Imaging Evaluation of Suspected Appendicitis in a Pediatric Population: Effectiveness of Sonography Versus CT

Carlos J. Sivit[1]
Kimberly E. Applegate[1]
Anthony Stallion[2]
David L. Dudgeon[2]
Ann Salvator[2]
Mark Schluchter[3]
Sheila C. Berlin[1]
Melissa T. Myers[1]
Valerie J. Borisa[1]
Dayna M. Weinert[1]
Stuart C. Morrison[1]
Enrique R. Grisoni[2]

OBJECTIVE. The purpose of this study was to compare the diagnostic accuracy of graded compression sonography with that of helical CT for the diagnosis of appendicitis in a pediatric and young adult population.

SUBJECTS AND METHODS. Between June 1996 and April 1999, 386 pediatric and young adult patients with suspected appendicitis were examined using sonography, CT, or both: 233 underwent sonography only, 71 underwent CT only, and 82 underwent sonography and CT. All sonograms and CT scans were prospectively interpreted as showing positive or negative findings for appendicitis by one of six pediatric radiologists. CT and sonographic findings were correlated with surgical and histopathologic findings or findings at clinical follow-up.

RESULTS. Helical CT had a significantly higher sensitivity (95% versus 78%, $p = 0.009$) and accuracy (94% versus 89%, $p = 0.05$) than graded compression sonography for the diagnosis of appendicitis in children, adolescents, and young adults. The specificity of both techniques was 93%. Twenty of 82 patients who underwent both sonography and CT had discordance between the findings of the two examinations. The CT results were correct in a significantly greater number of patients with discordant examinations (17/20 patients [85%]).

CONCLUSION. Helical CT has a significantly higher sensitivity and accuracy than graded compression sonography for the diagnosis of appendicitis in a pediatric and young adult population, particularly in children more than 10 years old.

Appendicitis is the most common condition requiring emergent abdominal surgery in children [1]. The goal of imaging in the child with suspected appendicitis should be to identify the presence or absence of disease in patients with equivocal clinical findings. The ideal diagnostic test should be fast, noninvasive, highly accurate, and readily available. The principal imaging technique for evaluating children with suspected appendicitis over the past decade has been graded compression sonography [2–12]. The reported sensitivity of sonography for the diagnosis of appendicitis in children has ranged from 44% to 94%, and the specificity has ranged from 47% to 95% [2, 4–6, 8–12]. An overall sensitivity of 85% and specificity of 92% have been reported for sonography using metaanalysis of all studies published between 1986 and 1994 [13]. The use of helical CT for the diagnosis of appendicitis in adults has been reported in numerous studies [14–18]. Few prior studies have reported the use of helical CT for the diagnosis of appendicitis in children [12, 19, 20]. The reported sensitivity of CT for the diagnosis of appendicitis in children and adults has ranged from 84% to 100%, and the specificity has ranged from 89% to 98% [14–20]. Although the reported ranges of sensitivity and specificity of sonography and CT show some overlap, there is a greater range in the reported reliability of sonography. The purpose of this study was to compare the diagnostic accuracy of graded compression sonography with that of helical CT for the diagnosis of appendicitis in a pediatric and young adult population.

Subjects and Methods

Between June 1996 and April 1999, 386 pediatric and young adult patients with right lower quadrant pain and suspected appendicitis were examined with graded compression sonography, helical CT, or both. Two hundred thirty-three patients were examined with graded compression sonography only, 71 were examined with CT only, and 82 were examined with both sonography and CT. In the latter group, sonography was performed first, and sonographic and CT examinations were performed within 24 hr of each other. The study patients ranged in age from 1 to 21 years. Patient demographics are reported in Table 1. Sex and mean patient age were similar in patients undergoing

Received November 19, 1999; accepted after revision March 17, 2000.

[1] Department of Radiology, Rainbow Babies and Children's Hospital, University Hospitals of Cleveland and Case Western Reserve School of Medicine, 11100 Euclid Ave., Cleveland, OH 44106-5056. Address correspondence to C. J. Sivit.

[2] Department of Surgery, Rainbow Babies and Children's Hospital, University Hospitals of Cleveland and Case Western Reserve School of Medicine, Cleveland, OH 44106-5056.

[3] Department of Pediatrics, Rainbow Babies and Children's Hospital, University Hospitals of Cleveland and Case Western Reserve School of Medicine, Cleveland, OH 44106-5056.

AJR 2000;175:977–980

0361–803X/00/1753–977

TABLE 1 Demographic Characteristics of Pediatric and Young Adult Patients

Characteristic	Sonography Group (n = 315)	CT Group (n = 153)	Sonography and CT Group (n = 82)
Sex (%)			
Female	167 (53)	86 (56)	47 (57)
Male	148 (47)	67 (44)	35 (43)
Age (yr)			
Mean (SD)	10.5 (4.3)	10.9 (4.6)	10.8 (4.8)
≤10 (%)	138 (44)	61 (40)	34 (41)
>10 (%)	177 (56)	92 (60)	48 (59)

graded compression sonography and those undergoing helical CT.

The decision to examine a patient with suspected appendicitis with graded compression sonography, CT, or both during the study period was based on the clinical judgment of the referring pediatric surgeon or emergency department physician. Patients with clinically unequivocal appendicitis underwent immediate laparotomy without imaging studies, whereas those with equivocal clinical findings underwent graded compression sonography, CT, or both at the discretion of the referring physician. During the study period, 137 (52%) of 262 patients who underwent laparotomy for suspected appendicitis underwent sonography, CT, or both before surgery.

All sonographic examinations were performed using a 5.0- or 7.5-MHz linear array transducer (model XP10; Acuson, Mountain View, CA). Oblique, transverse, and longitudinal scans of the right lower quadrant were obtained using the graded compression sonographic technique. The cross-sectional diameter of the appendix was measured after the application of graded compression.

Appendicitis was diagnosed on sonography if the appendix was noncompressible with a maximal cross-sectional diameter exceeding 6 mm or if an appendicolith, adjacent complex fluid collection, or mass was noted. All other cases were considered normal. The identification of a normal appendix versus not identifying an appendix had no significance on our examination results. In fact, in most "normal" cases, we did not identify the appendix.

All CT examinations were performed using a helical CT scanner (PQ 5000; Picker International, Cleveland, OH). Helical scanning was performed from the diaphragm to the pubic symphysis in all patients. IV contrast medium (iothalamate meglumine [Conray 43], Mallinckrodt, St. Louis, MO; or iohexol [Omnipaque 240], Sanofi Winthrop, New York, NY) was administered at a dose of 3 mL/kg body weight (maximum dose, 120 mL) in 145 of 153 CT examinations. Opacification of the gastrointestinal tract was achieved through oral or rectal administration of a 3% meglumine diatrizoate solution (Gastrografin; Bristol-Meyers Squibb, Wallingford, CT) in 151 of 153 CT examinations. One hundred twenty-six patients received oral contrast material only, 21 received rectal contrast material only, and four received both oral and rectal contrast material. Collimation and image reconstruction through the upper abdomen ranged from 4 to 10 mm on the basis of patient age (<18 months, 4-mm collimation; 18 months–5 years, 8-mm collimation; >5 years, 10-mm collimation). Variable collimation and image reconstruction were used through the lower abdomen and pelvis. In 101 CT examinations, the collimation and image reconstruction through the lower abdomen and pelvis were 8–10 mm, dependent on age. In 52 CT examinations, a 4-mm collimation and a 4-mm image reconstruction were used to scan the lower abdomen and pelvis, originating approximately 3 cm above the iliac crest as identified on the initial digital radiograph. The route of contrast medium administration for each examination was selected by the attending radiologist monitoring the procedure. The collimation and image reconstruction through the lower abdomen and pelvis were changed from 8–10 to 4 mm during the study period because we found the thinner collimation allows better visualization of anatomic structures in the right lower quadrant.

Appendicitis was diagnosed on CT if the appendix did not fill completely with contrast material or air and exceeded 6 mm in cross-sectional diameter or if an appendicolith, adjacent extraluminal air, complex fluid collection, or mass was noted. The identification of a normal appendix on CT versus not identifying an appendix had no significance on our examination results. In many "normal" cases we did not identify the appendix.

All sonograms and CT scans were obtained under the supervision of and interpreted immediately by one of six pediatric radiologists. The examinations were prospectively interpreted as showing either positive or negative findings for appendicitis, and these findings were made immediately known to the treating physicians. The interpretation was both the official study result and the official radiology report for each patient.

The decision for operative intervention was made by the pediatric surgeon. The final diagnoses were established by surgical and histologic evaluation of the appendix in patients who underwent laparotomy and by clinical follow-up in patients treated nonoperatively.

Measures of test validity (sensitivity, specificity, and accuracy) and their 95% confidence intervals (CI) were determined for the diagnosis of appendicitis using graded compression sonography and helical CT. Generalized estimating equations logistic regression models were used to simultaneously estimate and compare the sonographic and CT test results. To examine possible interactions with sex and age, data were stratified by age (≤10 years and >10 years), and this model was run for both strata. The use of 10 years was an arbitrary decision based on the median age for the study group, which was between 10 and 11 years. In addition, the patients who underwent both sonography and CT (n = 82) were stratified into two groups on the basis of the presence or absence of appendicitis. The McNemar test for paired data was used to compare either the sensitivity or specificity of sonography and CT within each of these groups.

Results

A total of 315 pediatric and young adult patients underwent graded compression sonography, and 153 underwent helical CT. The prevalence of appendicitis was 26% (83/315) in patients undergoing sonography and 40% (61/153) in those undergoing CT. There were 65 true-positive diagnoses of appendicitis using graded compression sonography and 58 true-positive diagnoses of appendicitis using CT. Seventeen false-positive diagnoses of appendicitis were reported for graded compression sonography, and six false-positive diagnoses of appendicitis were reported for CT. There were 215 true-negative diagnoses for graded compression sonography and 86 true-negative diagnoses for CT. Eighteen false-negative diagnoses for graded compression sonography and three false-negative diagnoses for CT were found in patients with surgically proved appendicitis.

Graded compression sonography had a sensitivity of 78% (95% CI, 69–87%; 65/83), specificity of 93% (95% CI, 90–96%; 215/232), and accuracy of 89% (95% CI, 86–92%; 280/315) for the diagnosis of appendicitis (Table 2). CT had a sensitivity of 95% (95% CI, 90–100%; 58/61), specificity of 93% (95% CI, 89–97%; 86/92), and accuracy of 94% (95% CI, 90–98%; 144/153) for the diagnosis of appendicitis (Table 2). CT had a significantly higher sensitivity (p = 0.009) and accuracy (p = 0.05) than graded compression sonography for the diagnosis of appendicitis in the overall population. The difference in the specificity of the two modalities for the diagnosis of appendicitis was not significant (p = 0.69).

A comparison of the sensitivity, specificity, and accuracy of graded compression sonography with CT in patients 10 years old or younger versus patients older than 10 years is listed in Table 2. The comparison of patient groups stratified by age showed CT has a significantly higher sensitivity (p = 0.01) and a trend for a higher accuracy (p = 0.09) when compared with sonography for the diagnosis of appendicitis in patients more than 10 years old (Table 2). The difference in specificity between CT and sonography in this age group was not statistically significant. In patients 10 years old or younger, the findings of

the two imaging modalities were not significantly different.

The sensitivity, specificity, and accuracy for graded compression sonography and CT in the subgroup of 82 patients who underwent both examinations are listed in Table 3. Analysis of this subgroup of patients revealed discordance between sonography and CT in 20 (24%) of 82 patients (Table 4). The CT diagnosis was correct in 17 (85%) of 20 of these instances when the graded compression sonographic and CT findings were discordant. In the patients with appendicitis (n = 15), the CT results were correct in a significantly greater number of patients when there was discordance between CT and sonography (14/15 [93%], p = 0.002). In addition, CT findings were negative for appendicitis in three (75%) of four patients who did not have appendicitis but who had an initial sonogram with positive findings for appendicitis (Table 4).

Discussion

In the present study, helical CT was superior to graded compression sonography for the diagnosis of appendicitis. A significantly higher sensitivity was achieved with CT than with sonography for the diagnosis of appendicitis (95% versus 78%, p = 0.009). To our knowledge, only one prior study has compared the diagnostic efficacy of sonography with that of CT for the diagnosis of appendicitis in a pediatric population [20]. In that study, the sensitivity of CT for the diagnosis of appendicitis was also higher than that of sonography (84% versus 74%), although the difference was not statistically significant [20].

In our patient population, CT was particularly useful in patients with discordant examinations. Discordance between CT and sonographic findings occurred in 20 (24%) of 82 patients undergoing both examinations. The CT diagnosis was correct in 17 (85%) of these cases, whereas the sonographic diagnosis was correct in only three (15%). CT was particularly useful in the diagnosis of appendicitis in patients with normal findings on a sonographic examination. Fifteen patients for whom sonographic and CT findings were discordant had a histopathologic diagnosis of appendicitis. The CT diagnosis was correct in 14 (93%) of these 15 patients.

An important issue that should not be overlooked when evaluating the positive impact of an imaging examination on the assessment of patients with suspected appendicitis is the value of normal findings on an examination using a modality such as CT with a high sensitivity for diagnosing disease. The higher the sensitivity of the imaging examination, the lower the number of false-negative examinations, and, consequently, more trust can be placed on normal findings from that examination by caregivers. It is clear on the basis of the data presented that because of the significantly higher sensitivity of CT when compared with sonography for the diagnosis of appendicitis, a negative CT examination instills greater diagnostic confidence for the exclusion of appendicitis than do negative sonographic findings.

The principal imaging technique for evaluating children with suspected appendicitis over the past decade has been graded compression sonography [2–12]. Sonography can be performed quickly, is generally well tolerated, and uses no ionizing radiation. However, a wide range of values for the sensitivity and specificity of graded compression sonography has been reported for the diagnosis of appendicitis because of the large degree of operator dependency inherent to the technique, and the varied methodology of prior reports [2, 4–6, 8–12]. The sonographic diagnosis of appendicitis can be difficult in obese individuals because visualization of the appendiceal region may be limited. In addition, other reported potential pitfalls in the sonographic diagnosis of appendicitis include focal appendicitis limited to the distal appendix, retrocecal appendicitis, and perforated appendicitis [21]. An important factor accounting for the variability in diagnostic accuracy reported with graded compression sonography is that many sonographic examinations are not performed by radiologists having dedicated

TABLE 2 Comparison of Sensitivity, Specificity, and Accuracy of Graded Compression Sonography Versus Helical CT for Revealing Appendicitis When Categorized by Patient Age Group

Patient Age Group	CT		Sonography		p
	%	95% Confidence Interval	%	95% Confidence Interval	
≤10 yr					
Sensitivity	94	85–100	84	73–95	0.19
Specificity	87	75–99	86	79–93	0.81
Accuracy	90	83–97	86	80–92	0.28
>10 yr					
Sensitivity	97	91–100	71	56–85	0.01
Specificity	98	94–100	96	93–99	0.90
Accuracy	97	93–100	91	87–95	0.09
Overall					
Sensitivity	95	90–100	78	69–87	0.009
Specificity	93	89–97	93	90–96	0.69
Accuracy	94	90–98	89	86–92	0.05

TABLE 3 Graded Compression Sonography Versus Helical CT in 82 Patients Who Underwent Both Examinations

Variable	CT (%)	Sonography (%)
Sensitivity	93	48
Specificity	93	91
Accuracy	93	76

TABLE 4 Comparison of Imaging Findings with Outcome in 82 Patients Who Underwent Both Graded Compression Sonography and Helical CT

Outcome	Concordant Pairs (n = 62)		Discordant Pairs (n = 20)		p
	Both Positive (n = 15)	Both Negative (n = 47)	Positive Sonographic Findings and Negative CT Findings (n = 4)	Negative Sonographic Findings and Positive CT Findings (n = 16)	
Appendicitis found at surgery (n = 29)	13	1	1	14	0.002
No appendicitis found at surgery or follow-up (n = 53)	2	46	3	2	1.0

Note.—The p value is for comparison of discordant pairs.

expertise with the procedure. At many university hospitals, after-hours imaging studies may be obtained and interpreted by residents or fellows. Moreover, many patients with appendicitis are treated at community hospitals and the sonographic examination is performed by a general radiologist. For sonography to be successful on a large scale, a high degree of accuracy must be seen when performed by radiologists with various degrees of expertise. On the basis of the wide range of reported sensitivity and specificity values of sonography for the diagnosis of appendicitis in various series, this does not appear to be the case. Another factor that likely accounts for the wide range in reported sensitivity and specificity of graded compression sonography for the diagnosis of appendicitis across various series is that in some reports all patients with suspected appendicitis were examined on sonography, whereas in others only patients with an equivocal clinical diagnosis underwent imaging [2, 4–6, 8–12]. This practice may result in a larger percentage of atypical, early, or more subtle cases of appendicitis in the population undergoing selective imaging, thereby decreasing the apparent accuracy of the test.

The superiority of helical CT over graded compression sonography for the diagnosis of appendicitis in the present study was principally noted in patients more than 10 years old. CT showed a significantly higher sensitivity than sonography (97% versus 71%, $p = 0.01$) in this subgroup of patients, whereas the two imaging modalities were not significantly different in patients 10 years old or younger. This finding is not surprising given that graded compression sonography is typically easier to perform in individuals with a smaller body habitus, a subgroup one would expect to see more frequently in a younger age group. Conversely, it could be speculated that the paucity of body fat in younger patients may result in increased difficulty diagnosing appendicitis because of the inability to readily separate the appendix from adjacent structures. However, caution should be used in speculating that graded compression sonography should be the study of choice in younger children. Even though no statistically significant differences were seen between the sensitivity of graded compression sonography versus that of CT for the diagnosis of appendicitis in children less than 10 years old, the sensitivity of CT was higher than that of sonography in this age group (93% versus 84%). One possible reason that these values are not significant in the present series is that by stratifying the study group by patient age, the sample size was decreased. Therefore, a greater difference in the value between the two modalities is required to reach statistical significance.

A limitation of this study is that it did not permit a true comparison of sonography versus CT for the diagnosis of appendicitis because all patients did not undergo both imaging examinations. In addition, in the subgroup of patients who underwent sonography and CT, sonography was always performed first, and the radiologist monitoring the CT examination may have been the same person who performed the sonographic examination. Therefore, the radiologist interpreting the CT examination was not blinded to the sonographic findings. However, this procedure reflects how these two imaging examinations are used in our clinical practice. An additional limitation of the present study is that the scanning protocol for CT was not standardized in all children during the study period. The CT protocol was altered during the study period to include the use of a thin collimation through the lower abdomen and pelvis and the use of rectal rather than oral contrast material for gastrointestinal tract opacification.

There are several valid concerns regarding the use of helical CT as the primary imaging modality in children with suspected appendicitis. These concerns include the greater cost of CT versus sonography, the exposure to ionizing radiation, and the exposure to contrast agents. However, these concerns may be better addressed by placing more emphasis on the use of clinical variables for stratifying risk of disease and allowing more selective use of imaging [22]. Most patients with suspected appendicitis undergoing cross-sectional imaging do not have the disease. In the present study, only 26% (83/315) of patients undergoing graded compression sonography and 40% (61/153) of patients undergoing helical CT for suspected appendicitis had appendicitis. The patients who can be considered, on the basis of physical examination or laboratory findings, as having a very low or very high risk of disease should not require cross-sectional imaging [7]. Rather than using a less expensive but potentially less sensitive modality such as sonography, selective CT may improve clinical decision-making because of its higher accuracy. With the implementation of a more selective system for imaging, the utilization, cost, and patient risk would presumably decline because of reductions in the number of imaging examinations being performed.

In conclusion, helical CT has a high accuracy for the diagnosis of appendicitis in a pediatric and young adult population. CT was superior to graded compression sonography for the diagnosis of appendicitis particularly in patients more than 10 years old, for whom CT had a significantly higher sensitivity and accuracy than sonography.

References

1. Janik JS, Firor HV. Pediatric appendicitis: a twenty-year study of 1,640 children at Cook County Hospital. *Arch Surg* **1979**;114:717–719
2. Kao CS, Smith WL, Abu-Yousef MM, et al. Acute appendicitis in children: sonographic findings. *AJR* **1989**;153:375–379
3. Ceres L, Alonso I, Lopez P, et al. Ultrasound study of acute appendicitis in children with emphasis upon the diagnosis of retrocecal appendicitis. *Pediatr Radiol* **1990**;20:258–261
4. Rubin SZ, Martin DJ. Ultrasonography in the management of possible appendicitis in childhood. *J Pediatr Surg* **1990**;25:737–740
5. Vignault F, Filiatrault D, Brandt ML, et al. Acute appendicitis in children: evaluation with US. *Radiology* **1990**;176:501–504
6. Hayden CK, Kuchelmeister J, Lipscomb TS. Sonography of acute appendicitis in childhood: perforation versus nonperforation. *J Ultrasound Med* **1992**;11:209–216
7. Sivit CJ, Newman KD, Boenning DA, et al. Appendicitis: usefulness of US in a pediatric population. *Radiology* **1992**;185:549–552
8. Crady SK, Jones JS, Wyn T, et al. Clinical validity of ultrasound in children with suspected appendicitis. *Ann Emerg Med* **1993**;22:1125–1129
9. Quillin SP, Siegel MJ. Appendicitis: efficacy of color Doppler sonography. *Radiology* **1994**;191:557–560
10. Wong ML, Casey SO, Leonidas JC, et al. Sonographic detection of acute appendicitis in children. *J Pediatr Surg* **1994**;29:1356–1360
11. Ramachandran P, Sivit CJ, Newman KD, et al. Ultrasonography as an adjunct in the diagnosis of acute appendicitis: a 4-year experience. *J Pediatr Surg* **1996**;31:164–169
12. Garcia Pena BM, Mandl KD, Kraus SJ, et al. Ultrasonography and limited computed tomography in the diagnosis and management of appendicitis in children. *JAMA* **1999**;282:1041–1046
13. Orr RK, Porter D, Hartman D. Ultrasonography to evaluate adults for appendicitis: decision making based on meta-analysis and probabilistic reasoning. *Acad Emerg Med* **1995**;2:644–650
14. Malone AJ Jr, Wolf CR, Malmed AS, Melliere BF. Diagnosis of acute appendicitis: value of unenhanced CT. *AJR* **1993**;160:763–766
15. Balthazar EJ, Birnbaum RA, Yee J, et al. Acute appendicitis: CT and US correlation in 100 patients. *Radiology* **1994**;190:31–35
16. Lane MJ, Katz DS, Ross BA, Clautice-Engle TL, Mindelzun RE, Jeffrey RB Jr. Unenhanced helical CT for suspected acute appendicitis. *AJR* **1997**;168:405–409
17. Rao PM, Rhea JT, Novelline RA, et al. Helical CT technique for the diagnosis of appendicitis: prospective evaluation of a focused CT examination. *Radiology* **1997**;202:139–144
18. Rao PM, Rhea JT, Novelline RA, Mostafavi AA, Lawrason JN, McCabe CJ. Helical CT combined with contrast material administered only through the colon for imaging of suspected appendicitis. *AJR* **1997**;169:1275–1280
19. Sivit CJ, Applegate KE, Berlin SC, et al. Helical CT for the evaluation of suspected appendicitis in children (in press). *Radiology*
20. Karakas SP, Guelfuat M, Leonidas JC, et al. Acute appendicitis in children: comparison of clinical diagnosis with ultrasound and CT imaging. *Pediatr Radiol* **2000**;30:94–98
21. Sivit CJ. Diagnosis of acute appendicitis in children: spectrum of sonographic findings. *AJR* **1993**;161:147–152
22. Alvarado A. A practical score for the early diagnosis of appendicitis. *Ann Emerg Med* **1986**;15: 557–564