Use and Accuracy of Diagnostic Imaging by Hospital Type in Pediatric Appendicitis

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KEY WORDS

appendicitis, pediatrics, diagnostic imaging, computed tomography, ultrasound

ABBREVIATIONS

CI—confidence interval
CT—computed tomography
OR—odds ratio
WBC—white blood cell

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WHAT'S KNOWN ON THIS SUBJECT: Because pediatric appendicitis is challenging to diagnose, computed tomography (CT) is used frequently. Childhood radiation exposure is associated with increased risk of cancer. Ultrasound avoids radiation exposure but is less sensitive for appendicitis than CT.

WHAT THIS STUDY ADDS: Controlling for referral bias, evaluation at a community compared with a children's hospital is associated with higher CT and lower ultrasound use before appendectomy. CT and ultrasound accuracy for appendicitis in children varies with hospital type.

abstract

NIH

OBJECTIVE: Accurate, timely diagnosis of pediatric appendicitis minimizes unnecessary operations and treatment delays. Preoperative abdominal-pelvic computed tomography (CT) scan is sensitive and specific for appendicitis; however, concerns regarding radiation exposure in children obligate scrutiny of CT use. Here, we characterize recent preoperative imaging use and accuracy among pediatric appendectomy subjects.

METHODS: We retrospectively reviewed children who underwent operations for presumed appendicitis at a single tertiary-care children's hospital and examined preoperative CT and ultrasound use with subject characteristics. Preoperative imaging accuracy was compared with postoperative and histologic diagnosis as the reference standard.

RESULTS: Most children (395/423, 93.4%) who underwent an operation for appendicitis during 2009–2010 had preoperative imaging. Final diagnoses included normal appendix (7.3%) and perforated appendicitis (23.6%). In multivariable analysis, initial evaluation at a community hospital versus the children's hospital was associated with 4.4-fold higher odds of obtaining a preoperative CT scan (P = .002), whereas preoperative ultrasound was less likely (odds ratio 0.20; P = .003). Ultrasound and CT sensitivities for appendicitis were diminished for studies performed at community hospitals compared with the children's hospital. Girls were 4.5-fold more likely to undergo both ultrasound and CT scans and were associated with lower ultrasound sensitivity for appendicitis.

CONCLUSIONS: Widespread preoperative imaging did not eliminate unnecessary pediatric appendectomies. Controlling for factors potentially associated with referral bias, a CT scan was more likely to be performed in children initially evaluated at community hospitals compared with the children's hospital. Broadly-applicable strategies to systematically maximize diagnostic accuracy for childhood appendicitis, while minimizing ionizing radiation exposure, are urgently needed. *Pediatrics* 2013;131:e37–e44

Accounting for 84 000 hospitalizations per year in the United States,[1] appendicitis is the most common surgically-treated cause of pediatric acute abdominal pain. Because of nonspecific symptoms, examination findings, and laboratory abnormalities, the definitive diagnosis poses many challenges, especially in young children.[2] Several nonsurgical conditions, such as gastroenteritis, urinary tract infection, pneumonia, and ovarian pathology, can mimic appendicitis.[3] Such diagnostic difficulty contributes to the occurrence of "negative" appendectomy, or finding a normal appendix during operation, in 3.7%[4] to 13%[5] of cases. Expeditious diagnosis of appendicitis is a priority, because prolonged appendiceal inflammation progresses to gangrene or perforation, which is associated with lengthy recovery and greater risk of complications.[6]

To enhance accuracy in diagnosing appendicitis, imaging studies are obtained often during evaluation of children with acute abdominal pain. Preoperative abdominal pelvic computed tomography (CT) scan is highly sensitive and specific[7] and widely available. Disadvantages include associated cost and radiation exposure, up to 25 mSv per study.[8] Abdominal ultrasound is also highly specific but lacks radiation exposure; however, ultrasound sensitivity is variable,[7,9] and availability is less consistent.[10,11]

Recent concerns about pediatric radiographic imaging have emerged from the association of ionizing radiation exposure with subsequent development of cancer.[12] Increased solid cancer risk was found in survivors of the Hiroshima and Nagasaki nuclear bomb detonations with exposure >50 mSv and when exposure occurred at <6 years of age. The Image Gently campaign by the Alliance for Radiation Safety in Pediatric Imaging/Society for Pediatric Imaging has promoted radiation exposure reduction through the use of the minimal dose to obtain an adequate image.[13] However, children undergoing CT scans at nonpediatric hospitals might still receive inappropriately high radiation doses.[14] Moreover, the use of CT scans has markedly increased over the past decade.[8,15,16]

Here, we assessed contemporary preoperative imaging in the evaluation of children who underwent operation for appendicitis at a major urban children's hospital. CT and ultrasound accuracy in diagnosing appendicitis were evaluated with regard to specific patient characteristics.

METHODS

Design and Study Population

This retrospective, single-institution, cohort study was conducted to examine imaging utilization and accuracy in pediatric subjects who underwent an operation for appendicitis. After obtaining Washington University Human Research Protection Office approval, subjects treated at a tertiary-care children's hospital were identified from physician billing records by *Current Procedural Terminology* code and hospital operative logs by procedure name. To capture subjects with a preoperative diagnosis of acute appendicitis who had a normal-appearing appendix and did not undergo appendectomy, procedures coded for diagnostic laparoscopy and Meckel diverticulectomy were screened for study inclusion. Included subjects had undergone appendectomy for acute abdominal pain or operation for a preoperative diagnosis of acute appendicitis between January 1, 2009 and December 31, 2010. Excluded subjects were <1 or >18 years at the time of operation, had incomplete medical records, or underwent appendectomy incidentally or for chronic abdominal pain.

Data Collection and Study Variables

Data were extracted from institutional electronic medical records and managed by using REDCap, a Web-based database hosted at Washington University School of Medicine.[17] Variables included site of initial evaluation, age, gender, race/ethnicity, primary insurance source, duration of abdominal symptoms, weight, height, white blood cell (WBC) count, percentage of neutrophils, and preoperative radiographic imaging findings and diagnosis. Duration of abdominal symptoms was determined from a review of emergency unit and admission notes. BMI percentile by age and gender was calculated by using the Centers for Disease Control and Prevention Children's BMI Tool for Schools.[18] Underweight was defined as <5th percentile, overweight 85th to <95th percentile, and obese ≥95th percentile for BMI by age and gender.[19] Neutrophil count was calculated from the product of WBC count and percentage of neutrophils. Perforation of the appendix was assigned according to the surgeon's operative report. Negative appendectomy was defined as (1) operation with preoperative diagnosis of appendicitis, and (2) minimal or no histologic evidence of appendiceal acute inflammation if the appendix was removed, or normal appendiceal appearance if left in place. Radiographic impression and findings were derived from written radiologist reports or surgeon's impression as recorded in the admission note when the radiologist written report was not available.

Data Analysis

Statistical analysis was performed by using SPSS Statistics GradPack (version 17.0, IBM Corporation, Somers, NY) and SAS (version 9.3, SAS Institute Inc, Cary, NC). The primary outcome was preoperative imaging (none, ultrasound only, CT only, both ultrasound and CT), and independent variables included age, gender, BMI percentile, race/ethnicity, primary insurance type, duration of abdominal symptoms, WBC count, neutrophil count, and percentage of neutrophils. Univariate analyses included χ^2, Fisher exact, *t* test, Mann-Whitney *U* test, and multinomial logistic regression. Multivariable analysis was performed with multinomial logistic regression to control for confounders and referral bias. Independent variables included in the model had association with the dependent variable ($P < .20$) in univariate analysis and/or were potential confounders. Level of significance was set at $P < .05$.

Imaging accuracy was assessed by comparing CT and ultrasound impression regarding the appendiceal appearance (normal/indeterminate, acute, complicated/perforated) to final diagnosis (normal, acute/gangrenous appendicitis, or perforated appendicitis) as the reference standard. Indeterminate studies were included with normal findings (ie, not appendicitis). The Cohen weighted κ statistic was determined for the cohort overall and by subgroups, including location where the imaging study was performed, and subject age, gender, and weight classification by BMI percentile; 95% confidence intervals (CIs) were calculated by using normal approximation or exact method where appropriate. Sensitivities for any appendicitis (acute or perforated) and perforated appendicitis were calculated. Specificity, positive predictive value, and negative predictive value were not assessed, because the cohort did not include patients who had general abdominal pain who underwent imaging to evaluate for appendicitis and no operation.

RESULTS

We identified 423 children who underwent an operation for the preoperative diagnosis of appendicitis or appendectomy for acute abdominal pain during the study interval. Characteristics of the cohort are summarized in Table 1. Almost all children underwent laparoscopic appendectomy (*n* = 396, 93.6%), and 9 (2.3% of laparoscopic procedures) underwent conversion to an open approach. The proportion of negative appendectomy was low (*n* = 31, 7.3%). Perforated appendicitis was found in 23.6% (*n* = 100) (Table 1). Sixteen children diagnosed with perforated appendicitis were treated with intravenous antibiotics followed by delayed (interval) appendectomy (3.8% of entire cohort, 16.0% of perforated appendicitis subjects). Subjects who were initially evaluated at a community hospital were younger (10.7 ± 3.6 vs 11.8 ± 3.7, mean ± SD, $P = .003$), more frequently white ($P < .001$), and insured with Medicaid/government source ($P = .045$) than those evaluated initially at the children's hospital. There were trends toward shorter duration of abdominal symptoms (1.7 ± 1.4 vs 2.0 ± 1.9 days, $P = .10$) and higher initial total WBC count (15.8 ± 4.9 vs 14.8 ± 5.4, $P = .051$) in children initially evaluated at a community hospital in comparison with the children's hospital. The 2 groups did not differ in terms of gender, BMI percentile, percentage of neutrophils, and neutrophil count. Also, final diagnosis distribution of subjects referred from community hospitals did not differ from those primarily evaluated at the children's hospital.

Only 28 (6.6%) subjects underwent an operation without preoperative imaging, whereas 64 (15.1%) had both CT scans and ultrasound (Table 2). Univariate analysis of preoperative imaging utilization by multinomial logistic regression demonstrated significant differences by the site of initial evaluation, gender, race/ethnicity, BMI percentile, symptom duration, and WBC count. Of note, among subjects initially evaluated at community hospitals, 10 underwent CT scan and 30 had ultrasound at the children's hospital. Among subjects who were initially evaluated at the children's hospital, the primary physician ordered imaging studies (17 CT scans, 2 ultrasounds) that were performed at another facility.

Multivariable analysis of preoperative imaging revealed significant differences by site of initial evaluation (Table 3). Age, gender, race/ethnicity, BMI percentile,

TABLE 1 Cohort Demographics Overall and by Site of Initial Evaluation for Acute Abdominal Pain

Variable	Overall, *n* = 423	Community, *n* = 218	Children's, *n* = 205	*P*
Age, y	11.25 ± 3.70	10.74 ± 3.61	11.80 ± 3.73	.003
Gender				
Female, *n* (%)	170 (40.2)	88 (40.4)	82 (40.0)	.94
BMI percentile	61.90 ± 30.88	62.19 ± 30.39	61.57 ± 31.48	.85
Race/ethnicity, *n* (%)				<.001
White	345 (81.6)	193 (88.5)	152 (74.1)	
African American	56 (13.2)	16 (7.3)	40 (19.5)	
Other	22 (5.2)	9 (4.1)	13 (6.3)	
Insurance, *n* (%)				.045
Medicaid/government	127 (30.0)	77 (35.3)	50 (24.4)	
Private	283 (66.9)	134 (61.5)	149 (72.7)	
None/self-pay	13 (3.1)	7 (3.2)	6 (2.9)	
Symptom duration, days	1.86 ± 1.68	1.73 ± 1.43	2.00 ± 1.91	.10
WBC count, K/mm^3	15.32 ± 5.17	15.80 ± 4.90	14.81 ± 5.42	.051
Final diagnosis, *n* (%)				.64
Normal	31 (7.3)	17 (7.8)	14 (6.8)	
Acute	292 (69.0)	146 (67.0)	146 (71.2)	
Perforated	100 (23.6)	55 (25.2)	45 (22.0)	

Age, symptom duration, BMI percentile, and WBC count are expressed as mean ± SD. Percentage for gender, race/ethnicity, insurance, and final diagnosis represents column percentage.

TABLE 2 Univariate Analysis (Multinomial Logistic Regression) for Predictors of Preoperative Imaging Use

Preoperative Imaging	None	Ultrasound Only	CT Only	Ultrasound and CT	*P*
Overall, *n* (%)	28 (6.6)	113 (26.7)	218 (51.5)	64 (15.1)	
Initial evaluation, *n* (%)					<.001
Community	10 (4.6)	19 (8.7)	164 (75.2)	25 (11.5)	
Children's	18 (8.8)	94 (45.9)	54 (26.3)	39 (19.0)	
Age, y	11.93 ± 3.38	10.72 ± 3.87	11.53 ± 3.45	10.95 ± 4.26	.175
Gender, *n* (%)					.001
Female	8 (4.7)	42 (24.7)	80 (47.1)	40 (23.5)	
Male	20 (7.9)	71 (28.1)	138 (54.5)	24 (9.5)	
Race/ethnicity, *n* (%)					.011
White	19 (5.5)	84 (24.3)	192 (55.7)	50 (14.5)	
African American	5 (8.9)	22 (39.3)	19 (33.9)	10 (17.9)	
Other	4 (18.2)	7 (31.8)	7 (31.8)	4 (18.2)	
BMI percentile[a]	77.12 ± 24.68	55.24 ± 30.51	64.93 ± 30.60	56.39 ± 31.64	.003
Symptom duration, days	1.29 ± 0.68	1.54 ± 1.17	1.80 ± 1.52	2.88 ± 2.65	<.001
WBC count, K/mm^3[b]	15.63 ± 3.73	15.57 ± 5.60	15.65 ± 5.03	13.66 ± 5.17	.06

Percentage reflects row percentage for site of initial evaluation, gender, and race/ethnicity. Mean ± SD for age, BMI percentile, symptom duration, and WBC count is listed. Insurance type was not significantly different among the preoperative imaging groups (*P* = .31).

[a] BMI percentile missing in 51 subjects (12.1%).

[b] WBC count missing in 5 subjects (1.2%).

symptom duration, and WBC count were included in the model because of significant association in univariate analysis or to adjust for referral bias/confounding. Compared with no preoperative imaging, ultrasound alone was less likely (odds ratio [OR] 0.20; 95% CI 0.07–0.58; *P* = .003), and CT scan alone was more likely (OR 4.37; 95% CI 1.70–11.19; *P* = .002) with initial evaluation at a community hospital in comparison with the children's hospital. Preoperative imaging with ultrasound alone was less likely with higher BMI percentile (OR 0.98; 95% CI 0.96–0.99; *P* = .01), whereas CT alone was associated with white race (OR 5.39; 95% CI 1.31–22.19). Higher odds of obtaining both ultrasound and CT scan preoperatively was found with female gender (OR 4.51; 95% CI 1.47–13.82; *P* = .008), lower BMI percentile (OR 0.98; 95% CI 0.96–1.00; *P* = .03), longer symptom duration (OR 1.81; 95% CI 1.15–2.86; *P* = .01), and lower WBC count (OR 0.87; 95% CI 0.78–0.97; *P* = .01).

Agreement between the CT impression and final diagnosis was moderate overall (Table 4). CT scans performed at community hospitals tended to have less agreement with final diagnosis than those performed at the children's hospital. CT scans in older and nonobese children had the highest weighted κ, but the paucity of studies limited the calculation of κ in underweight children. Sensitivity for any appendicitis was high overall but trended lower in CT scans performed at community hospitals than at the children's hospital (*P* = .07) (Table 5). CT sensitivity for perforated appendicitis was low overall and significantly lower in CT performed at community hospitals.

Ultrasound accuracy for appendicitis was fair overall (Table 6). The rarity with which ultrasound was performed at community hospitals precluded calculation of weighted κ for this subgroup. Ultrasound-weighted κ was higher in the oldest age group (age, 13–18 years) and boys. Ultrasound sensitivity for any appendicitis was moderate overall and was significantly lower in studies performed at community hospitals and on girls (Table 7). Ultrasound detection of perforated appendicitis was generally poor. The high proportion of normal/indeterminate ultrasound studies (57/177, 32.2%) accounted, in part, for the fair accuracy and low sensitivity for appendicitis.

Among subjects who underwent both ultrasound and CT scans, ultrasounds were often normal or indeterminate (44/64, 68.8%), whereas few CT scans were normal or indeterminate (9/64, 14.1%). Most subjects underwent ultrasound before CT (46/64, 71.9%); normal/indeterminate ultrasound increased the odds of CT 17-fold (95% CI 7.7–37.0). Normal/indeterminate ultrasound and CT scans were found in 2 subjects with appendicitis and 5 subjects who had negative appendectomy.

TABLE 3 Multivariable Analysis (Multinomial Logistic Regression) of Initial Evaluation Location Impact on Preoperative Imaging With Adjustment for Other Variables

Preoperative Imaging	Ultrasound Only			CT Only			CT and Ultrasound		
	OR	95% CI	*P*	OR	95% CI	*P*	OR	95% CI	*P*
Initial evaluation									
Community	0.20	0.07–0.58	.003	4.37	1.70–11.19	.002	0.99	0.34–2.98	.99
Age, y	0.88	0.76–1.02	.08	1.03	0.90–1.18	.66	0.88	0.76–1.03	.11
Female gender	1.53	0.52–4.50	.44	1.30	0.47–3.59	.61	4.51	1.47–13.82	.008
Race/ethnicity									
White	2.63	0.59–11.71	.20	5.39	1.31–22.19	.02	4.48	0.75–26.66	.10
African American	3.29	0.48–22.50	.22	3.26	0.50–21.08	.22	4.42	0.48–40.58	.19
Other	Ref.			Ref.			Ref.		
BMI percentile	0.98	0.96–0.99	.01	0.99	0.97–1.01	.16	0.98	0.96–1.00	.03
Symptom duration, days	1.16	0.74–1.84	.52	1.44	0.93–2.24	.11	1.81	1.15–2.86	.01
WBC count, K/mm^3	0.96	0.87–1.06	.39	0.98	0.89–1.07	.65	0.87	0.78–0.97	.01

ORs and 95% CI for imaging (ultrasound only, CT scan only, ultrasound and CT) compared with no imaging (reference [Ref.]) are listed. Reference categories are children's hospital for site of initial evaluation, male for gender, and other for race/ethnicity. OR is change per unit specified for age, BMI percentile, symptom duration, and WBC count.

DISCUSSION

In this cohort of children operatively treated for presumed appendicitis at a single, tertiary-care children's hospital,

TABLE 4 Accuracy of Preoperative CT Impression Compared With Final Diagnosis: Agreement (Weighted κ)

CT Scan	κ	95% CI	*n*
Overall	0.54	0.44–0.64	282
Study location			
Community	0.48	0.36–0.60	196
Children's	0.69	0.54–0.85	86
Age, y			
1–6	0.35	0.05–0.65	30
7–12	0.56	0.40–0.71	104
13–18	0.58	0.44–0.72	148
Weight category			
Underweight/normal	0.58	0.46–0.70	169
Overweight	0.60	0.34–0.86	42
Obese	0.31	0.02–0.60	44
Gender			
Female	0.60	0.47–0.74	120
Male	0.49	0.35–0.63	162

the majority underwent preoperative imaging. Diagnostic imaging selection and accuracy varied with the site of initial evaluation. Controlling for factors potentially associated with referral bias and illness severity, the performance of preoperative abdominal-pelvic CT scan was significantly associated with initial evaluation at community hospitals, whereas abdominal ultrasound was more likely obtained with initial evaluation at the children's hospital. Variation in CT use by hospital type has been reported,[20,21] and, here, we extend the observation by examining ultrasound in combination with CT use and adjusting for subject characteristics that potentially influenced the likelihood of interfacility transfer. In addition, we found that CT and ultrasound studies performed at community hospitals in comparison with the children's hospital had diminished accuracy for diagnosing appendicitis.

Variation in diagnostic imaging use for pediatric appendicitis by initial evaluation location might stem from multiple factors, such as availability of imaging or the perceived need for diagnosis confirmation. First, compared with ultrasound, the ready availability of CT scans may account for frequent use in community hospitals. CT use for pediatric abdominal pain evaluation has markedly increased over the past decade in emergency departments, particularly nonpediatric-focused departments.[15,16] By contrast, ultrasound use over time has remained constant[16]; decreased or inconsistent availability of emergent ultrasound within community hospitals might contribute to this pattern.[10,11] Second, concern over diagnostic errors might prompt CT use. Appendicitis is among the leading diagnoses associated with pediatric diagnostic errors[22] and malpractice claims.[23] Low physician risk tolerance among emergency medicine physicians has been associated with more frequent CT use for evaluation of adult acute abdominal pain.[24] Finally, practitioners might have greater confidence in CT scans in comparison with ultrasound; a previous survey of North American pediatric surgeons in 2004 demonstrated preference for CT over ultrasound in appendicitis evaluation.[25] However, our finding of more frequent ultrasound use in the children's hospital may reflect conscious avoidance of ionizing radiation exposure. Interestingly, subjects who had both CT scan and ultrasound were more likely to be female and to have lower BMI percentile, longer duration of symptoms, and lower WBC count. Ultrasound may have served to evaluate for gynecologic pathology in girls. The longer duration of symptoms might have increased the perceived urgency to establish the diagnosis of appendicitis, although lower WBC count would not be expected with advanced or perforated appendicitis. Rather, imaging with both CT and ultrasound might have been obtained in clinically confusing cases, the identity of which cannot be discerned in retrospect. In many instances, CT scans followed nondiagnostic ultrasound, as recommended in several previous studies.[26–28]

Despite frequent use, CT accuracy was reduced when performed in the community setting. Although overall CT sensitivity for any appendicitis was similar to previous reports,[7] CT scans performed at the children's hospital were somewhat more sensitive than at referring institutions. For perforated appendicitis, CT studies from the children's hospital had significantly higher sensitivity. One potential reason for diminished accuracy is that multidetector CT, which is used at the children's hospital, might be less available at referring community hospitals. Multidetector CT offers the advantages of improved resolution through thinner sections and coronal reconstructions

TABLE 5 Accuracy of Preoperative CT Impression Compared With Final Diagnosis: Sensitivities for Any Appendicitis and Perforated Appendicitis

CT Scan	Any Appendicitis			Perforated Appendicitis		
	Sensitivity		*P*	Sensitivity		*P*
Overall	249/262	95.0%		42/73	57.5%	
Study location			.07			.045
Community	169/181	93.4%		24/49	49.0%	
Children's	80/81	98.8%		18/24	75.0%	
Age, y			.42			.77
1–6	26/28	92.9%		6/11	54.5%	
7–12	95/98	96.9%		16/30	53.3%	
13–18	128/136	94.1%		20/32	62.5%	
Weight category			.23			.17
Underweight/normal	145/155	93.5%		30/46	65.2%	
Overweight/obese	80/82	97.6%		9/20	45.0%	
Gender			.78			.35
Female	102/108	94.4%		20/31	64.5%	
Male	147/154	95.5%		22/42	52.4%	

TABLE 6 Accuracy of Preoperative Ultrasound Impression Compared With Final Diagnosis: Agreement (Weighted κ)

Ultrasound	κ	95% CI	*n*
Overall	0.33	0.22–0.44	177
Study location			
Community	—	—	16
Children's	0.36	0.24–0.48	161
Age, y			
1–6	0.27	0.002–0.55	28
7–12	0.29	0.10–0.49	67
13–18	0.38	0.22–0.54	82
Weight category			
Underweight/normal	0.33	0.20–0.47	120
Overweight/obese	0.36	0.14–0.59	34
Gender			
Female	0.28	0.14–0.43	82
Male	0.40	0.21–0.55	95

—, values unable to be calculated.

that could enable visualization of the appendix.[29] Lack of intravenous contrast,[30] suboptimal intravenous contrast bolus timing, and patient movement, especially in younger children, may have affected the quality of CT scans performed at referring hospitals in comparison with the children's hospital. Finally, the interpretation of CT by general versus pediatric radiologists may contribute to the CT accuracy difference.[31] Technical quality of imaging and radiologist type were not specifically captured in this study.

In contrast to CT scan sensitivity, ultrasound sensitivity for appendicitis was much lower than previously reported in a meta-analysis.[7] Ultrasounds performed at community hospitals were less sensitive for the detection of appendicitis and perforation. Although children evaluated at the children's hospital frequently underwent ultrasound alone, fair to moderate accuracy combined with a low negative appendectomy rate implies that clinical impression, derived from symptoms, physical examination findings, and laboratory results, influenced clinical decision-making when ultrasound findings were not definitive. Evaluation by a pediatric surgeon has been previously shown to have comparable accuracy to imaging studies in the assessment of children for appendicitis.[32] However, evaluation by a pediatric surgeon often necessitates transfer to a tertiary-care or children's hospital.

Patient-specific factors impacted both CT and ultrasound accuracy. Trends toward diminished CT accuracy were associated with younger patient age, obesity, and male gender, although κ was not significantly different, possibly because of the small numbers of studies. For ultrasound, κ trended lower in younger and female children. Previous studies have examined the impact of obesity on ultrasound and CT accuracy. For ultrasound, Butler et al[33] found a decreased likelihood of visualizing the appendix with increased abdominal wall thickness and retrocecal appendix location, and Schuh et al[34] found diminished accuracy for appendicitis in children who were obese in comparison with children who were lean. Abo et al[9] identified a trend toward decreased ultrasound sensitivity in overweight and obese children, but no difference in CT sensitivity. In this cohort, ultrasound sensitivity for any appendicitis was not affected by obesity; however, few obese children had ultrasound, possibly because of low confidence in the diagnostic utility of ultrasound for these children. Girls had significantly lower ultrasound sensitivity for any appendicitis compared with boys. This gender difference might reflect the use of ultrasound to exclude gynecologic causes of abdominal pain rather than to diagnose appendicitis.

To reduce reliance on CT scans, diagnostic algorithms and clinical scoring systems have been developed.[35–39] Most of these were validated in children's hospitals, and differing thresholds for imaging and operation were found even with the same scoring system.[35,36] Unfortunately, both symptoms and physical examination assessment have low correlation among practitioners,[40,41] which could account for the variable cut points. To address CT use within community hospitals, clinical decision tools are needed that are applicable to practitioners with varying levels of pediatric or surgical expertise at all points of evaluation. The identification of children likely to have appendicitis (high pretest probability) would potentially avoid CT scans before transfer to a center for operative treatment, while also limiting unnecessary transfers. Assessment of the reasons for obtaining CT would inform how to best reduce CT use. Optimal imaging may depend on multiple factors,

TABLE 7 Accuracy of Preoperative Ultrasound Impression Compared With Final Diagnosis: Sensitivities for Any and Perforated Appendicitis

Ultrasound	Any Appendicitis			Perforated Appendicitis		
	Sensitivity		*P*	Sensitivity		*P*
Overall	114/159	71.7%		19/43	44.1%	
Study location			.01			.50
Community	5/13	38.5%		0/2	0%	
Children's	109/146	74.7%		19/41	46.3%	
Age, y			.38			.80
1—6	21/27	77.7%		3/9	33.3%	
7–12	44/58	75.9%		8/18	44.4%	
13–18	49/74	66.2%		8/16	50.0%	
Weight category			.50			>.99
Underweight/normal	78/108	72.2%		14/32	43.8%	
Overweight/obese	20/31	64.5%		4/8	50.0%	
Gender			.03			.36
Female	46/73	63.0%		8/22	36.4%	
Male	68/86	79.1%		11/21	52.4%	

such as patient age, gender, body habitus, symptoms, potential alternate diagnoses, accuracy of imaging modality for patient subtype, and specific hospital resources. The value of diagnostic confirmation in avoiding unnecessary interfacility transfer, hospital admission, operations, and treatment delays must be balanced against the harm of radiation exposure from CT, and costs to maintain ultrasound technical proficiency and to provide pediatric expertise.

The retrospective and single-center study structure presents several limitations. Additional similar analyses in other sites will ascertain the generalizability of our findings. We cannot address what specific impact imaging had in the evaluation of children with possible appendicitis; the value of normal imaging in preventing an unnecessary operation or hospital transfer could not be assessed with this cohort. The initial symptoms and physical examination findings of subjects were not recorded with sufficient consistency to permit a detailed analysis of imaging utilization with regard to clinical presentation. Consequently, the few subjects who did not have imaging during initial evaluation may have had more obvious clinical evidence of appendicitis. Nonetheless, the high imaging utilization implies that at least some CT scans and ultrasounds were confirmatory rather than essential. The selection criteria for the cohort were chosen to capture negative appendectomies; despite this, the proportion of operations performed for a normal appendix may be underestimated if the appendix was not removed. Whether community physiciansobtain imaging in children with suspected appendicitis routinely or selectively to confirm the diagnosis before interfacility transfer for operative care cannot be determined from this study. Finally, the limited number of subjects within subgroups precluded multivariable analysis of CT and ultrasound accuracy.

CONCLUSIONS

The near universal use of preoperative imaging was associated with a low proportion of negative appendectomy in children who underwent operation for presumed appendicitis. Preoperative CT use was significantly higher in children initially evaluated at community hospitals in comparison with the children's hospital, whereas ultrasound use was significantly lower. Potential targets to streamline the evaluation for pediatric appendicitis include algorithm development with broad validity to decrease reliance on preoperative imaging and radiation exposure while avoiding unnecessary hospital transfers, admissions, operations, and missed diagnoses.

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