Chapter

Ultrasound of the Pediatric Gastrointestinal Emergencies

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Abstract

With recent technologies, ultrasound has become an extremely useful imaging modality for evaluating children with acute abdominal symptoms. Higher frequency transducers can be used in children than in adults, owing to their small body size, the presence of less fat tissue in the abdominal wall and peritoneal cavity leading to higher resolution than computed tomography in many circumstances without exposure to ionizing radiation. Real-time ultrasound imaging provides information about motion such as peristalsis, and newly developed harmonic imaging enables improved resolution with decreased artifacts. Beyond gray-scale ultrasound, color Doppler ultrasound provides information on vascularity which increases in inflammatory processes. Point-of-care examination includes ability to focus on the symptomatic area of the patient while performing real-time ultrasound imaging. Ultrasound is sufficient for the diagnosis of several gastrointestinal diseases that cause acute abdominal pain in pediatric patients helping to an accurate patient management in the emergency settings. Common gastrointestinal indications for abdominal ultrasound in children are hypertrophic pyloric stenosis, acute appendicitis, intussusception, inflammatory bowel disease, malrotation, midgut volvulus, hernia, and necrotizing enterocolitis. In this chapter, typical sonographic findings of aforementioned diseases, and possible differential diagnoses were discussed.

Keywords: Acute appendicitis, intussusception, inguinal hernia, necrotizing enterocolitis, hypertrophic pyloric stenosis, inflammatory bowel disease

1. Introduction

Non-traumatic acute gastrointestinal (GI) disorders are common causes of presentation in the pediatric emergency department. Children have wide range of potential diagnosis, different from adults including congenital and acquired lesions. The causes of acute abdomen vary according to ages of the children. Since children are unable to give reliable history, have atypical presentations and accompanying extra-abdominal manifestations; evaluation and establishing the correct diagnosis is challenging.

Traditionally, pediatric abdominal ultrasound (US) examination focuses exclusively on parenchymal organs, putting less interest on the gastrointestinal tract [1]. However, recent US technologies and new transducers are able to perform a detailed examination with great contrast resolution of each section of the digestive system in pediatric age because of their smaller body size and less impaired by gas content and adipose tissues. The other well-known advantages of US, particularly its lack of ionizing radiation, easy access, low-cost and without need of patient preparation, makes this imaging modality an ideal one for the evaluation of pediatric population in the emergency settings. Currently in many places, US is the first line of imaging over computed tomography (CT) and radiography for patients with acute abdominal pain. The main role of diagnostic imaging with US and color Doppler in the emergency is to determine whether the acute abdomen is due to a surgically or medically treatable disease, even though the exact pathology has not been diagnosed.

This chapter presents the basic aspects of US for evaluating the pediatric GI tract, including techniques, equipment, patient preparation and the anatomy. Then indications and sonographic findings of frequently encountered acute non-traumatic GI diseases in neonates, infants and children are highlighted with some exemplary cases. Acute traumatic GI tract injuries, oncologic emergencies, acute abdomen due to hepatobiliary or urogenital diseases are beyond the scope of this chapter.

2. Ultrasound technique and appropriate equipment

New generation ultrasound equipment including the wide spectrum frequency probes provides high quality images of the gastrointestinal system, adjacent mesentery and related structures. Children's small body habitus and the presence of less fat tissue in the abdominal wall enable examination with high frequency transducers. Therefore US is increasingly used as the initial and follow-up study for investigating gastrointestinal tract pathologies in children and it is sufficient for the radiological diagnosis in majority of cases.

The contrast resolution of an US probe is dependent on the frequency, the velocity of sound in tissue and the number of cycles in the US pulse [2]. Depending on the age and size of the patient, a large convex-array (1–5 MHz) or smaller convex-array transducer (5–8 MHz) is a good option for beginning the examination for overview of the entire abdomen [3]. Following initial overview, a detailed analysis of the bowel wall and adjacent structures should be evaluated with a high frequency (10–18 MHz) linear-array transducer [1]. Tissue harmonic imaging is newly developed imaging software to increase resolution of the superficial parts of the field-of-view. It should be used to improve the delineation of bowel wall layers [2]. While evaluating anxious children in the acute setting, dynamic range should be lowered and the number of foci should be reduced to increase frame rate [4]. To demonstrate peristalsis, normal or abnormal motility, and motion of air bubbles in perforation or necrotizing enterocolitis; extended field-of-view can be helpful and cine clips should be recorded [5].

Doppler US evaluation is essential in GI system imaging, especially when looking at inflammatory diseases or neoplastic conditions. Doppler should be performed with a low wall filter and pulse repetition frequency should be adjusted as low as possible to prevent aliasing [6]. Power Doppler is a good method to overcome motion artifact in uncooperative children. As there are modern equipment and software, newer vascular imaging techniques, such as B-flow and superb microvascular imaging are brought into use by different vendors which are able to assess smaller vessels in the bowel wall [4].

US elastography is an emerging US technique to assess the stiffness of a tissue [5]. There are some studies in the literature regarding the usage of elastography for GI tract diseases, particularly in inflammatory conditions [7, 8]. The bowel is a hollow viscus with a lumen containing gas and fecal contents. The anatomy of the bowel is not ideal for US elastography as solid organs (e.g. liver or kidney). However, bowel wall thickening due to inflammation or tumor often reduces motility and luminal contents that enable to perform US elastography more reliable [2]. Some studies suggest using US elastography in inflammatory bowel disease to differentiate inflammatory and fibrotic stenosis [9, 10].

Contrast enhanced US (CEUS) can be used to evaluate bowel wall vascularity and perfusion in real time [5]. It is performed after the intravenous injection of microbubbles that resonate and give rise to more intensely reflected signals [2]. Enhancement pattern, contrast quantification at peak intensity and dynamic contrast enhancement can be analyzed with CEUS [11, 12]. Enhancement pattern following bolus injection is used as a qualitative parameter. For example, patients with absent bowel wall enhancement can be separated from those with detected enhancement [2]. It can also be used in patients with complicated GI disorders when trying to differentiate a phlegmon from an abscess [13].

US examination of GI system must involve a systematic approach. While evaluating large bowel, the transducer is applied to the right iliac fossa to identify the cecum. Afterwards, colon can be followed through the ascending colon, transverse colon, descending colon, sigmoid colon and finally the rectum. Since the rectum is visualized behind the bladder, filled bladder is better to evaluate rectum and sigmoid colon. Longitudinal placement of the transducer is often better to identify the haustrations of colon segments [2]. The examination of the small intestine begins with the identification of ileocecal valve and the terminal ileum at the right iliac fossa. The examiner should identify the appendix, often inferior to the terminal ileum and follow the ileum as far as possible. Tracking the whole small bowel is generally not possible, therefore the abdomen should be scanned cranially and caudally parallel scans covering the whole abdominal area. The scanning approach may differ according to clinical scenario. For surgical disorders or trauma, a faster and a targeted approach are preferred, whereas for general and nonspecific complaints, more detailed examination can be performed.

Graded compression is a simple, essential and effective technique to push away gas filled bowel segments or intraabdominal fat [3, 4]. It decreases the distance between the transducer and target organ and enables to reach deeper with high frequency transducers. Although it was introduced for the diagnosis of acute appendicitis by Puylaert [14], now it has been performed for detection of bowel thickening and compressibility, and for specific diseases such as diverticulitis and colonic polyps [15, 16].

3. Patient preparation and clinical indications

As a general principle, no preparation of the patient is required to perform gastrointestinal US, particularly in the emergency setting. However, to decrease the amount of food and gas in the gut, and to examine the gallbladder and biliary tree, a fasting period of 3 hours in newborn and 5 hours in children is recommended [1]. Physical activity also reduces the splanchnic flow, therefore patients should avoid from extensive activity before the examination [2]. Since the cold gel is one of the major complaints of children, gel warmer to warm the coupling gel can be used. If the infants or neonates are anxious and reluctant to be scanned; examiner can sit them on their mother's lap, get her lie down on the couch along with the child.

For stomach and pyloric examination, oral fluid intake or fluid ingestion via nasogastric tube is useful [4]. The distention of colon with anechoic fluid (water) ingestion, or with oral administration of hyperosmotic solutions allows the detailed examination of the haustration of colonic wall and adjacent structure [2]. The scanning of small intestine following the ingestion of iso-osmolar polyethylene glycol (PEG) solution is called US enterography or small intestine contrast US (SICUS).

Since the PEG solution is non-absorbable in the small bowel, retained fluid distends the intestine and induces the wall contractility. The PEG solution moves distally and distends whole loops of the entire small bowel. Following PEG ingestion, small bowel lumen diameter > 30 mm and wall thickness > 3 mm is abnormal [17].

Before beginning a US examination, examiner should be familiar with the abdominal symptoms, clinical presentations and laboratory findings of acute GI diseases. The most common presentations are pain, vomiting, diarrhea, fever, hematochezia and melena. Although some diseases have peculiar clinical findings, majority of cases have non-specific symptoms and clinical appearances [3]. US is generally suggested as the first line imaging modality in children with acute abdomen. Most common indications for gastrointestinal US in children are acute appendicitis, intussusception, hernia, hypertrophic pyloric stenosis, inflammatory bowel disease, and volvulus. Further indications involve necrotizing enterocolitis, duplication cysts, malrotation of the bowel [4]. Also US is widely performed for the disease of other intraabdominal structures such as mesenteric lymphadenitis, lymphoid hyperplasia of the appendix, infectious enterocolitis, omental infarct, epiploic appendagitis, specific inflammations such as tuberculosis, colitis with hemolytic uraemic syndrome and Henoch-Schönlein purpura [4]. The recent COVID-19 pandemic associated multisystem inflammatory syndrome in children (MIS-C) can also manifest with gastrointestinal system dysfunction which has been also a novel US indication since 2020 [18].

4. Challenges of GI ultrasound

Major challenges of US is based on its operator-dependency and reproducibility [5]. The European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) suggests to set standards of training and education curriculum for GI system US to provide high quality performance in clinical practice [2]. According to EFSUMB recommendations; the operator should be able to recognize the normal anatomy of small intestine and large bowel initially. Following recognizing normal appearance of normal GI tract, the investigator should be able to perform a complete scanning of the gut; evaluation for focal or diffuse diseases, the presence of diverticular disease and its complications (perforation and obstruction), the peritoneal cavity, the mesentery, and the omentum for the inflammatory, infectious or malignant diseases [2].

There are other challenging factors related to the patient such as noncollaboration, obesity and interposition of large amount of gas [5]. Particularly retroperitoneal, paraaortic and retroduodenal areas are often danger zones that are not well delineated on US. If the graded compression technique is ineffective to eliminate gas interposition and US findings are unremarkable; intravenous contrast enhanced CT should be performed in patients with acute abdominal pain, especially if there is suspicion of gut perforation.

5. Normal anatomy

While examining normal anatomy of GI structures; position, size, wall thickness and stratification should be evaluated. Many GI disorders appear as bowel wall thickening but normal bowel wall thickness may vary depending on peristalsis and the degree of distention [3]. Recent studies with high frequency transducers suggest that both normal small and large bowel wall thickness should be <2 mm when distended [19]. The exceptions are the pylor/duodenal bulbus and rectum wall which should be < 3 mm and < 4 mm respectively [20]. If the measurements were made from collapsed bowel wall, it should be reported since the wall of collapsed bowel is shown as thicker [2].

When examined with high frequency transducers, five sonographic layers of the bowel wall can be seen. When imaging the anterior wall (closer to transducer); the innermost echogenic layer is called as the mucosa-lumen interface which is not a part of actual GI wall. The second hypoechoic layer correspond to the deep mucosa, the third hyperechoic layer is submucosa which is most prominent in the colon [3]. The muscularis propria is the hypoechoic fourth layer which is most pronounced in the stomach. The outermost hyperechoic layer is the interface between muscularis and serosa. As the interface are hyperechoic and located distal to the real tissue, correspondence of histology and US layers are slightly different in the dorsal wall [2]. Therefore, evaluation of the layers should be made from the anterior bowel wall in diffuse inflammatory diseases. Bowel wall thickness measurement should be made perpendicular to the wall from innermost to the outermost echogenic layers [2].

The small intestine has three segments. The duodenum passes into the jejunum at the ligament of Treitz located in the left upper quadrant. The jejunum is often located in the left upper quadrant and usually collapsed with prominent folds, also known as valvula conniventes. They decrease and shorten from jejunum to ileum and best demonstrated at the fluid filled loops [2]. The ileum is located at the right lower quadrant and frequently involves fluid in normal patients. Sometimes cecum may be located intraperitoneal in variable positions even at the left lower quadrant of abdomen. The cecum and ileocecal valve is important landmarks to identify appendix which is usually below to the ileocecal valve. Although appendix is typically seen over the iliopsoas muscle medial to the cecum, lateral elevation or retrocecal course are not infrequent [2]. The normal appendix can be visualized in about 70% of healthy children with graded compression and it may increase depending on the experience of examiner and the resolution of transducer [21].

6. Acute appendicitis

Acute appendicitis accounts for 80% of all abdominal surgical emergencies in pediatric population [22]. It is most frequently seen in second decade and is rare in children under two years of age, probably due to the funnel shape of appendix in infancy, which reduces the possibility of obstruction [23, 24]. Possible predisposing factors include lymphoid hyperplasia (due to past viral infection), dehydration, and low dietary intake of fiber [24]. Although the typical clinical presentation is acute onset of abdominal pain that may occur in the periumbilical area, radiating to the right lower quadrant, one-third of children have atypical clinical findings and symptoms, especially younger ones [23]. Other clinical signs are; fever, elevated acute phase reactants, nausea, vomiting and leg pain. Diarrhea is not present unless there is perforation and peritonitis, more frequently occurs in young children and confused with gastroenteritis [24]. Following clinical assessment and laboratory findings, imaging is the third component while evaluating the patients with suspected appendicitis. The routine US examination in suspected appendicitis reduces the negative appendectomies 50% and decreases the surgical complications and costs [25].

In patients with localized pain, transducer is applied to the point of maximum tenderness or pain. Self-localization facilitates the scanning, especially in patients with an aberrantly located appendix, and reduces the time of examination. If the patient cannot localize the pain or uncooperative; systematic evaluation starts in transvers plane to identify ascending colon. Lowermost part of the ascending colon is the cecal pole and medial to the cecum ileocecal valve can be demonstrated. The most common origin of the appendix is 2–3 cm below to the ileocecal valve [26]. Pressure is gradually increased to displace gas and fecal materials in the cecal lumen to adduct appendix to the transducer. In obese children, a left oblique body position or an upward graded compression technique may be useful to displace the fat tissue of the abdominal wall [27]. Anatomical variations require a systematic approach to evaluate appendix and experience plays an important role in examination. There are several US features to distinguish between normal and inflamed appendix which are valid for both children and adults (**Table 1**) [25, 26, 28, 29].

The inflamed appendix is shown as a fluid-filled non-compressible distended aperistaltic tubular structure with a blind end (**Figure 1**). In the axial plane, it has a target appearance with thickened echogenic mucosal interface and hypoechoic muscular wall. Appearance of an appendicolith, which is an echogenic focus with a posterior acoustic shadowing, is supportive finding for the diagnosis (**Figure 1C**) [23]. However, intraluminal air is also echogenic and can mimic appendicolith (**Figure 1D**). A heterogeneous mass around appendix representing phlegmon, and a walled-off fluid collection representing abscess are often the signs of complicated appendicitis and perforation [23]. Complicated appendicitis can occur either as a gangrenous appendicitis (focal or diffuse necrosis of the wall) or as a perforation. There is continuous transition from phlegmonous uncomplicated to gangrenous appendicitis during the disease course. The most important indicator of gangrenous appendicitis is the loss of normal hyperechoic mucosa-lumen interface [30]. Other ancillary finding is the lack of vascularity on color Doppler. The rate of perforation following acute appendicitis is around 60% for a 3-year-old child, 50% for a 5-year-old child, and this incidence reduces with increasing age, because of limited ability to communicate and define complaints in little ones [31]. Moreover, small children are more prone to peritonitis and abscess formation, rather than phlegmon, following perforation due to underdeveloped omentum which confines purulent material [24].

Non-visualization of the appendix is an important problem while evaluating appendicitis. The major reason for false-negative scanning is inexperience examiner in GI US. Other challenging situations are retrocecal or pelvic position of appendix, thick abdominal fat tissue in very obese patients, or focal appendicitis confined to distal tip that account for 5% of cases [25]. Thus, the entire appendix should be delineated clearly [32]. In perforated appendicitis, an abscess may be misinterpreted as a gas-containing bowel loop. In these cases, indirect signs of appendicitis should be scrutinized around cecum [33].

Primary US findings of acute appendicitis	**Secondary US findings of acute appendicitis (adjacent structures)**
Maximum outer diameter > 6 (6–8 mm indicates borderzone)	Hyperechoic periappendiceal fat tissue
Maximum tenderness over the thickened appendix	Complex fluid collection (pericecal abscess)
Incompressibility of the inflamed appendix	Mesenteric / pericecal lymphadenopathy
Appendicolith (fecalith) within the appendix lumen	Periappendiceal reactive fluid
Hypervascularity in color Doppler in uncomplicated cases	
Loss of stratification and normal appearance of appendix wall in gangrenous appendicitis	

Table 1.
Primary and secondary sonographic features of acute appendicitis.

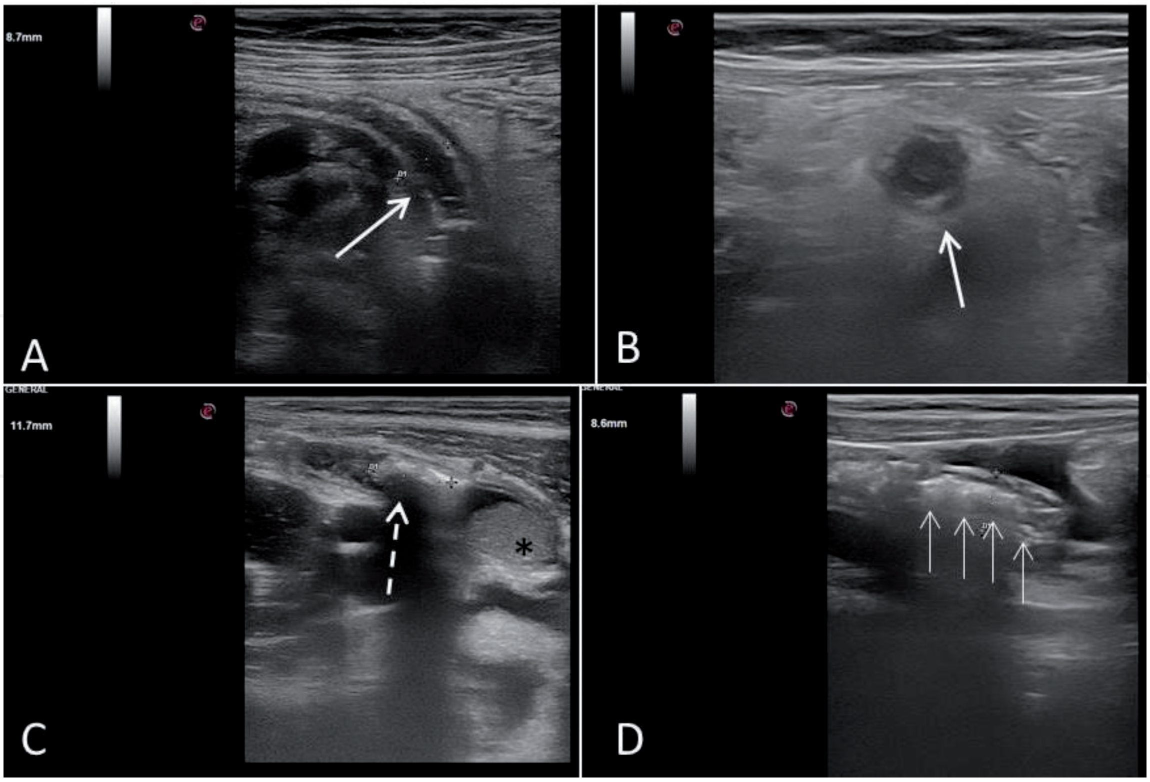

Figure 1.
Three different cases with acute appendicitis. Ultrasound images of an 8-year-old boy demonstrate longitudinal (A) and transverse (B) section of inflamed appendix (arrow) with a diameter of 8.7 mm, and hyperechoic inflamed periappendiceal fat tissue. Ultrasound image of a 9-year-old boy (C) shows appendicolith (dashed arrow) within the appendix lumen, fluid level (asterisk) and dilatation distal to the obstruction. Ultrasound image of a 5-year-old girl (D) demonstrates inflamed appendix with a diameter of 8.6 mm and periappendiceal reactive fluid. Despite the inflammation, lumen is filled with air seen as echogenicity with dirty posterior shadow (thin arrows).

Recent publications confirm the mild forms of appendicitis which is spontaneously resolved under antibiotic therapy without need for surgery [34]. Unfortunately, there are not any reliable criteria to differentiate mild courses on US that probably not require surgery [25]. Other pitfalls that lead to a false-positive diagnosis of acute appendicitis are; incorrect identification of the terminal ileum as inflamed appendix, Meckel's diverticulitis, cecal diverticulitis, dilated Fallopian tube or gonadal vein thrombosis [25]. Contrarily, appendiceal thickening can occur by other conditions such as Crohn's disease, infectious enterocolitis, peritonitis, ascites and appendiceal tumors such as mucocele, cystadenoma or carcinoid [25].

Over the last decades, the sensitivity of US for the diagnosis of appendicitis has reached to 95%, with specificity above 90% [23, 35, 36]. The accuracy of US is currently equivalent to CT and magnetic resonance imaging (MRI), even more accurate particularly in small children with less intraabdominal fat tissue. Point-of-care ultrasonography (POCUS) is increasingly done by emergency physicians for the diagnosis of appendicitis, but US is a highly operator dependent tool that requires experience and sufficient equipment. Consequently, adequate equipment, structured training program and quality control should be provided before clinical application. Consistent preoperative use of US for right lower quadrant pain can decrease the additional CT/MRI examinations to a low fraction [35, 37]. When initial US is inconclusive, second US following an observation period, or an additional MRI or CT examination can be considered. In children, MRI should be performed if possible to support the ALARA (radiation as low as reasonably achievable) principle. Some guidelines recommend several scoring systems for US to diagnose acute appendicitis [38]. Since these scoring systems roughly estimate the likelihood and do not prove appendicitis, they are not obligatory to use in routine practice [25].

7. Hypertrophic pyloric stenosis

Hypertrophic pyloric stenosis (HPS) is the most common cause of surgery in vomiting infants due to the failure of relaxation of the pyloric sphincter of stomach [39]. The disease usually appears between 2nd and 12th week of life and commonly affects white males [2, 39]. The typical complaint is non-bilious, projecting vomiting by a previously healthy infant after feeding. HPS is not an actual emergency unless severe dehydration or excessive electrolyte loss occur. HPS can be palpated as a pyloric mass in the epigastrium on physical examination (olive sign) [22]. Preoperative US is the gold standard radiologic modality for the diagnosis of HPS with sensitivity, specificity and accuracy of approximately 100% if adequate equipment is provided [40].

The US scanning begins with placing the baby in a supine or right lateral decubitus position. A high-frequency (10–18 MHz), linear-array transducer should be applied from sub-xiphoid area to the right paramedian area to search for pylorus [1]. If adequate fluid is not present in the stomach, breast feeding or oral sugar contained water can be given in order to displace the air in the stomach and to see the passage of the fluid [41]. Normal position of the pylorus can be demonstrated between the liver and the head of the pancreas, medial to the gallbladder. If abundant air present in the gastric antrum, the patient should be moved into the right lateral decubitus position, to displace air into the fundus and to move pylorus anteriorly [3]. To confirm the HPS, pyloric canal length and thickness of the pyloric muscle should be measured [1]. Pyloric muscle thickness > 3 mm, canal length > 17 mm, and antero-posterior diameter of pylorus >12 mm confirm the diagnosis of HPS with high accuracy (**Figure 2**) [1, 3, 22]. By the way, pylorus is a dynamic structure and muscle thickness may change due to peristalsis during a real-time US examination. Therefore, imaging for a sufficient time is needed to exclude pylorospasm from HPS, which is a transient phenomenon [41]. Other ancillary findings to diagnose HPS are the prolapsed mucosa into the gastric antrum (antral nipple or cervix sign) and trapped fluid within the crevices of mucosa. The main reason of false-negative result is the overdistention of stomach that moves antra-pyloric canal posteriorly [3]. To overcome this issue, gastric content can be aspirated via nasogastric or orogastric tube.

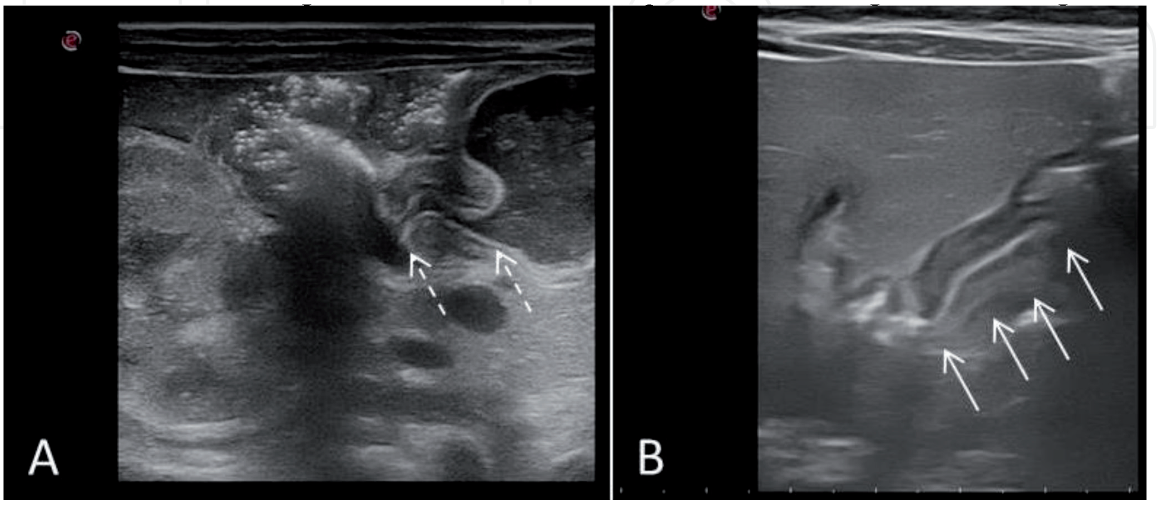

Figure 2.
(A) Normal appearance of pylor in a 25-day-old baby and (B) hypertrophic pyloric stenosis in a 30-day-old boy. Hypertrophic pylor (arrows) is thicker and longer than normal (dashed arrows) that does not permit the passage of gastric content into the duodenum.

8. Intussusception

Intussusception is the penetration of the bowel segment, either the small intestine or colon, into the distal lumen and propulsion as luminal content. It is the most common etiology of small bowel obstruction in infants, with a reported incidence of 56 cases per 100,000 hospitalizations per year in the United States [24]. More than 90% of cases present in the first two years after birth and peak age between 3 and 9 months. [1, 3, 22]. Depending on the localization, there are two subtypes; ileo-cecal (or ileocolic) comprises 90% of cases and ileo-ileal occurs in about 10% [42]. The most common symptoms are recurrent abdominal pain, vomiting and currant jelly stool. Additionally, previous episodes of infection in the upper respiratory tract or gastroenteritis may occur in the patient's clinical history. Most common localization of ileocecal intussusception is the subhepatic region, followed by upper abdominal midline and left upper quadrant [3]. It consists of three bowel segments; the inner prolapsing and returning limbs of the bowel are terminal ileum (called as intussusceptum) and attached mesentery and lymph nodes is dragged between these limbs [3, 39]. Outermost bowel receiving intussusceptum is the colon (called as intussuscipiens). Due to the compromised vascular supply, the thickest ileal segment is the returning limb of the ileum [3].

The diagnostic accuracy of US have verified with the several studies with a sensitivity of 97–100% and a specificity of 88–100% [24]. Thus, US has become as the primary modality of choice, replacing the contrast enema, in patients with suspected intussusception. Transverse section of intussusception appears as an oval or round mass with concentric rings and hypoechoic rim, described as 'doughnut' or 'target' configuration on US [1]. The crescentic shaped, hyperechoic, mesenteric fat can be seen in the center of the mass (called as 'the crescent in doughnut sign') (**Figure 3A** and **B**). The longitudinal appearance of intussusception is called as 'pseudo-kidney' or 'sandwich' sign (**Figure 3C**). On color Doppler US, double rings sign between the layers can be seen (**Figure 3B**) and absence of blood flow may indicate ischemia or irreducibility [22]. US can also be performed safely and accurately to monitor the hydrostatic reduction. Successful hydrostatic reduction rates are approximately 80% with a very few complication rates (2.7%to 4.26%) [24]. Some findings on US are useful to predict the success of enema or hydrostatic reduction such as; reduced vascular flow, thickened outer wall (>10 mm), trapped fluid and/or large (>1 cm short axis) lymph nodes within the intussusceptum [1, 3]. The appearance of intramural or subserosal air,

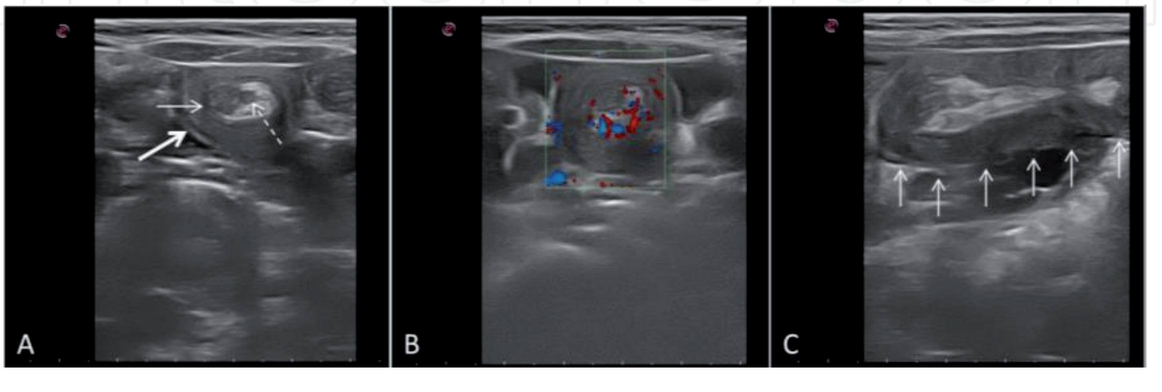

Figure 3.
A 5-month-old boy with intussusception. (A) Transverse section demonstrates "target sign" composed of intussusceptum (thin arrow), intussuscipiens (thick arrow) and a lymph node (dashed arrow) within the trapped mesenteric fat tissue. (B) Doppler shows swirling of arteries and veins within intussusception. (C) Longitudinal section shows typical "sandwich" or "pseudokidney" sign (arrows).

manifested as echogenic foci, indicates the risk of necrosis and perforation, for those enema/hydrostatic reduction is contraindicated [1].

The US can identify pathologic lead points in approximately two third of cases, particularly in older age group [43]. Similarly pathologic lead points may occur in younger than expected age group as < 3 months of age [24]. Common lead points are; Meckel's diverticulum, duplication cyst, lymphoma or polyp. Cystic fibrosis, Henoch-Schonlein purpura, or polyposis syndrome may cause recurrent intussusceptions. Lead points or underlying disease should be searched elaborately in a patient with unusual age, abnormal localization of intussusception, recurrent disease and long duration of symptoms [3].

Small bowel intussusception comprises 10% of cases and is usually transient and asymptomatic. Common locations are the periumbilical area, left upper or lower quadrant of the abdomen. Most cases are due to small bowel hyperperistalsis. They are usually smaller than ileocecal intussusception (<1 cm diameter) and involve shorter bowel segment. If small bowel intussusception is persistent and symptomatic or involving longer segment (>3.5 cm), the patient should be scrutinized carefully to identify pathological lead point [3].

9. Intestinal malrotation and volvulus

Intestinal malrotaton is not an infrequent phenomenon with a prevalence of 0,2–0,5% of live births. While the most patients are asymptomatic, 3–8% of malrotated bowel is symptomatic in the first year of life with bilious vomiting, pain and malabsorption [1]. The normal midgut rotates 270^0 counterclockwise in utero around the axis of superior mesenteric artery (SMA). Incomplete rotation of bowel during fetal period results in short mesenteric root, abnormal positioning of duodeno-jejunal junction and ileocecal valve and close proximity of duodenum and cecum [3]. Twisting of malrotated small bowel around its mesentery may cause obstruction and volvulus, an emergent situation that requires prompt surgical intervention [44].

The well-known sonographic finding of intestinal malrotation is the inversion of the SMA and superior mesenteric vein (SMV). Patients should be lay supine while US evaluation and transducer applied at the upper midline to recognize SMA at its point of origin on the abdominal aorta [1]. SMV can also be identified tracing from the main portal vein to the midline after giving branch of splenic vein. Normally, the SMV is found on the right side or anterior to the SMA. If SMV located ventrally or left to the SMA, it is an abnormal location, which raises suspicion but do not always indicate malrotation [3]. For evaluating duodenum and to see the passage or beak sign of acute volvulus, oral water instillation may be useful. In suspected malrotation patients, when US findings are abnormal or inconclusive, an upper GI study should be performed, as a gold standard, to confirm the diagnosis [45].

Midgut volvulus is a fatal complication of malrotation, and 90% of cases occur in the first year of life, even %75 of cases occur in the first month. The typical sonographic feature of volvulus is the 'whirlpool sign', which is the swirling of SMV and its tributaries around the SMA in clockwise direction, best appreciated on color Doppler. Associated US findings of malrotation are proximal duodenal dilatation with distal tapering, duodenal wall thickening (> 2 mm), fixed midline bowel, intraabdominal free fluid, dilatation of the distal SMV and increased resistive index on SMA [3, 39].

Off-midline scanning due to inappropriate position of the transducer may demonstrate SMV and SMA as an abnormal relation which is the most common cause of the false-positive diagnosis of malrotation. Another reason for false-positive diagnosis is the 'whirlpool' sign occurs due to normal counterclockwise rotation. False-negative diagnosis may also be observed due to severe abdominal distension, abdominal guarding, abundant bowel gas, and/or an inexperienced operator. If there is strong clinical suspicion, an emergency upper GI study should be performed to clarify the diagnosis [3].

10. Necrotizing enterocolitis

Necrotizing enterocolitis (NEC) is one of the most common and lethal gastrointestinal emergencies of neonates, usually affecting the terminal ileum and ascending colon [22]. Although it affects primarily preterm babies, NEC can also be seen in term infants. The clinical presentation ranges from feeding intolerance, abdominal distention, emesis, diarrhea, rectal bleeding to more severe systemic findings including respiratory failure and fulminant shock [41]. Bowel necrosis occurs in NEC without any precise cause, which compromises the mucosal integrity [6]. Pathogenic organisms become dominant in the gut flora, leading to the pneumatosis intestinalis, which subsequently leads to portal venous gas and consequently leads to perforation and pneumoperitoneum. While the disease progresses, both early and late clinical signs and laboratory tests are often non-specific for diagnosis of NEC, therefore imaging plays crucial role for accurate diagnosis.

Radiographs are still primary modality of choice for evaluation of neonates suspected of having NEC [46]. Plain abdominal radiographs demonstrate pneumatosis, increased thickness of bowel wall, free intraperitoneal air and portal venous air [22, 46]. The role of US has been increasingly appreciated, owing to its higher sensitivity than plain films in the detection of early changes such as wall thickening, intestinal pneumatosis, portal venous air and disturbed bowel wall perfusion on color Doppler [5, 46]. Recent publications stated that diagnostic performance of US for detecting NEC is accurate with sensitivity of 100% and specificity of 90%. However, role of US in the follow-up of NEC is uncertain [6].

In the early phase of the disease, US can show the bowel wall thickening due to inflammation. Whereas, bowel wall thinning (<1 mm) may occur as it becomes necrotic and progresses toward perforation [47]. Similarly, Color Doppler may display hyperemia in the early stages due to inflammation, and avascular wall in the advanced disease with bowel wall necrosis [6]. Pneumatosis intestinalis is seen as punctate or granular echogenic foci with 'dirty' posterior acoustic shadowing or linear echogenic ring within the bowel wall. The gas bubbles create twinkling artifact on color Doppler which is useful in equivocal cases. To differentiate intramural gas from intraluminal air, nondependent bowel wall should be evaluated. Moreover, true pneumatosis would not change with the motion of the patient, whereas intraluminal air is freely mobile. Placing the patient in multiple positions may be useful to observe movement of the air. For the detection of pneumatosis, US is more sensitive than plain radiography [48].

Portal venous gas manifests on US as the presence of curvilinear or punctate mobile echogenic foci within the portal venous system. It is commonly seen in the neonates after umbilical catheterization, and may occur in different neonatal diseases. Therefore, in the absence of pneumatosis intestinalis, other etiologies should be considered rather than NEC. In the case of NEC, fluid-filled dilated bowel, complex hyperechoic intraperitoneal free fluid, focal fluid collections are suggestive of perforation and have been correlated with a poor clinical outcome [47, 49]. Evaluation of bowel peristalsis by real-time examination is an important component of US in infants with suspected NEC, because necrotic or inflamed bowel segments have decreased or absent motility [6]. US may also be considered in the follow-up to decide the appropriate time to restore oral feeding and to evaluate post-enterocolitis stenosis [5].

11. Inflammatory and infectious bowel diseases

Inflammatory bowel disease (IBD) is a general term that covers a series of acute and non-acute diseases which do not require surgical treatment, ranging from self-limiting focal disorders to the debilitating and/or chronic diseases [1]. Diagnosis can be challenging due to nonspecific or atypical clinical presentation with extra-intestinal manifestations. US is useful in the diagnosis of IBD, especially in children by assessing bowel wall, peristalsis and surrounding mesentery with high-frequency transducers. Moreover, color Doppler increases the diagnostic accuracy and estimates the disease activity by showing vascularity. Presence of extra-intestinal complications such as abscess, fistula can also be evaluated with US.

While evaluating IBD, the thickening of the bowel wall can be divided into two categories according to US appearance [1]. 'Layered thickening' is shown as hyperechoic and organized wall thickening corresponds to mucosal inflammation with indirect involvement of submucosa. Whereas 'non-layered thickening' characterized by the loss of normal structure seen as a diffuse hypoechoic thickening without any reflective echoes. Based on the thickening type and localization, possible diagnoses are presented in **Table 2**.

Crohn disease is the most common IBD that requires frequent imaging because of its extensive involvement of GI tract, and phases of exacerbations and remissions [1, 6]. It is characterized as a chronic transmural inflammation of an unknown cause and can affect any part of GI tract. In 20% of cases, the disease first becomes symptomatic during childhood [39]. Although, the role in the diagnostic algorithm is emerging, bowel US in its current form cannot replace with CT or MRI but can provide complementary information in the evaluation of disease. The diagnostic performance of US for identifying lesions of Crohn disease has sensitivity of 75–94% and specificity of 67–100% [6]. The primary imaging features of Crohn disease are bowel wall thickening and loss of stratification. Affected segments are non-compressible, hypoperistaltic and have hypoechoic wall with a minimal thickness of >3 mm [6, 39]. The hallmark of active disease is increased vascularity of thickened bowel wall segments (> 5 mm) with 88% specificity and 95% positive predictive value [49]. Moreover, SMA flow volume is higher but resistive index is lower with active disease [6]. Remarkable extramural manifestations that can be seen on US include thickened, hyperechoic mesentery ('creeping fat' sign) and enlarged mesenteric lymph nodes (**Figure 4**). Strictures, fistula, phlegmon and abscess are common complications of Crohn disease that can be depicted on US but requires further evaluation with CT or MRI. On US strictures are identified in

	Ileum involvement	Colon involvement
Layered thickening	Infectious ileitis (Campylobacter or salmonella)	Infectious colitis (E.Coli, salmonella, shigella)
	Early Crohn disease	Chronic intestinal infectious disease (CIID)
Non-layered thickening	Henoch-Schönlein Purpura	Ischemic colitis prodromal of hemolytic uremic syndrome (HUS)
	Tuberculosis ileitis	Advanced IBD (ulcerative colitis or Crohn disease)
	Protein-losing enteropathy, Celiac disease	Pseudomembranous colitis
	Advanced Crohn disease	Neutropenic colitis

Table 2.
Sonographic pattern and location of common inflammatory bowel diseases.

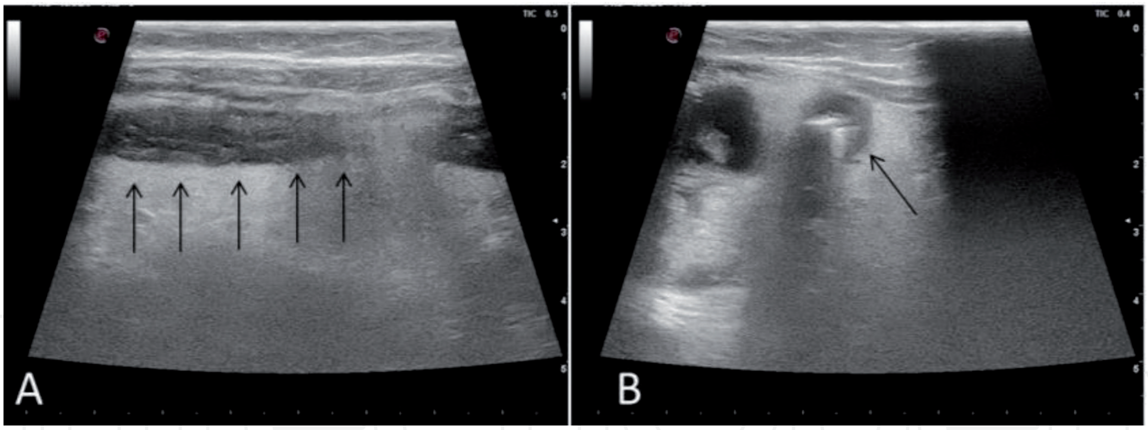

Figure 4.
An active Crohn's disease in an 11-year-old girl. Longitudinal (A) and transverse (B) section of inflamed bowel segments demonstrates layered wall thickening, increased echogenicity and prominent thickening of mesenteric fat tissue.

70–79% of cases as a narrowed bowel segment accompanying dilatation and hyperperistalsis at the proximal part [6]. Fistulas are less common in children than adults, and US is not a reliable modality to depict fistulas with the sensitivity of 31–87% in different publications [50]. An abscess can be delineated with US as an irregular thick-walled aperistaltic fluid collection including internal echoes and sometimes air. The sensitivity of US for the diagnosis of abscessranges from 83–91% [51]. An abscess may mimic a bowel loop, but bowel segments are thin-walled and peristalsis of bowel can be seen on real-time imaging.

Henoch-Schönlein Purpura (HSP) is the most common pediatric vasculitis that frequently involve GI tract [3, 39]. The pathogenesis of the disease originated from the thrombosis of small vessels, which in turn can cause ischemia of the small bowel [39]. Bowel wall thickening and edema can be seen on US in 50–60% of cases [52]. Although typical skin lesions are the hallmark of the disease, bowel wall thickening in duodenum and proximal small bowel may occur before the appearance of skin lesions. However, HSP can affect any segment of the bowel. The most common US feature is diffuse circumferential bowel wall thickening (**Figure 5**). Focal intramural hemorrhage can be revealed as a hyperechoic lesion in the mucosa or submucosa. With intramural hematoma, bowel wall thickening may increase up to 9–10 mm and multiple skip lesions can be demonstrated [3]. In HSP patients with obstructive symptoms such as vomiting or hemorrhagic stool, one or more intussusception can be seen with intramural hematoma as a lead point [53]. In the active stage of the disease, hypervascularity on color Doppler imaging may present. Other less common vasculitides involving the bowel may also occur with a variable presentation but similar findings on US.

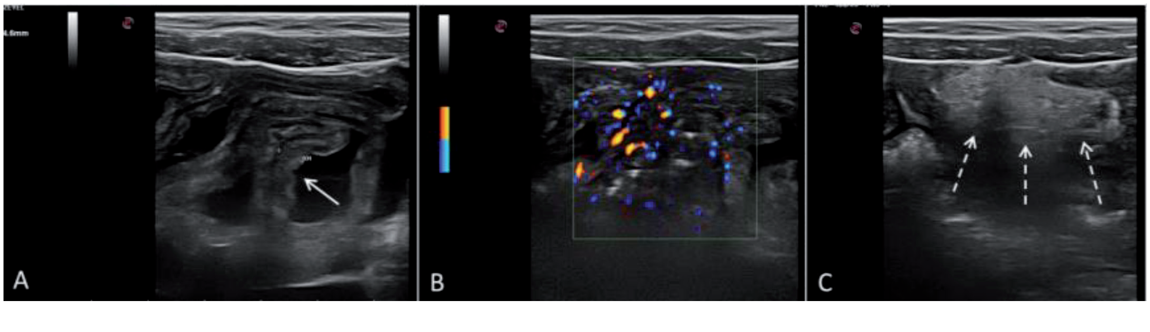

Figure 5.
An 8 year-old-girl with Henoch-Schönlein Purpura. (A) Ultrasound shows diffuse thickening of the intestinal wall (arrow). (B) Color Doppler demonstrates increased vascularity. Gray scale ultrasound from another part of abdomen (C) reveals hyperechoic mesenteric fat tissue (dashed arrows).

Bacterial enterocolitis can occur by a wide variety of pathogens, including *E. Coli*, *Salmonella*, *Shigella* and *Campylobacter*. Common location is ileocecal region and US features are similar to other inflammatory disease, such as bowel wall thickening, increased echogenicity, reactive mesenteric lymph nodes, and mild intraabdominal free fluid. Viral gastroenteritis generally does not increase the thickness of the bowel wall; however enlarged lymph nodes and free fluid may be present [41]. *Tuberculosis* may also present with bowel wall thickening along with hepatosplenomegaly, omental thickening, and typical internal echoes and septations within ascites [54]. Parasites can be revealed by US as mobile, tubular hypoechoic structures with hyperechoic rim in *Ascariasis* infection, with parallel echogenic lines representing digestive system [41].

Neutropenic colitis, also known as typhilitis, is a necrotizing inflammatory process of cecum and terminal ileum usually seen in severe neutropenic and immunocompromised patients [39]. The typical US features are asymmetric, prominent wall thickening, with decreased echogenicity and loss of layering due to transmural inflammation. Echogenic foci can be seen in the bowel wall caused by circumscriptive hemorrhages or intramural air suggestive of anaerobic infection [55]. In thyphilitis, increased wall thickness may have correlation with a worse prognosis of the disease [41].

Pseudomembranous colitis is caused by the superinfection with *C. difficile*, often following a prior course of antibiotic treatment or rarely associated with shock, uremia, heavy metal intoxication or severe cardiovascular disease. The enterotoxin of *C. difficile* leads to severe inflammatory reaction within the colon between 1 and 6 weeks after the antibiotic treatment [24]. The common clinical findings are severe generalized abdominal pain, watery diarrhea, fever, and leukocytosis. The disease causes marked mucosal thickening of the colon, even thicker than other infectious colitis. On US, apart from thick hypoechoic mucosal layer, narrowing of the gut lumen and thickened hyperechoic submucosa can be demonstrated. In the majority of patients, the hypoechoic muscularis layer, which is outer than hyperechoic submucosa, appears normal and relatively thin. Intraabdominal free fluid is present in up to 77% of cases [24].

12. Mesenteric lymphadenitis

Mesenteric lymphadenitis is a benign, self-limiting inflammatory condition that affects the mesenteric lymph nodes, more frequently pericecal ones. It may either occur as a primary inflammatory disease or may arise secondarily due to an abdominal disease. Clinically, this condition is commonly mistaken for appendicitis, since the symptoms are quite similar [22]. As the lymph node enlargement is the only finding on US, the diagnosis is made by excluding other possible etiologies of abdominal pain.

Various nomograms for normal ranges of mesenteric lymph node size have been reported and short axis of > 5 mm for lymph nodes are very common in healthy children [3]. Simanovsky et al. [56] suggested that, in the setting of normal appendix, cluster of > 3 lymph nodes with short axis of > 10 mm should be diagnosed as mesenteric lymphadenopathy. Enlarged lymph nodes are often oval and perinodal fat tissue may appear hyperechoic (**Figure 6**). A preserved fatty hilum is seen as a hyperechoic area at the center with vascular pedicle on color Doppler imaging. If the shape of enlarged lymph nodes is round rather than being oval, cortex is eccentrically thickened and there is loss of fatty hilum, neoplastic process should be suspected [3].

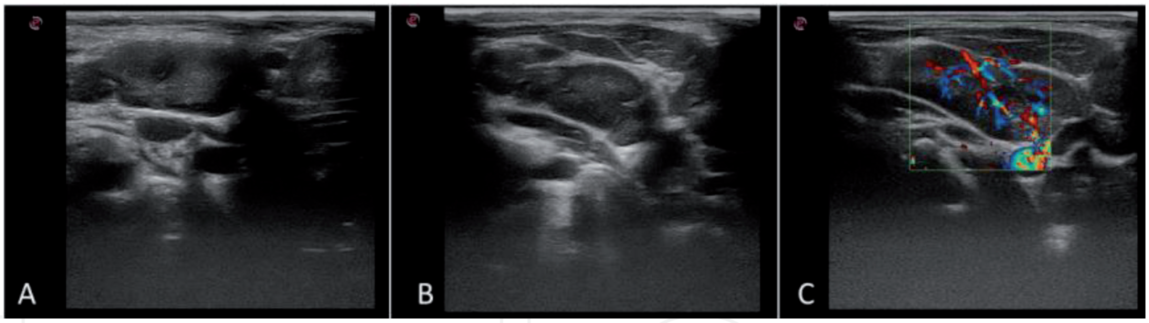

Figure 6.
Ultrasound (A,B) and color Doppler ultrasound (C) of the right lower quadrant of a 5-year-old girl diagnosed as mesenteric lymphadenitis. There are enlarged lymph nodes anterior to the iliac vessels. Color Doppler (C) demonstrates vascular supply from hilum of the lymph node.

13. Epiploic appendagitis and omental infarction

Epiploic appendagitis is the inflammation of epiploic appendages arise from the serosal surface of the large bowel. Torsion of the appendages results in venous occlusion, ischemia and inflammation [39]. Although predominantly encountered in adults, it is also described in children and should be kept in mind in the differential diagnosis of acute appendicitis because the treatment is supportive rather than surgery. Characteristic US feature is hyperechoic, fixed non-compressible oval mass-like lesion at the anti-mesenteric side of the bowel. CT is generally needed to confirm the exact diagnosis [57].

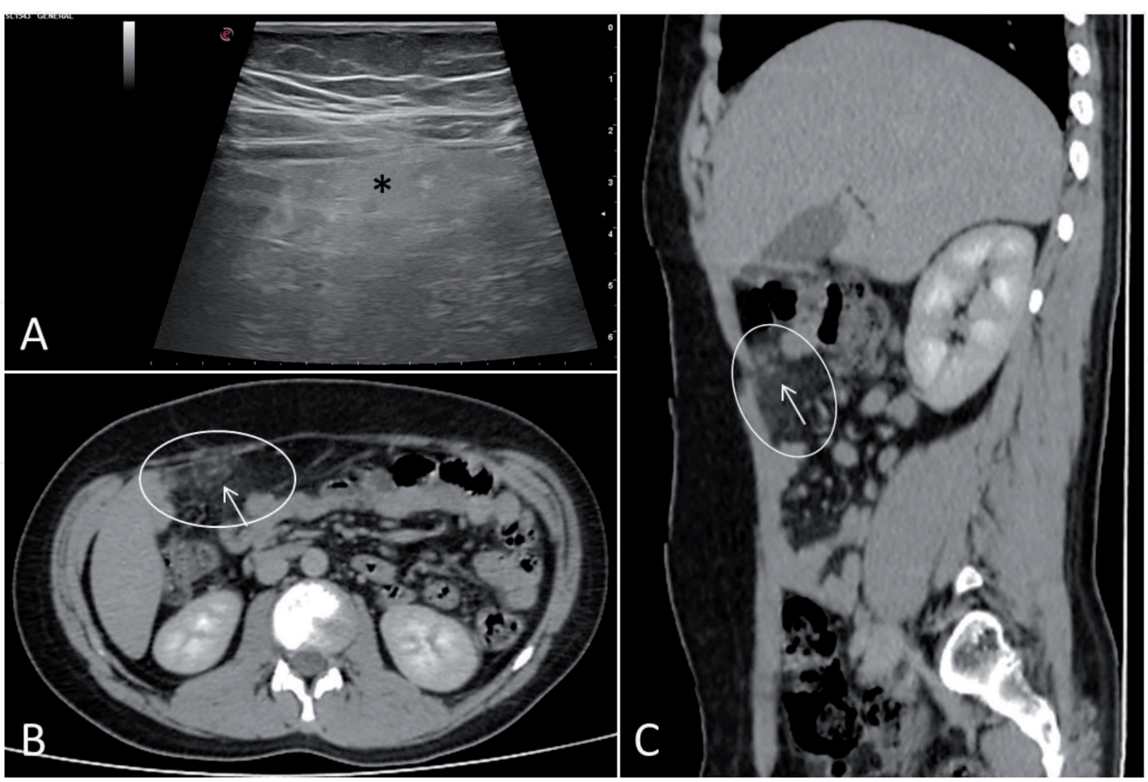

Figure 7.
Ultrasound image (A) of an 11-year-old boy demonstrates thickened hyperechoic mass (asterisk) with indistinct border beneath the anterior abdominal wall. Intravenous contrast enhanced axial CT (B) and sagittal reconstructed image (C) shows hyperdense omentum (white circles), hyperdense dot at the center of lesion (arrows). The dot can be followed on the contiguous images as a linear tortuous hyperdense structure consistent with twisted vein. Surgical removal of necrotic tissue confirmed the diagnosis of omental infarct.

Omental infarction is a rare cause of acute abdomen in children, even though 15% of all omental infarct cases occur in the pediatric population [3]. As the patients are commonly present with right-sided abdominal pain, it mimics appendicitis. However, associated nausea and vomiting is less frequent than appendicitis [24]. Predisposing factors include obesity, strenuous activity, coagulopathy and history of trauma to the affected region. The characteristic US feature is an ovoid or triangular hyperechoic mass located between the abdominal wall and the bowel, frequently in the right upper quadrant (**Figure 7**) [3]. In some cases, avascular hypoechoic tubular structure can be seen corresponds to a twisted vein. Although, some centers recommend conservative treatment, others prefer surgery to remove the necrotic tissue [24].

14. Inguinal hernia

In the setting of a groin mass or swelling, possible diagnoses are hernia, fluid collection, enlarged lymph nodes, and cryptorchidism, and for those US can be performed to differentiate. The most common type of inguinal hernia in children is the indirect inguinal hernia in which hernia sac protrude into the inguinal canal [41]. Inguinal hernia is more common in preterm neonates and more frequently occurs on the right side because the right processus vaginalis closes later than the left. One-third of all infants with hernias become symptomatic before 6 months after birth, and males are affected more than females with a ratio of 6:1 [58]. Hernia sac frequently includes fluid in the processus vaginalis with or without bowel loops and other abdominal structures such as omentum, testes, ovaries, bladder and fallopian tubes. If hernia sac contains intestine and other abdominal structures; possibility of spontaneous regression reduces and incarceration risk increases. Hence, early diagnosis and surgery is very important in order to prevent complications and possible damage to the ipsilateral testis [6, 58].

The diagnostic accuracy of US to detect inguinal hernia is 97% in surgically confirmed cases with the sensitivity of 92.7% and the specificity of 92.7% [6]. Internal inguinal canal diameter > 4 mm is 95% diagnostic for indirect inguinal hernia. Real-time imaging on US is the biggest advantage among other modalities, with the patient performing a Valsalva maneuver (or provoke to cry in infants or babies) in both supine and upright views that enlarge the hernia sac and protrude through the inguinal canal with increased intraabdominal pressure. US can also be able to reveal peristalsis of herniated bowel segment with dynamic scan. Large inguinal hernias may lead to testicular ischemia by compressing the gonadal vessels within the inguinal canal [59]. Therefore, ipsilateral testis should be evaluated with US and color Doppler to assess intratesticular blood flow in the setting of inguinal hernia. While, evaluating a patient with an inguinal hernia, US should be performed to both inguinal canals because a clinically occult contralateral hernia can be found in 88% of cases [58].

Incarceration is a remarkable complication of indirect inguinal hernia and occurs with a frequency of 31% in children [58]. The most common incarcerated contents of hernia sac are the bowel, ovaries, and fallopian tubes. An incarcerated inguinal hernia may gradually progress to a strangulation, in which vascular supply is compromised and the necrosis of incarcerated contents occur. On US, incarcerated bowel shows circumferential thickening of the wall, aperistalsis, fluid level in the herniated loop, free fluid in the hernia sac and intraabdominal bowel dilatation (**Figure 8**). Incarcerated or strangulated hernias may not demonstrate clear continuity with abdominal bowel loops. Color Doppler may demonstrate absent vascularity in the hernia sac as a late finding of strangulation [41]. The presence of peristaltic activity in the herniated bowel loop is strong evidence against strangulation.

Figure 8.
Ultrasound of an indirect inguinal hernia of an 8-week-old baby (A,B,C). Along with bowel, blind ending appendix (arrow) is herniated into the inguinal canal, called as Amyand hernia. (B) There is some fluid (dashed arrow) within the hernia sac and (C) transverse section of distal appendix is seen at the same level with penile shaft (asterisk).

15. Foreign bodies and gastric bezoar

Coins are the most common foreign material ingested, and most of them are not able to reach intraabdominal GI tract [41]. Two-third of those is located at the level of cricopharyngeus muscle that requires urgent endoscopic removal. In the radiologic evaluation of the ingested foreign body, plain radiographs are frequently the modality of choice. Nevertheless, all foreign bodies are not visible on plain films, depending on composition of the material and location within the body. US may provide additional information about the foreign bodies trapped in the intraabdominal GI tract [60]. However, diagnostic performance of US to detect intraabdominal foreign body is not known to date. Most of the foreign bodies in bowel appear as fixed, hyperechoic structure that often demonstrate posterior acoustic shadowing with a cleaner shadow than bowel gas [6]. Linear, high frequency transducers should be used with graded compression to evaluate intraluminal contents. Administration of 200–300 mL of oral water before the examination may facilitate the detection of foreign bodies within the stomach [41].

A bezoar consists of ingested foreign objects that cluster within the GI tract. The most common types are trichobezoars (composed of hair) and phytobezoars (composed of greengrocer fibers) and they usually accumulate in the stomach [39]. Sometimes enlarged bezoars reach to the small bowel and cause obstruction. Prior history of gastric surgery is an important predisposing factor to develop bezoar due to delayed gastric emptying [41]. On US, regardless of the originated fiber, bezoar is shown as an intraluminal mass with hyperechoic arc-like (curved or "inverted U" shape) anterior surface and prominent acoustic shadowing (**Figure 9**). Color Doppler

Figure 9.
A 12-year-old girl with a history of compulsive trichophagia disorder. Upper abdomen sonography with convex-array transducer (A) and linear-array transducer (B), demonstrates curvilinear echogenicities beneath the anterior wall of the stomach (arrow) and duodenum (dashed arrow) with clear, marked black posterior shadow. On endoscopy (C), trichobezoar was removed from her stomach and proximal duodenum.

can be used as a supportive modality which demonstrates 'twinkling artifact' behind the hyperechoic surface [39]. Bowel obstruction and proximal dilatation may be revealed as associated features.

16. Conclusion

While evaluating the etiology of acute abdominal pain in pediatric patients, US should be the initial imaging modality, as US is sufficient to diagnose several diseases that cause abdominal pain, far beyond only appendicitis and intussusception. Even if the underlying cause has not been identified, US will show indirect signs that indicate the need for a surgical exploration or provide supplemental information for CT and MRI. Therefore, it is crucial to be aware of the full potential of targeted bowel US with proper selection of the transducers, optimal positioning and the application of graded compression technique. Good quality examination requires experience, training, time and attention to perform a detailed evaluation of as many bowel loops as possible, minding their morphological features and their functional characteristics. Radiologists should be familiar with the sonographic appearance of both the normal and abnormal GI tract in order to provide the optimal treatment options for pediatric patients with acute abdominal diseases.

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