

Ultrasound Evaluation for Appendicitis Focus on the Pediatric Population: A Review of the Literature

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Appendicitis is a common diagnostic consideration in all patients presenting with abdominal pain; however, it remains of particular concern in children. Appendicitis is the most common pediatric surgical emergency,¹ occurring in 7% of healthy children.² With the need to make an appropriate diagnosis expeditiously and preferably without ionizing radiation, ultrasound is the ideal modality. However, identifying the appendix remains a challenge sonographically with a wide range of rates of identification reported, as well as variable experience among technologists and radiologists in recognizing the appendix on ultrasound. Familiarity of radiologists with optimal sonographic technique, imaging findings, and differential diagnoses is essential in accurately performing and interpreting these examinations.

Expectations

Varied visualization rates of the appendix on ultrasound are reported in the literature. Kessler et al³ reported identification of the appendix with the radiologist performing the exam in 86% of patients of all ages, 96% of patients with appendicitis, and 72% of patients

with a normal appendix.³ Others report identification of the normal appendix in only 5% to 10% of children.⁴

Many studies have shown high specificity of ultrasound for diagnosing appendicitis. A meta-analysis reviewing studies from 1986 to 2004, revealed an overall 88% sensitivity and 94% specificity for detection of appendicitis on ultrasound in the pediatric population.⁵ In one retrospective study, the suboptimal performance of right lower quadrant (RLQ) ultrasound at a single institution was scrutinized and compared to data in the literature.⁶ The appendix was seen in 24.4% of patients with 66.5% sensitivity, 95.9% specificity, 75.7% positive predictive value, and 93.6% negative predictive value. The exams were performed by technologists with some radiologist oversight. Pediatric-trained technologists identified the appendix at a rate of 38.7% vs. 19.3% among general sonographers. Notably, within the group of patients where the appendix was not seen (75.6% of the total patient population), 7.1% had appendicitis. This is in contradistinction to only 1% of patients with a normal appendix visualized who ended up with appendicitis. The false negative rate of all exams

(whether or not the appendix was seen) was 33.5%; however, when the appendix was seen, the false negative rate decreased to 0.9%.⁶

Computed Tomography (CT) vs. Ultrasound

The advantages of ultrasound compared to CT include the lack of ionizing radiation, lower cost, less patient preparation (no IV, no sedation), and the ability to derive direct information from the patient during scanning (ie, the patient has pain directly over the appendix). However, CT remains advantageous for less operator dependency, easier visualization of the appendix in retrocecal or aberrant locations, and a better overview in cases of complication/perforation. Pooled sensitivity in one meta-analysis for pediatric patients showed that CT was 6% more sensitive than ultrasound. This analysis also estimated that 10 to 48 cases of appendicitis per 1,000 children (based on differing prevalence of appendicitis in the studies reviewed) would be missed on ultrasound as compared to CT. However, high baseline sensitivity of ultrasound in the pediatric population should be weighed with risk of ionizing radiation.



FIGURE 1. Graded compression commencing in the RLQ using a linear high-frequency transducer.



FIGURE 2. Posterior manual compression is applied along with graded compression to aid in identification of the appendix.

The authors concluded that in children, there was no significant difference in the specificity of ultrasound and CT, and no significant change in false positive rates between the two.⁵

In another study analyzing ultrasound and CT for pediatric appendicitis, sensitivities varied between the modalities. This study assumed that a nonvisualized appendix on ultrasound was a negative exam for appendicitis. CT showed a sensitivity of 95%, specificity of 93%, and accuracy of 94% for appendicitis. Ultrasound had a lower sensitivity of 78%, equal specificity of 93%, and accuracy of 89%. However, when the patient population was further divided (younger or older than 10 years), the significant difference in sensitivities were in the older age group.¹ The sensitivity between the 2 modalities was similar in patients < 10 years old.

Technique

Graded compression of the RLQ remains the mainstay of sonographic technique for evaluating appendicitis (**Figure 1**). This technique was initially described by Puylaert in 1986. The patient is placed in the supine position, preferably after voiding. A high-frequency linear array transducer is used starting at the area of maximal tenderness or in the RLQ. The examiner exerts compression with the ultrasound

probe in the area of concern, usually beginning in the transverse plane. Compression is a slowly applied deep pressure with the transducer, with deeper pressure applied during expiration. It is well-tolerated by patients, as opposed to the quick application and release of pressure during physical exam, which can elicit rebound tenderness.⁷ Adequate pressure is applied if the psoas muscle and iliac vessels are visualized.⁸ The main advantages of the graded compression technique include decreasing the distance between the ultrasound probe and appendix and displacing bowel gas.⁷

Initially the ascending colon should be identified as a nonperistalsing structure with haustrations along the right lateral abdomen. The probe is then moved inferiorly to localize the terminal ileum (TI). The TI is smaller than the colon, compressible, and lacks haustrations and peristalses. The appendix arises from the cecum 10-20 mm inferior to the TI.^{8,9} The iliac vessels and psoas muscle can be used as landmarks, as most appendices are anterior to these structures. The 2 most common locations of the appendix are retroileal (53%) and subcecal (33%).¹⁰ Images should be obtained in transverse and longitudinal planes. Gray-scale images, with and without compression, and color Doppler images should be acquired.

If the appendix is not readily identifiable, posterior manual compression to the RLQ in an anteromedial direction with the operator's opposite hand, in conjunction with graded compression to the right anterior abdominal wall, may help (**Figure 2**). This proves useful in obese or muscular patients by decreasing the distance between the transducer and retrocecal space and potentially increasing spatial resolution. High-frequency linear transducers have limitation in depth penetrance, which can be somewhat overcome with increased compression. Posterior manual compression can increase appendiceal visualization from 85% with graded compression alone to 95% using both techniques simultaneously.¹⁰ The technique is limited more inferiorly due to the intervening bony pelvis.^{10,11}

Upward graded compression is helpful for a pelvic location of the appendix. This technique involves directed upward sweeping of the transducer in an attempt to move the low-lying cecum superiorly. Placing the patient in a left lateral decubitus position can help in visualizing a retrocecal appendix (**Figure 3**). This displaces the cecum and TI medially, making the retrocecal, retroileal, and even subcecal locations more accessible. Another consideration is using a lower frequency transducer for increased depth penetrance.¹¹



FIGURE 3. Left lateral decubitus positioning may help displace shadowing the cecum medially and make the appendix more apparent

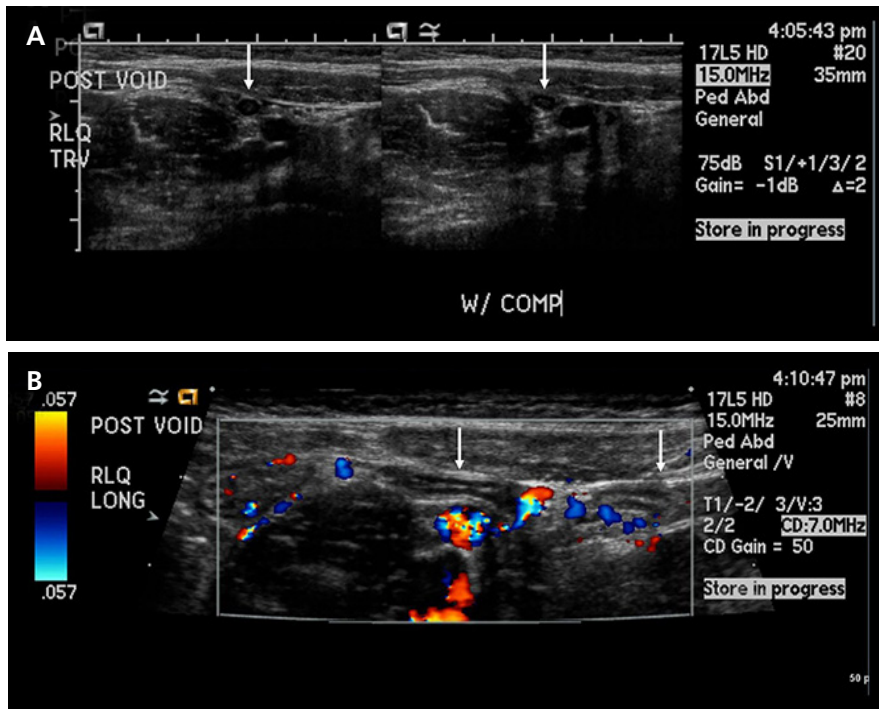


FIGURE 4. Normal appendix. Transverse gray scale (A) and longitudinal color (B) images of the RLQ in a 6-year-old boy presenting with periumbilical pain and vomiting demonstrate a non-enlarged (3-4 mm) appendix (arrows) with partial compressibility, no wall hyperemia, and preservation of wall architecture. No secondary signs of inflammatory process were present.

A sweep through the pelvis is recommended as part of routine examination to look for potential complications (eg, free fluid or abscess). One should consider graded compression evaluation up

to the liver tip and toward the midline, as the appendix can be found more superior and medial than expected. It is also helpful to assess for free fluid in Morrison's pouch.

Appendiceal Findings

The appendix is a blind-ending tubular structure with readily identifiable concentric, alternating hyper and hypochoic layers of the wall (bowel wall signature). The lumen is often filled with air. It arises from the inferior pole of the cecum. The appendix has a top normal diameter of 6 mm in short axis. An average appendiceal diameter of 4.2 mm (+/- 0.9 mm) was found in normal pediatric appendices.¹² A normal appendix should show compressibility, often to near obliteration. There is little to no blood flow in the wall (**Figures 4 and 5**).

Acute appendicitis results from obstruction of the appendiceal lumen and resultant secondary (usually bacterial) infection. The inflamed appendix is enlarged with a short axis diameter > 6 mm (**Figures 6-8**).¹¹ It is often non-compressible and fluid-filled (**Figure 6**). The distal portion of the appendix (tip) can be more dilated than the proximal portion.⁷ A diameter \geq 6 mm in one study (which measured the appendix under compression) showed 98% sensitivity and specificity for the diagnosis of appendicitis when present. Lack of compressibility was similar with 96% sensitivity and specificity for the diagnosis of appendicitis. A fluid-filled lumen was less sensitive (53%), but had a high specificity (92%) for appendicitis.³

The inflamed appendix can demonstrate hyperemia to the wall (**Figures 7 and 8**). Although blood flow to the appendiceal wall was only 52% sensitive for appendicitis, it had a high specificity of 96%. Blood flow on color imaging is rarely identifiable in a normal appendix.³ Caution is warranted, however, as lack of hyperemia in the wall may be associated with appendiceal perforation.¹³

An appendicolith can be seen in both normal and abnormal appendices. It is a hyperechoic focus within the appendiceal lumen with posterior acoustic shadowing (**Figure 9**).⁹ It remains controversial whether an appendicolith leads to an increased risk of appendicitis.¹⁴ However, in one study, the presence of

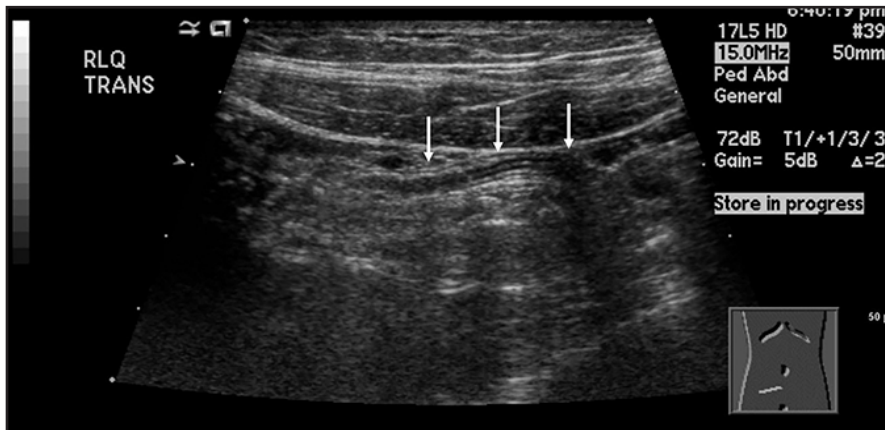


FIGURE 5. Normal appendix. Transverse gray scale image in an 18-year-old girl presenting with RLQ pain shows a normal appendix measuring 3 mm (arrows). Bowel wall signature in the wall of the appendix is readily identifiable. No secondary signs of inflammation were present.

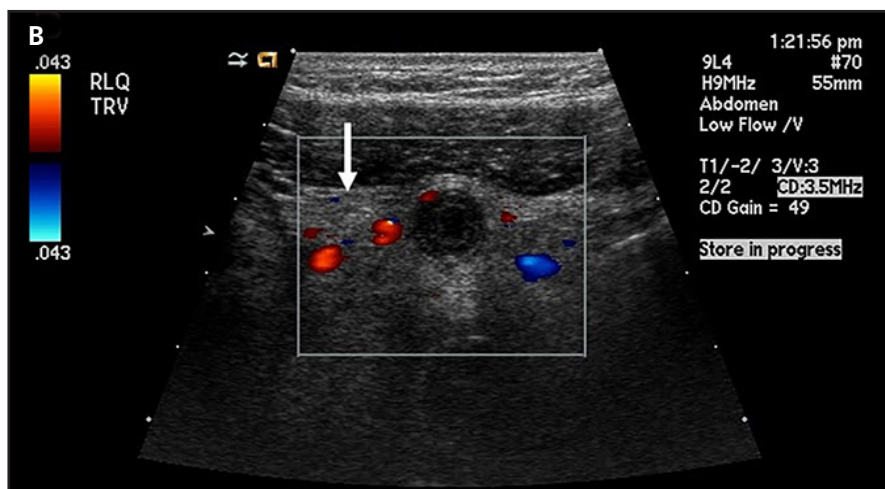
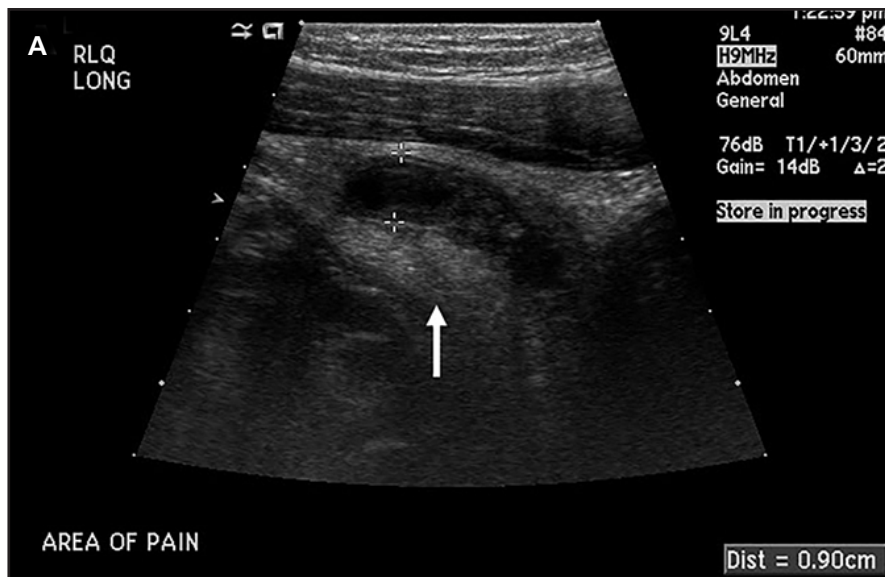


FIGURE 6. Acute appendicitis. Longitudinal gray scale (A) and transverse color (B) images of the RLQ in a 12-year-old boy presenting with periumbilical pain demonstrate a distended, fluid-filled appendix (calipers, A) measuring 9 mm with surrounding hyperechoic and hyperemic mesentery (arrows A and B). The appendix was noncompressible (not shown). There was acute suppurative appendicitis on pathology

an appendicolith, especially in children < 8 years old, had a 91.7% specificity for a perforated appendicitis.¹⁵

The appearance of appendiceal perforation is suggested when layers of the appendix wall are ill-defined with loss of the echogenic submucosal layer (Figure 10).¹³ The loss of the echogenic submucosal layer was 100% sensitive for perforation in children < 8 years but only 72.7% specific. Therefore, it is not recommended as sole identifier of perforation.¹⁵ An inflamed appendix surrounded by plegmon or abscess also indicates perforation.⁸

Appendicitis in the neonatal population is associated with significant rates of perforation and a 28% mortality rate. Neonatal appendicitis should raise concern for other pathology involving the bowel, such as necrotizing enterocolitis, cystic fibrosis, Hirschsprung disease, and inguinal hernias (in particular Amyand hernia, an inguinal hernia containing the appendix).¹⁴

Periappendiceal Findings

Identification of the abnormal appendix is the most accurate finding to diagnose appendicitis. However, there is a high percentage of studies where the appendix is not seen, so secondary signs are useful in identifying an inflammatory process (not necessarily appendicitis). These findings include increased echogenicity of the mesenteric fat, focal fluid collection, free fluid, thickened cecal wall, and hypoperistalsis of regional bowel.³ Studies do suggest that the presence of secondary signs alone (without direct visualization of the appendix) is enough to suggest the diagnosis of acute appendicitis.¹⁶

Hyperechoic mesenteric fat in the RLQ is a sensitive finding indicating inflammation (Figures 6, 9, and 10). This sign was 91% sensitive and 76% specific for appendicitis in one report.³ In another study, pericecal fat inflammatory changes were 98% specific for the diagnosis of appendicitis when the appendix was not seen.¹⁷

Free fluid is a nonspecific finding, especially a small amount in female

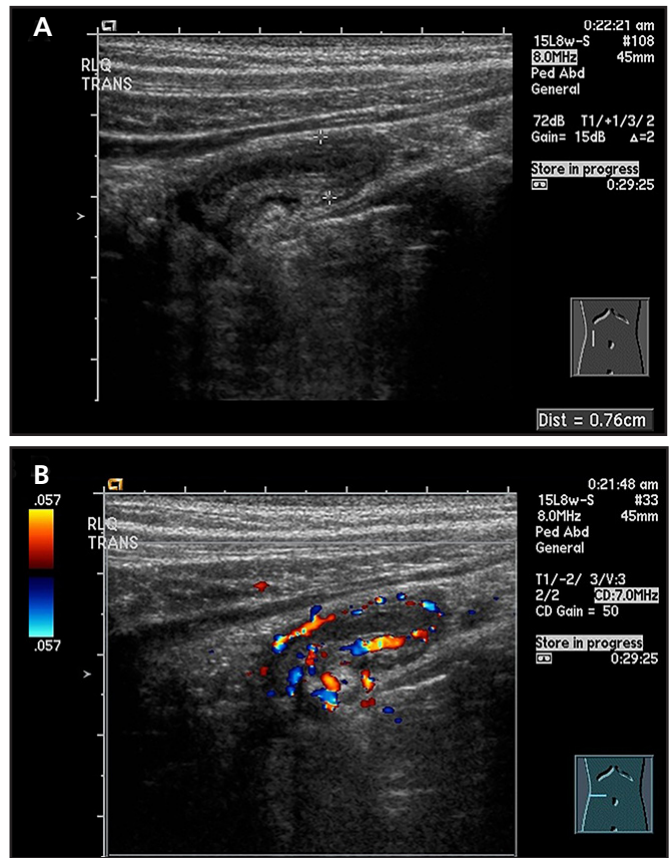
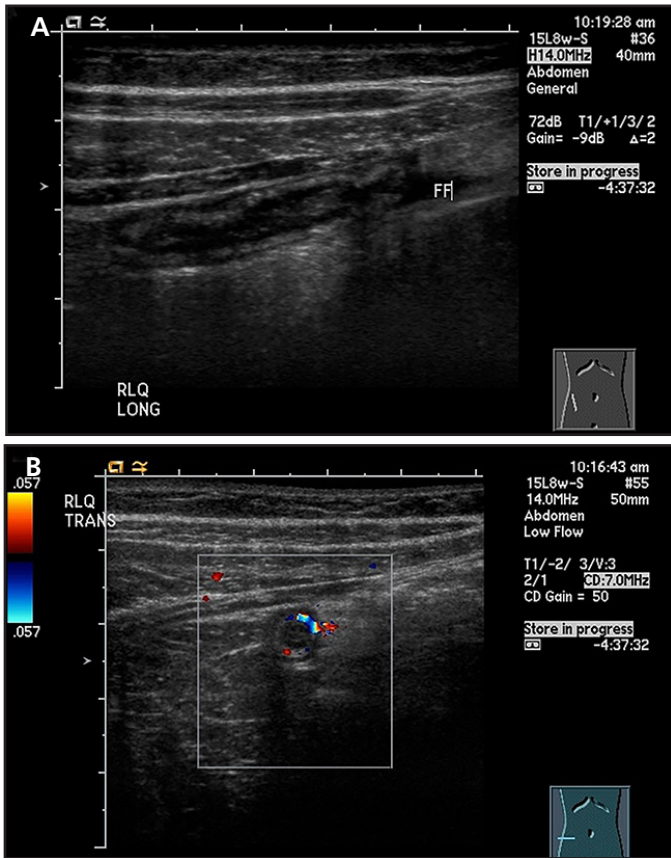


FIGURE 7. Acute appendicitis. Longitudinal gray scale (A) and transverse color (B) images of the RLQ in a 9-year-old boy presenting with leukocytosis and fever demonstrate a mildly dilated appendix (8 mm). A small amount of free fluid was present in the RLQ (FF, A). Wall hyperemia was present (B) with preservation of the wall architecture. The appendix was noncompressible (not shown). The patient had subacute and acute appendicitis on pathology.

FIGURE 8. Acute appendicitis. Transverse gray scale (A) and color (B) images of the RLQ in a 7-year-old girl presenting with pain reveal a dilated appendix (calipers, A) measuring 8 mm with wall hyperemia (B). No additional secondary signs were present. Pathology confirmed acute appendicitis.

adolescent patients. However, a moderate to large amount of free fluid has been shown to have 98% specificity for appendicitis, despite a low sensitivity, when the appendix is not visualized. Phlegmon had 100% specificity in the same study; however, it was rarely seen.¹⁷

Many reports have shown that the absence of secondary signs with or without direct visualization of the normal appendix can exclude the diagnosis of acute appendicitis.¹⁶ If ultrasound does not identify the appendix or any secondary signs of inflammation, the rate of appendicitis has been reported as 5.8% to 7.1% in one study.¹⁷ However, Trout et al had a 33% rate of false negative exams in their study, most of which were in patients with a nonvisualized appendix and no secondary signs.⁶ Thus, one must be cautious, exercise clinical judgement,

and be judicious with the use of CT in patients without visualization of the appendix and lack of secondary signs, especially when the person performing the exam has little experience and/or there is high clinical suspicion.

Certain secondary signs are associated with appendix perforation. One study showed the identification of dilated bowel (> 25 mm), echogenic fat in the right abdomen, and complex fluid in combination had a 99.5% specificity for perforated appendicitis (Figure 9). Individual secondary signs associated with a perforated appendicitis on ultrasound in the same study included abscess (Figure 11), loculated fluid, appendicolith, dilated bowel, and increased hepatic periportal echotexture compared to nonperforated appendicitis. The authors noted that although the presence of these

secondary signs were highly specific for perforated appendicitis, the absence of them did not confidently exclude appendicitis (low sensitivity).¹³

Secondary signs are also helpful when the appendix is identified but has equivocal size or incomplete compressibility. Lack of additional secondary findings of inflammation, especially mesenteric fat induration, should call into question whether the patient truly has acute inflammation of the appendix.¹⁸

Limitations

Limitations in visualizing the appendix include operator-dependent technical factors, a retrocecal or other aberrant location of the appendix, tip appendicitis, perforation, and obesity.^{9,10}

Aberrant possible locations of the appendix may be evaluated with a

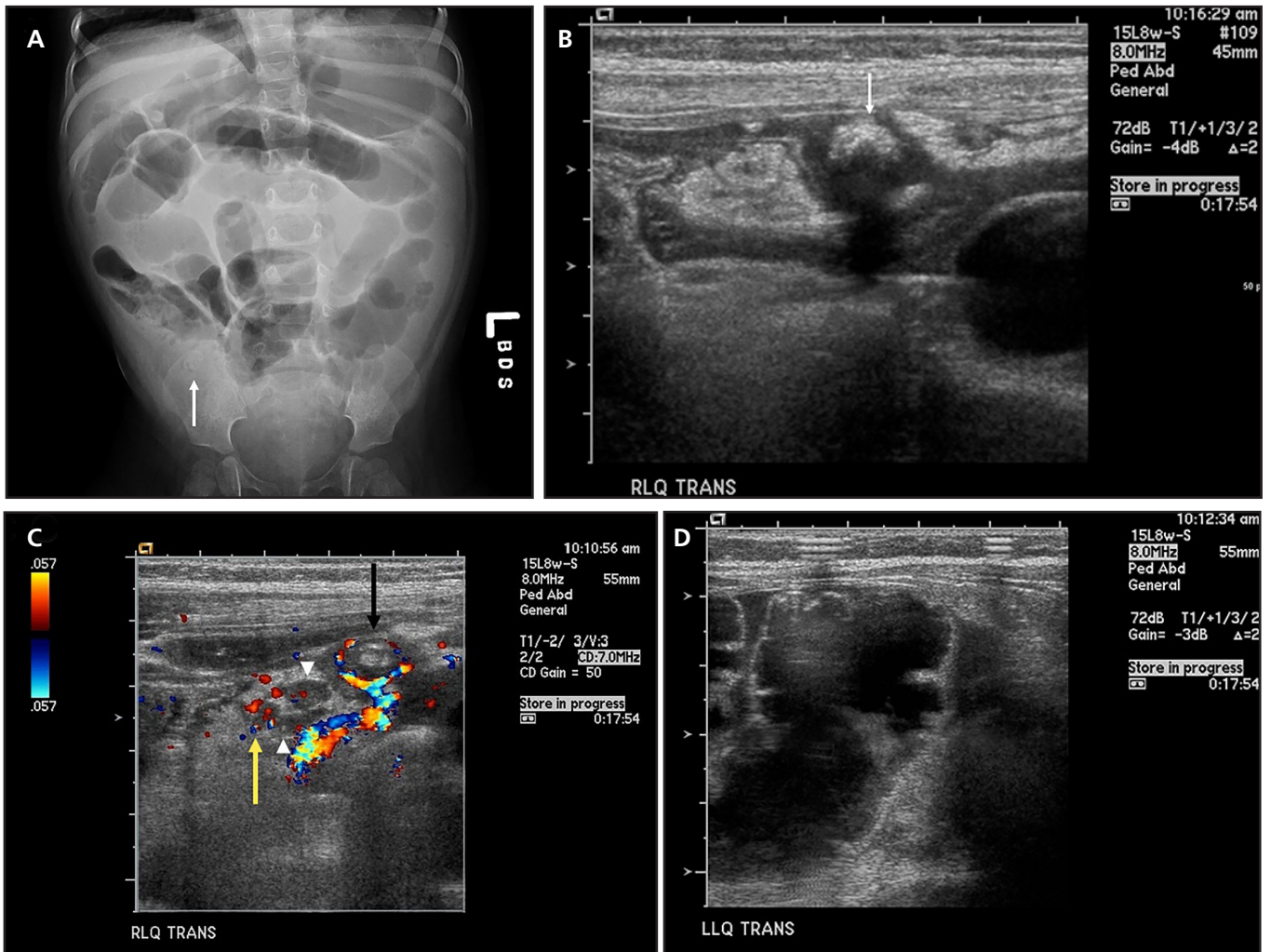


FIGURE 9. Appendicitis with appendicolith and perforation. Single frontal radiograph (A) reveals dilated bowel loops and RLQ calcification (arrow) in a 20-month-old girl. Transverse gray scale (B, D) and color (C) images of the RLQ in the same patient confirm an appendicolith (arrow, B) in a hyperemic, dilated appendix measuring up to 10 mm (black arrow, C). Secondary findings include hyperechoic and hyperemic adjacent mesentery (yellow arrow, C), lymph nodes (arrowheads, C), dilated bowel loops measuring > 25 mm (D), and free fluid. Operative findings included acute appendicitis with perforation and generalized peritonitis. Pathology concurred with acute suppurative appendicitis.

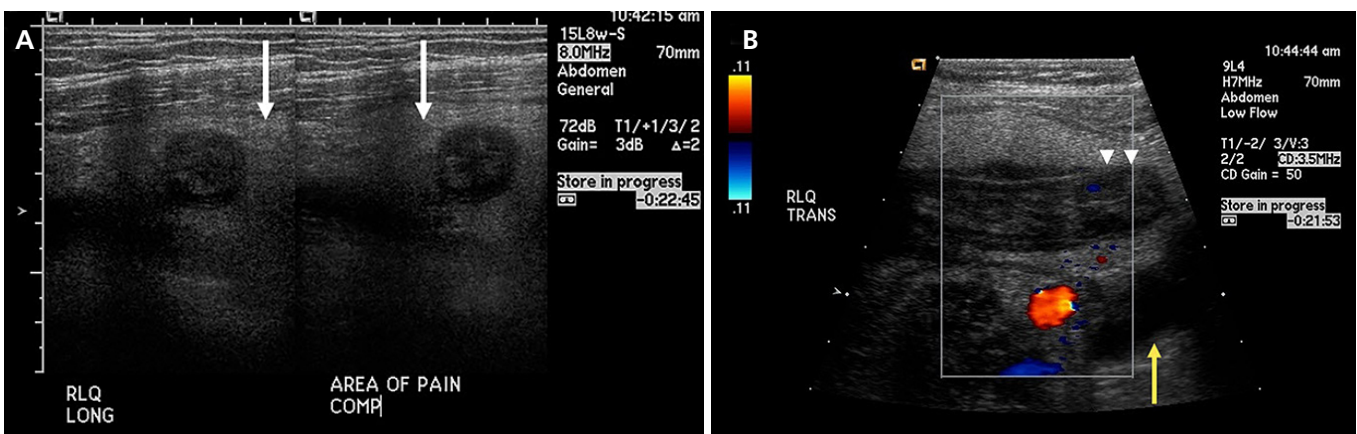


FIGURE 10. Appendicitis with perforation. Longitudinal gray scale (A) and transverse color (B) images of the RLQ in a 12-year-old boy presenting with RLQ pain demonstrate a noncompressible, distended appendix measuring 15 mm. There is little hyperemia, but prominent hyperechoic mesenteric fat is surrounding the appendix (white arrows, A). The echogenic submucosal layer is variably interrupted (arrowheads, B). Focal free fluid is present (yellow arrow, B). The patient had acute suppurative appendicitis with perforation and extensive periappendicitis on pathology.

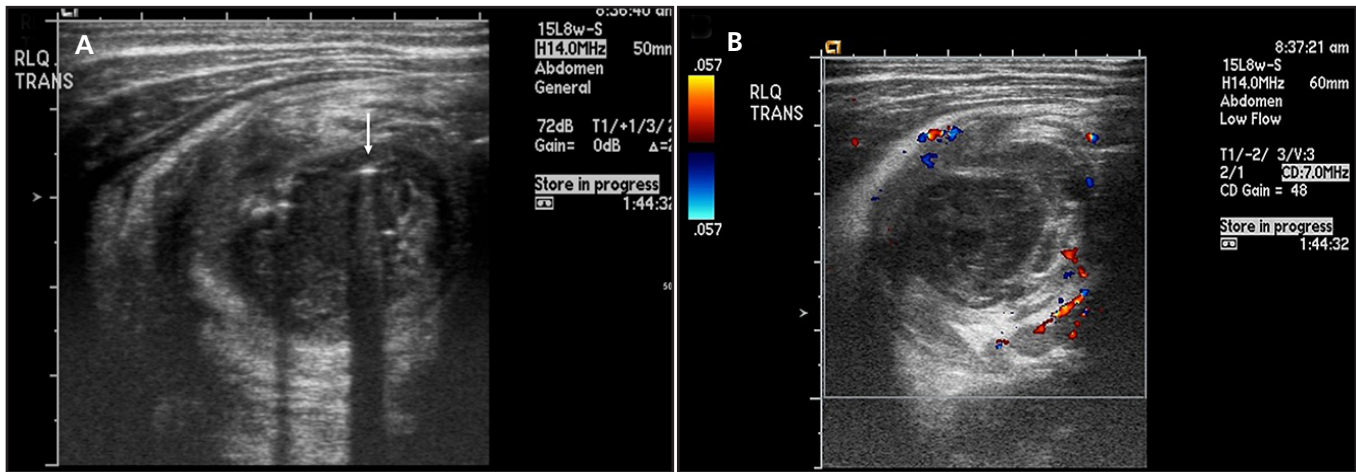


FIGURE 11. Abscess from perforated appendicitis. Transverse gray scale (A) and color (B) images of the RLQ in a 3-year-old boy presenting with RLQ pain demonstrate a complex fluid collection containing air (arrow, A) and peripheral blood flow. CT confirmed an RLQ abscess (not shown). Pathology at interval appendectomy 7 weeks after percutaneous drainage showed chronic inflammation and serosal thickening with adhesions involving the appendix.



FIGURE 12. Mesenteric adenitis. Transverse gray scale images of RLQ in a 5-year-old boy presenting with pain reveal clustered lymph nodes (arrows), > 3 in number and 5 mm in short axis. Diagnosis of mesenteric adenitis was made after CT exclusion of any other inflammatory process in the abdomen.

consistent scanning technique. Also, the patient's site of maximal tenderness helps to direct the exam. Most retrocecal appendices should be identifiable with adequate compression. It is important to follow the appendix along its entire course to assess for tip appendicitis, which is known to be a source of false negative exams.⁸

Perforation is estimated to occur in 23% to 73% of children with acute appendicitis,⁸ and is a limitation in visualizing the appendix on ultrasound.¹⁶ One study showed a lack of visualization of the appendix in 40% to 60% of cases with perforation,⁹ possibly due to decompression after perforation.¹³

Body habitus can hinder identification of the appendix. As body mass index (BMI) increases, identification of

the appendix decreases.⁶ The appendix was seen in 75% of underweight pediatric patients (less than 10th percentile), 67% of normal weight patients, and only 21% of overweight patients (> the 85th percentile).¹⁹ In adults with a BMI \geq 25, ultrasound is not recommended for evaluating appendicitis.²⁰

Differential Considerations

Not only is sonographic evaluation of the RLQ a technical challenge, it is also a diagnostic challenge given the spectrum of gastrointestinal (GI) and genitourinary pathologies that can mimic the clinical and imaging findings of acute appendicitis in children.

The most common alternative diagnosis in pediatric patients imaged for acute appendicitis is mesenteric adenitis.^{21,22} Mesenteric adenitis is inflammation of lymph nodes often due to a viral infection.²² Findings in mesenteric adenitis include borderline to mildly enlarged (> 5 mm short axis), clustered mesenteric lymph nodes (> 3, **Figure 12**). Enlarged mesenteric lymph nodes are nonspecific, however, and can be seen in reactive, inflammatory, and infectious causes.⁴ This often remains a diagnosis of exclusion.

Acute right pyelonephritis can present similar to appendicitis. The kidney can have a variable sonographic appearance from normal to focal or global enlargement and varied echogenicity.^{4,21} Urolithiasis can also overlap with acute appendicitis.²¹ Hematuria helps make a determination clinically in the setting of urolithiasis. If a shadowing hyperechoic

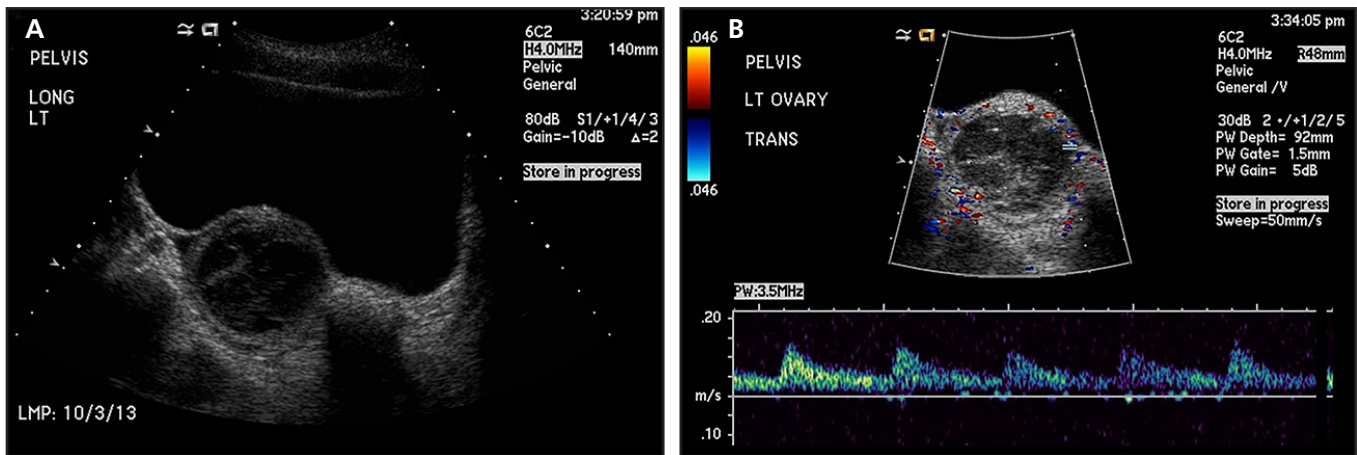


FIGURE 13. Hemorrhagic ovarian cyst. Longitudinal gray scale (A) and transverse color (B) images of the left adnexa in a 15-year-old girl presenting with lower abdominal pain reveals a hemorrhagic 43 mm ovarian cyst with lacy internal echoes and preserved ovarian blood flow. The appendix was not visualized.

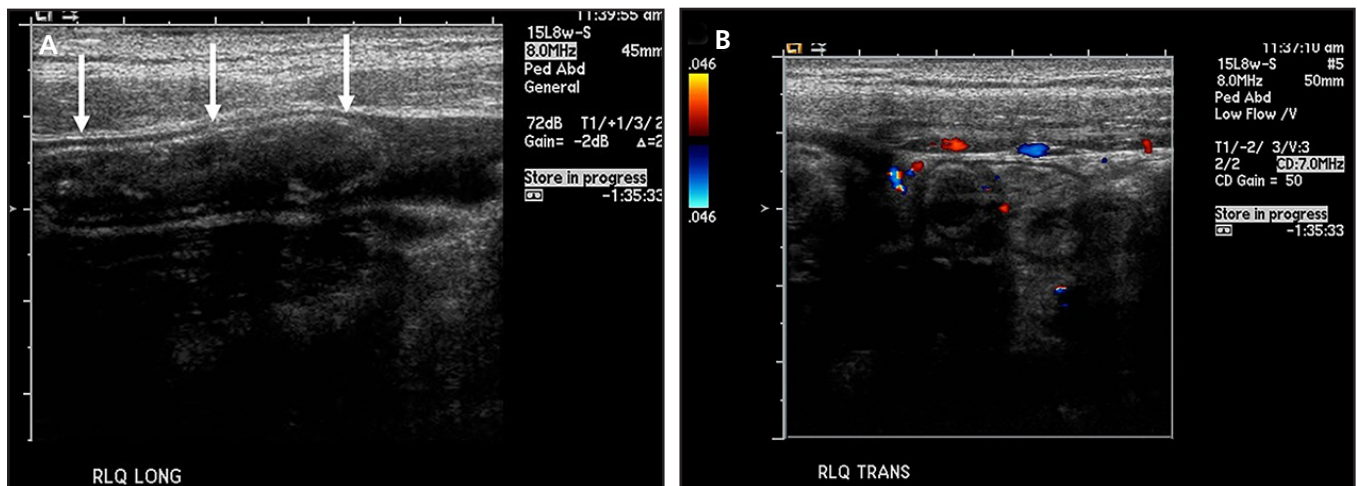


FIGURE 14. Cystic fibrosis (CF). Longitudinal gray scale (A) and transverse color (B) images of the RLQ in a 17-year-old boy with CF demonstrates a distended appendix measuring 10 mm with fecal debris resulting in shadowing. No hyperemia. There is preservation of the wall stratification (arrows, A). There was trace free fluid, but no other secondary signs of appendicitis. The patient was treated for complications of CF, not appendicitis.

stone is seen in the ureter, then the sonogram can solve the dilemma.

In female patients, right-sided pain should prompt consideration of gynecologic processes: ovarian cysts (usually with hemorrhage), ovarian torsion, and ovarian masses. Hemorrhagic ovarian cysts can cause lower abdominal pain, especially midway through the menstrual cycle.²³ Ultrasound findings include a complex ovarian cyst (classically central lacy echoes or layering debris) with peripheral blood flow in the ovarian parenchyma (Figure 13). Ovarian torsion is another consideration. Findings of ovarian torsion include an enlarged ovary (typically with a volume greater than 20 mL²⁴) and absence of blood flow, which is indicative of

torsion, but not always present.^{23,24} Due to an initial presentation of pain, 73% of pediatric patients with ovarian masses had a preliminary diagnosis of appendicitis according to one review.²⁵

Meckel's diverticulum is the most common congenital anomaly affecting the GI tract and often presents with painless rectal bleeding. However, when inflamed it can present similar to acute appendicitis. The inflamed diverticulum is also a blind-ending, noncompressible, hyperemic bowel structure in the right iliac fossa, often with a diameter of 8-12 mm, similar to an inflamed appendix but arising from distal ileal loops.^{21,26} The presence of an anomalous vessel to the diverticulum and cyst-like appearance compared to an inflamed appendix can

help differentiate a Meckel's diverticulitis from appendicitis.²⁶ Duplication cysts can also arise in the RLQ and have bowel wall signature, but they are more cystic in appearance compared to acute appendicitis.²¹

Cystic fibrosis (CF) can result in chronic distention of a normal appendix due to retained secretions. Asymptomatic CF patients have a mean appendiceal diameter of 8.3 mm due to mucoid impaction. The concentric layers of the wall of the noninflamed appendix are preserved (Figure 14). No adjacent inflammatory changes are present. The diagnosis of acute appendicitis, therefore, should rely on evidence of inflammatory changes within and around the appendix and focal pain, rather than solely

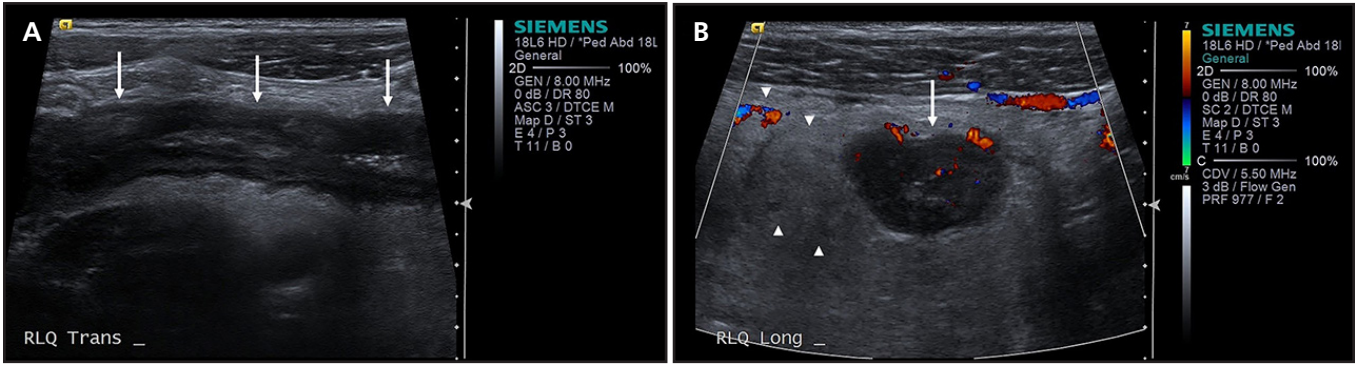


FIGURE 15. Crohn's disease. Transverse gray scale (A) and longitudinal color (B) images of the RLQ in a 17-year-old boy presenting with pain show wall thickening of a distal ileal loop up to 6 mm (white arrows) with surrounding echogenic mesenteric fat (arrowheads, B). The appendix was not seen. Findings were concerning for Crohn's disease, which was later confirmed.

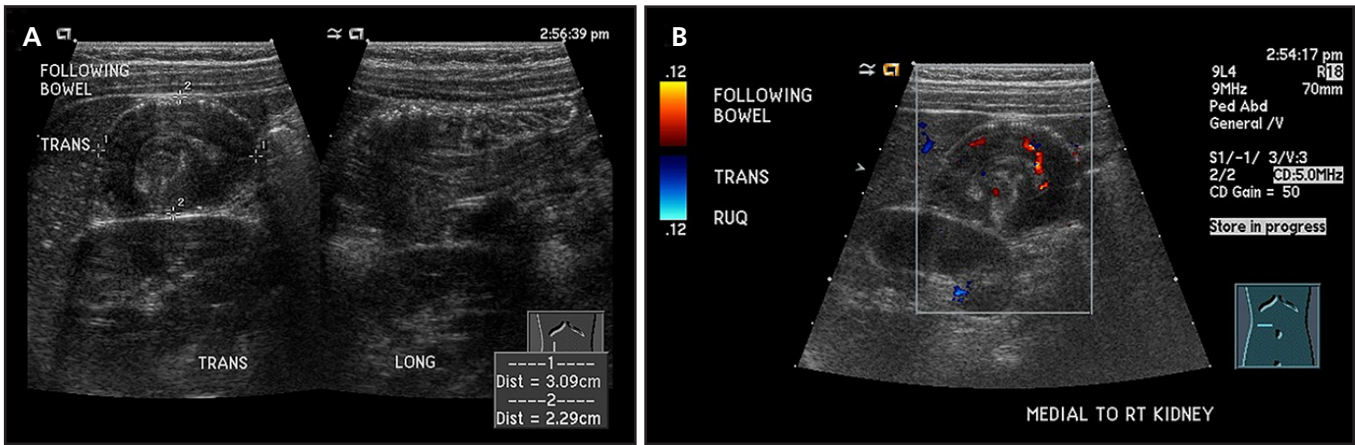


FIGURE 16. Intussusception. Dual screen gray scale (A) and longitudinal color (B) images of the right lateral abdomen in a 2-year-old boy presenting with intermittent, crampy abdominal pain reveal the "target" sign of intussusception in the transverse plane (calipers, A) with confirmation in the longitudinal plane.

size criteria in these patients.² CF patients have increased risk of perforation and other complications related to acute appendicitis due to delayed recognition.¹⁴

Inflammatory bowel disease can cause appendiceal inflammation. Unlike primary acute appendicitis, however, appendicitis in the setting of Crohn's disease is usually seen with terminal ileal or cecal involvement. Crohn's disease with isolated involvement in the appendix is uncommon.¹⁴ It is prudent to search for bowel wall thickening out of proportion to what is typically seen in acute appendicitis (Figure 15). Inflammatory bowel disease is many times overlooked.²⁷

Intussusception refers to invagination of bowel into the lumen of a contiguous bowel loop. It is a cause of acute abdominal pain in younger patients (3 months to 4 years) and difficult to distinguish

clinically from acute appendicitis. The "target sign" on ultrasound is classic for intussusception (Figure 16). In this age group, ileocolic intussusception is rarely due to a pathologic lead point. Intussusception of the appendix in isolation or as a part of ileocolic intussusception can occur. It is estimated that the appendix itself can be the lead point in 0.2% of ileocolic intussusceptions.¹⁴

Malignant neoplasms of the appendix are found in an estimated 0.9-1.4% of specimens with carcinoid tumors being the most common. The presentation is often similar to that of acute appendicitis, and tumor is an uncommon preoperative diagnosis.^{14,28} Non-Hodgkin's Lymphoma (usually Burkitt type) can involve the ileocecal region and appendix. Often there is more extensive bowel wall thickening, which can rapidly worsen in a matter of days. Mucoceles are also rare with pathology

ranging from benign (simple mucocele) to malignant (mucinous cystadenoma or mucinous cystadenocarcinoma). Precautions when performing appendectomy in such cases are taken due to the risk of recurrence and pseudomyxoma peritonei; however, it is rare to suspect this diagnosis preoperatively.¹⁴ Mucocele will often appear as a fluid-filled appendix on ultrasound.

Viruses, such as adenovirus, and parasites, such as *Enterobius vermicularis* (pinworms), can be a source of appendiceal inflammation. Adenovirus is associated with intussusception in children.^{14,29} Pinworms are prevalent worldwide and were found in 0.6-13% of resected appendices in one series.²⁹

Conclusion

The ongoing challenge of identifying the appendix on ultrasound needs to be addressed in all practices. It is

well-documented that visualizing the appendix on ultrasound greatly decreases the false-negative rate of the exam. Given the largely operator-dependent outcomes for visualizing the appendix, it is prudent that radiologists are actively involved with scanning, education, and oversight of these exams, especially in the pediatric population. Radiologists must also be aware of findings associated with both a normal and inflamed appendix, as well as appropriate differential diagnoses.

References

1. Sivit CJ, Applegate KE, Stallion A, et al. Imaging evaluation of suspected appendicitis in a pediatric population: effectiveness of sonography versus CT. *Am J Roentgenol* 2000;175(4):977-980.
2. Lardenoye SW, Puylaert JB, Smit MJ, et al. Appendix in children with cystic fibrosis: US features. *Radiology* 2004;232(1):187-189.
3. Kessler N, Cyteval C, Gallix B, et al. Appendicitis: evaluation of sensitivity, specificity, and predictive values of US, Doppler US, and laboratory findings. *Radiology* 2004;230(2):472-478.
4. Siegel, M, *Gastrointestinal Tract*. In: Siegel, M, *Pediatric Sonography* 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins 2011:339-383.
5. Doria AS, Moineddin R, Kellenberger CJ, et al. US or CT for diagnosis of appendicitis in children and adults? A meta-analysis. *Radiology* 2006;241(1):83-94.
6. Trout AT, Sanchez R, Ladino-Torres MF, et al. A critical evaluation of US for the diagnosis of pediatric acute appendicitis in a real-life setting: how can we improve the diagnostic value of sonography? *Pediatr Radiol* 2012;42:813-823.
7. Puylaert J, Acute Appendicitis: US Evaluation Using Graded Compression. *Radiology* 1986;158:355-360.
8. Sivit CJ, Siegel MJ, Applegate KE, et al. Special Focus Session. When appendicitis is suspected in children. *Radiographics* 2001;21(1):247-262.
9. Sivit CJ, Applegate KE. Imaging of Acute Appendicitis in Children. *Semin Ultrasound CT MR* 2003;24(2):74-82.
10. Lee JH, Jeong YK, Hwang JC, et al. Graded compression sonography with adjuvant use of a posterior manual compression technique in the sonographic diagnosis of acute appendicitis. *Am J Roentgenol* 2002;178(4):863-868.
11. Lee JH, Jeong YK, Park KB, et al. Operator-dependent techniques for Graded compression sonography to detect the appendix and diagnose acute appendicitis. *Am J Roentgenol* 2005;184:91-97.
12. Ozel, A, Orhan UP, Akdana B, et al. Sonographic appearance of the normal appendix in children. *J Clin Ultrasound* 2011;39:183-186.
13. Tulin-Silver S, Babb J, Pinkney L, et al. The challenging ultrasound diagnosis of perforated appendicitis in children: constellations of sonographic findings improve specificity. *Pediatr Radiol* 2014 December 4; epub ahead of print. DOI 10.1007/s00247-014-3232-5.
14. Dietz KR, Merrow AC, Podberesky DJ, et al. Beyond acute appendicitis: imaging of additional pathologies of the pediatric appendix. *Pediatr Radiol* 2013;43:232-242.
15. Blumfield E, Nayak G, Srinivasan R, et al. Ultrasound for differentiation between perforated and nonperforated appendicitis in pediatric patients. *Am J Roentgenol* 2013;200:957-962.
16. Wiersma F, Toorenvliet BR, Bloem JL, et al. US examination of the appendix in children with suspected appendicitis: the additional value of secondary signs. *Eur Radiol* 2009;19:455-461.
17. Estey A, Poonai N, Lim R. Appendix not seen, the predictive value of secondary inflammatory sonographic signs. *Pediatr Emerg Care* 2013;29(4):435-439.
18. Kim SH, Choi YH, Kim WS, et al. Acute appendicitis in children: ultrasound and CT findings in negative appendectomy cases. *Pediatr Radiol* 2014;44:1243-1251.
19. Hormann M, Scharitzer M, Stadler A, Ultrasound of the appendix in children: is the child too obese? *Eur Radiol* 2003;13:1428-1431.
20. Josephson T, Styurd J, Eriksson S. Ultrasonography in acute appendicitis. Body mass index as selection factor for US examination. *Acta Radiol* 2000;41(5):486-488.
21. Sung T, Callahan MJ, Taylor GA. Clinical and imaging mimickers of acute appendicitis in the pediatric population. *Am J Roentgenol* 2006;186(1):67-74.
22. Carty HM. Paediatric emergencies: non-traumatic abdominal emergencies. *Eur Radiol* 2002;12(12):2835-2848.
23. Garel L, Dubois J, Grignon A, et al. US of the pediatric female pelvis: a clinical perspective. *Radiographics* 2001;21(6):1393-1407.
24. Linam LE, Darolia R, Naffaa L, et al. US findings of adnexal torsion in children and adolescents: size really does matter. *Pediatr Radiol* 2007;37(10):1013-1019.
25. Pomeranz AJ, Sabnis S. Misdiagnoses of ovarian masses in children and adolescents. *Pediatr Emerg Care* 2004;20(3):172-174.
26. Baldisserotto M, Maffazzoni DR, Dora MD. Sonographic findings of Meckel's diverticulitis in children. *Am J Roentgenol* 2003;180(2):425-428.
27. Meyers AB, Deshmukh T, Boyd, KP. Comments and question regarding 'Beyond acute appendicitis: imaging of additional pathologies of the pediatric appendix.' *Pediatr Radiol* 2013;43:1053-1054.
28. O'Donnell ME, Carson J, Garstin WI. Surgical treatment of malignant carcinoid tumours of the appendix. *Int J Clin Pract* 2007;61(3):431-437.
29. Lamps LW. Infectious causes of appendicitis. *Infect Dis Clin North Am* 2010;24(4):995-1018.