19 Appendicitis in Adults and Children: Evidence-Based Emergency Imaging

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Key Points

- CT demonstrates superior sensitivity and specificity for appendicitis compared to ultrasound in the adult population, with less variability, and is the imaging modality of choice in nonpregnant patients (strong evidence).
- MRI shows similar specificity and sensitivity to CT for the diagnosis of acute appendicitis in the nonpregnant adult and pediatric population (moderate evidence).
- In the pediatric population, CT has higher sensitivity than ultrasound, but similar specificity, with a trade-off of exposure to ionizing radiation (strong evidence).
- Limiting exposure to ionizing radiation warrants the use of US followed by CT for negative or equivocal cases in (nonobese) pediatric patients (moderate evidence). The presence of an elevated absolute neutrophil count, nausea, or maximal tenderness in the right lower quadrant shows high sensitivity, but poor specificity in identifying pediatric patients with appendicitis (moderate evidence). Thus, these patients may benefit from imaging.
- Intravenous contrast enhanced CT is adequate for the diagnosis of acute appendicitis and obviates the need for enteral contrast (moderate evidence).
- There has been a decrease in the rate of negative appendectomy with use of preoperative imaging (moderate evidence).
- MRI is useful in pregnant women with suspected appendicitis, particularly beyond the first trimester (moderate evidence).

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Definition and Pathophysiology

Appendicitis, defined as inflammation of the vermiform appendix, is a prevalent disease whose etiology is not entirely understood [1, 2]. The common mechanism begins with obstruction, either by fecalith or lymphoid hyperplasia, with progressive increase in intraluminal pressure leading to compromised venous outflow, mucosal wall

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breakdown, and bacterial overgrowth [2, 3]. The most common pathogens involved are *Escherichia Coli* and *Bacteroides fragilis* [1]. Wall ischemia can lead to hemorrhagic ulceration and gangrenous necrosis extending to the serosa that can lead to perforation [3]. Demonstrable obstruction is commonly absent in appendicitis on imaging and likewise, visible obstruction does not necessarily imply an acute infection [1, 4]. Delayed diagnosis can result in serious complications leading to abscess formation, peritonitis, wound infection, sepsis, infertility, adhesions, bowel obstruction, and rarely death with a mortality rate of 0.08%, increasing to 0.5% when perforated [1, 5, 6].

Epidemiology

Acute appendicitis is a common condition, with an estimated lifetime incidence of 8.6% in males and 6.7% in females and a male to female ratio of 1.1 to 1 [7]. Appendicitis is most common between the ages of 10 and 19 years with more recent epidemiological studies confirming this but showing an increase within the 30- to 69-year-old range secondary to aging demographics [7, 8]. Acute appendicitis is the most common reason for abdominal surgery in pediatric patients [5, 9], with 70,000–100,000 pediatric cases each year, and is diagnosed in 1–8% of children presenting with abdominal pain to the emergency department [9, 10]. Appendiceal rupture is most common in the pediatric and elderly populations with an overall rate of 10–35.5% and increases in likelihood with prolonged symptoms [11, 12].

Overall Cost to Society

Comprehensive societal cost data for patients with suspected acute appendicitis is lacking. An analysis of the Nationwide Inpatient Sample of the Health Care Utilization Project estimated that there were 292,297 hospitalizations in 2010 due to suspected acute appendicitis [13]. Recent data from the CDC estimated approximately 264,882 appendectomies in 2012 [14]. These admissions accrued an average hospital charge of between $9206 and $10,584 per case, yielding an estimated national total of $2.44 to $2.76 billion dollars in hospital charges alone [14, 15]. Flum and Koepsell estimated the national cost of negative appendectomy at $741.5 million dollars [15].

For pediatric patients, appendectomy is the most common surgical procedure performed in the hospital for non-neonatal- or nonpregnancy-related conditions [13]. Nationwide, an average of 238 pediatric appendectomies are performed daily. Annually, appendicitis accounts for approximately 87,000 pediatric hospital stays in the USA, representing 4.2% of all hospital stays for pediatric illness [13]. Appendicitis is the second most common reason for hospitalization for children and adolescents 6–17 years old. The aggregate total charges related to care of pediatric patients with appendicitis nationwide sum to over $800 million annually [13]. At an institutional level, a retrospective chart review by Garcia Pena et al. showed that 308 pediatric patients who were observed for possible appendicitis collectively accumulated 487 inpatient observation days, with per patient cost of $5831 [16].

Goals of Imaging

Imaging goals for suspected acute appendicitis are to determine if the patient has appendicitis, aid in earlier diagnosis, and identify complications, such as perforation or abscess, which may alter surgical management.

Methodology

Previously, data were primarily obtained from the meta-analyses of Terasawa [17] and Doria [18] and their colleagues. This edition adds the meta-analysis and sensitivity analysis by Parker et al. [19], a reanalysis of the prospective work performed by Mittal et al. [20], and a systematic review of the role of MRI in children [21]. These studies were identified via an updated PubMed search of English language articles through May 2015 using a combination of MeSH and free terms *appendicitis* or *appendix* and *diagnostic imaging*, *ultrasonography*, *X-ray computed tomography*, *CT*, and *magnetic resonance imaging* or *MRI*. The bibliographies of relevant articles were searched for other potentially relevant articles. Studies were included if they were either prospective or retrospective evaluations of CT, graded compression ultrasound, or MRI with outcomes measured by surgical, pathological, or clinical follow-up.

Discussion of Issues

What Is the Accuracy of Imaging for Diagnosing Acute Appendicitis in Adults?

Summary of Evidence

- Computed tomography examination of adult patients has high sensitivity and specificity for acute appendicitis and is superior to graded compression ultrasound (moderate evidence).
- MRI has high sensitivity and specificity for diagnosis of appendicitis and is superior to graded compression ultrasound but less available (limited evidence).
- MRI appears to have moderately high diagnostic accuracy for appendicitis in pregnant patients after equivocal US (moderate evidence).

Supporting Evidence The meta-analysis by Parker et al. evaluated 74 studies published between 1999 and 2009 with data on appendicitis evaluating CT, US, or both for diagnosis [19]. Articles were included if sensitivity, specificity, NPV, and PPV were reported or calculable. Evaluation with US includes 8483 patients demonstrating a combined sensitivity of 87.5% (95% CI, 86.5–88.5%), a combined specificity of 92.7% (95% CI, 92.0–93.4%), a PPV of 91% (range 90.3–91.7), and a NPV of 89.8% (range 89.2–90.4). For the CT evaluation of appendicitis, there were 11,930 patients included demonstrating a combined sensitivity of 93.4% (95% CI, 92.7–94.1%), a combined specificity of 95.3% (95% CI, 94.8–95.8%), a PPV of 92.5% (range 91.9–93.1%), and a NPV of 95.9% (range 95.6–96.2%).

Sensitivities and specificities for the CT diagnosis of appendicitis were similar to those found previously by Terasawa et al., at 95% and 94%, respectively [17]. Both analyses showed that the diagnostic accuracy for the US diagnosis of appendicitis is more heterogeneous than CT. The sensitivity and specificity of US calculated by Terasawa were 86% and 81%, respectively. A 2013 review of the literature performed by Pinto et al. demonstrated large variability in diagnostic accuracy of appendicitis by US with sensitivities ranging from 44% to 100%, and specificities ranging from 47% to 99% [22]. The authors ascribe this variability to operator dependency and patient factors including obesity, anatomic variants, and varying patterns of bowel gas. See Tables 19.1 and 19.2.

As MRI cost and scan time have decreased and become more available, the utilization of MRI for acute appendicitis has increased. Most evidence describes the use of MRI for appendicitis in the pregnant patient. A 2011 meta-analysis by Blumenfeld et al. included five retrospective studies evaluating the accuracy of MRI for appendicitis in the pregnant patient [26]. Summary sensitivity, specificity, PPV, and NPV were 90.5%, 98.6%, 86.3%, and 99.0%, respectively. The 2010 meta-analysis by Barger and colleagues reviewed ten retrospective studies on the performance of MRI for appendicitis in adults, of which 266 were pregnant patients [27]. This study included eight articles that compared MRI with pathology or clinical follow-up as the reference standard. The absolute number of true-positive (TP), true-negative (TN), false-positive, and false-negative results or sufficient data to calculate these values was required for inclusion by the authors. MRI demonstrated a combined sensitivity of 97% (CI: 92–99%) and combined specificity of 97% (CI: 94–99%), with a LR+ of 16.3 (CI: 9.1–29.1) and a LR- of 0.09 (CI: 0.04–0.197). Overall diagnostic odds ratio was 299.8 (CI: 97.5–921.6). More recent work has assessed the impact of MRI on clinical outcomes in the nonpregnant patient. Two recent prospective studies included a total of 275 adults undergoing MRI for acute appendicitis and demonstrated a sensitivity of 97% and a specificity of 93% and 97% for the diagnosis of acute appendicitis [28, 29].

A prospective study by Fonseca et al. including 79 pregnant patients evaluated for appendicitis by MRI

Table 19.1 Sensitivity and specificity of imaging in patients with suspected acute appendicitis

	Sensitivity (%)	Specificity (%)	Positive predictive value[a] (%)	Negative predictive value[a] (%)
Adults[a]				
Ultrasound	92.7	87.5	91.0	89.8
CT	93.4	95.3	92.5	95.9
Pediatric[b]				
Ultrasound	88	94	87	95
CT	94	95	95	97
Ultrasound followed by CT[c]	95	93	86	98

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[a]From Parker et al. [19]
[b]From Doria et al. [18]
[c]Teo et al. [23], Garcia Pena et al. [24], and Kaiser et al. [25]

Table 19.2 Diagnostic performance of MRI in patients with suspected acute appendicitis

	Sensitivity (%)	Specificity (%)	Positive predictive value[a] (%)	Negative predictive value[a] (%)
Adults				
MRI (pregnant patients)[a]	90.5	98.6	86.3	99.0
MRI (pregnant patients)[b]	97	97	–	–
MRI (women)[c]	97	93	–	–
Pediatric[d]				
MRI	96.5	96.1	92.0	98.3

[a]From Blumfield et al. [26]. Meta-analysis
[b]From Barger et al. [27]. Systematic review
[c]From [28, 29]. Propsective studies (total N = 275)
[d]From Moore et al. [21]. Systematic review

showed higher discharge from the emergency department and an overall shorter length of stay compared to patients that did not undergo MRI [30]. The sensitivity and specificity of MRI were both 100%, with a positive likelihood ratio of 20. In a study by Rapp and colleagues, the conditional use of MRI following equivocal US in pregnant patients suspected of having appendicitis decreased the negative appendectomy rate (NAR) from 55% to 29% without any significant increase in perforation [31]. They found an overall sensitivity, specificity, PPV, and NPV of 89%, 97%, 74%, and 99%, respectively.

While the evidence related to MRI utilization and accuracy is increasing, most studies are small and single institution. Currently, the only consistent evidence demonstrating the value of MRI for appendicitis is conditional use in pregnant patients. As radiation exposure concerns remain a powerful driver in modality choice, the evidence in support of MRI may increase.

What Is the Accuracy of Diagnostic Imaging in Pediatric Patients?

Summary of Evidence

- CT is more sensitive than ultrasound with similar specificity (Tables 19.1 and 19.2) (moderate evidence).
- A protocol of US followed by CT in negative or equivocal subjects may achieve similar sensitivity and specificity to CT alone, with less

radiation exposure and increased cost effectiveness (moderate evidence).

- A protocol of US followed by MRI in negative or equivocal subjects may achieve similar sensitivity and specificity to US compared with conditional CT use and eliminates ionizing radiation (moderate evidence).

Supporting Evidence Cross-sectional imaging is also the mainstay of diagnosis of acute appendicitis in the pediatric patient. A meta-analysis by Doria et al. [18] found 26 prospective and retrospective trials of graded compression US and/or CT in pediatric patients with suspected acute appendicitis (mean age range of 7–12 years). The eight studies included in the analysis described results from ultrasound only, CT only, or combined ultrasound and CT in 6850, 598, and 1908 patients, respectively. The mean sample prevalence of appendicitis from these trials was 31% for both US and CT (range, 15–75%). The weighted perforation rate in positive appendicitis cases was 26.5% [18]. For CT, the pooled sensitivity was 94% (95% CI, 92–97%), specificity was 95% (95% CI, 94–97%), and the summary diagnostic odds ratio was 239 (95% CI, 118–487). For the extracted data, the positive and negative likelihood ratios were 18.8 and 0.06, respectively. When these test specifications were applied to a population with the mean prevalence of appendicitis found in the trials examined by Doria et al. (31%), the positive predictive value was 89% and the negative predictive value was 97% (Tables 19.1 and 19.2) [18].

There were 23 studies of graded compression ultrasound that met inclusion criteria in the Doria et al. study. With one outlier removed, the pooled sensitivity of ultrasound in pediatric populations was 88% (95% CI, 86–90%), the pooled specificity was 94% (95% CI, 92–95%), and the summary diagnostic odds ratio was 202 (95% CI, 159–258). The positive and negative likelihood ratios were 14.7 and 0.13, respectively [18]. The positive predictive value of graded compression ultrasound was 87%, and the negative predictive value was 95%, using the mean prevalence of 31% for calculations (Tables 19.1 and 19.2) [18].

Thus, in patients with suspected acute appendicitis in whom evaluation with imaging is desired, the Doria et al. article demonstrated that there is a significant difference in the weighted pooled sensitivities for CT, with no significant difference in specificity of CT compared to ultrasound. However, as the authors noted, pediatric patients in general demonstrate greater sensitivity to ionizing radiation. This radiation exposure from CT should be included as a factor when weighing the risk of excess false-negative cases when US is the diagnostic modality.

In a secondary analysis of a 10-center prospective observational study of children presenting to emergency departments with abdominal pain, 965 pediatric patients were assessed with US to evaluate for appendicitis [20]. US demonstrated an overall sensitivity of 72% (CI 95%: 58.8%–86.3%) and an overall specificity of 97% (CI 95%: 96.2% to 97.9%). However, there was significant sensitivity variation dependent on how often US was utilized at each of the 10 tertiary pediatric care centers. At three sites that utilized US in 90% of cases, the sensitivity was 77.7%. At a single site that utilized US in 50% of cases, the sensitivity was 51.6%. At the four remaining sites combined, the sensitivity was 35% when US was utilized only 9% of the time. The conclusion is that the sensitivity of US for the diagnosis of acute appendicitis is confounded by the utilization rate of US in a given center [20].

Limitations in the pediatric appendicitis imaging literature include verification and selection bias, as in adults. Additional difficulties in analysis included lack of randomization of patients to imaging groups in many studies. Generalizability may also be an issue as CT has been more commonly studied in North America whereas ultrasound is more prevalently used in Europe and Asia. In addition, relatively few children under the age of 5 years were included in many of the studies, so that the results may not hold true for all children.

Ideally, an imaging protocol would combine the sensitivity of CT with the lack of ionizing radiation afforded by US in order to maximize diagnostic accuracy and minimize patient risk. Two prospective studies were identified in the literature search that examined the combination of graded compression US as the initial imaging, followed by CT study if the appendix was not visualized or if the US was inconclusive for the diagnosis of appendicitis [23, 24]. Together, these trials enrolled 585 patients with a prevalence of appendicitis ranging from 23 to 43% with a pooled prevalence of 39%. The overall sensitivity varied from 77 to 97%, with a pooled sensitivity of 95% (95% CI, 83–100%). The range of specificity was 89–99%, with a pooled result of 93% (95% CI, 97–97%). These series demonstrated a greater sensitivity and lower specificity when the combined US followed by CT results were considered, as compared to cases when the US data was considered alone, with an associated increase in the negative predictive value of the testing algorithm. Another randomized trial of 600 patients compared results of CT and US versus US alone in a pediatric population [32]. This study demonstrated similar results to the two aforementioned series, with the combined CT and US protocol demonstrating a sensitivity of 99% and specificity of 89%, while US alone showed a sensitivity of 86% and specificity of 95% [32]. Subsequent pediatric studies have not shown such high sensitivity as the Doria paper, such as a recent one by Trout that reported 67% sensitivity at a high volume Children's Hospital, suggesting that there continues to be wide variation in sonographic performance [33].

An additional consideration in deciding on the use of US versus CT is patient body habitus. An elevated body mass index (BMI) can limit visualization of the appendix with ultrasound, with non-visualization of the appendix in 79% of overweight children compared to 33% in normal weight and 25% in underweight children [34]. Two prospective studies and one retrospective study concluded that there was a trend of decreasing sensitivity with increasing BMI, but no statistical significance [35–37]. Obese children had similar length of stay, perforations, and complications compared to children with normal BMI. However, obese children were three times more likely to undergo CT [36]. A retrospective study by Grayson et al. found that increased intraperitoneal fat was correlated with a significantly increased likelihood of visualizing a normal appendix on CT of pediatric patients [38].

A formal cost-effectiveness analysis compared a protocol based on US followed by CT if negative to use of CT and US alone. The Markov decision analytic model indicated that the incremental cost-effectiveness ratio (ICER) of the US followed by CT protocol was below $10,000 in both male and female pediatric patients [39]. This cost falls well below the threshold for societal willingness to pay of $50,000. Thus, the protocol of US followed by CT was found to be a cost-effective imaging strategy (moderate evidence).

The utilization of MRI alone or conditionally subsequent to equivocal or negative US was prospectively evaluated in two small trials demonstrating sensitivity and specificity ranges of 93.3%–100% and 98%–100%, respectively, for both conditional MRI and MRI alone [40, 41]. In a larger retrospective study, Aspelund et al. demonstrated that US selectively followed by MRI was comparable to CT with no difference in length of stay, negative appendectomy rate, perforation, or complications [42]. There were 662 patients included in the study divided into a CT cohort and US with conditional use of MRI, with 142 patients receiving MRI. Sensitivity, specificity, PPV, and NPV of the US with conditional MRI group were 100%, 98%, 98%, and 100%, which were equivalent to the CT cohort, suggesting a highly accurate non-ionizing pathway [42].

A recent systematic review of MRI by Moore et al. summarized the results from 11 studies comprising 1698 children [21]. Two of these studies reported outcomes including negative appendectomy rates of 1.4–3.1% [21, 42]. Importantly, the MR protocol most commonly used was limited to 4–5 sequences and did not require gadolinium contrast or oral contrast. Since the imaging time was short, the need for sedation was minimized. The key pulse sequence is the single-shot fast spin echo performed in both axial and coronal planes. Moore et al. suggest that four sequences have shown adequate accuracy for this diagnosis, by using T2w SSFSE without and with fat saturation inversion recovery (SPAIR) in axial and coronal planes. They note that in general, children under age five will need sedation.

Which Subjects Suspected of Having Appendicitis Should Undergo Imaging?

Summary of Evidence

- A pediatric clinical prediction rule that relies on signs and symptoms in conjunction with basic laboratory values may be useful in identifying subjects who do not need imaging (Table 19.3). This prediction rule has been revalidated and refined at multiple institutions (moderate evidence).
- The Alvarado score could be used to stratify patients who should undergo CT (limited evidence).
- Limited data and modeling studies suggest that CT is most useful when the clinical probability of acute appendicitis is intermediate to high, as a confirmatory test in subjects for whom surgery is considered (limited evidence).

Supporting Evidence Clinical exam and serum laboratory testing remains the standard initial method of determining which patients may have appendicitis. However, given the historical rates of both missed diagnosis and unnecessary laparotomy, a number of investigators have attempted to formalize the clinical exam into a valid scoring tool or decision rule for deciding which subjects are at risk of appendicitis. In 1986, Alvarado introduced a tool termed the MANTRELS criteria for scoring of appendicitis risk in adults. However, diagnostic accuracy is low, with significant inter-provider variability in the application of these criteria [44].

Table 19.3 Clinical decision rule for determination of pediatric patients at low risk for acute appendicitis

Presence of either prediction rule has a sensitivity of 98.1% and a NPV of 95.3% in identifying pediatric patients at low risk
1. Absolute neutrophil count (ANC) < $6.75 \times 10^3/\mu L$ and no maximal tenderness in the RLQ
2. Absolute neutrophil count (ANC) < $6.75 \times 10^3/\mu L$ and maximal tenderness in the RLQ but no abdominal pain with walking/jumping or coughing

Data from Kharbanda et al. [43]
Modified with kind permission of Springer Science+Business Media from Cooke EA, Blackmore CC. Imaging of Appendicitis in Pediatric Patients. In Medina LS, Applegate KE, Blackmore CC (eds.): *Evidence-Based Imaging in Pediatrics: Optimizing Imaging in Pediatric Patient Care*. New York: Springer Science+Business Media, 2010

Multiple recent studies suggest that the Alvarado score may be used for stratification of patients who should undergo CT. A recent meta-analysis of 29 studies evaluating the use of the Alvarado score found that children with a pretest probability of acute appendicitis of either 60% or 40% with Alvarado scores of 4 and 5, respectively, were negative by imaging. In adults with a pretest probability of either 60% or 40% and Alvarado scores of 8 and 9, respectively, ruled in the diagnosis [45]. Tan et al. conducted a retrospective study evaluating 358 subjects with suspected appendicitis and concluded that patients with an Alvarado score between 4 and 8 would benefit from CT [46]. Very recently, the same author conducted a small prospective study that found CT is beneficial mainly in patients with an Alvarado score of 6 and below in males and 8 and below in females [47].

Efforts have focused on using clinical and laboratory examination as a triage tool in pediatric subjects to determine children who are at sufficiently low risk for appendicitis such that imaging may be avoided. Kharbanda et al. developed, revalidated, and refined a clinical prediction rule resulting in a model that identified patients at low risk with [1] an absolute neutrophil count of $6.7 \times 10^3/\mu L$ or less and no maximal tenderness in the right lower quadrant or [2] an absolute neutrophil count of $6.75 \times 10^3/\mu L$ or less with maximal tenderness in the right lower quadrant but no abdominal pain with walking/jumping or coughing. This refined rule had a sensitivity of 98.1% (95% CI, 97.0%–98.9%), specificity of 23.7% (21.7%–25.9%), and negative predictive value of 95.3% (92.3%–97.0%) (Table 19.2). Application of this rule could allow for a reduction in use of CT by 20% [43]. Limitations in this study include the potential for enrollment bias and interobserver variability.

Garcia Pena et al. also performed recursive partitioning analysis of a retrospective cohort of 958 children with equivocal acute appendicitis, who were risk stratified into three groups based on clinical signs and symptoms and laboratory values [24]. Three different management guidelines with subsequent modeling of outcomes were developed. Outcomes included the number of negative appendectomies and missed or delayed diagnoses of appendicitis. The authors showed that management guidelines with more selective use of imaging could reduce the number of imaging exams with minimal increase in the negative appendectomy rate and the number of missed diagnoses of appendicitis. However, these guidelines have not yet been validated, so the effectiveness in clinical practice is uncertain.

There is only limited evidence as to which subjects at risk for appendicitis should undergo imaging. Recent investigations by Nathan et al. [48] and Kim et al. [49] suggest that imaging is more likely to be of value for clinical decision-making when performed in subjects determined clinically to be of high probability for acute appendicitis. In a study of community emergency physicians, Nathan et al. found that when the emergency physicians determined that appendicitis was unlikely, the diagnostic yield from CT was extremely low. However, neither emergency physicians nor consulting surgeons were able to define when appendicitis was certain. Kim et al. found that CT would substantially decrease the rate of negative laparotomy in subjects with clinically evident appendicitis [49]. In addition, modeling demonstrates the potential adverse effect of false-positive diagnoses if CT is used to screen a more low-risk population [50]. These results would suggest that the most appropriate use of CT is in subjects of intermediate risk as well as in subjects at high pretest probability for appendicitis. In effect, confirmatory CT should be performed in all subjects prior to being taken to the operating room (OR) for suspected appendicitis, but if it is unlikely that a patient is going to the OR, CT should be avoided [48].

What Is the Effect of Imaging on Negative Appendectomy Rate?

Summary of Evidence

- The negative appendectomy rate decreases with increasing use of preoperative imaging, in particular CT, in adults (strong evidence).
- The negative appendectomy rate decreases with increasing use of preoperative imaging in the pediatric population (moderate evidence).

Supporting Evidence The Krajewski et al. meta-analysis published in 2011 which compared the CT era to the pre-CT era included 10 studies with 4485 adult patients evaluated during the pre-CT era and 1629 patients during the CT era. Utilization of CT imaging saw a negative appendectomy rate (NAR) of 21.5% decrease to 10%. The cumulative pooled odds ratio for the NAR after CT was 0.57 (95% CI 0.45–0.72) demonstrating the benefit of CT [51]. The limitation of this analysis is primarily related to the fact that the studies included were retrospective, resulting in selection bias. However, since a selection bias would be expected to result in a smaller difference in the NAR, it is likely that the results represent valid conclusions.

The results from the meta-analysis are now supported with results from newer prospective studies. For example, a quality improvement effort in Washington State, the prospective Surgical Care and Outcomes Assessment Program (SCOAP) included 53 hospitals in Washington State, and reported a significantly lower NAR after imaging when describing the experience since 2006. The study included 19,327 patients (age >15) who underwent urgent appendectomy, with a NAR of 15.4% in subjects without imaging, 10.4% in subjects who underwent US, and 4.1% in those who underwent CT [52]. An 18-year retrospective study at a single institution saw a pre-imaging NAR of 23% decrease to 1.7% after routine CT [53].

The data in pediatric patients is relatively consistent. A large retrospective study performed by Bachur et al. included 55,227 children with appendicitis, demonstrating an overall NAR of 3.6%. The patient-level NARs among boys stratified by age were 16.9% (age >5 years), 1.3% (5–10 years), and 1.1% (>10 years). Among girls, the rates were 13.3% (age <5 years), 1.8% (5–10 years), and 5.5% (>10 years). US and/or CT imaging decreases the NAR in all children except those younger than 5 years [54]. Many smaller studies have found the same results [55–57]. The strongest study arguing against the liberal use of CT scans for NAR reduction is the study published in 2004 by Martin et al. [58]. This retrospective single-institution study reviewed results from 720 children undergoing appendicitis evaluation between 1998 and 2001 with US and/or CT. Although, during this period, the use of US decreased from 20.0% to 7.0% and the use of CT increased from 17.6% to 51.3%, no significant reduction of NARs observed.

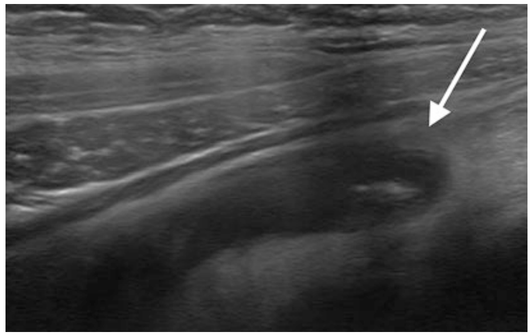

Fig. 19.1 Eleven-year-old male presented to the emergency department complaining of right lower quadrant (RLQ) abdominal pain, nausea, and emesis for less than 24 h. On physical exam, he was febrile and demonstrated right lower quadrant tenderness with guarding. Laboratory evaluation revealed a mildly elevated white blood cell count of 12,500 cells/mm^3. An ultrasound was obtained, demonstrating a blind-ending, noncompressible tubular structure in the right lower quadrant compatible with a dilated appendix, measuring 13 mm in diameter and containing an echogenic, shadowing fecalith. On appendectomy, gross and histological findings established the presence of a nonperforated but friable, suppurative appendix

Take Home Tables

Tables 19.1 and 19.2 cover the specificity and sensitivity of imaging for suspected acute appendicitis and the performance of MRI in detecting suspected acute appendicitis, respectively. Table 19.3 summarizes the clinical decision rule for determining pediatric patients at low risk for acute appendicitis.

Imaging Case Studies

Case 1

In Fig. 19.1, an 11-year-old male presented to the emergency department complaining of right lower quadrant (RLQ) abdominal pain, nausea, and emesis for less than 24 h.

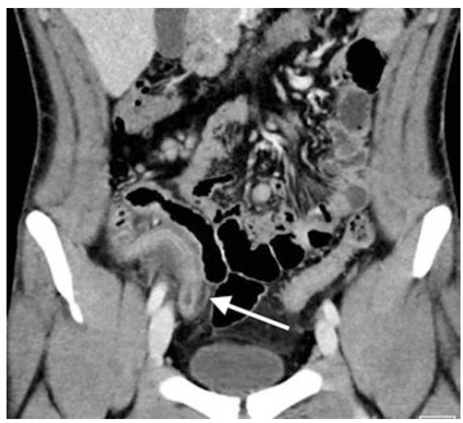

Fig. 19.2 Twenty-one-year-old male presents to the emergency department complaining of RLQ abdominal pain and nausea for 24 h. On physical exam, he was afebrile and demonstrated right lower quadrant tenderness with rebound pain. White blood cell count was elevated at 15,200 cells/mm^3. CT demonstrated a dilated, 12 mm appendix with mural thickening and inflammatory changes in the periappendiceal fat. Gross examination of the appendix after appendectomy revealed dilated, necrotic appendix

Case 2

In Fig. 19.2, a 21-year-old male presents to the emergency department complaining of RLQ abdominal pain and nausea for 24 h.

Case 3

In Fig. 19.3, a 23-year-old pregnant female presents to the emergency department complaining of right lower and right upper quadrant abdominal pain and nausea for 24 h.

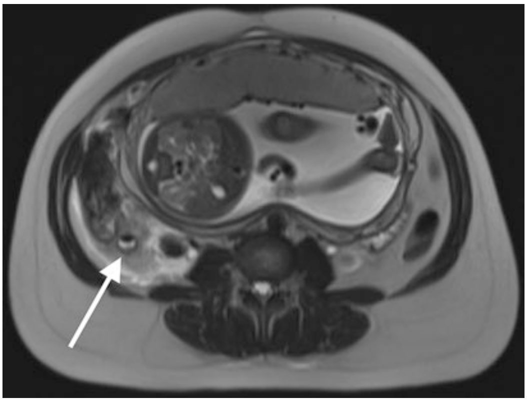

Fig. 19.3 Twenty-three-year-old pregnant female presents to the emergency department complaining of right lower and right upper quadrant abdominal pain and nausea for 24 h. On physical exam, she was febrile and demonstrated right lower quadrant tenderness with rebound pain. White blood cell count was elevated at 19,900 cells/mm^3. MRI demonstrated a dilated appendix with mural thickening and a fluid level. Gross examination of the appendix found that the mid portion of the appendix was gangrenous and perforated with fecal matter present within the encased cavity

CT Protocols for Suspected Appendicitis

There is no consensus in the literature as to the ideal CT protocol with respect to use of intravenous contrast, oral contrast, rectal contrast, or non-contrast technique; indeed, there are varying reports of the efficacy of these protocols [5, 59–63]. There is also significant variability in terms of recommendations regarding focused imaging of the appendiceal region versus complete scan of the abdomen and pelvis, with trade-offs between radiation dose and more complete exam [64, 65]. In general, CT protocols are institutionally dependent, and the best technique for a given patient may vary depending on [1] the ability to tolerate administration of oral or rectal contrast and [2] any contraindications to intravenous contrast. Use of radiation dose reduction techniques is critical particularly given the relatively young age of most subjects with clinically suspected appendicitis (peak age 10–30 years). There is, however, a trend in the use of IV contrast alone without enteric contrast for emergency department patients to improve the throughput of patients [61]. A large prospective study derived from the SCOAP trial that included 8089 patients found no improvement in the diagnosis of appendicitis following concomitant use of IV and enteral contrast [66]. Laituri and colleagues conducted a retrospective review demonstrating that contrast material does not reach the point of interest in 30% of patients receiving oral contrast for the CT evaluation of appendicitis. This is at the detriment of delayed diagnosis, emesis, and nasogastric tube placement [67].

ACR Appropriateness Criteria® Guidelines

Current ACR guidelines recommend that adults and adolescents with both classic and atypical signs and symptoms of appendicitis be imaged with enhanced CT of the abdomen and pelvis, with a rating of 8. Given discrepancy within the literature regarding the need for contrast, a non-enhanced CT abdomen and pelvis is a suitable alternative in suspected cases of appendicitis when the adult/adolescent patient presents with classic or atypical symptoms with ratings of 7 and 6, respectively. Abdominal US maintains a moderate rating of 6, although it is rarely utilized as a first line imaging modality in the United States despite its heavy utilization in Europe. Radiography maintains a role when the patient presents with atypical symptoms with a rating of 6. But when the patient presents with classic symptoms, radiography carries a lower recommendation of 4 [68].

The pregnant patient suspected of appendicitis is approached differently given the concern of ionizing radiation to the fetus. Abdominal US carries the highest recommendation with a rating of 8, followed by MRI and pelvic US with ratings of 7 and 6, respectively. CT abdomen and pelvis with contrast carries a moderate recommendation, with a rating of 5 and is often avoided unless absolutely necessary [68].

As with the pregnant patient, the pediatric patient (<14 years of age) requires a conservative approach to imaging. Abdominal US is widely accepted and remains first line imaging for the pediatric population with a rating of 8. CT abdomen and pelvis with contrast carries a high rating of 7 and is still very useful when US is equivocal or the pediatric patient is obese. Radiography carries a moderate rating of 6 and is commonly used in the pediatric population when atypical symptoms are present [68].

Future Research

- Multicenter validation of proposed clinical decision rules aimed at determining when imaging is indicated in patients with suspected appendicitis.
- Determination of the overall cost and cost-effectiveness of imaging in patients with suspected acute appendicitis.
- Potential paradigm shift towards antibiotic conservative management for the treatment of acute appendicitis may influence the role of emergent abdominal imaging. Ongoing research continues to question the need for surgical management and further studies are needed.

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References

1. Keyzer C, Gevenois PA. In: Keyzer C, Gevenois PA, editors. Imaging of acute appendicitis in adults and children. Berlin: Springer Science & Business Media; 2011. 265p.
2. Prystowsky JB, Pugh CM, Nagle AP. Appendicitis Curr Probl Surg. 2005;42(10):688–742.
3. Kumar V, Abbas AK, Aster JC. Robbins & Cotran pathologic basis of disease: Elsevier Health Sciences; 2014. 1472p.
4. Hale DA, Molloy M, Pearl RH, et al. Ann Surg. 1997;225(3):252–61.
5. Sivit CJ, Applegate KE. Semin Ultrasound CT MR. 2003;24(2):74–82.
6. Blomqvist PG, Andersson RE, Granath F, et al. Ann Surg. 2001;233(4):455–60.
7. Addiss DG, Addiss DG, Shaffer N, et al. Am J Epidemiol. 1990;132(5):910–25.
8. Buckius MT, McGrath B, Monk J, et al. J Surg Res. 2012;175(2):185–90.
9. Saito JM, Yan Y, Evashwick TW, et al. Pediatrics. 2013;131(1):e37–44.
10. Kwok MY, Kim MK, Gorelick MH. Pediatr Emerg Care. 2004;20(10):690-8- quiz 9-701.
11. Körner H, Söndenaa K, Söreide JA, et al. World J Surg. 1997;21(3):313–7.
12. Al-Omran M, Mamdani M, McLeod RS. Can J Surg. 2003;46(4):263–8.
13. Barrett ML, Hines AL, Andrews RM. Trends in rates of perforated appendix, 2001–2010: statistical brief #159. Rockville, MD: Agency for Health Care Policy and Research (US); 2006.
14. CDC. CDC Hospital Costs. 2015:1–3.
15. Flum DR, Koepsell T. Arch Surg. 2002;137(7):799–804. discussion
16. Garcia Pena BM, Taylor GA, Lund DP. J Am Acad Physician Assist. 2000;13(1):65–7, 70, 3-6 passim.
17. Terasawa T, Blackmore CC, Bent S. Ann Internal. 2004;141(7):537–46.
18. Doria AS, Moineddin R, Kellenberger CJ, et al. Radiology. 2006;241(1):83–94.
19. Parker L, Nazarian LN, Gingold EL, et al. AJR Am J Roentgenol. 2014;202(1):124–35.
20. Mittal MK, Dayan PS, Macias CG, et al. Acad Emerg Med. 2013;20(7):697–702.
21. Moore MM, Kulaylat AN, Hollenbeak CS, et al. Pediatr Radiol. 2016;46(6):928–39.
22. Pinto F, Pinto A, Russo A, et al. Crit Ultrasound J. 2013;5(Suppl 1):S2.
23. Teo EL, Tan KP, Lam SL, et al. Singap Med J. 2000;41(8):387–92.
24. Garcia Peña BM, Cook EF, Mandl KD. Pediatrics. 2004;113(1 Pt 1):24–8.
25. Kaiser S, Finnbogason T, Jorulf HK, et al. Radiology. 2004;231(2):427–33.
26. Blumenfeld YJ, Wong AE, Jafari A, et al. J Matern Fetal Neonatal Med. 2011;24(3):485–8.
27. Barger RL, Nandalur KR. Acad Radiol. 2010;17(10):1211–6.
28. Leeuwenburgh MMN, Wiezer MJ, Wiarda BM, et al. Br J Surg. 2014;101(1):e147–55.
29. Heverhagen JT, Pfestroff K, Heverhagen AE, et al. J Magn Reson Imaging. 2012;35(3):617–23.
30. Fonseca AL, Schuster KM, Kaplan LJ, et al. JAMA Surg. 2014;149(7):687–93.
31. Rapp EJ, Naim F, Kadivar K, et al. Radiology. 2013;267(1):137–44.
32. Kaiser S, Frenckner B, Jorulf HK, et al. Radiology. 2002;223(3):633–8.
33. Trout AT, Sanchez R, Ladino-Torres MF, et al. Pediatr Radiol. 2012;42(7):813–23.

34. Puig S, Staudenherz A, Felder-Puig R, et al. Semin Roentgenol. 2008;43(1):22–8.
35. Abo A, Shannon M, Taylor G, et al. Pediatr Emerg Care. 2011;27(8):731–6.
36. Sulowski C, Doria AS, Langer JC, et al. Acad Emerg Med. 2011;18(2):167–73.
37. Yiğiter M, Kantarcı M, Yalçin O, et al. J Clin Ultrasound. 2010;39(4):187–90.
38. Grayson DE, Wettlaufer JR, Dalrymple NC, et al. AJR Am J Roentgenol. 2001;176(2):497–500.
39. Wan MJ, Krahn M, Ungar WJ, et al. Radiology. 2009;250(2):378–86.
40. Thieme ME, Leeuwenburgh MMN, Valdehueza ZD, et al. Eur Radiol. 2014;24(3):630–7.
41. Orth RC, Guillerman RP, Zhang W, et al. Radiology. 2014;272(1):233–40.
42. Aspelund G, Fingeret A, Gross E, et al. Pediatrics. 2014;133(4):586–93.
43. Kharbanda AB, Dudley NC, Bajaj L, et al. Arch Pediatr Adolesc Med. 2012;166(8):738–44.
44. Brennan GD. CJEM. 2006;8(6):425–32.
45. Ebell MH, Shinholser J. Ann Emerg Med. 2014;64(4):365–72.e2.
46. Tan WJ, Pek W, Kabir T, et al. ANZ J Surg. 2013;83(10):748–52.
47. Tan WJ, Acharyya S, Goh YC, et al. J Am Coll Surg. 2015;220(2):218–24.
48. Nathan RO, Blackmore CC, Jarvik JG. AJR Am J Roentgenol. 2008;191(4):1102–6.
49. Kim K, Rhee JE, Lee CC, et al. Emerg Med J. 2008;25(8):477–81.
50. Blackmore CC, Terasawa T. J Am Coll Radiol. 2006;3(2):115–21.
51. Krajewski S, Brown J, Phang PT, et al. Can J Surg. 2011 Feb;54(1):43–53.
52. Drake FT, Florence MG, Johnson MG, et al. Ann Surg. 2012;256(4):586–94.
53. Raja AS, Wright C, Sodickson AD, et al. Radiology. 2010;256(2):460–5.
54. Bachur RG, Hennelly K, Callahan MJ, et al. Pediatrics. 2012;129(5):877–84.
55. Rao PM, Rhea JT, Rattner DW, et al. Ann Surg. 1999;229(3):344–9.
56. Smink DS, Finkelstein JA, Garcia Peña BM, et al. J Pediatr Surg. 2004;39(3):458–63- discussion -63.
57. Applegate KE, Sivit CJ, Salvator AE, et al. Radiology. 2001;220(1):103–7.
58. Martin AE, Vollman D, Adler B, et al. J Pediatr Surg. 2004;39(6):886–90.
59. Lowe LH, Penney MW, Stein SM, et al. AJR Am J Roentgenol. 2001;176(1):31–5.
60. Blackmore CC, Mann FA, Wilson AJ. Skelet Radiol. 2000;29(11):632–9.
61. Anderson SW, Soto JA, Lucey BC, et al. AJR Am J Roentgenol. 2009;193(5):1282–8.
62. Mun S, Ernst RD, Chen K, et al. Emerg Radiol. 2006;12(3):99–102.
63. Giuliano V, Giuliano C, Pinto F, et al. Emerg Radiol. 2005;11(5):281–5.
64. Mullins ME, Kircher MF, Ryan DP, et al. AJR Am J Roentgenol. 2001;176(1):37–41.
65. Fefferman NR, Roche KJ, Pinkney LP, et al. Radiology. 2001;220(3):691–5.
66. Drake FT, Alfonso R, Bhargava P, et al. Ann Surg. 2014;260(2):311–6.
67. Laituri CA, Fraser JD, Aguayo P, et al. J Surg Res. 2011;170(1):100–3.
68. Rosen MP, Ding A, Blake MA, et al. J Am Coll Radiol. 2011;8(11):749–55.