A CUTE APPENDICITIS IS THE MOST common cause for emergency abdominal surgery in childhood with 60,000 to 80,000 cases diagnosed per year in the United States.1,2 Morbidity and mortality of acute appendicitis in children remain high, mainly due to those complications associated with delayed diagnosis.2-8 Accurate diagnosis is difficult in the pediatric population as the initial presentation of appendicitis can be obscure and closely mimicked by other common disease processes.9-17

Diagnostic imaging studies traditionally have been reserved for those children in whom the diagnosis of appendicitis is uncertain. The use of ultrasonography in the diagnosis of childhood appendicitis has increased steadily; however, ultrasonography is highly operator dependent and rarely visualizes either an inflamed retrocecal appendix or a noninflamed appendix.18-22 Advances in computed tomography (CT) with high-resolution techniques have yielded sensitivities as high as 100% and specificities as high as 98%.23-33

See also Patient Page.
through the rectum. This technique improves diagnosis and reduces use of hospital resources in the adult population. Models using CT have been shown to reduce costs and improve diagnosis, management, and outcomes in pediatric appendicitis cases.

The purpose of this study was to determine prospectively the accuracy and effect of ultrasonography followed by limited CT with rectal contrast (CTRC) in the diagnosis and management of appendicitis in the pediatric population.

**METHODS**

**Study Subjects and Setting**

Children and adolescents between the ages of 3 and 21 years who presented to the emergency department (ED) of Children’s Hospital in Boston, Mass, from July to December 1998, with signs suggestive of acute appendicitis were prospectively identified. Pregnant patients as well as those with a previous appendectomy or a contraindication to rectal contrast were ineligible. A total of 108 patients were required to undergo radiographic evaluation with ultrasonography and CTRC for a power of 90% and α error of .05, based on the difference between the highest reported ultrasonography and CT. The study was approved by the hospital’s institutional review board, which waived the requirement for subject consent.

**Study Protocol**

The consulting senior surgical resident, who is in his/her fourth or fifth postgraduate year, under the supervision of an attending pediatric surgeon, evaluated all children with suspected appendicitis in the ED. Those patients with unequivocal clinical presentations for appendicitis underwent appendectomy without imaging studies. Those who did not have symptoms consistent with appendicitis were discharged home without imaging studies. Those patients with equivocal clinical findings constituted the study cohort and were initially evaluated with pelvic ultrasonography. If the ultrasonography was definitive for appendicitis and the clinical presentation consistent, laparotomy was performed.

If the ultrasonography result was normal but the appendix was not visualized or if the ultrasonography result was equivocal, limited CTRC of the pelvis was obtained. Results of both the ultrasonography and CTRC were immediately made known to the treating physicians. In addition, the primary investigator was informed of the ultrasonography results immediately after the examination was completed.

**Performance and Interpretation**

Pelvic sonographic studies were performed by 1 of 6 pediatric radiology fellows or 1 of 5 attending physicians using 5.0- and/or 7.5-MHz linear array transducers (Model XP10, Acuson, Mountain View, Calif) and the graded compression technique. The sonographic diagnosis of appendicitis was based on detecting a fluid-filled, noncompressible, distended structure (6 mm in diameter) with or without an appendicolith, which demonstrated no peristaltic activity; appeared constant in shape and position; and was located either anterior to the psoas muscle or in a retrocecal position. The presence of pericecal inflammatory changes in the absence of visualizing an abnormal appendix was considered suggestive but not specific for acute appendicitis.

Computed tomography with rectal contrast examinations were performed with GE 9800 HiLite scanners (GE Medical Systems, Milwaukee, Wis) using helical technique with limited scanning. Patients received between 200 and 1000 mL of 3% diatrizoate meglumine (Gastrografin, Bristol-Meyers Squibb Co, Princeton, NJ) saline solution through a rectal catheter by slow controlled drip immediately prior to scanning. Oral or intravenous contrast was not used. Thin-collimation helical scanning was performed from the top of L3 to the acetabular roof with a pitch of 1.5 (with 3-mm collimation for children 3-10 years old and 5-mm collimation for patients >10 years).

Each CTRC examination was immediately interpreted by 1 of 6 pediatric radiology fellows between 5 PM and 8 AM or an attending pediatric radiologist between 8 AM and 5 PM. The CTRC diagnosis of appendicitis was based on the visualization of an abnormal appendix and/or pericecal inflammation or abscess with or without the presence of an appendicolith. An abnormal appendix was defined as being a fluid-filled tubular structure measuring greater than 6 mm in its maximum diameter and/or perappendiceal inflammatory changes such as fat stranding, abscess, or phlegmon (FIGURE 1).

Highly suggestive signs included the presence of an appendicolith, focal cecal apical thickening, the arrowhead sign, and the cecal bar. Computed tomography with rectal contrast examinations were interpreted as negative for appendicitis if a normal appendix was visualized. If the normal appendix was not visualized, the scan was interpreted as negative if there was no associated periappendiceal inflammatory changes.

**Likelihood of Appendicitis**

Surgeons estimated the likelihood of each child’s having appendicitis on a scale from 1 to 10 along with their management plans before imaging, after ultrasonography, and after CTRC. The 3 management plans included: discharge home from the ED, admit to hospital for inpatient observation, or proceed to the operating room (OR) for appendectomy. Changes in the likelihood of appendicitis and management plans were determined by comparing the initial preimaging likelihood and management plans with those following ultrasonography and CTRC.

**Final Diagnoses and Follow-up**

The final clinical outcomes were determined at surgery and pathological examination of the appendix in patients who underwent laparotomy and by clinical follow-up in patients managed nonoperatively. All children who did not undergo surgery were followed up by telephone at 2 weeks after the ED visit. Medical records of all patients were reviewed 4 to 6 months after study completion.

**Statistical Analysis**

Measures of test validity (sensitivity, specificity, positive predictive value...
[PPV], negative predictive value [NPV], and accuracy) were determined for the ultrasonography-CTRC protocol and for ultrasonography and CTRC individually. Indeterminate results were considered false-positive or false-negative and incorporated into the final analysis. For example, an indeterminate result in a patient found to have appendicitis was considered to have had a negative test result. Changes in likelihood of appendicitis after ultrasonography and CTRC were evaluated with the paired sample 2-tailed t-test. Changes in management decisions after ultrasonography and CTRC were evaluated with 2-tailed Fisher exact test. All calculations were performed with SPSS for Windows, version 7.5 (SPSS Inc, Chicago, Ill).

RESULTS

One hundred seventy-seven children were evaluated for appendicitis during the 6-month study period (Figure 2). Four patients (2.3%) were discharged from the ED after surgical consultation without imaging studies. None of these patients returned with appendicitis, and all had resolved symptoms at 2-week follow-up. Thirty-four (19.2%) of the 177 patients went directly for surgical intervention without diagnostic imaging; 30 (88%) of the 34 patients had pathologically proven appendicitis and 9 (30%) of 30 patients had perforated appendicitis. The negative laparotomy rate was 4/34 (11.8%). One hundred thirty-nine patients had equivocal clinical findings and were enrolled as the study cohort.

Study Cohort

The mean (SD) age of the cohort was 11.1 (4.25) years (range, 3-20 years, median 11 years), 2 patients were older than 18 years. Seventy (50.4%) of the 139 patients evaluated with ultrasonography were male. Appendicitis was proven at surgery and pathologic examination in 50 (36.0%) patients. Eleven (22%) of the 50 patients who had perforated appendicitis, and 3 (6%) had a gangrenous appendix.

Thirty-one patients were imaged solely with ultrasonography. Of these, 19 underwent appendectomy immediately after ultrasonography. All patients who underwent appendectomy following a positive ultrasonography result had pathologically proven appendicitis. One 5-year-old boy had an equivocal ultrasonography examination result and did not undergo CTRC. He was admitted for inpatient observation, had progression of symptoms, and underwent appendectomy 8 hours after admission. Pathological examination revealed appendicitis. Of the 11 patients who had negative ultrasonography examination results, 7 (64%) did not undergo CTRC due to resolved symptoms, 1 (9%) had an established alternative diagnosis, 2 (18%) had visibly normal appendixes, and 1 (9%) was unable to retain the rectal contrast. The latter was an 11-year-old developmentally delayed boy with a negative ultrasonography examination result who was subsequently hospitalized after failed CTRC and discharged within 24 hours after his symptoms resolved.

He returned 3 days later with perforated appendicitis.

One hundred eight patients underwent CTRC imaging following negative or equivocal ultrasonography. Fifty-six patients (52%) were female. The mean (SD) age of these patients was 11.34 (4.28) years (range, 4-20 years; median, 11 years). Computed tomography with rectal contrast was well tolerated by all patients and there were no complications. One child required sedation. Thirty-one (29%) of the 108 patients who were evaluated with CTRC underwent appendectomy immediately following CTRC. Of these, 28 patients (90%) had pathologically proven appendicitis (Figure 2). Seven (25%) of these patients had perforated appendicitis and 2 had a gangrenous appendix. The first of these 3 patients with a negative laparotomy was a 17-year-old boy found to have lymphoma of the cecum. Computed tomography with rectal contrast was interpreted as perforated ap-
appendicitis. The second patient was a 17-year-old boy with marked cecitis and nonobstructive appendicitis. One child with an equivocal CTRC interpretation underwent surgery. She was a 13-year-old girl who had an appendicolith identified at CTRC and pathology but no appendiceal inflammation. Twenty-five (23%) of patients who were evaluated with CTRC were hospitalized for observation; 24 did not have appendicitis. One patient underwent interval appendectomy after initial CTRC was interpreted as terminal ileitis. He was subsequently diagnosed as having perforated appendicitis. Fifty-two patients (48%) were discharged home directly from the ED. None had appendicitis.

Diagnostic Value of Ultrasonography-CTRC Protocol

The ultrasonography-CTRC protocol was positive in 49 children (true-positive in 47 patients, false-positive in 2); negative in 86 children (true-negative in 84 patients, false-negative in 2); and equivocal in 4 children. The protocol yielded a sensitivity of 94% (47/50), specificity of 94% (84/89), PPV of 90% (47/52), NPV of 97% (84/87), and accuracy of 94% (131/139).

Diagnostic Value of Ultrasonography

Ultrasonography was positive for appendicitis in 22 children, negative in 104, and equivocal in 13 patients: true-positive in 22 patients on the basis of pathological examination and true-negative in 83 patients (TABLE 1). Ultrasonography had a sensitivity of 44% (29%-59%), specificity of 93% (89%-99%), PPV of 79% (62%-96%), NPV of 75% (66%-83%), and accuracy of 76% (68-83%). A normal appendix was identified in 2 (2.4%) of 83 patients without appendicitis.

Diagnostic Value of CTRC

Computed tomography with rectal contrast scans after negative or equivocal ultrasonography test results were positive for appendicitis in 30 children, negative in 75, and equivocal in 3 children: true-positive in 28 patients, false-positive in 2, and true-negative in 74 patients on the basis of clinical follow-up (TABLE 2). Computed tomography with rectal contrast after negative or equivocal ultrasonography test results had a sensitivity of 97% (88%-100%), specificity of 94% (87%-100%), PPV of 85% (71%-99%), NPV of 99% (95%-100%), and accuracy of 94% (89%-100%). A normal appendix was identified in 62 (84%) of the 74 patients without appendicitis.

Likelihood of Appendicitis and Changes in Management Decisions

In those children without appendicitis (TABLE 3), the results of ultrasonography did not make a significant difference on the surgeons’ estimated likelihood of appendicitis (P = .06). However, in these children, the surgeons’ estimated likelihood of appendicitis was significantly affected by the CTRC results (P < .001). In those children with appendicitis (TABLE 4), both ultrasonography and CTRC were found...
to have an effect on the surgeons’ estimated likelihood of appendicitis ($P = .001$ and $P < .001$, respectively).

Ultrasoundography resulted in a beneficial change in patient management in 26 (18.7%) of the 139 children, an incorrect change in 5 (3.6%), and no change in management in 108 (77.7%).

Computed tomography with rectal contrast resulted in a beneficial change in patient management in 79 (73.1%) of the 108 children who had received both ultrasonography and CTRC, an incorrect change in 2 (1.9%), and no change in management in 27 patients (25%). The beneficial management changes are shown in Table 5. Computed tomography rectal with contrast had a significantly stronger effect on beneficial patient management than did ultrasonography ($P < .001$).

**COMMENT**

Diagnostic imaging of the appendix has improved steadily over the past decade. Ultrasoundography has been used traditionally as the primary imaging modality in children with suspected appendicitis because it is relatively quick to perform, well tolerated, and uses no ionizing radiation. However, ultrasoundography instills less confidence in a negative result, and management strategies are rarely based on negative sonographic findings. Computed tomography with rectal contrast has been shown to be 98% accurate in the diagnosis of appendicitis in the adult population. In addition, the routine use of CTRC in adult ED patients has been shown to be safe, to be performed quickly, and to improve patient care while decreasing costs.

Our study is the first to evaluate limited scanning CTRC in the pediatric population. The ultrasonography and CTRC protocol proved to be 94% accurate. The addition of CTRC after a negative ultrasonography result increased the imaging sensitivity from 44% to 94%. The negative laparotomy rate in those children who underwent the imaging protocol was 6%, compared with 12% in those children who underwent immediate surgery. Furthermore, many of the patients with appendicitis would have been either discharged home or admitted to the hospital for an observation period. Thus, the imaging protocol was able to substantially reduce the time to appendectomy in these children.

Our study had some limitations. First, CTRC was evaluated following a negative or indeterminate ultrasound examination. Hence, the true sensitivity and specificity of CTRC was not determined since those patients with positive ultrasonography results did not undergo CTRC. Since the PPV of ultrasoundography is high, we believed it inappropriate for children with positive ultrasoundography findings to undergo unnecessary radiation. However, a strength of this design is that the sensitivity of CTRC after a negative or equivocal ultrasoundography result was determined. Hence, CTRC was evaluated in those children in whom the diagnosis is the most difficult, those with equivocal clinical findings and negative or indeterminate ultrasoundography interpretations.

Second, there may have been bias in the radiologists’ interpretation of the results.

**Table 2.** Computed Tomography With Rectal Contrast (CTRC) Findings Correlated With Surgical and Clinical Outcomes in 108 Children With Suspected Appendicitis

<table>
<thead>
<tr>
<th>Findings</th>
<th>Operatively Managed</th>
<th>Nonoperatively Managed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive for appendicitis</td>
<td>28</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>Negative for appendicitis</td>
<td>1</td>
<td>74</td>
<td>75</td>
</tr>
<tr>
<td>Equivocal</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>76</td>
<td>108</td>
</tr>
</tbody>
</table>

**Table 3.** Clinical Estimates and Mean Change of Pretest, Postultrasoundography, and Post–Computed Tomography With Rectal Contrast (CTRC) Likelihood of Appendicitis in Children Without Appendicitis

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Pretest</th>
<th>Mean (SD)</th>
<th>Post-CTRC</th>
<th>Mean (SD)</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>3.70 (1.75)</td>
<td>$-0.23 (1.05)$</td>
<td>1.89 (1.58)</td>
<td>$-1.59 (2.02)$</td>
<td>.06</td>
</tr>
<tr>
<td>Negative</td>
<td>6.59 (2.81)</td>
<td>$1.26 (1.58)$</td>
<td>8.76 (1.72)</td>
<td>$3.67 (2.52)$</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*CI indicates confidence interval.

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Pretest</th>
<th>Mean (SD)</th>
<th>Post-CTRC</th>
<th>Mean (SD)</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>5.53 (2.18)</td>
<td>$1.26 (2.50)$</td>
<td>5.09 (2.23)</td>
<td>$3.67 (2.52)$</td>
<td>.001</td>
</tr>
<tr>
<td>Negative</td>
<td>6.59 (2.81)</td>
<td>$1.26 (2.50)$</td>
<td>8.76 (1.72)</td>
<td>$3.67 (2.52)$</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*CI indicates confidence interval.†Patients with equivocal or negative ultrasoundography.

**Table 5.** Essential and Beneficial Changes in Patient Management With Ultrasonography and Computed Tomography With Rectal Contrast (CTRC) Imaging

<table>
<thead>
<tr>
<th>Change in Management</th>
<th>Ultrasonography</th>
<th>CTRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admit for observation</td>
<td>home</td>
<td>7</td>
</tr>
<tr>
<td>Admit for observation</td>
<td>operating room</td>
<td>14</td>
</tr>
<tr>
<td>Discharge home</td>
<td>admit for observation</td>
<td>0</td>
</tr>
<tr>
<td>Discharge home</td>
<td>operating room</td>
<td>3</td>
</tr>
<tr>
<td>Operating room</td>
<td>admit for observation</td>
<td>2</td>
</tr>
<tr>
<td>Operating room</td>
<td>discharge home</td>
<td>0</td>
</tr>
</tbody>
</table>

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ultrasonography examination and CTRC after knowing the surgeon’s estimated likelihood of appendicitis. However, this seems unlikely because the diagnosis of appendicitis is based on concrete radiographic criteria. Third, the radiologist performing the CTRC examination may have been the same person who performed the ultrasonography examination and, thus, was not blinded to the result when performing the CTRC scan. However, the ultrasonography findings were reported immediately to the clinicians who requested the study and to the primary investigator so that the CTRC results would not influence the initial reading of the ultrasonography examinations. Finally, the investigation was performed at only 1 institution, and its generalizability to other centers is unknown.

Our measurement of 44% sensitivity for ultrasonography in the diagnosis of appendicitis is lower than what has been previously reported.13-21 However, the sensitivity of ultrasonography for the diagnosis of appendicitis prior to the introduction of CTRC at our institution during the 2-year period between January 1996 and December 1997 was 50%, which is commensurate with our present findings.

Our computation of the measures of test validity were conservative in that we considered the indeterminate results to be false-positive or false-negative. An approach in which the equivocal results are considered positive for appendicitis would have yielded a sensitivity for the ultrasonography-CTRC protocol of 96%, a specificity of 94%, a PPV of 91%, an NPV of 98%, and an accuracy of 95%. The same approach applied to ultrasonography would have yielded a sensitivity of 58%, a specificity of 93%, a PPV of 83%, and an NPV of 80%. The approach applied to CTRC would have yielded the same results as the conservative approach since there were only 3 indeterminate scans, and they were considered false-negative in the analysis.

We believe that CTRC should be reserved for those children in whom, after full clinical evaluation, the diagnosis remains uncertain. Ultrasonography was able to diagnose appendicitis in almost 40% of patients with the disease noninvasively and without radiation. In a patient population with a low pretest probability of appendicitis, ultrasonography is a useful primary diagnostic modality. The indiscriminate use of CTRC could potentially result in a delay in diagnosis as well as unnecessary radiation exposure. While radiation exposure in the pediatric population should clearly be minimized, those children who undergo CTRC will receive approximately one third the average radiation exposure of a standard abdominopelvic CT examination.24 There may be a subset of children for whom CTRC may be justified without preliminary ultrasonography examination. Future studies are needed to determine the clinical characteristics of these children.

Acknowledgment: The authors thank Stephen Brown, MD, Cinzia Crawley, MD, Nakul Jerath, MD, Veronica Rooks, MD, Valerie Ward, MD, and Terri Williams-Weeks, MD, the radiology attendings, emergency medicine residents, fellows, and attendings and surgery residents, fellows, and attendings for their invaluable help and patience during the study period. Special thanks to Patrick M. Rao, MD, Constantino S. Peña, MD, E. Francis Cook, ScD, and Colleen Haigean, MD, for their encouragement and support.

References