Acute Appendicitis in Young Adults: Low- versus Standard-Radiation-Dose Contrast-enhanced Abdominal CT for Diagnosis[1]

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Purpose: To compare low and standard radiation doses in intravenous contrast material–enhanced abdominal computed tomography (CT) for the diagnosis of acute appendicitis in young adults.

Materials and Methods: The institutional review board approved this retrospective study and waived informed consent. The study included 257 patients (age range, 15–40 years) who underwent CT for suspected appendicitis performed by using a low radiation dose (n = 125) or a standard radiation dose (n = 132). Receiver operating characteristic (ROC) analysis, Fisher exact tests, and Mann-Whitney U tests were used to compare the diagnosis of appendicitis and diagnostic confidence as recorded in prospective CT reports between the two groups.

Results: For 55 low-radiation-dose (median dose-length product, 122 mGy · cm) and 44 standard-dose (median dose-length product, 544 mGy · cm) examinations, one of two abdominal radiologists made primary reports that served as final reports. For the remaining examinations, on-call radiologists with differing levels of experience issued preliminary reports and the two abdominal radiologists then provided final reports. In the primary reports, the low- and standard-dose CT groups did not significantly differ in area under the ROC curve (0.96 vs 0.97, P = .76), sensitivity (90% [38 of 42] vs 89% [47 of 53], P > .99), or specificity (92% [76 of 83] vs 94% [74 of 79], P = .74) in the diagnosis of appendicitis. There was also no significant difference between the two groups in the confidence level when diagnosing (P = .71) or excluding (P = .20) appendicitis in the primary reports. Similar results were observed for the final reports. The two dose groups also did not significantly differ in terms of appendiceal visualization, diagnosis of appendiceal perforation, or sensitivity for alternative diagnoses.

Conclusion: Low-dose CT may have comparable diagnostic performance to standard-dose CT for the diagnosis of appendicitis in young adults.

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Acute appendicitis is the most common cause of acute abdominal pain requiring surgery (1). Computed tomography (CT) has been increasingly used as the primary imaging test in adult patients suspected of having appendicitis (2–7). The potential risk of cancer resulting from CT scanning in this population is particularly important, considering the current frequent use of CT (2–6) and the high incidence of acute appendicitis (1), particularly in adolescents and young adults (8), who are likely to be more sensitive to the effects of radiation than the middle aged and elderly (9,10).

Therefore, efforts should be taken to reduce total CT radiation in the young population. Given that CT is considered to be an important diagnostic test in patient triage for acute abdominal pain (2–7), restricting the absolute number of CT studies may not be practical in many hospitals. An alternative, probably more realistic, way to reduce the total radiation to young patients would be to reduce the radiation dose per examination.

Several researchers (11–14) have introduced low-radiation-dose CT techniques for diagnosing acute appendicitis. Some of these investigators have advocated low-dose CT without the use of intravenous contrast material (11,12). However, this method may not be widely accepted because of its potential limitations for diagnosing incipient appendicitis and other diseases that clinically mimic appendicitis (15). To our knowledge, there have been only two studies (13,14) regarding low-dose CT with intravenous contrast material enhancement. In both of these studies, low-dose CT was simulated by adding image noise to standard-radiation-dose CT data rather than being actually performed, thus limiting the applicability of the study results to real examinations performed with a reduced tube current.

The purpose of our study was to compare low and standard radiation doses in intravenous contrast material–enhanced abdominal CT for the diagnosis of acute appendicitis in young adults.

Advances in Knowledge

- In the diagnosis of appendicitis in young adults, the performance of low-radiation-dose CT (median dose-length product, 122 mGy · cm) and standard-dose CT (median dose-length product, 544 mGy · cm) did not differ significantly in area under the receiver operating characteristic curve (0.96 vs 0.97, P = .76), sensitivity (90% [38 of 42] vs 89% [47 of 53], P > .99), or specificity (92% [76 of 83] vs 94% [74 of 79], P = .74).
- The radiologists' confidence in diagnosing (P = .71) or excluding (P = .20) appendicitis did not differ significantly between low- and standard-dose CT.

Implication for Patient Care

- Intravenous contrast-enhanced low-dose CT has the potential to become the first-line imaging test for patients suspected of having acute appendicitis.

Materials and Methods

The institutional review board of Seoul National University Bundang Hospital approved this study, and informed consent was waived owing to the retrospective nature of the study.

Study Subjects

We searched the electronic database of our institution and identified 261 consecutive patients from 15 to 40 years of age who had visited our Emergency Department and had then undergone abdominal CT for suspected acute appendicitis between November 2008 and April 2009 (Fig 1). Four of these patients were later excluded as they had been lost to follow-up. The remaining 257 patients (mean age, 27.6 years ± 7.5 [standard deviation])—111 male patients (mean age, 27.7 years ± 8.1) and 146 female patients (mean age, 27.5 years ± 7.1)—were ultimately included in the analyses. Of these 257 patients, 132 underwent standard-dose CT between November 2008 and January 2009 (standard-dose CT group), while the remaining 125 patients underwent low-dose CT between February 2009 and April 2009 (low-dose CT group) (Fig 1).

Body mass index (BMI) was calculated from the available data in the patients' medical records. Patients were categorized according to BMI into one of three groups: underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), and overweight to extremely obese (≥25 kg/m^2) (16).

CT Protocols

CT examinations were performed by using a 16–detector row (n = 253) or a 64–detector row (n = 4) CT scanner (Brilliance; Philips Medical Systems, Cleveland, Ohio). We did not use enteric contrast material, as the need for enteric contrast material is questionable according to recent studies (17,18). All patients were placed in the supine position and were scanned from the diaphragm to the symphysis pubis.

Before February 2009, our standard radiation dose for abdominal CT to evaluate appendicitis was set as approximately 8–10 mSv per study, similar to the reference values often quoted (19,20). In early February 2009, with greater awareness of the cancer risk from CT radiation according to recent publications (21), we lowered the radiation dose to approximately 2 mSv. The new CT

Published online before print
10.1148/radiol.11102247 **Content code:** GI

Radiology 2011; 260:437–445

Abbreviations:
BMI = body mass index
CI = confidence interval
ROC = receiver operating characteristic

Author contributions:
Guarantors of integrity of entire study, S.Y.K., S.H., J.E.R.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, S.Y.K., K.H.L., T.Y.K., H.S.L., H.S.K., Y.H.K., J.E.R.; clinical studies, S.Y.K., K.H.L., K.K., T.Y.K., H.S.L., K.J.S., Y.H.K., J.E.R.; statistical analysis, S.Y.K., K.H.L., S.H., K.J.S.; and manuscript editing, S.Y.K., K.H.L., K.K., H.S.K., J.E.R.

Potential conflicts of interest are listed at the end of this article.

protocol with the reduced radiation dose was used in patients from 15 to 40 years of age, for whom the long-term risks of radiation are more relevant. This "low" radiation dose was empirically determined on the basis of experience to depict the inflamed (12) or normal (22) appendix with a reduced tube current. This change was approved by our CT protocol committee after discussion by abdominal radiologists, on-call radiologists, referring physicians, and surgeons.

The effective tube current–time product generally ranged between 25–40 mAs and 110–200 mAs for the low- and standard-dose CT studies, respectively. The actual radiation dose was adjusted according to the patient's body size and body shape by automatically modulating the tube current (Dose-Right; Philips Medical Systems). The modulated radiation dose was recorded in terms of dose-length product. The other parameters were identical for the two groups: tube voltage was 120 kVp; collimation, 16 × 1.5 mm (for 16–detector row CT) or 64 × 0.625 mm (for 64–detector row CT); rotation speed, 0.5 second; and pitch, 1.25 (16–detector row CT) or 0.891 (64–detector row CT). Patients were given 2 mL iopromide (Ultravist 370; Schering, Berlin, Germany) per kilogram of body weight intravenously at a rate of 3 mL/sec via the antecubital vein, and scanning was initiated 60 seconds after the enhancement of the descending aorta reached 150 HU. From each helical scan, two transverse image data sets were reconstructed with different section thicknesses—that is, thick (5-mm) and thin (2-mm) sections. The technical advantages of this two-tier (thick and thin) image reconstruction method have been previously described (23).

Radiologists

The CT images were prospectively interpreted as a part of daily clinical practice. During the daytime, CT reports were initially made and then immediately verified by one of two abdominal radiologists (K.H.L and S.Y.K.) with 8 and 4 years of clinical experience in abdominal CT, respectively. CT examinations performed after hours were given

Figure 1

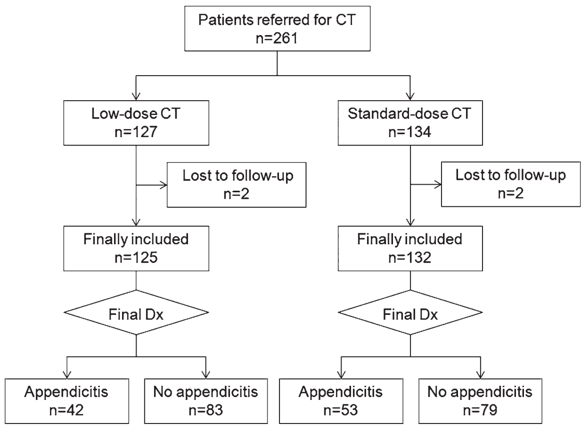

Figure 1: Flow diagram of study sample. *Dx* = diagnosis.

preliminary reports by on-call radiologists who had different levels of experience in abdominal CT. The preliminary report was reviewed the next morning by one of the two abdominal radiologists, who then added the final report. Any important changes in the reports were immediately conveyed to the referring physician. The interval between the preliminary and final reports did not exceed 15 hours. Hereafter, primary CT reports refer to the reports initially made by the two abdominal radiologists or the preliminary reports made by the nonabdominal radiologists, while final reports refer to reports verified or added by the two abdominal radiologists. The reports initially made by one of the two abdominal radiologists served as final reports in our practice and therefore were analyzed as both primary and final reports in our study.

We analyzed both primary and final reports separately as we considered that each analysis can represent different facets of our practice according to the availability of experienced radiologists. Because the abdominal radiologists were not always available around the clock, some of the addendum final reports might have been made after patient disposition in regard to surgery. Even in the cases in which the addendum report had clearly been made before patient disposition, it was difficult to objectively determine how the addendum report may have altered or consolidated the clinical decision regarding patient disposition. Therefore, the analysis of the final reports would overestimate our actual diagnostic performance to some extent, while the analysis of the primary reports was considered to underestimate our actual diagnostic performance to some extent.

Interpretation of CT Images

The radiologists reviewed the thick transverse sections on a picture archiving and communication system workstation (DS3000, Impax version 4.5; Agfa Healthcare, Mortsel, Belgium). Whenever they were not totally confident in their interpretation, they also reviewed the thin sections by using the sliding slab averaging technique (AquariusNET; TeraRecon, San Mateo, Calif), which is a real-time image postprocessing system available with most commercial CT reviewing workstations. This technique can enhance the depiction of a normal (22) or diseased appendix (12,24,25) by taking full advantage of the capability of modern thin-section CT scanners. Importantly, the technique reduces the noise on the image that is finally displayed by averaging the pixel values within the slab, particularly in grainy low-dose CT images. The technical details and usefulness of this technique have been described in a previous study (26).

The CT reports were made in the predefined structured format (Table 1) that we have been routinely using since March 2004 in patients suspected of having appendicitis. We had introduced the structured report to improve the clinical process by standardizing the reporting

Table 1

Structured CT Report for Patients Suspected of Having Acute Appendicitis

Analyzed Finding and Rating	Description
Confidence score for appendicitis*†‡	
1	Definitely absent
2	Probably absent
3	Indeterminate
4	Probably present
5	Definitely present
Visualization of appendix	
0	Not identified
1	Unsure or partly visualized
2	Clearly and entirely visualized
Likelihood of appendiceal perforation§	
0	Absent
1	Present

* Analyzed in both primary and final reports. Other findings were analyzed only in final reports.

† The primary diagnostic criteria for appendicitis included visualization of enlarged appendix (≥6 mm in diameter), appendiceal wall thickening, appendiceal wall hyperenhancement, and periappendiceal fat stranding. Secondary diagnostic criteria included the presence of an appendicolith, inflammatory mass, and/or abscess.

‡ For cases in which the score for the diagnosis of appendicitis was 3 or lower, radiologists could propose an alternative diagnosis that would explain the abdominal pain.

§ For cases in which the confidence score for the diagnosis of appendicitis was 3 or greater, the diagnosis of perforation was based on the presence of a periappendiceal abscess or phlegmon, extraluminal air, extraluminal appendicolith, or a defect in the enhancing appendiceal wall.

terms in a concise and unambiguous manner (27), since many radiologists and referring physicians and surgeons, including rotating residents, are involved in the communication of the CT results. In both the primary and final reports, the confidence score for the presence of appendicitis was rated on a five-point scale. The final reports also included additional findings—that is, appendiceal visualization, appendiceal perforation, and alternative diagnosis. Visualization of the appendix was rated on a three-point scale. In cases where the confidence score for appendicitis was 3 or greater, the presence or absence of appendiceal perforation was determined. In cases where the confidence score for appendicitis was 3 or lower, an alternative diagnosis that could explain the abdominal pain was proposed whenever possible.

Additional Imaging Testing

If the diagnosis of appendicitis was not determined with the initial CT study as well as clinical observation and blood laboratory tests, additional abdominal imaging test(s), such as ultrasonography (US), could be performed. We defined the additional imaging test as one performed within 48 hours of the initial CT examination to diagnose or rule out appendicitis.

Final Diagnosis

An emergency physician (K.K.) reviewed the medical records to establish the final diagnosis. In 104 patients who underwent surgery, the final diagnosis was based on surgical and pathologic findings (n = 103) or on surgical findings alone (n = 1). A histopathologic diagnosis of acute appendicitis was based on neutrophil infiltration in the appendiceal wall (28). The presence of appendiceal perforation was based on spillage of the appendiceal contents, peritonitis, or abscess observed during surgery or was pathologically confirmed as an appendiceal wall defect caused by transmural necrosis. In 153 of 157 patients who did not undergo surgery, the final diagnosis was based on the patient's medical records, as well as a telephone interview conducted at least 4 months after the patient's initial presentation. The remaining four patients were lost to follow-up at the time of the telephone interview. We excluded these four patients from the subsequent analyses, as their final diagnoses were considered to be unclear. Therefore, 257 patients with established final diagnoses were finally included in the analyses.

Statistical Analysis

The low- and standard-dose CT groups were compared for patient demographics and radiologist who made the primary report—that is, the two abdominal radiologists or other on-call radiologists.

Receiver operating characteristic (ROC) analysis was performed to compare the diagnostic performance in the diagnosis of appendicitis between the two dose groups. If we did not find a significant difference in the comparison of ROC curves between the two dose groups, we performed a post-hoc power analysis. The sensitivity and specificity in the diagnosis of appendicitis were compared between the two dose groups, with a decision threshold of a confidence score of 3 or greater considered as positive. This decision threshold was based on previous reports (29) that showed that appendicitis is actually present in up to 73% of patients with CT findings that were interpreted as equivocal. Multiple logistic regression analyses were performed to test the effect of patient sex, BMI, the radiologist who made the primary reports, and the radiation dose (low vs standard) on the correct diagnosis. Diagnostic confidence was compared in terms of the confidence score and the frequency of an inconclusive diagnosis (a score of 3). These analyses were performed for both the primary and final reports separately.

Additional analyses were performed for the final reports as follows: Appendiceal visualization was compared between both groups in terms of the visualization score and the frequency of nonvisualization of the appendix (a score of 0). In patients with confirmed appendicitis, the two dose groups were compared for the sensitivity and specificity in the diagnosis of appendiceal perforation. In patients with established alternative diagnoses, the sensitivity of CT in helping propose such alternative diagnoses was compared between the two dose groups.

The two dose groups were compared for the number of patients who needed the additional imaging tests to diagnose or rule out appendicitis. In patients who were confirmed as having acute appendicitis, the time interval from CT examination to surgery was compared between the two dose groups. Finally, the two groups were compared regarding the negative appendectomy rate and the appendiceal perforation rate (30,31). These are two important reciprocal measures of the clinical outcome of a diagnostic system, as they represent false-positive diagnoses and delayed diagnoses, respectively. A negative appendectomy rate was defined as the percentage of unnecessary appendectomies among all of the nonincidental appendectomies. The appendiceal perforation rate was defined as the percentage of cases of perforated appendicitis among all confirmed cases of appendicitis.

Fisher exact tests were performed to compare the nominal variables, and Mann-Whitney *U* tests were performed to compare the ordinal variables between the two dose groups by using software (MedCalc, version 9.30, Mariakerke, Belgium; GraphPad InStat, version 3.05, San Diego, Calif). Clopper-Pearson 95% confidence intervals (CIs) were calculated. For all statistical analyses, $P < .05$ was considered to indicate a significant difference.

Table 2

Patient Demographic Characteristics

Characteristic	Low-Dose Group (n = 125)	Standard-Dose Group (n = 132)	P Value
Male-to-female ratio	55:70	56:76	.80
Age (y)*	26.8 ± 7.5	28.3 ± 7.6	.11
Male patients	26.6 ± 7.9	28.8 ± 8.2	.76
Female patients	27.0 ± 7.2	28.0 ± 7.1	.75
BMI			.13
Underweight (<18.5 kg/m^2)	23	17	
Normal (18.5–24.9 kg/m^2)	84	84	
Overweight to extremely obese (≥25 kg/m^2)	18	31	

Note.—Unless otherwise specified, data are numbers of patients.

* Data are means ± standard deviations.

Results

Patient Characteristics

There was no significant difference between the two groups in terms of age, sex, or BMI (Table 2). The median dose-length product was 122 mGy · cm (range, 76–145 mGy · cm; interquartile range, 118–126 mGy · cm) in the low-dose CT group and 544 mGy · cm (range, 303–672 mGy · cm; interquartile range, 518–578 mGy · cm) in the standard-dose CT group.

Radiologists

In 55 (44%) of the 125 low-dose CT examinations and 44 (33%) of the 132 standard-dose CT examinations (P = .10), one of the two abdominal radiologists made primary reports that also served as final reports. For the remaining 70 low- and 88 standard-dose CT examinations, primary reports were made by non–abdominal radiologists, including eight attending radiologists with 3–10 years of experience after board certification (n = 74), three fellows with 1–5 years of experience after board certification (n = 3), and 17 3rd-year residents (n = 81); the two abdominal radiologists then added final reports.

Additional Imaging Testing

One of the 125 patients (0.8%) in the low-dose CT group and one of the 132 patients (0.8%) in the standard-dose CT group needed additional US to diagnose or rule out appendicitis ($P > .99$). Both patients were confirmed as not having appendicitis. There was no patient who needed repeat CT examination.

Final Diagnosis

Appendicitis was pathologically confirmed in 95 (37%) of the 257 patients ultimately included in our study, including 42 patients in the low-dose CT group and 53 patients in the standard-dose CT group (P = .30). The mean time interval from CT examination to surgery was slightly but not significantly greater in the low-dose CT group (8.5 hours ± 5.9 [standard deviation], n = 42) than in the standard-dose CT group (7.2 hours ± 5.0, n = 53) (P = .42). The remaining 162 patients were confirmed as not having appendicitis on the basis of surgical and pathologic findings (n = 8), surgical findings alone (n = 1), or medical records and a telephone interview (n = 153). Telephone interviews confirmed that none of the patients underwent appendectomy at other hospitals during the follow-up period of 4–8 months (Fig 1).

Of the 162 patients without appendicitis, 66 were considered to have an alternative diagnosis explaining the cause of the abdominal pain on the basis of various diagnostic techniques (Table 3). The sensitivity in proposing such an alternative diagnosis did not differ significantly between the low-dose (80% [24 of 30]) and standard-dose (81% [29 of 36]) groups ($P > .99$). The remaining 96 patients were regarded as having nonspecific abdominal pain, as their symptoms were not explained by using any diagnostic test and resolved without specific treatment.

Diagnostic Performance of CT for Appendicitis

In the primary reports, the values of the areas under the ROC curves for low- and standard-dose CT were 0.96 and 0.97, respectively (P = .76) (Fig 2). In the post-hoc power analysis, the power to detect a difference in ROC analysis was 6.1% for primary reports. With a decision threshold of a score of 3 or greater as positive, the diagnostic sensitivity of the low-dose group versus

Table 3

Alternative Diagnoses

Definite Diagnosis	Diagnostic Technique for Definite Diagnosis	Low-Dose Group		Standard-Dose Group	
		Suggested Diagnosis*	Definite Diagnosis†	Suggested Diagnosis*	Definite Diagnosis†
Complicated ovarian cyst	CT, US, normal findings at follow-up US, surgery	7	7	9	9
Enterocolitis	CT, laboratory results, relief of symptoms after treatment	1	4	5	10
Right colon diverticulitis	CT, relief of pain after treatment	6	6	9	9
Pelvic inflammatory disease	History, pelvic examination, vaginal smear, relief of pain after treatment, surgery	1	3	2	4
Ureter stone	CT, calculi excretion	3	3	1	1
Acute pyelonephritis	Urine analysis, urine culture	0	1	1	1
Epiploic appendagitis	CT, relief of pain after conservative management	2	2	0	0
Crohn disease	CT, colonoscopy, surgery	2	2	0	0
Peptic ulcer perforation	CT, surgery	1	1	0	0
Adhesive ileus	CT, follow-up radiography, relief of pain after conservative management	1	1	1	1
Meckel diverticulum	Surgery	0	0	1	1
Total		24	30	29	36

Note.—Data are numbers of patients.

* Suggested at CT.

† Based on various diagnostic techniques.

the standard-dose group was 90% (38 of 42) versus 89% (47 of 53) ($P > .99$), and the specificity was 92% (76 of 83) versus 94% (74 of 79) ($P = .74$). In the final reports, the values of the area under the ROC curves for low- and standard-dose CT were 0.98 and 1.00, respectively ($P = .27$). In the post-hoc power analysis, the power to detect a difference in ROC analysis was 28.3% for final reports. The sensitivity of the low-dose group versus the standard-dose group was 98% (41 of 42) versus 98% (52 of 53) ($P > .99$), and the specificity was 93% (77 of 83) versus 91% (72 of 79) ($P = .78$) (Table 4). The P value for the overall fit of the multiple logistic regression model was .78 for the primary reports and .83 for the final reports, thereby suggesting that none of the tested variables, including patient sex, BMI, radiologist, and radiation dose, affected the correct diagnosis.

Figure 2

Figure 2: Transverse 5-mm-thick intravenous contrast material–enhanced low-dose CT image in 29-year-old man who was confirmed to have acute appendicitis. The BMI was 23.3 kg/m^2. The dose-length product was 130 mGy · cm. Image shows enlarged appendix with wall thickening, wall hyperenhancement, and surrounding fat strand, suggesting appendicitis (arrows). *C* and *tl* = cecum and terminal ileum, respectively. Both the primary report by an on-call radiologist (3rd-year resident) and the final report by an abdominal radiologist assigned a score of 5 (definitely present) for the diagnosis of appendicitis.

Diagnostic Confidence

The low- and standard-dose CT groups did not differ in terms of the radiologists' confidence in diagnosing appendicitis in both the primary (median score, 5 vs 5; $P = .71$) and final (median score, 5 vs 5; $P = .56$) reports. The two groups did not differ in terms of the radiologists' confidence in excluding appendicitis in both the primary (median score, 1 vs 1; $P = .20$) and final (median score, 1 vs 1; $P = .30$) reports (Table 5). There was no significant difference in the frequency of an inconclusive diagnosis (a score of 3) between the two groups—5.6% (seven of 125) versus 6.1% (eight of 132) in the primary reports ($P > .99$), and 6.4% (eight of 125) versus 7.6% (10 of 132) in the final reports ($P = .81$).

Appendiceal Visualization

For the 162 patients confirmed as not having appendicitis, the two groups did not differ in the appendiceal visualization score (median score, 2 vs 2; $P = .12$) (Table 6). The appendix was not identified (a score of 0) in six (4.8% of the

Table 4

Diagnostic Performance of Low-Dose and Standard-Dose CT

	Primary Reports			Final Reports		
Parameter	Low-Dose CT	Standard-Dose CT	*P* Value	Low-Dose CT	Standard-Dose CT	*P* Value
Area under ROC curve	0.96 (0.90, 0.98)	0.97 (0.92, 0.99)	.76	0.98 (0.93, 1.00)	1.00 (0.96, 1.00)	.27
Scores of 3 or greater as positive for the diagnosis						
No. of true-positive findings	38	47		41	52	
No. of false-positive findings	7	5		6	7	
No. of true-negative findings	76	74		77	72	
No. of false-negative findings	4	6		1	1	
Sensitivity (%)	90 (77, 97)	89 (77, 96)	>.99	98 (87, 100)	98 (90, 100)	>.99
Specificity (%)	92 (83, 97)	94 (86, 98)	.74	93 (85, 97)	91 (83, 96)	.78
PPV (%)	84 (71, 94)	90 (79, 99)	.54	87 (74, 95)	88 (77, 95)	>.99
NPV (%)	95 (88, 99)	93 (84, 97)	.75	99 (93, 100)	99 (93, 100)	>.99

Note.—Data in parentheses are 95% CIs. NPV = negative predictive value, PPV = positive predictive value.

Table 5

Confidence Scores for Diagnosis or Exclusion of Appendicitis

Group and Diagnostic Confidence Score	Primary Reports: Low-Dose CT	Primary Reports: Standard-Dose CT	Final Reports: Low-Dose CT	Final Reports: Standard-Dose CT
Patients with appendicitis				
1	1 (2.4)	2 (3.8)	1 (2.4)	0
2	3 (7.1)	4 (7.5)	0	1 (1.9)
3	2 (4.8)	3 (5.7)	3 (7.1)	3 (5.7)
4	9 (21)	7 (13)	6 (14)	5 (9.4)
5	27 (64)	37 (70)	32 (76)	44 (83)
Patients without appendicitis				
1	59 (71)	63 (80)	66 (80)	71 (90)
2	17 (21)	11 (14)	11 (13)	1 (1.3)
3	5 (6.0)	5 (6.3)	5 (6.0)	7 (8.9)
4	0	0	0	0
5	2 (2.4)	0	1 (1.2)	0

Note.—Data are numbers of patients, with percentages in parentheses. Percentages may not add up to 100% because of rounding.

Table 6

Visualization Scores for Appendix

Group and Visualization Score	Low-Dose CT	Standard-Dose CT
Patients with appendicitis		
0	0	0
1	4 (9.5)	0
2	38 (91)	53 (100)
Patients without appendicitis		
0	6 (7.2)	2 (2.5)
1	13 (16)	5 (6.3)
2	64 (77)	72 (91)

Note.—Data are numbers of patients, with percentages in parentheses. Percentages may not add up to 100% because of rounding.

125 patients in the low-dose CT group and in two (1.5%) of the 132 patients in the standard-dose CT group (P = .16). None of the patients whose appendix was not identified was confirmed to have appendicitis.

Diagnosis of Appendiceal Perforation

Appendiceal perforation occurred in 14 patients in the low-dose CT group and seven in the standard-dose CT group. The low- and standard-dose CT groups showed sensitivities of 50% (seven of 14) versus 71% (five of seven) (P = .64) and specificities of 78% (21 of 27) versus 80% (36 of 45) (P > .99) for the diagnosis of appendiceal perforation. These calculations include 93 of the 95 patients confirmed as having appendicitis. In the remaining two patients—one in the low-dose group and the other in the standard-dose group—the presence of appendiceal perforation was not determined in the CT reports, as the diagnosis of appendicitis in the final report was a false-negative result.

Negative Appendectomy Rate and Appendiceal Perforation Rate

A total of 103 appendectomies were performed in our study patients. Five patients (three in the low-dose CT group and two in the standard-dose CT group) underwent incidental appendectomy combined with another surgical procedure for the treatment of other diseases. Of the remaining 98 nonincidental appendectomies, three (two in the low-dose group and one in the standard-dose group) yielded negative pathologic results for appendicitis. Therefore, the negative appendectomy rate was 4.5% (two of 44 [95% CI: 0.6%, 15.5%]) and 1.9% (one of 54 [95% CI: 0.1%, 9.9%]) in the low- and standard-dose groups, respectively (P = .59).

The appendiceal perforation rate was significantly higher in the low-dose group at 33% (14 of 42 [95% CI: 20%, 50%]) than in the standard-dose group at 13% (seven of 53 [95% CI: 6%, 25%]) (P = .03).

Discussion

In our results, the two groups, who underwent intravenous contrast-enhanced CT performed by using either a low radiation dose or our previous standard radiation dose, did not significantly differ in terms of the diagnostic performance for appendicitis in young adults. Our diagnostic sensitivity and specificity in the two groups were comparable to those (sensitivity of 91% [95% CI: 84%, 95%] and specificity of 90% [95% CI: 85%, 94%]) reported in a recent meta-analysis (6) of studies in which CT was performed with a radiation dose similar to our standard dose. In addition, the two CT techniques did not differ in the radiologists' diagnostic confidence in the diagnosis or exclusion of appendicitis, appendiceal visualization, and sensitivity for suggesting an alternative diagnosis.

The median dose-length product in the low-dose group (122 mGy · cm) was less than one-fourth that in the standard-dose group (544 mGy · cm). Using a very simplified approach with a conversion factor of 0.015 mSv · mGy^{-1} · cm^{-1} (32), the median dose-length products in the two groups correspond to effective doses of 1.8 mSv and 8.2 mSv, respectively. These doses can be compared with the effective dose of abdominal radiographs of approximately 0.7 mSv (20), as well as with the average annual effective dose from background radiation of approximately 3.1 mSv in the United States (33), although these effective doses cannot precisely project the excess carcinogenic risk in our patients with ages limited to 15–40 years.

As with any other imaging study involving x-rays, the radiation dose for CT in the diagnosis of appendicitis should be optimized following the "as low as reasonably achievable" principle. The results of present and previous studies (11–14,22) suggest that CT scanning protocols in many medical centers, as shown in a survey (34), are likely to deliver radiation greater than that required. We believe that a low-radiation-dose technique such as ours has the potential to become the first-line imaging test for young adults suspected of having acute appendicitis.

In addition to the radiologic measures of diagnostic performance, we assessed the negative appendectomy rate, as well as the appendiceal perforation rate. However, as shown by the wide range of 95% CIs, our study is limited in terms of sample size, particularly for the two clinical outcomes that have been measured with greater precision in previous studies (35,36). In our results, while the negative appendectomy rate did not differ significantly between the two groups (4.5% vs 1.9%), the appendiceal perforation rate was higher in the low-dose group than in the standard-dose group (33% vs 13%). The difference in appendiceal perforation rate may be partly attributable to the observed (although nonsignificant) difference in the mean time interval from CT examination to surgery between the two groups. Nevertheless, the significant difference in the appendiceal perforation rate should not necessarily lead to a conclusion not in favor of the clinical usefulness of the low-dose CT technique, as appendiceal perforation can be associated with many other factors, including disease severity at the time of presentation and nonmedical factors delaying treatment (8,37), neither of which we assessed or controlled in the two groups.

Our study had limitations. First, it should be noted again that our study was limited in terms of sample size. Although we did not observe a significant difference between the two groups, concerns remain regarding type II error, which was seen as a low power in our study to detect a difference in ROC analyses. However, the low power should be interpreted cautiously, as retrospectively calculated power always corresponds to observed P value and rarely changes the interpretation of our observations (38,39). Instead, the considerable overlaps in 95% CIs of the areas under the ROC curves between the two groups imply that the two CT techniques may be virtually comparable in the diagnostic performance. A larger randomized controlled trial, ideally with a noninferiority design and with clinical outcome end points such as the negative appendectomy rate and appendiceal perforation rate, will be needed to establish low-dose radiation CT as the first-line imaging test in patients suspected of having acute appendicitis. Second, the nature of the single-institution, retrospective study design limits the ability to generalize our results. A majority of our patients were examined with a single type of CT scanner. Although the primary reports were made by multiple radiologists with different levels of clinical experience, all of the final reports were made by the two abdominal radiologists who were motivated in introducing the low-dose CT technique. We did not measure interobserver variability, as we retrospectively reviewed the original CT reports rather than having retrospective interpretation of the CT images performed by several radiologists. We chose to use the former rather than the latter study design as we believed it would better reflect clinical practice.

In conclusion, intravenous contrast-enhanced CT performed by using a low radiation dose may have diagnostic performance comparable to that of standard-radiation dose CT in the diagnosis of appendicitis in young adults. A larger randomized controlled trial measuring clinical outcomes is warranted to establish low-dose radiation CT as the first-line imaging test in young adults suspected of having acute appendicitis.

Acknowledgment: The authors thank Bonnie Hami, MA, for editorial assistance in preparing the manuscript.

Disclosures of Potential Conflicts of Interest: **S.Y.K.** No potential conflicts of interest to disclose. **K.H.L.** No potential conflicts of interest to disclose. **K.K.** No potential conflicts of interest to disclose. **T.Y.K.** No potential conflicts of interest to disclose. **H.S.L.** No potential conflicts of interest to disclose. **S.H.** No potential conflicts of interest to disclose. **K.J.S.** No potential conflicts of interest to disclose. **H.S.K.** No potential conflicts of interest to disclose. **Y.H.K.** No potential conflicts of interest to disclose. **J.E.R.** No potential conflicts of interest to disclose.

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