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## 10.1 Introduction

Appendicitis is the most common cause of acute abdominal pain that requires surgical intervention in the pediatric population.

It is one of the major causes of hospitalization in children.

Appendicitis typically develops in older children and young adults; it is rare under the age of 2 years. The peak incidence of appendicitis occurs between 10 and 19 years of age.

Appendicitis occurs with equal frequency in males and in females.

Patients with appendicitis may present with a wide variety of symptoms that can lead to confusion and delay in diagnosis and treatment.

The delayed diagnosis of appendicitis has severe consequences, including perforation, abscess, peritonitis, sepsis, bowel obstruction, wound infection, infertility, adhesions, and death (Klein 2007).

Early diagnosis is essential to reduce morbidity. Morbidity and mortality in acute appendicitis are related to appendiceal perforation.

The prevalence of appendiceal perforations varies from 23 % to 73 % (Tseng et al. 2016).

The advent of antibiotics and effective surgical management have substantially reduced appendicitis-related mortality; however, deaths from appendicitis still occur, particularly in the elderly.

The normal appendix is a blind-ended tubular structure (Fig. 10.1) with a diameter of less than 7 mm and a wall thickness of less than 2 mm and arises from the posteromedial wall of the cecum, approximately 3 cm below the ileocecal valve. Except for its proximal part, the remainder portion of the appendix is free and can occupy different positions in the abdominal cavity (Gaitini 2011).

The appendix may lie in a retrocecal, subcecal, retroileal, preileal, or pelvic site, and this variability in location may influence the clinical presentation (Fig. 10.2).

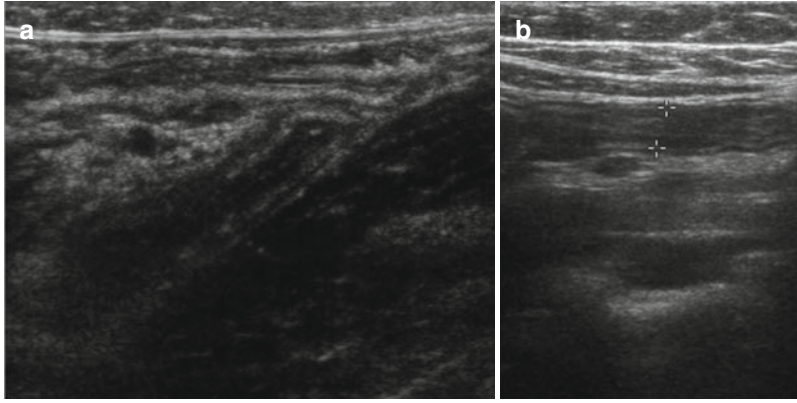
There are a variety of other conditions in childhood that occur with abdominal pain that must be differentiated from acute appendicitis.

The majority of children with acute abdominal pain have self-limited nonsurgical disease, such as viral syndrome, gastroenteritis, and constipation.

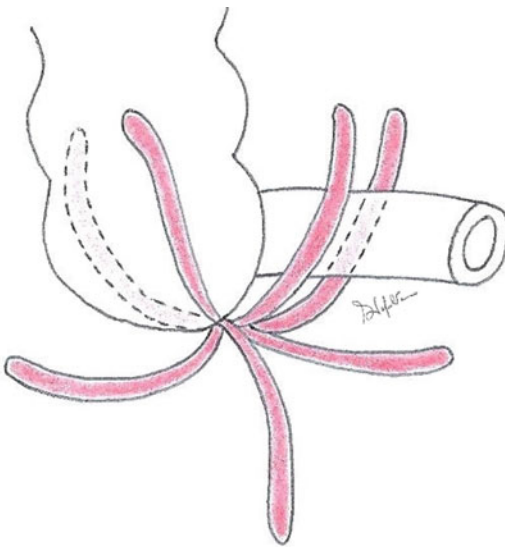
Clinical signs and symptoms associated with acute appendicitis include crampy, periumbilical, or right lower quadrant pain, nausea, vomiting, point tenderness in the right lower quadrant, rebound tenderness, and leukocytosis; the pain often radiates to the right leg, causing lameness (Taylor 2004).

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**Fig. 10.1** (a, b) US scan: normal appendix is a blind-ended tubular structure which arises from the posteromedial wall of the cecum



**Fig. 10.2** The figure represents the various positions in which the appendix may lie (retrocecal, subcecal, retroileal, preileal, or pelvic site)

Approximately one-third of children with acute appendicitis have atypical clinical findings.

Recurrent and chronic forms of appendicitis occur with an, respectively, incidence of 10% and 1% (Koike et al. 2014).

## 10.2 Pathogenesis

Appendicitis is usually the result of the obstruction of its lumen.

The lumen obstructed becomes distended; the pressure through the walls increases with consequent reduction of the mural perfusion. If appendectomy is not performed, gangrene and perforation occur.

The first pathogenetic event in most patients with acute appendicitis is the obstruction of the lumen that can be caused by fecaliths, lymphoid hyperplasia, foreign bodies, parasites, and tumor. Once the obstruction is verified, the continuous secretion of mucus causes an increase in intraluminal pressure and a distension of the lumen. At this stage abdominal pain is mild, is poorly localized, and disappears in 4–6 h; anorexia, nausea, and vomiting are often associated.

The increased intraluminal pressure exceeds the capillary perfusion pressure causing venous engorgement, arterial compromise, and consequent tissue ischemia.

Such as mucosal barrier is compromised, the bacteria proliferate and invade the wall of the appendix and determine transmural inflammation (Brennan 2006). Continued tissue ischemia results in appendiceal infarction and perforation. Inflammation then may extend to the parietal peritoneum and adjacent structures, which include the terminal ileum, cecum, and pelvic organs.

At this stage the typical migration in the right lower quadrant of pain occurs that is continuous and more severe than the early visceral pain.

Patients with acute appendicitis usually are afebrile or have low-grade fever.

Perforation should be suspected when the patient's temperature exceeds 38.3 °C.

If perforation does occur, periappendiceal phlegmon or abscess will result.

Peritonitis usually develops if there is free perforation into the abdominal cavity.

Clinical findings suggesting possible perforation include progression from localized right lower quadrant to generalized abdominal pain, temperature greater than 38 °C, and signs of peritonitis or a right lower quadrant mass at physical examination.

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### 10.3 Clinical Diagnosis

The clinical diagnosis of acute appendicitis is often not simple because one-third of children with appendicitis have atypical clinical signs and symptoms.

The clinical diagnosis of acute appendicitis is based primarily on typical symptoms that include poorly localized periumbilical pain, followed by nausea and vomiting, with subsequent migration of pain to the right lower quadrant.

This classic presentation occurs in only 50–60% of patients, and the diagnosis may be missed or delayed when atypical patterns of disease are encountered.

The rate of misdiagnoses at initial presentation is high, as 57% in children younger than 12 years and as 100% in children younger than 2 years.

Younger children often present with nonspecific signs and symptoms and are unable to clearly describe their symptoms or localize pain. As a result, delayed or incorrect diagnoses and complications such as appendiceal perforation are common.

Results of laboratory tests, such as white blood cell count and C-reactive protein level, can be helpful but are not specific (Gendel et al. 2011).

The classic presentation is the onset of periumbilical pain that migrates to the right lower quadrant at McBurney's point over a period of

12–24 h, with associated anorexia, leukocytosis, and, often, low-grade fever.

Since younger children are not able to describe their symptoms and up to one-third have atypical clinical findings, the correct diagnosis may delay, and in 30–74% serious complications occur such as perforation, peritonitis, sepsis, or even death.

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### 10.4 Radiological Findings

When the presentation is typical, most investigators and clinicians agree that imaging is unnecessary; however, the presentation is atypical in approximately 35–45% of patients, and for these patients imaging plays a key role in the diagnosis of suspected appendicitis (Sivit 2004; Hagendorf et al. 2004).

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### 10.5 US Normal Appendix

The evaluation of the appendix by US should be performed using a high-resolution linear-array transducer (5–12 MHz).

Graded-compression ultrasonography has been proved to be an effective aid in the diagnosis of acute appendicitis (Strouse 2010).

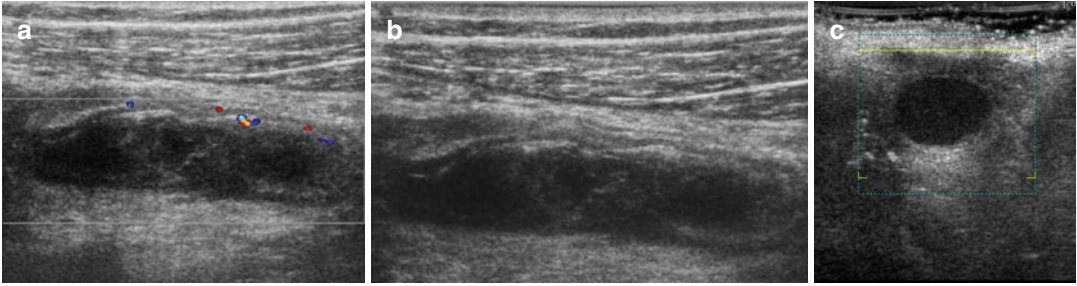
Gradual pressure is applied with the probe to displace bowel loops (Binkovitz et al. 2015).

Graduated compression with the probe helps differentiate between normal compressible intestinal loops and inflamed appendix that is not compressible (Fig. 10.3).

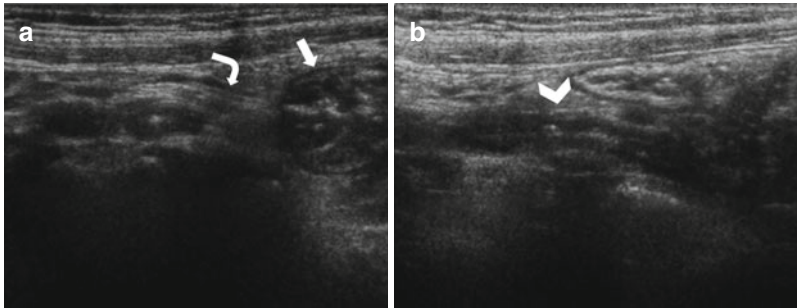
Key anatomic landmarks that must be visualized include the cecum, iliac vessels, and psoas muscle (Fig. 10.4).

The cecum is recognized as an aperistaltic large-caliber bowel that contains gas and fluid and is contiguous with the ascending colon.

The terminal ileum ends into the cecum at the ileocecal valve and is a readily compressible structure that demonstrates active peristalsis. The appendix arises from the posteromedial surface of the cecal base a few centimeters inferior to the ileocecal valve, although its distal tip may have a variable location.



**Fig. 10.3** (a–c) US: inflamed appendix appears like a blind-ended tubular structure that is not compressible at the graduated compression with the probe



**Fig. 10.4** (a, b) US, key anatomic appendix landmarks: the cecum (*arrow*) is recognized as an aperistaltic large-caliber bowel that contains gas and fluid; the terminal

ileum (*curved arrow*) ends into the cecum at the ileocecal valve and is a readily compressible structure that demonstrates active peristalsis; appendix (*arrow head*)

Measurement of the maximal mural thickness (MMT) is one of the most important morphologic criteria used to identify a normal or abnormal appendix (Fig. 10.5a) (Je et al. 2009; Simonovsky 2002).

The mural thickness of the appendix was defined as the distance from the hyperechoic luminal interface to the outer hyperechoic line.

The thickening of the appendiceal walls is due to mucosal edema, as a result of reactive changes.

The mean MMTs in the young children, older children, and adolescent are  $1.9 \text{ mm} \pm 0.4$ ,  $2.0 \text{ mm} \pm 0.5$ , and  $2.1 \text{ mm} \pm 0.5$ , respectively.

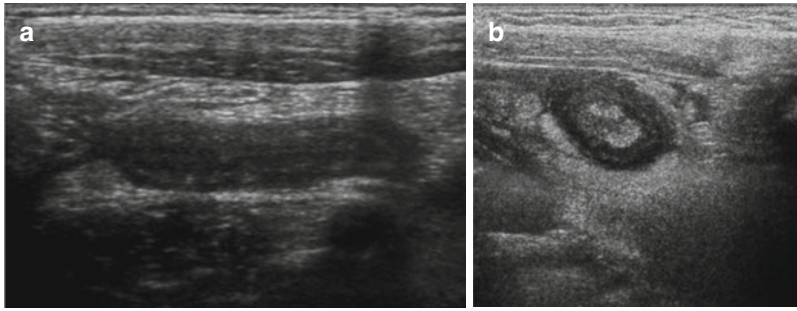
Although MMT evaluation can be considered a valuable index of the status of the appendix in patients with suspected appendicitis, it should be stressed that the accuracy is higher when there are several US criteria simultaneously, such as the presence or absence of periappendiceal inflamed fat, tenderness at the site of the appendix, and hyperemia at power or color Doppler US.

In children aged 6 years or younger, the appendiceal mural thickness should be regarded as normal only when it is less than 3 mm.

Although MMT measurement is more accurate, it is also using the maximal outer diameter (MOD) (Prendergast et al. 2014), which measures the outer wall to outer wall diameter at the widest point of the appendix during transducer compression (Fig. 10.5b). To measure diameters, the electronic calipers were placed between the outer borders of the hypoechoic tunica muscularis. The outer diameters were measured in the transverse plane of the appendix.

The MOD limits suggested to be positive for appendicitis vary between 6 mm or greater and greater than 7 mm (Goldin et al. 2009).

The normal appendix measures 6 mm or less in maximal outer diameter, is compressible, and lacks adjacent inflammatory changes. In addition, it has no demonstrable flow at color flow Doppler imaging.



**Fig. 10.5** Longitudinal and transverse US scan: the maximal mural thickness (MMT) is the distance from the hyperechoic luminal interface to the outer hyperechoic line (a). Cross-sectional image of a distended normal

appendix: the maximal outer diameter (MOD) measures the outer wall to outer wall diameter at the widest point of the appendix (b)

A normal appendix should have an outer wall diameter of 6 mm or less, and its lumen should at least partially collapse under compression. Occasionally, a normal appendix may be slightly larger than 6 mm in diameter but will remain compressible.

## 10.6 Imaging of Acute Appendicitis

Although abdominal radiography remains a widely used examination in children with acute abdominal pain, it has been shown to be a relatively insensitive and nonspecific means for evaluating appendicitis, and its use adds unnecessary cost and radiation exposure; furthermore the findings that can be seen in the RX are totally nonspecific and consist of the display of an appendicolith and signs of paralytic ileus (greater evidence of the margin of the psoas and analgesic convexity of the spine) (Doria 2011).

Although magnetic resonance (MR) imaging shows promise in the presurgical assessment of patients who are suspected of having appendicitis, the application of this modality to the pediatric patient is yet undeveloped; furthermore the length of the MR imaging examination may substantially curtail its utility in younger patients who would need sedation (Kearl et al. 2016).

The principal imaging technique for evaluating children with suspected appendicitis is

graded-compression US. The clinical utility of US lies primarily in those children with present equivocal clinical findings (Leeson and Leeson 2013; Fonio et al. 2013; Di Giacomo et al. 2015).

Tip appendicitis is a rare condition that occurs when the inflammation is focally confined to the distal portion of the appendix (Mazeh et al. 2009); the pathophysiology in tip appendicitis is much less clear than acute appendicitis. The prevalence of this condition has been reported as high as 5% (Lim et al. 1996).

## 10.7 US

Although computed tomography (CT) can help clinicians rapidly and accurately diagnose or exclude acute appendicitis, CT represents potential risks of radiation exposure, need for sedation, risk of contrast medium, and high cost.

Because of the concern over excessive radiation exposure, several institutions have emphasized ultrasonography (US) as the primary initial modality for use in the assessment of possible pediatric appendicitis (Krishnamoorthi et al. 2011).

Although today computed tomography (CT) has become the predominant imaging method used to diagnose appendicitis in children in the United States, outside of the United States, ultrasonography remains the predominant imaging method to diagnose appendicitis in children (Hryhorczuk et al. 2012).



US is in fact an extension of the clinical examination. The sonographer can ask the child where it hurts and directly scan the painful region.

The sensitivity of US in children has ranged from 44% to 94%, and the specificity has ranged from 47% to 95%. But in experienced hands, US has reported sensitivities of 75–90%, specificities of 86–100%, accuracies of 87–96%, positive predictive values of 91–94%, and negative predictive values of 89–97% for the diagnosis of acute appendicitis (Pastore et al. 2014).

Scanning is performed in both longitudinal and transverse planes, and the examination begins with the identification of the ascending colon, which appears as a nonperistaltic structure containing gas and fluid (Fig. 10.4).

The transducer is then moved inferiorly to identify the terminal ileum, which is easily compressible and displays active peristalsis.

The cecal tip where the appendix arises is approximately 1–2 cm below the terminal ileum, and it is located anteriorly to the iliac vessels and psoas muscle.

Gentle, gradual pressure is used to compress the anterior abdominal wall, resulting in displacement and compression of normal bowel loops (Butler et al. 2011).

Normal appendix appears as a blind-ended lamellated structure without peristalsis.

On longitudinal images, the inflamed, nonperforated appendix appears as a fluid-filled, noncompressible, blind-ended tubular structure, and the maximal appendiceal diameter is greater than 6 mm (Fig. 10.6).

If fluid is present within the appendiceal lumen, a target appearance, characterized by a fluid-filled center and surrounded by an echogenic mucosa and submucosa and hypoechoic muscularis, may be seen when imaging in the axial plane.

Other findings of appendicitis include an appendicolith, which appears as echogenic foci with acoustic shadowing (Fig. 10.7); pericecal or periappendiceal fluid (Fig. 10.8); increased periappendiceal echogenicity representing fat infiltration (Figs. 10.8 and 10.9); and enlarged mesenteric lymph nodes (Fig. 10.9).

But the only US sign that is specific for appendicitis is an enlarged, aperistaltic, and noncompressible appendix measuring greater than 6 mm in maximal diameter.

The use of color Doppler US provides a useful adjunct in the evaluation of suspected acute appendicitis; the color Doppler US of nonperforated appendicitis typically demonstrates peripheral wall hyperemia, reflecting inflammatory hyperperfusion (Fig. 10.10).

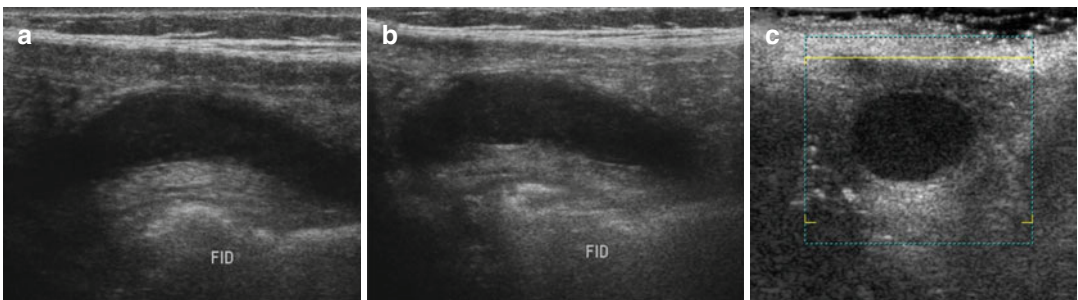
In early inflammation, color flow may be absent or limited to the appendiceal tip.

Color flow may also be absent in gangrenous appendicitis.

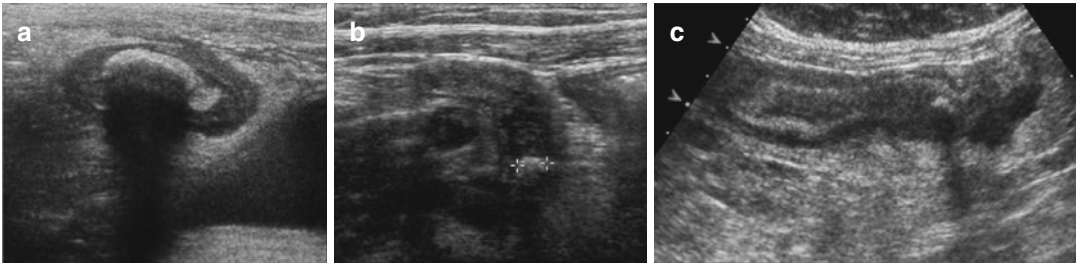
Depending on its location, the appendix can be classified as retrocecal, abdominal, midpelvic, or deep pelvic.

Abdominal appendices were those located in the abdominal cavity above a horizontal line defined by the iliac crests.

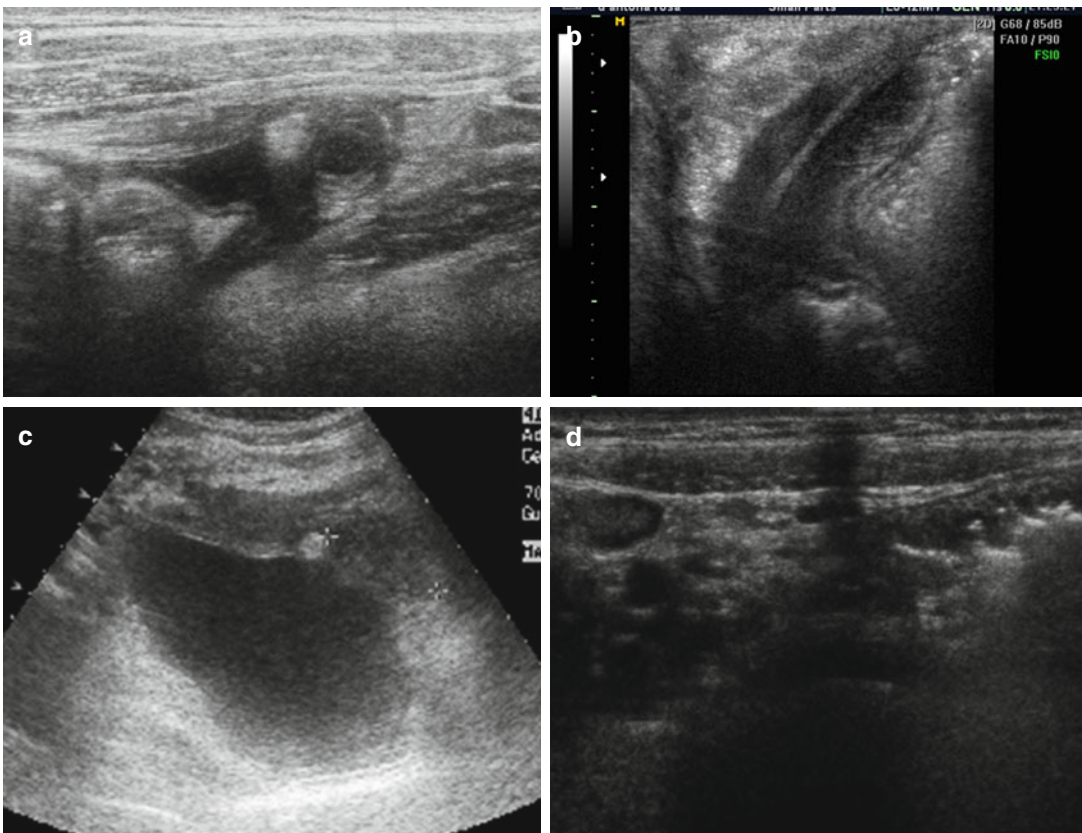
Midpelvic appendices were those located above the iliac vessels (external iliac artery and



**Fig. 10.6** Longitudinal (a, b) and transverse (c) US scan shows inflamed appendix as a fluid-filled, noncompressible, blind-ended tubular structure, with maximal appendiceal diameter greater than 6 mm



**Fig. 10.7** (a–c) US images show a dilated appendix that contains an appendicolith, which appears as echogenic foci with acoustic shadowing

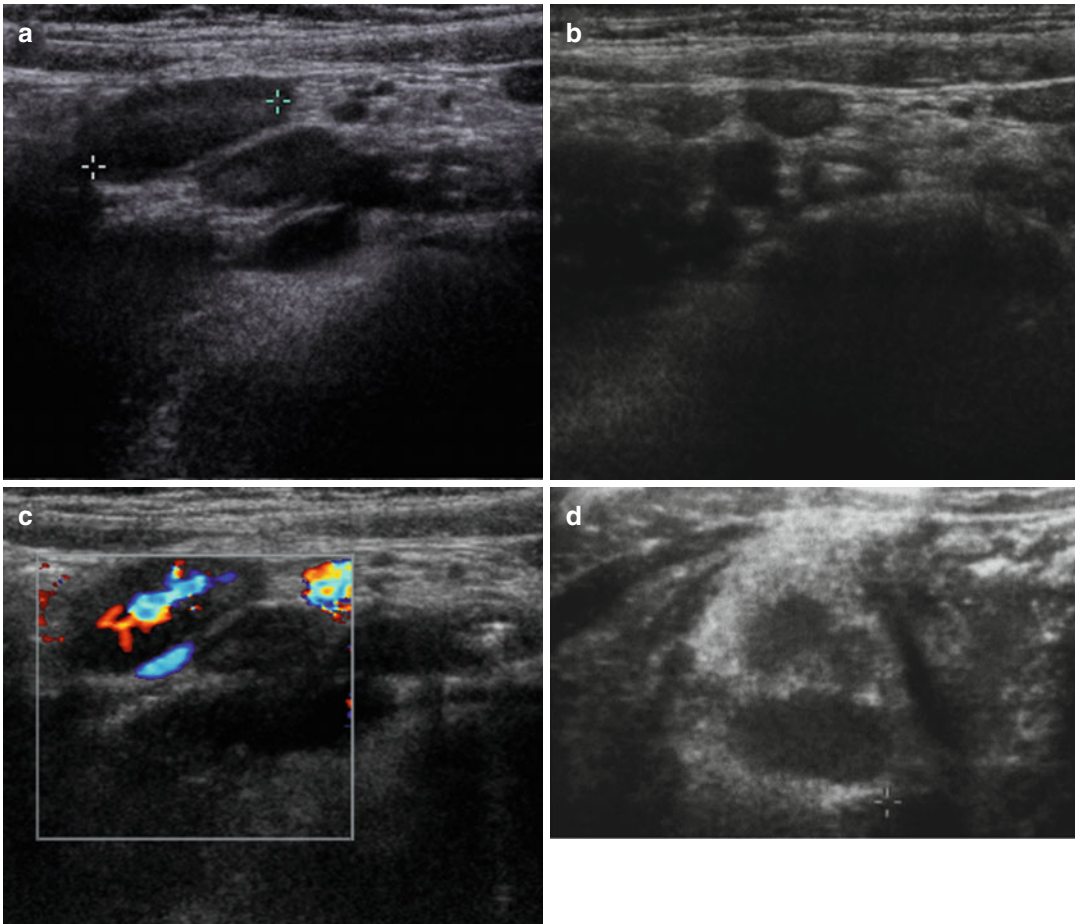


**Fig. 10.8** Ultrasonographic findings in appendicitis, such as pericecal or periappendiceal fluid (a) and increased periappendiceal echogenicity that represents fat infiltration (b)

vein in the pelvis). Appendices were classified as deep pelvic when they extended beyond the iliac vessels toward the pelvis minor or when the cecum was located in a lower position in relation to these vessels.

The course of appendicitis can be variable.

The presence of appendicoliths appears as bright, echogenic foci with distal acoustic shadowing. Their identification within the appendix or in the adjacent perienteric soft tissue after perforation is highly associated with a positive diagnosis (Lovrenski et al. 2016).



**Fig. 10.9** Ultrasonographic findings of appendicitis, such as increased periappendiceal echogenicity that represents fat infiltration (a) and enlarged mesenteric lymph nodes (a–d)

Phlegmonous change manifests as hypoechoic zones with poor margination within the inflamed fat that blend imperceptibly at its margins with the fatty tissue. Liquefaction and abscess formation will manifest as an actual fluid component (Fig. 10.11).

Some authors proposed the use of contrast-enhanced ultrasound (CEUS) to differentiate abdominal phlegmon and abscess. CEUS should be used to confirm these conditions primarily identified at US (Ripollès et al. 2013).

Although this method is still little used in non-traumatic pediatric emergencies (Catalano et al. 2004; Farina et al. 2015), its use however is well established in traumatic pediatric emergencies

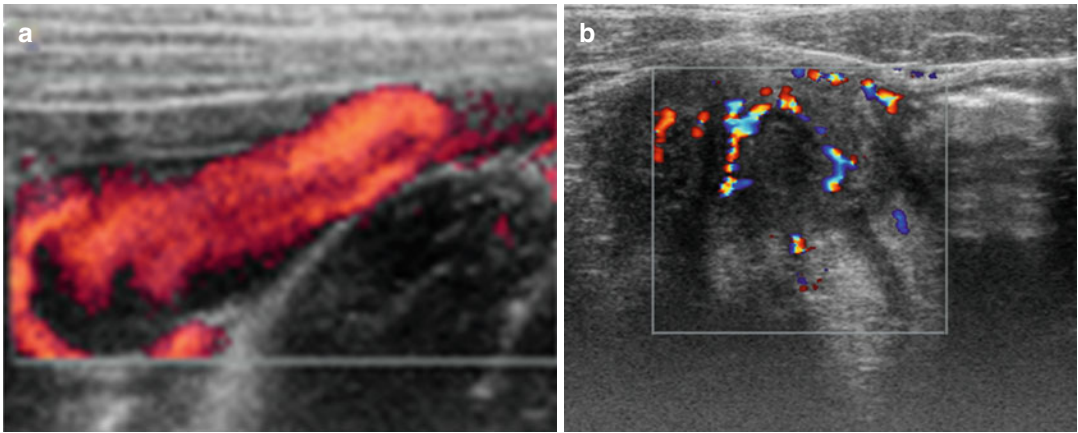
(Pinto et al. 2014, 2015; Miele et al. 2015, 2016a, b, c; Sessa et al. 2015; Menichini et al. 2015).

Gas bubbles within a collection suggest perforation (Blumfield et al. 2013).

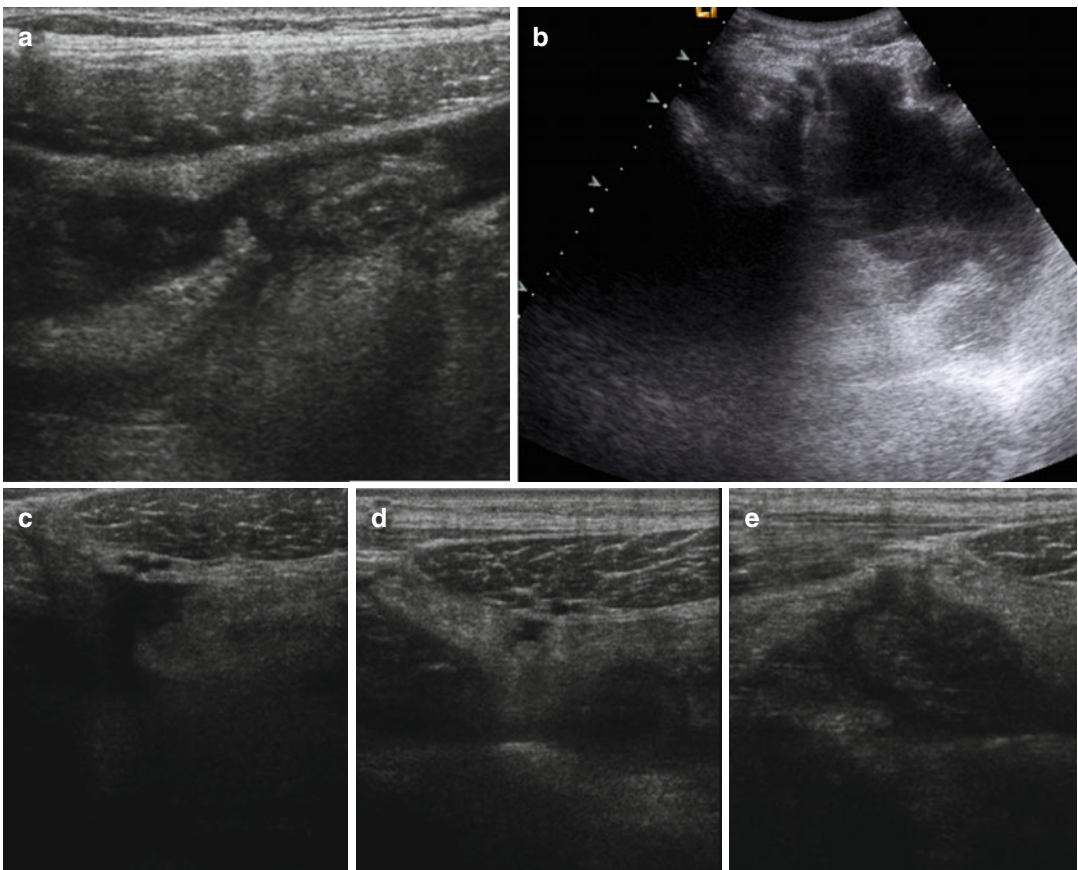
In conclusion the most accurate US finding for acute appendicitis is an outer wall diameter greater than 6 mm under compression, with reported positive and negative predictive values of 98% (Cohen et al. 2015).

Less sensitive and specific US findings for appendicitis include hyperemia within the appendiceal wall on color Doppler images, echogenic inflamed periappendiceal fat (Trout et al. 2012), and the presence of an appendicolith.





**Fig. 10.10** (a, b) The color Doppler US demonstrates peripheral wall hyperemia, reflecting inflammatory hyperperfusion



**Fig. 10.11** (a–e) US scan demonstrates hypoechoic zones with poor margination within the inflamed fat corresponding to phlegmonous appendicitis. Liquefaction and abscess formation will manifest as an actual fluid component

The principal advantages of US are its lower cost and wide availability, its lack of ionizing radiation, and its ability to assess vascularity through color Doppler analysis, provision of dynamic information through graded compression, and delineation of gynecologic disease which is a common mimic of acute appendicitis.

However US is operator dependent, and often technical failures are due to the presence of severe pain or patient obesity.

## 10.8 US of Perforation

Despite the relatively high incidence of appendicitis, the clinical diagnosis is very commonly delayed or missed, leading to high rates of appendiceal perforation, particularly in young children less than 5 years of age. Because diagnostic delays arise from the interpretation of the history and physical examination results, diagnostic imaging has become an essential tool in the evaluation of children suspected of having appendicitis.

The classic findings of bowel perforation, abscess, and extraluminal air are well known but are not always present in patients with perforated appendicitis (Pinto et al. 2016).

The presence of an appendicolith in a child with appendicitis has been associated with earlier and higher rate of perforation.

If perforation has occurred, the appendix may not be recognizable as a discrete structure.

The US features of perforation include loss of the echogenic submucosal layer and presence of a loculated periappendiceal or pelvic fluid collection or abscess.

These findings occur in 50–70% of cases of perforated appendicitis.

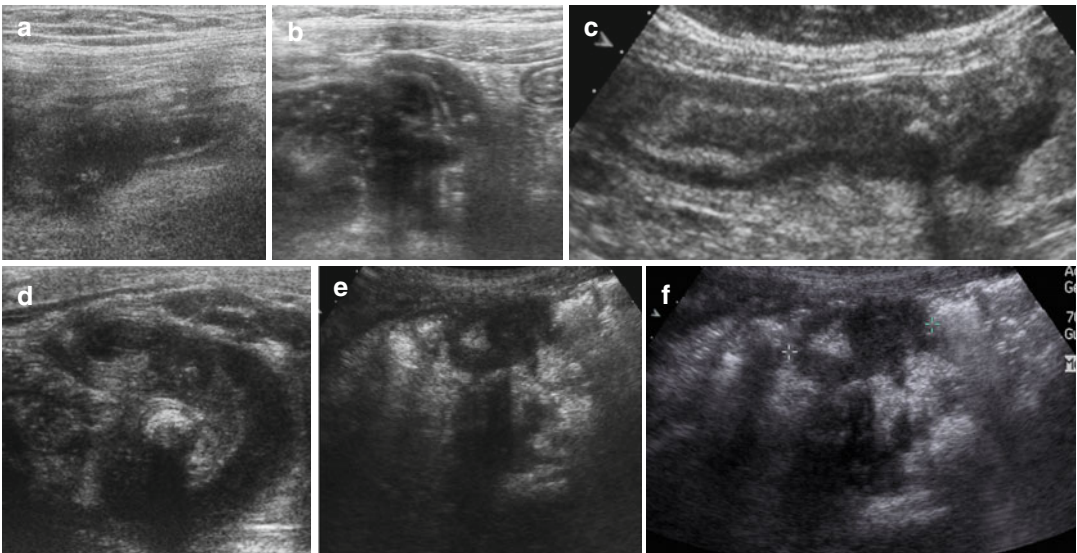
Color Doppler findings of appendiceal perforation include hyperemia in the periappendiceal soft tissues or within a well-defined abscess.

Specific findings indicative of perforated appendicitis are abscess, phlegmon, extraluminal air, extraluminal appendicolith, and a defect in the enhancing appendiceal wall (Fig. 10.12).

An abscess was characterized by a well-delineated, discrete collection with rim enhancement (Fig. 10.13).

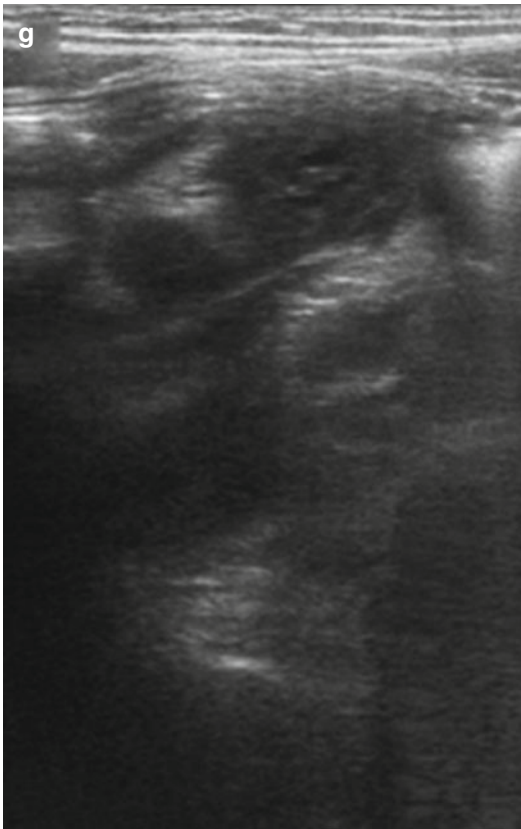
A phlegmon was characterized by diffuse and substantial inflammation of the periappendiceal fat with ill-defined fluid collections (Fig. 10.14).

Preoperative knowledge of whether the appendix is perforated has clinical relevance (Kaiser et al. 2004).



**Fig. 10.12** (a–f) US of perforation: US findings include loss of the echogenic submucosal layer, hyperemia in the periappendiceal soft tissues, and the presence of a locu-

lated periappendiceal or pelvic fluid collection or abscess. The appendix may not be recognizable as a tubular structure



**Fig. 10.12** (continued)

Once perforation has occurred, the complications increase.

US criteria for perforation include loculated pericecal fluid, prominent pericecal fat greater than 10 mm, and circumferential loss of the echogenic submucosal layer. For perforation, the reported US sensitivities vary from a low of 29% (Mazeh et al. 2009) to a high of 84% (Lim et al. 1996).

But extraluminal air, extraluminal appendicoliths, and interloop abscesses are more easily detected with the use of CT that demonstrates more sensitivity than US for perforated appendicitis (Cogley et al. 2012).

## 10.9 Pitfalls and Differential Diagnosis

Although common, acute appendicitis can be a difficult diagnosis to make on clinical grounds alone, because a number of other common

pathologic abdominal processes share a similar clinical presentation (Levine et al. 2004).

Relatively low sensitivity or specificity has been reported for individual symptoms and signs in patients clinically suspected of having appendicitis, including nausea (sensitivity of 67.5%, specificity of 38.9%), anorexia (sensitivity of 61.0%, specificity of 59.3%), fever (sensitivity of 17.9%, specificity of 72.2%), chills (sensitivity of 6.9%, specificity of 96.3%), right lower quadrant pain (sensitivity of 95.9%, specificity of 3.7%), and rebound tenderness (sensitivity of 69.5%, specificity of 38.9%).

The most common sources of error in the overdiagnosis of appendicitis with US include misinterpretation of the terminal ileum as the appendix and misinterpretation of a normal appendix as an inflamed appendix. The terminal ileum, in contrast to the appendix, does not attach to the base of the cecum, is not blind ended, and shows frequent peristaltic activity.

Also, the terminal ileum usually is oval in cross section as compared with the appendix, which is round.

Another cause of a false-positive examination is periappendiceal inflammation due to Crohn disease; interpretation of US findings may be difficult since the appendix may be involved in the inflammatory process of Crohn disease, or, conversely, appendicitis may be the first manifestation of this disease (Sung et al. 2006).

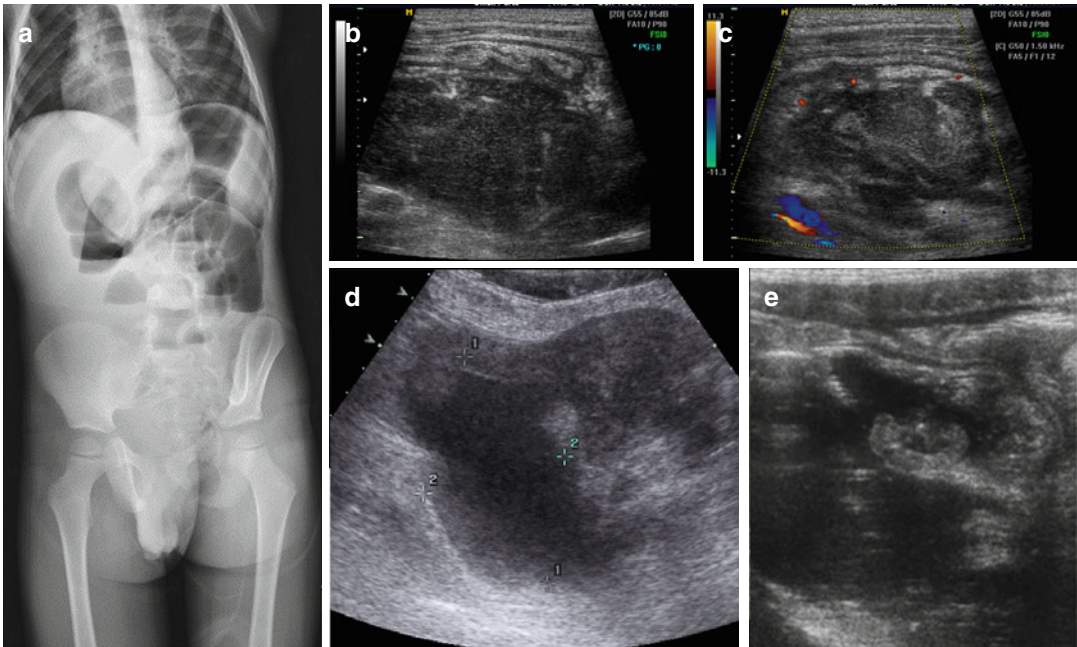
More causes of a false-positive examination that may mimic acute appendicitis are inflamed Meckel's diverticulum (Marin et al. 2016; Miele et al. 2001) and pelvic inflammatory disease (Miele et al. 2002).

Other problems in diagnosis may be related to a position of the appendix that makes it more difficult to appreciate, in particular when it is in the true pelvis and when it is retrocecal.

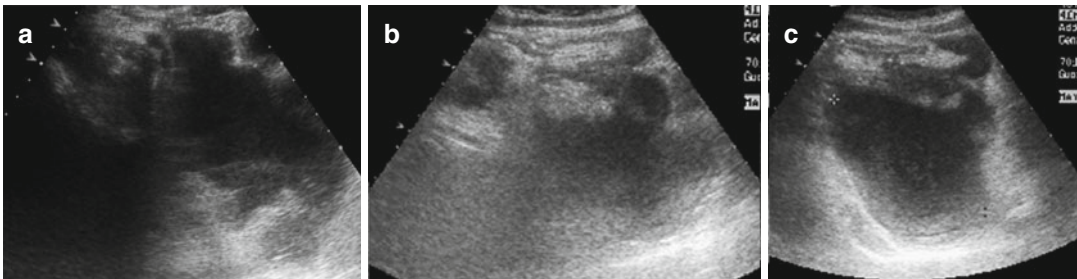
The most common alternate diagnoses included mesenteric adenitis, ovarian abnormality, constipation, colitis, intussusception, and pyelonephritis.

*Mesenteric adenitis* has been reported as the second most common cause of right lower quadrant pain after appendicitis (Xu et al. 2016). The clinical presentation may mimic that of





**Fig. 10.13** (a) X-ray and (b–e) US scan of abscess; the RX image shows intestinal obstruction with air-fluid levels; the US demonstrates a well-delineated fluid collection with rim enhancement and peripheral wall hyperemia



**Fig. 10.14** (a–c) US of phlegmon: diffuse inflammation of the periappendiceal fat with ill-defined fluid collections

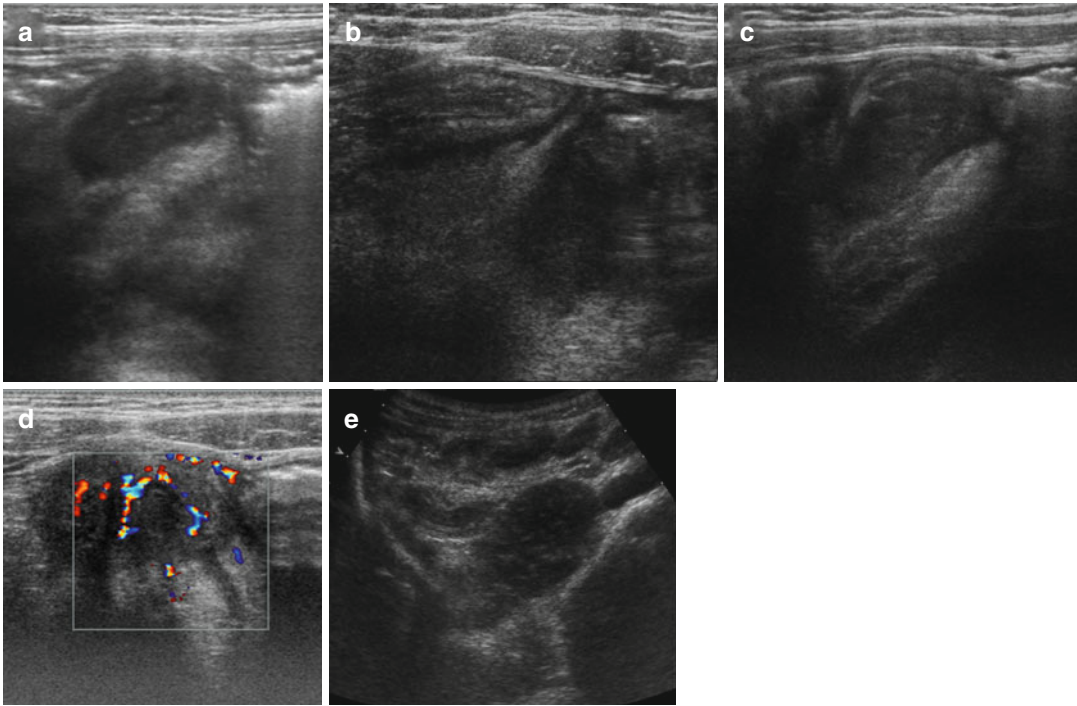
appendicitis; however, it is a benign self-limiting condition that does not require surgery. US findings consist of multiple enlarged RLQ mesenteric lymph nodes in the absence of other diseases.

Another nonsurgical mimic of appendicitis is terminal *ileitis-ileocectitis of infectious* (*Yersinia*, *Salmonella*, or *Campylobacter* species) or inflammatory (e.g., Crohn disease) origin. Acute or subacute RLQ pain is the predominant symptom, and diarrhea may be absent or only mild in cases with an infectious origin.

Up to one-third of patients with Crohn disease initially present with acute onset of symptoms mimicking appendicitis. A thickened terminal ileum may be the only finding at US (Fig. 10.15), and it is imperative not to confuse terminal ileitis with a dilated appendix.

Only when US findings were equivocal and the diagnosis cannot be certain should be considered to use the CT subsequent to US to avoid invasive interventions when they are not needed.





**Fig. 10.15** (a–e) US images demonstrates thickened terminal ileum that may be the only finding at US for Crohn disease presentation

## 10.10 CT

Computed tomography (CT) has become the predominant imaging method used to diagnose appendicitis in children in the United States.

The diagnosis of appendicitis with CT is made by identifying an abnormal appendix and periappendiceal signs of appendicitis, whereas exclusion of appendicitis is predicated on visualization of a normal appendix and the absence of indirect signs of appendicitis.

Pediatric abdominopelvic CT with nonvisualization of the appendix has a high negative predictive value (98.7%) for appendicitis, which does not differ significantly from that in cases with a partially or even fully visualized normal appendix.

Helical CT has been shown to be a highly sensitive and specific modality for the diagnosis of acute appendicitis in children and adults.

The reported sensitivities of CT are 90–100%, specificities of 91–99%, accuracies of 94–98%, positive predictive values of 92–98%, and negative predictive values of 95–100% for the diagnosis of acute appendicitis (Kim et al. 2015).

The advantages of CT over US are reduced operator dependence, superior contrast sensitivity, and the capability for viewing the entire range of air, soft tissue, fat, and bone attenuation values inherent to the abdomen. CT is also more useful than US for evaluating complications of acute appendicitis, such as phlegmon and abscess. It can precisely delineate the location and extent of associated fluid collections including interloop abscesses, which facilitates drainage procedures (Doria et al. 2006).

The normal appendix can be identified at CT in over three-fourths of children. The appendix arises from the posteromedial wall of the cecum, approximately 1–2 cm below the ileocecal junction (Ozturkmen Akay et al. 2007).

The maximal normal appendiceal diameter is variable; although it usually is 7 mm or less, it may occasionally be larger.

CT features of acute appendicitis include a distended appendix greater than 7 mm in maximal diameter, appendiceal wall thickening and enhancement, the presence of appendicolith, circumferential or focal apical thickening, pericecal fat stranding, adjacent bowel wall thickening, free peritoneal fluid, mesenteric lymphadenopathy, intraperitoneal phlegmon, or abscess (Figs. 10.16 and 10.17).

The only CT findings specific for appendicitis are an enlarged appendix and cecal apical changes, which represent contiguous spread of the inflammatory process to the cecum.

Identification of an appendicolith in an individual with acute right lower quadrant pain is also considered highly suggestive of acute appendicitis.

The principal advantages of CT include less operator dependency than US and enhanced delineation of disease extent in perforated appendicitis. Furthermore CT is particularly valuable in obese patients, since they are typically difficult to evaluate with US (Wan et al. 2009).

The most popular and conservative approach is to perform helical CT scanning of the entire abdomen and pelvis with intravenous contrast

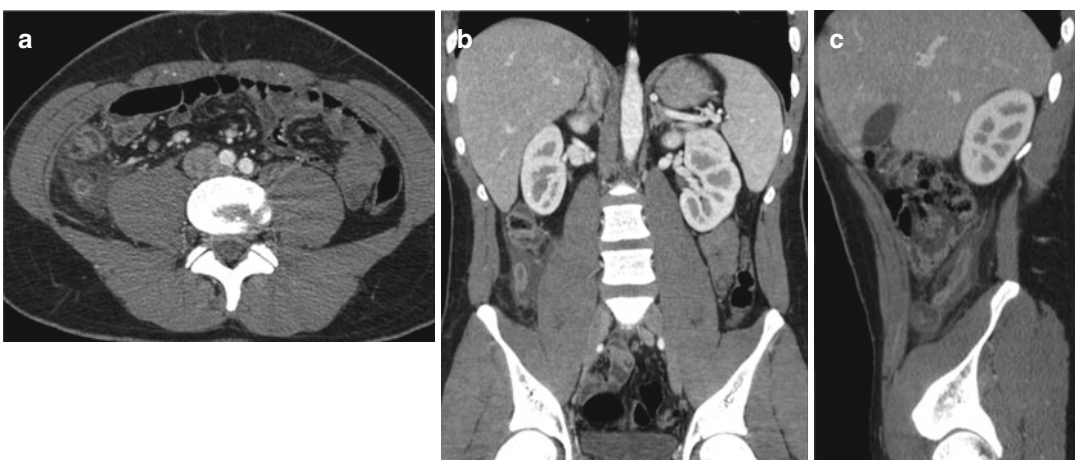
material, since contrast-enhanced CT is essential in the diagnosis and staging of numerous inflammatory diseases that may cause acute abdominal pain and may simulate appendicitis.

When seen, the normal appendix appears as a tubular or ringlike pericecal structure that is either totally collapsed or partially filled with fluid, contrast material, or air. In our experience, the normal appendiceal wall measures less than 1–2 mm in thickness.

The periappendiceal fat should appear homogeneous, although a thin mesoappendix may be present.

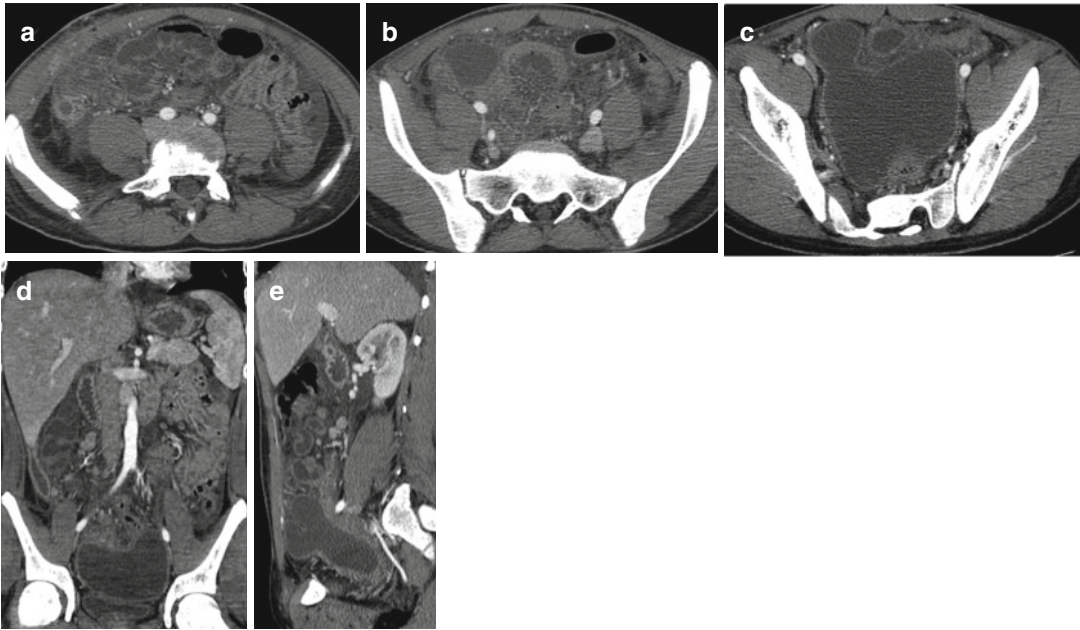
The CT findings are most subtle in patients with mild, nonperforating appendicitis who undergo scanning shortly after the onset of symptoms. In these patients, the appendix may appear as a minimally distended, fluid-filled, tubular structure 5–6 mm in diameter surrounded by the homogeneous fat attenuation of the normal mesentery. This appearance is seen in only the most incipient forms of acute appendicitis (Horrow et al. 2003).

The main CT criteria for the diagnosis of acute appendicitis include identification of a thickened appendix with a wall diameter greater than 6.0–7.0 mm, periappendiceal inflammatory changes, and a calcified appendicolith (Fig. 10.18). Circumferential and symmetric wall thickening is nearly always present and is best demonstrated on



**Fig. 10.16** CT axial (a) and coronal and sagittal reconstruction (b–c) images demonstrate features of acute appendicitis: distended appendix greater than 7 mm in

maximal diameter, appendiceal wall thickening and enhancement, pericecal fat stranding, and free peritoneal fluid



**Fig. 10.17** (a–c) CT, axial scans and (d–e) coronal and sagittal reconstructions show a fluid-filled appendicitis, with thickened wall and periappendiceal inflammatory changes. CT demonstrates the real extent of periappendiceal inflammation and the presence of periappendiceal abscess

images obtained with intravenous contrast material enhancement. The thickened wall usually is homogeneously enhanced, although mural stratification in the form of a target sign may be noted.

Periappendiceal inflammation is present in 98 % of patients with acute appendicitis.

Perforated appendicitis is usually accompanied by pericecal phlegmon or abscess formation. Associated findings include extraluminal air, marked ileocecal thickening, localized lymphadenopathy, peritonitis, and small-bowel obstruction (Fig. 10.19).

CT can be used to accurately stage the extent of periappendiceal inflammation and to reliably differentiate periappendiceal abscess from phlegmon. This distinction is of critical importance to the surgeon.

### 10.11 US Versus CT

There are several fundamental differences between CT and US that affect the diagnostic accuracy achieved by using each.

The sensitivity of US ranges between 44 % and 98 %, and its specificity ranges between 47 % and 95 %, whereas the sensitivity and specificity of CT range between 87 % and 100 % and 89 % and 99 %, respectively (Shah et al. 2014).

US is rapid, noninvasive, and inexpensive and requires no patient preparation or contrast material administration. Because US involves no ionizing radiation and excels in the depiction of acute gynecologic conditions, it is recommended as the initial imaging study in children.

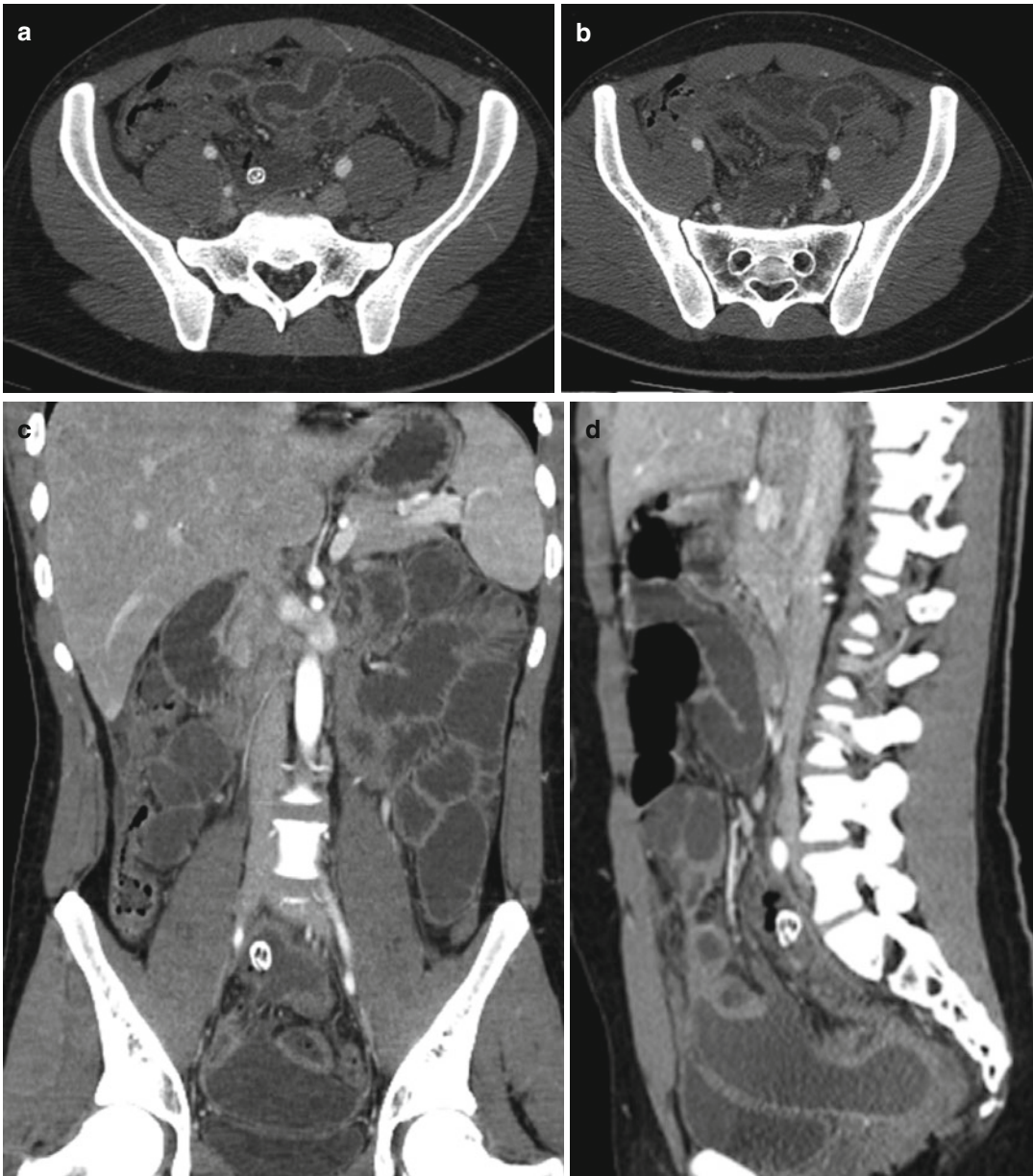
Operator dependency is the major disadvantage of US in evaluating for appendicitis.

Another important limitation of US is the sensitivity and specificity for perforated appendicitis.

CT is preferred in patients suspected to have appendiceal perforation because diagnostic accuracy remains high and because CT is particularly useful for characterizing periappendiceal inflammatory masses.

CT was shown to be more accurate in staging periappendiceal inflammation, more useful in diagnosing acute abdominal conditions unrelated to appendicitis, and more sensitive in





**Fig. 10.18** (a–b) CT, axial scans and (c–d) coronal and sagittal reconstructions: acute appendicitis. The figures show a thickened appendix with a wall diameter greater than 6.0–7.0 mm, periappendiceal inflammatory changes, and a calcified appendicolith in an individual with acute right lower

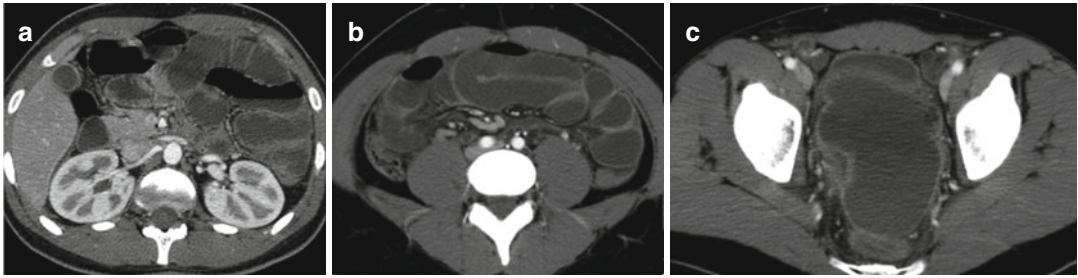
quadrant pain. This condition is considered highly suggestive of acute appendicitis. Perforated appendicitis is usually accompanied by pericecal phlegmon or abscess formation, extraluminal air, marked ileocecal thickening, localized lymphadenopathy, peritonitis, and small-bowel obstruction

demonstrating a normal appendix and in excluding acute appendicitis from the differential diagnosis.

Analysis of the data for CT and US revealed similar specificities (89% vs 91%, respec-

tively) and positive predictive values (96% vs 95%, respectively); however, CT demonstrated higher sensitivity (96% vs 76%), accuracy (94% vs 83%), and negative predictive value (95% vs 76%).





**Fig. 10.19** (a–c) CT axial, same patient: evidence of small-bowel obstruction and peritonitis

US is able to differentiate many pathologic processes in the female pelvis that may cause pain. Because the symptoms in such patients and the symptoms of girls with appendicitis often overlap and radiation exposure may be avoided with US, US is clearly the imaging modality of choice in the adolescent female with right lower quadrant or pelvic pain.

US has limitations in large or obese patients in the presence of abundant bowel gas and in anomalous appendiceal location. These are not limitations with CT (Yiğiter et al. 2011).

Another limitation of US is the inability to see the appendix in most patients when it is normal and the inability to see the entirety of the normal appendix.

Conversely CT may require sedation or general anesthesia, and the use of intravenous contrast material is not without complications, such as contrast material extravasation, anaphylactoid reactions, and contrast material-induced nephropathy.

The overriding disadvantage of CT, however, is the dependence of CT on ionizing radiation. The approximate dose to a child for single-phase CT of the abdomen and pelvis performed with appropriate, age-adjusted CT parameters is 5 mSv. Although this dose is small, it is not negligible. Younger patients, including young adults, are more radiosensitive (Bachur et al. 2015).

US can help us to use CT more effectively and in the practice the US examination must precede the use of CT.

Whenever the diagnosis can be definitively made at US, CT is avoided, as the patient can undergo surgery directly. Whenever an alternative diagnosis is made at US, CT is avoided.

In conclusion, a staged US and CT imaging protocol in which US is performed first for suspected acute appendicitis in children is highly accurate and offers the opportunity to substantially reduce radiation. A definitive US result, either positive or negative, is sufficiently accurate to guide therapy without performing subsequent CT.

Patients with right lower quadrant pain and an equivocal clinical diagnosis should be triaged to imaging examination, with US as the primary imaging modality in patients who are suspected of having gynecologic abnormalities. US may be used first in patients who are suspected of having appendicitis, but a US examination with negative findings should not lead to a dismissal of the diagnosis.

CT scans should be used judiciously, by using scanning parameters that are appropriate for patient size, and should be optimized for diagnosis with a single pass; additional passes are additional examinations, which are typically unnecessary (Srinivasan et al. 2015; Miele et al. 2006; Miele and Di Giampietro 2014).

## 10.12 RM

Children are particularly at risk for the adverse effects of ionizing radiation, and even low-dose radiation is associated with a small but significant increase in lifetime risk of fatal cancer.

Magnetic resonance (MR) imaging can be used to evaluate for abdominal disease without the use of ionizing radiation. In most emergency departments, however, the use of MR imaging as a primary modality for the evaluation of a child

with abdominal pain is still impractical due to its high cost, its limited availability, and the frequent need for sedation to obtain diagnostic-quality images in young children (Ditkofsky et al. 2014).

Ultrasonography (US) remains the standard imaging technique to investigate acute appendicitis.

MR imaging may be used as a complementary examination when US is inconclusive or when it is important to avoid exposure to CT radiation or contrast material in children with signs and symptoms of appendicitis (Aspelund et al. 2014; Herliczek et al. 2013).

Magnetic resonance (MR) imaging has been proposed as an alternative to CT for imaging suspected acute appendicitis. Like US, MR imaging does not expose patients to ionizing radiation. Unlike US, it is readily available at many adult facilities due to the need for 24-h-a-day stroke imaging and is less operator dependent.

MR imaging without contrast material demonstrates high diagnostic performance for suspected pediatric appendicitis with sensitivity of 93.3 %, specificity of 98 %, positive predictive value of 96.5 %, and negative predictive value of 96.2 % (Orth et al. 2014).

MR imaging must be conducted with an equipment from 1.5-T imager and a surface phased-array coil.

Four sequences were performed: axial T1-weighted fast SE, axial T2-weighted fast SE, axial T2-weighted fat-saturated fast SE, and coronal T2-weighted fast SE.

The sequences were acquired at a 4-mm section thickness without intersection gaps.

All images were obtained with the patient free breathing.

The coronal T2-weighted sequence was performed to identify the position of the cecum. Axial sections were defined according to the position of the cecum in each subject. The cranial section was at least 10 cm above the cecum and extended to the most caudal point of the pubic symphysis.

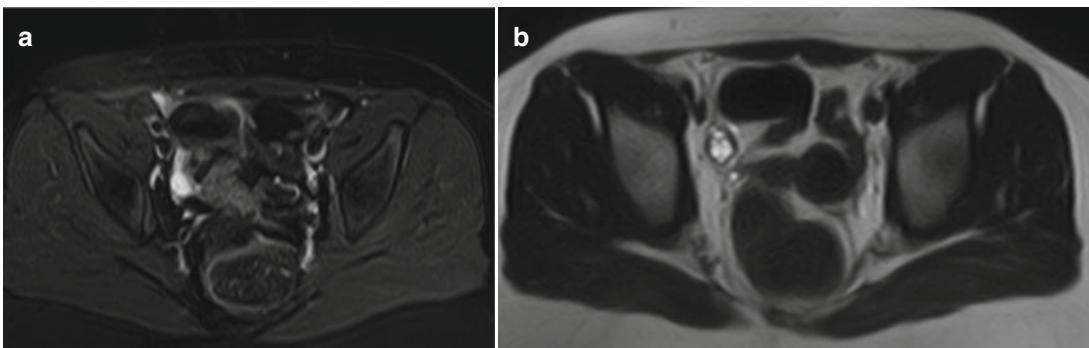
The axial T2-weighted fast SE sequence was the most useful in the detection of the normal appendix, with the appendix being detected in 48 % of cases, as compared with lower detection rates for axial T1-weighted (15 %), axial T2-weighted fat-saturated (10 %), and coronal T2-weighted (10 %) fast SE sequences.

The internal appendiceal contents were hyperintense on the T2-weighted images (Fig. 10.20). On the T1-weighted images, the internal contents were hypointense.

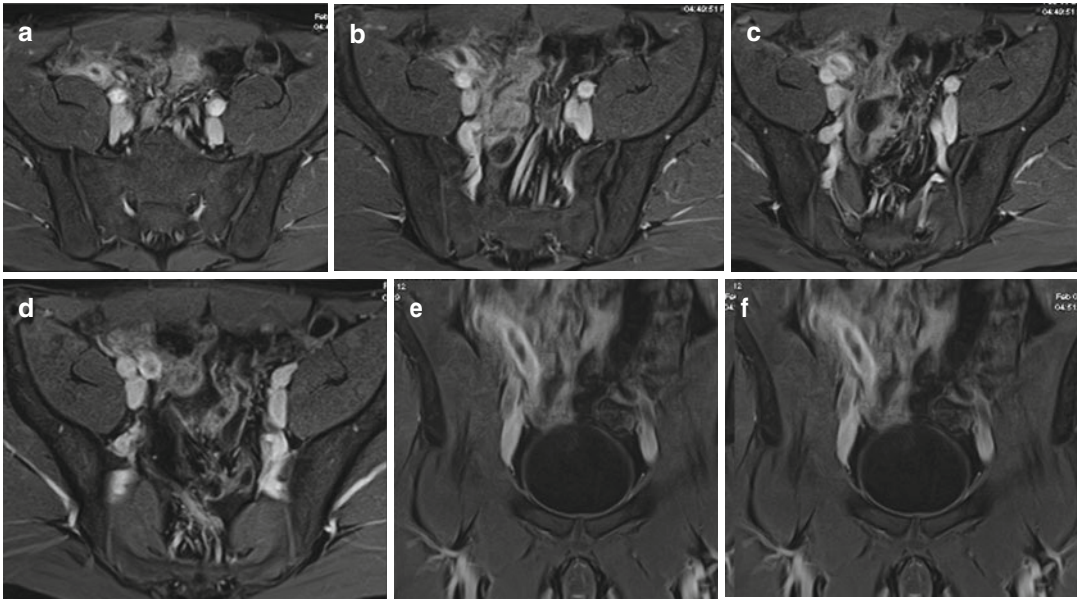
The appendiceal walls were isointense on T1- and T2-weighted images (Chang et al. 2016).

Each examination lasted 7 min for the four sequences. The total examination time was 20 min and included intervals between sequences, stops during acquisition, subject's entry into the room, positioning, and exit. All examinations were performed without intravenous contrast material (Rosines et al. 2014).

The criterion to define the normal appendix was the visualization of a blind-ended tubular

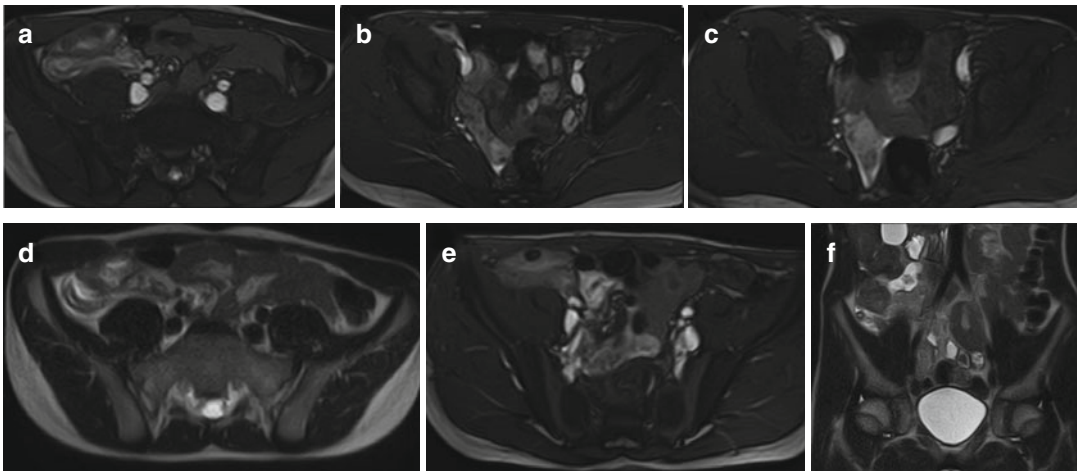


**Fig. 10.20** MRI, (a) axial T2-weighted fat-saturated fast SE and (b) axial T2-weighted fast SE demonstrate the internal appendiceal contents hyperintense on the T2-weighted images



**Fig. 10.21** (a–f) MRI with gadolinium: the appendiceal walls were hyperintense on T1-weighted images. The normal appendix was the visualization of a blinded tubular structure that extended from the cecum and had a trans-

verse diameter less than or equal to 6 mm. MRI images show distended appendix greater than 7 mm in maximal diameter, appendiceal wall thickening and enhancement, and free peritoneal fluid



**Fig. 10.22** (a–f) MRI with gadolinium: the appendiceal walls were isointense on T2-weighted images. The normal appendix was the visualization of a blinded tubular structure that extended from the cecum and had a transverse

diameter less than or equal to 6 mm: MRI images show distended appendix greater than 7 mm in maximal diameter, appendiceal wall thickening and enhancement, and free peritoneal fluid

structure that extended from the cecum and had a transverse diameter less than or equal to 6 mm (Swenson et al. 2016).

This criterion is the same one used for the detection of the normal appendix at CT and US.

The detection of the appendix was positive when it was visualized with at least one MR sequence (Figs. 10.21 and 10.22).

One of the greatest limitations of US is the detection of retrocecal appendixes.

With the use of MR imaging, however, appendices in this position were easily detected, particularly because of the fat between the posterior wall of the cecum and the posterior abdominal wall.

MR imaging examinations in children and adolescents were easily performed.

However MR imaging is expensive, and sedation is necessary to examine some pediatric patients. Therefore, MR imaging should be used only in cases in which US studies are not diagnostic: when it is available, MRI is preferable to CT as a second-level investigation, avoiding the use of radiation and contrast media. Nonenhanced MR imaging is highly accurate for the diagnosis of pediatric appendicitis, with test performance characteristics similar to those of US.

Nonenhanced MR imaging demonstrates high diagnostic performance similar to that of US for suspected pediatric appendicitis.

In conclusion, graded-compression ultrasonography (US) of the right lower quadrant is a valuable imaging modality for appendicitis, with sensitivities ranging from 75 % to 90 %, although such complications are often better delineated with CT or MRI (Epifanio et al. 2016).

Then, the second-level investigations can therefore be used in the follow-up of complications (e.g., abscesses) or when the clinical and laboratory tests are discordant.

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