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REVIEW

Abdominal ultrasonography of the pediatric gastrointestinal tract

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Abstract

Ultrasound is an invaluable imaging modality in the evaluation of pediatric gastrointestinal pathology; it can provide real-time evaluation of the bowel without the need for sedation or intravenous contrast. Recent improvements in ultrasound technique can be utilized to improve detection of bowel pathology in children: Higher resolution probes, color Doppler, harmonic and panoramic imaging are excellent tools in this setting. Graded compression and cine clips provide dynamic information and oral and intravenous contrast agents aid in detection of bowel wall pathology. Ultrasound of the bowel in children is typically a targeted exam; common indications include evaluation for appendicitis, pyloric stenosis and intussusception. Bowel abnormalities that are detected prenatally can be evaluated after birth with ultrasound. Likewise, acquired conditions such as bowel hematoma, bowel infections and hernias can be detected with ultrasound. Rare bowel neoplasms, vascular disorders and foreign bodies may first be detected with sonography, as well. At some centers, comprehensive exams of the gastrointestinal tract are performed on children with inflammatory bowel disease and celiac disease to evaluate for disease activity or to confirm the diagnosis. The goal of this article is to review up-to-date imaging techniques, normal sonographic anatomy, and characteristic sonographic features of common and uncommon disorders affecting the gastrointestinal tract in children.

Key words: Ultrasound; Pediatric; Gastrointestinal tract; Bowel; Enteritis

Core tip: Ultrasound is increasingly utilized to evaluate gastrointestinal disorders in children. Recent improvements in ultrasound technique allow detailed evaluation of bowel pathology. We present a comprehensive review of bowel pathology in children with emphasis on ultrasonographic technique and findings. This review will describe the variety of sonographic techniques available to optimize

assessment of bowel disease and sonographic features of normal bowel will be described. Common and uncommon disorders of bowel in children will include congenital, acquired, inflammatory and neoplastic processes.

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INTRODUCTION

Ultrasound is an ideal imaging modality in the pediatric population because it is a real-time, non-invasive, relatively low cost examination without ionizing radiation that requires no sedation. Several recent reviews have emphasized the utility of ultrasound in the evaluation of pediatric bowel pathology[1-3]. Ultrasound of the bowel in children is typically a targeted examination, designed to answer a specific question, and common indications include evaluation for appendicitis, intussusception, and pyloric stenosis. Other focused examinations include evaluation of congenital abnormalities detected prenatally, confirmation of suspected hernia, and problem solving in the patient with necrotizing enterocolitis (NEC). Unsuspected bowel abnormalities may be found during screening for non-specific abdominal pain, including foreign body, tumor, infection, or bowel hematoma. A more comprehensive examination of the entire bowel is used at some centers to evaluate inflammatory bowel disease (IBD) and celiac disease in children.

IMAGING TECHNIQUE

Ultrasound examinations are typically performed with the patient supine without any preparation. Recent improvements in ultrasound technology, including high-resolution linear probes (12-15 MHz) and harmonic and panoramic imaging, improve image quality[3,4]. Color Doppler evaluation can detect increased perfusion in inflamed loops of bowel. Ultrasound cine clips document bowel motility, and graded compression assesses compressibility and improves resolution by displacing air from the bowel lumen. Oral administration of non-carbonated fluid 30 min prior to the examination will reduce air in the bowel[4]. Other promising newer techniques include oral contrast agents, such as iso-osmolar polyethylene glycol (PEG), to improve bowel distension, referred to as small-intestine contrast enhanced ultrasound[5]. Intravenous contrast agents are not approved for children but are increasingly utilized off-label, particularly in pediatric patients with IBD[4,6]. The pattern of contrast enhancement has been useful to assess disease activity and adjacent inflammatory changes[7]. Lastly, bowel elastography may have applications in the assessment of bowel wall edema and/or fibrosis, particularly in IBD[8].

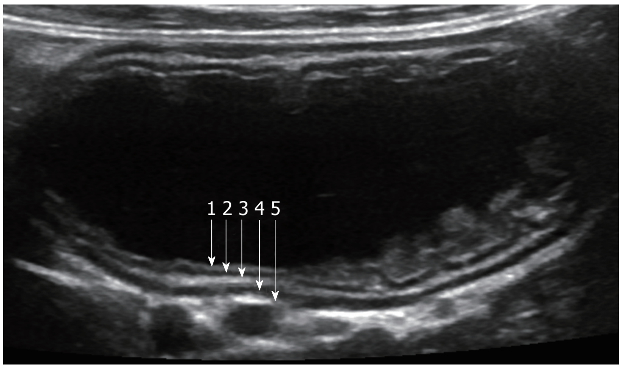

Figure 1 Normal small bowel. Ultrasound image of small bowel obtained after ingestion of water, using high-resolution linear probe. Five wall layers include: 1-mucosal interface with lumen (hyperechoic), 2-mucosa (hypoechoic), 3-submucosa (hyperechoic), 4-muscularis (hypoechoic), and 5-serosa (hyperechoic).

NORMAL ANATOMY

Normal bowel loops have a stratified pattern on high-resolution ultrasound with the following 5 layers: Mucosal interface with lumen (hyperechoic), mucosa (hypoechoic), submucosa (hyperechoic), muscularis (hypoechoic) and serosa (hyperechoic) (Figure 1). Typically, however, only 2 layers are visible on ultrasound, including an inner hyperechoic layer and outer hypoechoic layer. In normal children, small bowel loops are compressible, show minimal vascularity, and have wall thickness < 2.5 mm[9]. Jejunal loops have more folds and peristalse more than ileum, and the colon contains more air, fewer folds, and wall thickness is < 2 mm[9].

SPECTRUM OF PEDIATRIC GASTROINTESTINAL DISORDERS

Congenital abnormalities

Intestinal malrotation: Intestinal malrotation occurs when the midgut does not undergo its expected rotation around the axis of the superior mesenteric artery during fetal development[10]. Symptoms of malrotation are most commonly caused by volvulus or obstructing peritoneal bands, which typically manifest during the first year of life[10]. Ultrasound may be performed in the vomiting infant to evaluate for pyloric stenosis and malrotation may be an unexpected finding (Figure 2). On ultrasound, there is usually reversal of the position of the superior mesenteric artery (SMA) and superior mesenteric vein (SMV). When volvulus is present, transverse sonographic images show dilated fluid-filled duodenum with alternating rings of low and high echogenicity at the base of the mesentery ("concentric circle sign")[11]. Color Doppler ultrasound can reveal a spiral appearance of the mesenteric vessels, termed

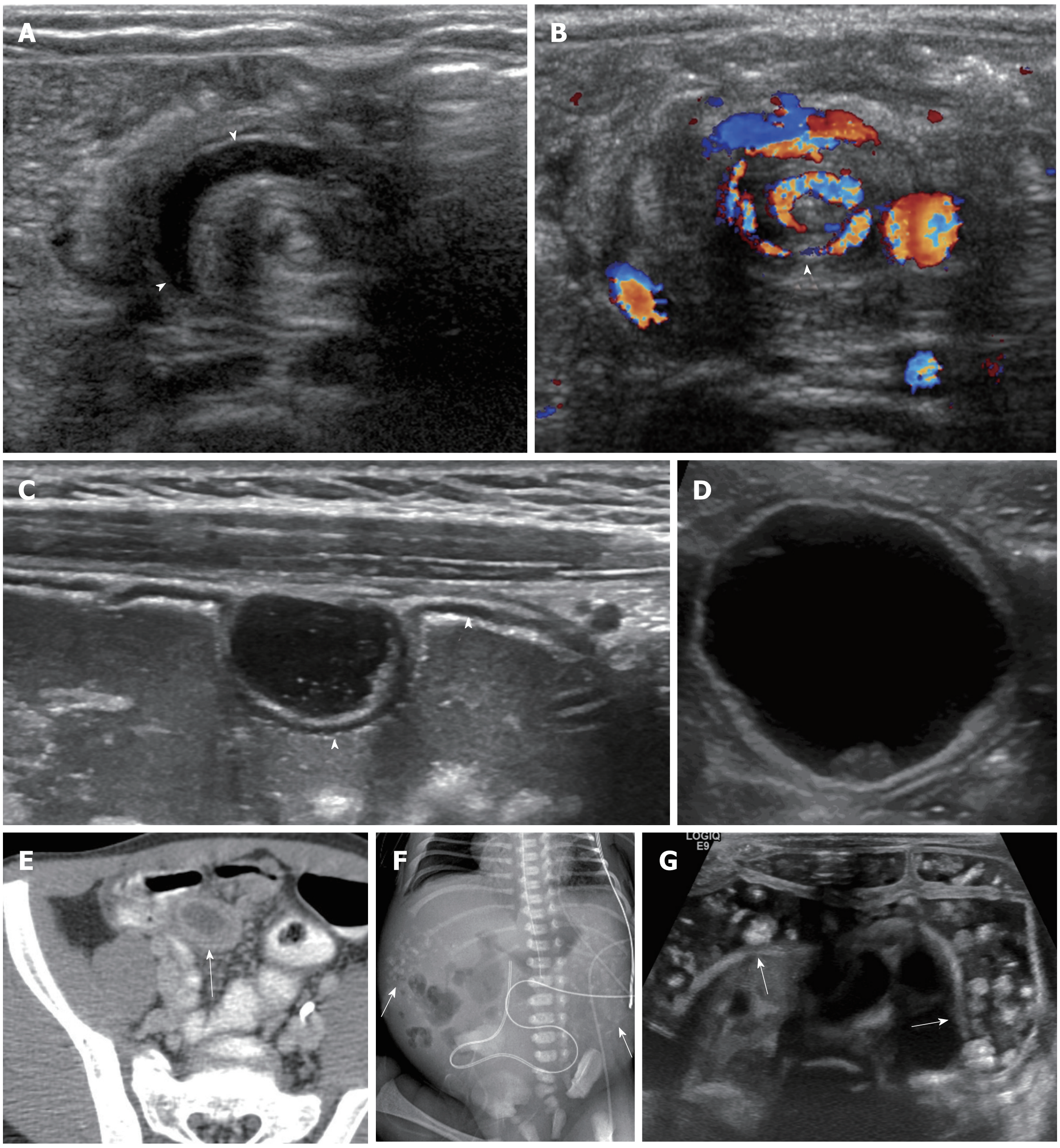

Figure 2 Congenital bowel abnormalities. A, B: Malrotation. Unsuspected finding in an 8-wk-old vomiting infant being evaluated for pyloric stenosis. Transverse midline images show alternating rings of high and low echogenicity with "whirlpool" sign on grayscale (A) and color Doppler (B) images (arrowheads); C: Gastric duplication cyst. Five-year-old girl with enteric duplication cyst near the gastroesophageal junction detected prenatally (not shown). A second cyst was noted incidentally in the anterior wall of the stomach on subsequent imaging. The cyst demonstrates bowel signature (2 layers), and shares its hypoechoic, muscularis propria layer with the anterior gastric wall (arrowheads); D, E: Meckel diverticulum. Four-year-old with abdominal pain. Ultrasound shows a cyst with bowel signature (D). Computed tomography abdomen is shown for correlation (E, arrow); F, G: Rectourinary fistula with enteroliths. Newborn with abdominal calcifications on radiograph (F, arrows); confirmed to be enteroliths on ultrasound (G, arrows). The fistula was later confirmed with contrast enema (not shown).

the" whirlpool sign"[10,11]. There may be dilatation of the distal SMV[12]. Some authors advocate ultrasound evaluation of the 3rd portion of the duodenum to confirm its location behind the SMA to exclude malrotation, however, this has not found general application[13].

Gastrointestinal duplication cyst: Gastrointestinal duplication cyst is an additional segment of fetal gut that can occur from the esophagus to the rectum, most commonly at the terminal ileum[14-17]. Gastrointestinal duplication cysts demonstrate a connection with the gastrointestinal (GI) tract by a common wall of serous and muscle membrane, usually without luminal communication, and may contain ectopic pancreatic tissue[15-17]. Complications include ulceration, hemorrhage, perforation, and inflammation[15].

On ultrasound, gastrointestinal duplication cysts are fluid-filled structures, typically with a central anechoic component[15]. The mucosal and submuscosal layers are echogenic, and the shared muscularis layer is hypoechoic[15,17] (Figure 2C). Rarely, other abdominal cysts may have a "pseudo gut signature", including mesenteric cysts and teratomas; high-resolution transducers should delineate multiple bowel wall layers in true duplication cysts[18,19]. Further characterization can be performed with Tc-99m nuclear scintigraphy, which targets parietal cells in gastric mucosa[15].

Meckel diverticulum: Meckel diverticulum is the most common malformation of the small bowel, which results from partial or complete failure of involution of the omphalomesenteric duct[10]. It is a true diverticulum that contains all layers of the intestinal wall, and it may contain heterotopic gastric and pancreatic mucosa[10] (Figure 2). It is seen in 0.3%-3% of the population, and approximately 2%-4% of affected patients become symptomatic[10]. Complications include bleeding, small bowel obstruction, inflammation (Meckel diverticulitis), and neoplasm[10]. Sonographic imaging findings are reflective of the specific complication, and can include wall thickening, intussusception, and associated mass[10]. A surrounding hyperemic and echogenic layer is suggestive of associated perforation[20].

Annular pancreas: Annular pancreas is a rare congenital abnormality that can present in childhood with duodenal obstruction or pancreatitis[21]. In the vomiting infant, ultrasound may show narrowing of the 2nd portion of the duodenum, with a surrounding ring of pancreatic tissue. The anomalous branch of the pancreatic duct may be seen on ultrasound coursing obliquely and to the right, anterior to the duodenum[21,22].

Rectourinary fistula: Rectovesical or rectourethral fistula typically occurs in patients with an anorectal malformation such as imperforate anus[23,24]. Neonates with rectourinary fistula may develop enterolithiasis due to mixing of meconium and urine[23,24]. Enterolithiasis appears as calcifications on radiographs, and can be further evaluated with high-frequency, high-resolution real time ultrasound to confirm intraluminal location and distinguish this entity from meconium peritonitis[24] (Figure 2). Enterolithiasis can also be seen in other cases of intestinal obstruction such as ileal stenosis, jejunal atresia, and functional obstruction of the ileum[23,24]. Transperineal ultrasonography can also be performed in patients with anal atresia to identify the internal fistula[25].

Acquired disorders

Intussusception: Intussusception is the most common cause of bowel obstruction in children, and it typically occurs between ages 6 mo and 2 years. The most common type is ileocolic, and most cases are idiopathic. Ultrasound is critical for a prompt and accurate diagnosis of intussusception, and has nearly 100% sensitivity for detection[26]. Imaging features of intussusception are characteristic, described as the "pseudokidney" or "donut sign", with alternating hyperechoic and hypoechoic concentric layers. Fluid trapped between layers of the intussusception and absence of color flow may reflect decreased likelihood of reduction and bowel ischemia. Lead points are typically seen in older children and may be detected by ultrasound, including Meckel diverticulum, duplication cyst, juvenile polyp, and lymphoma (Figure 3A). Ileo-ileocolic intussusception is associated with decreased reduction rate and increased morbidity[27].

It is critical to differentiate ileocolic intussusception from small bowel-small bowel intussusception, as the latter are typically managed conservatively and air reduction is not indicated. A recent review noted that larger intussusception diameter and the presence of lymph nodes within the intussusception favored ileocolic intussusception[28]. In one review, mean AP diameter of ileocolic intussusception was 2.53 cm compared to 1.38 cm of small bowel intussusception[29]. Small bowel intussusceptions have very little fat centrally and occur in older children with bowel disorders such as Henoch-Schonlein Purpura, Crohn disease, and celiac sprue; they are also seen in post-operative patients and in patients with small bowel mass acting as a lead point. Small bowel intussusception length greater than 3.5 cm is a strong predictor of need for surgical intervention[30]. However, most small bowel intussusceptions are idiopathic and transient[31].

Hypertrophic pyloric stenosis: Hypertrophic pyloric stenosis (HPS) is an idiopathic cause of gastric outlet obstruction, which typically occurs during the 2nd to 7th week of life and is more common in boys than girls[1,32,33]. Ultrasound is performed in supine and right lateral decubitus positions with a high-frequency linear-array transducer (12-5 MHz). If sufficient fluid is not present within the stomach to outline the antrum and pylorus, 1-2 ounces of sugar water can be given orally. Axial sonographic images demonstrate the "donut sign", characterized by a rim of thickened muscle and an echogenic center of mucosa and submucosa[32]. In longitudinal plane, the pylorus remains closed and no fluid passes into the duodenum[32,34]. The mucosa can protrude into the distended distal gastric antrum, creating the "nipple sign"[32,34].

Current guidelines for ultrasound diagnosis of HPS are pyloric muscle thickness > 3 mm, pyloric length > 15 mm, pyloric diameter > 11 mm, and pyloric volume > 12 mL[1,35]. Patient age and weight correlate with pyloric muscle wall thickness, and a lower ultrasound threshold for diagnosis should be used in smaller neonates[36,37]. Imaging the pylorus over time allows the differentiation of HPS and pylorospasm, the latter being a transient phenomenon[3]. Follow-up can be utilized in equivocal cases[3].

Inguinal hernia: Ultrasound is 95.5% accurate for detecting inguinal hernias in boys[38]. The internal ring is measured at rest and with straining (standing, crying, coughing, or bearing down)[38]. In boys of any age, inguinal canal diameter > 4 mm at the internal ring (width of the spermatic cord) is 95% accurate in diagnosing inguinal hernia at surgery[39,40]. Fluid in the processus vaginalis or bowel loops/other peritoneal structures within the inguinal canal are also diagnostic of hernia[39,41]. Contralateral hernias occur in up to

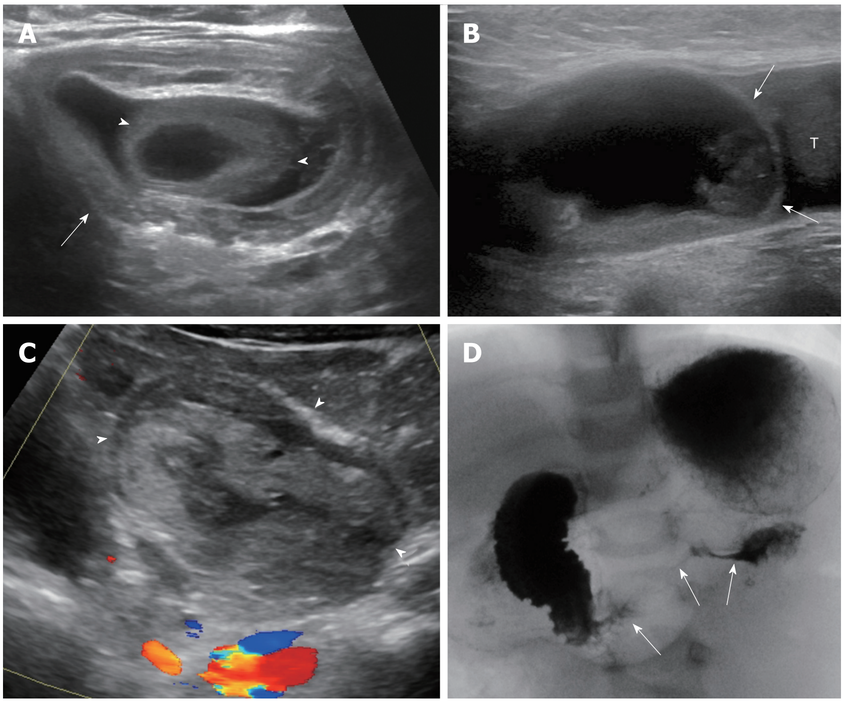

Figure 3 Acquired bowel disorders. A: Ileocolic intussusception with Meckel diverticulum as lead point. Six-month-old with small bowel obstruction on radiograph (not shown) and intussusception (arrow) demonstrated on ultrasound with lead point (arrowheads); B: Incarcerated inguinal hernia. Two-year-old boy with abdominal pain and left groin mass. Sagittal image of the left inguinal region show a cystic structure that did not clearly communicate with abdominal bowel loops (B, arrows; T = testicle). Testicular edema was also noted (not shown); C, D: Duodenal hematoma secondary to child abuse. One-year-old with abdominal pain and distension. Sagittal midline ultrasound image shows a complex mass in the expected location of the duodenum (C, arrowheads). Upper gastrointestinal series confirmed duodenal narrowing (D, arrows). Abuse was later confirmed.

22.4% of patients, and bilateral ultrasonography can guide pre-operative planning[42].

Indirect hernias, the most common type of inguinal hernia in children, occur superolateral to the epigastric vessels, direct hernias occur inferomedial to the epigastric vessels, and femoral hernias occur below the inguinal ligament[38,43]. In the case of herniated bowel loops, ultrasound is used to assess bowel peristalsis, wall thickness, and vascularity. Incarcerated hernias may not show clear continuity with abdominal bowel loops (Figure 3B). Inguinal hernias can compress gonadal vessels and cause testicular hypovascularity and enlargement on ultrasound[44].

Hiatal hernia and gastroesophageal reflux disease: To evaluate for hiatal hernia and gastroesophageal reflux disease (GERD) with ultrasound, the transducer is placed inferior to the xiphoid process in sagittal plane and directed cranially. The diameter of the esophageal hiatus is measured in transverse plane using the liver as an acoustic window[45]. Esophageal hiatal diameters have been shown to be greater in patients with hiatal hernias compared to control subjects[45]. Absence of paraesophageal fat may be a more reliable indicator than hiatal widening because it is not affected by age, obesity, or BMI[46].

Although ultrasound is not recommended for evaluation of GERD, it can be used in cases of unusual posturing or aspiration, because episodes of retrograde passage of gastric contents detected on ultrasound can be correlated temporally with symptoms[47,48]. It can be helpful to detect GERD in an infant with suspected HPS and a normal pylorus. A short intra-abdominal segment of esophagus and/or a wide esophageal angle have been shown to be associated with reflux[48,49].

Duodenal intramural hematoma*:* Duodenal hematomas in children are typically post-traumatic. If there is no history of trauma, there is a high association with child abuse and additional imaging is warranted (Figure 3). Hematomas may also result from endoscopic biopsy of the duodenum or in children with bleeding disorders[50-52]. Once identified, the hematoma can persist for at least two weeks, typically resolving by 6 wk. On ultrasound, duodenal intramural hematomas appear as a heterogeneous, nonvascularized mass along the course of the duodenum, which can obstruct the duodenal lumen and/or the common bile duct[50-52]. During resolution, the hematoma becomes cystic. Differential diagnostic considerations include duodenal duplication, abscess, pancreatic pseudocyst, or tumor. Ultrasound is also useful for serial follow-up to document either resolution or worsening obstruction requiring intervention.

Infectious and inflammatory disorders

Appendicitis: Appendicitis is one of the most common surgical emergencies in children, and delay in diagnosis can result in morbidity from an associated complication such as appendiceal rupture or bowel obstruction[53,54]. Non-operative management of acute uncomplicated appendicitis in children is also used in select cases[55,56]. Symptoms of acute appendicitis are variable and can include periumbilical and/or right lower quadrant pain, anorexia, nausea, fever, and leukocytosis[54,57].

Ultrasound is the first imaging choice for suspected appendicitis at most centers[53,57]. Both grayscale and color Doppler imaging are utilized with 5-MHz curved, 9-MHz linear, or 15-MHz linear transducers[58]. Ultrasound is 88% sensitive and 94% specific for the diagnosis of acute appendicitis[59]. Diagnostic criteria for appendicitis include appendiceal diameter > 6 mm (outer wall to outer wall) and associated evidence of inflammation including appendiceal non-compressibility, wall thickening > 2 mm or hyperemia, fluid-filled appendix, increased echogenicity of periappendiceal fat, and/or presence of periappendiceal fluid[58]. Ultrasound diagnosis of perforated appendicitis is made by the presence of marked inflammatory changes in the right lower quadrant with or without visualization of the appendix, an appendicolith without visualization of the appendix, echogenic free fluid, or a fluid collection indicating peritonitis or abscess[58].

Equivocal findings on ultrasound are associated with surgical appendicitis in 12.5%-50% of cases[58,59]. Increasing the size threshold to 7.5-8 mm in equivocal cases has been shown to increase specificity and accuracy[58,60]. Children at low risk for appendicitis with equivocal ultrasound findings are amenable to observation and reassessment[59]. When the patient's white blood cell count is < 11.0 × 10^9/L, a non-diagnostic ultrasound or non-visualized appendix on ultrasound are associated with negative predictive values of 95.59% and 96.99%, respectively[61].

Necrotizing enterocolitis: Necrotizing enterocolitis (NEC) is a common cause of morbidity and mortality in premature infants. In NEC, there is bowel necrosis of unknown etiology; mucosal integrity may be compromised, leading to pneumatosis and portal venous gas[62]. The clinical presentation ranges from feeding intolerance or abdominal distension to fulminant shock and death[63]. Indications for surgery in NEC are pneumoperitoneum and deterioration with medical treatment alone. Patients with bowel necrosis may also benefit from surgery, and ultrasound has been shown to be 100% sensitive and 95.4% specific identifying necrosis[63].

Radiographs are the primary imaging tool when evaluating for NEC; ultrasound can be used as a problem-solving tool in select cases when surgery is considered. For diagnosis of NEC, ultrasound evaluates for (1) wall hyperechogenicity (greater than anterior abdominal wall musculature); (2) wall thickening (≥ 3 mm); (3) wall thinning (< 1 mm); (4) intramural gas; (5) hypervascularity; (6) hypovascularity; and (7) aperistalsis[63-66]. The peritoneal cavity is evaluated for ascites and fluid collections, and the portal venous system is evaluated for gas (Figure 4). Small amounts of free air may be more easily seen with ultrasound than with radiography[66]. In one recent review, poor outcome was associated with dilated and fluid-filled bowel, echogenic free fluid, focal fluid collections, increased bowel wall echogenicity, and increased bowel wall thickness[66]. Free intraperitoneal air and focal fluid collection predicted poor outcome in another series[64].

Infectious enteritis/typhlitis: Bacterial enterocolitis may be caused by a variety of pathogens, including *Salmonella, Shigella, E. Coli* and *Campylobacter*. Ultrasound findings include bowel wall thickening, hyperechogenicity, and hyperemia, usually in the terminal ileum and cecum[67] (Figure 4C). Adjacent lymph nodes, free fluid, and echogenic mesenteric fat are common. Viral gastroenteritis usually does not demonstrate bowel wall thickening, though ascites and enlarged nodes may be present[67]. Intestinal tuberculosis may show bowel wall thickening, typically with associated hepatosplenomegaly and omental thickening; findings may mimic Crohn disease[68,69]. Typhlitis, or inflammation of the cecum, is more frequently seen in immunocompromised patients and is characterized by marked thickening and hypervascularity; increased thickness of the wall may correlate with a worse prognosis[70,71]. Ascariasis infection can be detected with ultrasound; worms are mobile, tubular hypoechoic intraluminal structures with echogenic walls (Figure 4D). Parallel echogenic line or lines within the worm represent the digestive tract[72].

Allergic gastroenterocolitis: Allergic proctocolitis from cow's milk allergy is the main cause of rectal bleeding in infants[73,74]. It occurs from early exposure to heterologous proteins such as cow's milk or cow's milk proteins derived from maternal breastfeeding. Ultrasound shows colitis with bowel wall thickening (≥ 3 mm) and increased vascularity, especially in the descending and sigmoid colon[73]. Increased Doppler vascularity is measured as 5 or more vessels in the bowel wall in a segment of approximately 2 cm^2[73]. The most pronounced thickening is visualized in the mucosa, and the highest number of vessels is seen in the submucosa. In some cases bowel layers are not well defined. Allergic gastritis may mimic HPS on ultrasound; in allergic gastritis the mucosal and submucosal layers are thickened, while in HPS only the muscular layer is thickened[75] (Figure 4). In some patients, allergic gastritis and HPS may coexist[76].

Inflammatory bowel disease: Ultrasound has been found to have a high correlation with MR imaging findings in pediatric small bowel Crohn disease[77]. Ultrasound demonstrates mural thickening with loss of wall stratification, hyperemia, and decreased peristalsis. Fluid collections, fistulae, lymph nodes, and mesenteric inflammation can also be seen[7,9,78] (Figure 4). Strictures

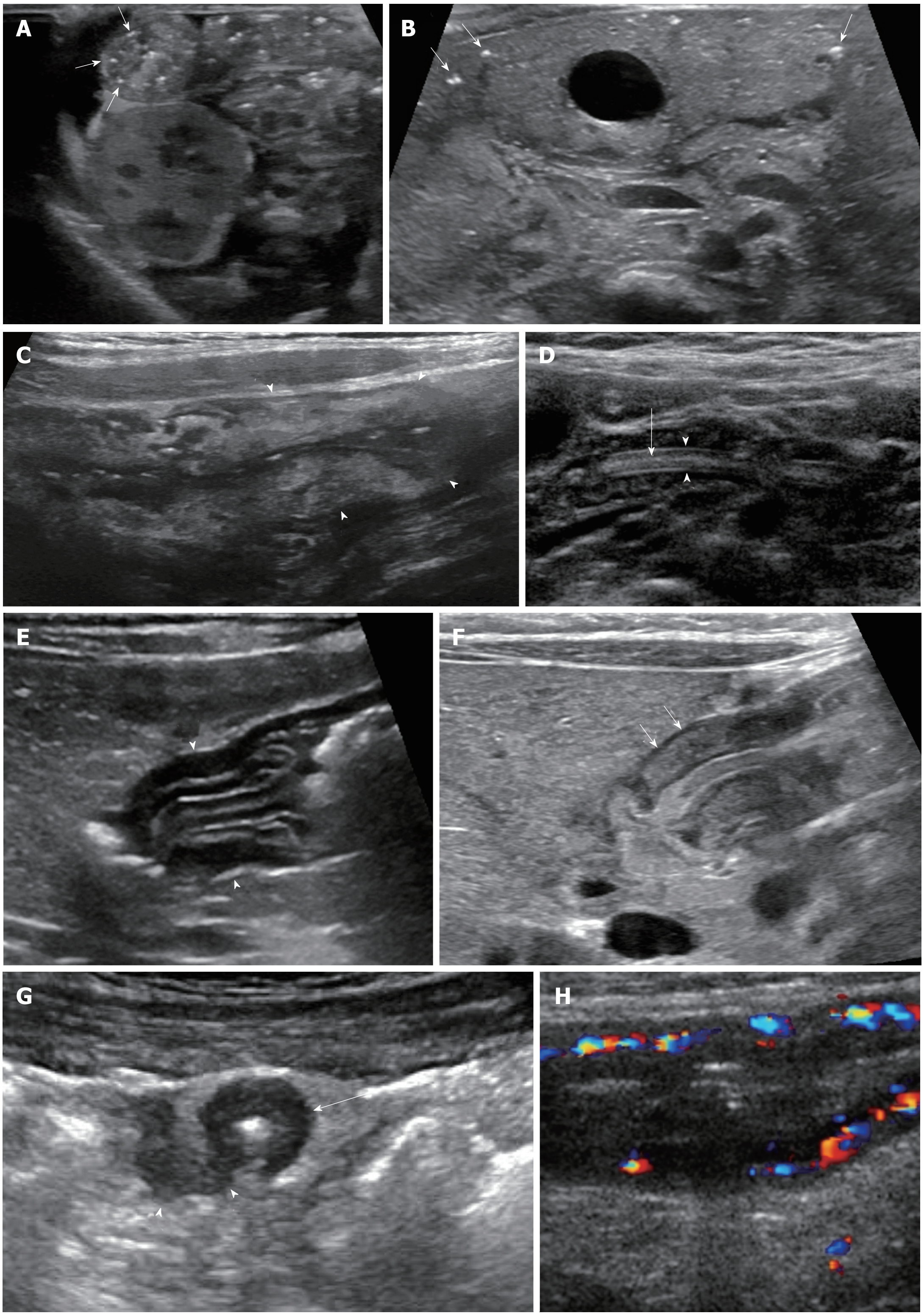

Figure 4 Infectious and inflammatory bowel disorders. A, B: Necrotizing enterocolitis. Targeted ultrasound of the abdomen in a premature infant shows bowel wall thickening and echogenic intramural air (A, arrows). This corresponded to an area of pneumatosis on recent radiograph (not shown). Transverse image of the liver show punctate, echogenic foci in the liver periphery, consistent with portal venous gas; the foci of air are too small to cause posterior artifact (B, arrows); C: Campylobacter enterocolitis. Ten-year-old with fever and abdominal pain with suspected appendicitis. Sagittal right lower quadrant ultrasound image shows mural thickening and increased echogenicity in the cecum and ascending colon (arrowheads). Stool cultures confirmed the diagnosis; D: Ascariasis. Two-year-old boy from Africa with abdominal pain. Ultrasound of the small bowel shows a mobile, hypoechoic, tubular structure with echogenic walls (arrowheads) and central linear echogenicity (arrow). Worms were later identified in the stool; E, F: Allergic (eosinophilic) gastritis. Ultrasound of the stomach in a 3-mo-old infant with persistent vomiting shows mural thickening in the antrum with prominent mucosal and submucosal layers (E, arrowheads). Endoscopy confirmed the diagnosis. Ultrasound of child with pyloric stenosis (F), for comparison, shows thickening primarily of the muscularis layer (arrows); G, H: Crohn disease. Transverse image of the right lower quadrant in a 15-year-old girl with longstanding Crohn disease shows a thick-walled ileum in cross section (arrow) with a fistula extending posterolaterally (arrowheads), confirmed with MRI (not shown) (G, arrows). Color Doppler ultrasound image in another patient with Crohn disease demonstrates mural thickening and hyperemia of the inflamed terminal ileum (H).

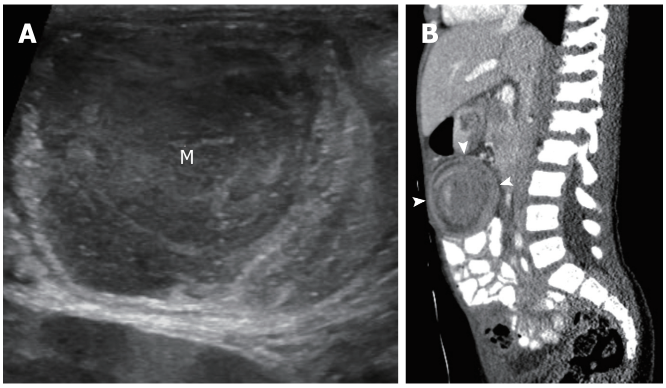

Figure 5 Burkitt lymphoma. Eight-year-old boy presented with weight loss and abdominal pain. Abdominal ultrasound showed ileocolic intussusception with soft tissue mass (M) as a lead point (A). Bilateral renal masses were also present (not shown). Sagittal reformatted computed tomography image shows ileocolic intussusception (B, arrowheads). Diagnosis was confirmed with biopsy.

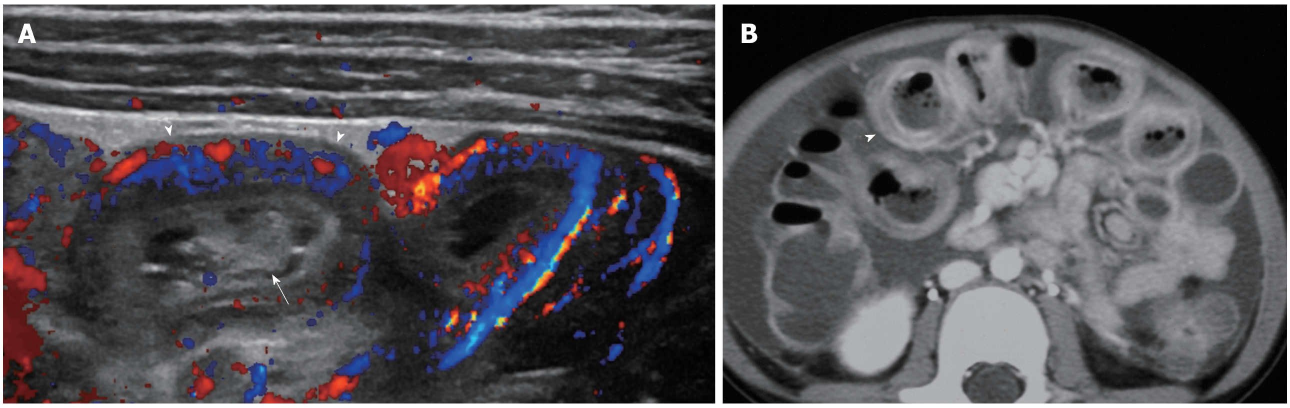

Figure 6 Henoch Schonlein purpura. Seven-year-old boy with purpuric rash and abdominal pain. Ultrasound image with color Doppler shows thick walled and hyperemic small bowel loops (A, arrowheads) and small bowel-small bowel intussusception (A, arrow). Computed tomography shows stratified enhancement of thick walled small bowel with submucosal edema (B, arrowhead).

may be identified, associated with prestenotic dilatation, hyperperistalsis, and fecalization[9]. Small intestine contrast ultrasonongraphy, using oral administration of iso-osmolar PEG, improves evaluation of the small bowel in patients with Crohn disease[79]. Contrast enhanced ultrasound using IV administration of microbubble contrast shows promising results; the pattern of mural enhancement may aid in assessment of disease activity and/or response to therapy[80]. Ultrasound elastography, a technique that measures tissue stiffness, may help to differentiate inflammation from fibrosis in Crohn disease[77].

Ultrasound also has a role in evaluating ulcerative colitis. In children, the sensitivity and specificity of ultrasound for colonic inflammatory lesions is 88% and 93%, respectively[81]. Characteristic features include colonic and ileal wall thickening (⩾ 3 mm), wall hypervascularity, loss of haustra coli, altered stratification of the bowel wall, and enlarged mesenteric lymph nodes[81].

Celiac disease: Celiac disease is an autoimmune malabsorptive enteropathy caused by gluten intolerance[82]. Ultrasound for celiac disease is performed with 5-2 MHz convex and 12-5 MHz linear transducers in the morning after fasting 10 h[82]. All abdominal quadrants are scanned with the lower frequency transducer for a preliminary survey followed by the higher frequency transducer for improved bowel detail[83]. Oral administration of 750 mL isotonic polyethylene glycol can improve visualization of bowel walls and fold pattern[83]. Ultrasound findings include dilated small bowel (> 2.5 cm including the wall), bowel wall thickening (⩾ 3 mm), increased or decreased peristalsis, mesenteric lymphadenopathy, ascites, reversed jejunoileal fold pattern (effaced mucosa in the jejunum and thickened folds in the ileum), and small bowel-small bowel intussusception[82-86].

Neoplastic disorders

Ultrasound is the preferred study for the initial evaluation of suspected abdominal masses to determine the organ of origin and the characteristics of the mass in the pediatric population. GI tumors are rare in children, and benign tumors are more common than malignant tumors[87]. Benign lesions include polyps, hemangiomas, neurofibromas, leiomyomas, gastrointestinal stromal tumors, lipomas, and neurofibromas. Isolated juvenile polyp is the most common polyp in children; ultrasound (US) may demonstrate a hyperemic intraluminal mass in the bowel[88]. The most common malignant GI tumor in children is lymphoma, typically Burkitt lymphoma. Ultrasound findings are often unsuspected in a child imaged for non-specific abdominal symptoms and may show hypoechoic bowel wall thickening, enlarged mesenteric or retroperitoneal lymph nodes, and intussusception (Figure 5).

Vascular disorders

Vasculitis: Henoch-Schonlein purpura is the most common vasculitis in children. It is an immune-mediated vasculitis affecting multiple organs, and it typically presents with a palpable purpuric rash and abdominal pain. The jejunum and ileum are commonly involved; ultrasound shows small bowel wall thickening that may reflect hemorrhage, inflammation or infarction. Transient small bowel-small bowel intussusception, obstruction, and pneumatosis intestinalis may be present[89] (Figure 6). Bowel wall hyperemia suggests inflammation, while absent color Doppler flow reflects ischemia and potential risk for perforation[90].

Vascular malformation: Vascular malformations of the small bowel are uncommon in children, but when present can cause hematochezia and anemia[91,92]. Ultrasound findings include bowel wall thickening, luminal narrowing, and tubular anechoic structures within the bowel wall that demonstrate color Doppler flow. Hemangiomas may be seen in isolation or in patients with diffuse hemangiomatosis, Klippel-Trenauney syndrome, or Osler-Weber-Rendu disease[87]. Slow-flow vascular malformations typically show venous waveforms and possibly thrombosis[91].

Foreign body

Linear, high-frequency transducers can be used to evaluate for foreign bodies and can help guide selection of subsequent targeted radiographs[93-97]. Metallic and non-metallic foreign bodies are typically echogenic with posterior shadowing[93]. Administration of water by mouth during the examination can help facilitate detection of foreign bodies within the stomach by serving as an acoustic window. Coins are the most common object ingested, and approximately 2/3 are located at the level of the cricopharyngeus muscle, aortic arch, or lower esophageal sphincter, and will need urgent endoscopic removal. The remaining 2/3 are in the stomach at initial radiologic evaluation and most likely will be spontaneously excreted (94%)[93].

Gastrointestinal bezoars usually form in the stomach, and they can pass into the small bowel and potentially cause obstruction. Children with prior gastric surgery are prone to bezoar development due to impaired gastric emptying. Bezoars are intraluminal masses, which show an echogenic arc-like surface and acoustic shadow[98,99]. Bezoars have been shown to demonstrate twinkle artifact on color Doppler imaging, which can increase diagnostic confidence with ultrasound and help differentiate this entity from intraluminal gas or stool[100].

CONCLUSION

Ultrasound is increasingly utilized for the evaluation of abdominal disorders in children, given its lack of ionizing radiation or need for patient sedation. Ultrasound is the often the initial modality detecting abnormalities of the GI tract in children, either as part of a targeted exam at the site of symptoms or as an incidental finding. Radiologists interpreting US examinations in children should be familiar with the sonographic appearance of both the normal and abnormal GI tract in order to provide the best care for pediatric patients with abdominal diseases.

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