

Gastrointestinal Imaging

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Index terms:

Appendicitis, 751.291
Appendix, 751.291
Appendix, CT, 751.12111,
751.12112, 751.12115
Appendix, US, 751.1299

Published online before print
10.1148/radiol.2251011780
Radiology 2002; 225:131–136

Abbreviations:

NAR = negative appendectomy rate
PPV = positive predictive value
PR = perforation rate

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Imaging for Suspected Appendicitis: Negative Appendectomy and Perforation Rates¹

PURPOSE: To determine which patients suspected of having acute appendicitis benefit from preoperative imaging.

MATERIALS AND METHODS: The medical records of 462 consecutive patients who underwent appendectomy for clinically suspected acute appendicitis and underwent preoperative evaluation at our institution were retrospectively reviewed. Patients were divided into four groups: women ($n = 166$), girls ($n = 46$), men ($n = 178$), and boys ($n = 72$). Preoperative computed tomography (CT) or ultrasonography (US), requested by the referring clinician, was performed in 313 of the 462 patients. Unnecessary, or negative, appendectomy and perforation rates were calculated for each group for preoperative evaluation with CT, with US, and with neither CT nor US. In addition, the sensitivity and positive predictive value of CT and US were calculated for diagnosing appendicitis.

RESULTS: In women, the negative appendectomy rate was significantly lower for those who underwent preoperative CT (7% [six of 85 patients], $P = .005$) or US (8% [four of 49 patients], $P = .019$), as compared with 28% [nine of 32 patients] for those who underwent no preoperative imaging ($P > .35$ for all groups). The negative appendectomy rates for girls, men, and boys were not significantly affected by preoperative imaging. The sensitivity of CT and US for diagnosing acute appendicitis exceeded 93% and 77%, respectively, in all groups. The positive predictive values for both CT and US were greater than 92% in all groups.

CONCLUSION: Women suspected of having appendicitis benefit the most from preoperative CT or US, with a statistically significantly lower negative appendectomy rate than women who undergo no preoperative imaging. Therefore, we propose that preoperative imaging be considered part of the routine evaluation of women suspected of having acute appendicitis.

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Although acute appendicitis can be preoperatively diagnosed on the basis of well-established clinical criteria, its clinical presentation may be atypical or mimic other conditions, yielding a clinical diagnostic accuracy of 80% (1–6). Furthermore, the broad overlap of symptoms of acute gynecologic and urinary tract abnormalities makes diagnosis in women even more challenging, yielding a diagnostic accuracy of 60%–68% (1–3,7). Surgical authorities have maintained that an unneeded, or negative, appendectomy rate of 20% is necessary to minimize the incidence of perforated appendicitis and its associated increased morbidity and mortality (1,8). However, unnecessary appendectomy carries potentially major risks and substantial costs, prompting many to advocate increased efforts to avoid unnecessary appendectomy (2,9–11).

Over the past 2 decades, the use of dedicated ultrasonographic (US) and computed tomographic (CT) techniques for the evaluation of patients clinically suspected of having acute appendicitis has led to improved diagnostic accuracy of 83%–98% (6,10–21). Both techniques are increasingly being incorporated into clinical practice, and several studies (6,10,11,17,18,22–25) have shown improved outcomes. However, controversy still exists

as to the role and benefit of imaging in the work-up for acute appendicitis, with a need to identify which specific groups of patients benefit from imaging (10,23,26). With this in mind, we performed a retrospective analysis of the effect of preoperative imaging on the removal of a normal appendix, with regard to negative appendectomy rates (NARs) and perforation rates (PR) in groups of patients of differing ages and sexes, to determine which patients with acute appendicitis benefit.

MATERIALS AND METHODS

Patients

We retrospectively reviewed the medical records of 1,130 consecutive patients who underwent appendectomy at Stanford University Medical Center from September 1997 to August 2000. Of these patients, 462 underwent appendectomy for clinically suspected acute appendicitis, as well as preoperative evaluation at our institution. These individuals composed the cohort of patients analyzed in our study.

In these 462 patients, there were 212 female patients and 250 male patients, with an age range of 2–82 years (mean, 16.3 years). The patients were divided into four groups based on sex and age: women ($n = 166$; age range, 16–82 years; mean age, 35.4 years), men ($n = 178$; age range, 16–78 years; mean age, 35.3 years), girls ($n = 46$; age range, 2–15 years; mean age, 9.5 years), and boys ($n = 72$; age range, 2–15 years, mean age, 9.9 years) (Table 1). Detailed information recorded for each patient included results of preoperative US and/or CT, preoperative and postoperative clinical diagnoses, final pathologic diagnosis, and appendiceal perforation noted at surgery and/or pathologic examination. The hospital institutional review board, which does not require informed consent for retrospective studies, approved this study.

Imaging Examinations

Preoperative imaging examinations were performed in 313 (68%) patients. Two hundred eight (45%) patients underwent CT, and 105 (23%) patients underwent US (Table 1). Patients were referred for imaging evaluation by surgeons and emergency medicine and primary care physicians. CT was performed in 85 of 166 (51%) women, 97 (54%) of 178 men, 11 (24%) of 46 girls, and 15 (21%) of 72 boys. US was performed in 49 (30%) of 166 women, 10 (6%) of 178 men, 21 (46%) of 46 girls, and 25 (35%) of 72 boys.

TABLE 1
Preoperative Imaging Evaluation Distribution according to Age and Sex of 462 Patients Suspected of Having Acute Appendicitis

Patient Group	CT	US	No Imaging
Women ($n = 166$)	85 (51)	49 (30)	32 (19)
Girls ($n = 46$)	11 (24)	21 (46)	14 (30)
Men ($n = 178$)	97 (54)	10 (6)	71 (40)
Boys ($n = 72$)	15 (21)	25 (35)	32 (44)
Overall	208 (45)	105 (23)	149 (32)

Note.—Data are numbers of patients. Data in parentheses are percentages.

All CT was performed with a helical CT scanner (HiSpeed Advantage; GE Medical Systems, Milwaukee, Wis). A single breath hold helical CT examination was performed from the top of the T12 vertebral body to the pubic symphysis by using 5-mm beam collimation and 8-mm/sec table speed (pitch, 1.6). No orally, rectally, or intravenously administered contrast material was used in 110 (52.9%) of the 208 patients. Forty-seven patients (22.6%) received oral and intravenous contrast material. Adult patients who received oral contrast material (about 150 mL injected at a rate of 2.5 mL/sec) (300 mg/mL iohexol, Omnipaque; Nycomed, Princeton, NJ) typically received about 450 mL of a barium sulfate suspension (Prepacat; Lafayette Pharmaceuticals, Lafayette, Ind) before scanning. Pediatric patients who received oral contrast material received a diatrizoate meglumine and diatrizoate sodium solution (1 mL per 0.45 kg of body weight at a varying rate dependent on age and weight) (Gastrografin; Bracco Diagnostics, Princeton, NJ) at a dose dependent on age. Forty-six (22.1%) other patients received only intravenous contrast material, and the five (2.4%) remaining patients received only oral contrast material. Images were reconstructed at 5-mm intervals and photographed by using standard soft-tissue (400-HU window and 40-HU level) display settings. The primary criteria used to establish the diagnosis of appendicitis included a dilated (>6 mm in anteroposterior dimension) appendix and periappendiceal inflammatory changes, such as fat stranding, of the mesoappendix or adjacent retroperitoneal fat.

US was performed with high-frequency, 5.0–7.5-MHz linear-array transducers with either a model XP-128 or Sequoia-512 unit (Acuson, Mountain View, Calif), by using a graded-compression technique, as described by Puylaert (27). US diagnosis of appendicitis was based on detection of a noncompressible distended (>6 mm in anteroposterior dimension) appendix. Periappendiceal inflammatory changes

in the absence of a visualized abnormal appendix were not considered specific for acute appendicitis.

Imaging examination results, based on radiology reports, were recorded as positive or negative for appendicitis. Inconclusive results were considered negative in six patients in the current study. In 31 patients who underwent multiple imaging examinations, only the results of the last examination were included for analysis.

Data Analysis

The patients were divided into four groups based on sex and age (<16 or ≥16 years): women, men, girls, and boys. The NAR and PR were calculated for each group, in accordance with their preoperative evaluation with CT or US or with no imaging. The NAR was defined as the proportion of patients who underwent removal of a normal appendix. PR was defined as the proportion of patients who had a perforated appendix, noted either at surgery or at pathologic examination, from all patients who had appendicitis proved at histologic examination. The sensitivity and positive predictive value (PPV) of CT and US for diagnosing acute appendicitis were also calculated. Statistical analysis was performed by using SPSS for Windows version 10.1 (SPSS, Chicago, Ill) and a one-sided Fisher exact test. Differences in NAR and PR between groups who underwent preoperative CT or US and groups who did not undergo preoperative imaging were analyzed. *P* values of less than .05 were considered to indicate a significant difference.

RESULTS

NAR Findings

Acute appendicitis was proved at pathologic examination in 421 of the 462 patients who underwent appendectomy for clinically suspected appendicitis, yielding an overall NAR of 9%. The NARs for

TABLE 2
NARs Correlated with Age, Sex, and Preoperative Imaging Evaluation in 462 Patients with a Clinical Diagnosis of Acute Appendicitis

Patient Group	CT		US		No Imaging NAR	Overall NAR
	NAR	P Value	NAR	P Value		
Women	6/85 (7)	.005	4/49 (8)	.019	9/32 (28)	19/166 (11)
Girls	4/11 (36)	.351	3/21 (14)	.456	3/14 (21)	10/46 (22)
Men	5/97 (5)	.368	0/10 (0)	.767	2/71 (3)	7/178 (4)
Boys	1/15 (7)	.694	2/25 (8)	.595	2/32 (6)	5/72 (7)
Overall	16/208 (8)	.210	9/105 (9)	.364	16/149 (11)	41/462 (9)

Note.—Data are numbers of patients. Numbers in parentheses are percentages.

TABLE 3
PR Correlated with Age, Sex, and Preoperative Imaging Evaluation in 421 Patients with Histologically Proven Acute Appendicitis

Patient Group	CT		US		No Imaging PR	Overall PR
	PR	P Value	PR	P Value		
Women	25/79 (32)	.021	7/45 (16)	.352	2/23 (9)	34/147 (23)
Girls	4/7 (57)	.352	3/18 (17)	.223	4/11 (36)	11/36 (31)
Men	24/92 (26)	.573	0/10 (0)	.063	18/69 (26)	42/171 (25)
Boys	7/14 (50)	.079	6/23 (26)	.533	7/30 (23)	20/67 (30)
Overall	60/192 (31)	.074	16/96 (17)	.144	31/133 (23)	107/421 (25)

Note.—Data are numbers of patients. Numbers in parentheses are percentages.

each group of patients according to age, sex, and preoperative imaging evaluation are summarized in Table 2. Men had the lowest NAR (4%, seven of 178 patients), followed by boys (7%, five of 72 patients), women (11%, 19 of 166 patients), and girls (22%, 10 of 46 patients).

In women, the NAR was significantly lower in those who underwent preoperative evaluation with CT ($P = .005$) or US ($P = .019$) than in those who did not. Nine (28%) of the 32 women who underwent no preoperative imaging evaluation had a normal appendix. In comparison, a normal appendix was found in six (7%) of 85 women who underwent CT and in four (8%) of the 49 women who underwent US. In girls, the NAR was high regardless of the preoperative imaging evaluation. Three (21%) of the 14 girls who did not undergo imaging had a normal appendix. Four (36%) of 11 girls who underwent CT and three (14%) of 21 girls who underwent US had a normal appendix.

In men and boys, the NAR in those who underwent preoperative imaging was similar to that in those who did not undergo imaging. Two (3%) of 71 men who did not undergo imaging had a normal appendix. Five (5%) of 97 men who underwent CT and none (0%) of 10 men who underwent US had a normal appendix. A normal appendix was found in two

(6%) of 32 boys who underwent no imaging, in one (7%) of 15 boys who underwent CT, and in two (8%) of 25 boys who underwent US.

PR Findings

Appendiceal perforation was observed in 107 of the 421 patients with proven acute appendicitis, for an overall PR of 25%. The PRs for each group according to age, sex, and preoperative imaging evaluation are summarized in Table 3. Women who underwent preoperative CT exhibited a significantly higher PR (32%, 25 of 79 patients), as compared with women who did not undergo preoperative imaging (9%, two of 23 patients; $P = .021$). None of the other three patient groups exhibited statistically significant differences between individuals who underwent preoperative CT or US and those who underwent no preoperative imaging. Trends toward higher PRs, which were not statistically significant, were observed when preoperative CT was performed in girls and boys but not in men.

Sensitivity and PPV of Imaging Examinations

The sensitivities and PPVs of CT and US for the diagnosis of acute appendicitis in each group of patients according to

age and sex are summarized in Table 4. The overall sensitivity of CT was 96% (184 of 192 examinations), with a PPV of 96% (184 of 191 examinations). In the 208 patients who underwent CT, acute appendicitis was correctly diagnosed in 184 (89%) and excluded in nine (4%). CT results were false-positive in seven (3%) patients and false-negative in eight (4%). In the seven patients with false-positive CT findings, the findings were a mildly dilated appendix associated with an appendicolith and periappendiceal inflammation in four patients and a mildly dilated appendix in the remaining three patients. In the eight patients with false-negative CT findings, the appendix appeared normal in three patients and was not visualized in five patients.

The overall sensitivity of US for the diagnosis of acute appendicitis was 86% (83 of 96 examinations), with a PPV of 95% (83 of 87 examinations). Of the 105 patients who underwent imaging with US, acute appendicitis was correctly diagnosed in 83 (79%) patients and excluded in five (5%) patients. In four (4%) patients, US findings were false-positive and in 13 (12%) patients, US findings were false-negative. In all four of the patients with false-positive US findings, the reported finding was a noncompressible appendix. In five of the 13 patients with false-negative US findings, a small amount

of fluid was seen in the right lower quadrant; in one patient, enlarged lymph nodes were noted; and in none of the patients was the appendix visualized. In two of the five patients with true-negative US findings, a small amount of fluid was seen in the right lower quadrant, and the appendix was visualized in only one of these two.

Thirty-one of the 313 patients who underwent imaging underwent more than one preoperative imaging examination. Twenty-eight patients underwent both CT and US examination, two patients underwent two CT examinations, and one patient underwent two US examinations. Sixteen of the 28 patients underwent CT, and the other 12 patients underwent US as the second examination. Discordance between the results of CT and US was observed in 11 of the 28 patients who underwent imaging with both modalities. In the three patients who underwent either two CT or two US examinations, the second examination resulted in the correct diagnosis of appendicitis. Within this subset of patients who underwent imaging more than once, appendicitis was correctly diagnosed in 29 patients and excluded in one patient. In one patient, imaging results were false-positive, and there were no patients with false-negative imaging results. Perforated appendicitis occurred in six (21%) of 29 patients, who had pathologically proved appendicitis and underwent imaging more than once.

DISCUSSION

The preoperative diagnosis of acute appendicitis has historically been established without imaging examinations on the basis of clinical history and physical examination findings. However, the symptoms of appendicitis in some patients may overlap with other gastrointestinal and genitourinary processes and cause a missed or delayed diagnosis. Thus, the overall clinical accuracy for diagnosis of appendicitis has been approximately 80%, with an NAR of 20% (1–6). The relatively recent advent of CT and US of the appendix has provided a valuable tool for the evaluation of patients suspected of having acute appendicitis, particularly those patients with atypical symptoms at presentation. Studies (6,10–21) have demonstrated the potential to achieve higher diagnostic accuracy with imaging techniques than may be achieved with clinical acumen alone. In addition to lowering the NAR, imaging examinations have the potential to expedite the diagno-

TABLE 4
Sensitivities and PPVs of CT and US for the Diagnosis of Acute Appendicitis, Correlated with Age and Sex in 313 Patients

Patient Group	CT		US	
	Sensitivity	PPV	Sensitivity	PPV
Women	74/79 (94)	74/78 (95)	39/45 (87)	39/41 (95)
Girls	7/7 (100)	7/7 (100)	14/18 (78)	14/15 (93)
Men	89/92 (97)	89/91 (98)	9/10 (90)	9/9 (100)
Boys	14/14 (100)	14/15 (93)	21/23 (91)	21/22 (95)
Overall	184/192 (96)	184/191 (96)	83/96 (86)	83/87 (95)

Note.—Data are numbers of patients. Numbers in parentheses are percentages.

sis of appendicitis, resulting in elimination of in-hospital observation days and establishment of alternative diagnoses that facilitate early treatments (6,10,11,17–19, 22,23). The questions remain, however, of how to best use the newer technologies of CT and US and of which patients suspected of having appendicitis benefit most from preoperative imaging.

Investigators in prior studies (1–4,7,22) have reported that NAR varies by patient sex, with a range of 5%–16% in men and 11%–34% in women. Similarly, in the current study, clinical acumen alone resulted in an NAR of 3% (two of 71 patients) in men, as compared with 28% (nine of 32 patients) in women, 6% (two of 36 patients) in boys, and 21% (three of 14 patients) in girls. These sex-based differences reflect the fact that the diagnosis of appendicitis on the basis of clinical presentation alone may be extremely difficult in female patients because of the broad overlap of symptoms of acute gynecologic abnormalities. In a retrospective study of nonpregnant women of childbearing age, Rothrock et al (7) found that 33% of women with appendicitis had received an initial clinical misdiagnosis, with the most common misdiagnoses being pelvic inflammatory disease, gastroenteritis, and urinary tract infection. Given the fact that NAR varies by patient sex, it is helpful to examine the performance of CT and US in the different patient subgroups based on sex.

The results of the current study demonstrate that of the four groups considered, women benefit the most from preoperative imaging evaluation when there is a clinical suspicion of acute appendicitis. On the basis of our data, women had the highest NAR (28%, nine of 32 patients) of the four groups when no preoperative imaging was performed. Their NAR decreased to 7% (six of 85 patients) when CT was performed and to 8% (four of 49 patients) when US was performed as part of their preoperative evaluation. The NAR was significantly lower when

preoperative imaging ($P = .005$ for CT and $P = .019$ for US) was performed. Our results are similar to those of Rao et al (22), who reported a significant ($P < .001$) decrease in NAR for women after the introduction of CT for the evaluation of appendicitis. In their series, the NAR for women decreased from 35% to 11% after the introduction of CT as part of the preoperative evaluation of appendicitis.

On the other hand, in girls, the NAR was lower in those who underwent US (14%, three of 21 patients) but higher in those who underwent CT (36%, four of 11 patients), as compared with that in those who underwent no preoperative imaging (21%, three of 14 patients). These differences in NAR, however, were not statistically significant. Our results differ from those reported by Applegate et al (25), who found a significantly lower NAR in children who underwent CT, as compared with that in those who underwent US or no preoperative imaging. However, in the current study, the group of girls had a relatively small number of patients ($n = 46$); therefore, discrepancies between our results and prior ones should be interpreted with caution.

The men and boys in our study had low NAR values regardless of whether preoperative imaging was performed. In men, the NAR was 5% (five of 97 patients) when preoperative CT was performed, 0% (zero of 10 patients) when US was performed, and 3% (two of 71 patients) when no imaging was performed. Similarly, in boys, the NAR was 7% (one of 15 patients) with CT, 8% (two of 25 patients) with US, and 6% (two of 32 patients) with no imaging. The differences between NARs with or without imaging in these groups were not statistically significant. Although Rao et al (22) reported lower NAR values for men and boys who underwent CT than for those who did not undergo imaging, the differences, as in the current study, were not significant. Our results may be a reflec-

tion of the fact that the clinical manifestation of acute appendicitis in men and boys is usually more straightforward; therefore, imaging is necessary only in difficult or atypical cases.

The overall PR of 25% (107 of 421 patients) in the current study is within the range of 14%–31% previously reported in the literature (1–5,17,22). Although the women, girls, and boys who underwent CT evaluation had higher PRs than those who underwent no preoperative imaging, the difference in PR was statistically significant only in women ($P = .021$). In men, the PR was similar for those who underwent CT and those who underwent no preoperative imaging. Our results differ from those of Rao et al (22), who reported an overall decrease in PR after the introduction of CT for the evaluation of acute appendicitis. Discordant results have also been reported between the PR in pediatric patients who underwent preoperative CT and that in pediatric patients who underwent no imaging. Karakas et al (24) reported a PR of 54% in children who underwent CT, as compared with a PR of 29% in children who underwent no imaging, and suggested that a delay in the performance of CT might have contributed in part to the higher PR. Applegate et al (25), on the other hand, reported a lower NAR, without a higher PR, in children who underwent CT than in children who underwent no imaging.

Although the higher PR associated with CT in the current study might have been related to in-hospital delay caused by the imaging examination, as reported by Karakas et al (24), we did not investigate times from presentation to CT to surgery and therefore cannot establish such a correlation. Results of previous studies (5,28), however, suggest that most of the delay in diagnosis that leads to perforation is due to patient delay in consulting a physician and that in-hospital delay does not play a major role in increasing the number of perforations. A possible explanation for the higher PR associated with CT in the current study may be that patients who are thought to have more complex cases, be more ill, and therefore be more likely to have perforations are more likely to undergo CT.

The sensitivity and PPV of CT and US for the diagnosis of acute appendicitis achieved in the current study are similar to those reported by other investigators. CT had a sensitivity of 96% (184 of 192 examinations) and a PPV of 96% (184 of 191 examinations), which are within previously reported ranges of 87%–100%

and 92%–99%, respectively (10–18,20). US had a sensitivity of 86% (83 of 96 examinations) and a PPV of 95% (83 of 87 examinations), as compared with reported values of 76%–92% and 83%–90%, respectively (6,19,20,23,29). Prior results (20,21) have shown CT to have a higher sensitivity than US for the diagnosis of acute appendicitis. Authors of two recent studies involving pediatric patients (24,25) also reported lower NARs in patients who underwent CT than in those who underwent US. In the current study, CT demonstrated higher sensitivity than US for diagnosing appendicitis in all groups, while both imaging modalities had similar PPVs.

Although imaging is very helpful in the evaluation of patients suspected of having acute appendicitis, clinical correlation is also extremely important. The 21 (eight CT and 13 US examinations) false-negative and 11 (seven CT and four US examinations) false-positive findings in the current study underscore this fact. If a patient's symptoms do not subside or progress, clinicians must question negative findings and consider repeat examination if the diagnosis is still unclear. In our cohort of 31 patients who underwent more than one imaging examination, repeated imaging resulted in 29 true-positive findings, one true-negative finding, one false-positive finding, and no false-negative findings, while not incurring an increase in PR (21%, six of 29 patients).

A number of limitations should be considered with regard to the current study. First, the study was retrospective and limited to the review of the pathology database and medical records. Second, the criteria for performing a preoperative imaging examination and selecting the type of examination were not clearly defined or standardized. Third, because the current study was based on patients who underwent appendectomy and did not include patients who underwent CT or US for suspected acute appendicitis and did not undergo surgery, we could not calculate the specificity, negative predictive value, and accuracy of CT and US, nor could we analyze alternative diagnoses made with imaging and how many appendectomies were averted.

Results of the current study demonstrate that women benefit substantially from preoperative imaging evaluation when there is a clinical suspicion of appendicitis. They had the highest NAR of all four groups when no imaging was performed and showed the most significant reduction in NAR when CT ($P = .005$) or US ($P = .019$) was performed. The NAR in

women decreased from 28% (nine of 32 patients) without imaging to 7% (six of 85 patients) with CT and to 8% (four of 49 patients) with US. CT and US were equally effective in decreasing the NAR in women. Because the NAR was significantly lower in the women who underwent preoperative imaging than in the women who did not, we propose that imaging be considered part of the routine evaluation of women suspected of having acute appendicitis. We did not identify a statistically significant benefit from preoperative imaging for the other three patient groups. Our data suggest that only patients in these groups who have confusing clinical signs and symptoms should undergo preoperative imaging rather than advocate routine imaging for all patients who may have appendicitis.

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