

Selective Imaging Strategies for the Diagnosis of Appendicitis in Children

Barbara M. Garcia Peña, MD, MPH*; E. Francis Cook, ScD‡; and Kenneth D. Mandl, MD, MPH§

ABSTRACT. *Background.* We previously reported an appendiceal imaging protocol in which children with equivocal clinical presentations for acute appendicitis undergo ultrasonography (US) followed by computed tomography (CT). However, risk groups of children who would benefit most from imaging studies have not been established.

Objective. To define and test selective imaging guidelines to increase diagnostic accuracy and reduce unnecessary testing for children with suspected appendicitis.

Methods. We modeled outcomes under 3 different management guidelines. Patients were risk-stratified by a recursive partitioning analysis of a retrospective cohort. Subjects included children with equivocal presentations of acute appendicitis evaluated between January 1996 and December 1999. By using recursive partitioning, 3 risk groups were identified: low, medium, and high risk for acute appendicitis. Three imaging guidelines were defined. Under the first guideline, representing standard clinical practice at Children's Hospital Boston at the time of the study, all children with equivocal signs and symptoms for acute appendicitis undergo US first. If the US is positive, the child proceeds to appendectomy. If the US is negative, the child undergoes CT. Under guideline 2, low-risk children undergo US and, if negative, are discharged from the hospital. High-risk children undergo CT, and medium-risk children undergo US followed by CT. Under the third guideline, low-risk children undergo no imaging and are admitted for observation. High-risk children proceed directly to appendectomy without imaging studies. Medium-risk children undergo US followed by CT. Clinical outcomes and the number of imaging studies performed were modeled under current practice and under each guideline.

Results. Identified were 1401 cases of equivocal appendicitis; 958 (68.4%) with complete data. The mean age was 11 ± 4.3 years. Of 958 children, 588 (61.4%) had acute appendicitis. One hundred forty-three patients were in the low-risk group, defined as neutrophils $\leq 67\%$, bands $< 5\%$, and no guarding on abdominal examination. Fifteen (10%) children had appendicitis. Two hundred twenty-five were high-risk for appendicitis defined as neutrophils $> 67\%$, white blood cell count $> 10\,000/\text{mm}^3$,

guarding, and abdominal pain > 13 hours. Of these, 202 (90%) had appendicitis. Under guideline 1, there were 22 negative appendectomies, 35 missed or delayed diagnoses, and 958 USs and 673 CT scans performed. Under guideline 2, there would have been 23 negative appendectomies, 36 missed or delayed diagnoses, and 733 USs and 637 CT scans performed. Under guideline 3, there would have been 36 negative appendectomies, 37 missed or delayed diagnoses, and 590 USs and 412 CT scans performed.

Conclusions. Selective imaging guidelines can reduce the number of radiographic studies performed with minimal diminution in accuracy of diagnosis of pediatric appendicitis. *Pediatrics* 2004;113:24-28; *appendicitis, computed tomography, ultrasonography, selective imaging guidelines.*

ABBREVIATIONS. US, ultrasonography; CT, computed tomography; WBC, white blood cell.

Accurate diagnosis of acute appendicitis in the pediatric population continues to pose a difficult challenge to clinicians, because the initial presentation of the disease is often obscure and closely mimicked by other common childhood diseases.¹⁻⁶ As a result, many children with suspected appendicitis are admitted to the hospital for a period of inpatient observation.⁷⁻¹⁰ However, the delayed diagnosis of appendicitis may lead to complications, which in turn lead to increased morbidity and mortality.¹¹⁻¹⁴ In addition, it has been reported that a normal appendix is removed in 15% to 40% of children who undergo appendectomy.¹⁵⁻¹⁷

Two diagnostic imaging modalities have provided clinicians with greater accuracy in diagnosing childhood appendicitis. Ultrasonography (US) is widely used in the pediatric population because it does not expose patients to ionizing radiation and is noninvasive.¹⁸⁻²¹ However, it is highly operator-dependent, and the normal appendix is rarely visualized.²² Computed tomography (CT) is increasingly being used in children for the diagnosis of appendicitis. The use of CT in children has increased ~7-fold in the past 10 years.²³ It has been shown to be 94% to 99% accurate for the diagnosis of pediatric appendicitis.²⁴⁻²⁷ However, many are concerned about the ionizing radiation, albeit small, associated with CT^{23,28-30} and the invasiveness of oral, intravenous, or rectal contrast in the pediatric population.

Although diagnostic imaging modalities can be very helpful in the diagnosis of appendicitis,³¹ they can also increase the time to diagnosis, the ionizing

From the *Division of Emergency Medicine, Miami Children's Hospital, Miami, Florida; †Department of Epidemiology, Harvard School of Public Health, Boston, Massachusetts; and ‡Division of Emergency Medicine, Children's Hospital Boston, Boston, Massachusetts.

Received for publication Feb 18, 2003; accepted May 9, 2003.

This work was presented in part at the Society for Pediatric Research on May, 2001 in Baltimore, MD.

Address correspondence to Barbara M. Garcia Peña, MD, MPH, Division of Emergency Medicine, Miami Children's Hospital, 3100 SW 62nd Ave, Miami, FL 33155. E-mail: barbara.pena@mch.com

PEDIATRICS (ISSN 0031 4005). Copyright © 2004 by the American Academy of Pediatrics.

radiation exposure, the utilization of hospital resources, as well as the discomfort of the child. Many clinicians may be tempted to order studies for children who have symptoms of classic appendicitis or nonspecific acute abdominal pain, neither of whom should necessarily require diagnostic imaging studies. The identification of children who would benefit most from imaging should occur based on their prior probability of having appendicitis. The purpose of this investigation was to define and test selective imaging guidelines based on risk stratification to increase diagnostic accuracy and reduce unnecessary testing for children with suspected appendicitis.

METHODS

Study Subjects and Design

The study was a recursive partitioning analysis of a retrospective cohort with subsequent development of guidelines and modeling of the outcomes under the guidelines. A cohort of children between 3 and 21 years old who were admitted to the hospital ward or operating room of Children's Hospital Boston with equivocal presentations for acute appendicitis between January 1996 and December 1999 were identified retrospectively. All patients who were admitted to the hospital for suspected appendicitis were eligible. Patients with equivocal presentations were defined as those children with concerning but not classic signs or symptoms for acute appendicitis. Children's Hospital Boston is a large, urban, pediatric teaching hospital with an emergency department that sees 50 000 patient visits and a general surgical service that performs 4000 operations annually. All radiographic studies are performed by either pediatric radiology attendings or fellows 24 hours a day. This study was approved by the institutional review board of Children's Hospital Boston.

Patients evaluated for acute appendicitis were identified through a query of the hospital database selecting patients with *International Classification of Diseases, 9th Revision (ICD-9)* codes for appendicitis, perforated appendicitis, appendectomy, and abdominal pain. A single reviewer using a standardized data collection tool abstracted data on symptoms, clinical examination findings, radiographic studies, and pathology reports. Final diagnoses were determined by pathologic examination of the appendix in those children who were managed operatively and by clinical follow-up in those children managed nonoperatively.

Stratification of Groups

Using CART 3.6, we conducted a recursive partitioning analysis to divide the cohort into children at high, low, and medium risk for appendicitis. Variables entered into the model included age, gender, hours of abdominal pain, nausea or vomiting, diarrhea, anorexia, temperature $>38.0^{\circ}\text{C}$, right lower quadrant tenderness, rebound tenderness, guarding, rectal tenderness, stool occult blood, white blood cell (WBC) count $>10\,000/\text{mm}^3$, neutrophil count, and bands $>5\%$. Ten-fold cross-validation and the Gini method for classification trees were used. We used the minimum-cost tree regardless of size for the standard error rule, and all surrogates counted equally. Missing a case of appendicitis was weighted as 10 times worse than diagnosing appendicitis in a child that did not have it.

Imaging Guidelines

We defined, a priori, 3 imaging guidelines for the diagnosis of acute appendicitis. Guideline 1 represents standard clinical practice at Children's Hospital Boston at the time of the study period.^{24,32} In that strategy, all children with equivocal signs and symptoms for appendicitis undergo US first. If the US is positive, the child proceeds to the operating room for appendectomy. If the US is negative, the child then undergoes CT scan. If the CT is positive for appendicitis, the child undergoes appendectomy. If the CT is negative, the child is discharged from the hospital with close follow-up. Outcomes under guideline 1 are all measured in clinical data.

Guidelines 2 and 3 are applied hypothetically to the cohort, and outcomes are modeled. These guidelines implement more selec-

tive imaging strategies aimed at reducing the use of radiography according to risk assessments. Under guideline 2, the low-risk patients undergo US only. If the study is negative for appendicitis, the child is discharged from the hospital. If the study is positive for appendicitis, the child proceeds to appendectomy. The high-risk patients undergo CT only. If the scan is negative, the child is discharged from the hospital. If the scan is positive, the child undergoes appendectomy. The medium-risk children default to the protocol for guideline 1 (standard clinical practice) where both US and CT are used.

In guideline 3, low-risk patients undergo no imaging while in the emergency department and are admitted for inpatient observation. Children at high risk for appendicitis receive no imaging and proceed directly to appendectomy. Again, medium-risk patients default to the protocol under guideline 1.

Modeling of Outcomes

By using the highest known sensitivities, specificities, positive predictive values, and negative predictive values of US, CT, and US followed by CT, the number of negative appendectomies and missed or delayed diagnoses of appendicitis were modeled for each strategy. The number of US and CT scans performed were also calculated based on how patients flowed through each guideline.

Statistical Analysis

Descriptive statistics were calculated with SPSS 7.5 for Windows (SPSS Inc, Chicago, IL). Recursive partitioning was performed with CART 3.6 for Windows (Salford Systems, Inc, San Diego, CA).

RESULTS

During the study period, 1401 children were identified, 958 of which (63.4%) had complete data. The mean age of the cohort was 11 ± 4.3 years. There were 526 of 958 (54.9%) males. More than half (588 of 958 [61.4%]) had acute appendicitis.

Stratification of Groups

Recursive partitioning analysis identified a low-risk group of 143 patients. These children all had a complete blood count with neutrophils $\leq 67\%$, bands $<5\%$, and no guarding on physical examination. Fifteen of these 143 (10.5%) patients had appendicitis (Fig 1). A high-risk group of 225 patients was identified. These patients had a complete blood count with neutrophils $>67\%$, WBC count $>10\,000/\text{mm}^3$, guarding on physical examination, and a history of abdominal pain >13 hours. Of 225 children in the high-risk group, 202 (90%) had appendicitis (Fig 1). The remainder of the patients (590 of 958 [61.6%]) comprised the medium-risk group. Appendicitis was diagnosed in 371 of 590 (62.9%) children in this group.

Imaging Guidelines

Fig 2 shows the actual data from the children managed under guideline 1 (which was standard practice during the period studied). More than half (588 of 958 [61.4%]) of the patients had acute appendicitis. The correct diagnosis was made in 901 of 958 (94%) children. Of the 370 patients without appendicitis, there were 22 (5.9%) negative appendectomies.

Outcomes under guidelines 2 and 3 are shown in Fig 3. Under guideline 2, there would be 36 cases (6.1%) of missed or delayed diagnosis of acute appendicitis and 23 (6.2%) cases of negative appendectomies. The correct diagnosis would be made in 899

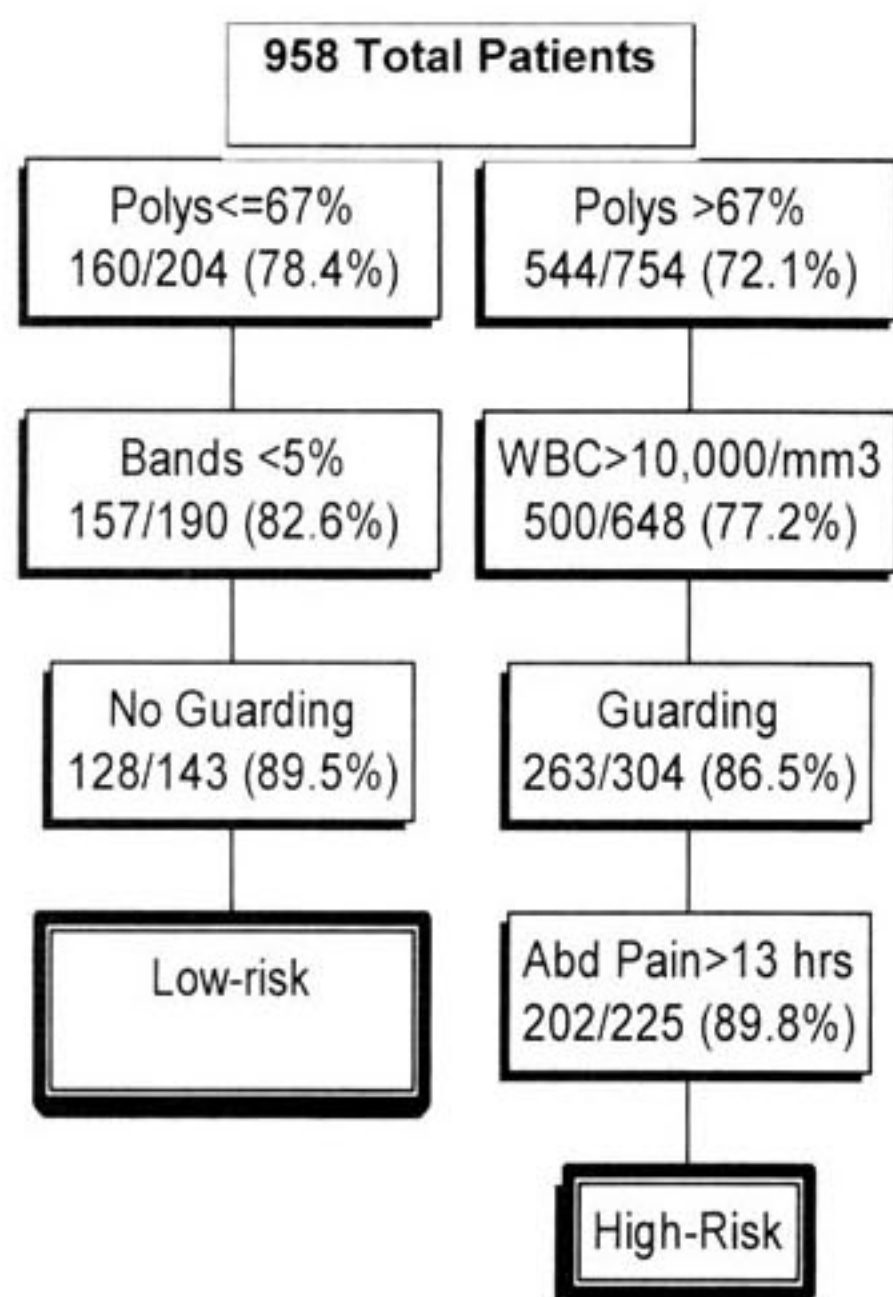


Fig 1. Low-risk and high-risk groups determined by recursive partitioning. The low-risk group is depicted on the left and the high-risk group is on the right.

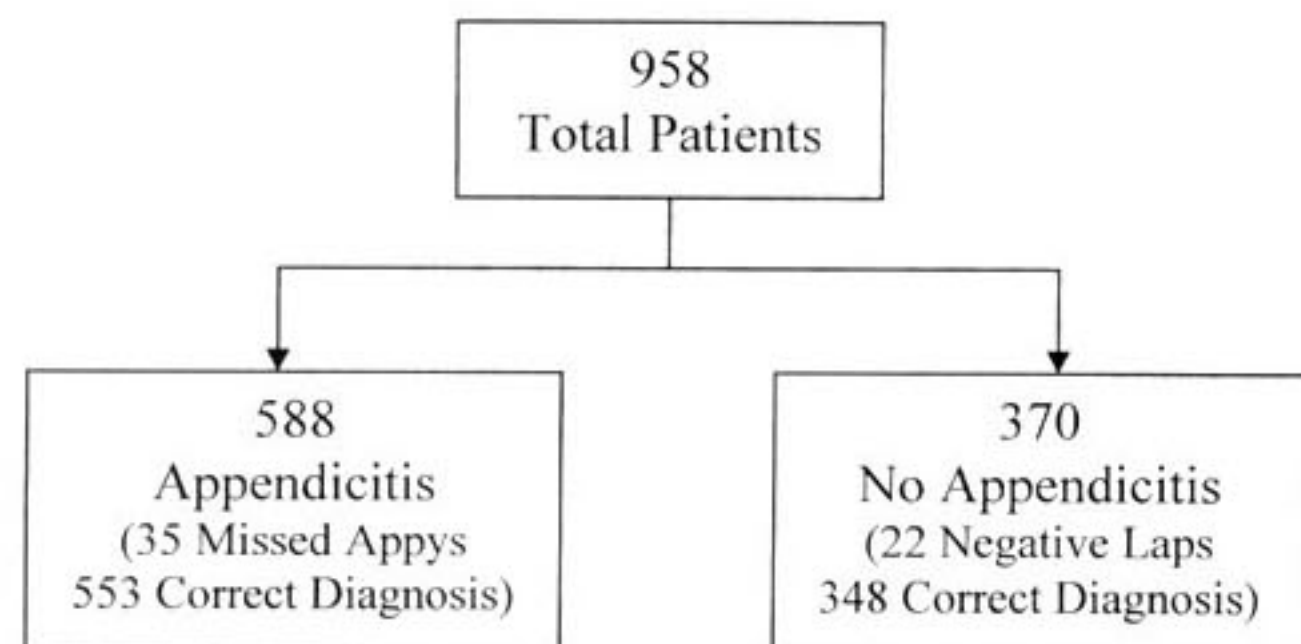


Fig 2. Guideline 1 (US followed by CT).

of 958 (93.8%) patients. Those children undergoing the protocol under guideline 3 would have had 37 (6.3%) cases of missed or delayed diagnosis of acute appendicitis and 36 (9.7%) cases of negative appendectomies. The correct diagnosis would be made in 885 of 958 (92.4%) patients.

Table 1 demonstrates the clinical outcomes as stated above and the number of radiographic studies for the current US-CT strategy and the proposed guidelines. Under guideline 1, there were 958 USs and 673 CT scans performed. There would have been 733 USs and 637 CT scans performed under guideline 2 and 590 USs and 412 CT scans performed under guideline 3.

Under guideline 1, one would have to perform 30.6 CT scans and 43.5 USs for each case of negative appendectomy avoided and 19.2 CT scans and 27.4 USs for each case of missed or delayed appendicitis prevented. Under guideline 2, one would have to perform 27.7 CT scans and 31.9 USs for each case of negative appendectomy avoided and 17.7 CT scans and 20.4 USs for each case of missed or delayed appendicitis prevented. Last, under guideline 3, 11.4 CT scans and 16.4 USs would have to be performed

to avoid one case of negative appendectomy and 11.1 CT scans and 15.9 USs to prevent one case of missed or delayed appendicitis.

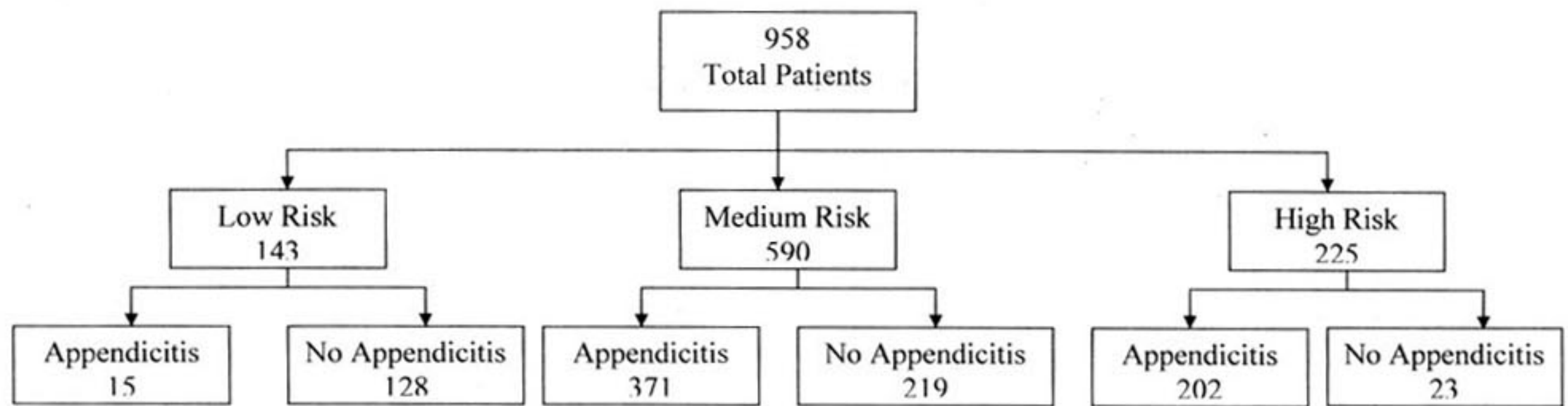
DISCUSSION

The diagnosis of acute appendicitis in the pediatric population remains difficult. Delayed diagnoses and subsequent appendiceal perforations with their concomitant complications continue to present a challenge for physicians even with the advent of improved diagnostic imaging techniques. In addition, the negative pediatric appendectomy rates across the United States remain relatively high. The use of US and CT has increased exponentially over the past decade and has provided a great increase in the accuracy of the diagnosis of acute appendicitis. However, there is a danger that radiographic studies may be obtained even when they may add little to the clinical impression based on history, physical examination, and basic laboratory studies. The use of CT in pediatric patients has become particularly concerning because of the potential long-term risks of ionizing radiation. Hence, protocols are required to reduce the number of unnecessary radiographic studies being performed for the diagnosis of acute appendicitis.

In this investigation, we have described 3 distinct risk groups of children with suspected acute appendicitis. Children with neutrophils $\leq 67\%$, bands $< 5\%$, and no guarding on physical examination comprise a group of patients at low risk for appendicitis, whereas children with neutrophils $> 67\%$, WBC count $> 10\,000/\text{mm}^3$, guarding on physical examination, and abdominal pain > 13 hours comprise a group of patients at high risk for appendicitis. The remainder of the children comprised the medium-risk group. Using these risk groups, we compared 3 selective imaging guidelines and calculated the numbers of missed or delayed diagnoses of appendicitis, negative appendectomies, and USs and CT scans performed for each strategy. We have shown that these guidelines for selective imaging based on risk stratification may reduce the number of radiographic studies performed for diagnosing appendicitis with a minimal increase in the negative appendectomy and missed diagnosis of appendicitis rates.

Limitations of this study include the hypothetical nature of proposed guidelines 2 and 3. The effectiveness of these guidelines in clinical practice is unknown and thus must be confirmed with prospective investigation. Second, there are many more management strategies using selective imaging protocols that can be explored, and those chosen may not be the ideal strategies for managing suspected appendicitis in many institutions. However, to model > 3 strategies would be unwieldy in the scope of a single investigation. Third, a second data set was not available to validate the risk groups that were created by the regression tree. However, the data were validated by the cross-validation methods provided by CART.

Although both the number of USs and CT scans performed were markedly decreased, the number of negative appendectomies and cases of missed or de-



#2	7 Correct Diagnosis 8 Missed Appys	119 Correct Diagnosis 9 Negative Laps	349 Correct Diagnosis 22 Missed Appys	206 Correct Diagnosis 13 Negative Laps	196 Correct Diagnosis 6 Missed or Delayed	22 Correct Diagnosis 1 Negative Lap
----	---------------------------------------	--	--	---	--	--

Appys

#3	15 Missed Appys or Delayed Diagnosis	128 Correct Diagnosis	349 Correct Diagnosis 22 Missed Appys	206 Correct Diagnosis 13 Negative Laps	202 Correct Diagnosis	23 Negative Laps
----	---	-----------------------	--	---	-----------------------	------------------

Fig 3. Modeled outcomes for guidelines 2 (low risk: US only; high risk: CT only; medium risk: US and then CT) and 3 (low risk: admit for observation; high risk: CT only; medium risk: US and then CT).

TABLE 1. Clinical Outcomes and Number of Radiographic Studies for Proposed Guidelines

	Guideline 1	Guideline 2	Guideline 3
Negative appendectomies	22	23	36
Missed or delayed diagnoses	35	36	37
No. of USs performed	958	733	590
No. of CT scans performed	673	637	412

layed diagnoses of appendicitis slightly increased in both proposed selective imaging strategies. Under guideline 1, one would have to perform 11.8 CT scans and 16.8 USs to prevent one case of incorrect diagnosis of appendicitis (either one negative appendectomy or one missed or delayed diagnosis). Under guideline 2, one would have to perform 10.8 CT scans and 12.4 USs, and under guideline 3, one would have to perform 5.6 CT scans and 8.1 USs to prevent an incorrect diagnosis. Hence, in choosing between guidelines 2 and 3, one would have to weigh the increase in negative appendectomies from 23 under guideline 2 to 36 under guideline 3 against the marked decrease in the number of USs and CT scans performed under guideline 3.

We have shown that selective imaging guidelines in low- and high-risk groups for suspected appendicitis may reduce the number of radiographic studies performed while keeping the negative appendectomy and missed diagnosis of appendicitis rates relatively stable. Selective imaging guidelines can reduce the number of radiographic studies performed with minimal diminution in the accuracy of diagnosis of pediatric appendicitis.

REFERENCES

- Gamal R, Moore TC. Appendicitis in children aged 13 years and younger. *Am J Surg.* 1990;159:589-592
- Putnam TC, Gagliano N, Emmends RW. Appendicitis in children. *Surg Gynecol Obstet.* 1990;170:527-532
- Scholer SJ, Pituch K, Orr DP, Dittus RS. Clinical outcomes of children with acute abdominal pain. *Pediatrics.* 1996;98:680-685
- Rothrock SG, Skeoch G, Rush JJ, Johnson NE. Clinical features of misdiagnosed appendicitis in children. *Ann Emerg Med.* 1991;20:45-50.
- Rothrock SG, Pagane J. Acute appendicitis in children: emergency department diagnosis and management. *Ann Emerg Med.* 2000;36:39-51
- Horwitz JR, Gursoy M, Jaksic T, Lally KP. Importance of diarrhea as a presenting symptom of appendicitis in very young children. *Am J Surg.* 1997;173:80-82
- White JJ, Santillana M, Haller JA. Intensive in-hospital observation: a safe way to decrease unnecessary appendectomy. *Am Surg.* 1975;41:793-798
- Graff L, Radford MJ, Werne C. Probability of appendicitis before and after observation. *Ann Emerg Med.* 1991;20:503-507
- Senbanjo RO. Management of patients with equivocal signs of appendicitis. *J R Coll Surg Edinb.* 1997;42:85-88
- Nauta RI, Magnant C. Observation versus operation for abdominal pain in the right lower quadrant: roles of the clinical examination and the leukocyte count. *Am J Surg.* 1986;151:746-748
- Wagner JM, McKinney WP, Carpenter JL. Does this patient have appendicitis? *JAMA.* 1996;276:1589-1594
- Brender JD, Marcuse EK, Koepsell TD, Hatch EI. Childhood appendicitis: factors associated with perforation. *Pediatrics.* 1985;76:301-306
- Rappaport WD, Peterson M, Stanton C. Factors responsible for the high perforation rate seen in early childhood appendicitis. *Am Surg.* 1989;55:602-605
- Lund DP, Murphy EU. Management of perforated appendicitis in children: a decade of aggressive treatment. *J Pediatr Surg.* 1994;29:1130-1134
- Lewis FR, Holcroft JW, Boey J, Dunphy JE. Appendicitis: a critical review of diagnosis and treatment in 1,000 cases. *Arch Surg.* 1975;110:677-684
- Velanovich V, Satava R. Balancing the normal appendectomy rate with the perforated appendicitis rate: implications for quality assurance. *Am Surg.* 1992;58:264-269

17. Izbicki JR, Knoefel WT, Wilker DK, et al. Accurate diagnosis of acute appendicitis: a retrospective and prospective analysis of 686 patients. *Eur J Surg.* 1992;158:227-231
18. Wade DS, Morrow SE, Balsara ZN, et al. Accuracy of ultrasound in the diagnosis of acute appendicitis compared with the surgeon's clinical impression. *Arch Surg.* 1993;128:1039-1046
19. Sivit CJ, Newman KD, Boenning DA, et al. Appendicitis: usefulness of ultrasound in diagnosis in a pediatric population. *Radiology.* 1992;185:549-552
20. Rubin SZ, Martin DJ. Ultrasonography in the management of possible appendicitis in childhood. *J Pediatr Surg.* 1990;25:737-740
21. Skaane P, Schistad O, Amland PF, Solheim K. Routine ultrasonography in the diagnosis of acute appendicitis: a valuable tool in daily practice? *Am Surg.* 1997;63:937-942
22. Rao PM, Rhea JT, Novelline RA, et al. Helical CT technique for the diagnosis of appendicitis: prospective evaluation of a focused appendix CT examination. *Radiology.* 1997;202:139-144
23. National Cancer Institute. Radiation and pediatric computed tomography: a guide for health care providers. Summer Newsletter; 2002;1-4
24. Garcia Peña 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
25. Sivit CJ, Applegate KE, Stallion A, et al. Imaging evaluation of suspected appendicitis in a pediatric population: effectiveness of sonography versus CT. *Am J Roentgenol.* 2000;175:977-980
26. Mullins ME, Kircher MF, Ryan DP, et al. Evaluation of suspected appendicitis in children using limited helical CT and colonic contrast material. *Am J Roentgenol.* 2001;176:37-41
27. Lowe LH, Penney MW, Stein SM, et al. Unenhanced limited CT of the abdomen in the diagnosis of appendicitis in children: comparison with sonography. *Am J Roentgenol.* 2001;176:31-35
28. Brenner DJ, Elliston CD, Hall EJ, Berdon WE. Estimated risks of radiation-induced fatal cancer from pediatric CT. *Am J Roentgenol.* 2001;176:289-296
29. Paterson A, Frush DP, Donnelly LF. Helical CT of the body: are settings adjusted for pediatric patients? *Am J Roentgenol.* 2001;176:297-301
30. Donnelly LF, Emery KH, Brody AS, et al. Minimizing radiation dose for pediatric body applications of single-detector helical CT. *Am J Roentgenol.* 2001;176:303-306
31. Garcia Peña BM, Taylor GA, Fishman SJ, Mandl KD. Effect of an imaging protocol on clinical outcomes among pediatric patients with appendicitis. *Pediatrics.* 2002;110:1088-1093
32. Garcia Peña BM, Taylor GA, Fishman SJ, Mandl KD. Costs and effectiveness of ultrasonography and limited computed tomography for diagnosing appendicitis in children. *Pediatrics.* 2000;106:672-676

SPEED EATING – A NEW “SPORT”?

“Speed eating has been around in one form or another for the better part of a century, practiced informally at country fairs and fraternity houses. In the last few years, however, it has been transformed into a national competitive circuit complete with television coverage, prize money and its own governing body, the International Federation of Competitive Eating. The federation oversees 150 events and counts 3000 eaters in its register. Its competitions boast strict rules and regulations – vomiting leads to automatic disqualification; any food in the mouth at the buzzer counts.”

New York Times. September 2003

-What an awful idea!

-JFL, MD