duodenum

Duodenal obstruction occurs due to duodenal atresia and web, annular pancreas, Ladd's band, or pre-duodenal portal vein. Assessment of duodenum is necessary to detect dilated obstructions especially in a child with bilious vomiting (7, 11, 30).

Duodenal hematoma typically occurs due to traumatic intramural duodenal hemorrhage in children and tends to localize in C-loop of duodenum. In sonography, there is thickening or a mass along the duodenal wall, causing obstruction or narrowing of the lumen (7, 11, 30).

Henoch-Schonlein purpura (HSP) is the most common vasculitis in children. Gastrointestinal manifestations can be found in roughly 67% of patients. Initially, duodenum and jejunum are involved, but recurrent episodes extend to ileum. The most common finding is segmental and circumferential echogenic wall thickening without intussusception. HSP-related intussusceptions are mostly ileo-ileal (40).

Peptic ulcer disease (PUD) rarely causes abdominal pain in children. It appears with focal thickening of gastric or duodenal wall with an echogenic center on ultrasound (11, 30).

3-2-5. Liver, Gallbladder and Biliary duct

On ultrasound scan, ***Hepatitis*** presents with hepatomegaly, parenchymal hypoechogenicity (starry sky sign) or hyperechogenicity (like fatty liver grade I), hilar reactive lymphadenopathy, and collapsed gallbladder with thickened multi-layered wall (30, 39).

Gallbladder Hydrops, characterized by massive distention of the gallbladder

without wall thickening, usually occurs in children with Kawasaki disease (11, 39).

Cholecystitis appears with distended gallbladder, thickened gallbladder wall (>3 mm), Murphy's sign, peri-cholecystic fluid, with/without gallbladder stone (30, 39).

Choledochal cyst is a cystic dilation of the common bile duct that should be distinguished from other intra-peritoneal cysts by its connection to biliary tree (11, 39).

Cholelithiasis occurs in less than 2% of children, most of whom have underlying diseases. In contrast, gallbladder pseudo-lithiasis (echogenic sludge) occurs in 30-45% of children treated with ceftriaxone (11, 39, 41).

Inspissated bile syndrome, in which tumor-like sludge is seen within the lumen of biliary ducts, rarely causes jaundice in neonates. Hemolytic anemic and intestinal diseases cause cholelithiasis and inspissated bile in children (41).

3-3. Other areas

3-3-1. Pelvis

Perinatal torsioned ovarian cyst is a cystic lesion in female newborns with the specific ultrasound "triple-layer wall" pattern, comprises a uni-locular cyst containing fluid-debris level with a bright wrinkled inner layer, a non-uniform middle layer, and an echogenic outer epithelial surface (42).

In ***Constipation***, fecal retention appears as increased transverse diameter of the rectum and pressure effects on the posterior wall of bladder, causing neurogenic bladder with signs like irregular thickening of the bladder wall (43).

Mittelschmerz can cause mid-cycle lower abdominal pain in menarche phase of puberty. The only ultrasound finding is posterior cul-de-sac fluid and all other clinical and paraclinical findings are normal (44, 45).

Imperforated hymen is a rare congenital anomaly causing genital tract distention due to the retention of blood or mucosal discharge. Ultrasound scan reveals distention and blood accumulation in vagina (hematocolpos) or uterine cavity (hematometrocolpos) (44, 45).

3-3-2. Urinary Tract

Urinary tract infection (UTI) is common in children. In sonography, the most common findings are bladder-wall thickening and debris. Kidneys should be examined for possible complications in children with UTI (46).

Renal colic is not common in children, but calyceal microlithiasis is a common cause of restlessness in infants. Pelvi-calyceal or ureteric dilation can indirectly indicate urolithiasis. Kidney stones can be better visualized using ultrasonography compared to ureter stones (47).

3-3-3. Scrotum

Indirect ***inguinal hernia*** is the most common type of inguinal hernia in children, which occurs when the processus vaginalis remains patent. The presence of >6 mm bowel or omentum in the canal or opening of deep inguinal ring on ultrasound helps diagnose inguinal hernia. The deep inguinal ring is lateral and cephalic to the origin of inferior epigastric vessels. Following the hypoechoic spermatic cord from testis through the canal can help finding possible hernias (48). Incarcerated hernia presents with thickened wall of the herniated bowel loop, fluid in hernia sac, and intra-abdominal bowel dilatation on ultrasound, while strangulation appears with dilated akinetic loop without vascularity (49).

Whirlpool sign on ultrasound, characterized by twisting of the spermatic cord in the superficial inguinal ring or scrotum, directly indicates ***testicular***

torsion. The most specific signs of testicular torsion on ultrasound are testicular parenchymal heterogeneity, avascular pattern of testicle and epididymis, and mass-like configuration and displacement of epididymis If an enlarged epididymis with an avascular round mass adjacent to testis or epididymis is seen on ultrasound, it should raise the suspicious of ***torsion of the testicular appendage*** (50).

3-3-4. Spleen

Splenic infarct is mostly caused by hemoglobinopathies or hematologic malignancies in children. Ultrasound initially shows diffuse hypoechogenicity of splenic parenchyma with interspersed hyperechoic linear striation and no vascular flow. As it progresses, the spleen size decreases and borders shrink with capsular and parenchymal calcification (51).

3-3-5. Peritoneum

Primary ***peritonitis*** is rare and occurs without an intra-abdominal source. Secondary ***peritonitis*** occurs in the context of abscess or phlegmon in perforated appendicitis or other intra-abdominal pathologies. Ultrasound findings are loculated ascites with debris or septa, omental thickening, and dilated small-bowel loops with wall thickening (52).

3-3-6. Sepsis

Sepsis is a life-threatening organ dysfunction caused by a dysregulated host response to an infection. In patients with sepsis, ultrasound may show hepatosplenomegaly, ileus, and specific focal signs of infections pertaining to each organ (53).

5- CONCLUSION

Fortunately, the most common causes of acute abdomen in children have abnormal sonographic features that help timely and accurate diagnosis and prevention of complications. As mentioned in our review, common causes of acute abdomen are often located in RLQ and epigastric area. In RLQ, by finding the terminal ileum using its specific ultrasound features i.e., Peyer's patches (hypoechoic) in its wall and its attachment to the cecum (13), we can easily diagnose nearly all the pathologies in that region. By starting from the right kidney or ascending colon anterior to the kidney and moving the probe down while observing the medial side of ascending colon, we can find terminal ileum attached to the cecum.

If terminal ileum is used as the starting point, the cecum would be located lateral to it, mesentery above it, Meckel's diverticulum medial to it, appendix and right ovary below it, omentum anterior to it, and psoas muscle, right ureter and right iliac vessels posterior to it. In epigastric area, by finding the mesenteric vessels, using a graded compression ultrasound exam from the sub-xiphoid to the umbilical region, we can easily diagnose nearly all the pathologies in that region.

Displacement of air-filled loops during expiration and between two crying sounds, especially in relaxed children, simultaneous with probe compression helps better visualize the mesenteric vessels. Fortunately, causes of acute abdomen outside these two areas, such as hydronephrosis, urolithiasis, ovarian or testicular torsion, peritonitis, and splenic injury can be easily diagnosed in children due to their distinctive clinical and imaging features. Therefore, a systematic approach to sonography in children with acute abdomen, with the main focus being on terminal ileum and mesenteric vessels, can help diagnose the major and common causes with favorable accuracy and save rime to prevent diagnostic delay.

6- CONFLICT OF INTEREST: None.

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