An Interdisciplinary Initiative to Reduce Radiation Exposure: Evaluation of Appendicitis in a Pediatric Emergency Department With Clinical Assessment Supported by a Staged Ultrasound and Computed Tomography Pathway

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Abstract

Objectives: In the emergency department (ED), a significant amount of radiation exposure is due to computed tomography (CT) scans performed for the diagnosis of appendicitis. Children are at increased risk of developing cancer from low-dose radiation and it is therefore desirable to utilize CT only when appropriate. Ultrasonography (US) eliminates radiation but has sensitivity inferior to that of CT. We describe an interdisciplinary initiative to use a staged US and CT pathway to maximize diagnostic accuracy while minimizing radiation exposure.

Methods: This was a retrospective outcomes analysis of patients presenting after hours for suspected appendicitis at an academic children's hospital ED over a 6-year period. The pathway established US as the initial imaging modality. CT was recommended only if US was equivocal. Clinical and pathologic outcomes from ED diagnosis and disposition, histopathology and return visits, were correlated with the US and CT. ED diagnosis and disposition, pathology, and return visits were used to determine outcome.

Results: A total of 680 patients met the study criteria. A total of 407 patients (60%) followed the pathway. Two-hundred of these (49%) were managed definitively without CT. A total of 106 patients (26%) had a positive US for appendicitis; 94 (23%) had a negative US. A total of 207 patients had equivocal US with follow-up CT. A total of 144 patients went to the operating room (OR); 10 patients (7%) had negative appendectomies. One case of appendicitis was missed (<0.5%). The sensitivity, specificity, negative predictive value, and positive predictive values of our staged US-CT pathway were 99%, 91%, 99%, and 85%, respectively. A total of 228 of 680 patients (34%) had an equivocal US with no follow-up CT. Of these patients, 10 (4%) went to the OR with one negative appendectomy. A total of 218 patients (32%) were observed clinically without complications.

Conclusions: Half of the patients who were treated using this pathway were managed with definitive US alone with an acceptable negative appendectomy rate (7%) and a missed appendicitis rate of less than 0.5%. Visualization of a normal appendix (negative US) was sufficient to obviate the need for a CT in the authors' experience. Emergency physicians (EPs) used an equivocal US in conjunction with clinical assessment to care for one-third of study patients without a CT and with no known cases of missed appendicitis. These data suggest that by employing US first on all children needing diagnostic imaging for diagnosis of acute appendicitis, radiation exposure may be substantially decreased without a decrease in safety or efficacy.

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Low-level radiation exposure in children potentially contributes to an increased rate of malignancies.[1] While the individual increased risk for low-dose radiation-induced carcinogenesis is low, the number of cancers that have been linked to exposure in children at a population level is a public health concern.[2,3] Yet, the number of diagnostic computed tomography (CT) scans in children performed in the emergency department (ED) has exponentially increased since the introduction of CT because of the widespread availability, ease of use, and superior diagnostic characteristics.[4]

In the ED, a significant proportion of pediatric radiation exposure occurs due to CT scans performed for the diagnosis of appendicitis.[5] Diagnosing appendicitis can be challenging, and the consequences of missing acute appendicitis severe. While the clinical history, exam, and laboratory findings are critical, CT scanning has reduced the number of cases of missed appendicitis as well as the number of negative appendectomies performed.[6] It is not a surprise that emergency physicians (EPs), surgeons, and radiologists prefer CT as a superior diagnostic technology in the individual patient, despite the increased risk of radiation.

Interest in the as-low-as-reasonably-achievable (ALARA) principles of radiation exposure has increased, supporting the idea that there is no completely safe dose of radiation, especially in the pediatric population. Efforts to reduce radiation exposure include using automated lower-dose CT scans, and refraining from CT scans when possible, including the use of radiation-free alternate imaging modalities such as ultrasound (US).[7]

Ultrasound as a single modality for the evaluation of appendicitis can be problematic, and its utilization varies widely depending on local resources.[8] US is operator-dependent and limited by the availability of skilled technicians. In addition, the graded compression technique employed for the appendicitis US can be time-consuming. Most importantly, while US is specific for acute appendicitis and has a low false-positive rate, its sensitivity may not be acceptable clinically, as the appendix is not visualized in a large number of cases.

The application of the ALARA principles in the diagnosis of acute appendicitis in children poses a dilemma for the EP. Should CT technology be used to assure an accurate diagnosis, or should US be used at the risk of an inaccurate diagnosis to avoid a small probability of a potential malignancy? For clinicians to be able to decrease radiation exposure in pediatric patients with possible appendicitis, accurate diagnostic alternatives and pathways must be readily available and coupled with an institutional and interdisciplinary change in the paradigm for diagnosis of appendicitis and CT use in children.

In 2003, the Stanford/Lucile Packard Children's Hospital (LPCH) pediatric ED started an interdisciplinary clinical imaging pathway for the diagnosis of pediatric appendicitis. In conjunction with the departments of pediatric surgery and pediatric radiology, a staged US and CT pathway was established to maintain the sensitivity and specificity of CT scanning alone, while reducing the number of CT scans performed in the pediatric ED on children. In this study, we retrospectively evaluate the efficacy of this pathway.

This study addresses an issue of major public health concern, that of increasing medical diagnostic radiation exposure causing population-level risks of radiation-induced cancers. CT scanning is sensitive, specific, and even cost-effective for the diagnosis of appendicitis. Second only to pathology, it remains the criterion standard for diagnosis. Save for concerns of radiation exposure in children who visit the health care system, there would be no imperative to apply US or staged imaging for the diagnosis of appendicitis. With this study we seek to contribute to this process.

METHODS

Study Design

This was a retrospective, outcomes-based chart review of the performance of our staged US and CT pathway for diagnosis of appendicitis. The study was approved by our institution's human subjects review committee.

Study Setting and Population

The study was conducted at Stanford LPCH, a suburban tertiary care facility. We receive approximately 12,000 pediatric patients per year. Patients from this ED presenting with possible appendicitis are likely representative of other university affiliated EDs around the country.

The study population was a comprehensive sample of patients presenting to the pediatric ED after hours (defined as between 6PM and 6AM on weekdays and 24 hours a day on weekends and holidays), over a 6-year study period (January 2003 to December 2008), for whom US was ordered as the first imaging study with the specific physician instruction to "rule out appendicitis."

Exclusion criteria were patients who went directly to the operating room (OR) based on clinical criteria alone, those referred to our site after evaluation and CT scan at an outside hospital, patients for whom complete medical records were not available, and patients on whom CT scans could not or would not be performed according to the pathway for reasons such as pregnancy or patient/parent refusal. Three investigators (NR, RK, and PG) performed the chart review of the 708 patients and entered abstracted data into the study database.

Study Protocol

Definitions. Imaging results were taken from the radiology report. The graded compression technique in US was used to identify the appendix and note any secondary signs. The number of views, length of the study, and mode of recording (single images vs. video) were at the discretion of the sonographer.

Positive US was defined as visualization of a ≥ 6 mm in diameter and noncompressible appendix. Other signs included the presence of an appendicolith, presence of periappendiceal fluid, and increased flow in the appendiceal wall with color Doppler. *Negative US* was defined as complete visualization of a compressible appendix measuring <6 mm in diameter; if an alternate diagnosis was identified, the US was categorized as negative for appendicitis. *Equivocal US* was defined as nonvisualization of the complete appendix.

Computed tomography scan was done per institutional pathway with intravenous contrast in all patients. In the early years of the study, oral contrast was frequently utilized. The on-call resident interpretation of the CT was used in this study. *Positive CT* was defined as visualization of an enlarged appendix measuring >7 mm in diameter in addition to inflammatory signs including hyperemia in the wall and periappendiceal fat stranding. The presence of an appendicolith was also called positive. *Negative CT* was defined as visualization of a normal appendix; if an alternate diagnosis was identified or no appendix was visualized, CT scan was categorized as negative for appendicitis. For *positive appendicitis* a pathology report of appendicolith or appendicitis was used as criterion standard for diagnosis.

These definitions have been used by our radiologists over the past 6 years to read their studies. The radiology dictations always include an impression of positive, negative, or equivocal. During chart review, positive and negative US were straightforward to classify based on the report. Nonvisualization of the appendix was always reported as equivocal. Equivocal US was sometimes problematic (such as "cannot exclude early acute appendicitis"). In these cases, two investigators (NR, RK) reviewed 10% of the radiology reports in a blinded fashion to ensure interrater reliability when sorting the reports into categories of positive, negative, and equivocal.

Imaging Pathway. In 2003, the pediatric radiology, pediatric emergency medicine, and pediatric surgery departments came together in an effort to introduce more selective imaging strategies for diagnosis of pediatric appendicitis in the context of an emerging national interest in ALARA. All three departments agreed to an imaging initiative that would establish US, instead of CT, as the default first imaging test for pediatric appendicitis.

If the US was clearly positive for appendicitis as read by the attending radiologist on call, the patient would be managed by pediatric surgery, usually operatively. If the US was clearly negative i.e., visualized a normal appendix with no inflammation, the patient would be managed by the ED. If the US was equivocal for appendicitis, a CT scan was recommended to confirm or reject the diagnosis of acute appendicitis.

The initiative was publicized in the participating departments. Training sessions were held to publicize the initiative. On the radiology side, the attending reviewing cases would review any clear violations of the protocol and educate the relevant physicians involved in the care of the patient.

Ultimately, however, the decision to order US as the first imaging test, as well as whether to obtain a follow-up CT, was left to the individual EP taking care of the patient. Specific clinical tests were not required. While our study sought to evaluate a pathway of radiologic imaging in conjunction with clinical correlation, we felt that strictly defining clinical criteria would make our results less generalizable and less accepted by physicians. EPs and surgeons were both allowed to opt out of the pathway based on their clinical judgment and the circumstances of the particular patient.

Rationale for Studying the After-hours Population. This retrospective outcomes analysis focuses on the after-hours population. During regular business hours, full-time US technicians are available in the ED. These technicians are experienced sonographers who are adept at scanning children for appendicitis. In addition, we have full-time pediatric radiology attending coverage in house during the daytime hours.

During the majority of the after-hours time frame, US is performed by a population more varied in experience and training, including radiology residents and on-call US technicians. The radiology residents also interpret these studies and give a preliminary read for both US and CT. If a surgical decision is being made to operate or not based on the imaging, an attending overread is made available to the EP or surgeon by a radiologist on call who reads the resident's US images. Although all US were eventually read by an attending, usually the next day, we used the preliminary read as our result.

Outcome Measures

Key outcome measures for the performance of the staged US-CT pathway were sensitivity, specificity, negative predictive value, positive predictive value, negative appendectomy rate, missed appendicitis rate, and number of CT scans avoided. Number of equivocal USs without follow-up CT scan is discussed.

Data Analysis

Study variables included age, sex, date and time of US study, US read (positive, negative, equivocal), CT read (positive, negative), and outcome (pathologic outcome and clinical outcome, including missed appendicitis as indicated by readmission and subsequent appendicitis diagnosis). For patients who were discharged following an equivocal US without a CT scan to rule out appendicitis, relevant information from the ED record was abstracted, including whether they were given an alternate diagnosis or if their symptoms improved. Return visits were linked with the patient record. Radiologic results were cross-tabulated with the clinical and pathologic outcomes for patients to identify the negative appendectomies and missed appendicitis by this pathway.

The negative appendectomy rate was calculated as the number of normal appendices removed (by pathology) divided by the total number of surgeries performed in the sample set. The missed appendicitis rate was calculated as the number of cases of appendicitis missed by imaging and diagnosed with appendicitis on subsequent admission. The number of CT scans potentially reduced was defined as the number of patients who followed the pathway and did not receive a CT scan. All calculations were performed with SPSS version 14.0 (SPSS Inc., Chicago, IL).

RESULTS

Of the 705 patients who met inclusion criteria for the study, 680 (96%) had complete data available. Of the

680 patients, 45% were boys and 55% were girls. A wide range of ages (1–22 years) were represented, but only 20 patients were above the age of 18 and only one patient of age 22. Similarly, only 14 children were under the age of 2. The interquartile ranges are found in Table 1. Figure 1 illustrates the imaging results of the interdisciplinary staged US-CT pathway to reduce radiation exposure.

Outcomes for Patients Who Were Evaluated With the Staged Pathway

Of the 680 patients evaluated for appendicitis over 6 years, 407 patients received US first and CT only if US was equivocal (Table 2). Interrater agreement on 10% of the US reports reviewed was 94% (64/68 reports), which yields an unweighted kappa coefficient of 0.93 (95% confidence interval = 0.90 to 1), representing substantial agreement. All outcomes for patients evaluated with the staged US-CT pathway are represented in Table 2 and Figure 2.

Of the 94 patients with a negative US and no follow-up CT, all were managed nonoperatively. One of these patients was discharged home after a negative US and returned with a perforated appendix and multiple abdominal abscesses. This is the only case of missed appendicitis in our data set. This patient was a 13-year-old boy who presented with abdominal pain and mild nausea with a reportedly benign abdominal exam. His US showed a structure consistent with a normal appendix with no wall thickening, but showed lymphadenopathy with the largest node measuring 1.7 cm. No abdominal free fluid was seen. He was discharged home with appendicitis precautions. His pain continued to increase and he returned 2 days later, presenting with a perforated appendix with phlegmon formation on abdominal CT scan. The patient was managed with antibiotics, CT-guided drainage of the abscess, and interval appendectomy. Another patient was operated on despite a negative study and had appendicitis on pathology.

Outcomes for Patients Evaluated Outside the Staged Pathway

A total of 228 of 435 (52%) patients with US equivocal for appendicitis did not receive further CT imaging (Figure 3). This was a clinical determination made by ED

Table 1
Population Characteristics

	US Negative	US Positive	US Equivocal	Total
Number	117	128	435	680
Median age, yr (IQR)	8 (6–12)	12 (9–15)	10 (7–14)	10 (7–14)
Female, *n* (%)	65 (56)	58 (45)	249 (57)	372 (55)
Male, *n* (%)	52 (44)	70 (55)	186 (43)	308 (45)

n = 680.
CT = computed tomography; IQR = interquartile range; US = ultrasound.

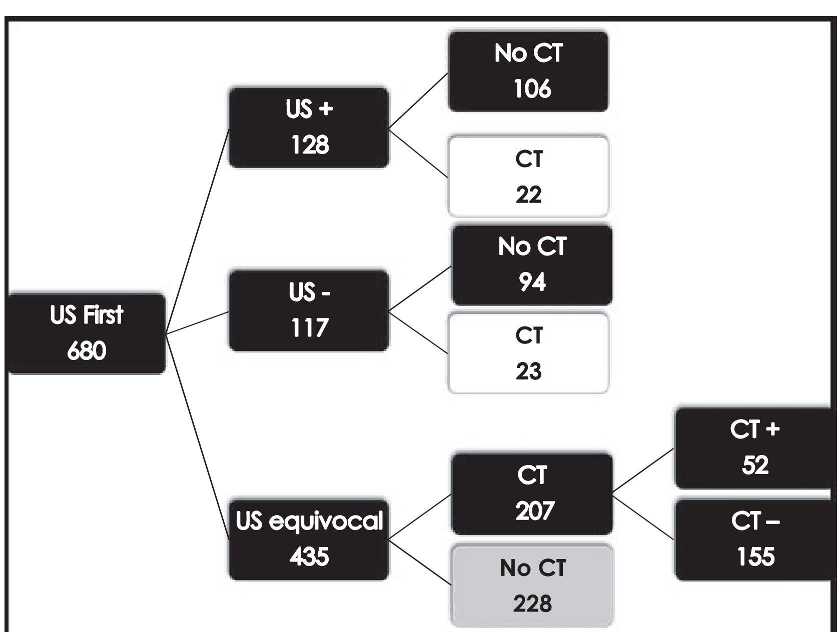

Figure 1. Staged ultrasound (US) and computed tomography (CT) pathway: imaging results of patients undergoing US followed by CT scans. Patients who followed the pathway are in black. The 228 patients in gray did not receive a CT scan following an equivocal US.

Table 2
Imaging Results and Outcomes for the Staged US-CT Pathway

			Operative Outcome (Path)		Nonoperative Management	
US	CT	Total	Negative Appendectomy	Positive Appendectomy	Not Appendicitis	Missed Appendicitis
Positive	—	106	5	91	10	0
Negative	—	94	0	0	93	1
Equivocal (n = 207)	Positive	52	3	43	6	0
	Negative	155	2	0	153	0
Totals		407	10	134	262	1
Study outcomes		200/407 (CT avoided)	10/144 (negative appendectomy rate)			1/407 (missed appendicitis rate)

n = 407. The pathway was followed for 407 patients whose outcomes are listed below. The CT scans saved, negative appendectomy rate, and missed appendicitis rate are listed in the final row. Patients undergoing nonoperative management were assumed to not have appendicitis.

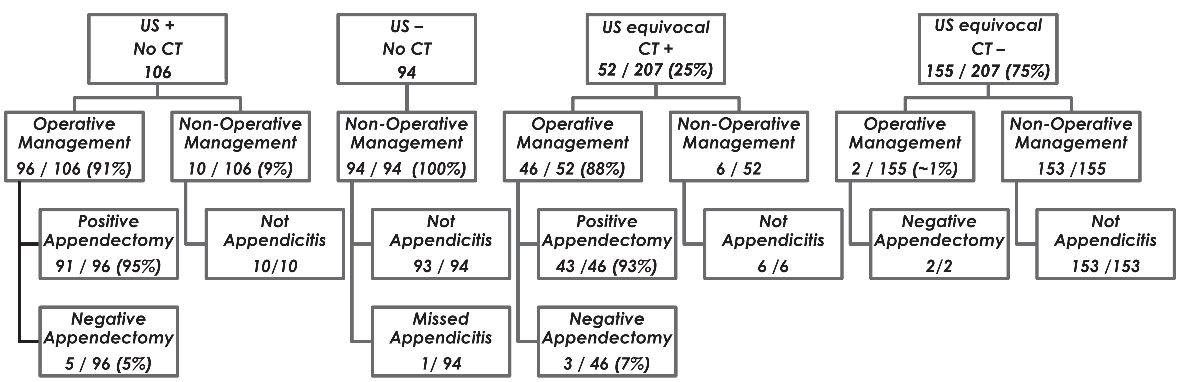

Figure 2. Imaging results and outcomes for the staged ultrasound (US)-computed tomography (CT) pathway.

and/or pediatric surgery physicians. Of these 228 patients, 10 (4%) were managed operatively and proceeded to the OR for an appendectomy based on clinical signs without a CT scan, and 1/10 had a negative appendectomy. An additional 120 (53%) improved clinically in the ED and their discharge diagnosis was "abdominal pain NOS, improved"; 98 (43%) were given alternative diagnoses including urinary tract infection, constipation, viral gastroenteritis, and mesenteric adenitis.

For patients with clearly positive or negative US (245), 45 received follow-up CT despite definitive US result. Twenty-three CTs were obtained despite negative US. Twenty-two CTs were obtained despite positive US. In 41/45 cases, CT was concordant with the US. In the other four cases, the US was concordant with the outcome in two patients, and the CT in the other two patients.

Pathway Diagnostic Characteristics, Negative Appendectomy Rate, and Missed Appendicitis Rate

Our staged US-CT pathway's diagnostic characteristics are reported in Table 3. A total of 407 of 680 patients (60%) received imaging according to the pathway. We report a total of 24 false-positives, of which 16 were clinically negative and eight resulted in negative appendectomies. We also had one false-negative that was a missed appendicitis. The sensitivity, specificity, negative predictive value, and positive predictive value of our staged US-CT pathway in the on-call hours were 99, 91, 99, and 85% respectively. The negative appendectomy rate in patients who followed the pathway was 7% (10/144 patients managed operatively). The missed appendicitis rate was <0.5% (1/407). The prevalence of appendicitis in the group that followed the pathway was 33% (135/407); the prevalence was 24% in the total data set (162/680).

Radiation Exposure in the Pediatric ED: Number of Potential CTs Avoided

Of the 407 patients evaluated by the pathway, 200 had definitive positive (106) or negative (94) US. Assuming that all of these patients would have had CT imaging as the initial modality in the absence of our protocol, 49% of CT scans (200/407) were avoided in this group.

In the 45 patients who did receive a CT scan following a definitive US, CT did not change management in 43/45 patients. CT was inaccurately discordant in 2/45 cases and accurate in 2/45 cases where it changed management. This is not different from our results with definitive US alone, and demonstrates that in this sample, definitive US findings can safely help limit radiation exposure.

DISCUSSION

The ED diagnosis of pediatric appendicitis remains largely a clinical diagnosis with history, examination,

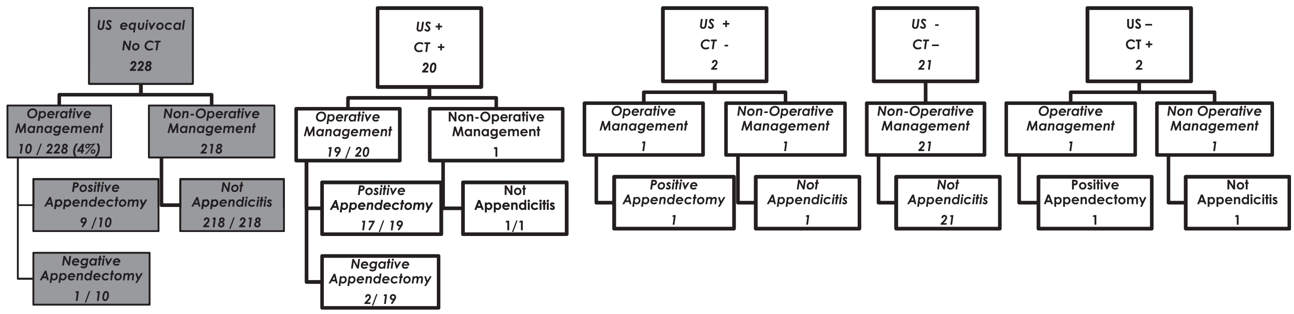

Figure 3. Outcomes for patients evaluated outside the staged ultrasound (US)-computed tomography (CT) pathway.

Table 3
Staged US-CT Pathway Diagnostic Characteristics for On-call Hours: Two-by-Two Table for the 407 Children That Followed the Pathway

	Appendicitis	Not Appendicitis	Total
Pathway positive	134	24	158
Pathway negative	1	248	249
Total	135	272	407

Sensitivity = 99%, specificity = 91%, negative predictive value = 99%, and positive predictive value = 85%. Of the 24 false-positives, there were eight negative appendectomies. The one false-negative was a case of missed appendicitis.

laboratory studies, and clinical course in the ED all playing a significant role in the physician's medical decision-making. US and CT are adjunct but imperfect imaging tools to aid in the diagnosis of appendicitis. US cannot currently be the only modality to rule out appendicitis in children. Pooled sensitivity and specificity for US versus CT are 86%–90% vs. 92%–97% and 92%–95% vs. 94%–97%.[6]

Few studies have examined staged imaging pathways as a method to decrease radiation and improve diagnostic accuracy. A prospective cohort study of 139 children at Children's Hospital, Boston, in 1998 evaluated a US first, staged imaging pathway for diagnosis of pediatric appendicitis.[9] It was found that CT following a US that was negative or indeterminate showed a sensitivity of 94% and a specificity of 94%. However, CT scans were performed following both negative and equivocal US, and no patients were managed without CT following equivocal US.

Strategies based on laboratory analysis, clinical observation, and repeated pediatric surgical evaluation with restricted imaging have been shown to be accurate for the diagnosis of pediatric appendicitis.[10–12] We did not analyze specific clinical parameters such as nature of pain, symptoms, or laboratory results. To design a generalizable pediatric imaging pathway for cases of diagnostically difficult pediatric appendicitis, we left the decision to activate the imaging pathway to the individual EP.

Role for US First to Evaluate Appendicitis in the Pediatric ED

Unlike the only other study evaluating an US and CT staged imaging pathway,[9] our pathway does not recommend CT scanning following a clearly negative US. Data from a dedicated children's hospital outside of North America, with substantial experience in sonographic evaluation, have shown that a normal appendix can be visualized in 82% of asymptomatic children,[13] and if the normal appendix can be visualized with US, appendicitis can be safely ruled out. In our series of 680 patients, the normal appendix was only visualized 118 times (approximately 17% of cases), more reflective of the North American experience with US. However, even with 17% visualization, 94 patients with negative US did not receive CT imaging. Our retrospective analysis has shown that this practice was effective with one case of missed appendicitis in the data set. However, CT remains a vital adjunct to US testing, specifically when the US is equivocal and there is persistent clinical suspicion for appendicitis. Approximately 20% of patients with equivocal US had appendicitis.

Role of Clinical Assessment Following an Equivocal US

One initially surprising result was the identification of 228 patients (almost one-third of total patients and half the patients with equivocal US) who did not get a CT scan following an equivocal US. While radiologists, surgeons, and EPs disagree on what to do with information from a nondiagnostic US, and while there is little literature to support clinical decisions, nondiagnostic US were used in clinical decision-making in our ED.

Nondiagnostic US can result from a variety of phenomena. The appendix may not be visualized at all, or the study may be incomplete, for example, when the tip of the appendix is not visualized. However, nondiagnostic US can have secondary signs such as increased echogenicity suggesting inflammation of mesenteric fat, lymphadenopathy, fluid collections, or dilation of the bowel without peristalsis suggesting focal peritonitis. If secondary signs of appendicitis are present, even without visualization of the appendix, the diagnosis of appendicitis is more likely. If no secondary signs are seen, appendicitis and other inflammatory processes becomes less likely.[14]

While our pathway clearly recommends CT for equivocal US, we believe that clinical correlation accounted for the 228 cases where CT was not performed following equivocal US. CT scans were available to EPs evaluating these patients and they were aware that CT was the recommended definitive test following an equivocal US. However, clinically an equivocal US without secondary signs, although not diagnostic, can be reassuring in a child with improving pain or with evolving symptoms pointing toward an alternate diagnosis. According to our chart review, 43% were given alternate diagnoses, and a small minority (4%) did go to the OR for appendectomy. Fifty-three percent improved clinically in the ED and were sent home with the diagnosis of "abdominal pain NOS, improved." To our knowledge, none of the 218 patients who were treated nonoperatively after a nondiagnostic US and no follow-up CT returned with missed appendicitis to our ED.

The decision to not obtain CT scans in half the patients with equivocal US, and to follow-up with CT scans for the other half, points to the active clinical assessment of the individual patient by our EPs based on a fluid combination of the patients history, exam, laboratory findings, imaging, and clinical course during observation. In Europe, a careful history and repeated clinical examination with admission along with the use of US is used to diagnose appendicitis. CT imaging is used very selectively, for example, in patients with a palpable mass or in patients with continued diagnostic dilemma after 48 hours of hospital observation.[15,16]

Through our experience over 6 years, we are able to confirm that this combination of clinical assessment with imaging appears safe and effective. It is tempting to characterize this decision-making process and to standardize it with appendicitis scores. However, a number of these decision-making rules and instruments have been developed for appendicitis and are not widely used.[17] We trust the clinical assessment and conservative nature of most EPs to rule out appendicitis and obtain imaging if they persistently suspect appendicitis. We postulate that the decision to allow our EPs to utilize their clinical assessments to opt out of the follow-up CT without strictly defined criteria makes the pathway more acceptable and translatable to initiatives in other institutions.

Depending on the degree of follow-up and parental ability, the EP may feel comfortable in the case of a nondiagnostic US to give appendicitis precautions and ensure close follow-up. The EPs at our institution give thorough appendicitis precautions to parents to ensure the return of any patient who might be at higher risk of appendicitis. This may be beneficial in reducing the number of CT scans performed as well.

The availability of and confidence in US may contribute to the increasing number of US studies performed at our institution and, accordingly, the number of nondiagnostic studies. It is possible that over the study period, our EPs have developed a lower threshold for obtaining US imaging for atypical abdominal pain given the lack of radiation exposure in cases that previously may not have been imaged. Parental requests for radiologic studies for appendicitis may also play a role in ordering more US resulting in increased numbers of nondiagnostic studies.

Factors Influencing US

It is well known that sex and the weight of the subject are particularly important in considering the feasibility and accuracy of a US for appendicitis. Our overall study population has more females than males, atypical for appendicitis. We believe that this reflects our inclusion criteria for the study that includes all patients for whom US was performed first. Female patients tend to have more US obtained to rule-out ovarian torsion, tubo-ovarian abscess, and other gynecologic causes of acute abdominal pain. This sex ratio should not affect the generalizability to a population of children undergoing imaging specifically for appendicitis. In addition, in an obese patient, US may be more likely to provide an equivocal result, which may not provide the same information to an EP with an equivocal result from a thin, young, male child.

Team Approach

Finally, we stress the importance of the interdisciplinary support to the pathway from all clinicians involved in the diagnosis of pediatric appendicitis. For the paradigm of imaging to change at our institution, education and training were implemented. The associated initiatives, including education in the ED by attending physicians with a focus in US and pediatrics, the availability of a radiology attending on call to overread the resident's report of the study (especially if a surgical decision is to be made on the patient), and the willingness of pediatric surgery to operate on patients with positive clinical and US findings alone are all significant milestones of cooperation that ensures an institutional shift in paradigm. This formal change in process allows the individual EP to maintain both duties to the patient-appropriate diagnosis and treatment and minimal radiation exposure. We believe that our experience is a promising example of interdisciplinary cooperation among physicians to tackle this complex problem and to apply the ALARA principles to the individual clinical decision-making in the ED.[18]

Next Steps

This retrospective study advances the literature in two significant aspects. In our experience, it is safe and effective to manage patients with negative US without follow-up CT. We also observe that physicians felt confident to provide a disposition on over half the patients with equivocal US without follow-up CT based on clinical considerations and observation. The next steps involve characterizing the accuracy of this practice prospectively. We are currently implementing a prospective protocol to evaluate the use of the pathway coupled with patient demographics, clinical characteristics, and phone follow-up to ensure that we identify misdiagnoses.

LIMITATIONS

The retrospective design did not allow for patient follow-up after discharge. Although many of our patients returned to our ED, we were unable to track patients who subsequently presented to other institutions. However, our EPs systematically give careful follow-up and appendicitis precautions to patients being discharged, often specifying rechecks with the primary care physician or in the ED. Also, the study was conducted at a single academic hospital.

Further, while the lack of specific clinical information (e.g., white blood cell count, fever, anorexia, guarding) could be considered a limitation, we purposely avoided clinical criteria. The EP's decision to obtain imaging would be based on a combination of clinical history, exam, and laboratory results. Since our study sought to evaluate a pathway of radiologic imaging in conjunction with clinical correlation, strictly defining clinical criteria would make our results less generalizable.

Relevant data that could affect the diagnostic characteristics of US or CT, such as child weight and secondary signs on US, were not systematically available in our data set. We did not evaluate whether the radiology reads were accurate or not. However, we were largely interested in how the staged pathway performed given the information that was available to the physicians at the time of their decision-making, which would not be affected by reviewing report accuracy.

Finally, the fact that many USs were not followed by CTs does not mean that these all represent CTs avoided. Since US is very low risk, physicians may have ordered an US when unwilling to order a CT. The fact that physicians were willing to treat patients who had equivocal US without a CT supports this.

CONCLUSIONS

To minimize radiation exposure without losing diagnostic accuracy, EPs need new tools and paradigms. Our interdisciplinary staged ultrasound–computed tomography pathway is a first step. Half of the patients who completed this pathway and may have received computed tomography scans in another context were managed with definitive ultrasound alone, with an acceptable negative appendectomy rate (7%) and a missed appendicitis rate of <0.5%. Visualization of a normal appendix (negative ultrasound) was sufficient to obviate the need for a computed tomography in our experience. EPs used an equivocal ultrasound in conjunction with clinical assessment to reach a disposition decision for one-third of study patients with no known cases of missed appendicitis. By employing ultrasound first on all children needing diagnostic imaging for diagnosis of acute appendicitis, radiation exposure may be substantially reduced without a decrease in safety or efficacy.

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