Appendicitis (General Pediatric Surgery of Abdomen)

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Abstract
Appendicitis is a surgical emergency, characterized classically by right lower quadrant pain, vomiting, and fever, due to an inflamed vermiform appendix. The lifetime risk of developing acute appendicitis is approximately 9%, with children aged 10–14 years being most commonly affected. The exact etiology of this condition is incompletely understood. Appendicitis may be complicated by perforation or formation of an intra-abdominal abscess or inflammatory mass. Diagnosis is primarily dependent on clinical parameters with radiological investigations such as ultrasound and computed tomography being of value in those with inconclusive clinical findings. A high index of suspicion is required in preschool children who commonly present with atypical features and more advanced appendicitis. Laboratory investigations lack sensitivity or specificity for diagnosis. Following diagnosis, expedient surgery following fluid resuscitation and broad-spectrum antibiotic therapy is appropriate in most cases. In those with an appendix mass, initial non-operative treatment with antibiotics followed by interval appendectomy may be the best approach. Laparoscopic appendectomy has several advantages over open appendectomy regarding postoperative pain control, ileus, return to diet, and duration of hospital stay. It is thus becoming a more frequently used operative modality for appendicitis. Surgical site infections and intestinal obstruction are the most commonly encountered complications. Postoperative antibiotics reduce the incidence of surgical site infection, especially in complicated appendicitis. While the principles of diagnosis and treatment of appendicitis have changed little in the last century, developments in laparoscopic technology, like single-port appendectomy, and changing evidence regarding non-operative treatment of uncomplicated appendicitis may improve patient outcomes in the future.

Keywords
Appendix · Appendicitis · Appendectomy · Laparoscopic · McBurney · fecalith · Appendicolith · RLQ

Introduction
Acute appendicitis is the most common surgical emergency in childhood. Appendicitis may present at any age, although it is uncommon in preschool children. Perforated appendicitis is found at approximately one third of appendectomies. Despite advances in improved fluid resuscitation and better antibiotics, appendicitis in children, especially in preschool children, is still associated with significant morbidity.

Although the structure of the appendix was not first described until 1522, by Berengarius Carpus, the constellation of clinical features characteristic of appendicitis has been recognized since antiquity (McCarty 1927). Indeed, many feel that the aphorism by Hippocrates, “Suppuration upon a protracted pain of the parts about the bowels is bad,” refers to appendicitis with abscess formation (McCarty 1927). Early reports of appendicitis were usually based on autopsy findings. In 1736, Amyand reported the first appendectomy for an appendix incarcerated in an inguinal hernia. The first case report describing the postmortem pathological appearances of appendicitis was by Parkinson in 1812; however, it was not until 1886 that Harvard pathologist Reginald Fitz
became the first author to use the term appendicitis, providing an extraordinary description of the signs and symptoms of both acute and perforated appendicitis (McCarty 1927; Livingston et al. 2007). In addition, he appreciated the role of luminal obstruction in the pathogenesis of appendicitis. He stressed the importance of early diagnosis and treatment by laparotomy. Although drainage of an appendiceal abscess had been performed earlier, Thomas G. Morton, in 1887, is credited as having performed the first successful appendectomy for perforated appendicitis (McCarty 1927). In 1889, McBurney published his classical description of typical tenderness in the right lower quadrant and recommended early operation. Although modern antibiotics and intravenous administration of fluids have improved the outcome for children with appendicitis, the basic principles of early diagnosis and appendectomy remain the same as described by McBurney over 100 years ago.

**Etiology and Pathogenesis**

The exact etiology and pathogenesis of appendicitis are poorly understood. While invasion of the appendiceal wall by microorganisms is the ultimate pathological event, the underlying cause for this is unknown and is probably multifactorial. Obstruction of the appendix lumen, by whatever cause, with resulting distension and interference with circulation, is still considered the major factor in the pathogenesis of acute appendicitis. Other factors implicated in the etiology include low intake of dietary fiber, bacterial and viral infections, and genetic factors (Nemeth et al. 2001).

Infections are thought to cause lymphoid hyperplasia leading to obstruction of the appendix lumen and ensuing appendicitis. Andersson et al. (1995) investigated temporospatial clustering and outbreaks (characteristics of infectious diseases) among appendicitis cases and found that appendicitis does occur in space-time clusters and outbreaks, thus supporting an infectious etiology theory (Andersson et al. 1995). The seasonal relationship between appendicitis and other common infections, e.g., influenza, suggests that similar host and nonhost factors may affect their incidence. Gauderer et al. (2001) investigated the relationship between heredity and appendicitis and found that children with appendicitis are at least twice as likely to have a positive family history of appendicitis as those with right lower quadrant pain without appendicitis or controls without abdominal pain (Gauderer et al. 2001).

As stated, luminal obstruction appears to be crucial to the pathogenesis of appendicitis. Both intraluminal and mural causes of obstruction can be considered. One most commonly cited cause of intraluminal obstruction is a fecalith, a small rounded lump of impacted stool, which is thought to occur in the setting of slow intestinal transit (Fig. 1). In a study involving 273 pediatric appendectomies, fecaliths were found in 29.9% of positive appendectomies, 22.2% of negative appendectomies, and 56.1% of cases with perforated appendicitis (Singh and Mariadason 2013). Other intraluminal causes of obstruction to be considered include parasitic infection (e.g.,

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**Epidemiology**

The incidence of acute appendicitis has been reported to vary substantially by country, geographic region, race, sex, and season, but the reasons for these variations are unknown. The lifetime cumulative incidence rate is 9% with children between the ages of 10 and 14 years having the highest rate of appendicitis according to the largest epidemiological study of appendicitis in recent years (Anderson et al. 2012). This study showed the incidence of appendicitis was highest in Caucasians and Hispanics and less common in African Americans and Asians. The incidence of appendicitis is known to vary seasonally, with peak rates occurring in summer months in the Northern Hemisphere from May to July and decreasing thereafter until February. The overall rate of appendicitis has been thought to be decreasing steadily over the past three decades; however, recent evidence suggests the incidence of non-perforated appendicitis has started to rise once more, despite no overall change in the incidence of perforated appendicitis (Livingston et al. 2007).
Enterobius spp.), which can cause luminal obstruction either directly or by inciting lymphoid hyperplasia, and foreign bodies (Feldman et al. 2010). Mural causes of luminal obstruction include neoplasms such as carcinoid tumors, present in ~0.5% of appendectomies, and lymphoid hyperplasia, which may be caused by a wide range of bacterial, viral, fungal, and protozoal infections (Feldman et al. 2010).

**Pathophysiology**

In his landmark paper describing the findings of appendicitis, Fitz proposed that the natural history of appendicitis involved progression from acute appendicitis to perforated disease, although he did note that 1/3 of appendices at autopsy in the pre-appendectomy era displayed evidence of previous inflammation (Livingston et al. 2007). Findings from aforementioned epidemiological studies, as well as studies of appendicitis management in remote environments, have suggested that this natural history does not apply in all cases of appendicitis (Livingston et al. 2007). Tsuji et al. (1993) reported significant perturbation of the local inflammatory response in acute appendicitis (Tsuji et al. 1993). While this was not in itself a surprising observation in the context of an acutely inflamed organ, it was particularly interesting that an abnormal immune response confined to immunocyte infiltration was seen throughout the entire organ in focal appendicitis. Focal appendicitis refers to those appendices that appear normal microscopically and are classified as normal histologically, if only a few sections are examined. However, when extensive sectioning is carried out, a focus of inflammation confined to an area of only a few serial sections is seen. The finding of selective lymphocyte infiltration of the lamina propria throughout the entire appendix in focal appendicitis suggests that focal appendicitis probably represents the earliest recognizable manifestation of acute appendicitis (Tsuji et al. 1993).

Nemeth et al. (2001) demonstrated increased expression of inflammatory markers (COX 1 and 2, PGE$_2$, iNOS, and MHC Class II antigens) in appendices, which were removed for suspected appendicitis, but histologically classified as normal (Nemeth et al. 2001). Their findings support the belief that there is a subgroup of appendicitis within the so-called histologically normal appendices in which evidence of an inflammatory pathologic condition is only obvious at a molecular level.

The entity of neuro-immune appendicitis was suggested by Di Sebastiano et al. in 1999, who observed larger numbers of substance-P immunoreactive and vasoactive intestinal peptide (VIP) immunoreactive nerves in appendectomy specimens from patients with clinical evidence of appendicitis but normal histology compared to normal controls (Di Sebastiano et al. 1999). Given the role of these neuropeptides in inflammatory pain, they hypothesize that an interaction between the nervous and immune systems can be

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**Fig. 1** Transverse computed tomography scan showing rounded opacity (white arrow) at the base of the appendix causing luminal obstruction representing an appendicolith. (Image courtesy of Children’s University Hospital, Dublin 1, Ireland)
Diagnosis

The diagnosis of appendicitis can be challenging in childhood, particularly in those less than 5 years old, where negative appendectomy rates are in the order of 15%. Opportunities for earlier diagnosis can be missed in anywhere from 70% to 100% of cases, depending on age, due to the frequency of atypical presenting features in the pediatric population (Rothrock and Pagane 2000; Becker et al. 2007; Naiditch et al. 2013). A definitive diagnosis at initial assessment occurs in up to 70% of cases, with the remainder being diagnosed after serial assessment (Cavusoglu et al. 2009). A high index of clinical suspicion, careful clinical assessment by an experienced clinician, and judicious use of appropriate investigations are all key factors in achieving a timely diagnosis.

Clinical Features

The patient’s history and clinical examination are the most important tools for the diagnosis of appendicitis. In the classical description of appendicitis, periumbilical pain is often the first symptom, followed by nausea and vomiting. When the inflammation progresses, the pain localizes to the right lower quadrant (RLQ), and right lower quadrant tenderness develops, accompanied by fever. This progression of symptoms occurs in less than 50% of patients (Rothrock and Pagane 2000). Migratory pain from the periumbilical area to the RLQ is associated with a higher likelihood of appendicitis than RLQ pain alone (Bundy et al. 2007). Patients may complain of worsening of pain with activities such as hopping or while traveling over speed bumps on the way to the hospital (cat’s eye symptom). Appendicitis may also frequently be associated with other symptoms such as diarrhea, anorexia, dysuria, and constipation, which can lead to misdiagnosis, especially if some of the aforementioned typical symptoms and examination findings are not present (Becker et al. 2007; Naiditch et al. 2013) (Fig. 2).

Examination findings can vary depending on age group. In those of school-going age, pyrexia (>38°C) is variable in presence, depending on the duration of symptoms, with one study reporting this finding in 64% of children symptomatic for 24–48 h (Rothrock and Pagane 2000). It was found to be the single most useful sign of appendicitis by a systematic review in 2007 (Bundy et al. 2007). Peritonism is an important examination finding in appendicitis. While RLQ tenderness is almost ubiquitous in children found to have appendicitis, it may be more diffuse in those with perforated appendicitis. It is accompanied by guarding in 51–91% of cases, depending on whether or not perforation is present (Rothrock and Pagane 2000). Rebound tenderness increases the likelihood of symptoms being due to appendicitis threefold (Bundy et al. 2007). Percussion tenderness in the RLQ has also been noted to be a specific sign of peritoneal irritation in appendicitis (Rothrock and Pagane 2000).

Other named signs of appendicitis include cough sign, Rovsing’s sign, psoas sign, and obturator sign. Rovsing’s sign is considered positive if
palpation in the left iliac fossa elicits tenderness in the RLQ, although the original description of the sign based on eliciting cecal distension. To test for psoas sign, the patient lies on his/her left side, and the examiner extends the right thigh, stretching the iliopsoas. Eliciting pain at this point implies a positive psoas sign and may suggest retrocecal appendicitis. A similar principle applies to the obturator sign, tested for by checking for pain on passive internal rotation of a flexed right hip. A positive obturator sign is associated with pelvic appendicitis.

Several clinical scoring systems have been devised to serve as clinical decision-making tools (Table 1). To date, none of these have demonstrated sufficient performance to be incorporated into routine clinical practice; however, in general, the Pediatric Appendicitis Score is more accurate than the Alvarado score in predicting the diagnosis of appendicitis (Kulik et al. 2013).

### Appendicitis in Preschool Children

Acute appendicitis in the preschool child accounts for a small fraction of all pediatric admissions with this diagnosis. One series reported children under 5 years of age as accounting for 15.3% of appendectomies over a 12-year period (Bansal et al. 2012). In children under 2 years of age, it represents 1% of all cases of appendicitis in childhood (Puri and O’Donnell 1978). The diagnosis of appendicitis in preschool children can be difficult, resulting in delay and more severe disease. The young child’s inability to communicate adequately with its parents, atypical disease presentation, and other associated illnesses may delay the diagnosis.

Neonatal appendicitis is associated with prematurity in 25–50% of cases and does not share the same typical etiology as appendicitis in older children (Rothrock and Pagane 2000). Some have proposed a similar localized form of the pathological process that occurs in necrotizing enterocolitis (NEC), with impaired immunity and vascular compromise due to hypoxic insult contributing to inflammation and perforation. The rate of perforated appendicitis in this age group is in the order of 80–100%. Neonatal appendicitis presents similarly to NEC with irritability, lethargy, abdominal distension, vomiting, cardiovascular and temperature instability, and palpable mass (Rothrock and

| Table 1 | Summary of the primary clinical scoring systems used to aid decision-making in children with suspected acute appendicitis |
|---------|---------------------------------------------------------------|
| **AIR score** | **Pediatric appendicitis score** | **Alvarado score** |
| Vomiting | 1 | 1 | 1 |
| Anorexia | | | 1 |
| Migratory RLQ pain | | | 1 |
| Pain with cough/hopping/percussion | | | 2 |
| Temperature | | | |
| >38.5 °C | 1 | >38 °C | 1 | >37.5 °C | 1 |
| Rebound tenderness | | | |
| Light | | | |
| Medium | 1 | 2 | 3 | 1 |
| Strong | | | |
| Tender in RIF | | | 2 | 2 |
| Neutrophilia | | | |
| 70–84% | 1 | >75% | 1 | >70% | 1 |
| >85% | 2 | | | |
| WBC count | | | |
| 10–14.9 | 1 | >10 | 1 | >10 | 2 |
| >15 | 2 | | | |
| CRP concentration (mg/mL) | | | |
| 1–4.9 | 1 | <5 Unlikely | 5 | Possible | 6 | Likely | 6 |
| >5 | 2 | | |
| Interpretation | | | |
| 0–4 Low probability | | | |
| 5–8 Indeterminate | | | |
| 9–12 High probability | | | |
| <5 Unlikely | 5 | Possible | 6 | Likely | 6 |
| 0–4 Unlikely | 5–6 Possible | 7–8 Probable | >9 Very probable |
Pagane 2000). It is often only diagnosed at laparotomy or even at autopsy and is associated with mortality rates of 25–35%, although rates of up to 100% have been recorded according to recent evidence (Rothrock and Pagane 2000; Karaman et al. 2003).

Typical features of appendicitis in older preschool children include vomiting, abdominal pain, fever, irritability, and anorexia, although atypical symptoms such as cough, diarrhea, and urinary symptoms are relatively common. Abdominal tenderness tends to be more localized to the RLQ in older preschool children, whereas it can be quite diffused in toddlers (Rothrock and Pagane 2000). Presentation and diagnosis in this age group are frequently delayed, and symptoms can be frequently attributed to conditions that occur far more commonly in preschool children – gastroenteritis, upper respiratory tract infection, otitis media, and intussusception (Rothrock and Pagane 2000; Naiditch et al. 2013). Perforation rates increase with decreasing age, with an overall perforation rate of 56–62% for this group of patients (Mallick 2008; Bansal et al. 2012). This ranges from 49% in those over 4 years to 89% in those under 1 year of age (Bansal et al. 2012). In this age group, perforated appendicitis is associated with a significant burden on morbidity, ranging from surgical site infection, pneumonia, bowel obstruction, incisional hernia, and enterocutaneous fistula (Mallick 2008; Bansal et al. 2012). Bansal et al. (2012) noted that while younger preschool children presented with more advanced appendicitis, their postoperative complication rate was lower than in older children (Bansal et al. 2012). In view of the frequency of atypical presentation and the increased incidence of advanced appendicitis, a high index of suspicion is necessary in preschool children presenting with acute abdominal pain. Early diagnosis is the key to reducing morbidity in the preschool child with appendicitis.

Laboratory Investigations

Laboratory investigations have proved neither sensitive nor specific in the diagnosis of appendicitis. Urinalysis is an essential investigation in children presenting with abdominal pain, although it must be borne in mind that pyuria or microscopic hematuria may be present in 7–25% of children with appendicitis (Rothrock and Pagane 2000). White cell count is probably the most widely available laboratory investigation utilized in the diagnosis of appendicitis. It can be raised in 70% of patients who have RLQ pain that is not due to appendicitis, and multiple studies have found it to be of limited utility in the diagnosis of appendicitis (Yu et al. 2013). C-reactive protein is synthesized in the liver in response to inflammatory conditions. Its diagnostic accuracy is highest in appendicitis complicated by perforation or abscess; its sensitivity in early appendicitis is poor, inferior to that of white cell count. Much attention has recently been given to procalcitonin, a precursor of calcitonin, as a promising marker of bacterial infection. While its diagnostic accuracy in diagnosing appendicitis is lower than that with C-reactive protein or white cell count, it is useful as a marker of severity of appendicitis (Yu et al. 2013). Several studies have also identified interleukin-6 as a useful marker of disease severity, with moderate diagnostic accuracy for appendicitis, similar to C-reactive protein (Sack et al. 2006). Despite these advances, most authors agree that normal inflammatory markers cannot exclude a diagnosis of appendicitis in a child presenting with RLQ pain.

Radiological Investigations

In many cases, the diagnosis of appendicitis can be reliably made without the use of laboratory or radiological investigations; however, their use in selected patients can serve to reduce the rate of negative appendectomy or clarify appendicitis severity and suitability for early or interval appendectomy. Plain radiography of the abdomen, which exposes the patient to the equivalent radiation dose of 35–50 chest x-rays, may demonstrate a radio-opaque appendicolith in 7–15% (Environment 2000; Weissleder et al. 2007) (Fig. 3). Despite its relatively frequent utilization in the work-up of children with acute abdominal pain,
its diagnostic value for appendicitis has been questioned by numerous studies, which have shown it to be neither sensitive nor specific, and sometimes misleading (Rao et al. 1999). Its use is therefore not recommended in the routine evaluation of children with suspected appendicitis, unless there is suspicion of bowel obstruction or an alternative diagnosis of urolithiasis based on clinical features. Contrast enemas are no longer seen to be of clinical value due to poor sensitivity and specificity.

Ultrasound is portable, fast, of modest incremental cost, useful in delineating gynecologic disease, and free of irradiation exposure. It is, however, highly operator-dependent. The appendix can be identified on ultrasound in approximately 24% of patients, although this rate is higher with dedicated pediatric sonographers (Fig. 4). Typical findings suggestive of appendicitis on ultrasound include a non-compressible appendix with appendiceal maximal outer diameter >6 mm enlargement, appendiceal wall thickness >3 mm, echogenic edematous mesenteric fat stranding, hypoechoic peri-appendiceal halo with associated wall edema, wall hyperemia on color Doppler, and the presence of an appendicolith (Goldin et al. 2011) (Fig. 5). A multivariate analysis carried out by Trout et al. (2012) found inflammation of the peri-appendiceal fat to be the only significant
independent predictor of appendicitis (Trout et al. 2012). A meta-analysis of the performance of ultrasound in children with appendicitis demonstrated a sensitivity and specificity of 88% and 94%, respectively (Doria et al. 2006). In a series of 2763 patients, Park et al. (2013) report positive and negative predictive values of 96.5% and 97.7%, respectively (Park et al. 2013). Many authors are now recommending ultrasound as a preferable first-line investigation to computed tomography (CT) in children, given the advantages discussed above, with the exception of obese children, in whom ultrasound detection rates are reduced (Park et al. 2013).

There has been a dramatic increase in the use of cross-sectional imaging with CT in the evaluation of children with abdominal pain over the past 10–15 years. The principal advantages of CT are its operator independency and enhanced delineation of disease extent in perforated appendicitis (Fig. 6). It has established itself as a highly sensitive and specific imaging modality in the diagnosis of appendicitis, with studies quoting sensitivity and specificity in the order of 96% and 97%, respectively, and positive and negative predictive values of up to 100% and 100%, respectively (Toorenvliet et al. 2010). These findings seem to be independent of body mass index, a major advantage over ultrasound. However, the radiation dose associated with nonselective CT of the abdomen or pelvis is equivalent to approximately 500 chest x-rays (Environment 2000). The risk of radiation-induced cancer in a 5-year-old who has a CT abdomen is 26.1 per 100,000 in girls and 20.4 per 100,000 in boys (Doria 2009). This has led to efforts on the part of many institutions to try and limit the use of CT in the evaluation of abdominal pain, where appendicitis is suspected, to a more selected population in whom clinical, laboratory, and sonographical findings are equivocal. Some centers have employed the use of a risk stratification protocol to aid in better patient selection for CT, mindful that careful history and examination by an experienced surgeon can have comparable diagnostic accuracy.

In patients with an uncertain diagnosis of acute abdominal pain, a policy of active observation in hospital is usually practiced (Surana et al. 1995). A repeated structured clinical examination is simple and noninvasive. However, the argument against this policy is that it may lead to a delay in specific management of these patients and may result in a high incidence of perforation. Conversely, numerous studies have found that active observation is not associated with higher rates of complicated appendicitis or morbidity and in many cases it improves accuracy of diagnosis.
An appendicectomy is currently considered the gold standard treatment for acute appendicitis. Recently, the need for surgery has been challenged both in adults and children. Several studies have recently reported that the non-operative treatment of uncomplicated appendicitis in children is safe and that this modality of treatment is gaining ground around the world (Knaapen et al. 2019). A number of multicenter randomized trials comparing non-operative treatment with appendicectomy for acute uncomplicated appendicitis are currently ongoing and should provide, in the near future, evidence regarding the potential of this treatment modality (Hutchings et al. 2018; Hall et al. 2017).

Preoperative Management

Once a child has been diagnosed with appendicitis, the principles of management are broadly similar, irrespective of disease severity. Opioid or non-opioid analgesia has been shown to be effective in reducing the pain associated with appendicitis, without obscuring clinical findings that allow a diagnosis of appendicitis to be made (Friday 2006). Intravenous fluid resuscitation is almost always indicated due to vomiting, poor oral intake, and increased insensible losses due to pyrexia. Resuscitation is guided by the degree of sepsis and dehydration on assessment. Broad-spectrum intravenous antibiotics therapy should be commenced at the time of diagnosis, with the choice of agent(s) determined by local antibiotic susceptibility patterns and hospital-specific antimicrobial usage guidelines. Antibiotic coverage should take account of the common organisms isolated from peritoneal swabs and be directed against gram-negative bacteria, anaerobes, and skin flora. Expeditious surgical treatment within 6–24 h has been traditionally accepted as the standard operative management for non-phlegmatous appendicitis. However, there is a mounting body of evidence suggesting that conservative management of appendicitis with antibiotics, with or without an interval appendectomy, may be an acceptable alternative to this approach.

Operative Technique

Open Appendectomy

McBurney described a muscle-splitting incision over what came to be known as McBurney’s point in 1893; this landmark lies at a point 2/3 of the way along a line from the umbilicus to the anterior superior iliac spine. The use of McBurney’s point as the anatomical landmark for this incision is based on the assumption that the base of the appendix lies below this point in the majority of patients. This incision has in recent times been largely superseded in children by the Lanz incision, an RLQ transverse skin crease incision, which, while still centered on McBurney’s point,
runs along Langer’s lines and gives a more cosmetically acceptable result. Anthropometric studies carried out by Karim et al. (1990) demonstrated the appendix to lie inferior to the interspinous line and McBurney’s point in 70% of patients, and in practice the Lanz incision may be modified to be higher or lower depending on surgeon preference (Karim et al. 1990). Dissection should proceed with splitting of the muscular layers in the direction of their fibers. On opening the peritoneum, a sample of peritoneal fluid can be taken for culture. While this may help direct postoperative antibiotic therapy in a small number of patients, the majority will receive adequate coverage from a standard broad-spectrum antimicrobial regimen. The mesoappendix is divided and the appendiceal base clamped and ligated. Inversion of the stump is a controversial practice. Best clinical evidence available presently suggests no benefit over simple ligation regarding rates of postoperative surgical site infection and the potential for distortion of cecal anatomy leading to the false impression of a cecal tumor on future radiological studies (D’Souza 2011). Any free pus should be suctioned and irrigation with saline may be performed. The abdominal wall is closed in layers. The skin is usually closed by subcuticular absorbable sutures even in the cases complicated by perforation. Primary wound closure after perforated appendicitis is safe, economical, and advantageous in pediatric practice (Henry and Moss 2005). The placement of peritoneal drains in children, even in complicated perforated appendicitis, is not recommended (Tander et al. 2003).

Laparoscopic Appendectomy
While it is almost 30 years since the first laparoscopic appendectomy was described, it is only in the last decade that its use has become commonplace, in some places superseding the open approach. A standard three-port laparoscopic appendectomy begins with insertion of an infraumbilical port. Access for this port should be gained using an open Hasson’s technique rather than a percutaneous technique. Following attainment of carbon dioxide pneumoperitoneum, two 5 mm infraumbilical incisions are placed under direct vision, either on each side of the midline or in the left iliac fossa and suprapubic regions. An additional RLQ incision is optional. After mobilization of the appendix, the mesoappendix is divided. The appendiceal stump is ligated with endo loops or an endoscopic stapler, and the appendix is excised and removed, either in an endoscopic bag or, if the appendix is thin, directly through a 10 mm port. Suction with or without saline irrigation is carried out as per open surgery. Evacuate all carbon dioxide to minimize referred shoulder tip pain. Closure of the fascia should certainly take place in all 10 mm ports, with many surgeons also electing to close the fascia in 5 mm ports in order to reduce the risk of port-site hernia. Skin closure can be with subcuticular sutures or adhesive skin glue. Infiltration of port site wounds with local anesthetic for postoperative analgesia is simple and efficacious (Fig. 7).

Single-port laparoscopic appendectomy is evolving as an alternative to the traditional three-port procedure. Broadly speaking, two approaches have been described – an extracorporeal approach and an intracorporeal approach (Ponsky and Krpata 2011). In the former a single umbilical port is used to exteriorize the appendix for appendectomy. There have been concerns that this may be associated with an increased risk of wound infection. In an intracorporeal approach, a multi-trochar port, or three separate trochars, are placed in the umbilicus, and the appendix is retracted using a transcutaneous stitch allowing dissection to take place (Ponsky and Krpata 2011). When compared to conventional laparoscopic surgery, single-port appendectomy is associated with longer operating time and increased perioperative narcotic usage (Li et al. 2013). It remains to be seen if the cosmetic advantages of this approach will lead to its use becoming more widespread with time.

Laparoscopic Versus Open Appendectomy
The role of laparoscopic surgery in the management of appendicitis in children has become more defined in recent times due to increasing numbers of large studies and meta-analyses addressing this
topic. In the main, laparoscopic appendectomy appears to be associated with less postoperative ileus, lower analgesic requirements, faster return to diet and normal activity, and shorter hospital stay than open surgery (Aziz et al. 2006; Sauerland et al. 2010). Operating times appear to be similar for uncomplicated appendicitis but longer with laparoscopy for complicated appendicitis. Although the incidence of wound infection appears to be lower with laparoscopic appendectomy, there is concern that it is associated with an increased risk of postoperative abscess formation (Sauerland et al. 2010). Laparoscopic surgery appears to be particularly advantageous in obese patients (Kutasy et al. 2011). Conversion from laparoscopic to open appendectomy occurs in approximately 0–25.9% but in general is less than 10% (Aziz et al. 2006). Where appropriately trained surgical staff and equipment are available, laparoscopic appendectomy has several advantages over open appendectomy indicating its preferential use (Sauerland et al. 2010).

Complicated Appendicitis

Perforated Appendicitis
The reported incidence of perforated appendicitis in children varies greatly depending on age, but recent large studies have reported the incidence to be approximately 30% (Anderson et al. 2012). The incidence is much higher in preschool children, with over one half of the children in this age group having perforated appendicitis (Mallick 2008). Mortality from perforated appendicitis is vanishingly uncommon, with better evidence advancing the management of postoperative complications in recent times. Antibiotics have a proven role in preventing postoperative wound infection and intra-abdominal abscess in acute appendicitis. There is still some disagreement about the duration of antibiotic therapy and which drugs to use. In those who have undergone appendectomy, the duration of intravenous antibiotic treatment should be determined by clinical criteria. A minimum course of 3 days may be effective, but 5 days of treatment is probably a more common regimen, with completion of a 7-day course using oral antibiotics being recommended. This approach is both efficacious and economical. As previously stated, even in cases of complicated appendicitis, the placement of a peritoneal drain is not recommended (Tander et al. 2003).

Laparoscopic appendectomy for perforated appendicitis compares well with open surgery, albeit with longer operating times and potentially higher rates of postoperative abscess (Aziz et al. 2006). Intraoperative irrigation of the peritoneal cavity, with or without antibiotics, was previously routinely practiced in children with perforated appendicitis. However, whether this adds any benefit regarding postoperative infection has yet to be demonstrated in high-quality studies. The placement of a peritoneal drain following perforated appendicitis has not been shown to improve

Fig. 7 Typical appearance of uncomplicated acute appendicitis seen at laparoscopy. It appears hypervascular, and there is fibrin peel seen following mobilization of the appendix from omentum.
outcome, with no reduction in the duration of hospitalization or nasogastric drainage time, and is therefore not advocated (Tander et al. 2003).

One area of continuing contention is the role of delayed operative management for perforated appendicitis. Compared with those in whom appendicitis has been complicated by phlegmon formation, successful initial non-operative management may be less likely in perforated appendicitis, with concern regarding the high risk of representation with recurrent appendicitis prior to planned interval surgery, with approximately one third having surgery earlier than originally planned. While some feel that an initial non-operative approach to care may have some merit in those with a long (>5 days) history of symptoms prior to presentation, a review of the literature on this topic has concluded that, despite lower complication rates, there is no evidence to support non-operative management of perforated appendicitis in children (Svensson et al. 2012). However, where perforated appendicitis is associated with abscess formation, there may be a role for initial percutaneous drainage as source control, followed by interval appendectomy, as it shortens operating time compared to immediate appendectomy (Fig. 8).

Appendix Mass
Appendicitis that is localized by edematous, adherent omentum and loops of small bowel results in an appendix mass. While appendiceal abscess formation can occur at any time in the course of appendicitis, it may also complicate an appendiceal mass. Clinically, it is not possible in most cases to distinguish with certainty between the two conditions. The incidence is higher during the first 3 years of life, when one third of the patients with appendicitis have been reported to present with an appendiceal mass (Puri et al. 1981). Abdominal examination under anesthesia prior to appendectomy is vital as many appendix masses are only discovered at this point. The management of an appendiceal mass in children is controversial, with evidence in support of both early appendectomy and non-operative management with antibiotics followed by interval appendectomy available in equal measure. The controversy over conservative management of appendiceal masses has arisen mainly from the belief that children, and particularly infants, have a poor ability to localize intraperitoneal inflammatory processes, and so children with an appendiceal mass should be managed operatively. Nonetheless the aforementioned high rate of mass formation in infants is evidence that the ability to localize appendiceal inflammation is present even in toddlers.

A suggested regimen for conservative management includes close clinical observation for deterioration, broad-spectrum parenteral antibiotic coverage with 2–3 agents, oral fluids, and diet as tolerated, with planned interval appendectomy, usually laparoscopic, in 4–6 weeks from hospital discharge. Progression to oral antibiotics depends on improvement of clinical parameters, and successful management is determined by the resolution of abdominal pain and the presence of normal

**Fig. 8** Transverse computed tomography imaging demonstrating a complex pelvic abscess in a girl with a 10-day history of abdominal pain and a diagnosis of appendicitis. Collections of this extent are ideal for percutaneous or transrectal radiologically guided drainage. (Image courtesy of Children’s University Hospital, Dublin 1, Ireland)
heart rate and temperature for 48 h (Gillick et al. 2001). Failure rates of non-operative management are generally reported to be in the order of 10–15% (Puri et al. 1981; Gillick et al. 2001). The increased technical difficulty and operating time with early appendectomy in this population, especially when performed laparoscopically, is widely acknowledged. While this approach is gaining favor in adult surgery, supporting evidence in the pediatric population is slow to accumulate. Most surgeons continue to practice initial non-operative management and interval appendectomy for the pediatric population, finding it to be associated with a low complication rate, faster return to diet postoperatively, and surgical advantages regarding ease of dissection and adhesiolysis, although does require two hospital admissions (Puri et al. 1981; Gillick et al. 2001). Some would argue that surgery is not required at all after successful non-operative treatment of an appendix mass given the low incidence of recurrent appendicitis in this setting and that an approach of “watchful waiting” can be encouraged. This approach may not be appropriate in cases where an appendicolith has been identified, and many would also argue that appendectomy also eliminates the possibility of missed pathology such as neoplasm and inflammatory bowel disease.

Complications and Outcomes

Advances in perioperative care and antibiotics have resulted in mortality rates that approach zero and low morbidity in children with appendicitis. The long-term outcome of the vast majority of patients who undergo appendectomy in childhood is very good. A small number of patients may develop early complications due to surgical site infection or stump appendicitis, or late complications, the most common of which is adhesive intestinal obstruction. More controversial putative outcomes such as adulthood infertility in girls who have previously had perforated appendicitis, inguinal hernia, and chronic pain are worthy of attention.

Postoperative Intra-abdominal Abscess

Intra-abdominal abscess formation after appendectomy prolongs hospital stay and duration of antibiotic therapy and healthcare costs. The incidence of postoperative intra-abdominal abscess is approximately 3.4% following open appendectomy and 3.8% following laparoscopic appendectomy (Aziz et al. 2006). Complicated appendicitis is generally considered to be associated with a higher risk of abscess formation. Occasionally retained fecaliths may form a nidus for abscess formation.

Typical findings in those with intra-abdominal abscess include undulating pyrexia, increasing abdominal or pelvic pain, diarrhea or irritative voiding symptoms, and persistent raised inflammatory markers, all of which may be resistant to antibiotic therapy. Imaging with ultrasound and with or without cross-sectional imaging using computed tomography (CT) is invaluable, not just as a means of confirming diagnosis but also in helping to plan management. Nonetheless, routine postoperative imaging of asymptomatic patients with complicated appendicitis is unlikely to provide any clinically detectable benefit.

Conservative treatment with broad-spectrum antibiotics alone is frequently all that is required depending on size, location, and the degree of sepsis. Radiologically guided percutaneous drain insertion, with ultrasound or CT, carried out transabdominally or transrectally, can provide excellent source control in those who have failed medical management, except where a retained appendicolith is forming the focus for infection. Surgical management is rarely indicated for post-appendectomy abscess and generally only takes place in situations where medical management has failed and a collection is present that is not amenable to percutaneous drainage. Laparoscopic abscess drainage is safe and effective and allows
excellent access to the whole peritoneum. Thus, it may be preferable to open drainage.

**Intestinal Obstruction**

Intestinal obstruction requiring surgery has been reported in approximately 0.7% of patients following appendectomy and is more common in those who have perforated appendicitis and in those who undergo open appendectomy (Tsao et al. 2007). The cause of increased adhesions after perforated appendicitis is evident as peritonitis induces adhesions although adhesive intestinal obstruction can occur even after removing a normal appendix. Most cases of intestinal obstruction occur in the early period after appendectomy, although late presentations are not uncommon.

Laparoscopic appendectomy appears to be associated with a lower incidence of adhesive small bowel obstruction compared to open appendectomy (Tsao et al. 2007). Band adhesions are frequently the cause of mechanical obstruction after appendectomy. This is often associated with a higher rate of failure of non-operative management.

**Stump Appendicitis**

Complications related to the appendix stump after appendectomy are thankfully rare. Stump appendicitis, also frequently referred to as recurrent appendicitis, has a similar pathogenesis and clinical course as traditional appendicitis. It has been reported after both laparoscopic and open appendectomies, and can occur up to 50 years after the initial surgery (Kanona et al. 2012). One of the key factors predisposing patients to this complication is an excessively long appendix stump left behind at appendectomy, often greater than 3 cm in length, although this problem has been described in a stump of 0.8 cm in length (Kanona et al. 2012). Excision of excess residual stump with or without purse-string invagination of the remaining stump appears to be an effective operative management. Of note the appendix stump can also become a lead point for intussusception or a site of malignancy or mucocele formation in later life.

**Nerve Entrapment After Appendectomy**

Neuralgia, usually as a result of entrapment of the ilioinguinal nerve, and less commonly the iliohypogastric nerve, is a rarely reported complication of appendectomy (Rauchwerger et al. 2008). These patients have the classic triad of the entrapment syndrome – pain accurately localized near the incision; objective sensory impairment in the appropriate area of the skin; and temporary relief by injection of local anesthetic agents. The symptoms may arise immediately after operation or several years later, implying that the nerve may be involved either directly by a suture or indirectly by pressure from mature scar tissue. Non-operative management with neuromodulators and nerve blocks is commonly employed, with a proportion of these patients going on to have neural stimulators or surgical management with neurectomy (Rauchwerger et al. 2008).

**Appendectomy and Subsequent Development of Right Inguinal Hernia**

Historically there has been a suggestion that appendectomy was associated with a higher incidence of subsequent right inguinal hernia. The cause of the right-sided inguinal hernia is thought to be damage to the nerve supply of the inguinal muscles during appendectomy. Malazgirt et al. (1992) investigated the effect of appendectomy on the subsequent development of right inguinal hernia in 583 patients. They found that the incidence of right inguinal hernia was no greater in patients who had previously undergone appendectomy compared with those who had not had their appendices removed (Malazgirt et al. 1992).
**Perforated Appendicitis and Subsequent Fertility in Girls**

The view that perforated appendicitis in girls is associated with an increased risk of tubal infertility is long-held and has been the basis for a more liberal attitude to surgical intervention in young females with suspected appendicitis. However, there is no convincing evidence base for this practice. Most early studies that examined the frequency of infertility in women who had undergone appendectomy for perforated appendix in adult life were based on a small number of cases, lacked detailed investigations of infertility, or had flawed methodology.

It is possible that in women who have borne children, there may have been damage to the right fallopian tube owing to its proximity to the appendix. However, the left tube in such cases may function normally—a situation that arises in cases of ectopic pregnancy in which salpingectomy has previously been carried out—and the other tube retains its normal physiological function. These data indicate that perforated appendicitis before puberty has little, if any role in the etiology of tubal infertility.

Several authors have compared fertility rates of those who have undergone appendectomy in childhood versus those who did not. None have demonstrated an association between subsequent tubal infertility and uncomplicated or perforated appendicitis (Puri et al. 1989). Those women who underwent appendectomy for perforated appendicitis and who subsequently had difficulty conceiving in these studies predominantly had alternative causes documented for subfertility, such as pelvic inflammatory disease, endocrine disorders, or partner subfertility. Thus, there is no quality or convincing evidence base for an association between perforated appendicitis and infertility in later life.

**Inflammatory Bowel Disease**

The etiology and pathogenesis of ulcerative colitis (UC) and Crohn’s disease (CD) are not known. Recent studies have suggested a link between appendectomy and the subsequent risk of developing an inflammatory bowel disease (Andersson et al. 2001). In a large cohort study of 212,963 patients who underwent appendectomy before the age of 50 years, Andersson et al. (2001) found that patients who had an appendectomy for an inflammatory condition (appendicitis or lymphadenitis) had a lower risk of subsequent UC (Andersson et al. 2001). This inverse relation was limited to patients who had surgery before the age of 20 years. In contrast to this, an increased risk of CD was found in patients who had an appendectomy at the age of 20 years and over (Andersson et al. 2003). Crohn’s disease patients with a history of perforated appendicitis generally had a worse prognosis. Recent evidence suggests that the increased risk of CD after appendectomy is transient and probably due to diagnostic bias (Kaplan et al. 2007). Further studies of the associations of inflammatory bowel disease and appendicitis are therefore warranted because such studies may give clues to the etiology and pathogenesis of both disease processes.

**Medicolegal Aspects**

**Missed Appendicitis**

Missed appendicitis remains a high-risk area in professional liability. The failure to diagnose appendicitis is routinely listed among important reasons for a malpractice suit to be brought to the accident and emergency physician. Diagnosing appendicitis accurately and early is therefore very important. One recurring feature of malpractice cases is the failure of the physician to re-examine patients within a reasonable timeframe, thus leading to delayed diagnosis.

Although classic symptoms are present in the majority of patients with appendicitis, atypical symptoms are not uncommon, especially in preschool children with appendicitis as previously alluded to. In one study 44% of children had six or more atypical features of appendicitis (Becker et al. 2007). In view of the atypical presentation and increased incidence of advanced appendicitis and morbidity, a high index of suspicion is
necessary in preschool children presenting with acute abdominal pain.

**Other Causes of Litigation Related to Appendicitis**

Despite the evidence presented above, putative damage to fertility continues to be a leading cause of successful litigation due to delayed diagnosis or treatment. Delayed re-intervention for complications such as postoperative abscess and iatrogenic injuries such as vascular injury secondary to port-site puncture are also quoted as factors in litigation.

**Conclusion and Future Directions**

Early recognition of the symptoms and signs of acute appendicitis can lead to expeditious treatment and lower rates of perforation and lower morbidity. Only about half of children with appendicitis present with the classic collection of symptoms and signs. Knowledge of the various atypical features that can manifest in children with appendicitis should allow the clinician to maintain an appropriately high index of suspicion for appendicitis when evaluating a child with abdominal pain. While recently evaluated biomarkers for appendicitis such as pro-calcitonin and interleukin-6 have been shown to be predictive of complicated appendicitis, there are, as of yet, no markers of early appendicitis that are sufficiently sensitive or specific to be of clinical use. In cases where the diagnosis is in doubt on clinical grounds, ultrasound appears to be a low-radiation, accurate diagnostic modality, with computed tomography being preserved for selected cases, such as the very obese. As experience with laparoscopic appendectomy becomes more widespread, it is becoming the operative treatment of choice, although open appendectomy still has a role, especially in the treatment of complicated appendicitis. It remains to be seen if the cosmetic benefits of single-port laparoscopic appendectomy will sufficiently outweigh its shortcomings to lead to its widespread adoption. Similarly, high-quality studies are required to determine if there is a role for non-operative treatment in the management of uncomplicated appendicitis in children.

**Cross-References**

- Crohn’s Disease Essay
- Fluids and Electrolyte Balance in Infants and Children
- Innovations in Minimal Invasive Surgery
- Principles of Minimal Invasive Surgery
- Principles of Pediatric Surgical Imaging Essay

**References**

Anderson JE, Bickler SW, Chang DC, Talamin MA. Examining a common disease with unknown etiology: trends in epidemiology and surgical management of appendicitis in California, 1995–2009. World J Surg. 2012;36:2787–94.

Andersson R, Hugander A, Thulin A, Nystrom PO, Olaison G. Clusters of acute appendicitis: further evidence for an infectious aetiology. Int J Epidemiol. 1995;24:829–33.

Andersson RE, Olaison G, Tysk C, Ekbom A. Appendectomy and protection against ulcerative colitis. N Engl J Med. 2001;344:808–14.

Andersson RE, Olaison G, Tysk C, Ekbom A. Appendectomy is followed by increased risk of Crohn’s disease. Gastroenterology. 2003;124:40–6.

Aziz O, Athanasiou T, Tekkis PP, Purkayastha S, Haddow J, Malinovski V, et al. Laparoscopic versus open appendectomy in children: a meta-analysis. Ann Surg. 2006;243:17–27.

Bansal S, Baneever GT, Karrer FM, Partrick DA. Appendicitis in children less than 5 years old: influence of age on presentation and outcome. Am J Surg. 2012;204:1031–5; discussion 5.

Becker T, Kharbanda A, Bachur R. Atypical clinical features of pediatric appendicitis. Acad Emerg Med. 2007;14:124–9.

Bundy DG, Byerley JS, Liles EA, Perrin EM, Katznelson J, Rice HE. Does this child have appendicitis? JAMA. 2007;298:438–51.

Cavusoglu YH, Erdogan D, Karaman A, Aslan MK, Karaman I, Tutun OC. Do not rush into operating and just observe actively if you are not sure about the diagnosis of appendicitis. Pediatr Surg Int. 2009;25:277–82.

D’Souza N. Appendicitis. BMJ Clin Evid (Online). 2011;2011:0408.
Rothrock SG, Pagane J. Acute appendicitis in children: emergency department diagnosis and management. Ann Emerg Med. 2000;36:39–51.
Sack U, Biereder B, Elouahidi T, Bauer K, Keller T, Trobs RB. Diagnostic value of blood inflammatory markers for detection of acute appendicitis in children. BMC Surg. 2006;6:15.
Sauerland S, Jaschinski T, Neugebauer EA. Laparoscopic versus open surgery for suspected appendicitis. Cochrane Database Syst Rev. 2010;(11):CD001546.
Singh JP, Mariadason JG. Role of the faecolith in modern-day appendicitis. Ann R Coll Surg Engl. 2013;95:48–51.
Surana R, O'Donnell B, Puri P. Appendicitis diagnosed following active observation does not increase morbidity in children. Pediatr Surg Int. 1995;10:76–8.
Svensson JF, Hall NJ, Eaton S, Pierro A, Wester T. A review of conservative treatment of acute appendicitis. Eur J Pediatr Surg. 2012;22:185–94.
Tander B, Pektas O, Bulut M. The utility of peritoneal drains in children with uncomplicated perforated appendicitis. Pediatr Surg Int. 2003;19:548–50.
Toorenvliet BR, Wiersma F, Bakker RF, Merkus JW, Breslau PJ, Hamming JF. Routine ultrasound and limited computed tomography for the diagnosis of acute appendicitis. World J Surg. 2010;34:2278–85.
Trout AT, Sanchez R, Ladino-Torres MF. Reevaluating the sonographic criteria for acute appendicitis in children: a review of the literature and a retrospective analysis of 246 cases. Acad Radiol. 2012;19:1382–94.
Tsao KJ, St Peter SD, Valusek PA, Keckler SJ, Sharp S, Holcomb GW 3rd, et al. Adhesive small bowel obstruction after appendectomy in children: comparison between the laparoscopic and open approach. J Pediatr Surg. 2007;42:939–42; discussion 42.
Tsui M, Puri P, Reen DJ. Characterisation of the local inflammatory response in appendicitis. J Pediatr Gastroenterol Nutr. 1993;16:43–8.
Weissleder R, Wittenberg S, Harisinghani MG, Chen JW. Primer of diagnostic imaging. 4th ed. Philadelphia: Mosby Elsevier; 2007.
Yu CW, Juan LI, Wu MH, Shen CJ, Wu JY, Lee CC. Systematic review and meta-analysis of the diagnostic accuracy of procalcitonin, C-reactive protein and white blood cell count for suspected acute appendicitis. Br J Surg. 2013;100:322–9.