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PICTORIAL ESSAY

Ultrasound in newborns and children suffering from non-traumatic acute abdominal pain: imaging with clinical and surgical correlation

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Abstract The purpose of this article is to review ultrasonographic appearance of the most common causes of non-traumatic acute abdominal pain in pediatric patients and to understand the applications and limitations of this technique giving a practical approach showing different clinical cases. A pictorial review of cases was made presenting the most common causes of neonatal and pediatric non-traumatic acute abdominal pain; sonographic features are discussed. Ultrasound in conjunction with Color Doppler imaging is a valuable tool in the evaluation of neonatal and pediatric non-traumatic acute abdominal pain; causes of acute abdomen in children could vary depending on the ages of the children.

Keywords Paediatric abdominal pain · Ultrasound · Appendicitis · Hypertrophic pyloric stenosis · Intestinal intussusception

Riassunto Lo scopo di questo articolo è stato di revisionare le caratteristiche ecografiche delle più comuni cause di dolore addominale in pazienti pediatrici, per comprendere le applicazioni ed i limiti di questa tecnica con un approccio pratico, presentando diversi casi clinici. Abbiamo revisionato i reperti ecografici delle più comuni cause di dolore addominale acuto pediatrico e neonatale non traumatico, infatti l'ecografia integrata dall'esame Color Doppler è uno strumento importante nella individuazione delle cause, che possono variare in base all'età dei pazienti.

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Background

Non-traumatic acute abdominal pain is a common cause of presentation in the Pediatric Emergency Department. Evaluation of the child with acute abdominal pain is challenging because of the wide range of potential diagnosis, which include congenital and acquired lesions [1]. In children the localization of abdominal pain is not indicative of a specific pathology as in the adults; inability to give reliable history, atypical clinical presentations and many extra-abdominal causes and the painful abdomen in children often causes difficulties in arriving at the correct diagnosis [2]. The causes of the acute abdomen in children vary depending on the ages of the children. The role of diagnostic imaging, in particular of ultrasound (US), is to determine whether the acute abdominal pain is due to a surgically or medically treatable disease and, when possible, to diagnose the exact nature of the pathology. The goal

of emergency management is to identify and treat any life-threatening medical or surgical condition and relief from pain. US in conjunction with color Doppler study is helpful for assessing organ perfusion and diagnosing inflammation [3]. US is extremely beneficial in the evaluation of acute pediatric abdominal diseases, allowing, in most cases, the visualization of the direct cause, without ionic radiation use, and helping in delineating the management plan of the patients [2, 4].

Gastrointestinal tract pathologies

Hypertrophic pyloric stenosis (HPS)

The classic clinical presentation of HPS is non-bilious, projectile vomiting and dehydration (with hypochloremic metabolic alkalosis) in a full-term newborn, which is between 2 and 8 weeks old. Premature infants tend to present HPS at 3–6 weeks from birth. In HPS, the circular muscle layer becomes thickened, narrowing the pyloric channel and elongating the pylorus. On physical examination, if the newborn is relaxed, a pyloric mass (i.e., olive) can be palpated in the epigastrium or upper abdominal quadrants. US is the golden standard technique for diagnosing HPS, specific signs are:

1. Elongation of the pyloric channel: DL >17 mm (range 15–20 mm)
2. Antero-posterior diameter of the pylorus >12 mm
3. Thickness: >2 mm (range 2.5–4 mm) (Fig. 1).

Ultrasonographic indirect signs of HPS include: gastric distension, gastric hyperperistalsis, alteration of gastric peristalsis and subsequent gastroesophageal reflux, shoulder sign (due to the bulging of the hypertrophied pyloric muscle visible on barium examination), beak sign (the entrance to the pylorus may be beak shaped), double track sign (Fig. 2) [7].

Cohen HL et al. performed a fluid-aided real-time ultrasonographic examination of ten cases of HPS, showing the US equivalent of the "double track" sign. This finding is the consequence of gastric fluid compressed into smaller tracks as it is impinged upon circumferentially by the thickened circular muscle and could be adopted as ultrasonographic diagnostic criterion. In case of negative US and persisting non-bilious vomiting, further radiological exams as gastrointestinal study should be employed. This study is more effectively to rule out other medical or surgical causes such as malrotation, antral web and gastroesophageal reflux [4, 7].

Intestinal intussusception

The incidence of intestinal intussusception is highest in the first and second year of life, with a peak age between 3 and 9 months. Intussusception is the acquired invagination of one portion of the intestine into adjacent bowel. The traditional diagnostic approach is being changed from plain radiography and enema examination to plain radiography and US [8]. The condition involves in 80–95 % of the cases ileum and cecum. The ileo-ileal, jejuno-jejunal, ceco-colic and colo-colic intussusceptions occur rarely. Intussusception is usually idiopathic in the first year of age, while in children older than 2 years a pathologic lead point could be suspected. Differential diagnosis includes different causes as: appendicitis, lymphoma, Meckel's diverticulum, celiachia, gastrointestinal duplication cyst, etc.

On cross section, the usual ultrasonographic image (Fig. 3) has a "target" or "doughnut" appearance (generated by alternating echogenic and hypoechogenic rings);

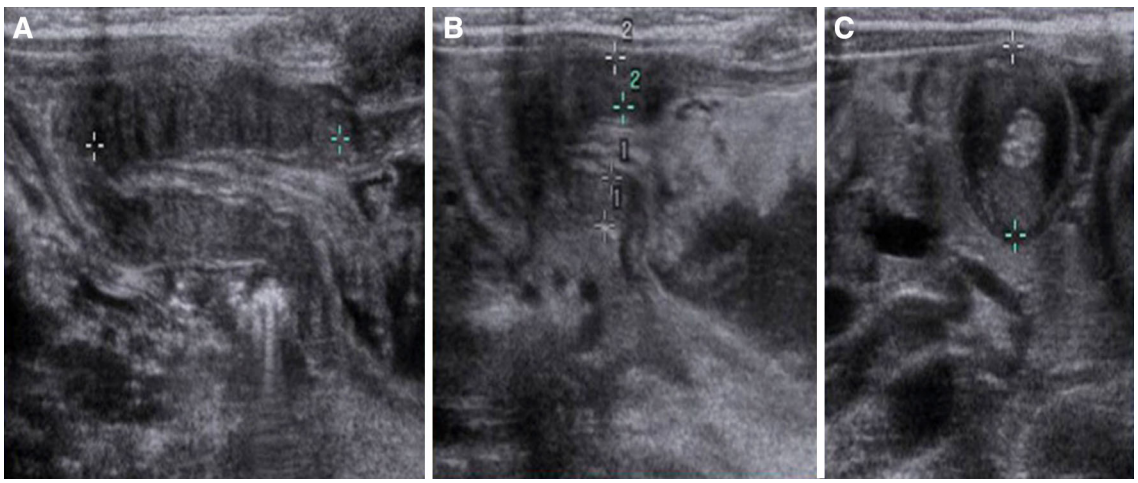

Fig. 1 HPS. US long-axis view through the hypertrophied pylorus shows an elongated (**a**) and thickened pyloric channel (**b**). Short axis (**c**) view shows an increased antero-posterior diameter of the pylorus; the muscularis layer is also hypoechoic

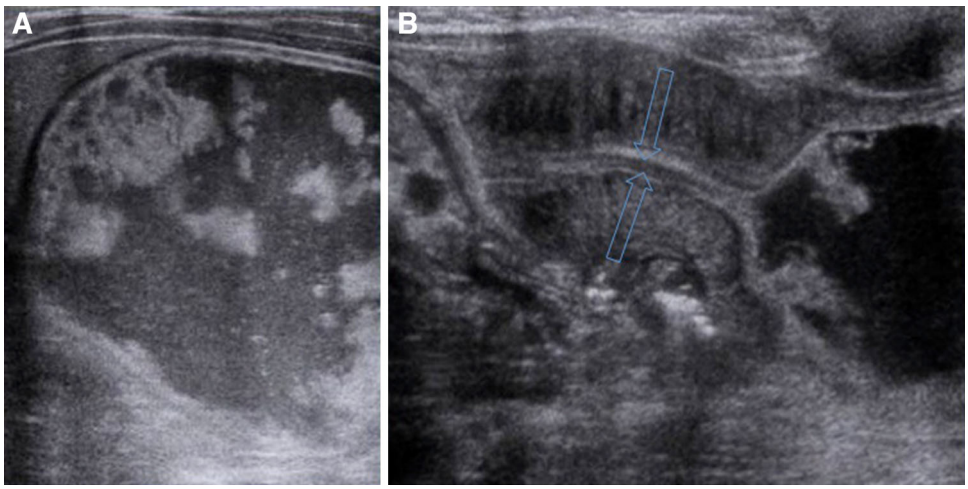

Fig. 2 Sonographic indirect signs of HPS. **a** Gastric distension, debris and fluid are seen in the stomach. **b** Longitudinal oblique sonogram through the pylorus showing the double track sign. *Two arrows* point to echopenic parallel lines noted within a thick-walled elongated pylorus

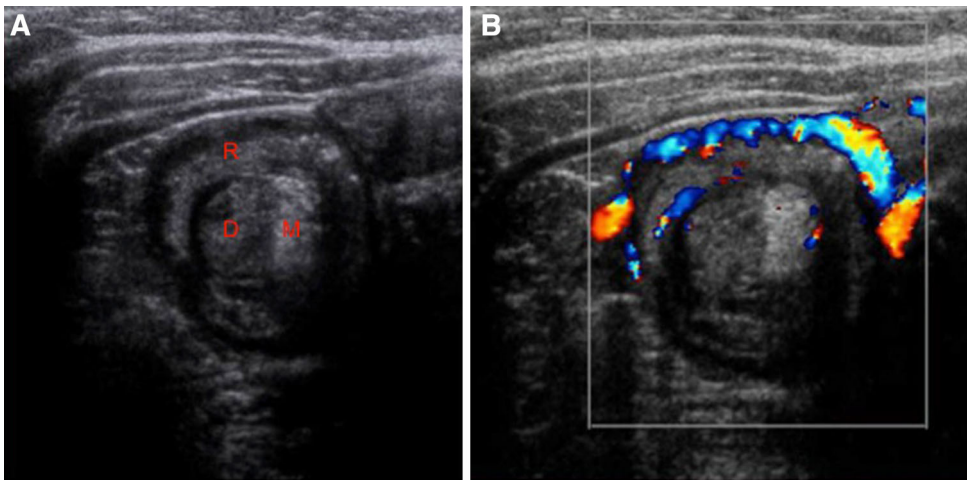

Fig. 3 Intestinal intussusception. **a** Sagittal US image demonstrates the target sign: the intussuscipiens (receiving loop *R*) contains the infolded intussusceptum (donor loop *D*), the attached mesentery (*M*) is dragged between the two limbs. **b** *Color Doppler image* shows the double ring sign

the longitudinal appearance is that of a pseudo-kidney characteristic of thickened bowel (the mesenteric fat, dragged into the intussusception, containing vessels, is reminiscent of the renal hilum and the edematous bowel recalls the renal parenchyma) [1, 8]. Other ultrasonographic signs suggestive of intussusception are: double ring sign at color Doppler US, large nodes, free fluid and bowel distention. In case of recent onset of intussusception and absent blood in the feces, it is possible to observe spontaneous resolution of the pathology during the US. Indicators of ischemia and irreducibility are: trapped fluid and absence of blood flow at color Doppler imaging. In our institution, we usually perform US-guided hydrostatic reduction by contrast enema (Fig. 4). Hydrostatic reduction is complete when the contrast medium freely flows through the ileocecal valve into the terminal ileum. The aim of enema therapy is to reduce the greatest number of intussusceptions without producing perforation. Barium, water-soluble contrast media, water, electrolyte solutions, or air may be used with radiographic or ultrasonographic guidance [5, 8].

Acute appendicitis

Acute appendicitis represents 80 % of surgical pediatric emergencies. Clinical presentation could be unusual, especially in the patients under 5 years, so it could be diagnosed in the later stage when an abscess or diffuse peritonitis has already occurred [9]. Clinical signs and symptoms of acute appendicitis are: abdominal pain, fever, elevated WBC, nausea, leg pain, lower right thoracic pain, etc. At US (Fig. 5) the appendix appears enlarged, thickened, with endoluminal fluid and/or appendicolith (Fig. 6); other US findings are the mesenteric hyperechogenicity, lymphadenopathies, free fluid, abscess (Fig. 7) [5, 9]. Color Doppler examination can show an increase of vascularity of the appendiceal wall in the first stage and loss of vascularity in the later stage [3]. Failure to identify the appendix by US or identification of a normal appendix less than 6 mm in diameter makes the diagnosis of appendicitis very unlikely. Differential diagnoses include: Crohn's disease, ovarian pathologies, mesenteric adenitis, nephrolithiasis and Meckel's diverticulitis (Fig. 8) [1, 3, 6, 7, 10].

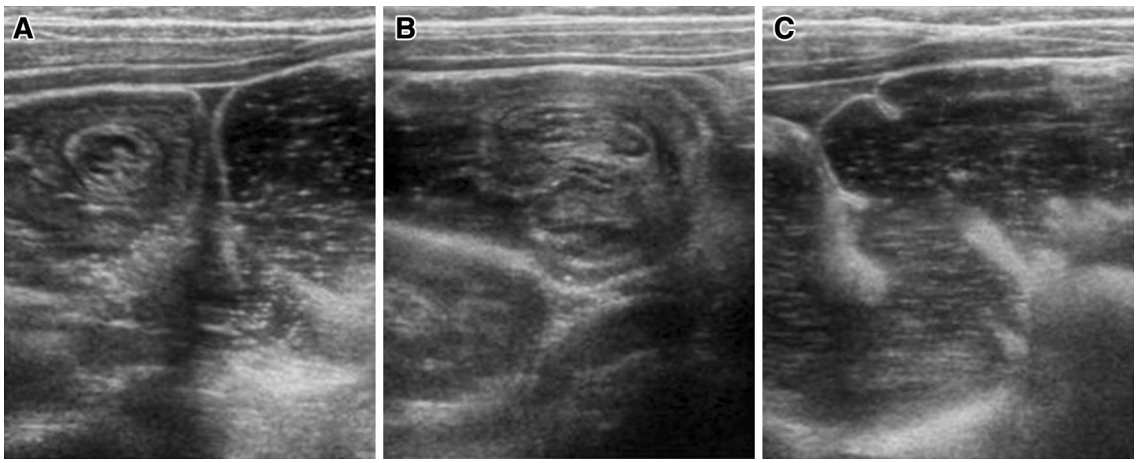

Fig. 4 US-guided hydrostatic reduction. **a** The head of intussusception is seen as the classical sandwich sign that is being pushed backwards by fluid enema in a 3-month-old boy with idiopathic intestinal intussusception. **b** The head of intussusception is surrounded by echo free fluid close to the ileocecal valve in the longitudinal plane. **c** After successful reduction, Ileal loops are visualized being fluid filled

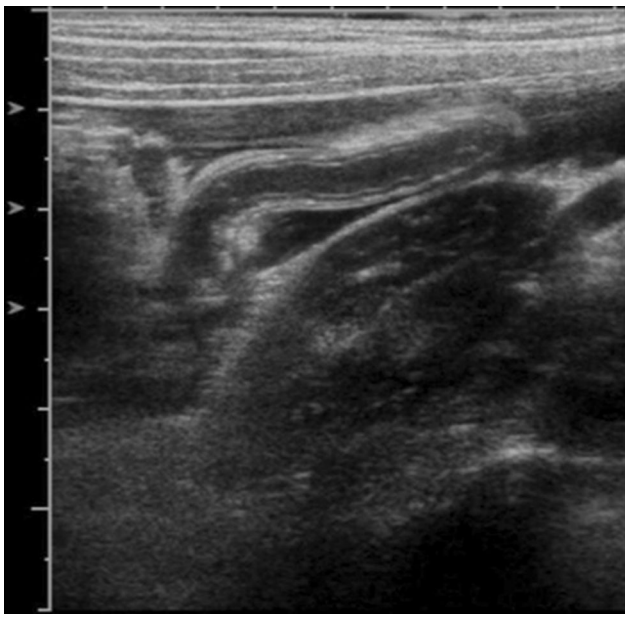

Fig. 5 Acute appendicitis. 11-year-old patient presenting with right lower quadrant pain. US image shows a typical blind-ending tubular structure, suggestive of appendix, measuring 12 mm in diameter, surrounded by free fluid. US image shows also echogenic periappendiceal fat, a finding that is sometimes referred to as a "hyperechoic halo" and indicates inflammation

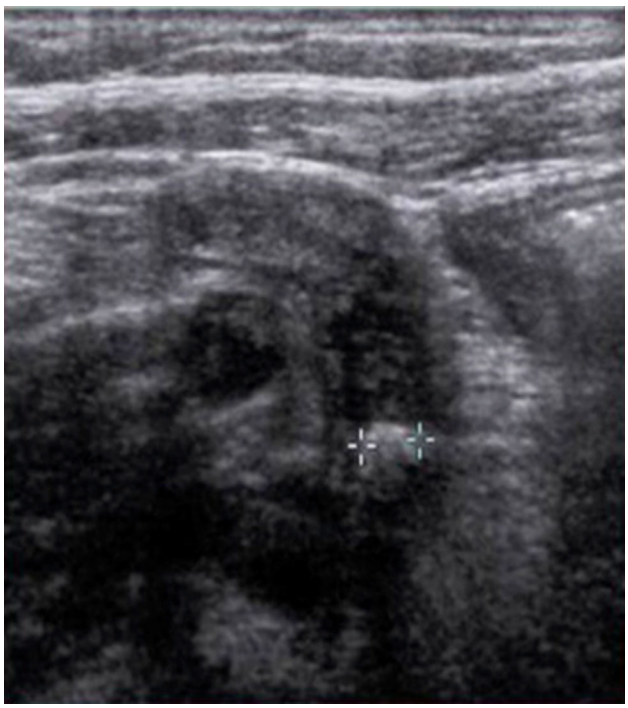

Fig. 6 Acute appendicitis. US image shows a dilated appendix that contains an echogenic appendicolith (caliper) with associated posterior acoustic shadowing

Mesenteric adenitis

Mesenteric adenitis is a self-limited inflammatory process that affects the mesenteric lymph nodes especially in the right lower quadrant. Commonly this condition is mistaken for appendicitis, as the signs and symptoms are very similar. It is classified as primary or idiopathic and secondary, depending on an identifiable inflammatory process [3, 7].

US (Fig. 9) shows several enlarged nodes in the mesentery, usually 5 or more nodes are present which are often clustered. Nodal tenderness in response to transducer pressure is typical. Nodes are more rounded and hypoechoic than normal. The demonstration of hyperemia within the node and surrounding mesentery with color Doppler imaging is variably reported.

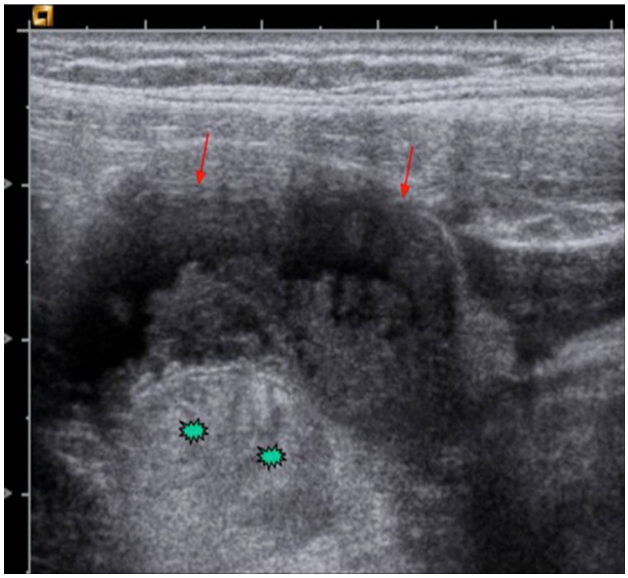

Fig. 7 Appendiceal abscess. 9-year-old boy presenting with right lower quadrant pain. US image shows a sausage-shaped heterogeneous collection (*red arrows*) in the right iliac fossa suggestive for abscess. The collection is surrounded by inflamed non-compressible hyperechoic tissue representing omentum and mesentery (*asterisks*). An appendiceal abscess was confirmed at surgery

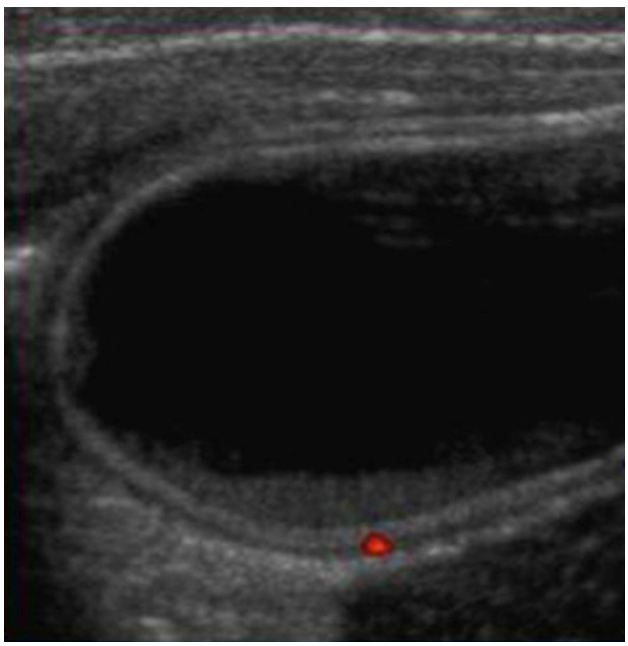

Fig. 8 Meckel's diverticulum. US shows a fluid-filled, blind-ending, structure in the right lower quadrant; it is also evident the hyperechoic mucosa (gut signature)

Omental torsion

Omental infarction is a rare cause of acute abdomen in children. It is found in 0.1–0.5 % of pediatric patients undergoing abdominal exploration for a suspected acute appendicitis. Torsion of the omentum is a condition in which the organ twists along its major axis to such an extent that its vascularity is compromised. Even if rare, omental torsion should be considered as a differential diagnosis by pediatric surgeon and radiologist for acute persisting abdominal pain, particularly in obese children [8, 9]. The typical ultrasonographic appearance (Fig. 10) of the infarcted omentum is a hyperechoic, no-compressible, ovoid intra-abdominal mass adherent to the anterior abdominal wall [11, 12].

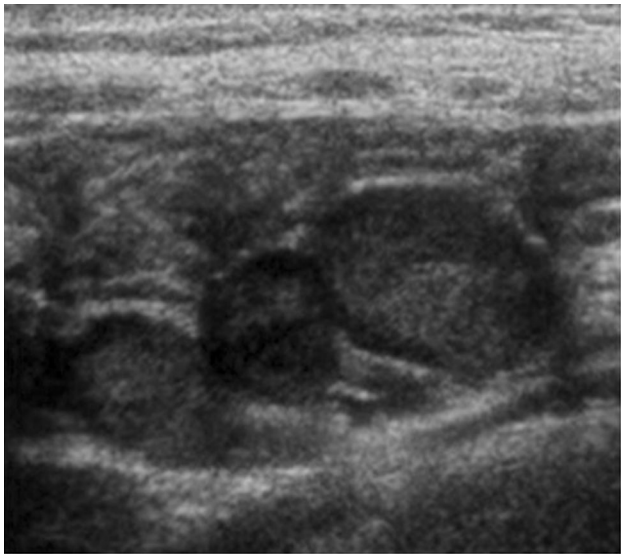

Fig. 9 Mesenteric adenitis: US image shows multiple, hypoechoic, rounded mesenteric lymph nodes in the *right lower quadrant*

Small intestine duplication

In 1937, Ladd introduced the term duplication of the alimentary tract. This condition consists of a group of congenital anomalies with the following three characteristics: a well-developed coat of smooth muscle is present; an epithelial lining which represents some portion of the alimentary tract; a straight connection with some portion of the gastrointestinal tract. Clinical presentation depends on the type, size, location, and mucosal lining of the duplication. They could be classified into cystic and tubular. Cystic duplications of the small intestine can be an anchor points for intussusception or can result in volvulus, whereas long tubular duplications with proximal communication drain poorly, and retention of intestinal contents can obstruct adjacent intestine. The diagnosis is often not established before surgery even if US could be helpful in identification of these lesions or their complications. The typical sonographic appearance (Fig. 11) of duplications is an inner hyperechoic rim of mucosal–submucosal tissue and an outer hypoechoic muscular layer [6, 10].

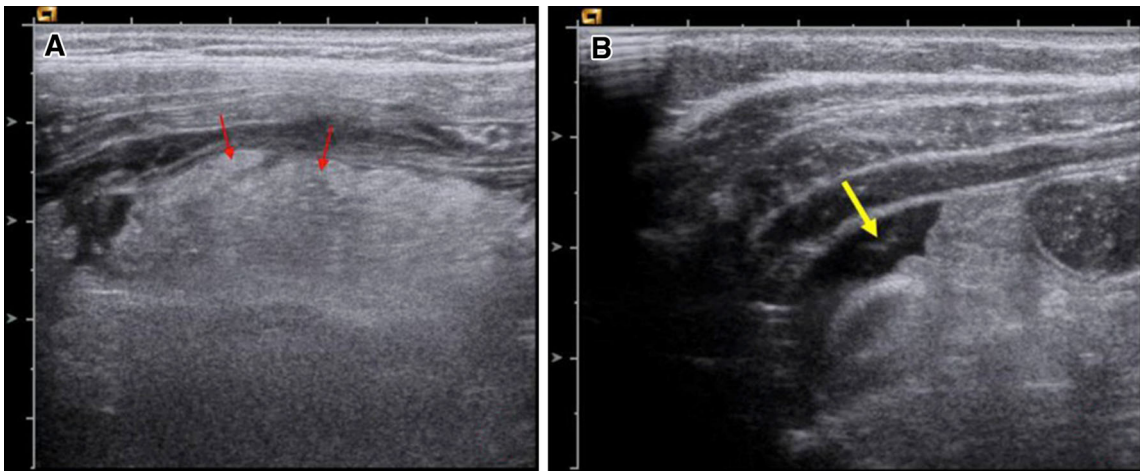

Fig. 10 Omental torsion. **a**, **b** 10-year-old boy presented with symptoms and signs suggestive of appendicitis. The ultrasound examination of abdomen showed hyperechoic intra-abdominal fat (*red arrows*) associated to the presence of intraperitoneal fluid (*yellow arrow* in **b**) and dilated bowel loops (*black arrow* in **b**). The appendix could not be visualized. Surgery revealed torsion of a segment of the greater omentum

Fig. 11 Duplication cyst. A well-defined transonic cystic structure adjacent to the small intestine. The cyst has a thick wall consisting of two distinct layers (*outer* hypoechoic, *inner* echogenic) and inhomogeneous fluid content

Other causes of gastrointestinal pain

Necrotizing enterocolitis

Necrotizing enterocolitis (NEC) is a serious abdominal disorder of premature newborn; it usually affects the terminal ileum and the ascending colon [1]. Clinical signs and symptoms include: abdominal distension, hematochezia, apnea, acidosis, temperature instability and lethargy.

Plain abdominal radiography is still the current modality of choice for the evaluation of neonates suspected of having NEC [13].

Abdominal radiographs show pneumatosis, a thick-walled bowel, free air and portal venous air [5]. US offers some potential advantages over radiography, because it can detect small amounts of intramural gas or changes in bowel wall thickness or peristalsis. It can depict bowel mural thickness and echogenicity of the terminal ileum and ascending colon and may be useful when perforation and abscess formation are suspected [1]. Free and focal intra-abdominal fluid containing echogenic debris or a loculated right lower quadrant mass may suggest perforation and abscess formation. Color Doppler study may estimate bowel wall perfusion. US may also help to decide the appropriate time to restore oral feeding in the patient [1, 3].

Congenital intestinal obstruction

Congenital intestinal obstruction, as intestinal atresia, Hirschsprung's disease, meconium ileus or malrotation, is a common condition causing a distended and tender abdomen in an irritable newborn. Diagnosis of obstruction is usually made by plain radiography or by oral contrast studies. US can show, in these cases, free fluid, bowel distension, thickened bowel wall, intra-abdominal calcifications, iperperistaltism and absence of peristalsis [6]. In low intestinal obstruction, US may help to differentiate between small bowel obstruction and colonic obstruction. In addition, US can identify meconium ileus and meconium peritonitis and it is useful to diagnose enteric duplication cysts. Malrotation may be suggested by US if

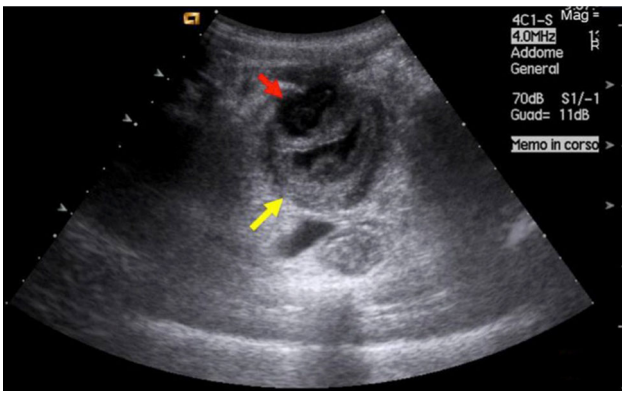

Fig. 12 Pyourachus. Axial US image shows a heterogeneous collection (*red arrow*) just beneath the anterior abdominal wall and adjacent to the dome of the bladder (*yellow arrow*)

the superior mesenteric vein is to the left or anterior to the artery [1].

Urinary tract pathologies

Acute dilatation of the renal pelvis can cause abdominal pain, particularly in younger children; obstruction is usually at the uretero-pelvic junction. Pyelonephritis with distension of the renal capsule can cause similar pain. In most children, pain is localized at the groin or flank. Clinical signs of urinary tract disorders are: dysuria, fever, abdominal pain, hematuria, pyuria, etc. US can show hydronephrosis and its degree (antero-posterior diameter), calyceal dilation, thinning of the renal parenchyma and stones. US is helpful in identifying thickened bladder walls and alteration of urine echogenicity.

Pyourachus

The urachal cyst originates from incomplete involution of the allantoic duct and the ventral cloaca between the umbilicus and the bladder. Infected urachal cysts, usually, present with lower abdominal pain, fever, midline hypogastric tenderness, palpable mass and evidence of urinary infection. US (Fig. 12) is usually employed for initial evaluation of suspected urachal cyst, which shows a midline cyst between the umbilicus and the bladder. In cases of infection (pyourachus), US can demonstrate wall thickening, internal debris and complex echogenicity [11, 14].

Gynecologic disorders

From birth through adulthood many gynecologic conditions may come to the surgeon and radiologist's attention.

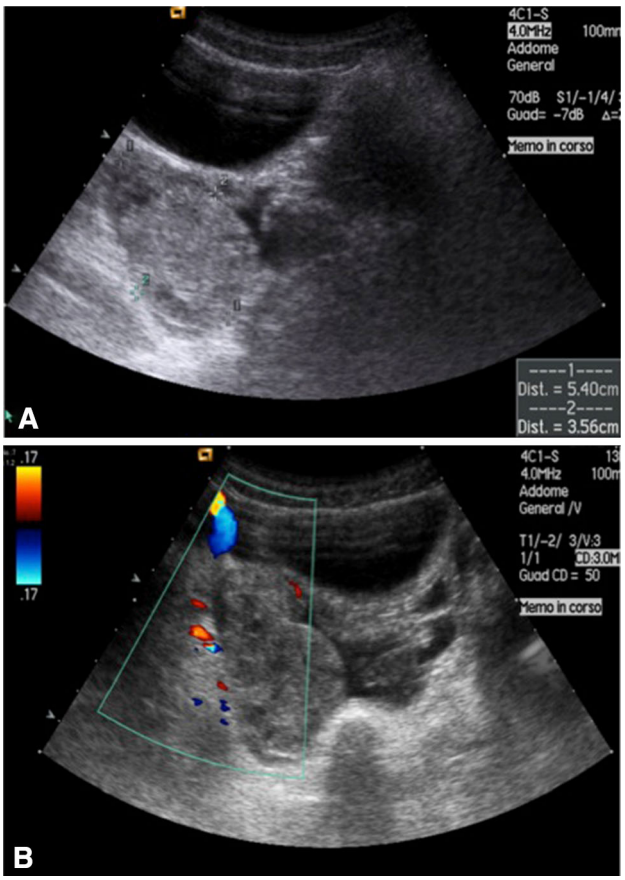

Fig. 13 Ovarian torsion. **a** Transabdominal sonogram showing a large, heterogeneous, left adnexa containing multiple small cystic spaces along its periphery. There is also free fluid surrounding the adnexa. **b** Color Doppler sonogram showing absent arterial and venous flow in the ovarian tissue

Acute gynecologic problems may mimic urologic or gastrointestinal surgical diseases. Imaging with US, or occasionally magnetic resonance imaging, is adjuvant to first-line examination and provides additional information on differential diagnosis.

Ovarian torsion

Ovarian torsion results from rotation of the ovary on its pedicle, producing vascular congestion and ultimately hemorrhagic infarction. It may occur in the presence of a cyst or a tumor or in normal adnexa. The twisted ovary appears, on US (Fig. 13), enlarged and with irregular echogenic areas within the ovary, corresponding to stromal edema and/or hemorrhage, is sonographically showed. Color Doppler US may be helpful in predicting vitality of adnexal structures by depicting blood flow within the twisted vascular pedicle and presence of central venous flow [1, 10].

Ovarian cysts

Ovarian cysts are one of the most common abdominal cystic lesions in the neonatal and infant females. The majority of ovarian cysts are asymptomatic. Symptoms may arise from complications such as torsion, rupture and hemorrhage. Simple cysts are anechoic, with thin wall, with no internal debris or septations whereas, on US, complex cysts show internal echoes, septations or debris, subsequent to hemorrhage (Fig. 14). Management depends on the size and presence of complications, US is crucial to make a correct diagnosis and to establish the best approach. In our institution, surgical treatment is indicated in presence of complex lesions or cysts measuring more than 5 cm, in diameter to avoid future complications [3, 7, 15].

Neonatal hydrometrocolpos

Neonatal hydrometrocolpos is a rare condition that follows congenital vaginal obstruction usually due to imperforated hymen or rarely by: vaginal stenosis, lower vaginal atresia, and cervical stenosis. It may present in infancy with a lower abdominal mass, or be delayed till menarche. The clinical features of hydrometrocolpos in the newborn are dominated by the abdominal mass with regional compression. Compression of the lower urinary tract has been reported to cause hydronephrosis, but compression of the gastrointestinal tract with obstruction to the passage of meconium is rare. On US an expanded fluid-filled vaginal cavity associated with distention of the uterine cavity characterizes it [12, 16].

Hematometrocolpos/hematocolpos

It refers to a blood-filled distended uterus and vagina. It occurs in presence of an imperforated hymen, vaginal

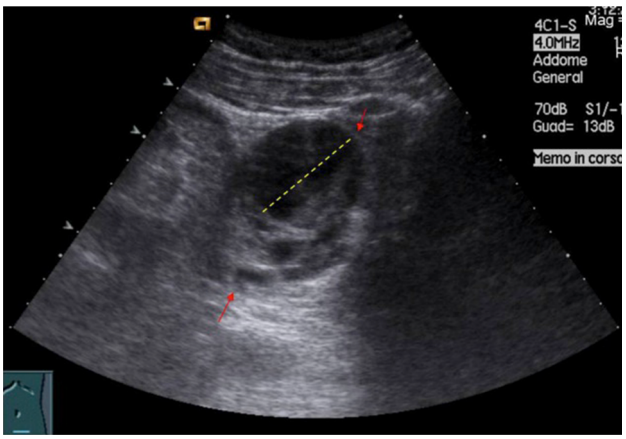

Fig. 14 Ovarian cyst. Ultrasound image shows fine fibrinous strands within the cystic mass (*yellow dotted line*) in the right ovary, findings typical for hemorrhagic cyst

Fig. 15 Hematocolpos. Sagittal US findings show enlarged vagina, fulfilled of blood products

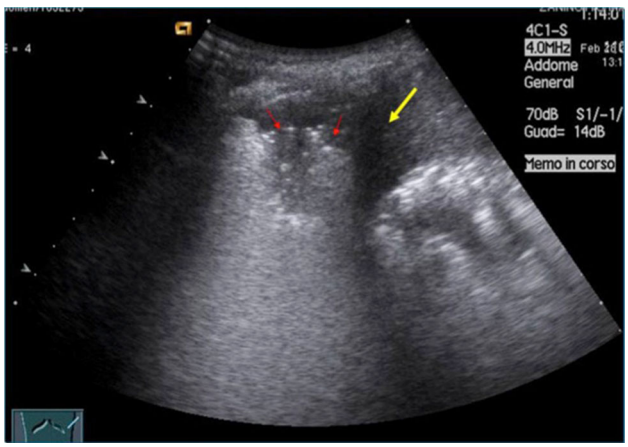

Fig. 16 Pneumonia. Lung consolidation (*red arrow*) with sonographic air bronchograms consistent with bacterial pneumonia. Pleural effusion is also seen (*yellow arrow*)

stenosis or vaginal atresia. The estimated incidence in teenagers is at ~1 in 1,000–2,000. Potential complications are: obstruction of regional lymph drainage or obstructive hydronephrosis. US provides a reliable means for rapidly diagnosing hematocolpos or hematometrocolpos (Fig. 15) showing enlarged and distended uterus and vagina [16].

Referred pain

Some extra-abdominal pathology, including diseases of the spine and chest, and metabolic disorders such as sickle cell anemia may appear as an acute abdomen. These conditions should be suspected if abdominal imaging findings are

negative. Pneumonia of the lower lobes may occasionally be diagnosed during the abdominal ultrasound examination (Fig. 16) [1].

Conclusion

In the different age groups of children admitted to the pediatric emergency department, non-traumatic acute abdominal pain may be caused by various etiologies. The most common causes in the newborns are: hypertrophic pyloric stenosis and intussusception; while in younger children are: intussusception, appendicitis and mesenteric adenitis. In the older children inflammatory bowel disease and ovarian pathology are also included in differential diagnosis. In the majority of cases, US is an optimal diagnostic tool in the initial evaluation of children with non-traumatic acute abdominal pain and can provide specific diagnoses, whereas in others valuable supplemental information can be obtained by computer tomography scan and magnetic resonance imaging [17]. Even when the underlying pathology is not identified, US will show indirect signs that indicate the need for a surgical exploration or further investigations [1, 10, 14, 15].

Conflict of interest Vincenza Di Giacomo, Margherita Trinci, Giulia Van Der Byl, Vincenzo Davide Catania, Alessandro Calisti and Vittorio Miele declare that they have no conflict of interest.

Human and animal studies The study described in this article does not contain studies with human or animal subjects performer by any of the authors.

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