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EFFECT OF COMPUTED TOMOGRAPHY OF THE APPENDIX ON TREATMENT OF PATIENTS AND USE OF HOSPITAL RESOURCES

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ABSTRACT

Background In patients with clinically suspected appendicitis, computed tomography (CT) is diagnostically accurate. However, the effect of routine CT of the appendix on the treatment of such patients and the use of hospital resources is unknown.

Methods We performed appendiceal CT on 100 consecutive patients in the emergency department who, on the basis of history, physical examination, and laboratory results, were to be hospitalized for observation for suspected appendicitis or for urgent appendectomy. Outcomes were determined at surgery and by pathological examination in 59 patients, and by clinical follow-up two months later in 41 patients. Treatment plans made before CT were compared with the patients' actual treatment. We also determined the costs of surgery that revealed no appendicitis (from data on 61 patients), one day of observation in the hospital (from data on 350 patient-days in patients with suspected appendicitis), and appendiceal CT (from data on all pelvic CT examinations in 1996).

Results Fifty-three patients had appendicitis, and 47 did not. The interpretations of the appendiceal CT scans were 98 percent accurate. The results of CT led to changes in the treatment of 59 patients. These changes resulted in the prevention of unnecessary appendectomy in 13 patients, admission to the hospital for observation in 18 patients, admission to the hospital for observation before necessary appendectomy in 21 patients, and admission to the hospital for observation before the diagnosis of other conditions by CT in 11 patients. The effects of performing appendiceal CT on the use of hospital resources included the prevention of unnecessary appendectomy in 13 patients (for a savings of $47,281) and the prevention of unnecessary hospital admission for 50 patient-days (for a savings of $20,250). After the cost of 100 appendiceal CT studies ($22,800) was subtracted, the overall savings was $447 per patient.

Conclusions Routine appendiceal CT performed in patients who present with suspected appendicitis improves patient care and reduces the use of hospital resources. (N Engl J Med 1998;338:141-6.)

EACH year in the United States there are at least 250,000 new cases of appendicitis, requiring hospital admission for more than 1 million patient-days.[1] A similar number of patients with suspected appendicitis are hospitalized but are found to have other conditions, such as mesenteric adenitis, pelvic inflammatory disease, or other gastrointestinal and gynecologic disorders.[2] The management options available to physicians evaluating patients with suspected appendicitis include hospital observation, diagnostic imaging, laparoscopy, and appendectomy.

In at least 20 percent of patients with appendicitis, the correct diagnosis is not made.[3-6] Missed appendicitis is the most frequently successful malpractice claim against emergency department physicians.[7] Delay in the diagnosis increases the risk of appendiceal perforation, which increases the risk of postoperative complications to 39 percent, as compared with 8 percent for simple appendicitis.[8,9] On the other hand, the appendix is normal in 15 to 40 percent of patients who undergo emergency appendectomy.[8,10-12]

Computed tomography (CT) is 93 to 98 percent accurate in confirming or ruling out appendicitis.[13-17] The highest accuracy has been reported with the use of helical CT after the instillation of 3 percent diatrizoate meglumine (Gastrografin)–saline solution into the colon. Appendiceal CT is safe, can be performed in approximately 15 minutes, and requires only one third of the radiation exposure of standard abdominopelvic CT.[17,18]

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Previous reports suggested that routine appendiceal CT could improve care and lower the use of hospital resources for patients suspected of having acute appendicitis.[19,20] This study was performed to determine prospectively the effect of routine appendiceal CT on the treatment of these patients.

METHODS

Study Subjects

We studied 100 consecutive patients (57 female and 43 male; age, 6 to 75 years) suspected of having acute appendicitis who presented to our emergency department directly or were referred there from a physician's office. Pregnant women and patients with any contraindication to the instillation of contrast material into the colon, such as toxic megacolon or ischemic colitis, were ineligible. All patients offered enrollment in this study participated, and none were lost to follow-up. The study was approved by the hospital's subcommittee on human studies, and informed consent was obtained from each patient or a parent. During the study, 17 other patients with suspected appendicitis were admitted to our hospital but were not referred for this study or for appendiceal CT.

All the patients underwent initial clinical evaluation, including history taking, physical examination, and laboratory tests. The presenting signs and symptoms are listed in Table 1. Patients whom a surgeon had decided to hospitalize for suspected appendicitis on the basis of history, physical examination, and laboratory results were eligible for appendiceal CT. Before CT was performed, the referring surgeon estimated the likelihood that the patient had appendicitis as definite (80 to 100 percent), probable (60 to 79 percent), equivocal (40 to 59 percent), or possible (20 to 39 percent).

Performance and Interpretation of Appendiceal CT

The patients underwent focused, helical, appendiceal CT after the instillation of 3 percent diatrizoate meglumine–saline solution into the colon as previously described.[17] All scans were obtained and interpreted within one hour after being requested. The actual imaging time was less than 15 minutes for most patients. CT was well tolerated by all patients, and there were no complications.

The scans were interpreted by one of three emergency department radiologists according to previously reported criteria for confirming or ruling out appendicitis.[16,17,21] The results were immediately reported to the referring physician as appendicitis, an alternative diagnosis, or normal appendix without alternative diagnosis. The consulting radiologist estimated the likelihood that the patient had appendicitis as definitely yes, probably yes, equivocally yes, probably no, or definitely no. All initial interpretations became both the official study results and the official radiology reports for the patients' records.

Effect of CT on Patient Care

The final clinical outcomes were determined at surgery and by pathological examination of the appendix after appendectomy or other surgery, or by clinical follow-up with one or more telephone calls or clinic visits at least two months after CT scanning. The final diagnoses were appendicitis, specific alternative conditions, or nonspecific abdominal pain.

Changes in patient care were determined by comparing the planned treatment (hospitalization for observation or urgent appendectomy) with the actual treatment (discharge from the emergency department, hospitalization for observation, treatment for an alternative condition, urgent appendectomy, or other surgery) after the CT findings had been taken into account. We assumed that each patient who avoided hospitalization for observation would have been hospitalized for only one day of observation if CT had not been performed.

TABLE 1. PRESENTING SIGNS AND SYMPTOMS IN 100 PATIENTS SUSPECTED OF HAVING APPENDICITIS.

SYMPTOM OR SIGN	PERCENTAGE OF PATIENTS
Right-lower-quadrant pain or tenderness	96
Duration of symptoms <5 days	80
White-cell count >10,000/mm^3	66
Temperature >37.5°C (99.5°F)	63
Nausea	62
Initial periumbilical pain	40
Vomiting	32
Rebound tenderness	26
Anorexia	24
Right-lower-quadrant guarding	21

Effect of CT on the Use of Hospital Resources

The mean cost of removing a normal appendix and of one day of observation in the hospital was determined by a retrospective analysis of patients seen at our hospital between October 1993 and June 1997. Cost data were obtained from the hospital's cost data base. Hospital charges were not considered in the analysis.

The mean cost of removing a normal appendix was determined for 61 consecutive patients. These patients had a diagnosis of appendicitis on admission, but their appendixes proved to be normal on pathological examination. The mean cost of initial emergency department evaluation was determined by adding the costs of the emergency department resources used and the laboratory and radiologic tests that were performed before appendiceal CT in patients with suspected appendicitis. To calculate the effect of CT on resource use, the mean cost saved by avoiding an unnecessary appendectomy was defined as the total cost of admission for appendectomy with removal of a normal appendix minus the cost of the initial emergency department evaluation that would be expected to occur before appendiceal CT was performed.

The mean cost of one day of hospital admission for observation was determined from a sample of 350 patient-days in patients with a diagnosis of appendicitis on admission. To calculate the effect of CT on resource use, the mean cost saved by avoiding one day of hospitalization for observation was defined as the cost of nursing care and the hospital room for a patient with the lowest level of severity of illness. At our hospital, the severity of a patient's illness is graded on a 4-point scale, with a score of 1 indicating least severe illness and a score of 4 most severe illness, and the severity of illness determines the use of nursing resources and, hence, nursing costs.

The mean cost of pelvic CT without intravenous administration of contrast material was determined from the hospital's data base for all patients who underwent pelvic CT in 1996 without the intravenous administration of contrast material. To calculate the effect of CT on resource use, the cost of an appendiceal CT scan was defined as the cost of pelvic CT without intravenous contrast.

The changes in the use of hospital resources were determined by comparing the treatment plans made before CT with the treatment patients actually received. The number of unnecessary appendectomies avoided was multiplied by the cost of removing a normal appendix. The number of hospital observation days avoided was multiplied by the cost of one hospital day at the lowest level of severity of illness. The overall cost of the routine use of

appendiceal CT in the emergency department was determined by subtracting the cost of performing 100 appendiceal CT examinations from the savings resulting from incorporating the CT results into treatment decisions.

RESULTS

Fifty-three patients (53 percent) had a final diagnosis of appendicitis, as confirmed at surgery and by pathological examination. In 47 patients (47 percent), appendicitis was ruled out during appendectomy (3 patients), other surgery (3 patients), or clinical follow-up (41 patients) (Fig. 1 and 2).

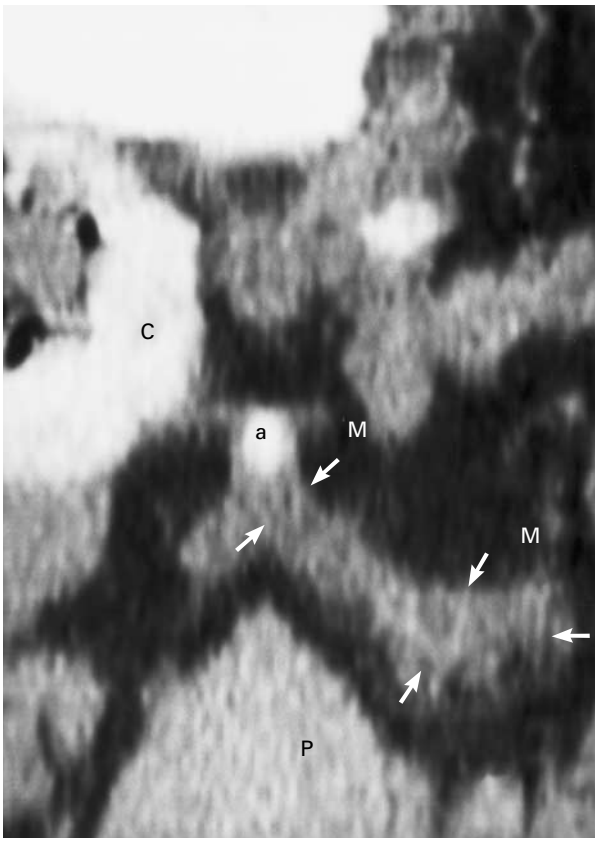
The results of CT were positive in 53 patients (all with surgical and pathological proof of appendicitis), negative in 45 patients (42 negative through clinical follow-up and 3 with pathological proof of a normal appendix), false positive in 1 patient (negative through clinical follow-up), and false negative in 1 patient (with surgical and pathological proof of appendicitis). The appendix was visualized in 44 of the 47 patients (94 percent) who proved not to have appendicitis. The CT interpretations had 98 percent sensitivity, 98 percent specificity, 98 percent positive predictive value, 98 percent negative predictive value, and 98 percent overall accuracy for diagnosing or ruling out appendicitis.[17]

Eighty-six patients (86 percent) had a specific diagnosis (Table 2). Appendiceal CT revealed the correct diagnosis in 81 of these patients (94 percent). The five patients with specific clinical conditions not detected by CT had the following: biliary colic (two), endometriosis (one), urinary tract infection (one), and appendicitis (one). Fourteen patients had nonspecific abdominal pain.

The clinical and radiologic likelihood of appendicitis before CT as compared with the final outcome is shown in Table 3, and the results are shown in the form of receiver-operating-characteristic curves in Figure 3.

There were 63 changes in treatment strategy for 59 patients because of CT findings. These changes involved prevention of the following: unnecessary appendectomy in 13 patients, admission to the hospital for observation in 18 patients, admission to the hospital for observation before necessary appendectomy in 21 patients, and admission to the hospital for observation before other conditions were diagnosed by CT in 11 patients.

The mean cost of hospital admission for unnecessary appendectomy in a patient without another condition requiring surgery was $4,248 (range, $1,733 to $8,708); higher costs resulted from intraoperative or postoperative complications. The mean cost of an emergency department evaluation was $611,[19] and thus the savings resulting from preventing an unnecessary appendectomy after the cost of the initial emergency department evaluation had been subtracted was $3,637 (Table 4). The overall cost sav-



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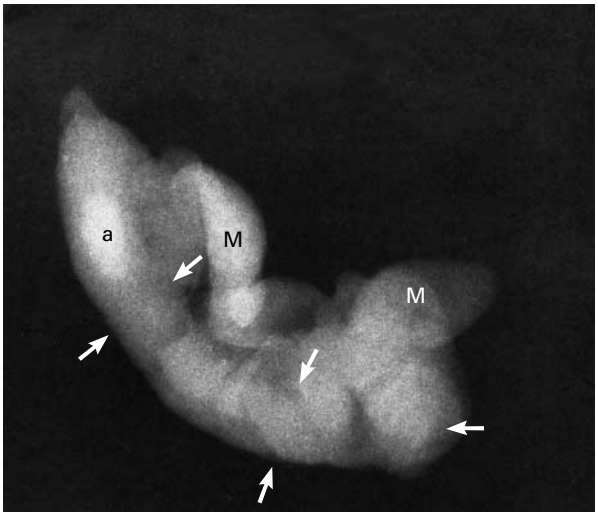

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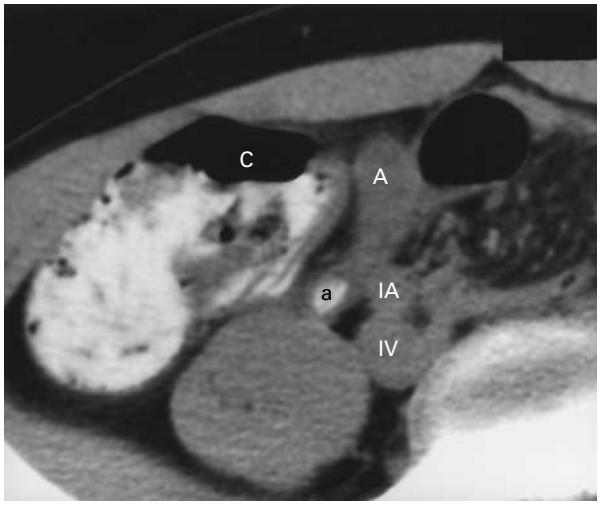
Figure 1. Results of Appendiceal CT in a 30-Year-Old Man with Suspected Appendicitis and Radiographic Appearance of the Specimen after Appendectomy.

Panel A is a coronally reformatted appendiceal CT scan showing an inflamed, unopacified appendix, 12 mm in diameter (arrows), with proximal appendolith (a). Also shown are the cecum (C), right psoas muscle (P), and appendiceal mesentery (M). Panel B is a radiograph of the inflamed appendix (arrows) and appendiceal mesentery after surgical removal.



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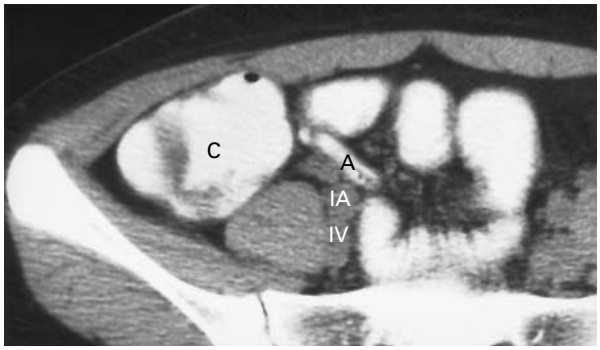

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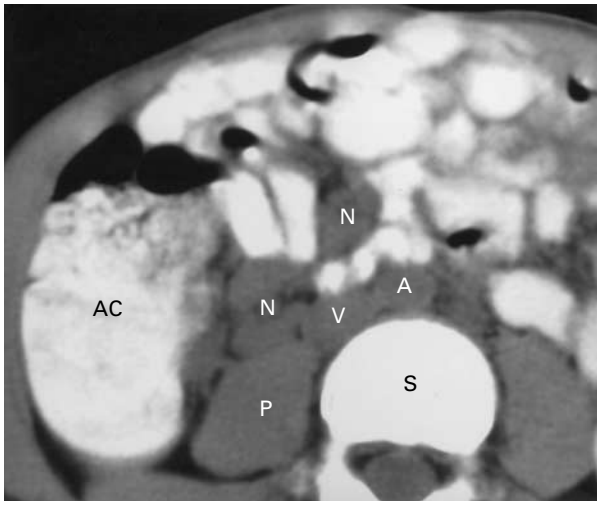

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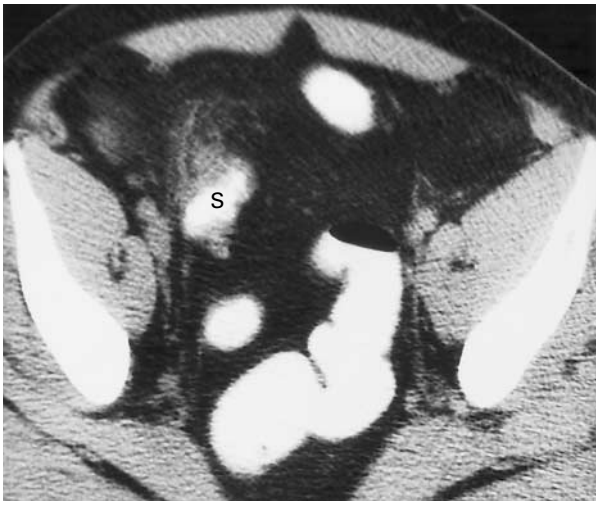

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Figure 2. Results of Appendiceal CT in Four Patients.

Panel A is a CT scan of a 17-year-old boy with suspected appendicitis. The axial image shows an inflamed, unopacified appendix, 15 mm in diameter (A), with proximal appendolith (a). Also shown are the cecum (C) and the common iliac artery (IA) and vein (IV). The image in Panel B is of a 21-year-old woman with suspected appendicitis. The axial image shows a tubular, opacified normal appendix. Panel C is a CT scan of an eight-year-old girl with suspected appendicitis. The axial image at the level of the ascending colon (AC) shows clumped, enlarged mesenteric lymph nodes (N), a finding consistent with a diagnosis of mesenteric adenitis. Also shown are the aorta (A), inferior vena cava (V), right psoas muscle (P), and lumbar spine (S). Panel D is an image of a 39-year-old man with suspected appendicitis. The axial image shows a focally inflamed, right-sided, redundant loop of sigmoid colon (S), a finding consistent with a diagnosis of sigmoid diverticulitis.

ings from the prevention of 13 appendectomies among the 100 patients was $47,281.

The mean cost of one hospital day of observation at the lowest level of severity of illness was $405.[19] At least 50 hospital days of observation were avoided because of the CT results: 18 days for patients discharged from the emergency department, 21 days for patients who had necessary appendectomies without being first hospitalized for observation, and 11 days for patients treated immediately for CT-diagnosed alternative conditions. Thus, the total cost savings from the 50 avoided days of hospital observation was $20,250.

The total cost of the 100 appendiceal CT examinations was $22,800. The overall effect of these 100 examinations on the use of hospital resources was a net savings of $44,731.

DISCUSSION

The difficulties of making a clinical diagnosis of appendicitis are well documented, and an accurate, safe, and quickly performed diagnostic test has long

TABLE 2. FINAL DIAGNOSES IN 100 PATIENTS SUSPECTED OF HAVING APPENDICITIS.

FINAL DIAGNOSIS	PERCENTAGE OF PATIENTS
Appendicitis	53
Mesenteric adenitis	18
Nonspecific abdominal pain	14
Right ovarian cyst	4
Right-sided colitis	2
Sigmoid diverticulitis	2
Biliary colic	2
Right tubo-ovarian abscess	1
Cecal carcinoma	1
Epiploic appendagitis	1
Endometriosis	1
Urinary tract infection	1

TABLE 3. ESTIMATED CLINICAL AND RADIOLOGIC LIKELIHOOD OF APPENDICITIS AS COMPARED WITH FINAL OUTCOME.

	FINAL OUTCOME	
	APPENDICITIS CONFIRMED	APPENDICITIS RULED OUT
Clinical likelihood*		
Definitely appendicitis	18	5
Probably appendicitis	19	15
Equivocally appendicitis	9	18
Possibly appendicitis	7	9
Total	53	47
Radiologic likelihood		
Definitely appendicitis	50	1
Probably appendicitis	2	0
Equivocally appendicitis	0	0
Probably not appendicitis	1	2
Definitely not appendicitis	0	44
Total	53	47

*Clinical likelihood was judged by the referring surgeon.

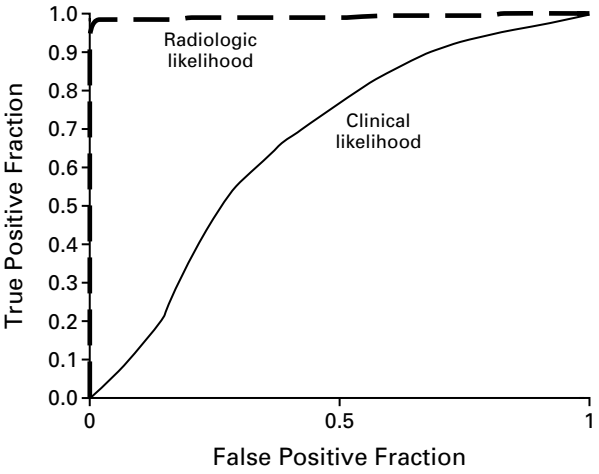

Figure 3. Correlation between Clinical and Radiologic Likelihood of Appendicitis and Final Outcome.

A comparison of receiver-operating-characteristic curves is shown.

TABLE 4. EFFECT OF CT ON TREATMENT AND THE USE OF RESOURCES FOR 100 PATIENTS WITH SUSPECTED APPENDICITIS.

TREATMENT CHANGE	NO. OF PATIENTS	SAVINGS OR COSTS PER PATIENT (DOLLARS)	TOTAL SAVINGS OR COSTS (DOLLARS)
Savings			
Avoided unnecessary appendectomy	13	3,637	47,281
Avoided observation for 1 day before appendectomy	21	405	8,505
Avoided observation for 1 day before treatment for CT-diagnosed alternative condition	11	405	4,455
Avoided observation for 1 day before discharge	18	405	7,290
Costs			
Appendiceal CT examinations	100	228	22,800
Overall cost savings			44,731

been sought to improve preoperative diagnostic accuracy.[8,9] Various clinical scoring systems, blood tests, and radiologic examinations have been used, but most of these tests have limitations, including low accuracy rates, high false negative rates, and high cost.[12,22-24]

The appendiceal CT technique used in this study overcame many of the limitations of other diagnostic techniques. The accuracy and interpretive confidence were high and the false negative rate was low. The procedure is neither technically challenging nor time-consuming, and it does not delay patient care.

If the initial, clinically based management plans had been the sole determinant of treatment (as is currently true in many emergency departments), at least 13 patients would have had an unnecessary appendectomy and 21 patients would have had a necessary appendectomy after a delay. If the CT results had been the sole determinant of treatment, one patient would have had an unnecessary appendectomy and one a necessary appendectomy after a delay. The integration of clinical and CT findings by the surgeon responsible for each patient's care actually resulted in three patients' having an unnecessary appendectomy and no patient's having a delayed necessary appendectomy.

This study included a cost analysis based on changes in patient care resulting from the routine use of appendiceal CT. The cost savings are probably understated, because the estimated number of ap-

pendectomies avoided was based on only the 13 patients whose initial, pre-CT treatment plan was for urgent appendectomy. On the basis of historical data at our hospital, up to 50 percent of the 52 patients initially hospitalized for observation in this study would eventually have undergone appendectomy. If we assume that 20 percent of the removed appendixes would have been normal (the national average), five more patients would have undergone unnecessary appendectomy. Also, we used the lowest level of severity of illness to determine the cost of hospital observation, and some of the patients who avoided being hospitalized for observation because of the CT results would have had more severe illness and higher observation costs. Finally, we did not attempt to quantify other benefits resulting from more timely and better treatment, such as reduction in disability and in lost productivity. However, only patients who met the clinical criteria for hospital admission for suspected appendicitis were eligible for appendiceal CT. Expanded use of appendiceal CT in patients in whom the suspicion of appendicitis is low would probably lessen the savings per patient.

At our hospital, the ratio of the average cost of removing a normal appendix to the average cost of an appendiceal CT was 16 to 1, as compared with 22 to 1 in a recent report.[20] The difference in these ratios is probably due to the fact that, on the average, removing an inflamed appendix costs more than removing a normal appendix.[19]

Widespread implementation of appendiceal CT in the emergency department would require readily available helical CT facilities and on-site radiologists familiar with appendiceal CT. We think that a radiologist would need experience with tens of cases to achieve consistently accurate results. Radiologists with previous experience in CT or gastrointestinal imaging would probably achieve proficiency more quickly.

In summary, the routine use of appendiceal CT in emergency department patients who meet the clinical criteria for hospital admission for suspected appendicitis improves patient care both by averting unnecessary appendectomies and by averting delays before necessary medical or surgical treatment. At the same time, the improved care lowers the use of hospital resources, because the savings achieved by eliminating unnecessary operations and hospitalization for observation outweighs the cost of routine appendiceal CT.

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