Effect of Reduction in the Use of Computed Tomography on Clinical Outcomes of Appendicitis

Richard G. Bachur, MD; Jason A. Levy, MD; Michael J. Callahan, MD; Shawn J. Rangel, MD; Michael C. Monuteaux, ScD

**Importance** Advanced diagnostic imaging is commonly used in the evaluation of suspected appendicitis in children. Despite its inferior diagnostic performance, ultrasonography (US) is now preferred to computed tomography (CT) owing to concerns about ionizing radiation exposure. With changes in imaging modalities, the influence on outcomes should be assessed.

**Objectives** To review trends in the use of US and CT for children with appendicitis and to investigate simultaneous changes in the proportions of negative appendectomy, appendiceal perforation, and emergency department (ED) revisits.

**Design, Setting, and Participants** We reviewed the Pediatric Health Information System administrative database for children who presented to the ED with the diagnosis of appendicitis or who underwent an appendectomy in 35 US pediatric institutions from January 1, 2010, through December 31, 2013.

**Main Outcomes and Measures** We studied the use of US and CT for trends and their association with negative appendectomy, appendiceal perforation, and 3-day ED revisits.

**Results** Our investigation included 52,153 children with appendicitis. Use of US increased 46% (from 24.0% in 2010 to 35.3% in 2013; absolute difference, 11.3%; adjusted test for linear trend, \( P = .02 \)), whereas use of CT decreased 48% (from 21.4% in 2010 to 11.6% in 2013; absolute difference, −9.8%; adjusted test for linear trend, \( P < .001 \)). The proportion of negative appendectomy declined during the 4-year study period from 4.7% in 2010 to 3.6% in 2013 (test for linear trend, \( P = .002 \)), whereas the proportion of perforations (32.3% in 2010 to 31.9% in 2013) and ED revisits (5.6% in 2010 and 2013) did not change (adjusted tests for linear trend, \( P = .64 \) and \( P = .84 \), respectively).

**Conclusions and Relevance** Among children with suspected appendicitis, the use of US imaging has increased substantially as the use of CT has declined. Despite the increased reliance on the diagnostically inferior US, important condition-specific quality measures, including the frequency of appendiceal perforation and ED revisits, remained stable, and the proportion of negative appendectomy declined slightly.
Beginning in the mid-1990s, use of advanced diagnostic imaging for suspected appendicitis was extensively investigated.\(^1\) The superior diagnostic performance of computed tomography (CT), rates of the use of CT for suspected appendicitis climbed through the first decade of the century.\(^5\) Although advanced imaging was originally intended for cases with atypical presentations and indeterminate clinical findings, its use expanded to include patients with more classic presentations and those with low levels of clinically suggestive symptoms to decrease the rate of negative appendectomy (ie, normal appendix at surgery). With increasing concerns about the long-term effects of exposure to ionizing medical radiation,\(^6\) ultrasonography (US) has become the preferred imaging modality for the evaluation of pediatric appendicitis.\(^10\)-\(^16\)

A previous investigation at major US pediatric institutions\(^5\) reviewed the imaging trends (2005-2009) and their relationship to clinical outcomes (eg, rate of negative appendectomy and appendiceal perforation), and the use of CT was shown to peak in 2009. Among those patients who underwent US imaging, centers with increased use of US had better clinical outcomes. Herein, we report the use of advanced imaging in children diagnosed as having appendicitis during a 4-year follow-up period, from January 1, 2010, through December 31, 2013. Our objectives were to review trends in the use of US and CT and to investigate changes in the frequency of negative appendectomy, appendiceal perforations, and revisits to the emergency department (ED). Knowing that US has an inferior diagnostic performance compared with CT, we anticipated that increased reliance on US would lead to worse clinical outcomes.

### Methods

#### Data Source and Design

This retrospective study used an administrative database, the Pediatric Health Information System (PHIS), managed by the Children’s Hospital Association, a business alliance of freestanding pediatric hospitals. Data quality and reliability were ensured through a joint effort between the Children’s Hospital Association and participating hospitals. For the purposes of external benchmarking, participating hospitals provided discharge and encounter data, including demographics, diagnoses, and procedures. Thirty-five of these hospitals also submitted data on use of resources (eg, pharmaceuticals, imaging, and laboratory) and performed more extensive validation of ED data. Patient information was deidentified at the time of data submission, and data were subjected to a number of reliability and validity checks before being included in the database. No patient-level clinical data exist in the database. The study was approved by the institutional review board and the administrators of the PHIS database. In accordance with PHIS policies, the identities of the institutions are not reported.

To examine the use of advanced imaging over time for children with appendicitis, we investigated all patients younger than 19 years (hereinafter referred to as children) with a final primary diagnosis of appendicitis in association with an ED encounter from January 1, 2010, through December 31, 2013.

#### Analytic Plan

We reviewed the use of US and CT for patients with appendicitis from 2010 through 2013. We classified patients into 1 of the following 4 groups, according to the advanced imaging they received: no CT or US, CT only, US only, and both modalities. Although the use of magnetic resonance imaging (MRI) for the diagnostic evaluation of pediatric appendicitis is rare, we excluded patients who underwent abdominal MRI from all groups. To test for trends of the use of imaging modalities over time, we estimated a multinomial logistic regression model with the 4-level imaging group as the dependent variable (with no CT or US designated as the reference group) and calendar year as the independent variable. We also included patient age, sex, and race as covariates. We used a robust variance estimator to accommodate the correlation resulting from the clustering of patients within hospitals.

#### Relevant Outcomes

To assess the impact of trends in diagnostic imaging, we studied 3 previously established outcomes relevant to the care of children with suspected appendicitis. First, we determined the proportion of negative appendectomies by dividing the number of patients in the ED who had an appendectomy (procedure codes 47.01, 47.09, or 47.19) without a final diagnosis of appendicitis from 2010 through 2013. An encounter was classified as an appendicitis case if any of the following codes from the International Classification of Diseases, Ninth Revision (ICD-9), was assigned as the primary diagnosis: 540.0, 540.1, 540.9, 541, or 542. Without clinical information, we made the following assumptions: diagnostic studies ordered for ED patients were performed for the purpose of evaluation of the primary diagnosis, and the final diagnosis of appendicitis was coded based on operative or pathologic findings. Data integrity was judged by testing the following conditions in the study sample: (1) all patients with the diagnosis of appendicitis were admitted to the hospital (99.5%); (2) all patients with acute appendicitis without abscess had an appendectomy at the index visit (96.2%); and (3) all patients with perforated appendicitis were administered antibiotics (99.3%). To investigate changes in the rate of negative appendectomies separately (defined below), we investigated all children who had an appendectomy performed in association with an ED encounter during the same study period.

#### At a Glance

- The purposes of this study were to review trends in ultrasonography (US) and computed tomography (CT) use among children with appendicitis from 2010 to 2013 at 35 pediatric emergency departments (ED) and to investigate simultaneous changes in the proportion of negative appendectomy, appendiceal perforation, and ED revisits.
- During the 4-year study, US showed a 46% increase in use (24.0% in 2010 to 35.3% in 2013; absolute difference, 11%), whereas CT showed a 48% reduction in use (21.4% in 2010 to 11.6% in 2013; absolute difference, 9.8%).
- The proportion of negative appendectomy declined during the 4-year study, whereas the proportion of appendiceal perforations and ED revisits did not change.
appendicitis by the total number of patients in the ED who had an appendectomy and no other surgical procedure (ie, release of ovarian torsion, manipulation of the intestine, removal of ectopic pregnancy, or repair of hernia) that may indicate an incidental appendectomy. Second, we calculated the proportion of appendiceal perforations by adding the number of cases of appendicitis with peritonitis (ICD-9 code 540.0) and the number of cases of appendicitis with abscess (ICD-9 code 540.1) and dividing the sum by all patients with any code of appendicitis. Third, we defined 3-day revisits as possible missed cases of appendicitis when any patient with a final diagnosis of appendicitis had undergone evaluation in the ED within the previous 3 days (using a unique patient identifier), regardless of the original visit diagnosis. To test for trends in these outcomes over time, we estimated 3 logistic regression models with each of the binary outcomes as the dependent variable and calendar year, age, sex, and race as the independent variables. Because we anticipated a decline in CT use, we also studied the use of plain abdominal radiography and the use of serial US (≥2 studies) for individual patients (for 2 calendar days starting with the day of the ED visit).

Validation Substudy
To support the validity of the data, the PHIS data for a single institution (Boston Children's Hospital) was linked to the medical record. All cases with a negative appendectomy (n = 55) and 100 sequential cases of appendicitis (of the 1311 reported cases) were reviewed manually for the accuracy of the diagnosis.

General Considerations
All statistical tests were 2 tailed, and the α value was set at .05. We conducted all analyses with a commercially available statistical software package (STATA, version 13.1; StataCorp).

Results

Study Population and Advanced Diagnostic Imaging
We identified 52,275 children with appendicitis. We excluded 122 patients (0.2%) who underwent abdominal MRI, leaving 52,153 patients stratified across our 4 imaging groups (Table 1). The sample was predominantly male, with a median age of 10.9 years. The most common principal diagnosis was appendicitis without mention of peritonitis (ICD-9 code 540.9), and 98.8% of all patients were admitted to the hospital from the ED. Most of the sample (93.6%) underwent an appendectomy. Of the 3339 children who did not undergo an appendectomy (6.4%), 80.4% were diagnosed as having appendiceal perforation (25.1% with appendicitis with generalized peritonitis [ICD-9 code 540.0] and 55.3% with appendicitis with peritoneal abscess [ICD-9 code 540.1]).

The percentage of each of the 4 diagnostic imaging categories by study year is shown in Figure 1. The use of US increased each year, whereas the use of CT decreased each year. The proportions of each group over time (adjusted for age, sex, and race) are presented in Table 2. The use of US alone showed a 46% increase, from 24.0% in 2010 to 35.3% in 2013 (absolute difference, 11.3%; adjusted test for linear trend, P = .02). However, the use of CT alone showed a 48% reduction, from 21.4% in 2010 to 11.6% in 2013 (absolute difference, −9.8%; adjusted test for linear trend, P < .001). No difference was found in the use of combined CT and US (from 4.4% in 2010 to 5.4% in 2013; absolute difference, 1.0%; adjusted test for linear trend, P = .14).

As the rates of CT use declined, the use of plain abdominal radiographs did not increase (test for linear trend, P = .24, adjusted for age, sex, CT use, and US use). Although the rates of CT use declined, the proportion of cases with serial US (≥2 studies) did not increase (adjusted percentages [95% CI], 0.7% [0.3%-1.0%] and 0.7% [0.3%-1.0%] for 2010 and 2013, respectively; test for linear trend, P = .63).

Outcomes
The relevant clinical outcomes are presented in Figure 2. The percentage of negative appendectomy declined during the study period from 4.7% in 2010 to 3.6% in 2013 (number of appendectomies, 51,734; test for linear trend, P = .002). However, we found no evidence of change during the study period for the percentage of cases with appendiceal perforation (from 32.3% in 2010 to 31.9% in 2013; adjusted test for linear trend, P = .64) or with ED 3-day return visits (5.6% in 2010 and 2013; adjusted test for linear trend, P = .84).

Discussion
Appendicitis remains the most common surgical emergency in children. Delays in diagnosis can lead to significant morbidity owing to appendiceal rupture. Assessment based on the history, physical examination, and routine laboratory studies is not sufficient for making a diagnosis in many pediatric patients, especially in young children or those presenting early in the disease course. Advanced imaging with CT or US is commonly incorporated into the diagnostic evaluation for suspected pediatric appendicitis. Based on strong evidence, CT has a greater diagnostic accuracy compared with US. A 2006 meta-analysis by Doria et al provided pooled estimates (95% CI) for both imaging modalities of sensitivity (for CT, 94% [92%-97%; for US, 88% [86%-90%]) and specificity (for CT, 95% [94%-97%]; for US, 94% [92%-95%]). In addition, CT has other advantages compared with US, including independence of operator technical skills, not limited by patient obesity or abdominal tenderness, better identification of a retrocecal appendix, and greater detail with complicated appendicitis. Ultrasonography has the advantage of no ionizing radiation exposure and no requirement of intravenous or enteral contrast, but can be limited in overweight patients and is highly operator dependent. Despite the diagnostic superiority of
CT, US has become the preferred modality to reduce the exposure to radiation in a young population with greater radiosensitivity.21-26 When CT was recommended as the best diagnostic modality for pediatric appendicitis in the late 1990s, the high sensitivity obviated the need for routine admission of patients with indeterminate clinical findings.27,28 Accordingly, reduced perforation rates were expected, because CT could identify early cases of appendicitis; this decrease in perforation rates has not been consistently appreciated in prior investigations.5,20,29-33 However, multiple studies have noted the inverse association between CT imaging and lower rates of negative appendectomy.2,5,20,30-34 With this knowledge, the dramatic decrease in CT rates during the first decade of the century was likely driven by the intent to achieve low rates of negative appendectomy. As the medical community and public raised concerns about medical radiation exposure, US rapidly became the preferred option when imaging was indicated, particularly in children. Unfortunately, US requires sonographers or on-site radiologists who are experienced in US acquisition, which is not standard in every setting. Furthermore, to avoid reliance

### Table 1. Demographic and Clinical Characteristics of the Patient Population*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Children With Appendicitis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All (n = 52,153)</td>
</tr>
<tr>
<td>Demographic</td>
<td></td>
</tr>
<tr>
<td>Male sex</td>
<td>31,477 (60.4)</td>
</tr>
<tr>
<td>Age, median (IQR), y</td>
<td>10.9 (8.1-13.7)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>35,251 (67.6)</td>
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<tr>
<td>Black</td>
<td>4314 (8.3)</td>
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<tr>
<td>Asian</td>
<td>1058 (2.0)</td>
</tr>
<tr>
<td>Other</td>
<td>8,494 (16.3)</td>
</tr>
<tr>
<td>Missing</td>
<td>3,036 (5.8)</td>
</tr>
<tr>
<td>Ethnicity</td>
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</tr>
<tr>
<td>Latino</td>
<td>16,113 (30.9)</td>
</tr>
<tr>
<td>Not Latino</td>
<td>30,620 (58.7)</td>
</tr>
<tr>
<td>Missing</td>
<td>5,420 (10.4)</td>
</tr>
<tr>
<td>Clinical</td>
<td></td>
</tr>
<tr>
<td>Principal diagnosis (ICD-9 code)</td>
<td></td>
</tr>
<tr>
<td>Appendicitis with generalized peritonitis (540.0)</td>
<td>11,456 (22.0)</td>
</tr>
<tr>
<td>Appendicitis with peritoneal abscess (540.1)</td>
<td>5,691 (10.9)</td>
</tr>
<tr>
<td>Appendicitis without mention of peritonitis (540.9)</td>
<td>33,799 (64.8)</td>
</tr>
<tr>
<td>Appendicitis, unqualified (541)</td>
<td>1,064 (2.0)</td>
</tr>
<tr>
<td>Other appendicitis (542)</td>
<td>143 (0.3)</td>
</tr>
<tr>
<td>Appendectomy performed</td>
<td>48,814 (93.6)</td>
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<tr>
<td>Disposition</td>
<td></td>
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<tr>
<td>Discharged from the ED</td>
<td>651 (1.2)</td>
</tr>
<tr>
<td>Admitted</td>
<td>51,502 (98.8)</td>
</tr>
<tr>
<td>Length of stay, median (IQR), d</td>
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<tr>
<td>Full sample</td>
<td>2 (1-4)</td>
</tr>
<tr>
<td>Appendicitis without perforation (540.9, 541, 542)</td>
<td>1 (1-2)</td>
</tr>
<tr>
<td>Appendicitis with perforation (540.0, 540.1)</td>
<td>5 (4-7)</td>
</tr>
</tbody>
</table>

Abbreviations: CT, computed tomography; ED, emergency department; ICD-9, International Classification of Diseases, Ninth Revision; IQR, interquartile range; US, ultrasonography.

* Includes pediatric patients undergoing evaluation in the ED and diagnosed as having appendicitis across 35 academic children’s hospitals (2010-2013). Unless otherwise indicated, data are expressed as number (percentage) of patients. Percentages have been rounded and may not total 100.

When CT was recommended as the best diagnostic modality for pediatric appendicitis in the late 1990s, the high sensitivity obviated the need for routine admission of patients with indeterminate clinical findings.27,28 Accordingly, reduced perforation rates were expected, because CT could identify early cases of appendicitis; this decrease in perforation rates has not been consistently appreciated in prior investigations.5,20,29-33 However, multiple studies have noted the inverse association between CT imaging and lower rates of negative appendectomy.2,5,20,30-34 With this knowledge, the dramatic increase in CT rates during the first decade of the century was likely driven by the intent to achieve low rates of negative appendectomy. As the medical community and public raised concerns about medical radiation exposure, US rapidly became the preferred option when imaging was indicated, particularly in children. Unfortunately, US requires sonographers or on-site radiologists who are experienced in US acquisition, which is not standard in every setting. Furthermore, to avoid reliance
As noted in the present study, rates of US have increased and those of CT have declined for patients with appendicitis. With the known limitations of US, we expected to observe negative consequences with increased frequency of negative appendectomies, appendiceal perforations, or cases of missed appendicitis as measured by revisits. To our surprise, the relative frequency of negative appendectomies declined during the study period, whereas the proportion of perforated appendices and revisits remained stable. The unexpected decrease in negative appendectomies cannot be fully understood from the administrative data but may suggest an improvement in the clinical practice, such as formal observation periods and serial examinations in the ED or through admission; this practice cannot be evaluated with the present study design but has the potential to influence the rate of negative appendectomies.

The present investigation is limited by the use of administrative data to judge clinical management and outcomes. We relied on assumptions that diagnostic coding has an accurate clinical correlate and that imaging was obtained for the purpose of the final diagnosis. The large data set allows trends to be observed, but patient level data would be necessary to determine diagnostic test performance accurately. Medical record review of our actual cases in the database supports the assumptions, but also reveals the underestimation of negative appendectomy by comparing final pathologic findings with the original discharge diagnosis; this underestimation is a known phenomenon, and we would expect the trends to be accurate even with this limitation. In addition, we cannot account for imaging that may have occurred before patient arrival; many of these hospitals serve as referral centers, and pretransfer imaging could influence the choice of subsequent imaging or the need for further imaging. At present, we have no reason to suspect major shifts during the study period in referral rates or prearrival imaging. Similarly, the choices of diagnostic imaging are determined by the timing of a patient’s presentation and the concern for complications that we were unable to assess; even without that patient-level information, the fraction of complicated appendicitis cases (with peritonitis or perforation with abscess) did not change during the study period. Finally, without patient level data, we cannot estimate other changes in clinical practice, such as formal observation periods and serial examinations, which may occur simultaneously with the changes in diagnostic imaging.

Conclusions

From 2010 through 2013, the use of US for abdominal imaging in children with appendicitis has increased at major pediatric hospitals in the United States. During the same period, the use of CT for children with appendicitis has declined substantially. Several
Important appendicitis-related quality measures have remained stable, despite increased reliance on US. These results suggest improvements in the diagnostic performance of US or other care processes in the management of suspected appendicitis in children. Future efforts should confirm these findings with patient-level data and comprehensively investigate other balancing measures for children with suspected appendicitis.

**REFERENCES**


