Effectiveness of a Staged US and CT Protocol for the Diagnosis of Pediatric Appendicitis: Reducing Radiation Exposure in the Age of ALARA[1]

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Purpose: To evaluate the effectiveness of a staged ultrasonography (US) and computed tomography (CT) imaging protocol for the accurate diagnosis of suspected appendicitis in children and the opportunity for reducing the number of CT examinations and associated radiation exposure.

Materials and Methods: This retrospective study was compliant with HIPAA, and a waiver of informed consent was approved by the institutional review board. This study is a review of all imaging studies obtained in children suspected of having appendicitis between 2003 and 2008 at a suburban pediatric emergency department. A multidisciplinary staged US and CT imaging protocol for the diagnosis of appendicitis was implemented in 2003. In the staged protocol, US was performed first in patients suspected of having appendicitis; follow-up CT was recommended when US findings were equivocal. Of 1228 pediatric patients who presented to the emergency department for suspected appendicitis, 631 (287 boys, 344 girls; age range, 2 months to 18 years; median age, 10 years) were compliant with the imaging pathway. The sensitivity, specificity, negative appendectomy rate (number of appendectomies with normal pathologic findings divided by the number of surgeries performed for suspected appendicitis), missed appendicitis rate, and number of CT examinations avoided by using the staged protocol were analyzed.

Results: The sensitivity and specificity of the staged protocol were 98.6% and 90.6%, respectively. The negative appendectomy rate was 8.1% (19 of 235 patients), and the missed appendicitis rate was less than 0.5% (one of 631 patients). CT was avoided in 333 of the 631 patients (53%) in whom the protocol was followed and in whom the US findings were definitive.

Conclusion: A staged US and CT imaging protocol in which US is performed first in children suspected of having acute appendicitis is highly accurate and offers the opportunity to substantially reduce radiation.

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Acute appendicitis is the most common cause of abdominal surgical interventions in children, with approximately 60 000–80 000 children treated for appendicitis in the United States each year (1). Imaging plays a key role in the accurate and prompt diagnosis of suspected appendicitis when the clinical presentation is equivocal (Figs 1, 2) (2–6). Furthermore, delayed diagnosis or missed appendicitis is associated with increased morbidity and mortality related to appendiceal perforation and associated complications (7). Imaging has also reduced the negative appendectomy rate (number of appendectomies with normal pathologic findings divided by the number of surgeries performed for suspected appendicitis) (8).

Although the benefits of imaging are well appreciated, there is increasing concern for the long-term population-based effects of radiation exposure, especially in children. Well-designed models show a low but finite population level risk of radiation and related cancer rates among children exposed to computed tomography (CT) (9,10).

The ideal characteristics of an imaging test for suspected appendicitis include high accuracy, minimal risk, and rapid access. Taking these parameters into consideration, an ideal imaging algorithm for suspected appendicitis in children would minimize radiation exposure by means of an alternative imaging modality such as ultrasonography (US) without compromising the diagnostic accuracy for appendicitis.

The reported specificity for the sonographic diagnosis of appendicitis is high; however, the reported sensitivity has shown great variability and is substantially less than that with CT (11). Given these limitations, the use of US alone may result in a substantial number of false-negative diagnoses and therefore has not gained wide acceptance by pediatric surgeons and emergency physicians.

To address this concern, in 2003 we introduced, in conjunction with the pediatric emergency department and pediatric surgery departments at our institution, a staged imaging pathway using US and CT. The goal of the pathway was to reduce the number of CT examinations performed in children suspected of having appendicitis without compromising diagnostic accuracy. This proposed pathway is consistent with the ALARA (as low as reasonably achievable) principle, which advocates for imaging with the lowest radiation dose possible to minimize potential risks. The purpose of this study was to evaluate the effectiveness of a staged US and CT imaging protocol for the accurate diagnosis of suspected appendicitis in children and the opportunity for a reduction in the number of CT examinations and associated radiation exposure.

Advances in Knowledge

- A staged US and CT imaging pathway in which US is performed first in children suspected of having appendicitis is effective in reducing radiation without compromising diagnostic accuracy; CT was avoided in 333 of the 631 patients (53%) who followed the protocol.
- An interdisciplinary effort involving pediatric surgeons, emergency department physicians, and radiologists is effective for implementing an imaging pathway change for suspected pediatric appendicitis.

Materials and Methods

Study Design

We performed an outcomes-based chart review study of the diagnostic characteristics of a staged US and CT pathway for suspected pediatric appendicitis. This retrospective study was compliant with the Health Insurance Portability and Accountability Act, and a waiver of informed consent was approved by the institutional review board.

Implication for Patient Care

- The use of a staged US and CT imaging pathway for the diagnosis of pediatric appendicitis reduces the number of CT examinations and, thus, radiation exposure in children.

Study Setting and Population

A study was conducted at the pediatric emergency department affiliated with a children's hospital. The study population included all patients 18 years of age and younger who presented to the pediatric emergency department during the 6-year study period (January 2003 to December 2008) and for whom US and/or CT were ordered to rule out acute appendicitis.

Patients were excluded from the study if they met any of the following conditions: *(a)* surgical intervention was performed on the basis of clinical criteria alone, *(b)* patients were referred to our site after CT had been performed at an outside institution, *(c)* complete medical records were not available, or *(d)* CT could not be performed (eg, owing to pregnancy or patient and/or parent refusal).

Staged US and CT Imaging Pathway

The departments of pediatric radiology, emergency medicine, and pediatric surgery established an imaging pathway in 2003 for suspected appendicitis in children in which US is performed first as part of an interdisciplinary initiative to reduce radiation exposure.

Under the pathway, CT is not performed if the US scan is definitively positive or negative for appendicitis on the basis of well-established criteria that have been previously reported in the literature (12–15) and described in Table 1 or helps establish an alternative diagnosis.

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Potential conflicts of interest are listed at the end of this article.

Figure 1

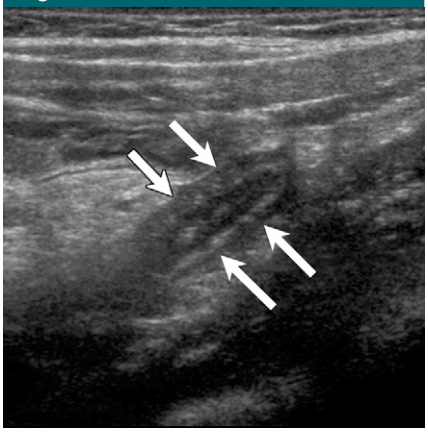

Figure 1: Sagittal US scan through the right lower quadrant of the abdomen in a 3-year-old boy with acute appendicitis demonstrates an enlarged appendix (arrows) measuring 8.0 mm in diameter.

Table 1

Definitions of US and CT Findings

Finding	Definition
US	
Positive	Visualization of noncompressible appendix ≥6.0 mm in diameter. Other signs included the presence of an appendicolith, periappendiceal fluid, and increased flow in the appendiceal wall with color Doppler US.
Negative	Complete visualization of a compressible appendix measuring <6.0 mm in diameter. If an alternate diagnosis was identified, the US scan was categorized as negative for appendicitis.
Equivocal	Nonvisualization of the complete appendix and no alternate diagnosis rendered.
CT	
Positive	Visualization of an enlarged appendix measuring ≥7.0 mm in diameter in addition to inflammatory signs including hyperemia in the wall, periappendiceal fat stranding, or appendicolith.
Negative	Visualization of a normal appendix; if an alternate diagnosis was identified or the appendix was not visualized, the CT scan was categorized as negative for appendicitis*

* Nonvisualization of the appendix at CT was defined in our study as a negative CT finding for appendicitis. Conversely, nonvisualization of the appendix at US was considered an equivocal study.

The choice of clinical tests, the first imaging study performed, and the decision to opt out of the imaging pathway after US was performed were ultimately left to the referring physician.

Imaging Technique and Equipment

US was performed by using the graded compression technique to identify and measure the appendix as previously described in the literature (12–15). US was performed with the Sequoia system (Siemens Healthcare, Mountain View, Calif). A linear-array transducer (15L8W, 8L5, or 6L3; Siemens Healthcare) was used during the course of this study. During daytime hours, US was performed by registered diagnostic medical sonographers. All examinations were interpreted concurrently by a resident or fellow with an attending pediatric radiologist.

After hours (6:00 PM to 8:00 AM), US was performed by either a US technologist or the senior radiology resident who was on call. Images obtained after hours were interpreted by a senior resident and over read (read again after the initial reading) by an on-call attending pediatric radiologist. For those after-hour cases in which a surgical decision was pending, a real-time interpretation was performed by the attending pediatric radiologist. It is our routine for radiologists to examine and image patients irrespective of whether a technologist is involved in the study.

CT was performed with intravenous contrast material. No rectal contrast material was used. Oral contrast material was used in a minority of patients. CT radiation dose was adjusted according to the child's age and weight. A 16-section multidetector CT scanner (Lightspeed; GE Medical Systems, Milwaukee, Wis) or a 64-section multidetector CT scanner (Somatom Sensation; Siemens Healthcare, Erlangen, Germany) was used in our study.

Chart Review

All final radiology reports were reviewed and classified as positive, negative, or equivocal according to the definitions in Table 1. The formal radiology report included an impression of positive, negative, or equivocal findings for appendicitis or an alternate diagnosis. During chart review, US scans were classified as positive, negative, or equivocal on the basis of the radiology report by using the definitions in Table 1. Results from the radiology report were final, and individual images were not reviewed by the authors.

Outcome Measures

Key outcome measures for the performance of the staged US and CT pathway included sensitivity, specificity, negative predictive value, positive predictive value, negative appendectomy rate, missed appendicitis rate, compliance with protocol, alternate diagnosis, and number of CT examinations avoided.

Data Analysis

The following study variables were analyzed: patient age, sex, year of imaging study (2003–2005 vs 2006–2008), US finding (positive, negative, or equivocal), CT finding (positive or negative), results of the combined imaging pathway, and outcome. Outcome was based on surgical pathology results for patients who underwent surgery and on clinical outcome for those who did not. The latter category included cases of missed appendicitis indicated by re-admission and subsequent appendicitis diagnosis. Imaging pathway results were cross-tabulated with the clinical and pathologic outcomes to calculate diagnostic characteristics of the imaging pathway and identify the negative appendectomy and missed appendicitis rates.

The negative appendectomy rate was calculated as the number of normal appendices removed (confirmed with pathologic examination) divided by the total number of surgeries performed in the sample set. The missed appendicitis

Figure 2

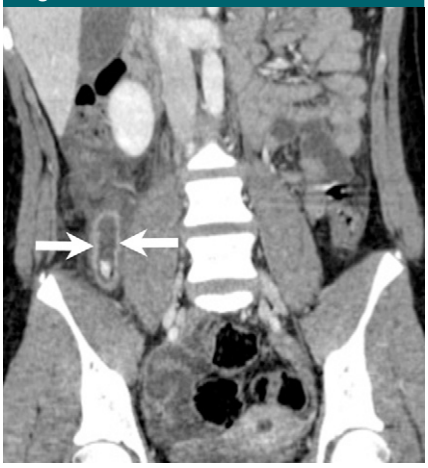

Figure 2: CT scan in a 13-year-old boy with acute appendicitis demonstrates a dilated appendix (arrows) measuring 14 mm in diameter and containing an appendicolith.

Table 2

Prevalence of Appendicitis in Compliant and Noncompliant Patients

Patient Group	Final Diagnosis*		Appendicitis Rate (%)†
	Appendicitis	No Appendicitis	
Compliant population (n = 631)	217	414	34.3 (30.7, 38.1)
Noncompliant population (n = 597)			
Patients who underwent CT only (n = 157)	61	96	38.9 (31.2, 46.5)
Patients who underwent CT despite definitive US findings (n = 70)	30	40	42.8 (31.3, 54.4)
Patients who underwent US only (CT was not performed despite equivocal US findings) (n = 370)	18	352	4.8 (3.7, 5.9)
Total	326	902	...

* Data are given as numbers of patients.

† Numbers in parentheses are the 95% confidence interval. The total population appendicitis rate was 26.5%.

rate was calculated as the number of confirmed appendicitis cases not diagnosed by means of the imaging pathway divided by the total number of patients confirmed to have appendicitis.

The data were also analyzed as different subsets on the basis of sex, age, and year of study to assess for any significant difference in the sensitivity and specificity of different subsets. The 95% confidence intervals of these proportions were calculated by using exact methods, and the proportions were not deemed to be significantly different if the confidence intervals overlapped. The number of CT examinations avoided was defined as the number of patients in whom the staged imaging pathway was followed who did not undergo CT. Alternate diagnoses determined with US and CT were noted. The complete data set was also analyzed for compliance with the protocol over the years of the study from 2003 to 2008. All calculations were performed with software (SPSS, version 14.0; SPSS, Chicago, Ill).

Results

During the study period, 1228 pediatric patients presented to the emergency department and underwent imaging for suspected appendicitis (Fig 3). Of those 1228 patients, 631 (51.3%) underwent imaging according to the pathway guidelines and were considered to be compliant with the staged imaging pathway. The prevalence of appendicitis in the patients who were compliant with our imaging pathway was not significantly different than that in patients who were referred directly to CT (34.3% vs 38.9%, respectively; Table 2). Of the 631 compliant patients, 287 (45.5%) were boys and 344 (54.5%) were girls. Patients ranged in age from 2 months to 18 years (median age, 10 years; mean age, 10.44 years). Only 23 patients were younger than 2 years of age. Boys ranged in age from 2 months to 18 years (mean age, 9.9 years), and girls ranged in age from 1 year to 18 years (mean age, 10.9 years).

Outcomes in Compliant Patients

Six hundred thirty-one patients were compliant with our staged imaging pathway (US was performed first, with CT performed only if findings at US were equivocal) (Table 3). One hundred seventy-six patients had a positive US scan and did not undergo follow-up CT; 160 of those 176 patients (91%) underwent surgery. Of those 160 children, 152 (95%) had pathologically proved appendicitis; the remaining eight patients had normal appendices at pathologic examination (negative appendectomy). Sixteen of the 176 patients (9.1%) were treated nonsurgically on the basis of clinical considerations; none of those 16 patients were subsequently diagnosed with or treated for appendicitis at our hospital.

One hundred fifty-seven patients had a negative US scan and did not undergo follow-up CT; two of those patients underwent surgery on the basis of clinical considerations. One of the two patients had pathologically proved appendicitis, and the other patient had a negative appendectomy. One hundred fifty-five of the 157 patients (98.7%) were treated nonsurgically. One of these patients was discharged home after a negative US scan and returned with a perforated appendix and multiple abdominal abscesses. This is the only case of missed appendicitis in our data set.

Two hundred ninety-eight patients had an equivocal US scan and underwent follow-up CT; CT scans were positive for appendicitis in 77 of the 298 patients (26%) and negative for appendicitis in 221 (74%). In two of the patients with equivocal US findings, the imaging report stated that the reader could not exclude early acute appendicitis and CT was performed as per protocol.

Of the 77 patients with an equivocal US scan and a positive CT scan, 67 (87%) underwent surgery. Of these 67 patients, five (7.5%) had negative appendectomies. Another 10 of the 77 patients (13%) were treated nonsurgically, with no subsequent diagnosis of appendicitis.

Table 3

Outcomes in Compliant Patients (*n* = 631)

	Final Diagnosis		Surgical Outcome		Nonsurgical Outcome	
Imaging Outcome	Appendicitis	No Appendicitis	Positive Appendectomy*	Negative Appendectomy	No Appendicitis	Missed Appendicitis†
US positive, no CT (*n* = 176)	152	24	152	8	16	0
US negative, no CT (*n* = 157)	2	155	1	1	154	1
US equivocal (*n* = 298)						
CT positive (*n* = 77)	62	15	62	5	10	0
CT negative (*n* = 221)	1	220	1	5	215	0
Total (*n* = 631)	217	414	216‡	19§	395	1

Note.—Data are numbers of patients.

* Appendicitis was diagnosed at pathologic examination.

† Missed appendicitis refers to appendicitis that was missed at the initial presentation, resulting in a delayed diagnosis.

‡ The positive appendectomy rate was 91.9%.

§ The negative appendectomy rate was 8.1%.

Table 4

Diagnostic Characteristics of the Staged US and CT Pathway

	Final Diagnosis		
Finding with the Staged US and CT Pathway	Appendicitis	No Appendicitis	Total
Positive	214	39	253
Negative	3	375	378
Total	217	414	631

Note.—Data are numbers of patients.

Of the 221 patients with an equivocal US scan and a negative CT scan, six (2.7%) were treated surgically. One of the six patients had pathologically proved appendicitis and five patients had negative appendectomies. Another 215 of the 221 patients (97.3%) were treated nonsurgically; none of those patients were subsequently diagnosed with appendicitis.

Diagnostic Characteristics of the Staged Imaging Pathway, Negative Appendectomy Rate, and Missed Appendicitis Rate

The sensitivity, specificity, negative predictive value, positive predictive value, and accuracy of our staged US and CT pathway were 98.6%, 90.6%, 99.2%, 84.6%, and 93.3%, respectively (Table 4). There were 39 false-positive findings and three false-negative findings among the 631 patients who were compliant with our imaging pathway.

Of the 39 patients with false-positive imaging studies (US = 24, CT = 15), 26 were treated nonsurgically on the basis of clinical considerations and 13 had negative appendectomies. Of the three patients with false-negative results, two patients underwent surgery on the basis of clinical considerations and one patient had a missed appendicitis.

Two hundred thirty-five appendectomies were performed, of which 19 were negative at pathologic examination; hence, the negative appendectomy rate was 8.1%. If all patients with positive findings with the imaging pathway had undergone appendectomy and all patients with negative findings with the imaging pathway had undergone nonsurgical treatment, the negative appendectomy rate would have been 13% (33 of 253 patients) instead of 8.1%.

Because only one of the three patients with false-negative imaging findings for appendicitis was treated nonsurgically, the missed appendicitis rate was 0.16% (one of 631 patients). If all three patients with negative findings with the imaging pathway had been treated nonsurgically, the missed appendicitis rate would have been 0.47% (three of 631 patients).

Reduction in Radiation Exposure: Number of CT Examinations Avoided

Of the 631 patients who were compliant with the staged imaging pathway, 333 (52.7%) had definitively positive (*n* = 176) or definitively negative (*n* = 157) US scans. These patients in another context would have undergone CT as the initial imaging modality. Thus, the reduction in CT examinations in patients compliant with the staged imaging pathway was 52.7% (333 of 631 patients).

Subset Analysis of the Compliant Population

Analysis of the compliant population with respect to patient age, year of study (2003–2005 vs 2006–2008), and sex showed no significant differences in sensitivity and specificity between these subsets (Table 5).

Alternate Diagnosis

An alternate diagnosis was suggested with US findings in 22 patients and with CT findings in 42. The most common alternate diagnoses included mesenteric adenitis, ovarian abnormality, constipation, colitis, intussusception, and

pyelonephritis (Table 6). Clinical management and follow-up was consistent with the suggested alternative diagnoses.

Outcomes in the Noncompliant Group

Five hundred ninety-seven patients did not follow the staged US and CT imaging pathway and were noncompliant (Fig 3, Table 7). Seventy of the 597 patients underwent follow-up CT despite having a definitive US scan, 370 did not undergo follow-up CT after an equivocal US scan, and 157 underwent CT without undergoing US due to the clinical decision of the treating physician. In three of the 370 patients with equivocal US scans, the report stated that the reader could not exclude early acute appendicitis and follow-up CT was not performed. There was no significant difference in the prevalence of appendicitis among the patients who were compliant with the imaging pathway, the patients who underwent CT without undergoing US, and the patients who underwent follow-up CT despite having definitive US findings.

Compliance with the Staged Imaging Pathway

The yearly compliance rate during the study period ranged from 46% to 57%, with no significant increasing or decreasing trends over the years (Fig 4).

Discussion

Acute appendicitis is the most common cause of abdominal surgical interventions in children. Because the clinical diagnosis is often challenging, imaging plays an important role in ensuring accurate and prompt diagnosis to minimize the morbidity and mortality associated with a perforated appendix. The radiation exposure associated with imaging and the potential risk for developing radiation-induced secondary malignancies has been increasingly recognized (16,17). These concerns must be balanced with a rational approach for appropriate CT utilization when indicated. An ideal imaging test for appendicitis would be highly accurate and minimize radiation exposure. The specificity of US has been reported to be similar to that of CT, ranging from 88% to 99%

Table 5

Diagnostic Characteristics of the Staged US and CT Pathway according to Subgroup

Subgroup	No. of Patients	Sensitivity*	Specificity*
Age (y)			
<4	62	1.0 (0.93, 1.04)	0.96 (0.90, 1.0)
5–12	341	0.99 (0.97, 1.0)	0.89 (0.85, 0.93)
>12	228	0.98 (0.95, 1.0)	0.91 (0.86, 0.96)
Study year			
2003–2005	209	0.98 (0.95, 1.0)	0.92 (0.88, 0.97)
2006–2008	422	0.99 (0.97, 1)	0.89 (0.86, 0.93)
Sex			
M	287	0.99 (0.96, 1.0)	0.92 (0.88, 0.95)
F	344	0.98 (0.96, 1.0)	0.89 (0.85, 0.93)

Note.—There were no statistically significant differences in the sensitivity and specificity among subsets (age: $P = .74$ for sensitivity and .28 for specificity; study year: $P = .587$ for sensitivity and .448 for specificity; sex: $P = .99$ for sensitivity and .40 for specificity).

* Numbers in parentheses are the 95% confidence interval.

Table 6

Alternative Diagnosis Suggested at US and CT

Alternate Diagnosis	No. of Diagnoses Suggested at US	No. of Diagnoses Suggested at CT
Mesenteric adenitis	5	19
Ovary-associated problems	7	2
Constipation	1	6
Colitis	0	6
Intussusceptions	5	0
Pyelonephritis	0	5
Nephrolithiasis	3	0
Hernia	1	0
Pneumonia	0	1
Cholelithiasis	0	1
Omental infarction	0	1
Terminal illeitis	0	1
Total	22	42

Figure 3

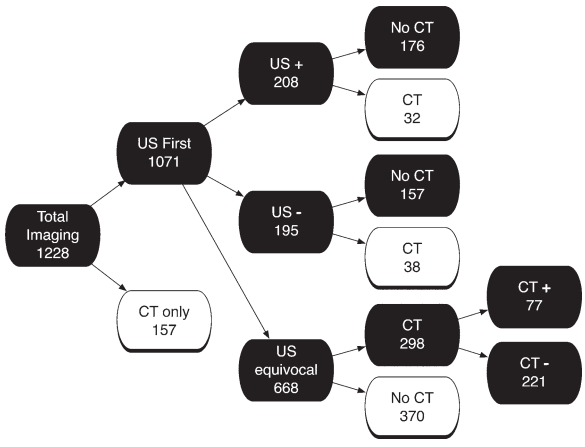

Figure 3: Diagram shows imaging results in patients who underwent imaging (US and/or CT) for suspected appendicitis. Patients who followed the pathway (compliant patients) are in black. Patients who did not follow the pathway (noncompliant patients) are in white and include patients who were referred directly to CT ($n = 157$), those who underwent CT after definitive US findings ($n = 70$), and those who did not undergo CT after equivocal US findings ($n = 370$).

Table 7

Imaging Protocol in the Noncompliant Population (*n* = 597)

Imaging Outcome	Final Diagnosis		Surgical Outcome		Nonsurgical Outcome	
	Appendicitis	No Appendicitis	Positive Appendectomy*	Negative Appendectomy	No Appendicitis	Missed Appendicitis†
CT only, no US (*n* = 157)						
Positive (*n* = 68)	61	7	61	3	4	0
Negative (*n* = 89)	0	89	0	2	87	0
Total	61	96	61	5	91	0
CT despite definitive US findings (*n* = 70)						
US positive, CT positive (*n* = 30)	26	4	26	2	2	0
US positive, CT negative (*n* = 2)	1	1	1	0	1	0
US negative, CT positive (*n* = 3)	2	1	2	0	1	0
US negative, CT negative (*n* = 35)	1	34	1	1	33	0
Total (*n* = 70)	30	40	30	3	37	0
US only, no CT (despite equivocal US findings) (*n* = 370)	18	352	18	1	351	0
Total for the noncompliant population	109	488	109‡	9§	479	0

Note.—Data are numbers of patients.

* Appendicitis was diagnosed at pathologic examination.

† Missed appendicitis refers to appendicitis that was missed at the initial presentation, resulting in a delayed diagnosis.

‡ The positive appendectomy rate was 92.4%.

§ The negative appendectomy rate was 7.6%.

Figure 4

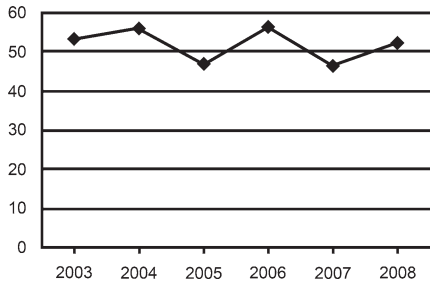

Figure 4: Graph shows the compliance rate with the staged US and CT pathway during the study period. There was no trend noted in compliance rate during the 6-year study period. Of the 1228 patients, 631 (51.3%) were compliant with the staged US and CT pathway.

for the diagnosis of acute appendicitis in children (2). The sensitivity reported for US, however, is heterogeneous and varies widely, ranging from 50% to 100%; the sensitivity reported for CT is 84%–100% (2). False-negative US scans diminish the acceptance of US by surgeons and emergency department physicians for the definitive diagnosis of appendicitis. In our study, we assessed the opportunity for reducing CT-related radiation without compromising accuracy by means of a staged US and CT protocol in children suspected of having appendicitis.

Use of the staged US and CT protocol reduced the number of CT examinations by 52.7% and had a sensitivity of 98.6%, which is comparable to that reported in the literature for CT alone (2,11,13–15,18,19). When we analyzed the 157 patients who were directly referred for CT, it was found that the performance of our US and CT protocol was as good as that of CT alone in terms of sensitivity, specificity, positive predictive value, and negative predictive value, with no statistically significant difference. In addition, there was no significant difference in the appendicitis rate among the patients who complied with the staged protocol, the patients who were directly referred for CT, and the patients who underwent CT despite having definitive US findings. A similar clinical protocol of US followed by CT was implemented in 1998 at Children's Hospital, Boston, Massachusetts, with a reported sensitivity of 94% in the diagnosis of appendicitis (13). The prevalence of appendicitis was 34.3% in our study and 36% in the Boston study, and the CT reduction rates were 52.7% and 22%, respectively. A possible explanation for the higher decreased rate of CT in our study is that our protocol called for CT only when US scans were equivocal and not when US scans were negative.

Wan et al (20), with use of a Markov decision analytic model, compared the cost effectiveness of US alone, CT alone, and US followed by CT if the initial US findings were negative. The model used by Wan et al was designed to determine which imaging strategy was most cost-effective for pediatric appendicitis, taking into account the risk of radiation-induced cancer from iatrogenic radiation exposure. US followed by CT was found to be the most costly and most effective. With our imaging protocol, CT was performed only when US findings were equivocal, and not when they were negative. CT was avoided in approximately 50% of our patients and resulted in a diagnostic accuracy for appendicitis comparable with that reported in the literature (2,11,13–15,18,19,21–24). We did not calculate cost parameters in our study. It is likely that a staged protocol is less expensive than

CT alone, given the reduction in the number of CT examinations and the relatively high cost of CT compared with US.

A potential concern for a sequential US and CT protocol is a delay in diagnosis. At our institution, CT and US scanners are located adjacent to the pediatric emergency department and, for children requiring a CT scan after US, the interval between examinations is routinely less than 1 hour.

In our series the normal appendix was visualized in 195 of the 1071 patients (18%). One hundred fifty-seven of the 195 patients (81%) with a negative US scan complied with the protocol pathway and, thus, avoided CT. The remaining 38 patients underwent CT because of continued clinical concern for appendicitis despite having a negative US scan.

Of the 195 patients with negative US scans, 191 (98%) had true-negative findings and four (2.0%) had false-negative findings. Of the four false-negative findings, only one case was managed nonsurgically; this case was ultimately diagnosed as missed appendicitis. This high reliability of a negative US scan supports the decision to defer CT in the case of a negative US scan.

Seventy patients (17.6%) with definitive US findings (positive or negative) underwent follow-up CT and thus were noncompliant with the study protocol. The possible reasons for performing CT following a definitive US scan include a search for an alternate diagnosis, lack of confidence in the US scan, or a high clinical suspicion for appendicitis despite the US report. This group of patients provides the opportunity to compare the two imaging modalities in the same patients. US and CT findings were concordant in 93% of cases. In the remaining 7.0% (five patients), the final diagnosis correlated with CT findings in three patients and with US findings in two. This supports US as definitive when findings are either positive or negative.

There was no significant difference in sensitivity and specificity when the study population was classified into subgroups on the basis of age and sex. This favors applying the protocol to all children up to 18 years of age irrespective of sex. The protocol performance did not vary significantly when analyzed according to year of study.

The staged US and CT imaging pathway was largely successful because of multidisciplinary cooperation and support involving emergency department physicians, surgeons, and radiologists. Our study illustrates the success of a cooperative imaging algorithm established across specialty lines in the interest of providing high-quality patient care in children.

Our study design was retrospective, which did not allow for patient follow-up after discharge. We could not track patients who might have subsequently presented to other institutions. However, follow-up instructions and appendicitis precautions were given to all patients at discharge.

In conclusion, a staged US and CT imaging protocol in which US is performed first for suspected acute appendicitis in children is highly accurate and offers the opportunity to substantially reduce radiation. A definitive US result, either positive or negative, is sufficiently accurate to guide therapy without performing subsequent CT. The success of the described imaging protocol can largely be attributed to a cooperative multidisciplinary effort between radiologists, emergency department physicians, and surgeons.

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References

1. Lund DP, Folkman J. Appendicitis. In: Walker WA, Durie PR, Hamilton JR, Walker-Smith JA, Watkins JB, eds. Pediatric gastrointestinal disease: pathophysiology, diagnosis and management. 2nd ed. St Louis, Mo: Mosby, 1996; 907–915.
2. Taylor GA. Suspected appendicitis in children: in search of the single best diagnostic test. Radiology 2004;231(2):293–295.
3. Paajanen H, Somppi E. Early childhood appendicitis is still a difficult diagnosis. Acta Paediatr 1996;85(4):459–462.
4. Peña BM, Taylor GA, Fishman SJ, Mandl KD. Effect of an imaging protocol on clinical outcomes among pediatric patients with appendicitis. Pediatrics 2002;110(6):1088–1093.
5. Rodriguez DP, Vargas S, Callahan MJ, Zurakowski D, Taylor GA. Appendicitis in young children: imaging experience and clinical outcomes. AJR Am J Roentgenol 2006; 186(4):1158–1164.
6. Williams N, Kapila L. Acute appendicitis in the under-5 year old. J R Coll Surg Edinb 1994; 39(3):168–170.
7. Velanovich V, Satava R. Balancing the normal appendectomy rate with the perforated appendicitis rate: implications for quality assurance. Am Surg 1992;58(4):264–269.
8. Applegate KE, Sivit CJ, Salvator AE, et al. Effect of cross-sectional imaging on negative appendectomy and perforation rates in children. Radiology 2001;220(1):103–107.
9. Brenner D, Elliston C, Hall E, Berdon W. Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR Am J Roentgenol 2001;176(2):289–296.
10. Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. N Engl J Med 2007;357(22):2277–2284.
11. Doria AS, Moineddin R, Kellenberger CJ, et al. US or CT for diagnosis of appendicitis in children and adults? A meta-analysis. Radiology 2006;241(1):83–94.
12. Puylaert JB. Acute appendicitis: US evaluation using graded compression. Radiology 1986;158(2):355–360.
13. Garcia Peña BM, Mandl KD, Kraus SJ, et al. Ultrasonography and limited computed tomography in the diagnosis and management of appendicitis in children. JAMA 1999;282(11): 1041–1046.

14. Kaiser S, Frenckner B, Jorulf HK. Suspected appendicitis in children: US and CT—a prospective randomized study. Radiology 2002; 223(3):633–638.

15. Karakas SP, Guelfguat M, Leonidas JC, Springer S, Singh SP. Acute appendicitis in children: comparison of clinical diagnosis with ultrasound and CT imaging. Pediatr Radiol 2000;30(2):94–98.

16. Hall EJ, Brenner DJ. Cancer risks from diagnostic radiology. Br J Radiol 2008;81(965): 362–378.

17. Robbins E. Radiation risks from imaging studies in children with cancer. Pediatr Blood Cancer 2008;51(4):453–457.

18. Fefferman NR, Roche KJ, Pinkney LP, Ambrosino MM, Genieser NB. Suspected appendicitis in children: focused CT technique for evaluation. Radiology 2001;220(3):691–695.

19. Kan JH, Fines BP, Funaki B. Conventional and hydrocolonic US of the appendix with CT correlation performed by on-call radiology residents. Acad Radiol 2001;8(12):1208–1214.

20. Wan MJ, Krahn M, Ungar WJ, et al. Acute appendicitis in young children: cost-effectiveness of US versus CT in diagnosis—a Markov decision analytic model. Radiology 2009;250(2):378–386.

21. Lowe LH, Penney MW, Stein SM, et al. Unenhanced limited CT of the abdomen in the diagnosis of appendicitis in children: comparison with sonography. AJR Am J Roentgenol 2001;176(1):31–35.

22. Mullins ME, Kircher MF, Ryan DP, et al. Evaluation of suspected appendicitis in children using limited helical CT and colonic contrast material. AJR Am J Roentgenol 2001;176(1):37–41.

23. Sivit CJ, Applegate KE, Stallion A, et al. Imaging evaluation of suspected appendicitis in a pediatric population: effectiveness of sonography versus CT. AJR Am J Roentgenol 2000;175(4):977–980.

24. Stephen AE, Segev DL, Ryan DP, et al. The diagnosis of acute appendicitis in a pediatric population: to CT or not to CT. J Pediatr Surg 2003;38(3):367–371, discussion 367–371.