Pediatric Appendicitis

Rebecca M. Rentea, MD[a], Shawn D. St. Peter, MD[b,*]

KEYWORDS

- Appendicitis • Surgery • Appendectomy • Children • Nonoperative management
- Abdominal pain • Right lower quadrant

KEY POINTS

- Appendicitis is less likely to present in a classic manner than commonly thought.
- Appendicitis can be managed nonoperatively in selected children.
- For children with perforated appendicitis, a laparoscopic appendectomy should be performed.
- The long-term risk of recurrence of appendicitis is unknown.

INTRODUCTION

Appendicitis is the most common surgical emergency in children.[1] The lifetime risk of developing appendicitis is 7% to 8%, with a peak incidence in the teenage years.[2] It is estimated that 86 cases of appendicitis per 100,000 people occur annually, with an estimated 70,000 pediatric appendectomies performed in the United States each year with a mean cost of $9000.[3,4] In the recent decade appendicitis has become more protocolized with greater efforts to minimize antibiotic durations and radiation exposure as well as to begin to study the nonoperative management of appendicitis. Much variation still exists, however, in the diagnosis and management of appendicitis. This article serves to highlight and update some of the controversies and recent literature regarding pediatric appendicitis.

Diagnosis

The peak incidence of appendicitis occurs in the second decade of life with the median age between 10 and 11 years. The male/female ratio is 1.4:1. There is a seasonal variation with increased presentation of appendicitis in the summer months with perforated appendicitis occurring more frequently in the fall and winter.[5]

Funding/Grant Support: None.
Disclosures: The authors have no disclosures or conflicts of interest.
[a] Department of Surgery, Children's Mercy Hospital, 2401 Gillham Road, Kansas City, MO 64108, USA; [b] Pediatric Surgical Fellowship and Scholars Programs, Department of Surgery, Children's Mercy Hospital, 2401 Gillham Road, Kansas City, MO 64108, USA
* Corresponding author.
E-mail address: sspeter@cmh.edu

Surg Clin N Am 97 (2017) 93–112
http://dx.doi.org/10.1016/j.suc.2016.08.009 surgical.theclinics.com

SYMPTOMS

The symptoms of appendicitis have been classically described as the gradual onset of dull periumbilical pain migrating to the right lower quadrant over the course of a day. Additional and variable symptoms include nausea, vomiting, anorexia, fever, and, less frequently, diarrhea. Classically, it is thought that perforation occurs within 24 to 36 hours from the onset of symptoms of pain. The pain, which was localized, improves and then becomes generalized. This description of symptoms, however, occurs in less than 50% of children.[6] Many other classic symptoms also variably present in children without appendicitis, including nausea, right lower quadrant guarding, or migrating pain.[7] Certain findings have been shown to increase or decrease the likelihood of appendicitis, including the midabdominal pain migrating to the right lower quadrant (likelihood ration [LR] 1.9–3.1) and the presence of fever (LR 3.4), which, if not present, lowers the likelihood of appendicitis by two-thirds.[6] The overlap in symptoms makes the diagnosis a clinical challenge, which is amplified in young children who do not understand or articulate the early symptoms.[8] Children less than 3 years of age present with perforated appendicitis more than 80% of the time compared with 20% of those aged 10 to 17 years.[6]

SIGNS

Physical examination findings include tenderness palpation and guarding in the right lower quadrant and rebound tenderness. Rovsing sign (left lower quadrant palpation resulting in referred pain to the right lower quadrat), obturator sign (internal rotation of the right lower extremity), and psoas sign (pain while lying on the left side and extending the right hip) are nonspecific physical examination findings of appendicitis. Only rebound tenderness has correlated with an increased likelihood of appendicitis (LR 2.3–3.9), whereas lack of tenderness in the right lower quadrant reduces the likelihood of appendicitis by half.[7,9]

LABORATORY STUDIES

Although no single laboratory value has a high sensitivity and specificity for appendicitis, white blood cell (WBC) count, absolute neutrophil count (ANC), and C-reactive protein (CRP) are most often used to aid diagnose appendicitis. The use of these laboratory tests alone is not helpful or predictive. WBC, ANC, and CRP all have wide ranges in specificity and sensitivity for predicting appendicitis.[9–14] An elevated WBC count does not predict appendicitis, as appendicitis may be present in children with a normal WBC count.[12] However, an increased WBC (>10–12,000 cells per cubic millimeter) increases the odds of appendicitis. In children less than 4 years of age, a normal WBC count has a negative predictive value of 95.6%, whereas the negative predictive value in those 4 to 12 years old is 89.5%. The negative predictive value of a low or normal WBC count among adolescents is 92%.[9] A left shift or increase in the number of immature forms of neutrophils also has a strong association with appendicitis, because only 3.7% of pediatric patients without a left shift have appendicitis. Although CRP is nonspecific as an isolated laboratory value, a higher mean level may predict complicated or perforated appendicitis or those children more likely to form an abscess.[12,15,16]

SCORING

The Alvarado score and the Pediatric Appendicitis Score (PAS) are the 2 systems that have been extensively evaluated for their ability to predict appendicitis based on symptoms, physical examination findings, and laboratory values (**Tables 1** and **2**).[17,18] The

Table 1
Alvarado score

Migration of pain	1
Anorexia	1
Nausea/vomiting	1
Right lower quadrant tenderness	2
Rebound pain	1
Increase in temperature (>37.3°C)	1
Leukocytosis (>10,000/mL)	2
Polymorphonuclear neutrophilia (>75%)	1
Total	10

From Alvarado A. A practical score for the early diagnosis of acute appendicitis. Ann Emerg Med 1986;15(5):558.

Alvarado score is composed of 8 components with a total score of 10 (migration of pain, anorexia, nausea/vomiting, right lower quadrant tenderness, rebound pain, increased temperature >37°C, leukocytosis >10,000/mL, polymorphonuclear neutrophilia >75%).[17] The PAS score is composed of 8 components with a total score of 10 (migration of pain, anorexia, nausea/vomiting, right lower quadrant tenderness, coughing/hopping/percussion tenderness in right lower quadrant, increase in temperature, leukocytes >10,000/mL, polymophoyclear neutrophila >75%).[18] Both systems have been divided into low, medium, and high range scores to aid in management and give a likelihood of appendicitis. Intermediate scores, or those with Alvarado scores of 5 to 8 or PAS scores of 4 to 7, typically precipitate further imaging. Both scoring systems initially demonstrated sensitivity, specificity, and negative and positive predictive values in the high 90s.[17,18] However, large validation studies have only found sensitivity and specificity in the 70s and 80s.[19–23] In specific groups of children, such as adolescent girls, the scoring ranges and cutoff values further decrease, underscoring the need for further investigation of the scoring systems performance in specific subpopulations.[24] When the PAS score was compared with the Alvarado score in 311 patients, the investigators concluded that both scoring systems can be of assistance in the diagnosis of acute appendicitis but that neither has adequate predictive values to be definitive.[22]

Table 2
Pediatric Appendicitis Score

Migration of pain	1
Anorexia	1
Nausea/vomiting	1
Right lower quadrant tenderness	2
Cough/hopping/percussion tenderness in right lower quadrant	2
Increase in temperature	1
Leukocytes >10,000/mL	1
Polymorphonuclear neutrophilia >75%	1
Total	10

From Samuel M. Pediatric appendicitis score. J Pediatr Surg 2002;37(6):878.

CLINICAL PATHWAYS

Clinical pathways consist of multidisciplinary management tools based on evidence-based practice for a specific group of patients in order to decrease unnecessary variation and improve outcomes while reducing fragmentation and cost.[25] Additional qualities of a pathway are standardization, efficiency, and reproducibility. Pathways have been able to reduce hospital costs and time spent in the hospital for patients with acute and perforated appendicitis.[26] Many investigators noted that utilization of clinical pathways decreased the use of radiation exposure demonstrated by decreased utilization of computed tomography (CT) scans and the ability to discharge patients with low probability of having appendicitis.[27–30]

DIFFERENTIAL DIAGNOSIS

The differential diagnosis for right lower quadrant abdominal pain is exhaustive. The authors of a previous review on appendicitis, the authors characterize 5 general categories: inflammatory, infectious, vascular, congenital, and genitourinary conditions. Inflammatory mimickers of appendicitis include mesenteric adenitis (primary or secondary), inflammatory bowel disease, intussusception, omental infarction, epiploic appendagitis, and cecal diverticulitis. Infectious causes include viral infections, bacterial infections, and parasitic infections. Among vascular causes, Henoch-Schönlein purpura can initially present as severe abdominal pain. Congenital causes include Meckel diverticulum, Meckel diverticulitis, and duplication cysts. Genitourinary causes include pyelonephritis, nephrolithiasis, ovarian torsion, ovarian tumors, hemorrhagic ovarian cysts, pelvic inflammatory disease, and infected urachal remnants. Constipation cannot be forgotten when evaluating pediatric patients because it is often a culprit in abdominal pain.[31]

Imaging

Imaging provides an adjunct to the diagnosis of appendicitis. Ideal imaging is rapid, inexpensive, and reproducible and has high sensitivity and specificity. In settings where operative care for children with appendicitis is not available, resources for appropriate pediatric imaging and interpretation of radiographic findings may also be lacking.[32] These children should avoid diagnostic imaging and be transferred to an appropriate pediatric facility. In an era of increased reliance on imaging, clinical judgment remains paramount, as it has been documented that a pediatric surgeon can differentiate appendicitis from other abdominal disorders with 92% accuracy.[33]

ULTRASOUND

In centers with experience and high utilization of ultrasound (US), US has been adopted as an adjunct in the diagnosis of appendicitis. Advantages are its lack of sedation, contrast agents, and radiation and low cost.[34–36] Sensitivity and specificity for US is 88% and 94%.[37] Disadvantages of US include the following: operator experience is required; there may be a lack of regular availability during off hours; and visualizing the appendix can be difficult in obese individuals or those with low clinical suspicion.[37–41] Increased sensitivity and specificity using US can be obtained by changing parameters of thickness of the appendix (>7 vs 6 mm), having dedicated sonographers, using US with greater frequency, and increased duration of abdominal pain (>48 vs <12 hours).[42–45] Studies have also demonstrated that surgeon-performed US with clinical evaluation may yield similar accuracy as radiologist-performed US.[46]

COMPUTED TOMOGRAPHY

CT scans combine the advantages of many other imaging modalities, including rapid acquisition time and a lack of operator dependency.[42] The sensitivity of CT scan for appendicitis is 97%, specificity of 99%, positive predictive value of 98%, negative predictive value of 98%, and accuracy 96%. Intravenous (IV) contrast enhances the CT scan sensitivity and specificity,[35,47,48] whereas contrast administered enterally (oral or rectal) in observational studies does not further improve test performance over IV contrast CT alone.[49,50] The accuracy of CT scan for perforation is around 72%, with a sensitivity of 62% and specificity of 82%.[51] Nonvisualization of the appendix on CT scan has been shown to have a high negative predictive value (98.7%).[52] The advantages of CT scan come at the cost of ionizing radiation. One CT scan of the abdomen in a 5-year-old child increases the lifetime risk of radiation-induced cancer to 26.1 per 100,000 in women and 20.1 per 100,000 in men.[53] In order to lower overall radiation dose, one study evaluated decreasing the radiation dose by 50% and another examined targeted CT imaging; both demonstrated high sensitivity and specificity.[37,54] It has been shown that a dedicated pediatric facility has much lower doses of radiation when using CT to diagnoses appendicitis compared with adult centers without pediatric-specific protocols.[55]

MRI

MRI has a high diagnostic accuracy for appendicitis and does not expose the child to ionizing radiation. The obvious disadvantages, though, have limited its utility, including lack of availability at many hospitals, lengthy acquisition time, high cost compared with CT and US, and often requires sedation or anesthesia.[56–59] Overall sensitivity and specificity are 96.8% and 97.4%, with a negative appendectomy rate of 3.1%.[58] Future research is required to define its role and position in the workup of appendicitis.

TREATMENT

Antibiotics

Antibiotics are initiated once the diagnosis of appendicitis is made. Initially a triple-antibiotic regimen consisting of ampicillin, gentamicin, and clindamycin was used. With the changes in the adult antibiotic regimens, pediatric surgery has evolved as well. Both piperacillin/tazobactam and cefoxitin have been shown to be at least as efficacious as the triple-drug regimen and may also decrease length of stay (LOS) and pharmaceutical costs.[60] Other studies suggest that metronidazole must be added to a third-generation cephalosporin to cover anaerobic isolates.[61,62] The authors' center begins with a single dose of ceftriaxone sodium (Rocephin) and metronidazole (Flagyl). If children are perforated, they receive additional IV doses until they are ready for discharge, at which time a WBC count, if elevated, results in discharge with a 5-day oral antibiotic course.[63] A recent prospective observational study of 1975 adult and pediatric patients with acute and perforated appendicitis demonstrated there was no difference in either 3 or 5 days of antibiotic treatment on the development of infectious complications after laparoscopic appendectomy for complicated appendicitis.[64]

Nonoperative Management of Acute Appendicitis

Although appendectomy is generally a simple procedure, it requires general anesthesia and is an abdominal operation with inherent risks and potential complications. Complications related to surgery or anesthesia occur in more than 10% of children within 30 days of appendectomy.[65] Even with current imaging methods, 6.3% of children in Canada and 4.3% in the United States undergoing appendectomy are subsequently found to have a normal appendix.[66] Consequently, this could be considered an unnecessary operation.

The interest in nonoperative management of appendicitis has largely been revived by the research and management of several intra-abdominal infectious processes, including diverticulitis, abscess resulting from Crohn disease, and tubo-ovarian abscess, that are all now treated with antibiotics alone with surgery reserved for failures of medical management.[67,68] Nonoperative management of uncomplicated appendicitis has been studied in several international adult trials (**Table 3**).[69–75] Overall, these trials demonstrated successful nonoperative management of acute appendicitis in 70% to 85% of cases at the 1-year follow-up. A 2012 meta-analysis concluded that, although there were benefits to nonoperative treatment, including fewer complications, better pain control, and shorter sick leave, the combined failure and recurrence rates in nonoperative patients made this approach less effective overall.[76] Predictors of failure of nonoperative management in the literature were abdominal pain greater than 48 hours; presence of an appendicolith, phlegmon, or abscess on imaging; and elevated laboratory measures, specifically WBC greater than 18,000 and CRP greater than 4 mg/dL.[69–75]

There is a moderate amount of existing literature on the nonoperative management of pediatric appendicitis. This literature consists of a mix of retrospective and prospective cohort studies[77–85] and one pilot randomized controlled trial.[84] Previous studies in children revealed a success rate ranging from 75% to 80% with no increased rates of perforated appendicitis in patients initially managed nonoperatively. In a patient choice study from 2007 to 2013 with an average 4.3-year follow-up, 78 chose nonoperative management with a 99% success rate initially but a 29% recurrence at 1 year.[85] In a feasibility study, 24 patients aged 5 to 18 years with less than 48 hours of symptoms of acute appendicitis were compared with 50 controls.[80] At a mean follow-up of 14 months, 3 of the 24 failed on therapy and 2 of those 21 returned with recurrent appendicitis. Two patients elected to undergo an interval appendectomy despite absence of symptoms. The appendectomy-free rate at 1 year was, therefore, 71% with no patient developing perforation or other complications and having an overall cost savings of $1359 (from $4130 to $2771 per nonoperatively treated patient).[80] Minneci and colleagues[83] performed a prospective single-institution patient choice trial in which a total of 102 patients were enrolled (65 chose appendectomy, 37 families chose nonoperative management). The inclusion criteria were 7 to 18 years of age, less than 48 hours of abdominal pain, WBC less than 18,000 cells per microliter, and US or CT demonstrating an appendix less than 1.2 cm in diameter without appendicolith, abscess, or phlegmon. Patients in the operative arm received urgent laparoscopic appendectomy. Those patients in the nonoperative arm received a diet after 12 hours; if at 24 hours they had no clinical improvement, they underwent laparoscopic appendectomy. The success rate of nonoperative management was 89.2% with an incidence of complicated appendicitis of 2.7% in the nonoperative group and 12.3% in the surgery group (8 of 65 children). These investigators demonstrated that nonoperative patients reported higher quality-of-life scores at 30 days and fewer days off and overall lower costs associated with the hospitalization.[83]

The only randomized controlled trial performed to date was a recently performed pilot study in Sweden evaluating 24 nonoperative and 26 operative pediatric patients with a follow-up to 1 year. The investigators reported a 92% (24 of 26 patients) successful treatment with antibiotics.[84] Based off the results of a pilot randomized controlled trial,[84] there is currently an international, multicenter, randomized trial to

Table 3
Existing literature relating to nonoperative treatment of acute uncomplicated appendicitis in children

Study	Country of Origin	Study Design	No. of Children Receiving NOM	Comparative Study[a]	Criteria	No. Days IV Antibiotics in NOM	No. Days Hospital Stay	No. Children Requiring Appendectomy in NOM	Follow-up Interval (mo)
Kaneko et al,[81] 2004	Japan	Prospective cohort	22	No	3–15 y US classification	4.2	NR	6 (27.3%)	13
Abes et al,[77] 2007	Turkey	Retrospective cohort	16	No	5–13 y US	5.0	5.0	2 (13.3%)	12
Armstrong et al,[78] 2014	Canada	Nonrandomized retrospective cohort	12	Yes	<18 y US	1.5	1.5	3 (25%)	12
Koike et al,[82] 2014	Japan	Retrospective cohort	130	No	1–15 y Clinical diagnosis	6.7	6.7	24 (19.2%)	2–36
Gorter et al,[79] 2015	Holland	Nonrandomized prospective cohort	25	Yes	7–17 y Imaging	2–4	4.0	2 (8%)	1.5

(*continued on next page*)

Table 3
(*continued*)

Study	Country of Origin	Study Design	No. of Children Receiving NOM	Comparative Study[a]	Criteria	No. Days IV Antibiotics in NOM	No. Days Hospital Stay	No. Children Requiring Appendectomy in NOM	Follow-up Interval (mo)
Hartwich et al,[80] 2016	United States	Prospective parent preference-based feasibility trial	24	Yes	5–18 y Clinical diagnosis	1.0	2.0	7 (29%)	14
Minneci et al,[83] 2016	United States	Prospective parent preference-based trial	30	Yes	7–17 y US/CT	1.0	2.0	3 (10%)	1
Svensson et al,[136] 2015	Sweden	Pilot RCT	24	Yes	5–15 y Clinical diagnosis	2.0	2.0	9 (37%)	12
Steiner et al,[137] 2015	Israel	Nonrandomized prospective cohort	45	No	4–15 y US	3.3	3.8	7 (16.6%)	6–14
Tanaka et al,[85] 2015	Japan	Nonrandomized retrospective cohort	78	Yes	5–15 y US	6.0	6.6	22 (28.6%)	12

Abbreviations: NOM, nonoperative management; NR, not recorded; RCT, randomized controlled trial.
[a] Included a comparison group who underwent appendectomy.

evaluate the nonoperative management of acute pediatric appendicitis. Inclusion criteria are children aged 5 to 16 years, clinical and/or radiological diagnosis (US and/or CT scan) of acute nonperforated appendicitis, and written informed parental consent. Exclusion criteria include suspicion of perforated appendicitis, presentation with an appendix mass or phlegmon (on physical examination and/or imaging), nonoperative management (2 or more doses of IV antibiotic) initiated at an outside institution, previous episode of appendicitis or appendix mass/phlegmon treated nonoperatively, and current treatment of malignancy.

One of the greatest predictors of failure of nonoperative management seems to be the presence of an appendicolith on imaging studies.[84,85] A prospective nonrandomized trial comparing the nonoperative management of uncomplicated acute appendicitis with an appendicolith performed in children aged 7 to 17 years was halted early because the failure of nonoperative management was 60% (3 of 5 patients) at a median follow-up of 5 months.[86] Another interesting point in many of the patient/family choice–based nonoperative trials is that despite patient characteristics being similar up until treatment selection, parents may ultimately be able to recognize if their child would be successful at nonoperative management.

One of the more complex aspects of understanding this pediatric appendicitis is changing the previous misconceptions and perceptions of the diagnosis of appendicitis. A feasibility study performed highlighted the striking knowledge gap in the participant perception of appendicitis. One hundred subjects (caregivers and patients $\geq$15 years of age) were questioned before and after an education session about their understanding of appendicitis. Eighty-two percent of respondents thought it was *likely* or *very likely* that the appendix would rupture if the operation was at all delayed and that rupture of the appendix would rapidly lead to severe complications and death. These feelings increased when subjects knew at least one friend or relative who had a negative experience with appendicitis. The investigators concluded that appropriate education can correct anecdotally supported misconceptions. Adequate education may empower patients to make better-informed decisions about their medical care and may be important for future studies in alternative treatments for appendicitis in children.[87]

Surgical Options for Appendicitis

Appendicitis presents in a spectrum from acute to perforated with and without organized abscess. The goals of surgical care for appendicitis are to minimize complications and cost, alleviate patient anxiety, and improve quality of life.

Acute appendicitis

Traditional thinking was that emergent appendectomy should be performed at the time of diagnosis. When comparing emergent appendectomy (within 5 hours of admission) with urgent appendectomy (within 17 hours), no difference in gangrenous/perforated appendixes, operative length, readmission, postoperative complications, hospital stay, or charges have been noted.[88] Many centers now perform appendectomies in the morning for patients presenting at night, although it is recommended that patients begin antibiotics at the time of diagnosis.[31] A recent multicenter study including 1300 patients demonstrated that delay in appendectomy did not impact the incidence of surgical site infections.[89] A recent study in 230 children with appendicitis presenting with greater than 48 hours of symptoms had 4.9 times increased odds of perforation and 56% greater hospital LOS than those presenting within 0 to 23 hours. From diagnosis to appendectomy, those taken at 0 to 3 hours, 4 to 6 hours, or longer than 6 hours after diagnosis to the operating room (OR) had no statistically significant difference in hospital LOS or perforation rates and no clinically significant difference in OR times. The investigators were unable to demonstrate a difference in perforation rates based on emergency department LOS before surgery.[90] Thus, putting together the data that exist suggesting overnight appendectomies place stress on the family, surgeon, and hospital, midnight appendectomies are no longer justified.[91–93]

Perforated appendicitis

Perforation is defined as a hole in the appendix or a fecalith in the abdomen.[1] Approximately 30% of children with appendicitis present with perforated appendicitis.[94] The postoperative risk of an intra-abdominal abscess is approximately 20% for children with perforated appendicitis, and the risk for children with nonperforated appendicitis to develop an abscess is less than 0.8%.[1] There are still several controversies that exist in the management of children who present with perforated appendicitis. Three options exist: antibiotics only, antibiotics followed by an interval appendectomy, and an appendectomy at the time of presentation.

Children treated with antibiotics initially avoid a difficult operation while the peritonitis resolves. A wide range of recurrent appendicitis has been demonstrated in prospective studies, between 8% and 15%, with an unknown lifetime risk. It is estimated that the risk of appendicitis is 1% to 3% per year, which if true would argue for an appendectomy in children. Although infrequent, a small rate of pathologic findings in interval appendectomy specimens, including appendiceal neoplasms, has not resulted in a clear answer regarding the management of children with a history of perforated appendicitis and an appendicular mass.[95,96] Additionally, the lumen in most appendix specimens from interval appendectomy are found to be patent, with less than 16% being completely obliterated.[97,98]

Currently most surgeons surveyed would perform an interval appendectomy in a patient with previously perforated appendicitis.[99] The risk in the interval between treatment and presentation for elective operation is recurrent appendicitis, with an increased rate of recurrence among patients with appendicoliths or contamination beyond the right lower quadrant on imaging.[96,100–102] Additional problems with this management pathway are the difficulty in being able to predict perforation on a CT scan accurately (<80% accuracy to predict perforation by CT scan).[51] Treating a child with nonperforated appendicitis with a protracted course of antibiotics and interval appendectomy results in complications from antibiotic overuse and overtreatment.

Another point of controversy is when to perform interval appendectomy in a child with perforated appendicitis. Many studies have been performed; a meta-analysis evaluating early versus delayed appendectomy for perforated appendicitis concluded that patients who underwent a delayed operation were associated with significantly less overall complications, wound infections, intra-abdominal abscesses, bowel obstructions, and reoperations. No differences were found in the duration of first hospitalization, the overall duration of hospital stay, and the duration of IV antibiotics.[103] A randomized controlled trial compared appendectomy on presentation with initial antibiotic therapy and appendectomy 6 to 8 weeks later for children with presumptive perforated appendicitis with and without abscess. Early appendectomy, compared with interval appendectomy, significantly reduced the time away from normal activities (mean, 13.8 vs 19.4 days; $P<.001$). The overall adverse event rate was 30% for early appendectomy versus 55% for interval appendectomy (relative risk with interval appendectomy, 1.86; 95% confidence interval, 1.21–2.87; $P = .003$). Of the patients randomized to interval appendectomy, 23 (34%) had an appendectomy earlier than planned owing to failure to improve (n = 17), recurrent appendicitis (n = 5), or other reasons (n = 1). Importantly, children who had delayed appendectomy had higher costs and were more likely to receive a central line.[104] Children with a preoperative diagnosis of perforated appendicitis, thus, benefit from early laparoscopic appendectomy.

Patients who present with a well-defined abscess on imaging studies present another controversial group. Given the perceived technical demands of laparoscopic appendectomy and the expected postoperative morbidity in patients with a well-defined abscess, initial percutaneous drainage has become an attractive option.[105–108] Fifty-two patients with well-formed abscesses following perforated appendicitis were studied to evaluate outcomes following drainage of the abscess or drain placement. During the interval between initial presentation and interval appendectomy, 9 recurrent abscesses developed (17.3%) and 6 patients (11.5%) required another drainage procedure. The mean total charge to the patients was $40,414.02. There were 4 significant drain complications (ileal perforation, colon perforation, bladder perforation, and buttock/thigh necrotizing abscess).[105] A randomized trial comparing 40 patients with well-formed abscess to drainage with interval appendectomy versus early laparoscopic appendectomy at presentation demonstrated that, although operative time was slightly longer in those patients receiving initial appendectomy, overall quality-of-life assessments were improved.[105,109] Although the rare child may be doing clinically well at presentation, the authors recommend most children with abscesses receive early primary laparoscopic appendectomy.

OPERATIVE APPROACHES

In 1894, McBurney[110] first described the traditional appendectomy through a muscle-splitting incision in the right lower quadrant, 4 years before he wrote his article regarding the utility of rubber gloves in surgery.[110,111] Today, laparoscopic appendectomies have largely replaced the open approach, as greater than 91% of appendectomies are performed laparoscopically versus 22% in the late 1990s.[112] Several different operative approaches using various minimally invasive techniques have been described and summarized,[31] including a traditional 3-port appendectomy, transumbilical laparoscopic appendectomy (2 ports) whereby the appendix is ultimately delivered through the umbilicus, and single-incision laparoscopic appendectomy whereby instruments are placed through the same incision used for the camera port with an intracorporeal or extracorporeal appendix. Many trials have evaluated single-incision versus traditional 3-port appendectomy, and no differences have been found between the groups regarding outcomes.[113,114] Cosmetically, the initial excitement of a single incision fades at a longer interval follow-up between the two patient groups.[115]

Higher postoperative abscess rates were initially described following laparoscopic appendectomy compared with traditional open appendectomy.[116,117] Meta-analysis and multi-institutional reviews have found no differences in intra-abdominal abscess rates and continued low rates of wound infections at the port sites as well as less adhesive small bowel obstruction.[118–126]

IRRIGATION

Following operative intervention, the question of abdominal irrigation has been studied. No clear data existed from previous studies on the role of irrigation for peritoneal contamination in perforated appendicitis.[127] As late as 2004, more than 93% of North American surgeons reported using irrigation.[128] Two retrospective studies comparing laparoscopic irrigation with no irrigation during appendectomy demonstrated an increase in abscesses resulting from the use of irrigation.[129,130] A randomized trial of 220 patients comparing normal saline irrigation of greater than 500 mL to suction alone during laparoscopic appendectomy for perforated appendicitis in children demonstrated no differences in abscess rates or other clinical measures or hospital costs.[127]

INCIDENTAL APPENDECTOMIES

Incidental appendectomies (IAs), defined as the removal of the appendix accompanying another operation without evidence of acute appendicitis, are not routinely advocated except in specific situations, including any surgery that has a right lower quadrant incision, such as a Meckel diverticulectomy or intussusception reduction. A patient with an appendicolith evaluated for other issues is not an indication for appendectomy, as the risk of appendicitis is less than 5.8%.[131] Performing an appendectomy converts a procedure from clean to clean-contaminated. Most importantly, in a comprehensive review on IAs, the investigators concluded that the decision to perform a pediatric IA relies on informed consideration of the individual patient's comorbid conditions, the indications for the initial operation, the future utility of the appendix, and the risk of future appendiceal pathology.[132]

POSTOPERATIVE CARE

Postoperative care is best protocolized.[133] Children with acute appendicitis can be discharged a few hours following operative intervention.[134] Nonoperative management has yet to determine the optimal duration of admission, but 12 to 24 hours' duration seems to be sufficient. For children with perforated appendicitis, antibiotics are continued until fevers are no longer present and patients are tolerating a diet. Normalization of WBC is not required, and before discharge patients get a WBC and are sent home on additional oral antibiotics if the WBC count is elevated. If prolonged ileus and failure to progress results in a stay greater than 6 days, a CT scan is obtained to evaluate for intra-abdominal abscesses, which are then drained. Nasogastric tubes, abdominal drains, central lines, total parenteral nutrition, prolonged use of Foley catheters, and complex wound packing schema have been largely abandoned.[135]

SUMMARY

1. Appendicitis occurs most frequently between 10 and 11 years of age.
2. Classic symptoms include migrating pain to the right lower quadrant and fevers but are present in less than half of the children presenting with appendicitis.
3. Clinical judgment and judicious studies are the best methods when assessing for appendicitis. Scoring systems have been shown to be useful with the addition of selective imaging and laboratory tests.
4. US imaging continues to be the study of choice as CT increases radiation exposure.
5. Laparoscopic approaches now make up more than 90% of the operative approaches for appendicitis.
6. Nonoperative management for carefully selected children with acute appendicitis is possible.
7. Complex appendicitis with perforation is best managed with a minimally invasive operative technique in children without a well-defined abscess.

REFERENCES

1. St Peter SD, Sharp SW, Holcomb GW III, et al. An evidence-based definition for perforated appendicitis derived from a prospective randomized trial. J Pediatr Surg 2008;43(12):2242–5.

2. Addiss DG, Shaffer N, Fowler BS, et al. The epidemiology of appendicitis and appendectomy in the United States. Am J Epidemiol 1990;132(5):910–25.
3. Healthcare Cost and Utilization Project (HCUP). The SAGE encyclopedia of pharmacology and society. SAGE Publications. Available at: www. hcup.ahrq.gov. Accessed November 12, 2015.
4. Brennan GD. Pediatric appendicitis: pathophysiology and appropriate use of diagnostic imaging. CJEM 2006;8(6):425–32.
5. Deng Y, Chang DC, Zhang Y, et al. Seasonal and day of the week variations of perforated appendicitis in US children. Pediatr Surg Int 2010;26(7):691–6.
6. Pearl RH, Hale DA, Molloy M, et al. Pediatric appendectomy. J Pediatr Surg 1995;30(2):173–81.
7. Becker T, Kharbanda A, Bachur R. Atypical clinical features of pediatric appendicitis. Acad Emerg Med 2007;14(2):124–9.
8. Paulson EK, Kalady MF, Pappas TN. Suspected appendicitis. N Engl J Med 2003;348(3):236–42.
9. Wang LT, Prentiss KA, Simon JZ, et al. The use of white blood cell count and left shift in the diagnosis of appendicitis in children. Pediatr Emerg Care 2007;23(2): 69–76.
10. Beltrán MA, Almonacid J, Vicencio A, et al. Predictive value of white blood cell count and C-reactive protein in children with appendicitis. J Pediatr Surg 2007; 42(7):1208–14.
11. Benito J, Acedo Y, Medrano L, et al. Usefulness of new and traditional serum biomarkers in children with suspected appendicitis. Am J Emerg Med 2016; 34(5):871–6.
12. Grönroos P, Huhtinen H, Grönroos JM. Normal leukocyte count value do not effectively exclude acute appendicitis in children. Dis Colon Rectum 2009; 52(5):1028–9.
13. Mekhail P, Yanni F, Naguib N, et al. Appendicitis in paediatric age group: correlation between preoperative inflammatory markers and postoperative histological diagnosis. Afr J Paediatr Surg 2011;8(3):309.
14. Siddique K, Baruah P, Bhandari S, et al. Diagnostic accuracy of white cell count and C-reactive protein for assessing the severity of paediatric appendicitis. JRSM Short Rep 2011;2(7):59.
15. Chung J-L, Kong M-S, Lin S-L, et al. Diagnostic value of C-reactive protein in children with perforated appendicitis. Eur J Pediatr 1996;155(7):529–31.
16. Rodríguez-Sanjuán JC, Martín-Parra JI, Seco I, et al. C-reactive protein and leukocyte count in the diagnosis of acute appendicitis in children. Dis Colon Rectum 1999;42(10):1325–9.
17. Alvarado A. A practical score for the early diagnosis of acute appendicitis. Ann Emerg Med 1986;15(5):557–64.
18. Samuel M. Pediatric appendicitis score. J Pediatr Surg 2002;37(6):877–81.
19. Bhatt M, Joseph L, Ducharme FM, et al. Prospective validation of the pediatric appendicitis score in a Canadian pediatric emergency department. Acad Emerg Med 2009;16(7):591–6.
20. Goldman RD, Carter S, Stephens D, et al. Prospective validation of the pediatric appendicitis score. J Pediatr 2008;153(2):278–82.
21. Mandeville K, Pottker T, Bulloch B, et al. Using appendicitis scores in the pediatric ED. Am J Emerg Med 2011;29(9):972–7.
22. Pogorelić Z, Rak S, Mrklić I, et al. Prospective validation of Alvarado score and pediatric appendicitis score for the diagnosis of acute appendicitis in children. Pediatr Emerg Care 2015;31(3):164–8.

23. Schneider C, Kharbanda A, Bachur R. Evaluating appendicitis scoring systems using a prospective pediatric cohort. Ann Emerg Med 2007;49(6):778–84, 784.e1.
24. Scheller RL, Depinet HE, Ho ML, et al. Utility of pediatric appendicitis score in female adolescent patients. Acad Emerg Med 2016;23(5):610–5.
25. Panella M, Marchisio S, Di Stanislao F. Reducing clinical variations with clinical pathways: do pathways work? Int J Qual Health Care 2003;15(6):509–21.
26. Warner BW, Kulick RM, Stoops MM, et al. An evidenced-based clinical pathway for acute appendicitis decreases hospital duration and cost. J Pediatr Surg 1998;33(9):1371–5.
27. Anandalwar SP, Callahan MJ, Bachur RG, et al. Use of white blood cell count and polymorphonuclear leukocyte differential to improve the predictive value of ultrasound for suspected appendicitis in children. J Am Coll Surg 2015;220(6):1010–7.
28. Fleischman RJ, Devine MK, Yagapen MA, et al. Evaluation of a novel pediatric appendicitis pathway using high- and low-risk scoring systems. Pediatr Emerg Care 2013;29(10):1060–5.
29. Garcia Pena BM, Taylor GA, Fishman SJ, et al. Costs and effectiveness of ultrasonography and limited computed tomography for diagnosing appendicitis in children. Pediatrics 2000;106(4):672–6.
30. Saucier A, Huang EY, Emeremni CA, et al. Prospective evaluation of a clinical pathway for suspected appendicitis. Pediatrics 2014;133(1):e88–95.
31. Pepper VK, Stanfill AB, Pearl RH. Diagnosis and management of pediatric appendicitis, intussusception, and Meckel diverticulum. Surg Clin North Am 2012;92(3):505–26, vii.
32. Klein MD. Referral to pediatric surgical specialists. Pediatrics 2014;133(2):350–6.
33. Williams RF, Blakely ML, Fischer PE, et al. Diagnosing ruptured appendicitis preoperatively in pediatric patients. J Am Coll Surg 2009;208(5):819–25.
34. Binkovitz LA, Unsdorfer KML, Thapa P, et al. Pediatric appendiceal ultrasound: accuracy, determinacy and clinical outcomes. Pediatr Radiol 2015;45(13):1934–44.
35. Peña BMG. Ultrasonography and limited computed tomography in the diagnosis and management of appendicitis in children. JAMA 1999;282(11):1041.
36. Rosen MP, Ding A, Blake MA, et al. ACR Appropriateness Criteria® right lower quadrant pain—suspected appendicitis. J Am Coll Radiol 2011;8(11):749–55.
37. 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.
38. Burr A, Renaud EJ, Manno M, et al. Glowing in the dark: time of day as a determinant of radiographic imaging in the evaluation of abdominal pain in children. J Pediatr Surg 2011;46(1):188–91.
39. Butler M, Servaes S, Srinivasan A, et al. US depiction of the appendix: role of abdominal wall thickness and appendiceal location. Emerg Radiol 2011;18(6):525–31.
40. Schuh S, Man C, Cheng A, et al. Predictors of non-diagnostic ultrasound scanning in children with suspected appendicitis. J Pediatr 2011;158(1):112–8.
41. Yiğiter M, Kantarcı M, Yalçin O, et al. Does obesity limit the sonographic diagnosis of appendicitis in children? J Clin Ultrasound 2010;39(4):187–90.
42. Bachur RG, Dayan PS, Bajaj L, et al. The effect of abdominal pain duration on the accuracy of diagnostic imaging for pediatric appendicitis. Ann Emerg Med 2012;60(5):582–90.e3.

43. Goldin AB, Khanna P, Thapa M, et al. Revised ultrasound criteria for appendicitis in children improve diagnostic accuracy. Pediatr Radiol 2011;41(8):993–9.
44. Mittal MK, Dayan PS, Macias CG, et al. Performance of ultrasound in the diagnosis of appendicitis in children in a multicenter cohort. Acad Emerg Med 2013; 20(7):697–702.
45. 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(7):813–23.
46. Burford JM, Dassinger MS, Smith SD. Surgeon-performed ultrasound as a diagnostic tool in appendicitis. J Pediatr Surg 2011;46(6):1115–20.
47. Callahan MJ, Kleinman PL, Strauss KJ, et al. Pediatric CT dose reduction for suspected appendicitis: a practice quality improvement project using artificial gaussian noise—part 1, computer simulations. Am J Roentgenol 2015;204(1): W86–94.
48. Sivit CJ, Applegate KE, Stallion A, et al. Imaging evaluation of suspected appendicitis in a pediatric population. Am J Roentgenol 2000;175(4):977–80.
49. Laituri CA, Fraser JD, Aguayo P, et al. The lack of efficacy for oral contrast in the diagnosis of appendicitis by computed tomography. J Surg Res 2011;170(1): 100–3.
50. Servaes S, Srinivasan A, Pena A, et al. CT diagnosis of appendicitis in children: comparison of orthogonal planes and assessment of contrast opacification of the appendix. Pediatr Emerg Care 2015;31(3):161–3.
51. Fraser JD, Aguayo P, Sharp SW, et al. Accuracy of computed tomography in predicting appendiceal perforation. J Pediatr Surg 2010;45(1):231–4 [discussion: 234].
52. Garcia K, Hernanz-Schulman M, Bennett DL, et al. Suspected appendicitis in children: diagnostic importance of normal abdominopelvic CT findings with nonvisualized appendix 1. Radiology 2009;250(2):531–7.
53. Hall EJ. Lessons we have learned from our children: cancer risks from diagnostic radiology. Pediatr Radiol 2002;32(10):700–6.
54. Fefferman NR, Roche KJ, Pinkney LP, et al. Suspected appendicitis in children: focused CT technique for evaluation. Radiology 2001;220(3):691–5.
55. Sharp NE, Raghavan MU, Svetanoff WJ, et al. Radiation exposure - how do CT scans for appendicitis compare between a free standing children's hospital and non-dedicated pediatric facilities? J Pediatr Surg 2014;49(6):1016–9 [discussion: 1019].
56. Johnson AK, Filippi CG, Andrews T, et al. Ultrafast 3-T MRI in the evaluation of children with acute lower abdominal pain for the detection of appendicitis. Am J Roentgenol 2012;198(6):1424–30.
57. Koning JL, Naheedy JH, Kruk PG. Diagnostic performance of contrast-enhanced MR for acute appendicitis and alternative causes of abdominal pain in children. Pediatr Radiol 2014;44(8):948–55.
58. Kulaylat AN, Moore MM, Engbrecht BW, et al. An implemented MRI program to eliminate radiation from the evaluation of pediatric appendicitis. J Pediatr Surg 2015;50(8):1359–63.
59. Orth RC, Guillerman RP, Zhang W, et al. Prospective comparison of MR imaging and US for the diagnosis of pediatric appendicitis. Radiology 2014;272(1): 233–40.
60. Goldin AB, Sawin RS, Garrison MM, et al. Aminoglycoside-based triple-antibiotic therapy versus monotherapy for children with ruptured appendicitis. Pediatrics 2007;119(5):905–11.

61. Guillet-Caruba C, Cheikhelard A, Guillet M, et al. Bacteriologic epidemiology and empirical treatment of pediatric complicated appendicitis. Diagn Microbiol Infect Dis 2011;69(4):376–81.
62. St. Peter SD, Little DC, Calkins CM, et al. A simple and more cost-effective antibiotic regimen for perforated appendicitis. J Pediatr Surg 2006;41(5):1020–4.
63. Desai AA, Alemayehu H, Holcomb GW 3rd, et al. Safety of a new protocol decreasing antibiotic utilization after laparoscopic appendectomy for perforated appendicitis in children: a prospective observational study. J Pediatr Surg 2015;50(6):912–4.
64. van Rossem CC, Schreinemacher MH, van Geloven AA, et al. Antibiotic duration after laparoscopic appendectomy for acute complicated appendicitis. JAMA Surg 2016;151(4):323–9.
65. Tiboni S, Bhangu A, Hall NJ. Outcome of appendicectomy in children performed in paediatric surgery units compared with general surgery units. Br J Surg 2014;101(6):707–14.
66. Cheong LH, Emil S. Outcomes of pediatric appendicitis: an international comparison of the United States and Canada. JAMA Surg 2014;149(1):50–5.
67. Broderick-Villa G. Hospitalization for acute diverticulitis does not mandate routine elective colectomy. Arch Surg 2005;140(6):576.
68. Ricciardi R, Baxter NN, Read TE, et al. Is the decline in the surgical treatment for diverticulitis associated with an increase in complicated diverticulitis? Dis Colon Rectum 2009;52(9):1558–63.
69. Di SS, Sibilio A, Giorgini E, et al. The NOTA Study (Non Operative Treatment for Acute Appendicitis): prospective study on the efficacy and safety of antibiotics (amoxicillin and clavulanic acid) for treating patients with right lower quadrant abdominal pain and long-term follow-up of conservatively treated suspected appendicitis. Ann Surg 2014;260(1):109–17.
70. Hansson J, Körner U, Khorram-Manesh A, et al. Randomized clinical trial of antibiotic therapy versus appendicectomy as primary treatment of acute appendicitis in unselected patients. Br J Surg 2009;96(5):473–81.
71. Hansson J, Körner U, Ludwigs K, et al. Antibiotics as first-line therapy for acute appendicitis: evidence for a change in clinical practice. World J Surg 2012;36(9):2028–36.
72. Salminen P, Paajanen H, Rautio T, et al. Antibiotic therapy vs appendectomy for treatment of uncomplicated acute appendicitis: the APPAC randomized clinical trial. JAMA 2015;313(23):2340–8.
73. Shindoh J, Niwa H, Kawai K, et al. Predictive factors for negative outcomes in initial non-operative management of suspected appendicitis. J Gastrointest Surg 2009;14(2):309–14.
74. Styrud J, Eriksson S, Nilsson I, et al. Appendectomy versus antibiotic treatment in acute appendicitis. A prospective multicenter randomized controlled trial. World J Surg 2006;30(6):1033–7.
75. Vons C, Barry C, Maitre S, et al. Amoxicillin plus clavulanic acid versus appendicectomy for treatment of acute uncomplicated appendicitis: an open-label, non-inferiority, randomised controlled trial. Lancet 2011;377(9777):1573–9.
76. Mason RJ, Moazzez A, Sohn H, et al. Meta-analysis of randomized trials comparing antibiotic therapy with appendectomy for acute uncomplicated (no abscess or phlegmon) appendicitis. Surg Infect (Larchmt) 2012;13(2):74–84.
77. Abeş M, Petik B, Kazıl S. Nonoperative treatment of acute appendicitis in children. J Pediatr Surg 2007;42(8):1439–42.

78. Armstrong J, Merritt N, Jones S, et al. Non-operative management of early, acute appendicitis in children: is it safe and effective? J Pediatr Surg 2014;49(5):782–5.
79. Gorter RR, van der Lee JH, Cense HA, et al. Initial antibiotic treatment for acute simple appendicitis in children is safe: short-term results from a multicenter, prospective cohort study. Surgery 2015;157(5):916–23.
80. Hartwich J, Luks FI, Watson-Smith D, et al. Nonoperative treatment of acute appendicitis in children: a feasibility study. J Pediatr Surg 2016;51(1):111–6.
81. Kaneko K, Tsuda M. Ultrasound-based decision making in the treatment of acute appendicitis in children. J Pediatr Surg 2004;39(9):1316–20.
82. Koike Y, Uchida K, Matsushita K, et al. Intraluminal appendiceal fluid is a predictive factor for recurrent appendicitis after initial successful non-operative management of uncomplicated appendicitis in pediatric patients. J Pediatr Surg 2014;49(7):1116–21.
83. Minneci PC, Mahida JB, Lodwick DL, et al. Effectiveness of patient choice in nonoperative vs surgical management of pediatric uncomplicated acute appendicitis. JAMA Surg 2016;151(5):408–15.
84. Svensson JF, Patkova B, Almström M, et al. Nonoperative treatment with antibiotics versus surgery for acute nonperforated appendicitis in children. Ann Surg 2015;261(1):67–71.
85. Tanaka Y, Uchida H, Kawashima H, et al. Long-term outcomes of operative versus nonoperative treatment for uncomplicated appendicitis. J Pediatr Surg 2015;50(11):1893–7.
86. Mahida JB, Lodwick DL, Nacion KM, et al. High failure rate of nonoperative management of acute appendicitis with an appendicolith in children. J Pediatr Surg 2016;51(6):908–11.
87. Chau DB, Ciullo SS, Watson-Smith D, et al. Patient-centered outcomes research in appendicitis in children: bridging the knowledge gap. J Pediatr Surg 2016;51(1):117–21.
88. Taylor M, Emil S, Nguyen N, et al. Emergent vs urgent appendectomy in children: a study of outcomes. J Pediatr Surg 2005;40(12):1912–5.
89. Boomer LA, Cooper JN, Anandalwar S, et al. Delaying appendectomy does not lead to higher rates of surgical site infections. Ann Surg 2016;264(1):164–8.
90. Mandeville K, Monuteaux M, Pottker T, et al. Effects of timing to diagnosis and appendectomy in pediatric appendicitis. Pediatr Emerg Care 2015;31(11):753–8.
91. Stahlfeld K, Hower J, Homitsky S, et al. Is acute appendicitis a surgical emergency? Am Surg 2007;73(6):626–9 [discussion: 629–30].
92. Surana R, Quinn F, Puri P. Is it necessary to perform appendicectomy in the middle of the night in children? BMJ 1993;306(6886):1168.
93. Yardeni D, Hirschl RB, Drongowski RA, et al. Delayed versus immediate surgery in acute appendicitis: do we need to operate during the night? J Pediatr Surg 2004;39(3):464–9.
94. Barrett ML, Hines AL, Andrews RM. Trends in rates of perforated appendix, 2001-2010: statistical brief #159. Healthcare Cost and Utilization Project (HCUP) statistical briefs. Rockville (MD): Agency for Health Care Policy and Research (US); 2006.
95. Gahukamble DB, Gahukamble LD. Surgical and pathological basis for interval appendicectomy after resolution of appendicular mass in children. J Pediatr Surg 2000;35(3):424–7.

96. Puapong D, Lee SL, Haigh PI, et al. Routine interval appendectomy in children is not indicated. J Pediatr Surg 2007;42(9):1500–3.
97. Knott EM, Iqbal CW, Mortellaro VE, et al. Outcomes for interval appendectomy after non-operative management of perforated appendicitis: what are the operative risks and luminal patency rates? J Surg Res 2012;172(2):189.
98. Mazziotti MV, Marley EF, Winthrop AL, et al. Histopathologic analysis of interval appendectomy specimens: support for the role of interval appendectomy. J Pediatr Surg 1997;32(6):806–9.
99. Chen C, Botelho C, Cooper A, et al. Current practice patterns in the treatment of perforated appendicitis in children. J Am Coll Surg 2003;196(2):212–21.
100. Aprahamian CJ, Barnhart DC, Bledsoe SE, et al. Failure in the nonoperative management of pediatric ruptured appendicitis: predictors and consequences. J Pediatr Surg 2007;42(6):934–8.
101. Ein SH, Langer JC, Daneman A. Nonoperative management of pediatric ruptured appendix with inflammatory mass or abscess: presence of an appendicolith predicts recurrent appendicitis. J Pediatr Surg 2005;40(10):1612–5.
102. Levin T, Whyte C, Borzykowski R, et al. Nonoperative management of perforated appendicitis in children: can CT predict outcome? Pediatr Radiol 2006;37(3): 251–5.
103. Simillis C, Symeonides P, Shorthouse AJ, et al. A meta-analysis comparing conservative treatment versus acute appendectomy for complicated appendicitis (abscess or phlegmon). Surgery 2010;147(6):818–29.
104. Blakely ML. Early vs interval appendectomy for children with perforated appendicitis. Arch Surg 2011;146(6):660.
105. Keckler SJ, Tsao K, Sharp SW, et al. Resource utilization and outcomes from percutaneous drainage and interval appendectomy for perforated appendicitis with abscess. J Pediatr Surg 2008;43(6):977–80.
106. Janik JS, Ein SH, Shandling B, et al. Nonsurgical management of appendiceal mass in late presenting children. J Pediatr Surg 1980;15(4):574–6.
107. Morrow SE, Newman KD. Current management of appendicitis. Semin Pediatr Surg 2007;16(1):34–40.
108. Owen A, Moore O, Marven S, et al. Interval laparoscopic appendectomy in children. J Laparoendosc Adv Surg Tech 2006;16(3):308–11.
109. St. Peter SD, Aguayo P, Fraser JD, et al. Initial laparoscopic appendectomy versus initial nonoperative management and interval appendectomy for perforated appendicitis with abscess: a prospective, randomized trial. J Pediatr Surg 2010;45(1):236–40.
110. McBurney C IV. The incision made in the abdominal wall in cases of appendicitis, with a description of a new method of operating. Ann Surg 1894;20(1): 38–43.
111. McBurney C IV. The use of rubber gloves in operative surgery. Ann Surg 1898; 28(1):108–19.
112. Jen HC, Shew SB. Laparoscopic versus open appendectomy in children: outcomes comparison based on a statewide analysis. J Surg Res 2010;161(1): 13–7.
113. St. Peter SD, Adibe OO, Juang D, et al. Single incision versus standard 3-port laparoscopic appendectomy. Ann Surg 2011;254(4):586–90.
114. Zhang Z, Wang Y, Liu R, et al. Systematic review and meta-analysis of single-incision versus conventional laparoscopic appendectomy in children. J Pediatr Surg 2015;50(9):1600–9.

115. Gasior AC, Knott EM, Holcomb GW 3rd, et al. Patient and parental scar assessment after single incision versus standard 3-port laparoscopic appendectomy: long-term follow-up from a prospective randomized trial. J Pediatr Surg 2014; 49(1):120–2 [discussion: 122].
116. Gasior AC, St. Peter SD, Knott EM, et al. National trends in approach and outcomes with appendicitis in children. J Pediatr Surg 2012;47(12):2264–7.
117. Lintula H, Kokki H, Vanamo K, et al. Laparoscopy in children with complicated appendicitis. J Pediatr Surg 2002;37(9):1317–20.
118. Aziz O, Athanasiou T, Tekkis PP, et al. Laparoscopic versus open appendectomy in children. Ann Surg 2006;243(1):17–27.
119. Esposito C, Borzi P, Valla JS, et al. Laparoscopic versus open appendectomy in children: a retrospective comparative study of 2,332 cases. World J Surg 2007; 31(4):750–5.
120. Guller U, Hervey S, Purves H, et al. Laparoscopic versus open appendectomy. Ann Surg 2004;239(1):43–52.
121. Horwitz JR, Custer MD, May BH, et al. Should laparoscopic appendectomy be avoided for complicated appendicitis in children? J Pediatr Surg 1997;32(11): 1601–3.
122. Jaschinski T, Mosch C, Eikermann M, et al. Laparoscopic versus open appendectomy in patients with suspected appendicitis: a systematic review of meta-analyses of randomised controlled trials. BMC Gastroenterol 2015;15(1):48.
123. Katkhouda N, Mason RJ, Towfigh S. Laparoscopic versus open appendectomy: a prospective, randomized, double-blind study. Adv Surg 2006;40:1–19.
124. Menezes M, Das L, Alagtal M, et al. Laparoscopic appendectomy is recommended for the treatment of complicated appendicitis in children. Pediatr Surg Int 2008;24(3):303–5.
125. Paterson HM, Qadan M, de Luca SM, et al. Changing trends in surgery for acute appendicitis. Br J Surg 2008;95(3):363–8.
126. Yau KK, Siu WT, Tang CN, et al. Laparoscopic versus open appendectomy for complicated appendicitis. J Am Coll Surg 2007;205(1):60–5.
127. St Peter SD, Adibe OO, Iqbal CW, et al. Irrigation versus suction alone during laparoscopic appendectomy for perforated appendicitis. Ann Surg 2012; 256(4):581–5.
128. Muehlstedt SG, Pham TQ, Schmeling DJ. The management of pediatric appendicitis: a survey of North American pediatric surgeons. J Pediatr Surg 2004; 39(6):875–9.
129. Hartwich JE, Carter RF, Wolfe L, et al. The effects of irrigation on outcomes in cases of perforated appendicitis in children. J Surg Res 2013;180(2):222–5.
130. Moore CB, Smith RS, Herbertson R, et al. Does use of intraoperative irrigation with open or laparoscopic appendectomy reduce post-operative intra-abdominal abscess? Am Surg 2011;77(1):78–80.
131. Rollins MD, Andolsek W, Scaife ER, et al. Prophylactic appendectomy: unnecessary in children with incidental appendicoliths detected by computed tomographic scan. J Pediatr Surg 2010;45(12):2377–80.
132. Healy JM, Olgun LF, Hittelman AB, et al. Pediatric incidental appendectomy: a systematic review. Pediatr Surg Int 2016;32(4):321–35.
133. Willis ZI, Duggan EM, Bucher BT, et al. Effect of a clinical practice guideline for pediatric complicated appendicitis. JAMA Surg 2016;151(5):e160194.
134. Aguayo P, Alemayehu H, Desai AA, et al. Initial experience with same day discharge after laparoscopic appendectomy for non-perforated appendicitis. J Surg Res 2014;186(2):535.

135. Knott EM, Gasior AC, Ostlie DJ, et al. Decreased resource utilization since initiation of institutional clinical pathway for care of children with perforated appendicitis. J Pediatr Surg 2013;48(6):1395–8.
136. Svensson JF, Patkova B, Almstrom M, et al. Nonoperative treatment with antibiotics versus surgery for acute nonperforated appendicitis in children: a pilot randomized controlled trial. Ann Surg 2015;261(1):67–71.
137. Steiner Z, Buklan G, Stackievicz R, et al. A role for conservative antibiotic treatment in early appendicitis in children. J Pediatr Surg 2015;50(9):1566–8.