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Comparison of Conventional and Simulated Reduced–Tube Current MDCT for Evaluation of Suspected Appendicitis in the Pediatric Population

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Abstract

OBJECTIVE—The purpose of this study was to compare CT with conventional and simulated reduced–tube current in the evaluation for acute appendicitis in children.

MATERIALS AND METHODS—Validated noise-addition (tube current–reduction) software was used to create 50% and 75% tube current reductions in 60 CT examinations performed for suspected appendicitis, resulting in 180 image sets. Three blinded pediatric radiologists scored the randomized studies for the following factors: presence of the normal appendix or appendicitis (5-point scale; 1 = definitely absent and 5 = definitely present), presence of alternate diagnoses, and overall image quality (1 = nondiagnostic and 5 = excellent). Truth was defined by the interpretation of the conventional examination.

RESULTS—For conventional examinations, the total number of reviews (60 cases × 3 readers = 180) in which the normal appendix was identified was 120 of 180 (66.7%), compared with 108 of 180 (60%) in the 50% ($p = 0.19$) and 91 of 180 (50.6%) in the 75% ($p = 0.002$) tube current–reduction groups. Appendicitis was identified in a total of 39 of 180 (21.7%), 38 of 180 (21.1%), and 37 of 180 (20.6%) examinations, respectively ($p > 0.05$). This translates to sensitivities of 97% and 95% for the 50% and 75% tube current–reduction groups, respectively. Alternate diagnoses were detected in 14%, 16%, and 13% of scans, respectively. Compared with conventional–tube current examinations, reader confidence and assessment of image quality were significantly decreased for both tube current–reduction groups.

CONCLUSION—Simulated tube current–reduction technology provides for systematic evaluation of diagnostic thresholds. Application of this technology in the setting of suspected

appendicitis shows that tube current can be reduced by at least 50% without significantly affecting diagnostic quality, despite a decrease in reader confidence and assessment of image quality.

Keywords

appendicitis; CT; radiation dose

Appendicitis is a common disorder, especially among children, with a cumulative lifetime incidence approaching 7% [1]. The use of CT in evaluating for acute appendicitis has increased substantially over the last decade, resulting in a decrease in the rate of negative appendectomy [2]. However, radiation and potential cancer risk from CT has been a topic in both the lay press and the medical literature [3, 4]. Although radiation and risks from levels of radiation seen with CT in children have been discussed [5], support for better overall diagnostic performance of CT compared with sonography can be found, including identification of a normal appendix and periappendiceal inflammation and detection of diagnoses other than appendicitis that may account for the patient's clinical presentation [3, 6]. This diagnostic performance may partly underlie the observation that CT use increased by fivefold in emergency settings from 1995 to 2008 [7].

Because of the increasing radiation exposure from CT in acute abdominal presentations in children, it would be worthwhile to assess the diagnostic impact of CT radiation dose reduction in the setting of appendicitis. One way to reduce radiation is to reduce tube current. However, serial evaluations using reduced-tube current scanning in an acute setting in the same child would be extremely problematic to justify as a research method. One method that obviates serial scanning is simulated tube current reduction through the addition of noise [8]. This type of technology has been previously applied to pediatric appendicitis by Fefferman and colleagues [9], but those investigators were not able to provide threshold recommendations because the chosen level of simulated tube current resulted in insufficient diagnostic quality. Therefore, guidelines for a threshold of radiation exposure necessary to obtain a diagnostic-quality image in children in the setting of the acute abdomen have not been determined.

To the best of our knowledge, there has not been a systematic investigation of CT and pediatric appendicitis that assesses incremental increases in image noise to determine diagnostic thresholds. Therefore, the purpose of our study was to compare the diagnostic yield and reader confidence of a range of reduced-tube current CT images with conventional-tube current images in the evaluation of possible acute appendicitis in children.

Materials and Methods

Patient Selection

This study was HIPAA compliant and was approved by our institutional review board with a waiver of informed consent. We retrospectively identified cases from patients 18 years old or younger who had undergone conventional abdominal and pelvic 64-MDCT for the

workup of appendicitis at a tertiary care children's hospital between October 2005 and March 2007. A total of 60 cases (21 boys and 39 girls) met entry criteria and were included.

CT Technique

Examinations were performed on a 64-MDCT scanner (VCT, GE Healthcare) using clinical weight-based color-coded protocols (now accredited by the American College of Radiology). The range of parameters for the scans were as follows (ranges are for younger and smaller to older and larger patients): pitch, 0.984–1.375; gantry cycle time, 0.4 second; slice thickness, 3.75–5.0 mm; tube current, 42.5–65 mA ceiling; tube current modulation, 6.5–14 noise index values; and tube voltage, 120–140 kVp. Protocols called for use of a small bowtie filter or a large bowtie filter, according to the diameter of the patient, and an effective beam width of 40×0.625 mm. The dose indexes (volume CT dose index, 32 cm) for our protocols are in the range of 3.0–3.6 mGy for infants, 4.5–6.0 mGy for children, and 5.2–8.2 mGy for early second decade of life [10], all well below maximums for American College of Radiology CT accreditation. Further details regarding imaging protocols used at our institution during the study period are described elsewhere [11]. The scan range in all cases was from the lung base to just below the pubic symphysis. Scans were performed during the portal venous phase of enhancement after the IV administration of iodinated contrast media; when a delayed phase was performed at the discretion of the supervising radiologist (resident, fellow, or attending physician) at the time of the original scan, these additional series were not included for evaluation. The need for delayed imaging in the setting of appendicitis occurs less than 2% of the time at our institution.

Size-based doses of both oral and IV contrast media are routine. The dose of IV contrast material is 2.0 mL/kg up to an adult dose used at the time of the study of 150 mL. The protocol calls for power injection of IV contrast agent at 2.0–4.0 mL/s depending on the gauge of the IV catheter and the age of the child, with an option to use a manual injection. These options were left up to the discretion of a dedicated radiology nursing staff. Rectal contrast agent administration is not in the routine protocol and was not used in any case.

Pilot Study

We chose not to include a 25% tube current–reduction series that was also created because prior work indicated that this amount of tube current reduction did not result in significant changes in diagnostic capability. The three readers (see qualifications later in this section) were asked to review the conventional and 25% tube current–reduction scans for four separate cases and to complete 5-point Likert scales (detailed later in this section) assessing the presence or absence of appendicitis, as well as reader subjective assessment of image quality. There was no difference in performance (or subjective assessment of image quality) for the conventional and 25% tube current–reduction groups. As such, to improve the efficiency of the observer study, only the conventional, 50%, and 75% tube current–reduction scans were used for interpretation.

CT Image Simulation

Validated (prior work assured reliable noise amount as well as noise texture) proprietary noise-addition software (Noise Addition Tool version 3.5, GE Healthcare) was used to

simulate reduced-tube current images for each of the original cases. The use of this noise-addition tool allows the assessment of multiple tube current levels without having to scan a given patient more than once. The simulation technique and validation studies are described in detail elsewhere [8, 12]. In brief, the software works by adding noise to transaxial image data, thereby simulating how each slice would appear had the scan been obtained at a lower tube current. This technology cannot be applied to coronal reconstructions, which are currently a routine part of clinical evaluation at our institution.

The software allows the user to choose between three different parameters for simulation: a specific tube current value, a specific percentage reduction in tube current, or a specific noise index. For this study, we opted to simulate the scans using a specific percentage reduction in tube current. We thought that this option was most appropriate given that the CT examinations used in this study were obtained using automatic tube current modulation, a technique that often results in a range of tube current values within one patient scan. The tube current achieved for each axial image in the patient's dataset were all individually reduced by 50% and then by 75%. By simulating a specific percentage reduction in tube current, the unique modulation of tube current was maintained for each examination despite simulated tube current reduction.

Using this software, noise was added to each of the 60 original ("conventional") scans to simulate 60 additional scans at 50% tube current reduction and another 60 at 75% tube current reduction, yielding a total of 180 image sets. To ensure accurate 50% and 75% tube current-reduction simulations, we verified ROI noise measurements on a subset of examinations using the methods represented in Figure 1. We then calibrated the tool so that ROI noise measurements were consistent with predicted values for a given percentage tube current reduction. The original and simulated examinations were then sent to a research PACS station under standard clinical reading conditions.

CT Image Review

Each of the 180 image sets (60 conventional, 60 with 50% tube current reduction, and 60 with 75% tube current reduction) was interpreted independently by three fellowship-trained radiologists, all with current American Board of Radiology subspecialty certification in pediatric radiology and 8–17 years of attending experience. All examinations were reviewed in an identical setting, including lighting on a standard diagnostic-quality PACS, including the monitor. The images at the three tube current settings were viewed randomly, and the readers were blinded to all technical parameters. All standard PACS image review tools were available and used at the discretion of the radiologists. The readers were aware that the scans were obtained in the workup of possible appendicitis, but they were blinded to the original interpretation, other clinical information, and results obtained from other radiology studies or laboratory tests. There were no time limits for viewing a study, but readers were instructed to approximate the time used for interpretation of an abdominal and pelvic CT in the clinical setting. All scans were interpreted over a 2-month period.

For each image set, readers completed a one-page score sheet, modeled after score sheets used in similar tube current-reduction studies performed at our institution. The score sheet begins with a series of yes-or-no questions related to the presence of oral and IV contrast

agent, as well as whether the oral contrast agent filled the bowel in the region of the appendix. The readers were also asked whether they could identify the appendix and, if so, whether it appeared normal. If the readers indicated that the appendix did not appear normal, they were asked to evaluate for a number of specific signs associated with acute appendicitis: mural enhancement, mural thickening, thickened or distended appendix (> 6 mm), presence of appendicolith, extraappendiceal inflammatory changes, fat stranding, extraluminal gas, focal fluid collection, cecal or colonic wall thickening or inflammation, and presence of small-bowel obstruction. Each of these features was given a score on a modified 5-point Likert scale (1 = definitely absent, 2 = probably absent, 3 = uncertain, 4 = probably present, and 5 = definitely present). In addition, if applicable, readers were asked to record the greatest diameter of the abnormally distended appendix and the number of appendicoliths present.

Next, the readers completed a separate 5-point Likert scale to assess their confidence in the presence or absence of appendicitis (1 = definitely absent, 2 = probably absent, 3 = uncertain, 4 = probably present, and 5 = definitely present). Two additional 5-point scales were completed; the first assessed the overall study quality in terms of noise, and the second assessed overall study quality independent of noise (1 = nondiagnostic, 3 = good, and 5 = excellent). If the latter variable was scored as a 3 or less, readers were asked to identify factors other than noise (e.g., patient motion, inadequate contrast agent, and streak artifact) that may have compromised the quality of the examination. Finally, readers were asked to list alternate diagnoses that could account for abdominal pain or otherwise have clinical importance.

Statistical Analysis

For each of the tube current–reduction groups, identification of a normal appendix was calculated as a frequency because readers' scores for this variable were binary (1 = normal appendix identified and 0 = normal appendix not identified). The frequency of diagnosis of appendicitis was calculated similarly, though reader scores were collapsed from a 5-point Likert scale to a binary score; scans given the scores 4 (probably present) or 5 (definitely present) for appendicitis were counted as positive, all others were considered negative. Once calculated, these frequencies were compared between the conventional and each tube current–reduction group using the Wilcoxon signed-rank test.

For all other scored variables, the 5-point Likert scale scores for the three readers were combined and averaged. Wilcoxon signed-rank tests were used to compare the mean for each scored variable of the simulated reduced–tube current scans with the conventional–tube current scan to determine the threshold tube current reduction at which the variables became significantly different. In addition, interreader agreement (as measured by the Cohen kappa statistic [13]) was assessed across the five potential categories on the Likert scale for the presence or absence of appendicitis (1 = definitely absent, 2 = probably absent, 3 = uncertain, 4 = probably present, and 5 = definitely present). A kappa value of less than 0.2 signified poor agreement, 0.21–0.40 indicated fair agreement, 0.41–0.60 indicated moderate agreement, 0.61–0.80 indicated good agreement, and 0.81–1.00 indicated excellent

agreement. For all analyses, statistical significance was set at p less than 0.05. Statistical software was used (SAS version 9.2, SAS Institute).

Results

Visualization of Normal Appendix

For each tube current level, the percentages of cases in which the normal appendix was identified are represented in Table 1. For the conventional–tube current group (reference standard), the normal appendix was identified in 120 of 180 reviews (60 studies $\times$ 3 readers = 180) for a mean of 40 of 60 (66.7%). This is compared with 108 of 180 reviews for the 50% tube current–reduction group (mean, 36/60 [60%]; $p = 0.19$), and 91 of 180 reviews for the 75% tube current–reduction group (mean, 30.33/60 [50.6%]; $p = 0.002$). Figure 2 illustrates how a single axial slice from one of the normal cases appeared at the three tube current levels.

Diagnosis of Appendicitis

The rates of detection of appendicitis are summarized in Table 2. Scans given the scores of 4 (probably present) or 5 (definitely present) for appendicitis were counted as positive. For the conventional–tube current group (reference standard), appendicitis was identified in 39 of 180 reviews, for a mean of 13 of 60 (21.7%). This is compared with 38 of 180 reviews for the 50% tube current–reduction group (mean, 12.66/60 [21.1%]; $p = 0.89$), and 37 of 180 reviews for the 75% tube current–reduction group (mean, 12.33/60 [20.6%]; $p = 0.80$). There were no significant differences. On the basis of these data, appendicitis was detected with 97% sensitivity in the 50% tube current–reduction group and 95% sensitivity in the 75% tube current–reduction group. There were no false-positives, and, therefore, specificity was fixed. Figure 3 illustrates how a single axial slice for a positive appendicitis case appeared at all three tube current levels.

Radiographic Signs of Acute Appendicitis

For the 21.7% of conventional–tube current cases identified as positive for acute appendicitis, the two tube current–reduction groups were compared with the conventional group in terms of average reader scores for the various signs of acute appendicitis. Table 3 shows the mean ($\pm$ SD) scores for the conventional and 50% tube current–reduction groups, as well as the p values calculated using the Wilcoxon signed-rank test. None of the comparisons between the scores for the conventional and 50% tube current–reduction group showed a statistically significant difference.

Also included in Table 3 are the mean scores for the conventional and 75% tube current–reduction groups. Four parameters (mural enhancement, mural thickening, fat stranding and cecal or colonic wall thickening or inflammation) were statistically different between the conventional and 75% tube current–reduction group. These four features are important in the diagnosis or exclusion of appendicitis, but they are often subtle and are expected to become less apparent with increased noise. In contrast, more obvious features such as small-bowel obstruction were easily identified even at 75% tube current reduction. It should be noted that only cases considered positive for acute appendicitis were analyzed, and the sample size

may not have been large enough to detect all differences in the rates of identification of certain features between the conventional and tube current–reduction groups.

Alternate Diagnoses

Of the 180 total cases interpreted by each reader (60 in each tube current category), alternate diagnoses were detected in 25 (14%) scans using conventional tube current, 29 (16%) scans using 50% tube current reduction, and 23 (13%) scans using 75% tube current reduction. The most common alternate diagnosis was adnexal cysts, followed by other genitourinary pathologic entities, subjective assessment of constipation, and colitis. Given that this study did not include chart review, these alternate diagnoses were not confirmed on follow-up. Further breakdown of each pathologic entity by reader and tube current-reduction group is shown in Table 4.

Reader Confidence

Reader confidence in diagnosing or excluding appendicitis was measured in terms of deviation from the indeterminate, which was defined as a score of 3 on the 5-point Likert scale for the presence of appendicitis. Higher tube current was generally associated with increased reader diagnostic confidence. The mean deviation from the indeterminate for the conventional–tube current group was 1.81 ± 0.39 , compared with 1.66 ± 0.56 for the 50% reduction group ($p < 0.01$) and 1.38 ± 0.66 for the 75% reduction group ($p < 0.01$).

Reader Assessment of Image Quality

Overall reader assessment of image quality decreased significantly with each decrease in simulated tube current. The average score for image quality in the conventional–tube current group was 4.37 ± 0.81 , followed by 3.44 ± 1.10 and 2.31 ± 0.85 for the 50% and 75% tube current–reduction groups, respectively. The difference between each of the tube current–reduction groups and the conventional–tube current group was statistically significant ($p < 0.01$).

Readers also scored overall study quality independent of noise. The average score was 4.35 ± 0.81 for the conventional–tube current group, 4.19 ± 0.76 for the 50% tube current–reduction group ($p = 0.02$), and 3.99 ± 0.83 for the 75% tube current–reduction group ($p < 0.01$). If a scan was assigned a score of 3 (good) or lower, the reader was asked to list factors that lessened the quality of the study (i.e., motion, poor or absent contrast media in area of interest, and hardware artifact). The most commonly listed factor was suboptimal oral contrast media in the region of the appendix, with approximately 17% of total cases identified as having this limitation.

Interreader Agreement

The kappa values for interreader agreement for the conventional, 50%, and 75% tube current–reduction groups were 0.76, 0.61, and 0.51, respectively. These values correspond with “good” agreement in the conventional and 50% tube current–reduction group and “moderate” agreement in the 75% tube current–reduction group.

Discussion

In this study of 60 cases of suspected pediatric appendicitis, simulated 50% tube current–reduction scans were found to be comparable to conventional–tube current scans in terms of identification of a normal appendix and detection of appendicitis. Furthermore, 75% tube current–reduction scans allowed detection of appendicitis at rates comparable to that of the conventional group, though there was a significant decrease in identification of a normal appendix. Both tube current–reduction groups differed significantly from the conventional group in terms of diagnostic confidence and subjective assessment of image quality.

The use of CT for the evaluation of children in the emergency setting, including acute abdominal pain, is increasing [7, 14]. It is, therefore, important for the medical community to investigate ways to minimize risk from CT-related ionizing radiation, especially in radiosensitive populations such as children [15]. The development of noise-addition software has allowed circumvention of obstacles that previously made tube current–reduction experiments difficult to design and perform. Using the software, one set of patient scans can be used to generate a number of study groups, which results in no unnecessary radiation exposure for the study patients. In addition, this technology makes it possible to use archived images and to control all scan parameters other than tube current and can be used in many clinical scenarios in which CT is useful in children [16, 17].

The results of our study add to a growing body of evidence pertaining to tube current reduction for pediatric CT. Fefferman et al. [9] used a phantom-based simulation technique to compare original pediatric abdominal CT studies (median tube current, 112 mA) to reduced–tube current studies simulated to 20 mA (approximately 82% dose reduction). Investigators found the decrease in sensitivity between the original and low–tube current scans to be unacceptable, decreasing from 91.5% to 77% ($p < 0.001$). In their discussion, the authors recommend further investigations with incremental low-dose image simulation, which we have presented here.

Karmazyn et al. [16] used a previous version of the noise-addition software applied in this study to investigate diagnostic tube current thresholds in pediatric nephroureterolithiasis. In their study, original abdominal CT scans (most ranging between 140 and 260 mA) were compared with simulated reduced–tube current scans, one group simulated to 80 mA and another to 40 mA. The investigators found that the percentage of kidneys in which at least one renal stone was detected was not significantly different between the original group and the 80-mA group, though there was a significant difference between the original group and the 40-mA group ($p = 0.05$). Furthermore, the percentage of scans considered optimal was significantly decreased between the original and both tube current–reduction groups, which is consistent with the findings of our study. This technology has also been used in evaluation of adult urolithiasis [18, 19] as well as adult appendicitis (Paulson EK et al., presented at the 2010 annual meeting of the Radiologic Society of North America). A recently published study from Kim et al. [20] prospectively compared the rates of negative appendectomy for standard- and low-dose CT in 891 young adults (15–44 years old). They found that low-dose CT did not differ significantly from standard-dose CT in terms of the occurrence of negative appendectomy, appendiceal perforation, or need for additional imaging, though they stated

that there was decreased diagnostic confidence in the low-dose group compared with the standard-dose group [20].

In our study, the diagnostic performance of the 50% reduced-tube current CT scans was comparable to that of conventional scans, but diagnostic confidence and accuracy were not maintained for 75% tube current reduction, indicating a threshold somewhere between these two values (50% and 75% simulated tube current reduction). With the data from the scans (dose-length product), one can estimate the reduction in risk associated with the 50% reduction in tube current using data on lifetime attributable risk of cancer [21–24]. In prior work, for example, risk estimates were derived in an age- and sex-specific manner. Such values are, of course, only estimates, and one must be careful to always weigh the risk of radiation exposure against the risk of missing an important and, as in the case of appendicitis, potentially life-threatening diagnosis. Nevertheless, regardless of what the actual magnitude of risk for a given patient might be, a 50% reduction of that value, provided that it does not negatively affect diagnostic accuracy as shown in our study, should be implemented and encouraged as a meaningful reduction in irradiation burden.

Though the scans included in the study were obtained in the course of working up suspected appendicitis, alternate diagnoses were identified in approximately 14% of the conventional-tube current (reference standard) scans. Because of the wide range of alternate diagnosis categories and the small number of cases in each category, we were not able to statistically compare the conventional and reduced-tube current groups in terms of the frequency of detection of alternate pathologic abnormalities, nor was there confirmation that these CT diagnoses were present or the cause of the presentation. The raw numbers, however, are comparable for all three groups, with the highest rate of detection in the 50% tube current-reduction group. Between the conventional and 50% tube current-reduction scans, all three readers indicated at least one additional alternate diagnosis for the lower-tube current scan.

Our study had several limitations. First, it was a retrospective study with a small sample size, though the number of examined cases was comparable to those in similar previously published studies [16, 18]. Our results show no statistically significant difference between the conventional and 50% tube current-reduction group in both visualization of the normal appendix and diagnosis of appendicitis, but it is possible that any difference that exists may become significant with a larger sample size. In addition, this study assessed only simulated reductions in tube current using scan data from one vendor (peak kilovoltage, pitch, and number of detector rows); CT equipment from other manufacturers was not evaluated. However, the noise addition and effect on image quality should apply to any CT examination because these are fundamental physical principles. In addition, our protocol and techniques (e.g., tube current, contrast material, and scan range) may not be the same as those used at other sites. For example, the doses used at our institution are well below the American College of Radiology accreditation threshold for abdominal CT and would be appropriate only for similar CT examination quality. It is reasonable to expect, however, that scanning performed at doses that have less image noise than the noise in our baseline scans would benefit even more from application of tube-current reductions providing sufficient diagnostic quality in this investigation.

The institutional review board approval for this study was for comparisons between imaging studies, with the reference standard defined as the interpretation of the conventional–tube current study. The reader interpretations (appendicitis, no appendicitis, or alternate diagnoses) were therefore not correlated with clinical, surgical, or pathologic outcomes. This limitation affects our ability to interpret the higher number of alternate diagnoses in the 50% tube current–reduction group, because we were not able to assess false- versus true-positives according to clinical outcomes.

There were some aspects in which the research environment differed from a normal day-to-day clinical setting for a radiologist. First, readers could view the axial slices using all of the basic PACS tools, but slices in other planes (coronal or sagittal) were not available to aid in interpretation. Coronal reconstructions can increase reader confidence in visualizing the appendix, as well as diagnosing or excluding appendicitis [25], and it is possible that the mean confidence scores for our readers would have been higher had these reconstructions been obtainable with the simulation software. Second, all three of the readers for this study are fellowship-trained pediatric radiologists with a combined 35 years of experience as faculty at our institution. This level of training may not reflect the other settings in which appendicitis cases may be interpreted, and this limitation should be considered before generalizing our results to all clinical settings. Finally, though the readers were blinded to all clinical data and technical parameters, they knew that this was a simulated tube current–reduction experiment and that each patient case would be reviewed at three different noise levels. Randomization allowed us to partially control for this memory bias, though we did not formally assess to what extent it may have affected our results. Also, we did not test the role of other imaging methods, such as ultrasound, in the evaluation of appendicitis. At our institution, it is routine to first consider ultrasound examination in patients with suspected appendicitis. All the patients in this study were deemed to be appropriate candidates for CT, most often because of equivocal ultrasound results.

Tube current is just one parameter that can be modified to reduce radiation exposure from CT. Other strategies to reduce dose include limited scanning (e.g., lower edge of liver to pelvis) [26], adjustments in peak kilovoltage [27], and the use of new iterative reconstruction technology [28, 29]. These approaches, combined with computer-simulated tube current reduction used in this study, represent potential future directions in CT dose-reduction research.

The use of CT for the evaluation of suspected appendicitis in children is common, and systematic dose-reduction investigations such as this one are becoming increasingly important. The results presented here have immediate and significant clinical application for pediatric CT dose reduction in a common clinical scenario.

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Fig. 1.

16-year-old girl with acute appendicitis. Abdominal CT scans show relationship between tube current reduction and increase in noise.

A, Noise within region of interest (ROI) (*circle*) is 9.2 HU.

B, When tube current is decreased by factor of 2 (compare **A** to **B**), noise increases by approximately 2 (1.4 HU), giving ROI (*circle*) noise of 12.5 HU.

C, Similarly, when tube current is decreased by factor of 4 (compare **A** to **C**), noise increases by approximately 4 (2 HU), yielding ROI (*circle*) noise of 18.2 HU.

Fig. 2.

11-year-old boy with normal appendix.

A–C, Images show effect of simulated tube current reduction. Conventional (**A**), 50% tube current–reduction (**B**), and 75% tube current–reduction (**C**) scans show air-filled appendix (*arrows*) in cross-section.

Fig. 3.

3-year-old girl with acute appendicitis.

A–C, Images show effect of simulated tube current reduction. Conventional (**A**), 50% tube current–reduction (**B**), and 75% tube current–reduction (**C**) scans show abnormal appendix (*arrows*) anterior to sacrum. Note also that bowel obstruction is readily evident in all tube current examinations.

TABLE 1
Frequency of Identification of Normal Appendix Using Conventional Tube Current as the Referent

Tube Current	Reader 1	Reader 2	Reader 3	Average	<i>p</i>
75% Reduction	27/60 (45.0)	43/60 (71.7)	21/60 (35.0)	30.33/60 (50.6)	0.002
50% Reduction	32/60 (53.3)	46/60 (76.7)	30/60 (50.0)	36/60 (60.0)	0.19
Conventional	37/60 (61.7)	46/60 (76.7)	37/60 (61.7)	40/60 (66.7)	Referent

Note—Data are no. of cases/total (%). Wilcoxon signed-rank test was used to compare the average number of scans in which a normal appendix was identified at the low-tube current setting versus the conventional CT parameters.

TABLE 2

Percentage of Scans in Which Appendicitis Was Identified Using Conventional Tube Current as the Referent

Tube Current	Reader 1	Reader 2	Reader 3	Average	<i>p</i>
75% Reduction	13/60 (21.7)	13/60 (21.7)	11/60 (18.3)	12.33/60 (20.6)	0.80
50% Reduction	13/60 (21.7)	13/60 (21.7)	12/60 (20.0)	12.66/60 (21.1)	0.89
Conventional	14/60 (23.3)	13/60 (21.7)	12/60 (20.0)	13/60 (21.7)	Referent

Note—Data are no. of cases/total (%). Positive identification was defined as a score of 4 (probably present) or 5 (definitely present) on 5-point Likert scale. Wilcoxon signed-rank test was used to compare the average number of scans in which appendicitis was identified at the low-tube current setting versus the conventional CT parameters.

TABLE 3
Comparison of Average Combined Reader Scores for Signs of Appendicitis in the Conventional and Tube Current–Reduction Groups

Parameter	Conventional Tube Current	50% Tube Current Reduction	p^a	75% Tube Current Reduction	p^b
Mural enhancement	4.83 ± 0.38	4.46 ± 0.98	0.23	3.95 ± 0.79	<0.01
Mural thickening	4.43 ± 0.99	4.21 ± 0.93	0.24	4.00 ± 0.76	0.03
Thickened or distended appendix	4.79 ± 0.51	4.89 ± 0.34	0.66	4.43 ± 0.75	0.06
Greatest diameter	10.13 ± 2.77	10.82 ± 3.27	0.41	10.86 ± 3.71	0.81
Appendicolith	4.06 ± 1.66	4.16 ± 1.53	0.94	3.86 ± 1.60	0.052
Extraappendiceal inflammatory changes	4.79 ± 0.48	4.63 ± 0.84	0.58	4.56 ± 0.66	0.12
Fat stranding	4.68 ± 0.71	4.50 ± 0.89	0.33	4.22 ± 0.89	0.01
Extraluminal gas or free air	2.46 ± 1.66	2.47 ± 1.57	0.92	2.14 ± 1.06	0.84
Focal fluid collection (i.e., abscess)	3.84 ± 1.64	3.66 ± 1.68	0.49	3.57 ± 1.48	0.20
Cecal or colonic wall thickening or inflammation	4.22 ± 1.29	3.85 ± 1.55	0.27	3.68 ± 1.16	<0.01
Small-bowel obstruction	2.35 ± 1.64	2.21 ± 1.51	0.66	2.38 ± 1.46	0.79

Note—Data are mean ± SD for all three readers. Wilcoxon signed-rank test was used to compare the average scores for each variable in the conventional and tube current–reduction groups.

^aConventional group versus 50% tube current–reduction group.

^bConventional group versus 75% tube current–reduction group.

TABLE 4

Detection of Alternate Diagnoses by Tube Current Level

Alternate Diagnosis	Reader 1			Reader 2			Reader 3		
	Conventional Tube Current	50% Tube Current Reduction	75% Tube Current Reduction	Conventional Tube Current	50% Tube Current Reduction	75% Tube Current Reduction	Conventional Tube Current	50% Tube Current Reduction	75% Tube Current Reduction
Adnexal cyst	6	7	7	6	5	4	3	4	4
Other genitourinary pathologic entities	2	2	2	1	2	1	2	2	0
Constipation	2	2	2	0	1	1	2	2	2
Colitis	1	1	0	0	0	0	0	1	0
Total	11	12	11	7	8	6	7	9	6

Note—Data are no. of cases of 60 total in which the given diagnosis was made.