Acute Appendicitis in Children: Emergency Department Diagnosis and Management

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Early diagnosis of appendicitis in infants and children can prevent perforation, abscess formation, and postoperative complications, and can decrease cost by shortening hospitalizations. This article reviews the epidemiology, physiology, and age-specific clinical presentation of childhood appendicitis. The accuracy of diagnostic adjuncts is reviewed, as are strategies for avoiding misdiagnosis and improving emergency department evaluation and management.

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INTRODUCTION

Despite considerable recent expansion of knowledge concerning appendicitis, accurate diagnosis remains suboptimal, especially in children. Initial misdiagnosis rates range from 28% to 57% for children 12 years old or younger[1,2] to nearly 100% for those 2 years or younger despite the multiple diagnostic modalities now available to clinicians.[3-6] Importantly, delays in diagnosis lead to increased morbidity and mortality and risk of malpractice litigation.[1,7]

Recent health care trends have influenced the presentation of pediatric appendicitis. From the 1980s to the 1990s, the time from a child's first visit to a physician until surgery increased by mean of 12 to 15 hours.[8] Debate exists as to the influence of insurance on the presentation of appendicitis. Although it has been suggested that gatekeepers and managed care organizations are responsible for diagnostic delays,[8] others have found that patients with Medicaid or no insurance present for care later, have more complications (eg, perforation), and experience longer hospitalizations compared with children who have health insurance (including health maintenance organizations).[9,10]

Although a WBC count is commonly obtained in children with suspected appendicitis, the accuracy of this test is limited. Newer modalities including nuclear medicine scans, ultrasonography, and computed tomography (CT) have been used increasingly to evaluate children with suspected appendicitis over the past decade. However, some authors have suggested that these tests simply increase costs without increasing diagnostic accuracy.[11,12]

The article contrasts the presentation of appendicitis at various ages, critically evaluates the utility of laboratory and radiologic adjuncts, details common reasons for delayed diagnoses, and proposes strategies for expediting emergency department evaluation and management.

EPIDEMIOLOGY

Appendicitis is the most common atraumatic surgical abdominal disorder in children aged 2 years or older.[13-15] Appendicitis is ultimately diagnosed in 1% to 8% of children who present to pediatric EDs with acute abdominal pain.[13-15] Males and females have a lifetime appendicitis risk of 8.6% and 6.7%, respectively.[16] The incidence rises from 1 to 2 cases per 10,000 children per year between birth and 4 years to 25 cases for every 10,000 children per year between 10 and 17 years.[16,17] Appendiceal perforation is nearly universal in children 3 years or younger compared with less than 15% in adolescents.[16-19] Although appendicitis is uncommon in infants and younger children, neonatal and even prenatal cases have been described.[20-22] A seasonal variation in the presentation of appendicitis was noted in an epidemiologic analysis of all appendectomies performed from 1970 to 1984 with 11% more cases occurring from May to August compared with November through February.[16] This variation may be due, in part, to seasonal outbreaks of enteric infections.

Decreased dietary fiber and ingestion of refined carbohydrates are significant risk factors for appendicitis. Societies with high fiber intake (eg, Asia, India, and Africa) have less than one tenth the incidence of appendicitis compared with locations where fiber intake is lower (eg, Europe, North America).[23,24] African immigrants who adopt American diets have a correspondingly increased risk of appendicitis.[25] A US case-control study found that children in the upper 50th percentile for fiber intake had a 30% lower risk of developing appendicitis compared with children in the lowest quartile.[26] A high-fiber diet speeds stool transit times, reduces fecal viscosity, and inhibits fecalith formation, theoretically decreasing the potential for appendiceal lumen obstruction.[25-27]

The incidence of appendicitis increases during viral epidemics and outbreaks of amebiasis and bacterial gastroenteritis.[16,28,29] Mumps, coxsackievirus B, and adenovirus antibody titers are significantly higher in children with appendicitis compared with controls supporting a role for an infectious etiology in appendicitis.[29,30]

Extended breast-feeding appears to significantly diminish the risk of developing appendicitis. It has been postulated that a milk-induced alteration of the immune response makes lymphoid tissue at the base of the appendix less reactive later in life. Alternately, prolonged breast-feeding may be a surrogate marker for an unknown socioeconomic or dietary feature that diminishes the risk of appendicitis.[31]

There is a genetic predisposition for developing appendicitis. A history of appendicitis in a first-degree relative is associated with a 3.5 to 10.0 relative risk for developing this disorder.[32-35] The strongest familial associations have been noted when children develop appendicitis at unusually young ages (birth to 6 years).[33]

ANATOMY AND PATHOPHYSIOLOGY

The appendix is a long, thin diverticulum arising from the inferior tip of the cecum. The neonatal appendix averages 4.5 cm in length compared with 9.5 cm for adults.[36] The appendix is funnel-shaped in neonates and infants, limiting its propensity to obstruct. By 1 to 2 years of age, the appendix assumes a normal adultlike conical shape. The function of the appendix is unknown, although its lymphatic tissue and secretion of immunoglobulins suggest that it may play a specialized role in the immune system. The appendix is lined with colonic epithelium with interspersed submucosal lymphoid follicles. An increase in lymphoid follicle hyperplasia occurs until follicles reach their maximal size in the late teenage years, corresponding to the time period with the highest risk of developing appendicitis.[16,37]

Appendicitis is typically precipitated by luminal obstruction from lymphoid follicle hyperplasia, fecaliths, foreign bodies, or parasites.[37] In other cases, direct mucosal ulceration with bacterial invasion occurs without luminal obstruction.[29,37] Fecaliths form when inspissated feces act as a nidus with progressive layering of calcium salts and fecal debris over time. When they enlarge to the point of obstructing the lumen, epithelial cells lining the appendix continue to secrete mucus, distending the structure and eventually inhibiting lymphatic and venous drainage. Bacterial invasion of the wall ensues with edema and blockage of arterial blood flow.

Eventually, if surgery is delayed, the appendix perforates and the spillage of pus into the peritoneal cavity leads to diffuse peritonitis or abscess formation. Typically 3 to 10 different organisms can be recovered from the peritoneal fluid of each patient.[38-41] The most common isolates are *Escherichia coli, Bacteroides fragilis, Peptostreptococcus,* and *Pseudomonas* species.[38-41]

Anatomic and developmental differences account for the age-based differences in presentation of pediatric appendicitis. Sensory afferents are conveyed centrally along the 10th thoracic spinal nerve manifesting clinically as vague periumbilical pain following appendiceal distention and inflammation. As inflammation spreads to the parietal peritoneum, pain typically localizes to the right lower quadrant. For unknown reasons, this classic migration of pain is not observed in more than one quarter of adult and one third of pediatric cases.[42] After perforation, either diffuse peritonitis ensues or a localized abscess forms. In younger children, an underdeveloped omentum often cannot contain the purulent material.[42] Accordingly, diffuse peritonitis more frequently follows perforation in younger children (≤5 years) than older children (>5 years).[43]

The classically described location of the appendix, McBurney's point, is one third of the distance (1.5 to 2 inches in adults) from the right anterior superior iliac spine to the umbilicus.[44] However, 75% of normal appendices lie inferior and medial to this point with 50% located 5 to 10 cm and 15% more than 10 cm from this point.[44,45]

The most common appendiceal locations at surgery and autopsy are retrocecal in 28% to 68% and pelvic in 27% to 53%.[37,46-48] Clinical features typically do not differ between retrocecal (posterior to the cecum) and nonretrocecal appendicitis.[49-51] When the appendix is extraperitoneal (ie, posterior to the peritoneum with no peritoneal lining, unlike more cases which are intraperitoneal) and retrocecal, patients exhibit less abdominal pain, less focal abdominal tenderness, more back or flank pain, a longer duration of symptoms before diagnosis, and higher perforation rates.[49-52] Other appendiceal locations include subcecal (2%), anterior or preilial (1%), within a hernial sac (2%), right upper (4%), and left upper and lower quadrants (<0.1% each).[37,48] Fetal and infant appendices have greater mobility and are less likely to be fixed by mesenteric connections to the cecum, ascending colon, or abdominal wall.[53] This anatomic variation may account for the lower incidence of locally contained abscesses in younger children.

CLINICAL PRESENTATION

Classically, the first symptom of appendicitis is periumbilical pain, followed by nausea, right lower quadrant pain, and later vomiting with fever. Although this sequence of events is noted in only 50% of adults, it is even less common in children.[1] Many of the presenting features in appendicitis are age-dependent. Knowledge of these age-related differences may serve to improve diagnostic accuracy.

Neonates (birth to 30 days)

More than 120 neonatal appendicitis cases have been reported.[20,21,54] At this age, mortality surpasses 80% in some series with the majority of cases diagnosed at autopsy.[21,54] Most cases occur in premature neonates,[20] with a pathologic cause for inflammation or obstruction found in one third.[20,21] Appendix luminal obstruction caused by a fecalith has not been reported[21]; instead, appendiceal inflammation follows distal colonic obstruction (eg, Hirschsprung's disease), blockage from an internal or external hernia, cardiac anomalies (causing emboli), or mesenteric infarction (similar to a localized area of necrotizing enterocolitis).[20,55,56] Clinical features are nonspecific with irritability or lethargy in 22%, abdominal distention in 60% to 90%, and vomiting in 59% of cases.[20,21,54] Other features include a palpable mass in 20% to 40%,[20] abdominal wall cellulitis (12% to 16%), hypotension, hypothermia, and respiratory distress.[21,54,57]

Infancy (2 years or younger)

In the first 9 to 12 months of life, the cecum is tapered and the appendix is funnel-shaped making it less prone to obstruction.[58] This anatomic characteristic, a soft-food diet, and less prominent lymphoid tissue are believed to account for the lower incidence of appendicitis in infancy.[3-6] Vomiting and irritability because of pain are common features of many disorders at this age including gastroenteritis, otitis media, upper respiratory tract infections, and intussusception.

The most common symptoms in children 2 years or younger are vomiting (85% to 90%), pain (35% to 77%), diarrhea (18% to 46%), and fever (40% to 60%).[3,4,6] Other potentially misleading clinical features at this age include irritability (35% to 40%), grunting respirations (8% to 23%), cough or rhinitis (40%), and right hip complaints (pain, stiffness, or limp) in 3% to 23%.[3,6,18,59,60] A temperature greater than 37°C (98.6°F) (87% to 100%) and diffuse abdominal tenderness (55% to 92%) occur in most infants, whereas localized right lower quadrant tenderness is noted in less than 50%.[3,4,6,60-62] Other signs include lethargy (40%), abdominal distention (30% to 52%), abdominal rigidity (23%), and an abdominal mass or rectal mass (30%).[3,4,6,18] Because of the nonspecificity of presenting symptoms, the mean time to correct diagnosis after the onset of symptoms is 4 days.[3,6] Delayed diagnoses contribute to perforation rates of 82% to 92%, and bowel obstruction is noted in up to 82% of infants.[18,19]

Preschool (2 to 5 years)

Beyond 2 years of age, children begin to acquire communication skills that permit earlier identification of appendicitis. Appendicitis is still rare at this age, with children 5 years or younger accounting for less than 5% of all pediatric appendicitis.[63] The majority of preschool children have had symptoms for 2 days or longer, and up to 17% have had symptoms for 6 days or longer before diagnosis.[63,64]

Abdominal pain (89% to 100%), vomiting (66% to 100%), fever (80% to 87%), and anorexia (53% to 60%) predominate in most preschool children with appendicitis.[6,63,65-67] In contrast to infants, right lower quadrant tenderness is more common (58% to 85%) than diffuse tenderness (19% to 28%).[66] One study found that young children with appendicitis more frequently manifested involuntary guarding (85% versus 32%), rebound tenderness (50% versus 20%), and a temperature greater than 37.5°C (99.5°F) (82% versus 52%) compared with children with acute abdominal pain not related to appendicitis.[68] No differences were found in the frequency of vomiting, right lower quadrant pain, and diarrhea.[68] Although adult studies indicate that pain almost always precedes vomiting, this typical sequence is less common in preschool children. Vomiting is often the first symptom noted by parents and a history of vomiting that precedes pain is common.[1]

School-aged children (6 to 12 years)

In school-aged children, the incidence of appendicitis increases and the history and physical examination become more reliable. Older children are better able to relay descriptors including onset of centrally located pain that later migrates to the right lower quadrant. This typical sequence is absent in more than one third of older children with appendicitis who have pain that begins and remains in the right lower quadrant or pain that begins and remains diffuse.[42] Pain is worse with movement in 41% to 75%, described as steady or constant in 52% to 57%, and reported as colicky in 11% to 35%.[42,69] Other potentially useful symptoms detailed in adult studies are worsened right lower quadrant pain with coughing (cough sign) in 95%,[70] driving over bump (cat's eye sign) in 80%,[71] or standing on toes and dropping heels to ground (heel drop sign) in 93%.[72] The accuracy of these signs in children has not been studied.

As many as 10% to 36% of children with appendicitis report a prior similar pain episode[42,73] suggesting that appendicitis may sometimes spontaneously resolve and then reoccur. Vomiting occurs in 68% to 95% of school-aged children with appendicitis, with nausea in 36% to 90%.[42,69] Vomiting may precede or begin concurrent with pain in up to 18%.[42] Anorexia is described in 47% to 75%, whereas diarrhea (9% to 16%) and constipation (5% to 28%) are common enough to potentially confuse the diagnosis.[1,42] Another potentially confounding symptom is dysuria noted in 4% to 20% of children with appendicitis.[1,69]

The physical examination varies based on the time course of the disease. One study found that a temperature greater than or equal to 38°C (100.4°F) was present in only 4% of children with symptoms of less than 24 hours' duration, whereas 64% had a temperature greater than or equal to 38°C if symptoms had been present 24 to 48 hours, and 63% had a temperature greater than 39°C (102.2°F) if symptoms had been present longer than 48 hours.[74] Almost all children in this age range manifest tenderness in the right lower quadrant. However, tenderness may involve the entire lower abdomen, or may be diffuse in 15% of children without perforation and up to 83% with perforation.[42] Bowel sounds are either normal or hyperactive in 93% and hypoactive in just 7%.[73] Guarding and rebound each occur more frequently in perforated cases, 51% to 91% and 41% to 83%, respectively.[42,69] Although not studied in children, an adult study of consecutive patients presenting with acute right lower quadrant pain indicates that rebound tenderness is the most sensitive (82%) method for eliciting peritoneal irritation, whereas percussion tenderness is the most specific (86%) indicator.[71] No studies have adequately detailed the sensitivity or specificity of a psoas sign, obturator sign, or Rovsing's sign in diagnosing pediatric appendicitis.

The contribution of the rectal examination to the evaluation of children with suspected appendicitis is controversial. Retrospective series report that abdominal abscesses and rectal masses are found on rectal examination in up to 30% of infants with appendicitis and accordingly some authors believe this examination should be routine in this setting.[3,4,6,18] In older children, adolescents, and adults, however, rectal tenderness is noted in 30% to 72% with and 4% to 63% without appendicitis.[75-82] In 6 of 8 studies that compared the rectal examination in patients with and without appendicitis, rectal tenderness was found with equal or greater frequency in those without appendicitis.[75-80] One of two studies in which rectal tenderness was more common in appendicitis found that all patients with right-sided rectal tenderness also had right lower quadrant tenderness.[81,82] Accordingly, rectal tenderness is a nonspecific and insensitive finding, and a rectal examination cannot be considered mandatory in the evaluation of patients with suspected appendicitis who are not infants. Despite a lack of evidence supporting its value, failure to perform a rectal examination has been cited in appendicitis-related malpractice lawsuits.[83]

Compared with those with nonperforated appendicitis, children with perforated appendicitis are significantly younger, have a longer duration of symptoms before diagnosis, have more physician visits before correct diagnosis, have higher temperatures, and are more likely to exhibit vomiting, diffuse abdominal tenderness, and peritoneal signs.[8,38,84] Perforation generally occurs 36 to 48 hours after the onset of symptoms; the prevalence of perforation is 7% when symptoms are present less than 24 hours, 38% when symptoms are present less than 48 hours, and 98% when symptoms are present for more than 48 hours.[85-87] Wound infections, abscesses, and prolonged hospitalizations are more common with perforation.[1,84,85]

One study prospectively evaluated the signs and symptoms of consecutive ED children with acute abdominal pain. The authors found that 28 (97%) of 29 children with appendicitis had at least 2 of 4 specific features (vomiting, right lower quadrant pain, abdominal tenderness, or guarding), whereas only 96 (28%) of 348 without appendicitis had 2 of these features.[13] Each of these 4 clinical features was statistically associated with appendicitis, whereas patient age, temperature, duration of pain, presence of diarrhea, urinary symptoms, anorexia, and rectal tenderness did not differ between groups.[13] This clinical decision rule has not been validated.

Adolescents (13 years or older)

The incidence of appendicitis peaks in adolescence and the late teen years.[16] The history and physical examination are relatively more reliable in this age group, particularly in males. In females of child-bearing age, pelvic pathology is common and is easily confused with appendicitis.[88] After pregnancy is excluded, other considerations include ovarian cysts, ovarian torsion, and pelvic inflammatory disease.

REASONS FOR MISDIAGNOSIS

The list of erroneous diagnoses in children ultimately found to have appendicitis is extensive and includes gastroenteritis, upper respiratory tract infections, pneumonia, bronchiolitis, urinary tract infections, ovarian pathology, pelvic inflammatory disease, sepsis, encephalitis, meningitis, hernia, testicular torsion, orchitis, nephrolithiasis, blunt abdominal trauma, right hip septic arthritis, cholecystitis, constipation, intussusception, dehydration, and inflammatory bowel disease[1,59,64,65,88-92] (Table 1). Difficulties in interpreting the history and physical examination findings account for many of these misdiagnoses.

Nonspecific signs and symptoms together with the rarity of this disorder in infancy account for overall misdiagnosis rates of 70% to 100% in those 3 years or younger.[3-6] In fact, up to 28% of children at this age with appendicitis are admitted to the hospital with an incorrect diagnosis.[59] In preschool-aged children, misdiagnosis rates range from 19% to 57%[63,65,66,68] with perforation in 43% to 72%.[58,61,63,67,68] The misdiagnosis rate falls to 12% to 28% for school-aged children and less than 15% for adolescents.[1,93,94]

Before a diagnosis of appendicitis is made, 28% of children have been previously evaluated by a physician (ie, ED, clinic, hospital, or office) for their symptoms, and 7% have been previously seen in the same ED where the correct diagnosis was ultimately made[1,95] (Table 1). One

Table 1.
Initial misdiagnoses in childhood appendicitis.[1]

Misdiagnosis	% of Cases
Gastroenteritis	42
Upper respiratory tract infection*	18
Pneumonia	4
Sepsis	4
Urinary tract infection	4
Encephalitis/encephalopathy	2
Febrile seizure	2
Blunt abdominal trauma	2
Unknown	22

*Includes diagnoses of otitis media, sinusitis, pharyngitis, and upper respiratory tract infection.
From Rothrock SG, Skeoch G, Rush JJ, et al. Clinical features of misdiagnosed appendicitis in children. *Ann Emerg Med.* 1991;20:45-50.

study found that children with misdiagnoses more frequently complained of vomiting preceding pain (29% versus 8%), dysuria (20% versus 4%), constipation (17% versus 5%), diarrhea (37% versus 10%), and respiratory signs and symptoms (27% versus 2%) compared with children with correct diagnoses.[1] Fifty percent of children with misdiagnoses had minimal or no abdominal tenderness on their initial physician visit, whereas 43% had right lower quadrant tenderness believed to be related to nonappendiceal disease.[1] Children with misdiagnoses more frequently exhibited perforation and abscess formation and comprised the only deaths in this series.[1]

Female adolescents are a unique group at risk for misdiagnosis; in one third of girls 15 years or older with appendicitis the disease is initially misdiagnosed. The most common misdiagnoses are pelvic inflammatory disease, gastroenteritis, or urinary tract infections.[88] Girls whose disease is misdiagnosed more frequently exhibit diffuse or bilateral lower abdominal tenderness (80%), vaginal discharge (24%), cervical motion tenderness (32%), and right adnexal tenderness (48%) compared with those with correct diagnoses.[88]

LABORATORY ADJUNCTS

Although a WBC count is frequently ordered in children with suspected appendicitis, it is nonspecific and insensitive for this disorder. A low WBC threshold (>10,000 to 12,000 cells/mm^3) is 51% to 91% sensitive for appendicitis; however, use of a higher threshold (>14,000 to 15,000 cells/mm^3) reduces the sensitivity to 41% to 68%.[69,96-103] One study found that leukocytosis (defined as a WBC count ≥15,000 cells/mm^3 if <10 years and >13,000 cells/mm^3 if ≥10 years) was 18% sensitive for appendicitis if symptoms had been present for less than 24 hours, whereas it was 90% sensitive if symptoms had been present 48 hours or longer.[74,99] This study also found that neutrophilia was more sensitive than an elevated WBC count (95% versus 18%) for diagnosing appendicitis if symptoms had been present less than 24 hours.[74,103] Either the WBC count or the neutrophil percentage is elevated in 90% to 96% of children with appendicitis, although the specificity of using these measures in combination is uncertain.[74,96,101,102,104] The WBC count is nonspecific for appendicitis as elevations are noted in nearly half of all patients with gastroenteritis, mesenteric adenitis, pelvic inflammatory disease, and other infectious disorders.[1,77,82,105] The WBC count cannot discriminate between perforated and nonperforated appendicitis.[84,106] Two adult studies of sequential WBC counts have found this strategy unable to discriminate between patients with and without appendicitis.[107,108]

C-reactive protein (CRP) is a nonspecific inflammatory mediator. This test has been reported to be 43% to 92% sensitive and 33% to 95% specific for appendicitis in children with acute abdominal pain.[97-100,103,109,110] The wide ranges may be due to the varied cutoffs used for defining an elevated CRP level (0.9 to 5.0 mg/dL).[97-100,103,109,110] A meta-analysis that primarily evaluated adult studies concluded that the WBC count was more accurate than CRP.[111] However, limited studies suggest that CRP may be more sensitive (>90%) than the WBC count in detecting appendiceal perforation and abscess formation, conditions more common in children.[103,106,109,110] Sequential CRP measurements may be more sensitive than a single measurement. In one adult study, use of this strategy increased sensitivity for diagnosing appendicitis from 60% on admission to 86% for a second CRP determination (4 hours later), 95% for a third CRP (8 hours later), and 100% for a fourth CRP (12 hours later).[108] Specificity (55% to 67%) did not improve or decline during sequential testing.[108]

Children with possible appendicitis require a urinalysis if urinary infection or nephrolithiasis is suspected. Abnormal urine findings results may lead to misdiagnosis, however, as 7% to 25% of children with appendicitis have more than 5 WBCs or RBCs per high-power field.[1,58,92]

The only mandatory test in patients with suspected appendicitis is a pregnancy test in female patients of child-bearing age. The decision to obtain a WBC count, neutrophil count, CPR determination, or urinalysis is complex involving the timing and nature of presenting symptoms, the pretest suspicion that appendicitis is present, and the preference of the emergency physician and consulting surgeon. If symptoms are present less than 24 hours, no weight should be given to the WBC count or CRP level. For patients whose symptoms have been present more than 36 to 48 hours, clinicians must consider the pretest probability that appendicitis is present based on the patient's presenting features. A normal WBC count (or CRP level) in the setting of a low pretest probability of appendicitis (ie, a patient who a clinician is considering discharging) decreases the probability that appendicitis is present but does not exclude the diagnosis. However, a high WBC count (or CRP level) in this setting increases the likelihood of appendicitis, and clinicians should consider further radiologic testing, admission, or surgical consultation. For patients with a moderate to high pretest probability of appendicitis, a normal WBC count (or CRP level) cannot exclude the diagnosis, whereas a high WBC count (or CRP level) provides further support to the clinical diagnosis of appendicitis. With the availability of newer more accurate diagnostic techniques (eg, ultrasound and focused CT), clinicians should limit the weight given to the WBC count in decisionmaking.

RADIOLOGIC EVALUATION

Plain abdominal radiographs have been recommended as potentially useful for evaluating children with suspected appendicitis.[112-118] Radiographic findings believed to be suggestive of appendicitis include rightward scoliosis (43%), soft tissue masses (48%), localized ileus (30%), bowel obstruction (10%), and "free peritoneal fluid" (63%).[114] Each of these findings were significantly more common in appendicitis, according to a study in which blinded radiologists compared radiographs in children with and without appendicitis.[114] Another study noted the following findings in perforated childhood appendicitis: bowel obstruction (43%), a right lower quadrant mass (24%), and a calcified fecalith (20%).[119] Of these features, the most specific for appendicitis is a calcified appendicolith found in up to 13% to 22% with appendicitis and less than 1% to 2% without appendicitis.[63,114,118-122] When this feature is present, perforation is found in 45% to 100% of cases.[63,114,118-123] More recent studies found that plain radiographs were normal or misleading in 77% of children with appendicitis and that these films rarely altered a patient's diagnosis or management.[124-126] Because radiologic findings in uncomplicated appendicitis are insensitive and nonspecific, a recently published evidence-based clinical pathway for pediatric surgeons recommends plain films in suspected appendicitis only if free air, bowel obstruction, or a mass is suspected, or if there is a prior history of renal stones or cholelithiasis.[127]

Radioisotope-labeled WBC scanning in children with suspected appendicitis has shown variable sensitivity (27% to 97%) and specificity (38% to 94%).[128-130] Disadvantages of this technique include the lengthy duration of this study (1 to 3 hours), poor interrater interpretation agreement (κ=0.38 in one study),[128] and unfamiliarity of most centers with this technique.[128-130] Accordingly, radioisotope studies cannot be recommended for evaluating children with possible appendicitis.

Ultrasonography has been studied extensively in the evaluation of children with suspected acute appendicitis.[131,132] Although the 2 largest (>5,000 total children) studies found ultrasonography to be 90% to 92% sensitive and 97% to 98% specific for appendicitis,[131,132] other studies have noted sensitivities and specificities as low as 80% and 86%, respectively.[133-141] Diagnostic ultrasound findings in nonperforated appendicitis include an appendiceal diameter more than 6 mm (82% to 100%), a target sign with 5 concentric layers (52%), distention or obstruction of appendiceal lumen (47%), high echogenicity surrounding the appendix (13% to 54%), an appendicolith (18% to 29%), pericecal or perivesical free fluid (0 to 5%), muscular wall thickness greater than 2 mm, and absent appendiceal peristalsis.[131,139,142] Although the appendix is not visualized in 33% to 51% of children with normal appendices, it is also not visualized in up to 10% of appendicitis cases.[131,142,143] In fact, nonvisualization of the appendix has been identified as the cause of 98% of false-negative ultrasound studies.[131] Reasons for nonvisualization included superimposed air or feces, obesity, abdominal wall rigidity or pain, an uncooperative child, less experienced examiners, or an atypical appendiceal location (eg, malrotation, nonrotation, retrocecal).[131]

Ultrasound findings of perforated appendicitis include a "target sign and tubular structure with inhomogeneous structure or missing layers in the wall" (71%), an inhomogeneous pericecal or perivesical mass without peristalsis (64%), pericecal or perivesical free fluid (51% to 73%), a fluid-filled noncompressible appendix greater than 6 mm in diameter (30%), thickened bowel loops with reduced peristalsis (23% to 53%), an appendicolith (23%), and sludge in the urinary bladder.[131,139,144] Early studies that relied on ultrasound findings to diagnose nonperforated appendicitis had only 29% to 55% sensitivity for perforated appendicitis.[145,146] Studies that have incorporated more recent ultrasound criteria for diagnosis of perforated appendicitis noted a sensitivity of 73% to 100%.[131,137,144] In addition to identification of perforated and nonperforated appendicitis, ultrasound findings identify alternate diagnoses in 24% to 41% of children without appendicitis.[140,143]

The accuracy of CT scanning has been studied in 10 prospective reports, each including consecutive patients with suspected appendicitis who either underwent laparotomy or were followed to exclude the diagnosis.[147-156] Sensitivity in these studies ranged from 87% to 100% and specificity was 83% to 97%.[147-156] Reports using oral and colonic contrast with a focused appendiceal CT technique (5-mm cuts starting 3 cm above the cecum and extending distally 12 to 15 cm) had the highest sensitivity (97% to 100%).[147-150] Although 8 of 10 studies included children, none separately calculated accuracy in the pediatric population.[147-149,151-155] One author noted that CT scanning was associated with a decrease in the number of normal appendices removed in children with suspected appendicitis.[157] CT was only able to identify 50% to 80% of inflamed appendixes in 2 small retrospective studies of children (42 total appendicitis cases).[158,159] However, if suggestive CT findings (eg, abscess, pericecal phlegmon, appendicoliths associated with bowel dilation, and pericecal inflammation) were considered diagnostic, sensitivity in these studies increased to 95%.[158,159] A third retrospective study included 75 children (44 with appendicitis) who underwent CT and found this test to be 97% sensitive and 97% specific for diagnosing appendicitis.[160] The only prospective study of CT in pediatric appendicitis used a strategy of initial ultrasonography in children with equivocal findings suggestive of appendicitis followed by focused CT with rectal contrast if the ultrasound scan was normal.[161] The overall protocol was 94% sensitive and 94% specific for diagnosing appendicitis, whereas CT alone was 97% sensitive and 94% specific for diagnosing appendicitis.[161] Importantly, all ultrasound and CT studies were interpreted by pediatric radiologists and pediatric radiology fellows, and few preschool-age children and no infants with appendicitis were enrolled.[161]

The most sensitive findings of appendicitis on CT include fat streaking (100%), an appendix more than 6 mm in diameter (93%), and focal cecal apical thickening (69%).[162] Other less common findings include adenopathy, appendicoliths, abscesses, an arrowhead sign (cutoff of colonic contract at the proximal appendiceal lumen), and a cecal bar (separation of contrast in the cecal lumen from a proximal appendicolith).[162] In one study, CT identified an alternate diagnosis in 80% of patients without appendicitis (eg, mesenteric lymphadenitis, ureteral obstruction, diverticulitis, colitis, ovarian cyst, and cecal obstruction).[148]

Several authors have suggested CT may be less accurate in younger children compared with adults.[157-160] A relative lack of body fat makes it difficult to identify fat streaking and visually separate an inflamed appendix from surrounding tissue or bowel.[158] This may be especially true in younger children and infants where the appendix is smaller and body fat is lower. Furthermore, a normal appendix may be difficult to distinguish from surrounding lymph nodes.[158] A recent study found that identifying at least 3 lymph nodes, each 5 mm or more in their short axis, associated with a normal appendix was useful in diagnosing mesenteric adenitis and excluding appendicitis.[163]

Magnetic resonance imaging (MRI) has been evaluated in a limited number of children with appendicitis. In a single study, using unenhanced MRI, nonblinded radiologists were able to detect all cases of nonperforated appendicitis that were seen on ultrasound scans.[164] Potential advantages of this technique include avoiding the use of radiation and contrast. Larger studies of MRI are needed to better establish its sensitivity and specificity for diagnosing appendicitis.

Although limited studies suggest that focused appendiceal CT is superior to ultrasonography for diagnosing pediatric appendicitis, more experience is required before this technique can be routinely recommended over ultrasonography for diagnosing pediatric appendicitis. Two alternatives for imaging exist. Ultrasonography may be preferred as the initial diagnostic technique because it is noninvasive (ie, no rectal contrast), requires no radiation exposure, and is highly specific for appendicitis. In this instance, if ultrasound findings are normal, CT should be performed. Alternately, focused appendiceal CT can be performed initially as long as clinicians realize that experience with this technique in children is limited and rectal contrast must be administered to achieve maximal diagnostic accuracy. Regardless of technique used, it is expected that more widespread use of imaging techniques (ultrasonography or CT) in children with equivocal features suggestive of appendicitis will serve to improve diagnostic accuracy. Implementation of these radiologic techniques requires that clinicians be aware of the accuracy, limitations, and pitfalls of each diagnostic test.

SCORING SYSTEMS AND COMPUTERS

Several studies have evaluated computerized scoring systems for increasing diagnostic accuracy in children with suspected appendicitis. Although these studies have reported improved diagnostic accuracy in adults, only a marginal benefit for children has been demonstrated.[165-168]

One of the simplest numerical scoring systems used in patients with suspected appendicitis is the MANTRELS score.[169] This system, originally derived from adult data, assigns points for specific features[169] (Table 2). Two studies of the MANTRELS score in children found that a score of 7 or higher was 88% to 90% sensitive and 72% to 81% specific for appendicitis.[170,171] Three other studies that evaluated a modified MANTREL score (excluding shift in WBC count) found that a score of 7 or higher was 76% to 90% sensitive and 50% to 81% specific for pediatric appendicitis.[172-174] The authors of each of these 5 studies concluded that the MANTRELS score was not accurate at discriminating between children with and without appendicitis.[172-174] Despite this conclusion, one study found that a MANTRELS score of 5 or higher was 100% sensitive for appendicitis, although this lowered the specificity to 37%.[170] There may be a limited role for using the MANTRELS score to risk-stratify children with suspected appendicitis.

ED MANAGEMENT

Children with suspected appendicitis should receive nothing by mouth and have intravenous volume replacement if there is evidence of dehydration or sepsis. Broad-spectrum intravenous antibiotics effective against enteric aerobes and anaerobes should be administered immediately to all children with obvious perforation (diffuse peritonitis, temperature >38° to 38.5°C [100.4° to 101.3°F], ill appearance) or sepsis without delay for surgical consultation. Traditional therapy consists of ampicillin, gentamicin, and clindamycin,[175] although single-drug formulations including ampicillin/sulbactam, ticarcillin/clavulanate, cefoxitin, or piperacillin/tazobactam are equivalent to traditional multiple-drug regimens in preventing sequelae from ruptured pediatric appendicitis.[176] There is debate as to whether prophylactic antibiotics are useful in uncomplicated appendicitis in children.[99,177] Therefore, antibiotic decisions in this group can be safely deferred to the preference of the admitting surgeon.

One retrospective audit of adults with appendicitis who underwent interhospital transfer concluded that low-risk patients could be safely transferred.[178] Despite this finding, children with appendicitis suffer higher morbidity than adults, and there is no evidence to support the safety of transferring primarily for economic reasons (eg, insurance convenience). Accordingly, transfers of children with appendicitis should be limited to those requiring a higher level of care (eg, complicated appendicitis requiring a pediatric surgeon, or pediatric ICU).

Although a surgical consultation is necessary for children in whom there is a moderate or high suspicion for appendicitis, no clear-cut guidelines can be given for appropriateness and timing of surgical consultation when there is a low clinical suspicion or when classic features are absent. Radiologic imaging should be considered in this population. Inpatient observation by a surgeon also can assist in discriminating between children with atypical appendicitis and nonsurgical disorders,[179] and lower-risk patients can be asked to return to the ED in 8 to 12 hours for repeat evaluation.

As evidenced by high misdiagnosis and perforation rates, the diagnosis of appendicitis in children can be extremely difficult. No single test and no combination of clinical or laboratory features is 100% reliable in discriminating between children with and without appendicitis. More widespread use of CT and ultrasonography may decrease misdiagnosis rates. Knowledge of age-dependent physiologic and clinical parameters and atypical features in children with appendicitis will improve physicians' diagnostic accuracy. Understanding each of these factors will enable physicians to reduce the substantial incidence of misdiagnosis and associated morbidity and mortality in children with appendicitis.

Table 2.
MANTRELS score.[169]

Feature	Points
Migration of pain from central area to right lower quadrant	1
Anorexia or acetonuria	1
Nausea with vomiting	1
Tenderness in the right lower quadrant	2
Rebound tenderness	1
Elevated temperature ≥38°C (100.4°F)	1
Leukocytosis (>10,400 cells/mm^3)	2
Shifted WBC count (>75% neutrophils)	1
Total possible points	10

From Alvarado A. A practical score for the early diagnosis of acute appendicitis. *Ann Emerg Med.* 1986;15:557-564.

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