Value of Focused Appendicitis Ultrasound and Alvarado Score in Predicting Appendicitis in Children: Can We Reduce the Use of CT?

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OBJECTIVE. The purpose of this study was to evaluate the effectiveness of focused appendicitis ultrasound combined with Alvarado score to accurately identify appendicitis in children in whom it is suspected, thereby reducing unnecessary CT examinations and associated radiation exposure.

MATERIALS AND METHODS. We retrospectively evaluated the focused appendicitis ultrasound, CT, clinical, and laboratory findings of 522 consecutively registered children (231 boys, 291 girls; mean age, 13.04 [SD, 5.02] years; range, 0.74 months–21 years) who underwent focused appendicitis ultrasound for abdominal pain in a pediatric emergency department from January 2008 through October 2009. All children underwent surgery or clinical follow-up to exclude missed appendicitis. Sonographic findings were characterized as positive, negative, or inconclusive (appendix not visualized). Alternative diagnoses were noted. Alvarado score (0–10 points based on multiple clinical criteria) was determined. Focused appendicitis ultrasound and Alvarado score results were compared with surgical and pathologic reports.

RESULTS. Both focused appendicitis ultrasound results and Alvarado score were associated with likelihood of surgery for appendicitis ($p = 0.0001$). Focused appendicitis ultrasound had conclusive results: 105 positive and 27 negative in 132 of 522 (25.2%) children. In the 390 of 522 (74.7%) children with inconclusive focused appendicitis ultrasound findings, 43 of 390 (11.0%) eventually had a diagnosis of appendicitis with CT ($n = 26$) or Alvarado score ($n = 17$). Among children with inconclusive focused appendicitis ultrasound findings and an Alvarado score less than 5 (241/522, 46.1%), only one patient had appendicitis. The negative predictive value (NPV) of inconclusive ultrasound findings and low Alvarado score combined was 99.6%. Among children with inconclusive focused appendicitis ultrasound findings and an Alvarado score of 5–8, the NPV decreased to 89.7%.

CONCLUSION. Children with inconclusive focused appendicitis ultrasound findings and a low Alvarado score are extremely unlikely to have appendicitis (NPV, 99.6%). Avoiding unnecessary CT of these patients is a safe approach to diagnosis.

Keywords: Alvarado score, appendicitis, body mass index, radiation reduction, ultrasound

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Appendicitis is the most common acute surgical condition in the United States [1]. The accurate diagnosis of appendicitis relies on a combination of clinical and imaging findings. Several scoring systems have been developed in attempts to quantify and improve the accuracy of clinical assessment. The initial and most well known was devised by the surgeon Alfredo Alvarado in 1986 [2] and is based on eight clinical criteria. The criteria for the Alvarado score are shown in Table 1. Since then, many studies have confirmed that the Alvarado score is a useful adjunct in predicting the presence of appendicitis but that it does not have sufficient positive predictive value (PPV) to be used exclusively [3–5].

Imaging is vital to accurate and prompt diagnosis when the clinical presentation is equivocal. Ultrasound and CT remain the mainstay of diagnostic imaging. Although CT is considered the most accurate method of diagnosis, the radiation exposure associated with CT has developed as a concern, particularly among pediatric patients. Multiple studies have confirmed a small but statistically significant increase in lifetime radiation risk for pediatric CT because of both the increased dose per milliampere-second and the greater lifetime risk per unit dose [6, 7]. Moreover, the use of CT is increasing in pediatric emergency departments in the United States [8].

Therefore, in the pediatric age group, ultrasound, which does not entail ionizing radiation, may be valuable as an initial imaging study for patients with equivocal clinical evaluation findings [9–11]. Several studies have shown that although the specificity of ultrasound approaches that of CT, the sensitivity is diminished [12–14]. Because of the large number of inconclusive studies, ultrasound has not gained widespread acceptance among pediatric surgeons and emergency department physicians, particularly at referring as opposed to children's hospitals [15].

In an effort to improve diagnostic accuracy at our institution, in 2008 we introduced focused appendicitis ultrasound to evaluate appendicitis and other common causes of abdominal pain. This technique entails focal evaluation of the right lower quadrant, gallbladder, Morrison pouch, right ovary, and cul-de-sac. Despite this intervention, there remained a large number of patients with inconclusive focused appendicitis ultrasound findings for whom CT was undesirable. To address this concern, we worked in conjunction with pediatric emergency physicians to develop an algorithm based on degree of clinical suspicion as defined by the Alvarado score to further stratify patients with inconclusive focused appendicitis ultrasound findings. The goal of the algorithm was to avoid CT of patients in whom the clinical diagnosis was either highly unlikely or highly likely. The purpose of this study was to evaluate the effectiveness of focused appendicitis ultrasound combined with Alvarado score to accurately identify the presence of appendicitis in children in whom it is suspected, thereby reducing unnecessary CT examinations and associated radiation exposure.

Materials and Methods

Study Design

The study was a retrospective review of medical and imaging records and was approved by the institutional review board. Patient data collection and storage were HIPAA compliant.

Study Setting

The study was conducted in the pediatric emergency department affiliated with an urban children's hospital. The study population included all consecutively registered children younger than 21 years (231 boys, 291 girls; mean age, 13.04 [SD, 5.02] years; range, 0.74 months–21 years) who underwent focused appendicitis ultrasound for abdominal or pelvic pain during the period January 2008 to October 2009. Children were excluded who did not have complete laboratory or physical examination records and did not undergo surgery without a subsequent follow-up visit to rule out missed appendicitis.

TABLE 1: Components of the Alvarado Score

Clinical Criterion	No. of Points
Migration of pain to the right iliac fossa	1
Anorexia or ketones in the urine	1
Nausea or vomiting	1
Right lower quadrant tenderness	2
Rebound tenderness	1
Fever of 37.3°C or more	1
Leukocytosis of > 10,000/μL	2
Neutrophilia > 75%	1
Total possible points	10

Imaging Technique and Evaluation

Ultrasound was performed with either a GE Healthcare Logiq E9 or a Philips Healthcare IU22 unit with a linear-array transducer (15L8W). The time of the study, either during regular hours (8 am–5 pm) or after hours (5 pm–8 am) was noted. Studies were performed by a trained pediatric ultrasound technologist during regular hours and either a trained technologist or radiology resident after hours. Four studies performed after hours were repeated during regular hours the following day. Both regular and after-hours studies were read by one of three pediatric radiologists (certificates of added qualification and a combined 41 years' experience) without knowledge of the Alvarado score. Positive findings of after-hours studies were confirmed by the attending radiologist on call. Studies were characterized as conclusive (positive, n = 105; normal, n = 27) or inconclusive (n = 390). Alternative diagnoses (n = 55) were noted (Table 2). The criterion for a negative focused appendicitis ultrasound result was a visualized compressible appendix 6 mm in diameter or smaller (Fig. 1). The criterion for a positive ultrasound result was a noncompressible appendix larger than 6 mm in diameter (Fig. 2). Hyperemia (Fig. 3) and adherent omentum (Fig. 4) were also considered positive findings if the appendix was thickened. A right lower quadrant or pelvic abscess was considered a positive finding of ruptured appendicitis, even if the appendix was not visualized (Fig. 5). Studies in which the appendix could not be definitively visualized and had no abscess were considered inconclusive (Fig. 6).

In addition, 105 of the 522 patients also underwent CT. The decision to perform CT was made at the discretion of the clinician and was not the focus of this study. CT was performed with a 64-MDCT scanner (LightSpeed, GE Healthcare) with oral and IV contrast administration (iodixanol, Visipaque 320, GE Healthcare) at a dose of 1–2 mL/kg. The tube current–time setting and tube voltage were adjusted according to the child's height and weight with a color-coded protocol provided by the manufacturer. Final CT reports were characterized as positive, negative, or inconclusive.

TABLE 2: Alternative Diagnoses for Inconclusive Focused Appendicitis Ultrasound Findings Without Appendicitis

Diagnosis	No. of Patients (n = 55)
Ruptured or hemorrhagic ovarian cyst	25
Enterocolitis, colitis	6
Hemoperitoneum	4
Cholecystitis, gallstones	3
Hepatitis	2
Ovarian dermoid	2
Obstructive hydronephrosis	2
Abscess	1
Cystitis	1
Ectopic pregnancy	1
Epididymoorchitis	1
Ovarian torsion	1
Pancreatitis	1
Pelvic inflammatory disease	1
Polycystic kidney disease	1
Polycystic ovary syndrome	1
Pyelonephritis	1
Small-bowel obstruction	1

Medical Records Review

Physical examinations were performed and the findings recorded in the patient's chart by pediatric house staff in the pediatric emergency department under the direct supervision and confirmation of trained pediatric emergency attending physicians. An independent pediatric emergency department physician using the criteria listed in Table 1 calculated the Alvarado score retrospectively on the basis of the clinical findings and laboratory values documented in the patient's chart. The surgical pathologic reports of all patients who underwent surgery were evaluated.

All children who were discharged without surgery had a clinical follow-up visit from 1 week to 1 year after the initial focused appendicitis ultrasound examination to exclude missed appendici-

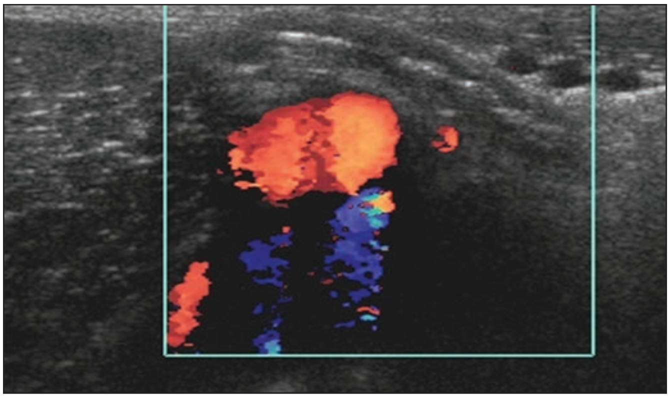


Fig. 1—4-year-old boy with abdominal pain. Transverse ultrasound image of right lower quadrant obtained with linear transducer shows 4-mm normal appendix that drapes over iliac artery and vein.

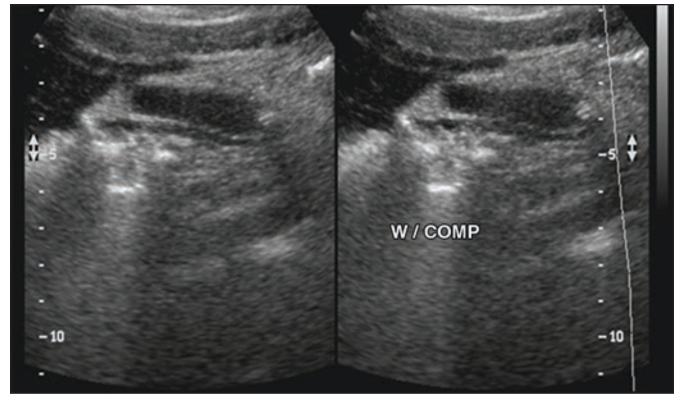
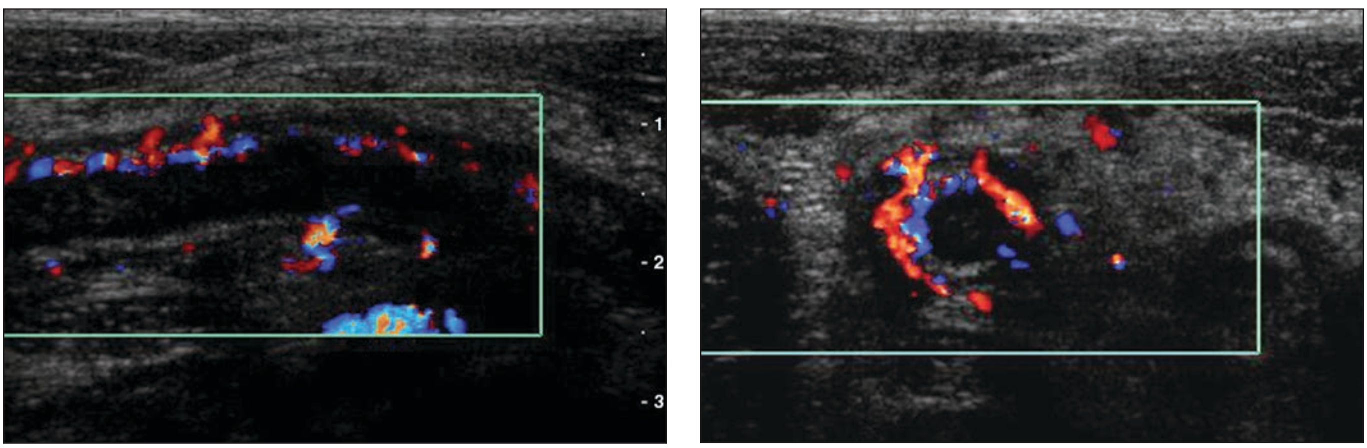


Fig. 2—8-year-old girl with right lower quadrant pain. Longitudinal ultrasound images of appendix obtained with vector transducer show thickened, 9-mm appendix that does not change with graded compression (*right*). Inflamed appendix was found at surgery.



A

B

Fig. 3—6-year-old boy with acute appendicitis.
A and **B,** Longitudinal (**A**) and transverse (**B**) color Doppler ultrasound images of appendix show substantial hyperemia.

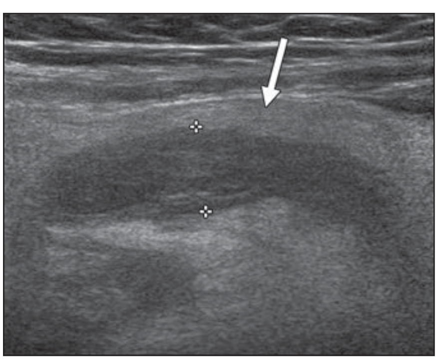


Fig. 4—9-year-old boy with acute appendicitis. Longitudinal ultrasound image of appendix shows thickened appendix (*calipers*) with surrounding increased echogenicity (*arrow*) found at surgery to represent adherent omentum.

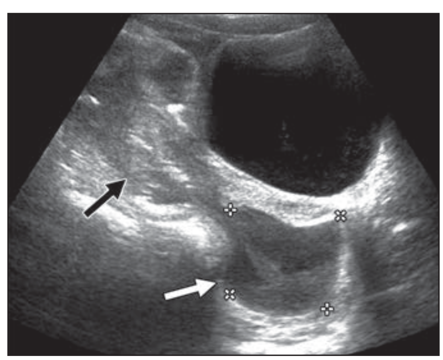


Fig. 5—7-year-old girl with ruptured appendicitis. Longitudinal ultrasound image obtained with vector transducer shows pelvic abscess (*white arrow, calipers*) from surgically proven ruptured appendicitis. Thickened loop of bowel (*black arrow*) is evident in superior aspect.

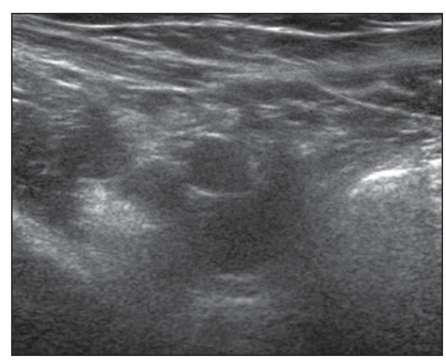


Fig. 6—12-year-old girl with right lower quadrant pain. Longitudinal ultrasound image obtained with linear transducer is obscured by bowel gas and does not show appendix or any secondary signs of appendicitis. Findings are considered inconclusive.

tis. In addition, body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters for all children who had both weight and height recorded in the medical record (n = 401). The mean BMI for our patient population was compared with national standards of the U.S. Centers for Disease Control and Prevention [16, 17].

Statistical Analysis

Descriptive statistics are presented as mean and SD for patient age and median and range for Alvarado score (0–10) in patients with inconclusive focused appendicitis ultrasound findings. Relative frequencies are presented for sex, time of focused appendicitis ultrasound examination, focused appendicitis ultrasound result (positive, negative, alternative diagnosis, or inconclusive), CT result (positive, negative, or inconclusive), and surgical pathologic result (positive or negative for appendicitis). Outcome was based on the surgical pathologic result for patients who underwent surgery and on findings at the first clinical follow-up visit for those who did not. The negative appendectomy rate was calculated as the number of normal appendixes removed (confirmed at surgical pathologic examination) divided by the total number of operations performed in the sample set.

The association between Alvarado score in patients with inconclusive focused appendicitis ultrasound findings and both surgery for appendicitis and positive surgical pathologic result was assessed by the Mantel-Haenszel chi-square and Wilcoxon rank sum tests. PPV and negative predictive value (NPV) were calculated at each level of clinical risk of appendicitis: Alvarado score 0–4, low; 5–8, intermediate; 9–10, high. For the purposes of this study, inconclusive focused appendicitis ultrasound findings in patients who had appendicitis were considered false-negative results.

Logistic regression analysis was used to identify whether Alvarado score was significantly predictive of either surgery or pathologic examination accounting for CT results, age, and sex. The number of CT examinations that would have been avoided if the final conclusions of this study had been followed was determined.

Differences in BMI of patients with a nonvisible (inconclusive focused appendicitis ultrasound finding) versus visible (positive and negative focused appendicitis ultrasound findings) appendix were assessed by Wilcoxon rank sum test. All analyses were performed with SAS software (version 9.2, SAS Institute). Significance tests were two-tailed and conducted at an alpha value of 0.05.

Results

Among the 522 focused appendicitis ultrasound studies, 223 were performed during regular hours, and 299 were performed after hours. The four after-hours studies repeated the following day had no difference in final interpretation. Overall, there was no significant difference in results between studies performed during regular hours and those performed after hours ($p = 0.38$).

Results of Imaging Studies

Focused appendicitis ultrasound results were conclusive for appendicitis in 132 of the 522 (25.2%) patients (positive, $n = 105$; normal, $n = 27$). The results were inconclusive in 390 (74.8%) patients. Alternative diagnoses were noted in 55 of the 390 (14.1%) patients with findings inconclusive for appendicitis. By far the most common alternative diagnosis was ruptured ovarian cyst; enterocolitis was next. Among the 105 focused appendicitis ultrasound patients who underwent CT, the CT results were positive in 27 (25.7%) patients, negative in 77 (73.3%) patients, and inconclusive in one (1.0%) patient.

TABLE 3: Focused Appendicitis Ultrasound Versus Surgical Finding of Appendicitis

Surgery Performed	Focused Appendicitis Ultrasound Finding			Total
	Inconclusive	Negative	Positive	
No	343	27	7	377
Yes	47	0	98	145
Total	390	27	105	522

TABLE 4: Alvarado Scores for Patients With Inconclusive Focused Appendicitis Ultrasound Versus Surgical Findings of Appendicitis

Positive Surgical Finding of Appendicitis	Alvarado Score				Total
	0–4	5–6	7–8	9–10	
No	240	74	33	0	347
Yes	1	11	28	3	43
Total	241	85	61	3	390

Outcomes in Sample Set

All 98 patients with focused appendicitis ultrasound findings positive for appendicitis who underwent surgery had appendicitis. Seven patients met the ultrasound criteria of a finding positive for appendicitis but were not considered ill enough to need surgery and were therefore considered to have false-positive focused appendicitis ultrasound findings. There were no cases of missed appendicitis in the study population. Table 3 shows the results of focused appendicitis ultrasound versus the surgical findings of appendicitis.

Forty-seven of 390 (12.1%) patients with inconclusive focused appendicitis ultrasound findings eventually underwent surgery. Forty-three had surgical pathologic results positive for appendicitis, two had negative results, and two had other diagnoses (cystic teratoma and infected lymphangioma). The total negative appendectomy rate among patients who underwent surgery with either positive or inconclusive focused appendicitis ultrasound findings was 2 of 145 (1.4%). Of 43 cases of a surgical finding of appendicitis with inconclusive focused appendicitis ultrasound findings, 26 cases were diagnosed with CT and 17 with Alvarado score. Table 4 shows the results for Alvarado score versus surgical findings positive for appendicitis.

Statistical Significance and Descriptive Statistics

Focused appendicitis ultrasound findings positive for appendicitis were significantly associated with the likelihood of undergoing surgery for appendicitis ($p = 0.0001$). Alvarado score was significantly associated with the presence of appendicitis ($p = 0.0001$). In patients with inconclusive focused appendicitis ultrasound findings, the median Alvarado score for children without appendicitis was 3 (range, 0–8). The median Alvarado score for children with appendicitis was 7 (range, 2–9).

Overall, the sensitivity and specificity of focused appendicitis ultrasound (conclusive and inconclusive findings combined) were 67.6% and 98.1%. In children with inconclusive focused appendicitis ultrasound findings and a low Alvarado score (0–4) (241/522 [46.2%]), only one patient (0.41%) had appendicitis. The NPV of inconclusive focused appendicitis ultrasound findings and low Alvarado score combined was 99.6%. In children with inconclusive focused appendicitis ultrasound findings and both low and intermediate (5–8) Alvarado scores combined, the NPV decreased to 89.7%. In children with inconclusive focused appendicitis ultrasound findings and a high Alvarado score (9–10) combined, the PPV was 100%.

Radiation Reduction: Number of CT Examinations Avoided

Of 241 patients with inconclusive focused appendicitis ultrasound findings and low clinical suspicion (Alvarado score, 0–4), only one had appendicitis (0.41%). If CT had not been performed in this group after focused appendicitis ultrasound, 43 of 241 (17.8%) CT examinations would have been avoided in this sample. Two additional CT examinations would have been avoided if not performed in the group with high clinical suspicion (Alvarado score, 9–10). The total reduction in CT examinations achieved would be 42.8% (45 of 105 patients who underwent CT).

Body Mass Index Evaluation

The mean BMI of children with a nonvisualized appendix (inconclusive focused appendicitis ultrasound finding, $n = 291$) was 22.66 (range, 10.28–43.69). The mean BMI of children with a visible appendix (positive or negative focused appendicitis ultrasound finding, $n = 110$) was 21.2 (range, 12.03–41.45). There was a significant difference in BMI between the two groups ($p = 0.0419$). The BMI and age means for our patient population stratified by sex were BMI of 20.97 and age of 11.71 for boys and BMI of 23.34 and age of 13.99 years for girls. Both boys and girls were well above the U.S. mean BMI for age percentiles: 86% for boys [16] and 85% for girls [17].

Discussion

Acute appendicitis is the most common abdominal surgical problem in pediatrics. The diagnosis of appendicitis is often complex, particularly in children who are nonverbal and in whom signs and symptoms may be imprecise. The presentation may be atypical in as many as 45% of patients [18]. Imaging therefore plays an essential role in the prompt and accurate diagnosis of appendicitis. The decision to perform CT has been questioned as awareness has increased about the stochastic effects of imaging-associated radiation and its link to the risk of radiation-induced malignancy [19, 20].

Although the trend has been to use ultrasound as the initial imaging modality to diagnose appendicitis in children, the lower sensitivity of ultrasound has led to diverging opinions. Some authors favor judicious use of CT, citing the risk of perforation and worsening peritonitis versus unnecessary surgery in patients with symptoms [10]. Results of a 2011 study by Krishnamoorthi et al. [21] suggested the effectiveness of a staged ultrasound and CT protocol in which ultrasound is performed first for children with suspected acute appendicitis; CT is performed if the ultrasound findings are equivocal. In our study, we expanded this approach, aiming to further reduce the use of CT by stratifying patients with equivocal (inconclusive) ultrasound findings into groups based on clinical risk of appendicitis and eliminating those at either very low or very high risk from the group of patients for whom follow-up CT would be beneficial.

Clinical scoring systems have been used by pediatric emergency departments to codify often confounding physical and laboratory findings. The Alvarado score, using the eight clinical criteria in Table 1, was introduced in 1986. The Samuel pediatric appendicitis score is a further modification purported to be simpler and more cost-effective [22]. Results of several studies have confirmed that these systems have insufficient PPV to be used exclusively, particularly for the mid-range clinical scores. Nonetheless, they have been useful in reducing the use of CT [23, 24].

Our results agree with those of Rezak et al. [25], who found that an Alvarado score of 4 or less was not associated with appendicitis and that CT of the abdomen was not beneficial in this patient group. Fleischman et al. [26] also found that low-risk clinical criteria had good sensitivity in ruling out appendicitis. In our study, we found only one case of appendicitis in 241 patients with low clinical suspicion. Our results suggest that patients with an equivocal Alvarado score of 5–8 may benefit from additional CT. In our study an Alvarado score of 9 or 10 was 100% predictive of appendicitis.

At our institution, most children with right lower quadrant pain are referred for focused appendicitis ultrasound. Given the low incidence of appendicitis in patients with a low Alvarado score, this may be a misuse of medical resources. The principal value of focused appendicitis ultrasound in this patient group lies in finding alternative diagnoses, particularly in adolescents with ovarian abnormalities. In our study, 55 of 390 (14.1%) of focused appendicitis ultrasound findings that were inconclusive for appendicitis yielded an alternative diagnosis. Forty of the patients were girls, and 20 (50%) had ovarian abnormalities. We also found a significantly higher BMI among patients with inconclusive findings of focused appendicitis ultrasound than among those with a visible appendix. Focused appendicitis ultrasound findings may be masked in patients with a higher BMI and may not be as accurate in these patients as in others.

The results of this study suggest that CT could have been eliminated in the evaluation of patients with an Alvarado score less than 5 without substantial risk of missed diagnosis. If this suggestion had been followed during the study period, 43 CT examinations would have been eliminated. An additional two CT examinations could have been eliminated in the group at high risk.

In certain instances, CT may be useful in children when the ultrasound or clinical findings are positive for appendicitis. CT is particularly helpful for finding complications such as bowel obstruction, septic seeding of mesenteric vessels, and gangrenous appendicitis, and for determining the extent and location of abscess collections. Delayed CT may help guide either percutaneous drainage or surgical planning.

The limitations of our study include retrospective calculation of Alvarado score and performance of the physical examinations by several emergency department physicians; therefore, the clinical data may not be precisely reproducible. Our pediatric patient population is more overweight than the general pediatric population, as found both in our previous research [27] and in the current study. Therefore, our results may not be generalizable to different patient populations.

Conclusion

Our results show that collaboration between radiologists and pediatric emergency physicians results in optimal utilization of radiology resources in children with suspected appendicitis. Children with both inconclusive focused appendicitis ultrasound findings and a low Alvarado score are extremely unlikely to have appendicitis, the NPV being 99.6%. CT can be safely avoided in these patients without clinical harm.

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