Gastro-Intestinal Tract Radiology

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The main diagnostic techniques for gastrointestinal pathology in childhood have always been and still are plain abdominal radiographs and conventional contrast studies. However, gastrointestinal imaging has continued to evolve over time, with new techniques and methods gradually being added to the diagnostic procedures, particularly ultrasound (US), magnetic resonance imaging (MRI), and computed tomography (CT).

For gastrointestinal studies in children, it is important to know the indications for the different imaging techniques, to understand the relationship between the techniques, and to consider the use of these newer techniques rather than conventional radiological studies, also considering the role of prenatal diagnosis and how this has, in some cases, changed the diagnostic process.

The different diagnostic techniques for gastrointestinal tract studies in children are described here, noting for each the main indications and specific characteristics, bearing in mind that a diagnosis can be determined by a single investigation or can be the result of one or more studies.

The indications for each imaging modality, and the order in which examinations must be conducted, should be considered carefully to avoid unnecessary examinations. In the radiological examination of children, the problem of radiation protection should be addressed first and foremost, regardless of the part of the anatomy being imaged.

2.1 Imaging Techniques

2.1.1 Plain Abdominal Radiograph

The *plain abdominal radiograph* uses the natural contrast agent of air, and in the neonatal period is the examination most frequently used; in some cases it is the only one required for the diagnosis. In a healthy neonate, air can usually be identified in the stomach within minutes of birth, and within 3 h the entire small bowel usually contains gas. After 8–9 h, healthy neonates demonstrate sigmoid gas.

Delayed passage of gas through the neonatal gut may occur as a result of traumatic delivery, hypoglycemia, septicemia, or brain damage. Absence of gas in the bowel may be noted in neonates with severe respiratory distress who are undergoing mechanical ventilation, and in neonates undergoing continuous nasogastric suction.

The diagnosis of obstruction is based on some interruption of this dispersion of air. Radiography

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is the most valuable means of determining whether obstruction is present. This modality is often diagnostic; even if it is not, however, it may help to determine the next most useful diagnostic procedure [1–5].

Congenital anomalies causing incomplete obstruction (e.g., stenoses, webs, duplications, malrotations, peritoneal bands, aganglionosis) may not manifest until later in life, and other types of examinations (e.g., US and barium enema studies) are generally needed for diagnosis.

Abdominal radiography is often performed only in the supine antero-posterior (AP) view, especially in the neonatal period; only if required is the trans-lateral view with a horizontal beam added, and this allows the recognition of air-fluid levels and facilitates the visualization of pneumoperitoneum (Fig. 2.1). In pneumoperitoneum, in equivocal cases, the study can be completed by an additional view in the left lateral (LL) decubitus position, with a horizontal beam.

All cases of *pneumoperitoneum*, however determined, and *upper-obstructive conditions* have an exclusively radiographic diagnosis – duodenal atresia with a double-bubble sign; less frequently pyloric atresia, with a single-bubble sign; and jejunal atresia, with a few dilated loops causing upstream obstruction and complete absence of air downstream (Fig. 2.2). None of these conditions usually require further radiological evaluation after radiography: contrast studies are usually contraindicated, and additional procedures are not usually helpful and may even delay surgery, resulting in death.

The role of the plain abdominal radiograph combined with a chest radiograph in the diagnosis of *esophageal atresia* should be mentioned; this disease is suspected at prenatal US by the combination of polyhydramnios, reduced intraluminal liquid in the fetal gut, and inability to detect the fetal stomach.

Radiological confirmation of esophageal atresia is based on findings on AP and lateral chest radiographs, which show a blind pouch of the proximal esophagus, which is distended with air. Radiographic evaluation should always include the abdomen to assess the presence of gastrointestinal air due to the existence of the fistula, allowing the classification of tracheo-esophageal

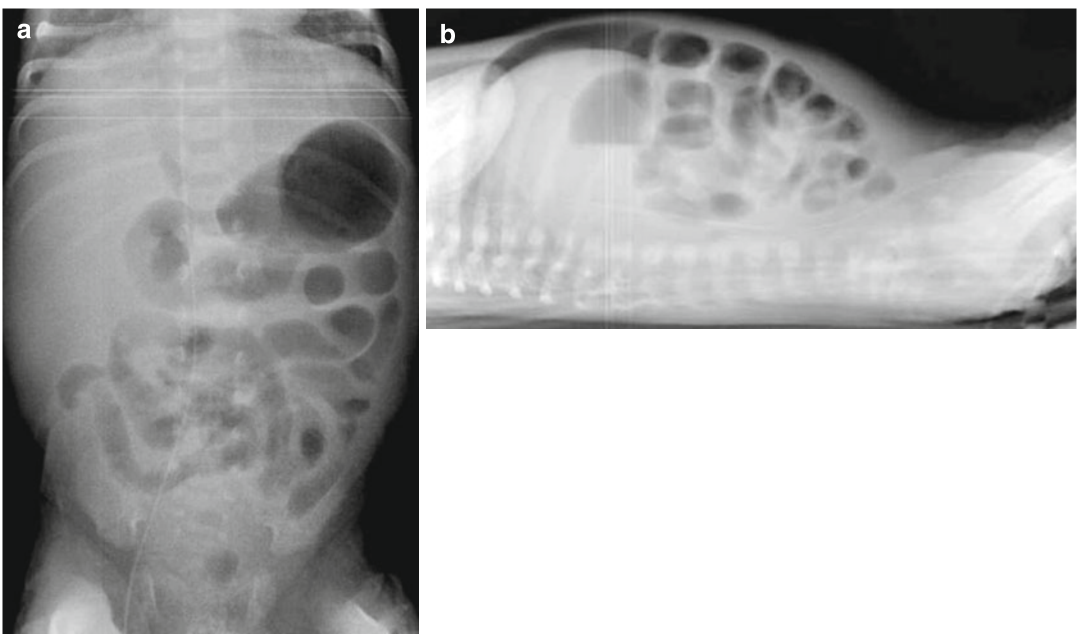

Fig. 2.1 Plain abdominal radiographs: supine antero-posterior view (**a**) and trans-lateral view (**b**) show the presence of pneumoperitoneum

atresia. In types I and II there is a complete absence of air in the stomach and bowel, whereas in types III and IV, air is commonly present.

When an H-shaped fistula without atresia is suspected, an esophagogram with low-osmolality water-soluble non-ionic contrast media can show the fistula [6].

The plain abdominal radiograph also has a role in the early diagnostic phase of *anorectal malformations*; in such cases, you need to perform, with classification intent, a plain abdominal radiograph in the trans-lateral prone view for the evaluation of the rectal cul-de-sac and its distance from the perineum.

Furthermore, this study allows you to detect the sacrococcygeal anomalies that are often found in caudal regression syndrome or other skeletal abnormalities in a more syndromic context (VACTERL association; vertebral defects, anal atresia, cardiac defects, tracheo-esophageal fistula, renal anomalies, and limb abnormalities).

2.1.2 Contrast Studies

Contrast studies remain as key to the demonstration of many diseases, both congenital and acquired. Their use, however, is slowly declining, thanks to the increased availability and dissemination of endoscopic techniques and video capsule endoscopy (VCE).

The aim of the modern radiologist is to work in close collaboration with the gastroenterologist and surgeon, to perform contrast studies only in selected patients, using the correct technique, at the lowest radiation dose possible to meet specific diagnostic questions.

Many diseases are also studied exclusively by a continuous fluoroscopy technique, by the last image-capture technique, or by pulsed fluoroscopy with capture of the acquired series. High-dose standard full exposures are reserved for cases of difficult diagnosis or when more definite anatomical detail is essential (e.g., in thin tracheo-esophageal fistulas).

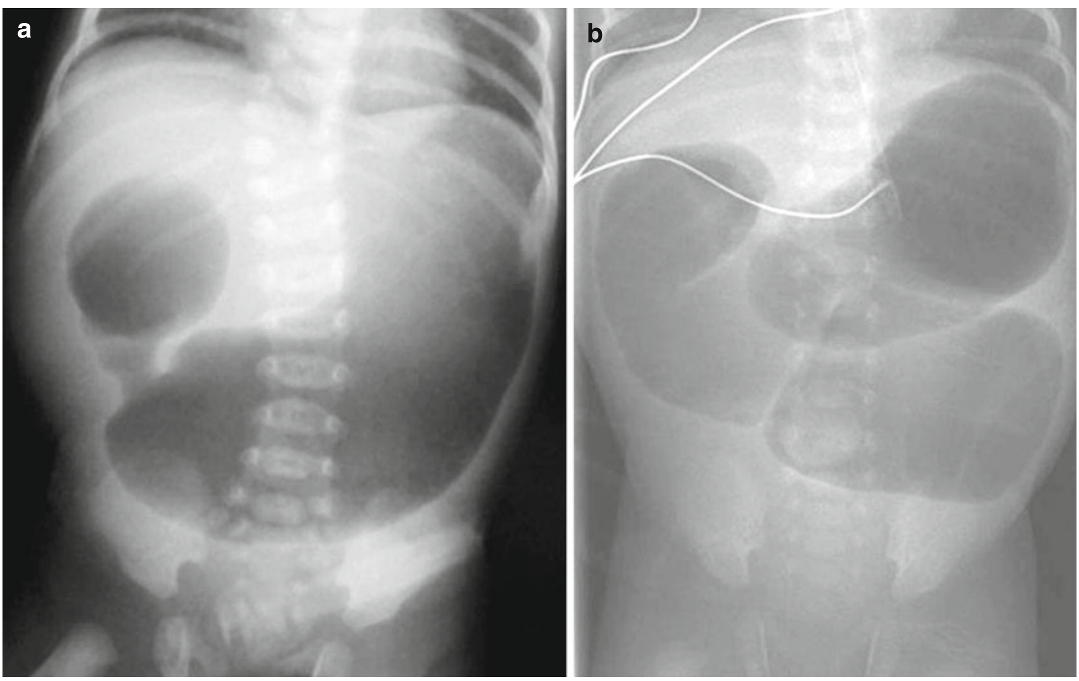

Fig. 2.2 Plain abdominal radiographs: duodenal atresia with the double-bubble sign, due to distension of the stomach and proximal duodenum (**a**) and jejunal atresia (**b**), with a few dilated loops and absence of air in the lower portion of the abdomen. Note the presence of thoracic right-side hemivertebra (**a**)

2.1.2.1 Contrast Studies of the Upper Gastrointestinal Tract

Contrast studies of the upper gastrointestinal tract are *upper gastrointestinal (UGI) series*, small bowel follow through (SBFT), and small bowel enema.

Upper Gastrointestinal (UGI) Series

In well infants or children, barium is the preferred contrast medium for UGI series.

For imaging of the esophagus, stomach, and duodenum there is a choice of barium formulations and the choice of preparation is at the discretion of the radiologist.

As mucosal detail is rarely required, or indeed obtainable in children, preparations with a lower density are used; these can be successfully diluted, do not settle out and set while in suspension, and do not flocculate in the time taken to perform the test.

In neonates, especially premature infants, and in circumstances where aspiration is a risk or a perforation of the gastrointestinal tract is suspected, a low-osmolality water-soluble non-ionic contrast medium is ideally used (Fig. 2.3).

The child should be starved for approximately 3–4 h before the study, or for the maximum gap between feeds if still breast-fed.

High-density high-osmolality water-soluble non-ionic contrast media should never be used because of the risk of aspiration and consequent possible serious complications, such as acute pulmonary edema [1, 3–5].

Although the 24-h pH probe is now the mainstay for making or confirming the diagnosis of reflux in children, UGI series are still used in many centers to confirm that the underlying gastrointestinal anatomy is normal. Conversely, the presence or absence of reflux during a routine UGI series should be noted, as this may be an important incidental finding.

Reflux often occurs immediately after the passage of the bolus (liquid or solid) through fractionally delayed closure of the gastro-esophageal junction (GEJ). Thus, if water is given (two or three consecutive mouthfuls are sufficient) even small amounts of reflux of barium at the GEJ may be captured. Beaking of the GEJ is a cardinal sign that reflux is likely to occur imminently, and if the radiologist sees this he/she should wait for a few more moments to see whether this is confirmed. If reflux does not occur after two or three episodes of drinking water then the child should be turned to the left lateral (LL) position and then slowly returned to supine. This encourages barium to wash over the GEJ, which may cause reflex relaxation of the GEJ with subsequent reflux. If after these two maneuvers reflux has not been demonstrated, then the study

Fig. 2.3 Upper gastrointestinal series: gastroesophageal reflux with massive aspiration

should be ended. There is no indication for tilting the child head down or for performing any other non-physiological reflux- or vomit-inducing maneuvers [3–5].

Although tube *esophagram* has traditionally been the gold standard examination for H-type tracheo-esophageal fistula, a contrast swallow (performed in the correct way) can be sufficient for making the diagnosis. However, a normal contrast swallow does not absolutely rule out the presence of a tracheo-esophageal fistula, and if high clinical concern remains, then a tube esophagram is still indicated.

The tube esophagram (as part of a UGI series) remains the test of choice in those children known to have a risk of aspiration or those being ventilated at the time of the study. UGI series may be performed for no other reason than to reveal an alternative explanation for the child's symptoms, such as significant reflux.

It is worth noting that even a contrast swallow followed by a high-quality tube esophagram does not always demonstrate an occult fistula, and in occasional cases bronchoscopy may also have to be performed. Similarly, bronchoscopy may miss a fistula revealed by a contrast study. The tests are therefore complementary [6].

SBFT and Small Bowel Enema

Both SBFT and small bowel enema examinations are in precipitous, and probably terminal, decline with the advent of VCE, MRI of the bowel, and the use of US in examining the bowel.

The SBFT may still be performed in specific circumstances, including the following: in preparation for elective gut resection for surgical planning, when information regarding small bowel transit is required (such as in pseudo-obstruction and dysmotility states); in suspected subacute obstruction, or obstruction (noting that in adults CT is now routinely used for this indication, but this is not standard practice in pediatrics due to radiation dose concerns); in confirming patency in anticipation of VCE in patients at high risk of stricture (including patients with *Crohn's disease*); in children who cannot tolerate VCE; and to assess complications of inflammatory bowel disease (IBD) if other modalities are not suitable.

The first part of the study is as for a UGI series, and the child can then sit outside the fluoroscopy room for another 20 min. The child should continue to slowly but steadily drink more contrast media during this time to ensure that there is a continuous column of contrast passing through the gut during the study. Serial images are then acquired at appropriate intervals to answer the clinical question [1–5].

2.1.2.2 Contrast Studies of the Lower Gastrointestinal Tract

Imaging of the lower gastrointestinal tract has not changed substantially over recent years, and a water-soluble contrast enema (for neonatal conditions) and, less frequently, a barium enema for older infants and children remain the mainstay of imaging [1–5, 7–11].

Loopograms have an important role in children who have a stoma. Low-density water-soluble contrast media is generally used, with the benefit that as more is instilled it does not become excessively dense and cause technical problems with exposure factors. However, there are a few instances, such as when trying to demonstrate a subtle fistula in an anorectal malformation, in which the limited use of denser water-soluble contrast media may be necessary to achieve sufficient definition. This will largely be at the discretion of the radiologist.

In neonates, enema studies are indicated in cases of bowel obstruction, especially lower intestinal obstruction.

Upper intestinal obstruction in neonates is characterized by bilious vomiting (which frequently occurs after the first feeding) and abdominal distension at clinical examination. Specific common causes of upper intestinal obstruction include atresia of the jejunum or proximal ileum and peritoneal bands. Partial obstruction can be caused by jejunal stenosis, peritoneal bands, duplication cyst, malrotation, and Meckel's diverticulum.

The generic diagnosis of upper intestinal obstruction is usually straightforward at radiography, which demonstrates a few dilated bowel loops, more than would be seen in duodenal atresia and fewer than in ileal atresia or other causes of lower bowel obstruction. There is no gas in the lower portion of the abdomen in jejunal atresia. The patient usually requires no further radiological investigation, although barium enema examinations are still performed in attempts to exclude second and third areas of atresia lower in the bowel. In isolated proximal atresia of the jejunum, the colon is normal in size, because the remaining small bowel distal to the atresia produces sufficient intestinal secretions to produce a normal-caliber colon [1–5].

Lower intestinal obstruction is defined as an obstruction that occurs in the distal ileum or colon. Signs include large bowel obstruction with vomiting, abdominal distension, and failure to pass meconium. The differential diagnosis includes ileal and colonic atresia, meconium ileus or peritonitis, Hirschsprung disease, and functional immaturity of the colon. Anorectal malformations are also an important cause of lower intestinal obstruction, but are almost always evident at physical examination.

The diagnosis of lower intestinal obstruction is usually apparent at abdominal radiography because of the presence of many dilated intestinal loops, but radiographic differentiation between ileal and colonic obstruction is difficult, if not impossible. This distinction can readily be made with a barium enema study, which helps to determine the presence of microcolon (Fig. 2.4), indicates the position of the cecum with regard to possible malrotation, and shows the level of the obstruction in colonic atresia [1–4].

Ileal atresia is an important cause of lower intestinal obstruction. Plain radiographs (AP and LL views) show numerous dilated loops of bowel occupying the entire abdominal cavity and multiple air-fluid levels. When this degree of distension is reached, the mucosal pattern of the small bowel is effaced and it may be impossible to differentiate small bowel from colon. In such a case, a barium enema study is mandatory to determine the presence of a colonic lesion. In ileal atresia, the colon has a normal location but a minute caliber (functional microcolon).

Fig. 2.4 Barium enema study shows severe functional microcolon

Colonic atresia is less common than ileal atresia. It is often indistinguishable from obstruction of the distal ileum, especially when the atresia is located in the ascending colon. The colon proximal to the point of atresia is often massively dilated, and a mottled pattern of gas and feces may be identified. Barium enema examination usually reveals a distal microcolon with obstruction to the retrograde flow of barium at the site of the atresia [2–5, 8].

Meconium ileus is the result of intraluminal obstruction of the colon and lower small bowel, due to the impaction of meconium, and represents the earliest clinical manifestation of cystic fibrosis. Mechanical obstruction occurs when desiccated meconium pellets occlude the distal small bowel and the more proximal small bowel loops are distended with tenacious meconium paste. The abdomen is filled with gas-distended loops and occasionally there is a relative absence of air-fluid levels due to abnormally thick intraluminal meconium. The admixture of gas with meconium may give rise to a soap-bubble appearance similar to the fecal pattern in the colon in older patients.

Contrast enema examination will show a functional microcolon, involving the entire large bowel, and may show impacted meconium pellets, particularly in the right colon or in the distal ileum, caused by retained meconium (Fig. 2.5). Meconium ileus is among the few pediatric conditions for which an enema is used, with high-osmolality water-soluble iodinated contrast, because of its therapeutic effects. Advantage is taken of the high osmotic pressure of the contrast medium: the surrounding tissue is forced to release considerable amounts of fluid, which then flows into the gut and dissolves the inspissated meconium. Therefore, the enema is both diagnostic and therapeutic, and can be followed by the expulsion of meconium during or after the procedure.

Meconium ileus may be complicated by volvulus of a distal intestinal loop, perforation, atresia, or peritonitis [2–4, 8, 9, 12].

Meconium peritonitis is a chemical peritonitis resulting from intrauterine bowel perforation. Common underlying disorders include small bowel atresia, meconium ileus, volvulus, and intussusception, although some cases are idiopathic. The extruded bowel contents provoke an intense peritoneal inflammatory reaction, leading to the formation of dense fibrotic tissue. This tissue often calcifies, resulting in the characteristic intraperitoneal calcifications identified prior to birth with US and after birth with abdominal radiography and US. The calcifications of meconium peritonitis may extend into the scrotum through a patent vaginal process to produce a calcified mass in the scrotum [2–5, 8, 9, 12].

Fig. 2.5 Contrast enema with high-osmolality water-soluble contrast in meconium ileus

Hirschsprung disease is a form of lower intestinal obstruction caused by the absence of normal myenteric ganglion cells in a segment of the colon. The aganglionosis varies in length but always extends proximally from the anal canal, and the rectosigmoid area is involved in most cases. Ultrashort segment disease (in which aganglionosis is essentially limited to the region of the internal sphincter) is very rare, as is aganglionosis involving the entire alimentary tract. In children with Hirschsprung disease, the absence of ganglion cells results in the failure of the distal intestine to relax normally. Peristaltic waves do not pass through the aganglionic segment and there is no normal defecation, leading to functional obstruction. Abdominal distension, constipation, and bilious vomiting are the predominant signs and symptoms of obstruction and appear within a few days after birth.

Radiography performed in children with Hirschsprung disease yields findings similar to those in other forms of lower small bowel obstruction: variable gaseous distension of the colon and small bowel, often with air-fluid levels. The colon is usually difficult to identify accurately, and gas is usually absent in the rectum.

Barium enema studies demonstrate patency of the colon, which is short but usually normal in caliber. A transition zone between the narrow and dilated portions of the colon, in the shape of an inverted cone, is the most characteristic radiological finding. When this transition zone is observed, the examination should be discontinued, because filling of the more proximal dilated bowel beyond the transition zone may lead to impaction (Fig. 2.6). However, the distension of

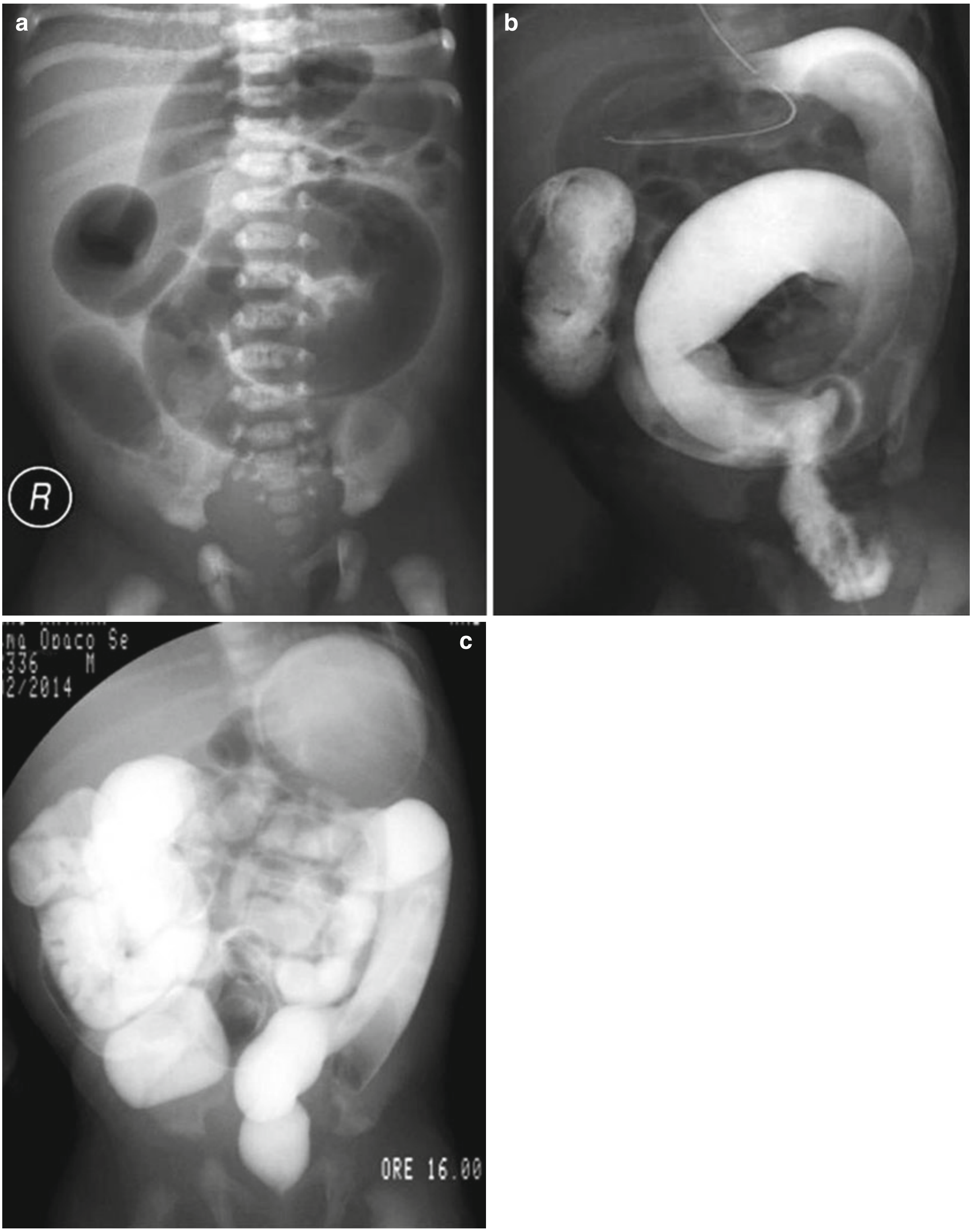

Fig. 2.6 Hirschsprung disease. Plain abdominal radiograph (**a**) and barium enema (**b**, **c**). Note in **c** the ascent of the contrast to the stomach in the late study, due to complete aganglionosis

the bowel proximal to the segment of deficient innervation is gradual, and a transition zone is seen in only 50% of neonates with Hirschsprung disease during the first week of life. Abnormal contractions and irregular peristaltic activity of the aganglionic portion of the colon may be useful indicators of the disease, although they are nonspecific findings that are also seen in colitis.

Twelve-hour-delayed postevacuation images are useful in dubious cases.

The radiological diagnosis of total colonic aganglionosis is difficult. Findings at barium enema examination may be normal or may include a short colon of normal caliber, microcolon, or a transition zone in the ileum [2–4, 10, 11].

Functional immaturity of the colon is a common cause of neonatal obstruction, particularly in premature neonates and in those whose mothers were treated during labor with magnesium preparations or sedatives; the condition also occurs in neonates with diabetic mothers. The condition has also been encountered in children with septicemia, hypothyroidism, or hypoglycemia. Functional immaturity of the colon comprises several entities, most notably small left colon syndrome and meconium plug syndrome. Affected patients have abdominal distension, difficulty in initiating evacuation, and sometimes vomiting; typically, however, the bowel distension is less severe than that seen with an organic obstruction. The condition is both diagnosed and treated with a contrast enema.

In *small left colon syndrome*, barium enema examination demonstrates a distended right and transverse colon with a transition to a very small-diameter descending and rectosigmoid colon near the splenic flexure. The rectum is usually quite distensible.

In *meconium plug syndrome*, barium enema examination with high-osmolality water-soluble contrast shows a small caliber of the left colon with a large meconium plug. The rectum is usually normal in size, unlike findings in Hirschsprung disease. The enema can be both diagnostic and therapeutic and is usually accompanied by the passage of meconium during or after the procedure [10, 11].

Typically, there is clinical improvement following the enema, and over the course of hours to days the radiographic and clinical signs of obstruction subside.

In older children the main indication for a barium enema is intestinal intussusception, with the enema used exclusively for therapeutic purposes, since the diagnosis is made by sonography.

The role of the enema in reducing intestinal intussusception is well known and recognized, but in the literature there are many differing reports about the contrast medium to be used; namely, air or liquid. An air enema is considered to be better at reduction, cleaner (appearance of peritoneal cavity at surgery when perforation occurs), safer, and faster, with less radiation when compared with a liquid enema. Reported perforation rates are not significantly different. The recurrence rates for air versus liquid enema reductions do not differ (approximately 10%). However, while the air enema may be preferred in experienced hands, the liquid enema is also safe and effective. Barium is no longer the liquid contrast medium of choice, due to the risk of barium peritonitis, infection, and adhesions when perforation occurs during the enema procedure. Neither sedation nor medications increase the enema success rate. More recent reports of air enema intussusception reduction show better results than liquid enema intussusception reduction. The air enema may use higher intraluminal pressure, which results in a higher reduction rate.

To avoid ionizing radiation exposure to children, the use of US with either water or air reduction techniques has been reported, showing intussusception reduction rates equivalent to those using *fluoroscopy*.

The use of delayed attempts (reports vary between 30 min and 1 day) after the initial attempt have shown further success in enema reductions of intussusceptions. Delayed enema should not be performed if the child is clinically unstable or if the initial enema does not partially reduce the intussusception.

The most important potential complication of enema use is bowel perforation (the mean perforation rate was 0.8%). There are no statistically significant differences between air and liquid enema perforation rates. This risk depends on each radiologist's patient population and technique, as well as on the duration of symptoms. Because of this small but real risk of barium peritonitis, infection, and adhesions when perforation occurs during the enema procedure, iodinated contrast is preferred over barium when using liquid enema reduction.

Children with evidence of peritonitis, shock, sepsis, or free air on abdominal radiographs are not candidates for enema use [4, 5].

2.1.3 Ultrasound (US)

Ultrasound (US) is an excellent imaging modality for the evaluation of the gastrointestinal tract in pediatric patients, so that it is now considered as an extension of the clinical evaluation, both in emergency conditions and for elective studies [13, 14].

In addition to the well established primary role of US in specific diseases, such as in hypertrophic pyloric stenosis and intestinal intussusception, the diagnostic reliability of US has been widely demonstrated in many other pathological conditions, such as in acute *appendicitis*, chronic intestinal inflammatory diseases (IBD), necrotizing enterocolitis (NEC), gastro-esophageal reflux, neonatal intestinal obstruction, intestinal malrotation, and acute volvulus in intestinal malrotation. Furthermore, US is successfully used even in less conventional applications, such as in esophageal atresia and anorectal malformations.

The well known advantages of US, particularly its lack of ionizing radiation and easy access, makes this imaging technique an ideal one for the evaluation of the pediatric patient with gastrointestinal tract diseases. Major drawbacks include its operator-dependency and reproducibility, apart from factors related to the patient, such as non-collaboration, obesity, and the interposition of a large amount of gas. Most of these limitations can be overcome with a comprehensive, careful, and dedicated examination technique using modern US capabilities.

US is also an excellent bedside high-yield imaging tool in intensive care units and it can also be used to guide therapeutic maneuvers, such as in the reduction of intussusception or in enema for meconium ileus.

In the past few decades, advances in US technology have greatly improved the quality of gastrointestinal US imaging, with a consequent positive impact on its diagnostic yield. Improvements in US probes, particularly high-resolution linear probes, permit better spatial resolution and better penetration in the far field, whereas improvements in contrast resolution can now be achieved with recent US modes such as image compounding, speckle/noise reduction filters, and (tissue) harmonic imaging.

Likewise, progress in Doppler techniques allows better depiction and quantification of even the slow flow of small vessels within normal and pathological gastrointestinal structures.

For any US examination the choice of adequate transducers, adjustment of basic parameters, and the choice of US modality is fundamental to obtain a proper image quality.

In general, the optimal transducer must have the highest possible frequency that is still able to penetrate the anatomical area of interest, providing the best spatial resolution.

The initial evaluation of the entire abdominal cavity is performed with a curved array transducer; then the individual structures of the gastrointestinal tract are specifically examined with a *high-resolution linear probe*, which allows detailed visualization of the esophageal wall, gastric wall, and bowel wall, as well as detailed visualization of the relevant surrounding structures. Not infrequently, curved array probes may also be needed in order to obtain a better access window to image deeper structures in older children (e.g., the esophago-gastric junction, the sigmoid colon, and the rectum) or to allow for a broader field of view.

In addition to the conventional trans-abdominal approach, other less common types of approaches might be necessary, and should be included in specific disease conditions, such as the suprasternal and mediastinal US approach to visualize the upper esophagus in tracheo-esophageal atresia or the *perineal US* approach to evaluate the anal canal or the distal rectal pouch location and its distance to the skin surface in anorectal or in cloacal malformations.

A well known limitation of US examinations is bowel gas interposition, but with a careful and proper bowel US technique this obstacle can often be partially overcome. Gentle graded compression is the essential technique in US of the gastrointestinal tract, as it displaces undesirable gas, shortens the distance to the skin surface, and isolates the bowel loops, while displacing adjacent ones. Furthermore, it helps to localize the origin of pain ("sonopalpation") and to assess the bowel compressibility.

In small patients and particularly in critically ill neonates, SBFT can be performed and followed by US.

Filling techniques are the basis for therapeutic maneuvers under US guidance, such as in the nonsurgical reduction of an ileo-colic intussusception or in the attempt to resolve meconium ileus.

2.1.3.1 Upper Gastrointestinal Tract US

In neonates *esophageal atresia* is usually diagnosed with frontal and lateral radiograms, but US can provide additional precious information to the surgeon. Besides the role of abdominal and cardiac US in searching for associated abnormalities, mediastinal US allows the characterization of the length, morphology, and structure of the wall in a blind upper esophageal pouch; this condition can be improved by the administration of a small amount of saline fluid through the esophageal tube. Rarely, even a tracheo-esophageal fistula may be recognized by US [13].

With a superior abdominal US approach, the cardia and the adjacent distal esophagus are often easily depicted, although visualization of the entire distal esophageal length behind the heart is difficult and restricted.

In neonates and infants with suspected *gastroesophageal reflux disease (GERD)*, US is a widely available, non-invasive, and sensitive method that can provide useful anatomical and functional information, although its role in GERD is still controversial and debated. The complex issue of GER and GERD is related to many factors, including the nonspecific nature of symptoms in young children, the difficult distinction between physiological and pathological GER, and the impasse in establishing a cause-effect relationship between GER and symptoms or complications related to GERD.

Nevertheless, US is considered by many authors as the primary non-invasive imaging tool in a child with vomiting, particularly in patients younger than 2 years of age, as it can provide alternative diagnoses other than GER and rule out gastric outlet obstruction.

More important than the US detection of GER, per se, is the fact that one can correlate the US findings with the occurrence of clinical symptoms. Furthermore, US can provide information on functional aspects such as the esophageal clearance of the refluxed gastric content, the opening of the gastroesophageal junction (GEJ), and gastric emptying, and US can potentially detect an associated hiatal hernia. Anatomical details of the gastroesophageal structure, such as the length of the abdominal esophagus and the gastroesophageal angle (angle of His), can be assessed, and these features seem to have high sensitivity and high positive predictive value for GER.

US is generally considered the modality of choice to confirm or exclude the diagnosis of *hypertrophic pyloric stenosis (HPS),* as both the lumen and the surrounding musculature are directly visualized [15–17]. The diagnosis of HPS is based on US morphological and dynamic findings: the most significant criteria are a thickened pyloric muscle (greater than 3 mm), a pyloric length greater than 18 mm, and the lack of luminal opening of the pyloric channel (Fig. 2.7). The usually distended stomach, seen as an indirect sign of gastric outlet obstruction, must be interpreted according to the time of the last meal. Changing the patient position may be necessary to improve visualization of the pyloric channel hidden by a distended stomach.

It is also important to evaluate the pyloric canal over time, to differentiate HPS from pylorospasm, a transient phenomenon that can have morphological features and measurements simi-

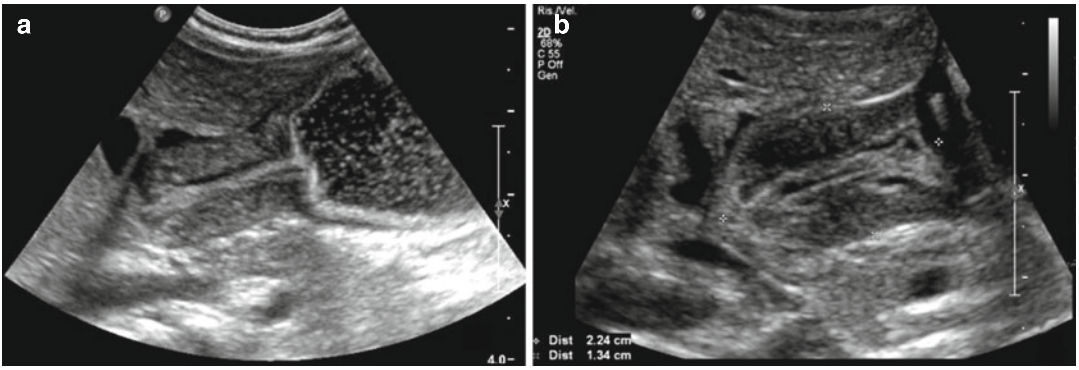

Fig. 2.7 (**a**, **b**) Hypertrophic pyloric stenosis. Ultrasound (US) study (**a**, **b**) shows a thickened pyloric muscle (greater than 3 mm), increase of pyloric length (greater than 18 mm), and distended stomach due to the lack of luminal opening of the pyloric channel

lar to those of HPS. In doubtful cases a repeated US after some time can clarify the diagnosis.

Gastric duplication cysts are usually easily recognized when they have the classic US appearance of localized fluid formations with a thick layered wall. Gastric emptying may be used to highlight the close relationship of the cyst with the gastric wall [18].

Other gastric pathologies can be suspected in abdominal US examinations performed in a child with vomiting, epigastric pain, or other nonspecific abdominal discomfort. Such pathologies may be a cause of focal or diffuse thickening of the stomach wall (e.g., eosinophilic gastritis, chronic granulomatous disease, tumoral diseases such as polyps and lymphoma), but also of intraluminal anomalies (e.g., bezoar, ingested foreign bodies).

After the US evaluation of the esophageal-gastric junction, stomach, and pylorus, the next step is to follow the duodenum to check the third duodenal portion, which normally passes between the abdominal aorta and the superior mesenteric artery; the normal position of the duodenojejunal junction can also be identified, on the left side of the aorta.

2.1.3.2 Small and Large Bowel US

US can also be used to recognize *intestinal malrotations* [12, 19–22]. The diagnosis of these abnormalities has been modified in the past few years. Barium enema and radiographic study of the upper gastrointestinal tract has been used to evaluate the duodenum morphology, duodenal-jejunum junction position, and cecum position, and this study is still considered the standard criterion. Actually, in addition to these invasive examinations that use X-rays, US examination with color Doppler is used to identify intestinal anomalies of rotation and fixation. The best known US finding is an abnormal relationship between the superior mesenteric artery (SMA) and the superior mesenteric vein (SMV), although a normal position does not exclude the presence of abnormal midgut rotation. In addition, the normal position of the third duodenal portion is believed to be a more reliable marker than the position of the mesenteric vessels to exclude intestinal malrotation (Fig. 2.8).

The finding of an abnormal relationship between the SMA and the SMV may be demonstrated either incidentally or on specific examination. The SMA/SMV relationship should be considered part of abdominal US screening in infants and children with abdominal pain or in asymptomatic pediatric patients to prevent future obstructive or ischemic complications.

Midgut volvulus is the most frequent cause of acute abdomen in newborns, and it is a common consequence of intestinal malrotation. However, it can affect children also. It is a life-threatening emergency; early diagnosis is important in this disease, to avoid the risk of intestinal infarct and necrosis. If not promptly diagnosed and treated, midgut volvulus leads to death or a lifelong

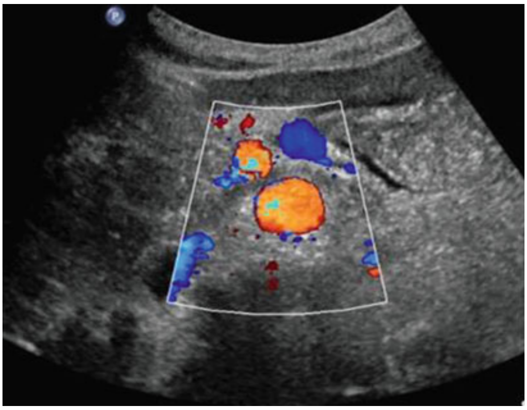

Fig. 2.8 Intestinal malrotation. US study shows abnormal relationship between the superior mesenteric artery and superior mesenteric vein, the latter seen to the left of the artery

dependence on total parenteral nutrition in survivors with short bowel syndrome.

Therefore, learning to recognize the US findings of midgut volvulus is imperative: the volvulus is responsible for a whirlpool-like appearance on cross-sectional images, created when the SMV and the mesentery wrap around the SMA in a clockwise direction. Visualization is enhanced by the vascular signal on color Doppler flow US [23–25] (Fig. 2.9).

For the neonate with the classic appearance of a whirlpool sign, additional imaging investigation is often unnecessary, and the surgeon should be alerted to plan for emergency surgery. The advantages of US for this age group are apparent, since it can be performed at the bedside in intensive care units and lacks the adverse effects of ionizing radiation.

The diagnosis of *neonatal bowel obstruction* or the confirmation of the prenatal diagnosis is based on clinical and radiological signs on a plain abdominal radiograph, occurring with a delay of 12–24 h; in very distal obstruction the signs may appear even later.

US can contribute to the diagnosis of neonatal bowel obstruction with important additional information; first of all, it can document the obstruction, showing severe distension of the proximal bowel loops (diameter from 16 to 40 mm) with thin walls and increased peristalsis, filled with fluid, and punctuated with echodense particles of gas. The distal bowel is small in size (3–4 mm) with echodense or target-like meconial content [19].

Furthermore, US allows the assessment of colon size and its content, a main marker to suggest the probable location of the obstruction, thus indicating the need to perform a contrast enema in case of lower bowel obstruction. The colon is of normal caliber (9–14 mm) in very proximal small bowel atresia, while microcolon (3–5 mm) is easily recognized in distal small bowel atresia and in meconium ileus. In meconium ileus, severe microcolon is present, but the small bowel is less dilated and less peristaltic than in other small bowel atresias. The most important finding is the characteristic appearance of the dilated bowel loops, which contain abnormal meconium: the thick meconium sticks to the bowel walls, resulting in a pseudo-thickening. The distal bowel loops, in the right lower quadrant, are small (3–4 mm), with a target-like appearance due to impacted meconial pellets.

Hydrocolon is present in *meconium plug syndrome* and *small left colon syndrome* [2, 3, 19].

Besides being observed in small bowel obstruction, hepatic, splenic, scrotal, and peritoneal calcifications are observed in *meconium peritonitis* with single or multiple meconium pseudo-cysts and free intraperitoneal fluid [2, 3, 7, 8].

Occasionally US study highlights the cause of obstruction, either intrinsic (e.g., duodenal web) or extrinsic (e.g., gastrointestinal duplication cyst or annular pancreas).

In *anorectal malformations*, the distance between the rectal cul-de-sac and the perineum can be reliably measured with perineal US [13, 26, 27]. Furthermore, US study can show associated genito-urinary tract and dysraphic abnormalities; therefore, all patients with congenital anorectal malformations should have a genito-renal tract and spinal US examination as a screening test in the early newborn period (Fig. 2.10).

US is still not routinely used for the diagnosis and follow up of *NEC*, but it can provide information that is not provided by plain abdominal radiography and that may affect the management of NEC. Like radiography, US can depict intramural gas, portal venous gas, and free intraperito-

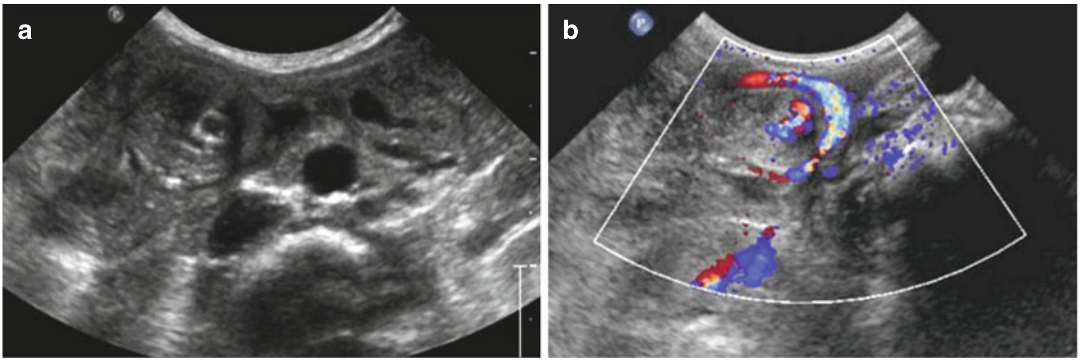

Fig. 2.9 US study (**a**) with color Doppler (**b**) showing the whirlpool sign, with the superior mesenteric vein and mesentery wrapped around the superior mesenteric artery in a clockwise direction

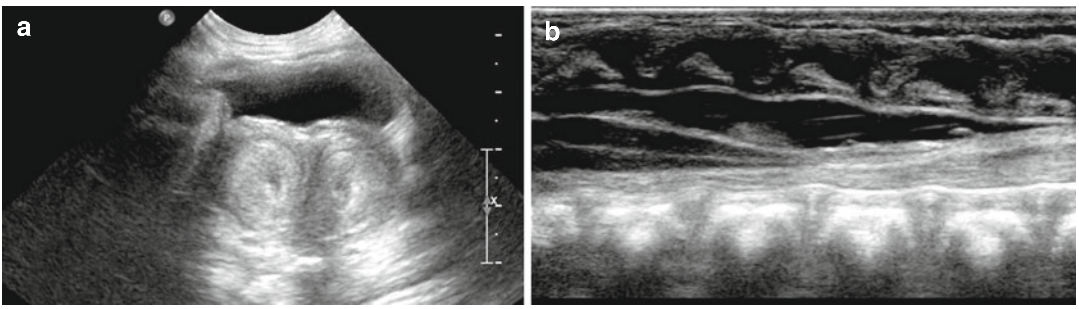

Fig. 2.10 Anorectal malformations. US of genital tract shows an associated didelphys uterus (**a**), while normal anatomy of the spinal cord on US spinal study (**b**) rules out occult myelodysplasia

neal gas; however, the main advantage of abdominal US over plain abdominal radiography, including color Doppler US, is that abdominal US can show intraabdominal fluid, bowel wall thickness, and bowel wall perfusion [28–31].

In NEC, the ability to depict abdominal fluid is the first major advantage of US study over plain abdominal radiography, showing whether the fluid is intraluminal or extraluminal and whether it is free in the peritoneal cavity or is a more localized fluid collection.

The second major advantage of abdominal US in NEC is its ability to visualize the bowel wall directly and to assess bowel wall thickness, echogenicity, and peristalsis.

With both bowel wall thickening and thinning the normal echogenicity of the wall (so-called gut signature) is lost and it may be difficult to differentiate the bowel wall from the echogenic intraluminal content in severely affected loops. Bowel wall thickening is accompanied by increased echogenicity of the full wall thickness; however, this is a nonspecific sign, as it is also seen in other causes of diffuse edema in the absence of inflammation or ischemia.

The third major advantage of abdominal US, including color Doppler, in NEC is the ability to directly assess arterial perfusion of the bowel wall, to infer the viability of individual loops.

Three categories of flow are recognized on color Doppler: normal, increased, and absent. The hyperemia is the result of the vasodilation of mural and mesenteric vessels secondary to intestinal inflammation, with specific flow patterns ("zebra" pattern, "Y" pattern, and "ring" pattern).

Flow is absent when no color Doppler signals are identified in the bowel wall.

Thinning of the bowel wall and lack of perfusion are highly suggestive of non-viable bowel and may be seen before visualization of pneumoperitoneum on plain abdominal radiography. As mortality is higher after perforation, earlier detection of severely ischemic or necrotic loops, before perforation occurs, could reduce morbidity and mortality in NEC (Fig. 2.11).

US is the modality of choice to accurately diagnose or exclude *intestinal intussusception*, determining the location (ileo-ileal or ileo-colic) and the type (idiopathic or secondary to the presence of a lead point), with a decisive impact on the therapeutic approach [13].

Typical signs of intussusception are the "target" and the "pseudo-kidney" signs, respectively, on transverse and longitudinal planes. A small amount of intraperitoneal free fluid can often be seen and should not preclude a non-surgical reduction attempt. The lower success rates of non-surgical reductions are related to the presence of trapped fluid within the intussusception and the absence of flow on color Doppler in the intussusception wall, indicative of vascular impairment of the bowel (Fig. 2.12). When these signs are present enema reduction should be performed with extreme caution, due to the high risk of perforation.

Small bowel intussusceptions, in contrast to intussusceptions of the large bowel, are transient, asymptomatic, and relatively common. They are usually encountered around the periumbilical region, are small in diameter (less than 2 cm), and tend to resolve spontaneously within a few minutes.

The diagnostic role of US in *IBD* in children, and particularly in Crohn's disease, continues to increase, as it has several advantages over other imaging techniques. Abdominal US is easily performed, readily available, and less expensive than other imaging modalities, and obviously it does not use ionizing radiation; the fact that ionizing radiation is not used is essential in pediatric patients with IBD, who are at higher risk of increased diagnostic radiation exposure than the general population, owing to repetitive imaging. Unlike with MRI, sedation, oral contrast, or bowel cleansing are not required with US.

Most published studies have found bowel US to be a valuable tool in children with suspected or known IBD [32–35]. Bowel wall thickening is the hallmark of intestinal disease: in the pediatric age group, thicknesses greater than 2.5 mm and 2 mm, respectively, for the small and the large bowel are considered abnormal. A careful and attentive US examination also reveals the location and extension of the involved segments, their vascular features on color Doppler, and the extramural signs of disease, such as hyperechogenicity of the surrounding fat planes, regional lymphadenopathy, abscesses, and fistulas; abnormal wall stratification and abnormal peristalsis can also be noted (Fig. 2.13).

The correlation of these findings with the clinical history and the laboratory data often permits us to narrow the differential diagnosis, thus directing further additional imaging.

Another important application of US in IBD is in the follow-up of patients with known disease to monitor treatment and to ensure early detection of intra-abdominal complications in relapse.

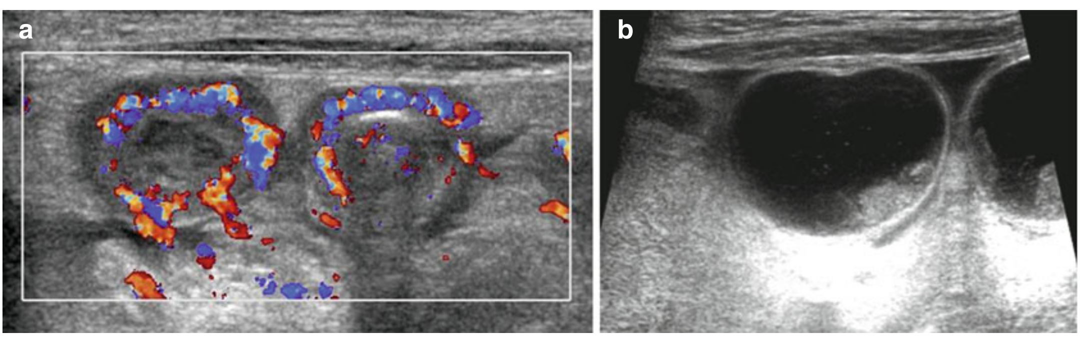

Fig. 2.11 Necrotizing enterocolitis (NEC). Color Doppler sonography (**a**) shows two loops with a thickened bowel wall and ring pattern with increased perfusion. Thinning bowel walls (**b**) are seen in a patient with a poor outcome

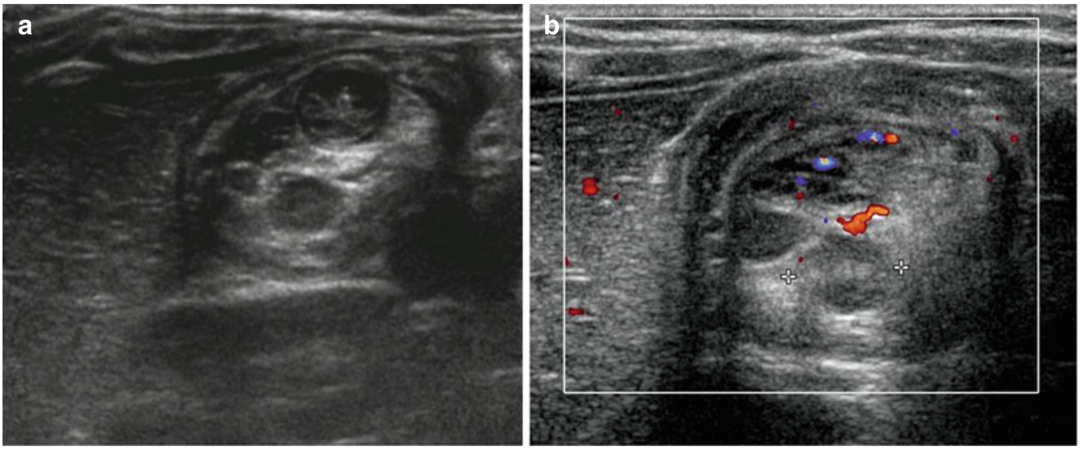

Fig. 2.12 US study with color Doppler. Intestinal intussusception with target appearance on tranverse plane. Note the presence of lymph nodes within the intussusception (**a**), with preserved vascular signal of the loop on color Doppler US (**b**)

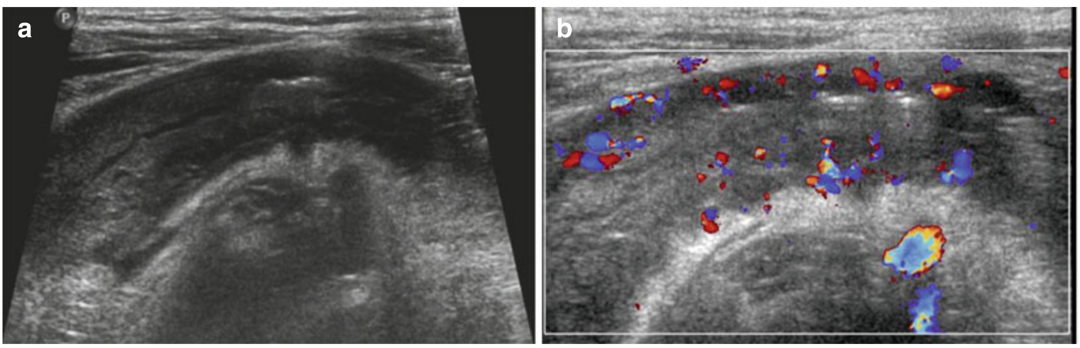

Fig. 2.13 Crohn’s disease: bowel wall thickening with narrowed lumen (**a**) and hyperemia on color Doppler (**b**) of the terminal ileum

Color Doppler US provides additional information about disease activity and it may help to distinguish between inflammatory and fibrotic bowel stenosis.

Appendicitis is the most common pediatric surgical emergency. US often provides a reliable contribution to the diagnosis by supporting or excluding appendicitis; it is helpful in the differential diagnosis, thus avoiding unnecessary radiation exposure when imaging is needed.

Typical signs of appendicitis include an aperistaltic, noncompressible, dilated appendix (outer diameter greater than 6 mm) and white target appearance in axial section, sometimes with appendicolith; other secondary changes include echogenic prominent pericecal fat and peri-appendicular free fluid and/or fluid collection. On color Doppler US, increased vascularity of the appendicular wall is observed in early inflammatory phases, whereas no flow can be detected if the appendix is necrotic or perforated.

Imaging is not necessary in every child suspected of having appendicitis, particularly in boys with a clear clinical picture. Conversely, US is especially valuable in girls, in whom ovarian conditions must be considered in the differential diagnosis, which is difficult to achieve clinically.

Mesenteric lymphadenitis is a self-limiting disorder showing inflammation of mesenteric lymph nodes, caused by various types of bacteria, mycobacteria, and viruses. It is a common cause of abdominal pain in children, sometimes mimicking acute appendicitis. It should be noted that some mesenteric lymph nodes are commonly seen on abdominal US in pediatric patients, even in those who are asymptomatic, and the nodes are not necessarily related to any pathological process.

Except for lymphoma, tumors of the small and large colon are rare in children. The most frequent subtype of non-Hodgkin lymphoma occurring in children is *Burkitt's lymphoma*, and it frequently affects the gastrointestinal tract, most commonly the ileocecal region and mesentery.

Burkitt's lymphoma has a rapid growth and can present with intestinal obstruction owing to secondary intussusception. On US it is seen as a mass with low or heterogeneous echogenicity, with low vascularity on color Doppler.

Several other diseases may first come to attention during an abdominal US examination, including intraluminal conditions, such as polyps or abnormal content (such as in cystic fibrosis); bowel wall involvement in various inflammatory (e.g., benign lymphoid hyperplasia), infectious (e.g., viral or bacterial enterocolitis), infiltrative, and hematological (e.g. Henoch-Schonlein purpura, graft versus host disease, neutropenic colitis) conditions; or traumatic disorders. US may also disclose other conditions, such as hernias, Meckel's diverticulum, duplication cysts, and other tumor and tumor-like conditions.

2.1.4 Magnetic Resonance Imaging (MRI)

Gastrointestinal study is a relatively recent *MRI* application. For several years, in fact, the long acquisition times have limited the use of MRI in the abdominal area, in which the study of structures with peristalsis led to low-quality diagnostic images because of the presence of motion artifacts. The continuous technological development of MRI, with a coil system gradient that currently allows us to capture images more quickly, is best suited to gastrointestinal study [35]; however, the duration of the investigation is still likely to require sedation in young children and/or in those who are non-cooperative.

The primary characteristic of MRI must also be emphasized – this is the obtaining of multiplanar images with high-resolution tissue contrast, without the use of *ionizing radiation*.

MRI for the study of the gastrointestinal tract sees continuous innovations, but the clinical indications are not always well defined. From this point of view, the study of certain diseases of the bowel, in particular chronic inflammatory diseases, can be carried out with MRI, with its diagnostic performance already established in the literature, while MRI studies of the esophagus, stomach, and colon are currently considered to be experimental [36] (Fig. 2.14).

MRI imaging is now used for the study of extraluminal pathologies and for the study of oncological diseases.

The use of MRI in the study of *anorectal abnormalities* deserves special mention, particularly in the preoperative evaluation of the newborn or infant prior to definitive pull-through repair surgery, and in the postoperative review of the older pediatric patient with continuing problems [27, 37]. Furthermore, when the radiographic or US examination is abnormal, MRI can be used also to accurately depict the likely associated intraspinal pathology, such as tethered cord, caudal regression syndrome, hydromyelia, or a lipoma of the terminal filum.

Examination during sedation or spontaneous sleep may provide more accurate estimation of the true level of an elevator sling.

MRI allows direct visualization of the distal rectum and related musculature (levator ani muscle, puborectal muscle, external sphincter) without additional ionizing radiation, but with multiplanar capabilities (Fig. 2.15). Associated lesions such as *sacrococcygeal hypoplasia* and lumbar spine or renal anomalies can be evaluated [27, 39].

2.1.4.1 Entero-MRI

MRI has good sensitivity and specificity for *IBD* in children. It is used to study the entire intestine, especially the small intestine, which still remains largely out of the range of the endoscope (Fig. 2.16).

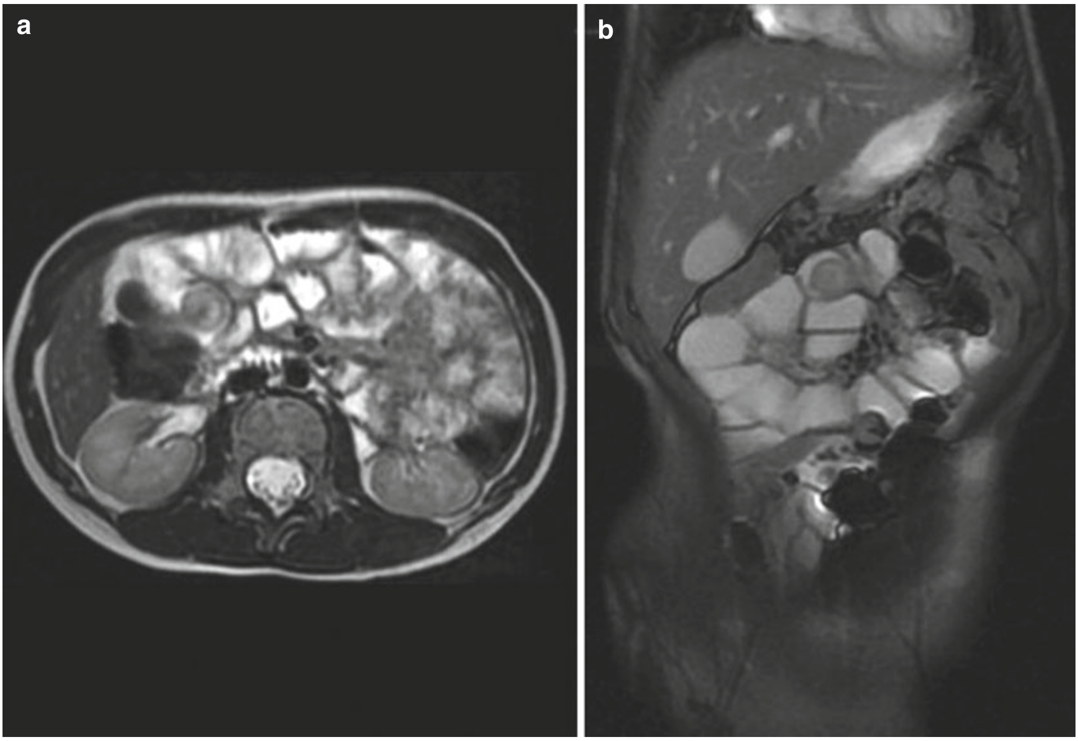

Fig. 2.14 Magnetic resonance imaging (MRI): axial T2-weighted image (**a**) and coronal T2-weighted image (**b**) show an ileal intraluminal filling defect (polypoid mass)

The survey preparation includes fasting from the night before the study in larger children, and exclusive intake of clear liquids on the day of the examination.

Entero-MRI also requires adequate bowel distension, obtained through the oral administration of contrast medium. The contrast medium used may be negative, positive, or biphasic. Biphasic media are preferred for better visualization of the bowel wall; they consist of aqueous solutions containing isoosmolar substances (polyethylene glycol) that possess the same intensity as the water signal, providing a high signal on T2-weighted sequences and a low signal on T1-weighted sequences. These characteristics make such media ideal in a digestive study, creating ideal conditions for contrast resolution between the lumen and wall. Positive contrast media, which were those used in the past, have poor contrast resolution, and negative media are used for a better definition of the wall signal.

The first acquisitions are possible after approximately 45 min from initiation of the contrast agent [40, 38].

Pharmacologically-induced hypotonia (with intravenous injection of hyoscine butylbromide) is performed to reduce possible artifacts from the intestinal peristalsis and prolong the relaxation time of the small bowel.

The use of MRI in the study of *anorectal abnormalities* deserves special mention, particularly in the preoperative evaluation of the newborn or infant prior to definitive pull-through repair surgery, and in the postoperative review of the older pediatric patient with continuing problems [27, 37]. When the radiographic or US examination is abnormal, then MRI can be used to accurately depict the likely associated intraspinal pathology, such as tethered cord, caudal regression syndrome,

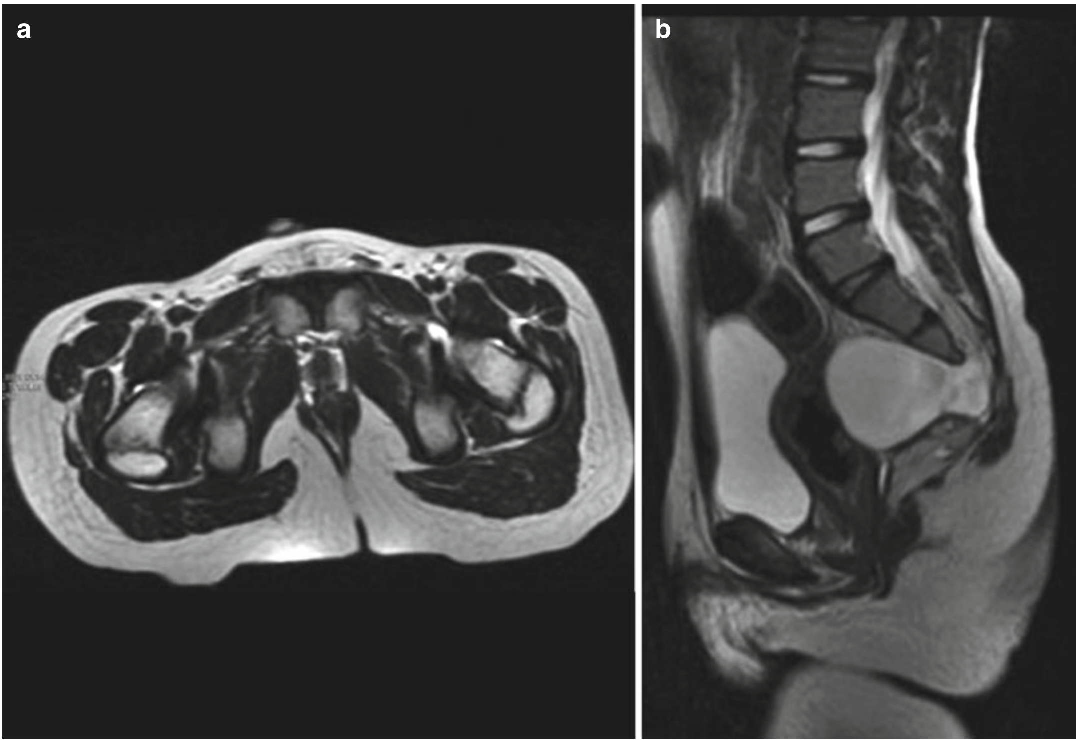

Fig. 2.15 Axial (**a**) and sagittal (**b**) T2-weighted MRI: postsurgical evaluation. Axial image shows *left-sided* puborectalis muscle that appears as a triangle with the apex directed posteriorly. Sagittal T2-weighted image (**b**) shows the presence of an associated sacral anterior meningocele

hydromyelia, or a lipoma of the terminal filum. Examination during sedation or spontaneous sleep may provide more accurate estimation of the true level of an elevator sling. MRI allows direct visualization of the distal rectum and related musculature (levator ani muscle, puborectal muscle, external sphincter) without additional ionizing radiation, but with multiplanar capabilities (Fig. 2.16). Associated lesions such as *sacrococcygeal hypoplasia* and lumbar spine or renal anomalies can be evaluated [27, 38].

The administration of paramagnetic contrast material by injection allows for proper evaluation of the intestinal walls; the enhancement following injection of the contrast agent provides information on the activity of the disease and indicates whether there is any hypervascularization of the intestinal wall, as well as helping to distinguish inflammatory processes by showing fibrotic aspects of thickened walls. The administration of paramagnetic contrast material with MRI can provide information about the wall thickness and the presence of fixed bowel loops, and can detect superficial mucosal abnormalities, creases and ulcerations, abnormal wall morphology, and extraluminal abnormalities (lymphadenopathy, increased mesenteric vasculature, abscesses, and fistulas) [37, 40].

2.1.5 Computed Tomography (CT)

CT investigation involves high doses of ionizing radiation, and in young patients it is therefore reserved for cases in which it can be valuable for diagnostic and therapeutic purposes and for management, taking into account the *ALARA (As Low As Reasonably Achievable) principle*, according to which the administration of the lowest possible radiation dose for the diagnostic purpose is planned.

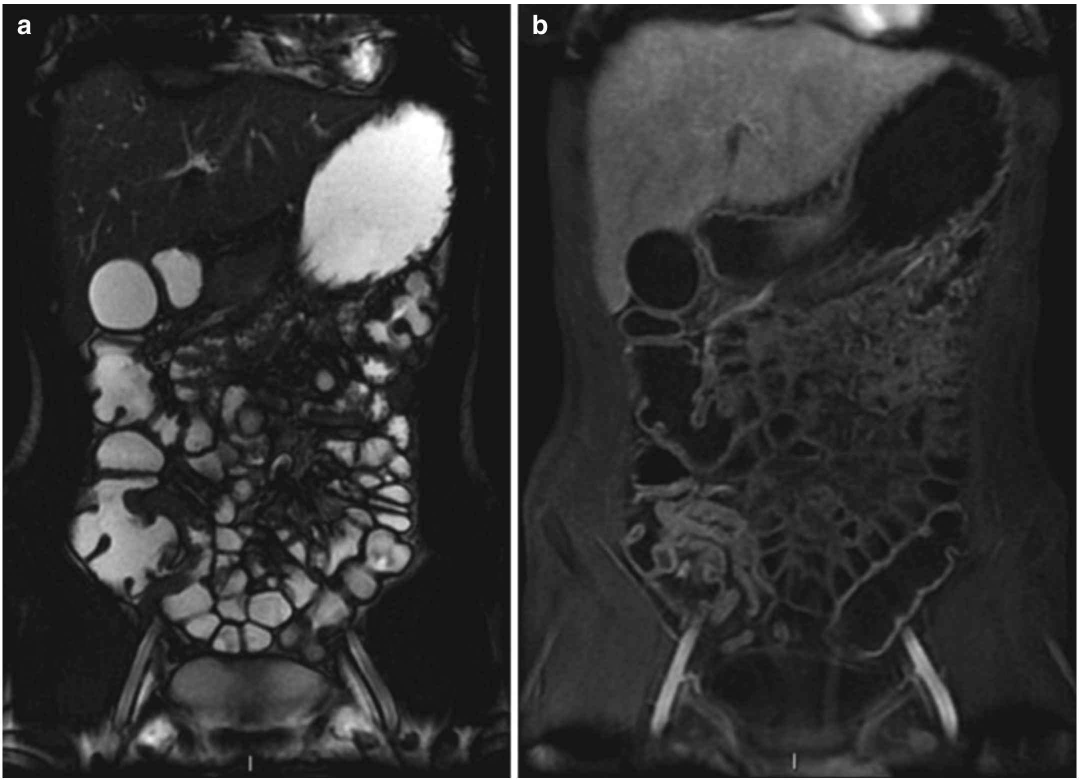

Fig. 2.16 Coronal MRI: T2-weighted dynamic FIESTA (**a**) and T1-weighted post-contrast image (**b**) show thickening of the terminal ileum, with important contrast enhancement

Because of the relative poverty of intra-abdominal adipose tissue, which greatly affects contrast between different structures, we do not routinely acquire CT scans without contrast medium, as these would lack diagnostic sensitivity. Thus, the CT scan is usually acquired only in the portal-venous phase, with considerable saving of the radiation dose administered to the patient.

Image acquisition during the arterial phase is reserved for cases where it is important to evaluate the arterial vascular anatomy or where it is necessary to typify extensive pathologies and their relationships with vascular structures.

The images are acquired with a 5-mm layer thickness, and are subsequently reconstructed in the thinnest layer (1–2 mm), with the possibility of multiplanar and three-dimensional (3D) reconstructions.

CT is therefore a level II methodology, and is used exclusively to further elucidate radiographic findings and US doubts, or where more accurate morphological and anatomical assessment is required, especially in settings of urgency, such as for the study of acute abdominal conditions (complications of appendicitis or cecal Meckel's diverticula) or acute complications of chronic inflammatory conditions (bowel perforation, fistulas, or bleeding in *Crohn's disease*) [41].

In common clinical practice, CT angiography is frequently used for the evaluation of vascular thoracic and abdominal anatomy. A typical example is that of research of abnormal vessels, one of the most frequently represented being an aberrant right subclavian artery (lusoria) originating directly from the medial aortic arch profile; in these cases CT-depth investigation is performed after a pathological esophagogram shows the classic compression sign, caused by the abnormal blood vessel, on the rear profile of the proximal esophagus (Fig. 2.17).

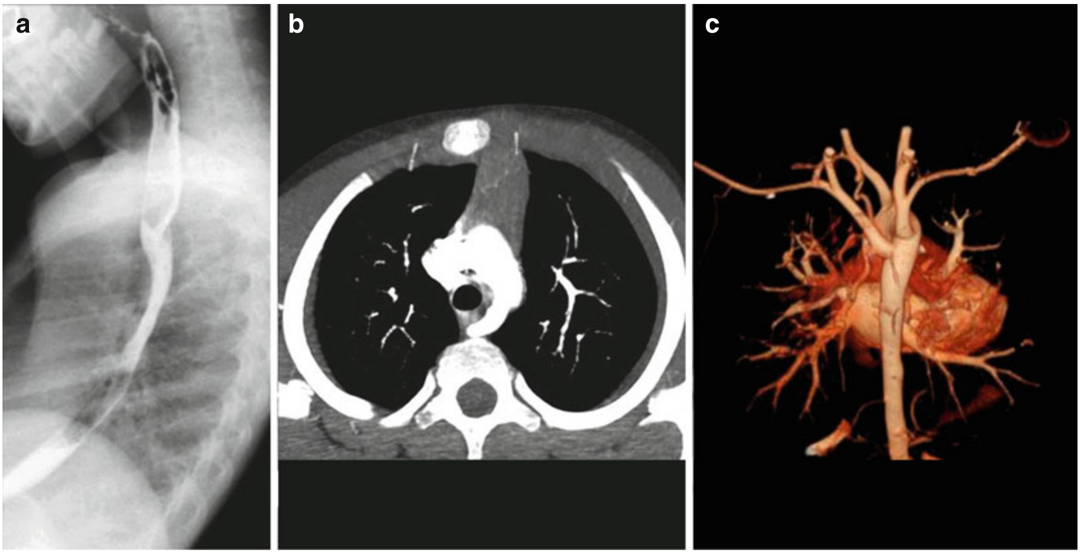

Fig. 2.17 Upper gastrointestinal (UGI) lateral view (**a**) of the esophagus shows a pathological compression of the rear profile of the proximal esophagus, confirmed by axial (**b**) and three-dimensional (3D) (**c**) images on computed tomography (CT) study

Another characteristic indication for CT angiography is in the study of suspected stenosis of mesenteric vessels or other pathological conditions that produce decisive changes in the normal vascular anatomy. Examples are portal cavernoma, a condition of pre-hepatic portal hypertension in the pediatric age group, where portal vein thrombosis occurs with subsequent arterialization of the hepatic blood flow and the progressive development of portal systemic shunt in typical locations (Fig. 2.18).

CT scans are also used in the evaluation of masses, especially in the thoracic region, and for the staging of tumors (Fig. 2.19); the most common form of tumor in children is undoubtedly Burkitt's lymphoma.

Finally, *entero-CT* deserves particular mention. This is the investigation used in the evaluation of the extension and complications of IBD, particularly Crohn's disease, and which allows us to obtain a simultaneous display of both luminal and extraluminal pathology, such as the presence of fistulae or abscesses. Adequate opacification and distension of the bowel loops with an oral contrast medium (most commonly water or oral low-density barium contrast medium) is important to avoid the misinterpretation of normal collapsed segments for masses or wall abnormalities [41–43].

The intravenous administration of iodinated contrast medium for entero-CT helps in the subsequent evaluation of the extension of tumor and inflammatory disease of the intestinal walls, and also helps in the evaluation of blood vessels and abdominal organs (Fig. 2.20).

Pharmacologically-induced hypotonia of the bowel to prevent movement artifacts is not indicated beacuse of the high speed of scanning of modern CT equipment.

In adult patients, entero-CT is used in both the acute setting of acute small bowel obstruction and in the elective situation with respect to IBD and the investigation of small bowel tumors. However, its use in children has remained limited due to the *radiation burden*, and MRI of the small bowel is now the preferred technique in children.

The benefits of CT when compared with MRI include better spatial resolution, fewer motion-related artifacts, increased availability, reduced cost, and shorter examination time. The benefits

Fig. 2.18 Axial and coronal CT images show the presence of portal cavernoma (**a**) and collateral venous vessels due to a portal systemic shunt (**b**, **c**)

Fig. 2.19 Coronal CT image shows an esophageal duplication

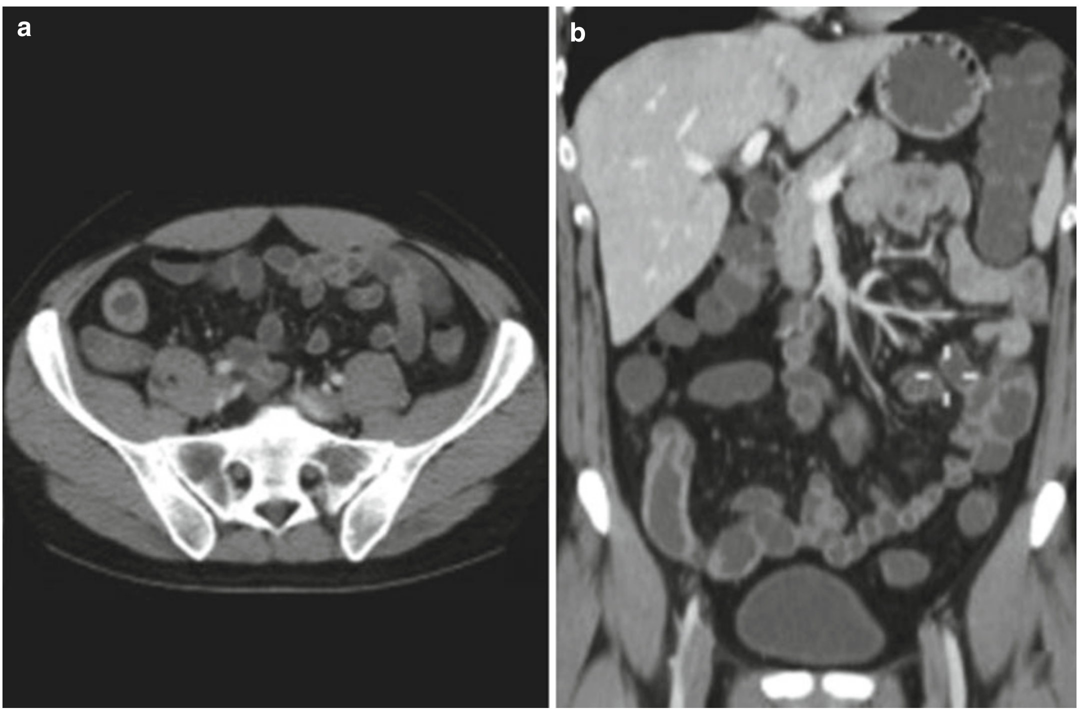

Fig. 2.20 Axial (**a**) and coronal (**b**) CT images show a pathological thickening of the terminal ileum

of MRI include better contrast resolution and the lack of ionizing radiation. It should be remembered that Crohn's disease is a chronic disease and any such patient is likely to be imaged more than once, so the cumulative radiation dose must be considered by the pediatric radiologist in this context. Recent studies have demonstrated similar sensitivities for CT and MRI in the detection of small bowel Crohn's disease [41–45].

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