Low-Dose Unenhanced Multidetector CT of Patients with Suspected Renal Colic

OBJECTIVE. This study is designed to assess the intraobserver and interobserver agreements and the diagnostic performances of low-dose unenhanced multidetector CT (MDCT) in patients with suspected renal colic.

SUBJECTS AND METHODS. The study included 106 patients who underwent unenhanced MDCT with 4 × 2.5 mm collimation, 120 kVp, 30 mAs, and, if necessary, additional focused acquisitions at 60 or 120 mAs on areas with an equivocal ureteral stone or with significant image noise. The effective radiation dose was computer-simulated with software based on the Monte Carlo model and International Commission on Radiological Protection recommendations. CT scans were archived and independently reviewed by three radiologists during two interpretation sessions on a workstation with three dimensions functions. Intraobserver and interobserver agreements were calculated with the kappa statistics. Accuracy for detection of ureteral stone on low-dose MDCT was calculated by comparison with combined clinical (stone passage), surgical (stone retrieval, extracorporeal shock wave lithotripsy), biologic (urinalysis, urine culture), and other imaging (excretory urography, standard-dose MDCT, follow-up sonography, and abdominal radiography) findings or by evidence for an alternative diagnosis.

RESULTS. Ureteral stones were present in 38 (36%) of 106 patients. Thirty-six of 38 ureteral stones were detected by low-dose MDCT. From reviewer to reviewer, the number of true-positive, false-positive, true-negative, and false-negative findings ranged, respectively, from 34 to 36, 1 to 4, 64 to 68, and 2 to 4. The corresponding sensitivity, specificity, and accuracy ranged from 89.5% to 94.7%, from 94.1% to 100%, and from 93.4% to 98.1%, respectively. The intraobserver and interobserver agreements were excellent, with kappa values ranging from 0.87 to 0.98. In 13 patients, an alternative diagnosis explaining the patient’s symptoms was proposed by all reviewers using images obtained at 30 mAs. No additional or alternative diagnosis was found at standard dose. At 30 mAs, the mean effective dose was 1.2 mSv in men and 1.9 mSv in women. Additional acquisitions at 60 mAs, all focused on the lower pelvis, were acquired in 20 patients, but the corresponding images were needed by the reviewers for only six of them. The acquisitions at 60 mAs were responsible for an additional mean effective dose of 0.5 in men and 0.8 mSv in women.

CONCLUSION. Our study shows that low-dose unenhanced MDCT is appropriate for the diagnosis of ureteral stones, and that it provides excellent intraobserver and interobserver agreements and does not obscure alternative diagnoses.

Unenhanced helical single-detector CT has high accuracy in the diagnosis of ureteral calculi in patients with acute flank pain [1, 2]. Compared with standard radiography, excretory urography, and nephrotomography, helical single-detector CT offers a more rapid diagnosis, better stone identification and localization, and a more accurate determination of stone size [2, 3]; obviates IV injection of contrast material [1–3]; and may provide the basis to suggest or establish alternative or additional diagnoses [4]. On the other hand, the reported radiation exposure induced by standard helical single-detector CT is three to five times higher than that induced by excretory urography with three views [5] or by low-dose helical single-detector CT [6]. As clinicians develop familiarity with helical CT, the indications for its use and the subsequent radiation dose delivered to the population are expanding [7, 8]. In addition, renal colic is a situation in which dose should be reduced because patients may be young and both the risk of recurrence and the lifetime exposure risk are high.

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With single-detector CT, dose re-
duction can be achieved by increasing the
pitch [6, 9, 10]. With the recently introduced
multidetector CT (MDCT) technology, it is
now possible to obtain high-resolution, coro-
nal and sagittal multplanar reformations from
thin-collimation acquisitions but with an
increased radiation dose when CT param-
ters are unchanged [11, 12]. With MDCT, the
can be reduced by modulating the milli-
ampere-second (mAs) settings.

The aim of this study was to determine the
intraobserver and interobserver agreements,
sensitivity, specificity, predictive values, and
accuracy of unenhanced MDCT obtained
with a low radiation dose based on 30 mAs
acquisition—corresponding to an effective-
with a low radiation dose based on 30 mAs
accuracy of unenhanced MDCT obtained
intraobserver and interobserver agreements,

**Subjects and Methods**

From October 2000 to March 2001, 106 consec-
tutive patients (53 males and 53 females) who pre-
sented with acute lumbar or flank pain were
referred to the radiology department for unen-
hanced helical CT. These patients were 15–84
years old (mean age, 45 years). Because of the or-
ganization of our hospital, patients underwent
scanning before 8:00 A.M. and 7:00 p.m.; patients
admitted at night underwent imaging the next
morning. The body mass index (BMI) was calcu-
lated, and patients were separated into groups ac-
cording to the recommendations of the National
Institutes of Health [13] as follows: underweight
(BMI < 18.5 kg/m²), normal (BMI range, 18.5–
24.9 kg/m²), overweight (BMI range, 25.0–29.9
kg/m²), obese (BMI range, 30.0–39.9 kg/m²), and
extremely obese (BMI ≥ 40 kg/m²). In the whole
study group, the mean BMI was 26.2 kg/m² (range,
18.0–48.7 kg/m²). The study protocol was ap-
proved by our institutional review board. Informed
consent was obtained from all patients and, for
those who were adolescents, from their parents.

**CT Examinations**

Images were obtained using a commercially
available MDCT scanner (Somatom Plus Volume
Zoom; Siemens Medical Systems, Erlangen, Ger-
many). Patients were examined while in a supine po-
sition, and none received contrast material. A 52-cm
scout image was first obtained at 120 kVp and 35
mAs, followed by a helical scan with simultaneous
acquisition of 4 × 2.5-mm collimations at 120 kVp
and 30 effective mAs. Effective mAs represent con-
stant mAs when increasing the pitch, owing to the
automatic tube current adaptation [14]. Table feed
was 15 mm per 0.5-sec scanner rotation (30 mm/
sec). These parameters result in a pitch (table feed
per scanner rotation divided by the collimation of
one detector row) of 6:1, equivalent to a pitch of
1.5:1 as defined by Silverman et al. [15]. All exami-
nations were performed from the upper pole of the
kidneys to the symphysis pubis. From the raw data,
3-mm-thick sections were reconstructed with a 2-
mm increment. If the staff radiologist who con-
ducted the examination considered that the image
quality was insufficient because of excessive noise,
a second acquisition—focused on the artifactual
zone —was obtained at 60 mAs and reconstructed
with the same parameters as the first acquisition.
If this second set of images was also unsatisfactory,
a third acquisition was obtained at 120 mAs.

**Effective Dose Calculations**

The effective dose was computer simulated with a
commercially available software installed on a per-
computer system (WinDose; Institut für Medizinische
Physik, Universität, Erlangen, Germany) [16]. This
software does not require phantom measurements. In-
puts corresponding to CT parameters, the patient’s
gender, and the scanned region, as represented on a
diagram of the Monte-Carlo phantom model, were
given to the program, which took into account the
multidetector nature of the CT examinations. The
height of the scanned region was calculated by the
difference in table position between the first and the
last image. The effective dose was then computed ac-
cording to the Monte-Carlo simulations for anthropo-
morphic phantoms as recommended by Zankl et al.
[17]. The conversion factors for CT used in this study
were generated according to recommendations ap-
priate for our scanner unit (ImpactMC) [18]. The
calculated effective doses were expressed following the
International Commission on Radiological Protec-
tion recommendations (ICRP60). CT parameters de-
termining the radiation exposure were verified both at
the beginning and at the end of the study. We also
used this software to calculate the effective dose deli-
ered by previously reported CT protocols [2, 3, 6, 9,
10–12, 19, 20]. As stated by Kalender and Schmidt
[21], comparisons of calculated radiation doses
showed good agreement with previously reported
measurements in adults with a maximal difference of less
than 15% for CT scanners listed in the GSF Report 3091
[17] as well as for other scanners.

**Image Analysis**

The images were stored on compact disks and re-
viewed, for the purpose of this study, on a clinical
workstation (Wizard; Siemens Medical Systems, Erlangen,
Germany). The images were assessed independently by
two board-certified radiologists (reviewers A and B)
who had more than 10 years’ experience in interpreting
abdominal CT scans and by one resident (reviewer C)
with 1 year of experience in radiology. These three
reviewers were unaware of the final results, the patient’s
BMI, and the side on which the pain was felt, but they
knew that the patient presented with acute lumbar or
flank pain suggestive of renal colic. Image interpret-
tation was performed in two separate and independent
sessions with an interval between sessions of more than
30 days. The reviewers were asked to record the pres-
ence of an intrarenal calcification as classified by
Souvirizen et al. [3]. The reviewers were also asked to
record the presence of the following indirect signs: re-
nal enlargement, dilatation of the excretory tract, perire-
oral or perinephric stranding as proposed by Smith et al.
[22] and Varanelli et al. [23]; and rim sign defined by
Henehan et al. [24]. When a ureretal calcification was
detected, its size and location were recorded; any alter-
native diagnosis and unsuspected CT findings were
also recorded.

Each reviewer analyzed the images obtained at
30 mAs and was allowed to use the three-dimen-
sional functions of the workstation, including mul-
tiplanar reformation, curved reformation, and
maximum intensity projection. The reviewer ex-
amined the images with the cine-viewing mode in
the axial plane and in the coronal and sagittal ref-
formations. If a reviewer found the images ob-
tained at 30 mAs of insufficient quality, images
obtained at 60 mAs were requested. If those images
also were found to be of insufficient quality, a
request was made for those obtained at 120 mAs.

**Methods of Reference**

The ureretal stone was considered to be definitely
present if at least one of the following criteria were
fulfilled: surgical retrieval of the stone, depiction of a
ureretal stone by contrast-enhanced imaging studies
(i.e., excretory urography, unenhanced or enhanced
standard-dose CT, or both, within 24 hr), subsequent
radiographs and sonograms showing evidence of cal-
culus migration, calculus excretion followed by relief
of pain, macroscopic hematuria, microscopic hema-
turia (minimum of two RBCs per high power field),
or positive dipstick urinalysis.

The ureretal stone was considered to be definitely
absent if at least one of the following criteria was
fulfilled: a negative microscopic or dipstick urinaly-
sis and relief of pain with no treatment, depiction of
abundance of ureretal stone and obstruction by imaging
studies (i.e., excretory urography, unenhanced or en-
hanced standard-dose CT, or both, within 24 hr);
low-dose CT depiction of an alternative diagnosis
and relief of pain after a specific treatment, a labora-
tory-based alternative diagnosis (e.g., urinary tract
infection), or abdominal radiographs or sonograms
obtained during the following days to look for an alter-
tative diagnosis that showed no abdominal calci-
fication or urinary tract dilatation.

Reviewer A acted as the main investigator. Af-
ter interpreting the images, he reviewed all clinical
data and calculated the results.

**Statistical Analysis**

The intraobserver and interobserver agreements
were evaluated with the use of kappa statistics. The
95% confidence intervals (CI) for the kappa statis-
tics were calculated, the null hypothesis of no
agreement between observers was tested, and the
associated p values were calculated [25]. All kappa
values were interpreted according to suggestions
from the literature [26]: a kappa value of less than
0.20 indicated poor agreement; 0.21–0.40, fair
agreement; 0.41–0.60, moderate agreement; 0.61–
0.80, good agreement; and 0.81–1.00, excellent
agreement. Sensitivity, specificity, negative predictive value, positive predictive value, and accuracy (proportion of the number of concordant observations among all) were also calculated. The McNe- 
mar test was used to compare the performances (estimated by the proportion of correct observations compared with the gold standard) between two assessments. Statistical significance for all tests was set at a p value of less than 0.05. All statistical analyses were performed with the StatXact 3 statistical software (Cytel, Cambridge, MA).

Results

Thirty-eight of the 106 patients (26 males and 12 females) were classified as definitely having a ureteral stone on the basis of one or more of the following results: surgical retrieval of the stone in 13 patients, one of whom had negative findings on urinalysis; depiction of a ureteral stone by enhanced standard-dose MDCT combined with excretory urography in 11 patients and by excretory urography alone in five patients; follow-up abdominal radiographs or sonograms showing the stone migration in 22 patients; spontaneous stone excretion followed by immediate relief of pain in 23 patients; or microscopic hematuria or positive dipstick urinalysis in 37 patients.

Sixty-eight of 106 patients (27 males and 41 females) were classified as definitely having no ureteral stone on the basis of one or more of the following results: negative microscopic or dipstick urinalysis findings and relief of pain with no treatment in 28 patients, depiction of absence of a ureteral stone and obstruction by contrast-enhanced imaging studies (excretory urography in five patients, unenhanced and enhanced standard-dose MDCT in 21 patients), CT depiction of an alternative diagnosis and relief of pain after a specific treatment in 11 patients (ovarian cysts in three patients, acute diverticulitis in three patients, abdominal wall herniation in two patients, lower lobe pneumonitis in one patient, pancreatitis in one patient, and pyelonephritis in one patient), biologic findings indicative of a urinary infection in 13 patients, and abdominal radiographs or sonograms performed during the following days that showed no abnormal calcification or urinary tract dilatation in 10 patients.

Intraobserver agreements as determined by using the kappa statistics were (mean ± SD) 0.98 ± 0.02 (95% CI, 0.94–1.00) for reviewer A, 0.96 ± 0.03 (95% CI, 0.90–1.00) for reviewer B, and 0.90 ± 0.04 (95% CI, 0.81–0.98) for reviewer C (resident), with all p values lower than 0.001. The lowest interobserver agreement was found between reviewers B and C, with a kappa value of 0.88 ± 0.04 (95% CI, 0.81–0.98), whereas the highest interobserver agreement was found between reviewers A and B, with a kappa value of 0.98 ± 0.02 (95% CI, 0.94–1.00) and all p values lower than 0.001. Thus, both intraobserver and interobserver agreements were excellent.

The three reviewers identified a ureteral stone on the CT scans of 36 patients. The number of true-positive, false-negative, true-negative, and false-negative findings, and the sensitivity, specificity, predictive values, and accuracy of both interpretation sessions of the three reviewers are listed in Table 1. In two patients classified as definitely having a ureteral stone on the basis of a positive urinalysis, none of the three reviewers reported a stone. These findings were probably not false-positives because the stone likely had been recently passed. Nevertheless, they were classified as false-negative because no alternative diagnosis was shown during the follow-up period.

Among the detected ureteral stones, 21 were left-sided and 15 were right-sided, nine were located in the upper third of the ureter, nine in the middle third of the ureter, and 16 close to or in the ureterovesical junction. The mean diameter of the stone was 4 mm (range, 2–9 mm). One patient had bilateral ureteral stones. In addition, renal calculi were seen in 17 patients. Two women in whom a ureteral stone in the distal ureter had been spontaneously excreted each had a simultaneous urinary infection shown by urine culture.

To evaluate possible differences in performances between the resident (reviewer C) and the board certified radiologists (reviewers A and B), we compared the number of correct and false diagnoses recorded by reviewer A and reviewer C in their first interpretation session. The number of correct diagnoses in 106 patients was higher for reviewer A (n = 104) than for reviewer C (n = 99). Nevertheless, this trend toward a difference in the number of false diagnoses did not reach statistical significance (p = 0.063, McNe- 
mar test). To evaluate a possible learning effect for the resident, we compared the number of correct and false diagnoses recorded during both of the resident’s sessions. The number of correct diagnoses in 106 patients was higher during the second interpretation session (n = 102) than during the first one (n = 99). Nevertheless, this trend toward an increase in the number of correct diagnoses did not reach statistical significance (p = 0.375, McNemar test).

The staff radiologist who conducted the examination obtained supplementary, focused MDCT acquisitions at 60 mAs in 20 patients (eight males and 12 females), none of whom were overweight. These acquisitions were obtained in three (6%) of 49 normal-weight patients, in eight (22%) of 37 overweight patients, in seven (44%) of 16 obese patients, and in two extremely obese patients (100%). All three reviewers asked for these corresponding

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Diagnostic Performances of Three Reviewers Using Low-Dose CT for the Detection of Ureteral Stones</th>
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<td>Findings</td>
<td>Interpretation Session 1</td>
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<tr>
<td></td>
<td>Reviewer A</td>
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<tr>
<td>True-positive (no.)</td>
<td>36</td>
</tr>
<tr>
<td>False-positive (no.)</td>
<td>0</td>
</tr>
<tr>
<td>True-negative (no.)</td>
<td>68</td>
</tr>
<tr>
<td>False-negative (no.)</td>
<td>2</td>
</tr>
<tr>
<td>Sensitivity (%)</td>
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<tr>
<td>Specificity (%)</td>
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<tr>
<td>Positive predictive value (%)</td>
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</tr>
<tr>
<td>Negative predictive value (%)</td>
<td>97.1</td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>98.1</td>
</tr>
</tbody>
</table>

Note.—Reviewers A and B were experienced radiologists; reviewer C was a radiology resident.
images for only six of the 20 patients (in one overweight, three obese, and two extremely obese patients). An illustrative case is shown in Figure 1. Three of these six patients definitely had a ureteral stone. The remaining 14 of 20 supplementary acquisitions obtained at 60 mAs were not needed by any reviewer. An illustrative case with an unnecessary acquisition at 60 mAs is shown in Figure 2. One patient also had an additional focused CT acquisition at 120 mAs, but the three reviewers did not need these images. No image at 60 mAs that had not been acquired by the staff radiologist who conducted the examination was requested by any of the three reviewers. In all patients in whom a supplementary acquisition was requested, the area with an equivocal ureteral stone or with significant image noise was the lower pelvis, at the level of the hips. Among the six patients in whom the 60-mAs images were requested by the reviewers, five patients had a BMI higher than 35.1. The diagnosis was reached at 30 mAs in only one of the six patients with a BMI higher than 35 kg/m². Figure 3 shows an example of multiplanar reformation images revealing the presence of a ureteral stone in an obese patient imaged at 30 mAs.

The mean height of the scanned region at 30 mAs was 31 cm (range, 20–36 cm). At 30 mAs, the calculated mean effective radiation dose was 1.2 mSv (range, 0.8–1.5 mSv) in men and 1.9 mSv (range, 1.5–2.3) in women. The mean height of the scanned region at 60 mAs was 11 cm (range, 7–15 mSv). The corresponding effective radiation dose was 0.5 mSv (range, 0.4–0.7) in men and 0.8 mSv (range, 0.6–1.1) in women. For the only patient who underwent scanning at 120 mAs, an extremely obese woman (BMI = 48.7 35 kg/m²), the height of the scanned region was 31 cm, and the corresponding effective dose was 7.6 mSv.

Discussion

Our study shows that in patients with suspected renal colic, low-dose unenhanced MDCT is a sensitive and specific method of detecting a ureteral stone. We found that both intraobserver and interobserver agreements are excellent and that performance does not depend on the radiologist’s experience. With an accuracy rate of more than 93%, the test performance of low-dose MDCT is similar to that of single-detector helical CT performed with standard [1–3, 19, 20] and low [6] radiation doses. On the other hand, with single-detector CT, the intraobserver and interobserver agreements are only good, with kappa values not higher than 0.71, and the reviewer’s experience does seem to influence performance [27, 28]. Two possible reasons may explain the capability to obtain both excellent intraobserver and interobserver agreements and high performances that are independent of the reviewer’s experience when using MDCT. First, as shown by Rimondini et al. [29] in phantom studies, 3 mm is probably the most appropriate slice thickness for imaging patients with suspected renal colic, and this is the thickness we used. Second, cine-viewing, multiplanar reformation, and curved reformatting.
tion provide unequivocal images focused on the ureteral stone. We used 3-mm collimation as recommended by Rimondini et al. [29] as a compromise between the resolution in the z axis and the dose. With 5-mm collimation, the weighted CT dose index as displayed on the scanner unit would have been 10% lower, but the Z resolution probably highly worsened. On the other hand, and as an example, with 1-mm collimation, the highest Z resolution would have been reached, but with a 22% increased dose and a worsened signal-to-noise ratio.

Because standard-dose helical CT has the highest accuracy in the assessment of ureteral stones, this technique is probably the most appropriate method of reference for comparative studies [1, 11, 20]. Performing both standard-dose and low-dose MDCT in all patients at the same time would therefore have been ideal in this regard but would have also resulted in an excessive radiation dose in a study group including young patients. We thus used various criteria validated by previous studies to establish the definite diagnosis [2, 3, 9, 22]. Probably this is not the most appropriate method of reference and, as a consequence, the clinicians may have ordered additional diagnostic tests when they doubted the proposed diagnosis made on the low-dose MDCT examinations. Thus, in our study, one third of the patients with or without a ureteral stone had excretory urography or standard-dose CT prompted by clinicians in the immediate follow-up period. With this study design, we also had two patients with a history consistent with recently passed stones who were classified as having false-negative findings on low-dose MDCT on the basis of positive findings on urinalysis—a method that is known to have a positive predictive value of only 76% [30]. These patients would probably have been classified as true-negative if standard-dose CT had been considered as the method of reference. If we consider these two patients as true-positive cases, the accuracy would range, among reviewers, from 95% to 100%.

One of the major advantages of CT is to provide alternative and supplementary diagnoses. In a retrospective analysis of 1000 patients with suspected renal colic who underwent standard-dose helical CT, Katz et al. [4] reported 101 examinations revealing alternative or supplementary diagnoses. We found 13 patients (12%) with an alternative diagnosis and 17 patients (16%) with renal stones. The spectrum of these diagnoses was similar to those reported by Katz et al. [4]. Twenty-one of 55 patients without ureteral stone in whom no alternative diagnosis was suggested on low-dose CT underwent standard-

![Fig. 2.—Low-dose unenhanced multidetector CT scans obtained with 4 × 2.5 mm collimation at 120 kVp in 38-year-old woman (body mass index, 23.5 kg/m²) with right acute flank pain. A, Axial image obtained at 30 mAs at level of right kidney shows no secondary renal signs. B, Axial image obtained at 30 mAs at level of ureteropelvic junction shows calcification (arrow) corresponding to phlebolith close to right ureteropelvic junction. This image was correctly diagnosed by reviewers A and B, who are experienced in interpreting CT, but not by reviewer C (resident with 1 year of experience) during first session. Reviewer C diagnosed this image correctly during second interpretation session. C, Axial image obtained at 60 mAs, reconstructed at same level as B was not needed by any reviewer. Calcification (arrow) corresponding to phlebolith close to right ureteropelvic junction was visible as in B.](image)

![Fig. 3.—Low-dose unenhanced multidetector CT scan obtained with 4 × 2.5 mm collimation at 120 kVp and 30 mAs in 29-year-old man who was obese (body mass index, 34.4 kg/m²) with acute left flank pain. Curved multiplanar reformation including left dilated ureter from left kidney to bladder shows ureteral stone (arrow) in distal ureter.](image)
dose CT. Among them, no additional alternative diagnosis was revealed, even in patients admitted to the emergency department the night before. As previously shown by Liu et al. [9] and by Diel et al. [10] in single-detector CT studies, an alternative diagnosis can be accurately identified with low radiation doses, despite increased pitch, volume-averaging artifacts, reduced mAs, and subsequent increased image noise.

In 14 of 20 patients in whom a focused acquisition was obtained at 60 mAs, these corresponding images were not needed by any of the reviewers. The staff radiologist who conducted the examination had to be absolutely sure that no ureteral stone could be missed and had to decide whether to request an additional acquisition with a higher dose within a few seconds in order not to disturb the day-to-day organization of our CT department. On the other hand, the reviewers involved in our study had no time constraints for the image analysis. All six examinations considered to be of insufficient quality when obtained at 30 mAs by the three reviewers had severe artifacts in the lower pelvis at the level of the ureteropelvic junction. To obtain high quality images in this region is critical because approximately half of ureteral stones are located in the distal ureter [1, 11]. In this particular anatomic region, which is not more than 10 cm in height, the tube current should be higher than that used in the flanks. Both the image quality and the radiation dose delivered to the patient should benefit from an on-line tube-current modulation dependant on the rotation angle of the X-ray beam. However, because images obtained at 60 mAs were needed by the reviewers in only one of 36 overweight and three of 16 obese patients, the low-dose acquisition obtained at 30 mAs should be sufficient except in extremely obese individuals. On the other hand, because the images obtained at 30 mAs did not permit a diagnosis of ureteral stone in five of six patients with a BMI higher than 35 kg/m², 60 mAs should primarily be used in these patients. Our results differ from those of Hamm et al. [6], who performed low-dose single-detector CT with an equivalent dose level. These authors propose a BMI threshold of 30 kg/m² for excluding patients from the low-dose technique. Our results suggest an intermediate dose acquisition at 60 mAs for these patients.

The mean effective dose delivered with MDCT at 30 mAs (1.2 mSv in men and 1.9 in women) is within the range of a three-film excretory urogram examination (1.5 mSv) [5] and is lower than that of six-film excretory urography (2.5 mSv) [31]. In addition, we have re-calculated the effective dose delivered in various protocols described in previous studies using single-detector helical CT scanners [3, 9, 10, 19, 21] and in two studies using a MDCT scanner [11, 12] (Table 2). The radiation dose delivered with our protocol is from one third to one fourth of that delivered with single-detector helical CT protocols, and as low as one ninth of that of a more standard MDCT technique. This radiation dose is similar to that from the study recently reported by Hamm et al. [6], which used a single-detector CT technique with 5-mm collimation, 70 mAs, and a pitch of 2. Other studies using single-detector CT reduced radiation dose by increasing the table feed by rotation, reaching a pitch of 2–3 [9, 10]. In these studies, mAs were maintained at high levels and the resulting effective doses were still relatively high, as listed in Table 2. Recent studies using MDCT were based on thin collimations ranging from 1 to 3 mm but with mAs settings similar to those previously used with single-detector CT, leading to an effective radiation dose increased by a factor of 2–3, as shown in Table 2 [11, 12]. However, when using MDCT scanners, the radiation dose can be dramatically reduced by decreasing the mAs. Factors permitting the dose reduction with these scanners are solid-state detectors more sensitive than previously used helium gas detectors, rotation time reduced to 0.5 sec, and easily used controls of the mAs settings directly available on the screen of the CT unit. In addition, with the new concept of effective milliampere-second (i.e., automatic adapted tube current when varying the pitch), the duration of acquisition can be adapted to the patient’s capability of breath-holding, with the radiation dose remaining constant [14].

As used in our study, the computer simulation of the effective dose has several limitations. Rainbow and Liu [32] recently pointed out that calculation of the effective dose provides an examination-specific estimate based on many assumptions and is not directly applicable to any individual because patient-specific estimates depend also on patient size and anatomy. In dose calculations based on the Monte Carlo model, the considered distance in a standard trunk between the upper pole of the kidneys and the lower aspect of the bladder is 40 cm [17, 23]. In our study group, the height of the scanned region was measured in each patient and the radiation dose calculated accordingly. Neither our program nor the Monte Carlo model take into ac-

<table>
<thead>
<tr>
<th>Researchers</th>
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<th>Acquisition Parameters</th>
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<tr>
<td>Liu et al. [9]</td>
<td>Single-detector CT</td>
<td>7  120  280  2:1  4.5  6.7</td>
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<td>Diel et al. [10]</td>
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<td>Hamm et al. [6]</td>
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<td>Van Beers et al. [11]</td>
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<td>4 × 2.5  120  280 effective</td>
<td>12.7  17.5</td>
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<tr>
<td>Caoili et al. [12]</td>
<td>Multidetector CT</td>
<td>4 × 2.5  120  140  0.75:1  13.1  18.0</td>
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<tr>
<td>Denton et al. [5]</td>
<td>Excretory urography</td>
<td>3 views</td>
<td>1.5</td>
</tr>
<tr>
<td>Wall et al. [31]</td>
<td>Excretory urography</td>
<td>6 views</td>
<td>2.1 (range, 0.8–5.6)</td>
</tr>
</tbody>
</table>

TABLE 2: Comparisons of Effective Radiation Doses for Helical CT Protocols and Excretory Urography

aCalculated with WinDose software (Institut für Medizinische Physik, Universität, Erlangen, Germany) for scanned region of 31 cm in height as mean in current study and with CT and urography parameters previously reported.
count the weight or the abdominal diameter of the patient. As shown by Huda et al. [33] with phantoms of various sizes scanned with constant kilovoltage and milliampere-seconds, the energy imparted on CT increases with the patient’s size, but the corresponding effective radiation dose is higher in smaller phantoms than in bigger ones. Because pelvic organs responsible for a significant part of the effective dose (i.e., the bladder, colon, and gonads) are close to the center of the pelvis, the effective dose should be lower in obese patients than in underweight ones. In other words, an increase in milliampere-seconds setting in patients with a high BMI may not result in an increased effective radiation dose.

Contrary to the suggestion by Haaga [34], we did not classify the patients according to their abdominal diameter but rather to their BMI for several reasons. First, the BMI is a practical measure of the body size because it does not require reference tables of ideal weight and is available before the CT examination. Second, with MDCT, four contiguous axial slices are acquired simultaneously, whereas only one is necessary to measure the abdominal diameter, the other slices resulting in useless radiation exposure. Third, the maximum abdominal diameter is usually close to the umbilicus, much more cranial than the lower pelvis where most artifacts related to the hip structures are seen.

In conclusion, our study suggests that, in the assessment of ureteral stones, using low-dose unenhanced MDCT scans obtained with an effective dose not higher than that of a three-film radiographic examination or of the lowest dose of single-detector CT results in excellent intraobserver and interobserver agreements and an accuracy equivalent to that of standard-dose single-detector CT.

Acknowledgments

We thank Christian Delcour, Ingrid Perlot, and Michel Vanhaevert for their support and advice. We also thank all the CT technicians for their kind help in archiving the CT data.

References

33. Huda W, Atherton JV, Ware DE, Cumming WA. A PC program for estimating organ dose and effective dose values in computed tomography. (reply to letter) Eur Radiol 2000;10[suppl 1]:304.
Comparison Between Low-Dose and Standard-Dose Multidetector CT in Patients with Suspected Chronic Sinusitis

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Jacques Widelec¹
Viviane De Maertelaer²
Jean-Marie Bailly¹
Christian Delcour¹
Pierre Alain Gevenois³

OBJECTIVE. This study was designed to compare low- and standard-dose multidetector CT (MDCT) findings in patients with suspected chronic sinusitis.

SUBJECTS AND METHODS. Fifty patients underwent MDCT at 10 and 150 effective mAs. The low-dose MDCT protocol delivered a radiation dose of 0.047 mSv in men and 0.051 mSv in women, whereas the standard-dose MDCT protocol delivered a radiation dose of 0.70 mSv in men and 0.76 mSv in women. Scans of the right and left sides of sinonasal cavities were reviewed by three radiologists, with each physician reviewing a scan twice over an interval of more than 2 weeks. The reviewers were asked to evaluate the scans for eight mucosal and two bone abnormalities. We calculated the number of discrepancies in observed abnormalities between pairs of reviewers, among all three reviewers, and between findings on scans acquired with the two radiation doses.

RESULTS. The mean number of discrepancies in observed abnormalities on scans acquired with different radiation doses ranged from 0 to 5.2. Discrepancies between pairs of reviewers ranged from 1.0 to 12.8 for low-dose scans and from 1.0 to 13.0 for standard-dose scans. Discrepancies among all reviewers ranged from 1.0 to 10.3 for low-dose scans and from 1.0 to 8.7 for standard-dose scans. In analyzing cases of significant discrepancies in observations, we found greater variation between pairs of reviewers and among all three reviewers than between findings obtained with different dose levels.

CONCLUSION. Dose reduction played a far less important role in discrepancies of detected abnormalities than did the human element of reviewer observation. Given this finding and the fact that low-dose MDCT delivers a radiation dose that is no higher than that delivered by a four-view radiographic examination, low-dose MDCT should be considered the imaging method of choice in patients with suspected chronic sinusitis.

Chronic sinusitis is a frequent disorder that develops in up to one third of patients with acute bacterial sinusitis. It may occur as a complication of a dental infection or tooth extraction or may accompany systemic allergic events [1]. CT has become the method of choice for identifying and staging any inflammatory sinus disease and is a routine examination for the diagnosis of chronic sinusitis [2–5]. Chronic sinusitis is, by definition, frequently recurrent, and sensitive organs such as eye lenses and the thyroid are potentially subject to high cumulative doses of radiation from repeated CT examinations [6].

Recommended acquisition parameters for single-detector CT are based on studies using 3-mm-thick contiguous sections obtained with high milliampere settings [2, 4–6]. Low-dose single-detector CT has been shown to provide scans of good image quality leading to acceptable diagnostic performance compared with that achieved using standard-dose single-detector CT [7–12]. The recent development of multidetector CT (MDCT) enables us to obtain 1-mm-collimation scans and subsequent high-quality multiplanar reformations, but this protocol requires a radiation dose approximately 20% higher than that delivered with the formerly used 3-mm collimation. Regardless of the CT acquisition parameters used, the radiation dose has not yet been reduced to that delivered by a four-view radiographic examination [13]. The aim of our study was, therefore, to compare low-dose MDCT scans obtained at a radiation dose no higher than...
that delivered during a four-view radiographic examination with MDCT scans obtained with the standard radiation dose.

**Subjects and Methods**

From January to March 2001, 50 consecutive patients (20 men and 30 women; age range, 18–79 years; mean age, 44 years) who presented with a headache suspected to be caused by chronic sinusitis were referred for MDCT of the head and the sinonasal cavities. They underwent both low-dose MDCT of the sinonasal cavities and standard-dose MDCT of the head. The study protocol was approved by the institutional review board. Informed consent was obtained from all patients.

**MDCT Examinations**

Scans were obtained using a commercially available four-channel MDCT scanner (Somatom Plus Volume Zoom, Siemens Medical Systems, Forchheim, Germany). Patients were examined while in a supine position, and none received contrast material. A lateral 25.6-cm scout scan was first obtained at 120 kVp and 50 mAs. We then obtained a low-dose MDCT scan that covered the region from maxillary dental arch to the top of the frontal sinuses, with simultaneous acquisition of 4 × 1 mm collimations at 120 kVp and 10 effective mAs. As defined by Mahesh et al. [14], effective milliampere-seconds is determined by dividing the number of milliampere-seconds by the pitch, which, as defined by Silverman et al. [15], is the ratio between the table feed per rotation and the X-ray beam width. Table feed was 8 mm per 0.5 sec of scanner rotation (16 mm/sec). These parameters result in a pitch of 2:1. Low-dose scanning was followed by a standard-dose MDCT scanning of the head that covered the area from the maxillary dental arch to the upper limit of the vertex with simultaneous acquisition of 4 × 1 mm collimations at 120 kVp and 150 effective mAs. Table feed was 3 mm per 1 sec of scanner rotation (3 mm/sec). These parameters result in a pitch of 0.75:1. From the raw data, 1.25-mm-thick sections were reconstructed with a 0.8-mm increment using a bone algorithm. From these scans, 2-mm-thick axial, frontal, and sagittal reformations were obtained with a 2-mm increment.

**Effective Dose Calculations**

The effective dose was simulated on a personal computer using commercially available software (CT Expo, Medizinische Hochschule, Hanover, Germany) that requires no phantom measurements. Inputs corresponding to MDCT parameters, the patient’s sex, and the scanned region as represented on a graph of the Monte Carlo phantom model [16] were given to the program. The effective dose was then computed according to the Monte Carlo simulations for anthropomorphic phantoms as recommended by Nagel [17] and conversion factors as reported by Zankl et al. [16, 18]. The calculated effective doses were expressed according to the International Commission on Radiological Protection recommendations [19]. We also used this software to calculate the effective dose delivered by previously reported CT protocols (Table 1) [2, 5–8, 10, 11, 20, 21]. For all calculations, we considered the height of the scanned region to be 12 cm.

**Image Analysis**

The multiplanar reformations were stored on compact disks and reviewed on a clinical workstation (Wizard, Siemens Medical Systems) by a general radiologist who had 14 years’ experience in interpreting CT scans and by two neuroradiologists—one who had 14 years’ and one who had 19 years’ experience in interpreting head and neck CT scans. To meet quality criteria for clinical studies as recommended by Arrive et al. [22], we organized scan interpretations as follows: Multiplanar reformations from low-dose MDCT scans were reviewed before multiplanar reformations from standard-dose MDCT scans, each interpretation being performed in separate sessions more than 2 weeks apart. Therefore, each multiplanar reformation was interpreted twice by all three reviewers.

These reviewers were asked to judge whether the appearance of 10 distinct features was normal, abnormal, or indeterminate (Figs. 1–4). The first eight features were mucosal abnormalities that could potentially be found in the anatomic structures defined by Rao and El-Noueam [4] and by Zinreich et al. [2]: the sphenoethmoidal recess, including the ostium of the sphenoïd sinus; the osteomeatal unit, including the maxillary ostium, uncinate process, and infundibulum; the nasofrontal duct, including the frontal sinus; the maxillary sinus, excluding the osteomeatal unit; the anterior ethmoid cells; the posterior ethmoid cells; the ethmoid bulla; and the basal

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**TABLE 1** Comparison of Effective Radiation Doses Delivered During Imaging of the Head by Low-Dose and Standard-Dose Multidetector CT (MDCT) and CT and Radiology Protocols Used in Previous Studies

<table>
<thead>
<tr>
<th>Researchers</th>
<th>Modality</th>
<th>Acquisition Parameters</th>
<th>Pitch</th>
<th>No. of Image Orientations</th>
<th>Effective Dose (mSv)a</th>
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<td>Collimation/Increment (mm)</td>
<td>kVp</td>
<td>mAs</td>
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<td><strong>Our findings</strong></td>
<td><strong>MDCT</strong></td>
<td>4 × 1</td>
<td>120</td>
<td>10 eff</td>
<td>&gt; 1</td>
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<tr>
<td><strong>Low-dose</strong></td>
<td><strong>MDCT</strong></td>
<td>4 × 1</td>
<td>120</td>
<td>150 eff</td>
<td>&gt; 1</td>
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<td>Zinreich et al. [2]</td>
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<td>3/3</td>
<td>125</td>
<td>80</td>
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<td>Single-detector helical CT</td>
<td>2</td>
<td>120</td>
<td>165</td>
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<td>120</td>
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<td>Mamooya et al. [7]</td>
<td>Single-detector incremental CT</td>
<td>5/5</td>
<td>120</td>
<td>23</td>
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<td>Duvoisin et al. [8]</td>
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<td>175</td>
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<td>40</td>
<td>1.0:1.0</td>
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<td>Hein et al. [20]</td>
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<td>1.3:1.0</td>
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<td>Hagveldt et al. [21]</td>
<td>Single-detector incremental CT</td>
<td>1</td>
<td>120</td>
<td>40</td>
<td>1</td>
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Note.—eff = effective, NA = not applicable.
aEffective dose was calculated with CT Expo software (Medizinische Hochschule, Hanover, Germany) for mean scanned region 12 cm high in our study and with the CT and radiography parameters previously reported for other studies.

bFour radiographic views: lateral, Caldwell, Waters, and submentovertex.
**Fig. 1.**—Axial multiplanar reformations of multidetector CT (MDCT) scans obtained at level of sphenoid recess in 35-year-old man who presented with headache suspected to be caused by chronic sinusitis. R = right; a = anterior ethmoid cell; b = basal lamina (arrowhead); p = posterior ethmoid cell. 

A, Reformation of low-dose MDCT scan shows normal right (curved arrow) and abnormal left (straight arrow) sphenoid recess. No discrepancies among reviewers or between pairs of reviewers were noted.

B, Reformation of standard-dose MDCT scan shows normal right (curved arrow) and abnormal left (straight arrow) sphenoid recess. As with A, no discrepancies among reviewers or between pairs of reviewers were noted.

**Fig. 2.**—Coronal multiplanar reformations of multidetector CT (MDCT) scans obtained at level of osteomeatal units (straight arrows) in 24-year-old woman who presented with headache suspected to be caused by chronic sinusitis. R = right; m = maxillary sinus; b = right ethmoid bulla.

A, Reformation of low-dose MDCT scan shows abnormal left ethmoid bulla (curved arrow). No discrepancies were noted.

B, Reformation of standard-dose MDCT scan shows abnormal left ethmoid bulla (curved arrow) seen in A. Discrepancies in findings of ethmoid bulla were noted between first and second interpretation sessions of reviewer 1 and between reviewer 1 and reviewers 2 and 3 in first interpretation session.

**Fig. 3.**—Sagittal multiplanar reformations of multidetector CT (MDCT) obtained at level of left maxillary sinus (m) in 52-year-old woman who presented with headache suspected to be caused by chronic sinusitis. Enlarged periodontal space (arrow) was consistently identified throughout all interpretations. P = posterior; f = frontal sinus; m = maxillary sinus.

A, Reformation of low-dose MDCT scan reveals enlarged periodontal space (arrow).

B, Reformation of standard-dose MDCT scan reveals enlarged periodontal space (arrow) as clearly as seen in A.
Sets of Comparisons for Sphenoethmoidal Recess

<table>
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$\rho = 0.006$

Sets of Comparisons for Osteomeatal Unit

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$\rho = 0.004$

Sets of Comparisons for Nasofrontal Duct

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$\rho = 0.006$

Sets of Comparisons for Ethmoid Bulla

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<td>4</td>
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$\rho = 0.030$

$\rho < 0.001$

$\rho < 0.001$

$\rho = 0.034$

$\rho = 0.034$

$\rho = 0.028$

$\rho = 0.041$

$\rho < 0.001$

$\rho < 0.001$

Figs. 5–8.—Graphs representing mean (± SEM) number of discrepancies in identifying abnormalities of sphenoethmoidal recess (Fig. 5), osteomeatal unit (Fig. 6), nasofrontal duct (Fig. 7), and ethmoid bulla (Fig. 8). X-axis represents sets of comparisons: 1, two-by-two comparisons between pairs of reviewers at both sessions interpreting low-dose multidetector CT (MDCT) scans; 2, two-by-two comparisons between pairs of reviewers at both sessions interpreting standard-dose MDCT scans; 3, intrareviewer comparisons between two interpretation sessions of low-dose MDCT scans; 4, intrareviewer comparisons between two interpretation sessions of standard-dose MDCT scans; 5, comparisons between interpretations of low- and standard-dose MDCT scans for each reviewer and for both interpretation sessions. In cases of statistically significant discrepancies, $\rho$ values from Tukey tests [24] are given. Solid line represents significant difference involving comparisons of low-dose and standard-dose scans among reviewers. Dashed line represents significant difference involving another comparison. Vertical bars extending on either side of mean point represent range.
lamina. Mucosa was considered to be normal if it was not visible and was considered abnormal (thickened) if it was visible. Indeterminate findings included those instances in which a reviewer was doubtful or in which the anatomic structure was not seen (e.g., the osteomeatal unit after a previous surgery of the maxillary sinus). The ninth feature consisted of bony abnormalities such as sclerosis, thickening, or lysis of any structures excluding the periodontal space, and the 10th feature was an enlargement of the periodontal space. As suggested by Fuhrmann et al. [23], the appearance of the periodontal space was scored as normal if it was not visible, abnormal if it was visible, and indeterminate if a patient had no teeth. In each patient, right and the left sides were reviewed separately, resulting in a total number of scans equivalent to the number obtained in 100 patients.

Two weeks before the first interpretation session, reviewers were familiarized with observation recording procedures in an exercise involving multiplanar reformations obtained in 20 patients not included in our study population.

**Statistical Methods**

Because a definite diagnosis from an independent method of reference cannot be obtained and because standard-dose MDCT is not an a priori gold standard, our study compared discrepancies among all three reviewers and between pairs of the reviewers and discrepancies between the MDCT findings obtained using the two radiation doses. For every 10 observations recorded, we calculated the number of scoring discrepancies for each 100 sets of patient data. In all, five sets of comparisons were made: two-by-two comparisons between pairs of the three reviewers (i.e., between reviewers 1 and 2, 1 and 3, and 2 and 3) of both interpretation sessions of the low-dose scans, producing six comparative combinations; two-by-two comparisons between pairs of the three reviewers for both interpretation sessions of the standard-dose scans, producing six comparative combinations; intrareviewer comparisons of each reviewer’s interpretations of the low-dose scans, producing three comparative combinations; intrareviewer comparisons of each reviewer’s interpretations of the standard-dose scans, producing three comparative combinations; and comparisons between the low- and standard-dose findings for each of the three reviewers and for both interpretation sessions, producing six different comparative combinations.

For every 10 observations, a one-way analysis of variance was performed to globally compare the mean discrepancies in these five sets of combinations. In cases of statistically significant discrepancies, we then performed Tukey tests [24] to detect which set statistically differed from the others. Statistical significance for all tests was set at a p value of less than 0.05. The statistical software used was SPSS for Windows (release 11.0, SPSS, Chicago, IL).

**Results**

The mean number of discrepancies for the five sets of comparisons ranged from one to 13 overall. Global differences in mean discrepancies reached statistical significance for the mucosal abnormalities in the sphenoethmoidal recess, osteomeatal unit, nasofrontal duct, posterior ethmoid cells, ethmoid bulla, basal lamina, and periodontal space. Tukey tests revealed which set of comparisons differed from the others. Figures 5–11 show these differences with the corresponding p values. Differences in discrepancies for the mucosal abnormalities in the anterior ethmoid cells and maxillary sinus and for bony abnormalities did not reach statistical significance. We found that in the scoring for any abnormality in which discrepancies reached statistical significance, the discrepancies between the findings obtained with the two radiation doses were smaller.
than the discrepancies among all reviewers or between pairs of reviewers.

The effective dose delivered by the low-dose MDCT protocol was 0.047 mSv in men and 0.051 mSv in women, whereas the effective dose delivered by the standard-dose MDCT protocol was 0.70 mSv in men and 0.76 mSv in women. The calculated effective doses delivered by previously reported protocols are listed in Table 1.

Discussion

Our results show that when identifying mucosal and bone abnormalities in the sinonasal cavities, the number of discrepancies between findings on the low-dose and findings on standard-dose MDCT scans either did not differ or were even fewer than the number of discrepancies among all reviewers and between pairs of reviewers, depending on the feature considered. In other words, observational variations associated with a decrease in radiation dose are fewer than those that can be attributed to the reviewers themselves.

Interpretation of MDCT scans showed discrepancies among all reviewers and between pairs of reviewers even for scans obtained with a standard radiation dose. Standard-dose MDCT, therefore, should not be considered the absolutely perfect method of reference, as has been suggested in previous studies [21]. Indeed, we had considered the findings obtained with standard-dose MDCT as representing the gold standard, we would have misclassified 1–13% of the low-dose MDCT findings (depending on the observation considered). Consequently, calculated diagnostic performances would not have reflected the real value of low-dose MDCT. Because we had no actual diagnosis established by an independent method of reference, we compared only discrepancies in the interpretations of the three reviewers against discrepancies between scans obtained at different radiation doses.

The CT technique for imaging the sinonasal cavities may vary depending on numerous factors, such as whether one is using a helical versus an incremental technique or scanning in the axial versus the coronal planes in addition to the peak kilovoltage and milliampere-seconds presets and selection of collimation, pitch, and slice increment. All these factors greatly influence the radiation dose. In our study, the acquisition protocol was intended to provide high-quality imaging in all planes, to prevent attenuation artifacts caused by metallic dental restorations in the coronal acquisitions, and to reduce the radiation dose to the dose delivered by a four-view radiographic examination. To attain this dose, we used 10 effective mAs. As shown in Table 1, this effective dose is three to 10 times lower than the one delivered in previously reported studies with incremental or helical single-detector CT scanning. In a recent study, Hagvret et al. [21] used noncontiguous incremental acquisitions to obtain 10 coronal CT sections with a radiation dose 50% lower than that delivered in our study using the low-dose MDCT protocol. However, because their scans were not contiguous, Hagvret et al. might have not been able to identify clinically relevant data such as mucosal abnormalities in the sphenoid re- ccess or enlargement of the periodontal space. An MDCT acquisition protocol using 15 effective mAs, 80 kVp, and 4  ×  1 mm collimation could achieve a radiation dose similar to the one proposed by Hagvret et al. but provide all advantages of three-dimensional imaging.

Discrepancies vary from observation to observation. For example, discrepancies were higher for the mucosal abnormalities in the eth- moid bulla than in the maxillary sinus. These differences may be explained by anatomic vari- ants. Indeed, the ethmoid bulla is a tiny structure close to the osteomeatal unit in a region with nu- merous anatomic variants [25]. In comparison, the maxillary sinus is a large sinonasal cavity that is quite easy to evaluate. Although delineation of bone structures is widely believed to require a high radiation dose, our study did not find any difference in discrepancies in recording bone abnormalities (including the periodontal space) between judgments based on low-dose scans and those based on standard-dose scans, as illustrated in Figures 3 and 4.

In conclusion, low-dose MDCT should be considered as the method of choice for imaging sinonasal cavities in patients with suspected chronic sinusitis because it exposes patients to a radiation dose no higher than that used for a four-view radiographic examination.

Acknowledgment

We thank Alain Van Mylsem for preparing the figures.

References

Comparisons of Standard-Dose and Simulated Low-Dose Multi-Detector-Row CT Pulmonary Angiography.

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ABSTRACT

Objective. To compare standard-dose and simulated lower-dose MDCT pulmonary angiography.

Materials and Methods. Raw data from 21 CTPA scans obtained at 90 effective mAs in 11 women and 10 men, aged from 25 to 74 years (mean 52 years), and with at least one filling defect within a pulmonary artery, were used to simulate low-dose CTPA at 60, 40, 20, and 10 mAs. Three independent readers coded each central and segmental pulmonary artery twice as positive, negative or inconclusive for filling defects. The reading of 90 effective mAs in the second session was considered the reference standard. The potential for results depending on the reader, on the radiation dose, and/or on the pulmonary arteries was investigated using an analysis of variance. Positive and negative consistent values of the first reading session at standard-dose and simulated low-doses were calculated. The branching order of the artery with the most distally detected filling defect was recorded. For each dose, the quality of intravascular contrast was scored on a five-point scale. Reader agreements were investigated with Kappa statistics.

Results. The frequency of positive and inconclusive results (P = 0.211 and 0.076, respectively), positive and negative consistent values (P = 0.191 and 0.340, respectively), and the branching order of the artery with the most distally located artery with a filling defect (P = 0.412) were not dependent on the radiation dose. Agreements between and within readers were higher for central than for segmental arteries but were not influenced by the dose reduction, whatever the artery. The quality of intravascular contrast was not significantly changed when reducing the dose from 90 to 40 mAs (P ranging from 0.102 to 1.000).

Conclusion. The parameters we evaluated remained stable when reducing the radiation dose from 90 (effective) to 10 (simulated) mAs for MDCT pulmonary angiography.
INTRODUCTION

CT is responsible for more than one-half of the collective radiation exposure delivered by diagnostic procedures (1, 2). During the 1990s, it has been shown that naturally existing contrasts are high within the lungs, enabling one to reduce the radiation dose delivered by unenhanced CT, including thin-section CT (3), conventional CT (4), and helical CT (5). Also during that decade, helical CT pulmonary angiography (CTPA) became a major diagnostic procedure in patients suspected of pulmonary embolism (PE) (6). The radiation dose delivered by CTPA is lower than that by conventional pulmonary angiography (7, 8) but, as CTPA is performed in almost all patients with suspected PE, the collective radiation dose delivered in ruling out PE is increasing (9). Furthermore, recent studies have shown that the actual prevalence of PE among patients investigated by CTPA ranges only from 9 to 35% (9-11). With such a large group testing negative for PE, there is an urgent need to reduce the radiation dose, particularly in young female patients who represent approximately 20% of investigated patients (11). The purpose of our study, therefore, was to compare standard-dose and simulated lower-dose MDCT pulmonary angiography.

MATERIALS AND METHODS

Subjects
From March to July 2002, raw data sets of CTPA obtained in 21 consecutive adult patients (11 women and 10 men), aged from 25 to 74 years (mean 52 years) with at least one pulmonary embolus detected on standard dose CTPA, were included in our study group. Their mean body mass index (BMI) calculated from data available in the medical chart (10), was \(24.8 \pm 0.4\) kg/m\(^2\) (range 20.7 - 28.3 kg/m\(^2\)). The institutional review board approved our research protocol and agreed to a waiver of patient informed consent since this study was based on manipulating existing data. There was neither additional interaction with, nor additional radiation exposure to patients.

CT Examinations
Scans were obtained using a commercially available four-channel multi-detector row CT scanner (Somatom Volume Zoom, Siemens Medical Systems, Forchheim, Germany). Patients were examined while in supine position with both arms lying over the head. A frontal 51 cm scout view was first obtained at 80 kVp and 50 mA, followed by a standard-dose CT acquisition in the caudo-cranial direction from the level of the posterior costophrenic angles to the lung apices with intravenous injection of 100 mL of iodine contrast (Iobitridol – Xenetix 350 \(^\circ\), 350mg%, Guerbet, Aulnay-sous-Bois, France) at 3 mL per second using a power injector (CT 9000; Liebel-Flarsheim, Cincinnati, Ohio). The start delay was automatically determined by bolus tracking in the main pulmonary artery when a predetermined threshold of 100 Hounsfield Units was reached. CT was performed with an acquisition of 4 x 1 mm collimation at 120 kVp and 90 effective mAs. No tube current modulation was applied during the acquisitions. As defined by Manesh et al. (13), effective mAs corresponds to mAs divided by the pitch, whereby the pitch is defined by Silverman et al. (14) as the ratio between the table feed per rotation and the X-ray beam width. Table feed was 7 mm per 0.5 sec scanner rotation (14 mm/sec). These parameters result in a pitch-factor of 1.75.

Simulated Low-Dose CTPA
We used a computer-assisted method to generate CTPA images simulating reduced doses. This process involved superimposing computer-calculated noise on the original
scan raw-data. In order to simulate scans obtained with effective mAs settings of 60, 40, 20, and 10 mAs, the amount of added noise was increased stepwise, whereby its magnitude was proportional to the square root of the measured X-ray attenuation for each detector channel (15). The resulting 105 raw data sets (21 originals and 84 simulated ones) were transferred to a CT unit and reconstructed with 1.25 mm-thick sections, 0.8 mm increment, and a soft tissue algorithm (Kernel B 20).

**Image Analysis**

Patient information and simulated mAs presets were erased from images that were randomly renumbered by using random tables by Fisher *et al.* (16). Three different readers independently read each 1.25 mm-thick image on a clinical workstation with 3D functionalities (Wizard, Siemens Medical Systems, Forchheim, Germany). The readers were comprised of a general radiologist with 18 years experience in reading CT (Reader 1 - PM), a chest radiologist with 12 years experience in all thoracic imaging techniques (Reader 2 - PS), and a medical student near completion of medical school with no training in radiology or experience in medical imaging (Reader 3 - WP). None of the readers were involved in selecting patients, in conducting the CT examinations on which PE was detected, or in preparing data sets but they knew that at least one filling defect was present in each patient. Images were analyzed twice by each reader, in two separate and independent reading sessions with at least a two-month interval between sessions. Each reading session was completed within two weeks. Readers were asked to record filling defects in pulmonary arteries. These were named main, right and left pulmonary arteries (MPA, RPA and LPA, respectively), right upper lobe pulmonary artery (RULPA), and right and left interlobar pulmonary arteries (RILPA and LILPA, respectively). For segmental arteries, we used the nomenclature outlined by Remy-Jardin *et al.* (17). This nomenclature is based on standard description by Jackson and Huber (18), and by Boyden (19), as adapted by Ghaye *et al.* (20). Segmental arteries were named from RA1 to RA10, and from LA1 to LA10 for the right and the left lung, respectively. If a filling defect was detected in a location more distal than a segmental pulmonary artery, that corresponding segmental artery was coded as ‘1’. Each artery was coded on a three-point scale (0 = no filling defect, 1 = at least one filling defect, 2 = inconclusive). Readers were also asked to record the branching order of the artery with the most distally detected filling defect and to grade the quality of intravascular contrast on a five-point scale. Difference between blood clots and enhanced normal vascular content was scored “0” if very difficult to see, “1” if difficult to see, “2” if clearly seen, “3” if very clearly seen, and “4” if exceptionally well seen.”

Two weeks before the first reading session, readers were familiarized with the scoring system in a training session using standard-dose CT scans obtained in 20 patients who were not included in our study group.

**Statistical Methods**

Agreements between and among readers were investigated by calculating Cohen’s $\kappa$ statistics with their asymptotic standard error (ASE) (21). Inter-reader agreements were assessed for both reading sessions. The hypothesis of no agreement between the two readers was tested and the associated P-values were calculated (22). All $\kappa$ values were interpreted as proposed in the literature (23): a $\kappa$ value lower than 0.20 indicates poor agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, good agreement; and 0.81-1.00, excellent agreement.

In order to compare diagnosis achieved by simulated low-dose CTPA with standard-dose CTPA on homogeneous groups of arteries, we pooled pulmonary arteries into the
The number of inconclusive results depending on the reader, on the radiation dose, and/or on the four groups of arteries was investigated using an analysis of variance with two repeated factors (three reader levels and five dose levels), one group factor (four artery group levels) and the two-way interactions between those factors. As in routine practice, images are usually read only once, the first reading session was considered. A same analysis was performed on the number of positive results.

In order to eliminate potential memorization by a reader of scans from one session to another, we separated reading sessions by at least two months. Additionally, changing dose produces two variables: the different doses themselves, and subjective interpretation of the second image set. In order to overcome the variable of reader subjectivity, we used the results from one reading session as a reference point to interpreting results from another session. Two other dynamics are also important to bear in mind: (i) the more images a reader reviews, the more adept he/she becomes at correctly interpreting noisy images, and (ii) in clinical practice there is only one reading. Consequently, we investigated the performance of standard- and simulated low-doses at the first reading session by comparison against the second reading session with 90 mAs as the reference. As there is thus no accounting for true positives and negatives, we considered positive and negative consistent values instead of positive and negative predictive values. For each reader and each artery group, the consistent values were compared between radiation doses with Fischer’s exact tests.

Mean branching order of the arteries with the most distally located filling defect, and of intravascular contrast quality scores were compared among radiation doses for the first reading session by each reader with Friedman tests, followed in case of significance with Wilcoxon tests for paired data.

Statistical significance for all tests was set at a P-value less than 0.05. The statistical software used were SPSS for Windows (release 11.0, SPSS, Chicago, Illinois), and StatXact 3 (Cytel, Cambridge, MA).

RESULTS
CTPA images acquired with 90 effective mAs and with simulated 60, 40, 20, and 10 mAs are shown in Figure 1. The number of inconclusive and positive results for each reading session, each reader and each radiation dose are given in Tables 1 and 2, respectively. The number of inconclusive results did vary according to the reader ($P < 0.001$), but not to the dose ($P = 0.076$) or to the artery group ($P = 0.248$). The number of positive results did not vary according to the reader ($P = 0.537$), to the dose ($P = 0.211$), or to the artery group ($P = 0.512$).

Representative $\kappa$-values ($\pm$ ASE) for intra-reader and inter-reader agreements at 90, 40, and 10 mAs are shown in Figure 2 and 3, respectively. For display simplicity, agreements at 60 and 20 mAs are not shown, but they were similar to those at 90, 40, and 10 mAs. Intra-reader reproducibility reached statistical significance except for Reader 3 for RA2 and RA4. Inter-reader reproducibility was higher between Reader 1 and 2 than between either one and Reader 3; $\kappa$-values generally did not reach
statistical significance when this reader was involved. However, $\kappa$ values at low-doses were within the same range as those at standard dose.

The relationship between negative and positive consistent values at the various mAs settings are shown for each reader in Figures 4 and 5. When reducing the radiation dose from 90 to 10 mAs, we did not observe, for each reader and each artery group, any significant difference in consistent values ($P$ ranging from 0.191 to 1.000 and from 0.340 to 1.000, respectively for positive and negative consistent values).

The relationship between the branching order of arteries with the most distally located filling defect and the mAs settings is shown for each reader in Figure 6. When reducing the radiation dose from 90 to 10 mAs, we did not observe, any significant difference in this branching order with $P$-value ranging from 0.412 to 0.548 from reader to reader.

The relationship between intravascular contrast quality and the mAs settings is shown for each reader in Figure 7. We did not observe any significant difference in the quality score from 90 to 40 mAs for any reader ($P$ ranging from 0.102 to 1.000), but we did observe a significant difference below 40 mAs for Reader 1 ($P = 0.005$), and below 20 mAs for Reader 2 ($P = 0.021$) and Reader 3 ($P = 0.003$).

**DISCUSSION**

This study shows that positive or negative consistent values of CTPA for the diagnosis of PE, as well as the observer agreements, remain stable when reducing the radiation dose from 90 to 10 mAs. In addition, identification of the branching order of the artery with the most distal filling defect is also not influenced by the dose reduction. However, intravascular contrast quality decreased, at least for one reader, when the mAs presets are lower than 40 effective mAs. Our study shows that although intra-reader agreement does depend on the reader’s experience and on the location of the emboli, it is not influenced by radiation dose. Thus, reducing the radiation dose of CTPA appears acceptable with 40 mAs as an appropriate preset.

We observed intra- and inter-reader agreement lower than those usually reported. This is likely due to the fact that our readers were required to identify emboli at more distal levels than usual (24, 25), and to record the specific location of that emboli rather than merely considering the examination as a whole as positive or negative. One might expect that perfectly reproducible readers would have achieved consistent values of 100% for the first reading session with 90 mAs as compared to the second reading session at the same mAs presets. Nonetheless, the corresponding consistent values for experienced readers range from 77 to 95%, i.e., a loss of 5 to 13%. However, for decreases in radiation dose from 90 to 10 mAs, consistent values do not vary significantly. In other words, repeating the reading has a much greater influence on consistent values than does reducing the radiation dose.

The number of inconclusive results was higher for Reader 3, a medical student with no training in radiology or experience in medical imaging, than for Reader 1 and 2, who were experienced radiologists. However, this number was not influenced by dose reductions. In addition we did not observe any dose for which filling defects were no longer detectable, but we cannot conclude that 10 mAs could be used for all sizes of patients, as data from obese patients were not included in our trial (in this trial BMI ranged from 20.7 to 28.3 Kg/m$^2$).
Obtaining a true negative or positive diagnosis for PE is the primary objective for examining patients with suspected PE; risk from radiation dose can, in principle, be regarded as less important. However, considering that CTPA is now often the first imaging technique used in these patients, together with the high number of patients who turn out not to have PE, the risk benefit ratio of radiation exposure becomes a more important issue. Dose reduction (adapted according to the patient’s body size) should, therefore, be recommended. A recent survey of practices and policies for CTPA (26) in pregnant women has revealed that the most often used method for reducing the radiation dose consists in reducing the Z coverage. The results of our study recommend reducing the mAs presets as well.

Our study has some limitations. First, simulating low-mAs presets by adding random noise in the raw data may not correspond exactly to scans actually acquired in patients with low-mAs presets. Nevertheless, in a validation trial made on unenhanced CT scans, experienced chest radiologists were unable to distinguish simulated reduced-dose from actually reduced-dose CT images (13). Further, there is no logical reason to believe that enhanced CTPA could differ from unenhanced CT regarding simulation of dose reduction. Second, the data that we had access to did not include obese patients. However, as the effective dose is lower in obese patients than in small ones (27), the need for mAs reduction appears less critical in obese patients. Nonetheless, dose reduction should be investigated in such individuals. Third, as only patients who actually had a filing defect were included in our study sample and as we had no independent method of reference, we were unable to investigate the possible influence of dose reduction on the false positive rate of CTPA. As opposed to usual clinical settings characterized by a majority of patients with no definite PE, our recruitment process has probably biased the results. Consequently, they must be only considered with respect to their stability while reducing the dose. Fourth, we did not address the possible influence of dose reduction on mixing artifacts. On our workstation, we use to discriminate intra-arterial clots and mixing artifacts by considering the contours of the hypoattenuated area on MPRs and by measuring its attenuation. As reducing the dose increases the standard deviation of the attenuation values calculated in the ROI but not the attenuation values themselves, dose reduction probably does not influence this discrimination.

In conclusion, the parameters we evaluated remained stable when reducing the radiation dose from 90 (effective) to 10 (simulated) mAs for MDCT pulmonary angiography. Further research is needed for optimizing mAs settings in a larger group of patients with suspected PE, including obese patients, and with regard to the diagnosis of PE, of alternative diseases and to patient outcome.
REFERENCES

LEGEND TO FIGURES

Figure 1
MDCT pulmonary angiography axial scans focused on the right lower lobe, acquired at 90 mAs (Fig 1a) and simulated at 60 mAs (Fig 1b), 40 mAs (Fig 1c), 20 mAs (Fig 1d), and 10 mAs (Fig 1e). A filling defect is seen in R10A at all radiation doses. Noise in the chest wall is clearly appearing at 20mAs and 10 mAs as compared to 90 mAs.

Figure 2
Intra-reader agreements. Closed circles, triangles and squares represent Kappa values for agreements within Reader 1, Reader 2, and Reader 3, respectively. MPA = main pulmonary artery; RPA = right pulmonary artery, LPA = left pulmonary artery, RULPA = right upper lobe pulmonary artery, RILPA = right interlobar pulmonary artery, LILPA = left interlobar pulmonary artery. Segmental arteries are named R1A to R10A and L1A to L10A for the right and the left lungs, respectively. For each artery, triplets of vertical lines show from left to right Kappa values for intra-reader agreements at 90, 40, and 10 mAs. Almost all triplets are grouped around the same Kappa values.

Figure 3
Inter-reader agreements concerning the first reading session. Open circles, triangles and squares represent Kappa values for agreements between Reader 1 and 2, Reader 2 and 3, and Reader 1 and 3, respectively. MPA = main pulmonary artery; RPA = right pulmonary artery, LPA = left pulmonary artery, RULPA = right upper lobe pulmonary artery, RILPA = right interlobar pulmonary artery, LILPA = left interlobar pulmonary artery. Segmental arteries are termed R1A to R10A and L1A to L10A for the right and the left lungs, respectively. For each artery, triplets of vertical lines show from left to right Kappa values for inter-reader agreements at 90, 40, and 10 mAs. Almost all triplets are grouped around the same Kappa values.

Figure 4
Graphs representing the variations of negative consistent values of CTPA as a function of the radiation dose for four groups of pulmonary arteries (central arteries, upper lobe arteries, middle lobe arteries, and lower lobe arteries) for Reader 1 (Fig 4a), Reader 2 (Fig 4b), and : Reader 3 (Fig 4c). Variations did not reach statistical significance (P ranging = 0. 340).
**Figure 5**
Graphs representing the variations of positive consistent values of CTPA as a function of the radiation dose for four groups of pulmonary arteries (central arteries, upper lobe arteries, middle lobe arteries, and lower lobe arteries) for Reader 1 (Fig 5a), Reader 2 (Fig 5b), and Reader 3 (Fig 5c). Variations did not reach statistical significance (P ranging = 0.191).

**Figure 6**
Graph showing variations in branching order of the artery with the most distally detected filling defect as a function of the mAs level. Readings by Reader 1 to 3 are presented as lozenges, rectangles, and triangles, respectively. Variations did not reach statistical significance (P ranging from 0.412 to 0.548).

**Figure 7**
Graph showing variations in quality score of intravascular contrast as a function of the mAs level. Significant reduction in the quality score was observed for Reader 1 at mAs preset lower than 40 mAs (P = 0.005), and for Readers 2 and 3 at mAs preset lower than 20 mAs (P = 0.021 and P = 0.003, respectively).
### Table 1: Inconclusive results at each reading session, for each reader, and at each radiation dose

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Table 2 Positive results at each reading session, for each reader, and each radiation dose

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Figure 4a

Reader 1

Negative Consistent Value

mAs

Central  Upper  Middle  Lower
Figure 4b

Reader 2

Negative Consistent Value

mAs

Central  Upper  Middle  Lower
Figure 4c

Reader 3

Negative Consistent Value

Central  Upper  Middle  Lower

mAs

60%  70%  80%  90%  100%
Figure 5a

Reader 1

Positive Consistent Value

Central
Upper
Middle
Lower
Figure 5b

Reader 2

Positive Consistent Value vs mAs

- Central
- Upper
- Middle
- Lower
Figure 5c

![Graph showing Positive Consistent Value vs. mAs for Reader 3. The graph has four curves, each representing Central, Upper, Middle, and Lower regions. The y-axis represents Positive Consistent Value ranging from 60% to 100%, and the x-axis represents mAs ranging from 90 to 10.](image-url)
Figure 6

Branching Order of Distal Emboli

Mean Branching Order vs. mAs
Figure 7

Quality of Vascular Enhancement

![Graph showing quality score vs mAs for Reader 1, Reader 2, and Reader 3.](image)

- Reader 1
- Reader 2
- Reader 3
Acute Appendicitis: Comparison of Low-Dose and Standard-Dose Unenhanced Multi–Detector Row CT

PURPOSE: To prospectively compare low- and standard-dose unenhanced multi–detector row computed tomography (CT) for the diagnosis of acute appendicitis.

MATERIALS AND METHODS: Ninety-five consecutive patients underwent two unenhanced multi–detector row CT examinations with 4 × 2.5-mm collimation, 120 kVp, and 30 and 100 effective mAs. Two radiologists independently read the images obtained at each dose during two sessions. Readers recorded visualization of the appendix and presence of gas in its lumen, appendicolith, periappendiceal fat stranding, cecal wall thickening, and abscess or phlegmon to measure the diameter of the appendix and to propose diagnosis (appendicitis or alternative). Data were compared according to dose and reader, with definite diagnosis established on basis of surgical findings (n = 37) or clinical follow-up. χ² tests and logistic regression were used. Measurement agreements were assessed with Cohen χ statistics.

RESULTS: Twenty-nine patients had a definite diagnosis of appendicitis. No difference was observed between the frequency of visualization of the appendix (P = .874) neither in its mean diameter (P = .101–.696, according to readers and sessions) nor in the readers’ overall diagnosis (P = .788) at each dose. Sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of each sign were not different between doses. Fat stranding, appendicolith, and diameter were the most predictive signs, regardless of dose, yielding approximately 90% of correct diagnoses. The ability to propose a correct alternative diagnosis was not influenced by the dose.

CONCLUSION: Low-dose unenhanced multi–detector row CT has similar diagnostic performance as standard-dose unenhanced multi–detector row CT for the diagnosis of acute appendicitis.

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Acute appendicitis is the most common cause of acute abdominal pain that requires surgical intervention in the Western world (1). However, the clinical diagnosis of appendicitis is accurate in only 80% of the cases (1–3). To increase diagnostic accuracy, computed tomography (CT) has been used more frequently during the past decade because it is reproducible, sensitive, specific, easy to perform, and causes little discomfort to the patient (1,2). Even without oral or intravenous administration of contrast material, diagnostic performances of greater than 95% have been reported (4,5). CT, however, also delivers ionizing radiation to patients. Since many individuals suspected of having acute appendicitis are young, with a mean age of 30 years (2), radiation dose is of particular concern. Reduction of the radiation dose has already been successfully used in conditions characterized by intrinsic high contrast between structures, that is, in pulmonary nodule screening, in diagnosis of nephrolithiasis and ureterolithiasis, and with CT colonography (6–11). It has not yet been used in conditions with low contrast between structures, such as acute appendicitis.

The aim of this study, therefore, was to prospectively compare low- and standard-dose unenhanced multi–detector row CT in patients suspected of having acute appendicitis.
MATERIALS AND METHODS

Consecutive patients seen in the emergency room of Academic Erasme Hospital between March and December 2002 were asked to participate in this prospective study. The inclusion criteria were age of older than 15 years and acute right lower quadrant abdominal pain for which CT examination was requested by the emergency room physician to evaluate for acute appendicitis. Exclusion criteria were prior appendectomy or pregnancy. The study group consisted of 95 (58 female and 37 male) patients aged 16–74 years (mean, 37 years). The mean age of female patients was 38 years (range, 16–74 years) and that of male patients was 36 years (range, 17–73 years). Body mass index (BMI) was calculated from the data available in the medical chart (12). The institutional review board approved our research protocol, and written informed consent was obtained from all patients; for those who were adolescents, consent was obtained from the parents.

CT Examinations

CT images were obtained by using a commercially available four-detector row scanner (Somatom Plus Volume Zoom; Siemens Medical Systems, Forchheim, Germany). Patients were examined in the supine position. A frontal 52-cm scout view was first obtained at 120 kVp and 50 mA, followed by acquisition of two helical scans at the top of the liver to the symphysis pubis with a 4 × 2.5-mm collimation, 120 kVp, and 30 and 100 effective mAs. The effective milliampere second, as defined by Mahesh et al (13), corresponds to milliampere second divided by the pitch, where pitch is defined by Silverman et al (14) as the ratio between the table feed per rotation and the x-ray beam width. Table feed was 15 mm per 0.5 second of scanner rotation (30 mm/sec), resulting in a pitch of 1.5:1.0. From the raw data of each acquisition, 3-mm-thick transverse sections were reconstructed with 1.5-mm increments. No patient received oral, rectal, or intravenous contrast material.

If the CT diagnosis remained uncertain, the radiologist conducting the examination was authorized to acquire additional scans with intravenous injection of iodinated contrast material (Ultravist 370; Schering, Berlin, Germany). These scans were obtained in 11 patients. Results of the CT examination were immediately interpreted and reported to the referring clinician, who integrated the results into the final case management decision. This interpretation was not taken into consideration for the present study.

Image Analysis

Reconstructed images were stored on compact disks and read, for the purpose of the present study, on a clinical workstation with three-dimensional functionalities (Wizard; Siemens Medical Systems). These images were read independently by a board-certified radiologist (D.T.) with 15 years experience in reading CT scans of the abdomen (reader A) and a 3-year radiology resident (P.B.) who had no specific coaching or training prior to the study (reader B). The readers were aware that the patient had presented with acute right lower quadrant pain but they were blinded to the interpretation by the radiologist who had conducted the examination, the results obtained from any other diagnostic technique (eg, laboratory results), and the definite diagnosis. They were not blinded to the radiation dose.

Reconstructions obtained from low-dose scans were read prior to those obtained from standard-dose scans in two independent reading sessions, with a minimum 2-week interval between the two sessions, and were presented to readers in the same patient order. One month later, reconstructions from low- and standard-dose scans were read again, also with a 2-week interval between each reading session. At each session, readers were asked to record whether the appendix was visible, to measure its largest outer transverse diameter (if seen) by using electronic calipers, and to code the presence of appendiceal lumen, appendicolith, periappendiceal fat stranding, cecal wall thickening, and abscess or phlegmon in the right iliac fossa. The presence of gas was considered to be a possible negative criterion for appendicitis, while the other signs were considered to be positive criteria suggestive of appendicitis. After separately coding each sign, readers were asked to propose an overall diagnosis of appendicitis or an alternative disease that could explain the acute right lower quadrant pain.

Effective Dose Calculations

The effective dose was computer simulated with commercially available software (CT-Expo; G. Stamm, Medizinische Hochschule, Hanover, Germany) installed on a personal computer. This software does not require any phantom measurements. CT acquisition parameters, patient sex, and the scanned region as represented on a graph of the Monte Carlo phantom model were entered into the program. The effective dose was then computed according to the Monte Carlo simulations for anthropomorphic phantoms, as recommended by Nagel (15); and conversion factors, as reported by Zankl et al (16,17). The calculated effective doses were expressed according to the International Commission on Radiological Protection recommendations (IRCP report no. 60). We also used this software to calculate the effective dose delivered in previously published studies in which CT acquisition parameters were available (4,5,18–20).

Definite Diagnosis

The definite diagnosis was based on surgical findings (n = 37) or findings from other diagnostic techniques (n = 58) consisting of ultrasonography (US), contrast material–enhanced standard-dose CT, barium enema, vaginal smear, colonoscopy with biopsy, and laboratory analysis. For all patients who did not undergo surgery, information from the clinical follow-up was obtained by reviewing the medical charts and telephone calls 1 month after the acute episode.

Statistical Analysis

Quantitative variables are expressed as mean ± standard error of the mean. Intrareader and interreader agreements in the assessment of the coded signs were investigated by calculating Cohen ω statistics with their asymptotic standard error (21). Intrareader agreements were assessed for both reading sessions. The null hypothesis of no agreement between the two observers was tested, and the associated P values were calculated (22). All ω values were interpreted as proposed in the literature (23). A ω value lower than 0.20 indicated poor agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, good agreement; and 0.81–1.00, excellent agreement.

We created receiver operating characteristic (ROC) curves and determined the threshold of appendiceal diameter that led to the optimal values of probabilities in correctly predicting the presence or absence of appendicitis. This optimal threshold was defined as the intersection of the ROC curve with the bisecting line at which sensitivity equated specificity (24).

To evaluate the performance of multi-detector row CT at each radiation dose, the number of misclassifications com-
pared with the number of definite diagnoses of appendicitis was summed according to readers and reading sessions for both low and standard radiation doses. The \( \chi^2 \) test was used to compare the number of misclassifications with the number of reading sessions according to doses. A similar procedure was used to compare the performance of readers.

At each dose and for each reader, stepwise logistic regression was used to predict the probability of correctly diagnosing appendicitis as a function of the different CT signs. The effect of sex, age, and BMI on the probability of appendix visualization was investigated with logistic regression for their symptoms were not elucidated with diagnostic technique and had resolved without any specific treatment. Consequently, 66 (45 female and 21 male) patients were thus classified as definitely not having acute appendicitis.

### Visualization and Diameter of the Appendix

The number of patients in whom the appendix was visualized is listed in Table 1. Thirty-one (19 female and 12 male) patients were considered as having nonspecific abdominal pain because their symptoms were not elucidated with any diagnostic technique and had resolved without any specific treatment. Consequently, 66 (45 female and 21 male) patients were thus classified as definitely not having acute appendicitis.

### RESULTS

#### Definite Diagnosis

Twenty-nine (13 female and 16 male) of the 95 patients were classified as definitely having acute appendicitis. There were more male (16 of 37) than female (13 of 58) patients (\( P = .032 \)). The diagnosis was confirmed with microscopic examination of the surgical specimens in all patients. Thirty-five (26 female and nine male) patients had an alternative diagnosis (Table 1). Thirty-one (19 female and 12 male) patients were considered as having nonspecific abdominal pain because their symptoms were not elucidated with any diagnostic technique and had resolved without any specific treatment. Consequently, 66 (45 female and 21 male) patients were thus classified as definitely not having acute appendicitis.

#### Table 1

<table>
<thead>
<tr>
<th>Alternative Diagnosis*</th>
<th>Diagnostic Technique</th>
<th>Reader A</th>
<th>Reader B</th>
<th>Reader A</th>
<th>Reader B</th>
<th>Reader A</th>
<th>Reader B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose</strong></td>
<td><strong>Low Dose</strong></td>
<td><strong>Standard Dose</strong></td>
<td></td>
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<tr>
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<td>4</td>
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<td>4</td>
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<tr>
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<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Standard</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Standard</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* Data in parentheses are the number of each definite diagnosis based on diagnostic modalities used as methods of reference.

† There was a 2-week interval between the reading sessions.

The number of patients in whom the appendix was visualized is listed in Tables 2 and 3 according to each reader, each interpretation session, and each radiation dose. No statistically significant difference was observed between readers (\( P = .425 \)) or between radiation doses (\( P = .874 \)). More important, the appendix was visualized in all 29 patients with a definite appendicitis, regardless of the reader, the interpretation session, or the radiation dose.

Measurements of the appendiceal diameter are summarized in Table 4. The mean appendiceal diameters were 11.7 mm ± 0.2 and 6.3 mm ± 0.3 in patients with and those without definite appendicitis, respectively, (\( P < .001 \)). Mean appendiceal diameters were also compared between reading sessions, readers, and radiation doses. No statistically significant difference was observed between reading sessions (\( P = .351–.792 \)) except for reader B at low-dose CT (\( P = .020 \)). The mean appendiceal diameter measured at the first reading session was compared between readers at each radiation dose. No statistically significant difference was observed with use of the standard dose (\( P = .550 \)), but a difference between readers was detected with use of a low dose (\( P = .015 \)). Last, the mean appendiceal diameter was compared between radiation doses for each reader and each reading
Intrareader and Interreader Agreements

The frequency of signs and the overall diagnosis from both readers during reading sessions at standard dose and low dose are shown in Tables 2 and 3. The \( \kappa \) values (\( \pm \)asymptotic standard error) for intrareader and interreader agreements at low dose and at standard dose are shown in Figures 1 and 2, respectively.

### Misclassifications Compared with Definite Diagnosis

Differences in misclassified signs between low-dose and standard-dose examinations and between readers were compared (Table 5). We did not observe any statistically significant difference in these comparisons except between readers for the overall diagnosis of appendicitis, where the number of misclassified overall diagnoses was lower for reader A than for reader B (\( P = .031 \)). No difference was observed between radiation doses (\( P = .788 \)).

The frequency of each alternative diagnosis proposed by each reader at each reading session and for each radiation dose compared with the frequency of definite alternative diagnosis is listed in Table 1.

### Diagnostic Performance

For each CT sign and overall diagnosis, we calculated the sensitivity, specificity, positive predictive value, negative predictive value, and accuracy. This was done for each reader and each reading session.
at low dose and at standard dose (Table 6). No statistically significant difference between low dose and standard dose was observed in diagnostic performances (P values .387 to .99).

For the appendiceal diameter, ROC curves were drawn. The sensitivity was equated to the specificity for each reader and each radiation dose (Fig 3). These values ranged from 88% to 91% and corresponded to an appendiceal diameter ranging from 7.7 to 8.6 mm. For standard dose, the area under the curve was 0.925 (95% CI: 0.857, 0.993) and 0.905 (95% CI: 0.838, 0.972) for readers A and B, respectively. For low dose, the area under the curve was 0.921 (95% CI: 0.852, 0.990) and 0.928 (95% CI: 0.873, 0.984) for readers A and B, respectively. The overlap between the 95% CIs indicates no significant difference in measurements of appendiceal diameter between radiation doses or between readers.

Logistic regression models showed that at low dose, the most predictive sign was perappendiceal fat stranding and the second (and only other) sign was appendicolith, together yielding 89% correct classification for the diagnosis of appendicitis by reader A. For reader B, the most predictive sign was appendiceal diameter and perappendiceal fat stranding, together yielding 88% correct classification. At standard dose, the most predictive sign was perappendiceal fat stranding and the second and last sign was appendiceal diameter, together yielding 94% correct classification. At standard dose, the most predictive sign again was appendiceal diameter and perappendiceal fat stranding, this time yielding 92% correct classification.

Effect of Sex, Age, and BMI

In the entire study group, the mean BMI was 24.0 kg/m² ± 4.6 (range, 16.4–40.7 kg/m²). Sex, age, and BMI were not found to influence the probability of appendix visualization, neither for dose nor for reader (P = .111–.788). We also did not elicit any lower or upper threshold of BMI where the appendix was not visible.

We assigned patients into the following three categories, which were adapted from the five BMI categories proposed by the World Health Organization (12): underweight (BMI range, 16.4–18.4 kg/m²; n = 9; included two patients with a definite diagnosis of appendicitis), normal to overweight (BMI range, 18.6–29.7 kg/m²; n = 76; included 24 patients with a definite diagnosis of appendicitis), and obese to extremely obese (BMI range 30.1–40.7 kg/m²; n = 10; included three patients with a definite diagnosis of appendicitis). Figures 4 and 5 illustrate findings from low- and standard-dose CT in an underweight and an extremely obese patient, respectively. Comparisons of sensitivity and specificity of each CT sign, as well as the overall reader diagnosis between BMI subgroups, did not reveal a statistically significant difference (P values from .051 to .99).

Effective Radiation Dose

The mean height of the scanned region was 39.0 cm ± 3.1 (range, 32.4–44.7 cm) for male patients and 37.6 cm ± 3.2 for female patients.
(range, 29.5–44.8 cm) for female patients. At 100 effective mAs, the calculated mean effective radiation dose was 5.2 mSv for male and 7.1 mSv for female patients. At 30 effective mAs, the calculated mean effective radiation dose was 1.4 mSv for male and 2.2 mSv for female patients. These radiation doses are compared with those delivered in previously published studies in Table 7.

**DISCUSSION**

Appendicitis is a potentially life-threatening condition but one that can be treated with simple and efficient surgical procedures. Consequently, it is imperative that diagnostic tests be highly sensitive with a very high negative predictive value (25). Unenhanced multi-detector row CT using low and standard doses was compared with previously published studies.

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**TABLE 5**

<table>
<thead>
<tr>
<th>Dose, Readings, and P Value</th>
<th>Gas in the Appendiceal Lumen*</th>
<th>Appendicolith (n = 95)</th>
<th>Periappendiceal Fat Stranding (n = 95)</th>
<th>Cecal Wall Thickening (n = 95)</th>
<th>Phlegmon or Abscess (n = 95)</th>
<th>Overall Diagnosis of Appendicitis (n = 95)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reader A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Session 1</td>
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<td>22</td>
<td>16</td>
<td>28</td>
<td>26</td>
<td>6</td>
</tr>
<tr>
<td>Session 2</td>
<td>67/83</td>
<td>26</td>
<td>16</td>
<td>34</td>
<td>27</td>
<td>5</td>
</tr>
<tr>
<td>Reader B</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Session 1</td>
<td>66/86</td>
<td>25</td>
<td>15</td>
<td>29</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>Session 2</td>
<td>59/83</td>
<td>24</td>
<td>12</td>
<td>28</td>
<td>26</td>
<td>7</td>
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<td>Standard</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reader A</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Session 1</td>
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<td>27</td>
<td>16</td>
<td>33</td>
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<tr>
<td>Reader B</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Session 1</td>
<td>65/84</td>
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<td>18</td>
<td>31</td>
<td>26</td>
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<td></td>
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</tr>
<tr>
<td>Low vs standard dose</td>
<td>.470</td>
<td>.621</td>
<td>.693</td>
<td>.697</td>
<td>.871</td>
<td>.788</td>
</tr>
<tr>
<td>Reader A vs reader B</td>
<td>.588</td>
<td>.869</td>
<td>.553</td>
<td>.816</td>
<td>.871</td>
<td>.031</td>
</tr>
</tbody>
</table>

* Numbers are patients with gas in the lumen/patients with visualized appendix.

**TABLE 6**

<table>
<thead>
<tr>
<th>Radiation Dose and Statistic</th>
<th>Air-filled Lumen in Visualized Appendix</th>
<th>Appendicolith (n = 95)</th>
<th>Periappendiceal Fat Stranding (n = 95)</th>
<th>Cecal Wall Thickening (n = 95)</th>
<th>Phlegmon or Abscess (n = 95)</th>
<th>Overall Diagnosis of Appendicitis (n = 95)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.72–0.90</td>
<td>0.21–0.34</td>
<td>0.97–1.00</td>
<td>0.07–0.34</td>
<td>0.10–0.14</td>
<td>0.97–1.00</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.69–0.79</td>
<td>0.91–0.95</td>
<td>0.77–0.82</td>
<td>0.85–0.92</td>
<td>0.97–0.98</td>
<td>0.80–0.94</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>0.56–0.67</td>
<td>0.55–0.67</td>
<td>0.65–0.71</td>
<td>0.22–0.55</td>
<td>0.67–0.80</td>
<td>0.69–0.88</td>
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<tr>
<td>Negative predictive value</td>
<td>0.84–0.93</td>
<td>0.73–0.76</td>
<td>0.98–1.00</td>
<td>0.68–0.75</td>
<td>0.71–0.72</td>
<td>0.98–1.00</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.71–0.81</td>
<td>0.72–0.73</td>
<td>0.85–0.87</td>
<td>0.64–0.71</td>
<td>0.72–0.73</td>
<td>0.86–0.95</td>
</tr>
<tr>
<td>Standard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.72–0.86</td>
<td>0.21–0.34</td>
<td>0.97–1.00</td>
<td>0.07–0.31</td>
<td>0.10–0.14</td>
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</tr>
<tr>
<td>Specificity</td>
<td>0.73–0.80</td>
<td>0.88–0.94</td>
<td>0.74–0.80</td>
<td>0.82–0.92</td>
<td>0.98–1.00</td>
<td>0.82–0.94</td>
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<tr>
<td>Positive predictive value</td>
<td>0.61–0.63</td>
<td>0.56–0.69</td>
<td>0.62–0.69</td>
<td>0.25–0.55</td>
<td>0.75–1.00</td>
<td>0.71–0.88</td>
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<tr>
<td>Negative predictive value</td>
<td>0.85–0.91</td>
<td>0.73–0.76</td>
<td>0.98–1.00</td>
<td>0.69–0.73</td>
<td>0.71–0.73</td>
<td>0.98–1.00</td>
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<tr>
<td>Accuracy</td>
<td>0.75–0.77</td>
<td>0.72–0.75</td>
<td>0.81–0.86</td>
<td>0.65–0.71</td>
<td>0.72–0.74</td>
<td>0.87–0.95</td>
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</tbody>
</table>

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Figure 3. Graphs show ROC curves used to describe test characteristics of appendiceal diameter in the diagnosis of acute appendicitis by readers A and B. Areas below dashed and bold lines refer to low- and standard-dose unenhanced multi-detector row CT, respectively, and are not significantly different.
row CT achieves this with sensitivity and a negative predictive value of 98% or more, even with a decrease in radiation dose. This value is even higher than previously reported, although there was a slightly lower specificity and positive predictive value (4,5,20). In addition, our study findings show that in patients suspected of having acute appendicitis, low-dose unenhanced multi-detector row CT provides the same diagnostic performance as does standard-dose unenhanced multi-detector row CT.

In all patients with appendicitis, both readers at both radiation doses visualized the appendix. Further, even in patients without appendicitis, the appendix was seen with the same frequency (~80%) at both radiation doses. This frequency is consistent with that in previous studies of unenhanced standard-dose single-detector row spiral CT (4,5,26).

Approximately one-third of our patients had a definite alternative diagno-

Figure 4. Oblique unenhanced CT reformation at (a) 30 and (b) 100 effective mAs obtained in a 36-year-old woman with definite diagnosis of acute appendicitis shows enlarged appendix (short arrow) containing appendicolith (long arrow) and periappendiceal fat stranding (arrowhead). Her BMI was 18.4 kg/m².

Figure 5. Oblique unenhanced CT reformation at (a) 30 and (b) 100 effective mAs obtained in a 44-year-old man with definite diagnosis of acute appendicitis shows enlarged appendix (short arrow) containing appendicolith (long arrow) and periappendiceal fat stranding (arrowhead). His BMI was 40.7 kg/m².
sis, which is similar to previously published studies (4,18–20,27–30). However, because of the small number of patients included in each of the various alternative diagnosis categories, we were unable to statistically compare the diagnostic performances of low- and standard-dose CT for each diagnostic category. Nevertheless, performance was similar regardless of the radiation dose.

In a previous study in which standard-dose single-detector row CT was used with oral and/or colonic contrast material, Rao et al (27) showed that the sensitivity and specificity of various CT signs vary. These previously reported values are comparable to the ones we obtained using unenhanced low-dose multi-detector row CT. Because CT signs can be more or less redundant to predict the diagnosis of appendicitis, and because this possible redundancy could differ according to radiation dose and reader’s experience, we classified the value of CT signs by using stepwise logistic regression for each radiation dose and for each reader. Periappendiceal fatstranding and appendiceal diameter are the two most predictive signs, that is, the signs with the highest probability of a correct diagnosis, at both radiation doses. For one reader, appendicolith was the second most important sign at low dose. More important, these signs are also the most reproducible.

When the two most predictive signs are positive, no other sign yields any additional information that could significantly contribute to the diagnosis of acute appendicitis. This is true regardless of the radiation dose or reader’s experience. Also, when CT signs were considered separately, misclassification was not different between readers with different levels of expertise. However, the more experienced reader makes a correct overall diagnosis more frequently than does the less experienced reader. This suggests that experience in reading abdominal CT scans helps in the integration of signs in the overall diagnosis.

Our study findings also showed no difference in the appendiceal diameter between either radiation dose. However, in the low-dose reading sessions, there were some differences between reading sessions by the less experienced reader and between both readers for their first reading session. Even if significant, these differences were small and they could be explained, at least in part, by the vermiculated shape of the appendix, whereby measuring its diameter at different levels could produce a wide range of values. In our study, the mean diameters of a normal and an abnormal appendix are ~6 and ~12 mm, respectively. The intersection of ROC curves with the bisecting line identifies an optimal threshold of ~8 mm for the appendiceal diameter, with no difference in the area under the ROC curve between radiation doses or between readers. This threshold for distinguishing a normal from an abnormal appendix at unenhanced CT is higher than previously reported—6 mm measured in the short axis of the organ (27–30). As shown by the area under ROC curve of more than 0.9, the appendiceal diameter is a valuable sign. But as was revealed with the logistic regression models, associated signs should simultaneously be taken into consideration.

Since noise on a CT image increases with the body size, we investigated the possible effects of BMI on the visualization of the appendix and on the diagnostic performance of unenhanced low-dose multi-detector row CT. Our results do not reveal any difference in visualization between BMI subgroups and do not indicate any upper or lower threshold in BMI for which the appendix would not be visible. We could speculate that the negative effect of an increase in BMI on the performance of low-dose CT could be, at least in part, balanced by the accumulation of peritoneal and retroperitoneal fat around the appendix.

In the present study, the radiation dose was reduced by lowering the effective mAs. At 30 effective mAs, the dose is approximately one-third of that delivered by single-detector row CT. This dose is similar to that obtained with a single-detector row CT technique with 5-mm collimation, 200–220 mAs, and a pitch of 1.5 focused on the pericecal region (19). Focusing the CT acquisition on the lower abdomen can indeed reduce the dose, but it introduces the risk of obscuring possible alternative diagnoses in adjacent abdominal regions. Increasing the pitch could also reduce the dose, but this is associated with a decreased image quality, principally as a result of increased volume-averaging artifacts related to the broadened section profile. Consequently, small structures such as the appendix itself and perappendiceal fat stranding—one of the most predictive signs of appendicitis—could be missed.

Our study did have several limitations. First, in patients who were not treated surgically, we had no absolute confirmation that they truly had no acute appendicitis. However, because this applied equally to low- and standard-dose CT, there is no risk for bias. Second, we did

<table>
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<th>Study</th>
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<th>Acquisition Parameters</th>
<th>Effective Dose (mV)</th>
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<td>Single-detector row CT</td>
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not evaluate the possible influence of the amount of peritoneal fat on the visualization of the appendix. This has been evaluated by Benjaminov et al (26), and they reported an increased rate of identification of the appendix when an adequate amount of fat was present. Third, we have not evaluated the possible effect that dose reduction had on a reader’s confidence in the proposed diagnosis. Fourth, patients were seen in the same order, but because 95 patients were included in our study group, the probability for a reader to remember the successive order of the results would be very low, certainly lower than recognizing particular CT appearances.

In conclusion, our study results showed that for the detection of both acute appendicitis and alternative diseases, low-dose unenhanced multi–detector row CT has the same diagnostic performance as does standard-dose unenhanced multi–detector row CT. Low-dose unenhanced multi–detector row CT can be recommended for evaluation of adult patients suspected of having acute appendicitis.

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Low-Dose Unenhanced Multi–Detector Row CT in Patients with Suspected Acute Colon Diverticulitis

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ABSTRACT

Objective: To prospectively compare the sensitivity and specificity of unenhanced low-dose multidetector-row CT (MDCT) with enhanced standard-dose MDCT in patients with suspected acute diverticulitis.

Materials and methods: The study protocol was approved by the institutional review board of CHUC, and written informed consent was obtained from all patients. One hundred and ten consecutive patients aged 30-82 years (mean, 57 years) with suspected acute diverticulitis underwent an unenhanced MDCT with 4 x 2.5-mm collimation, 120 kVp, 30 effective mAs, and an enhanced standard dose MDCT with the same parameters but with 120 mAs. All scans were independently read by four readers. Intra- and inter-observer agreements were calculated with the kappa statistic. Enhanced standard-dose MDCT scans read by three other experts and considered together with results from colonoscopy, surgery, and biology were used as reference. Differences in sensitivity and specificity between readers, radiation doses, and reading sessions were investigated. Pearson’s exact test and logistic regression models were used.

Results: Colon diverticulitis was present in 39 patients (34%); graded mild in 22 of these patients (56%) and severe in 17 (44%). Agreements within and between readers good to excellent. No statistically significant difference was observed in sensitivity (P ranging from 0.081 to >0.99) or in specificity (P ranging from 0.326 to >0.99) for any sign or overall diagnosis between radiation doses by all readers, except wall thickening, which for one reader had a higher specificity at low-dose than at standard-dose (P = 0.025). No significant difference in misclassification was detected between doses, regardless the reader (P ranging from 0.481 to >0.99). At both doses, the most predictive sign for acute diverticulitis was retroperitoneal fat stranding (P < 0.001).

Conclusion: Low-dose unenhanced MDCT has a diagnostic performance similar to enhanced standard dose MDCT in patients suspected acute diverticulitis.

Index Terms:

Computed tomography (CT), radiation exposure
Colon, diverticula
Computed tomography (CT), multi–detector row
Colon, CT
Radiations, exposure to patients and personnel
INTRODUCTION

The diagnosis of acute diverticulitis is often based on patient’s history and physical examination. However, because of the large variety of unspecific symptoms and signs, this approach by itself is not sufficient, and the rate of misdiagnosis approaches 34% (1-4). Consequently, for patients with suspected acute colon diverticulitis, computed tomography (CT) has become the optimal method for diagnosis, grading of severity, and quantification of the disease resolution (5). In addition, CT is faster than other imaging techniques and is able to suggest possible alternative and/or additional diagnoses (5-7). However, CT exposes a patient to a radiation dose 2-5 times higher than that delivered by other standard imaging techniques used in the same setting (8, 9). Further, with the recently introduced multidetector CT technology (MDCT), repeated acquisitions, extended Z coverage, and thin collimations may increased the radiation dose per examination by an additional 40%, as compared to single slice CT (9). This is especially concerning with regard to patients with diverticulitis. Patients with diverticulitis can be quite young and have a high risk of recurrence (1). These patients experience both a relatively high level of radiation exposure from these exams that is then compounded during frequent follow-up exams, which are usually required in these young patients.

A reduction in radiation dose has already been investigated for diagnostic examinations of conditions characterized by high intrinsic contrast between structures, such as pulmonary nodule screening (10), diagnosis of ureteral stone (5, 11-13), and CT colonography (14). Most recently, a reduced dose has been investigated for diagnosis of acute appendicitis. This resulted in a similar diagnostic performance as with standard-dose CT, even without oral, rectal, or intravenous administration of contrast material (15). Colon diverticulitis, however, is a low intrinsic contrast situation. Thus, the aim of the present study was to prospectively compare the sensitivity and specificity of unenhanced low-dose multidetector-row CT with enhanced standard-dose MDCT in patients with suspected acute diverticulitis.

MATERIALS AND METHODS

From February to August 2002, 110 consecutive patients (40 men and 70 women) with suspected acute diverticulitis, who presented with acute or subacute pain in the left iliac fossa for less than two weeks, were referred to the radiology department for a CT examination and were all included in the study group. These patients were 30-82 years old (mean, 57 years) and had a mean body mass index (BMI) of 27.2 Kg/m² (range: 17.6 – 39.1 Kg/m²). The study protocol was approved by our institutional review board, and written informed consent was obtained from all patients after radiation dose information including risks from CT radiations had been explained.

CT Examinations

Images were obtained by using a commercially available MDCT scanner (Somatom Volume Zoom, Siemens Medical Systems, Forchheim, Germany). Patients were examined while in supine position. A 51-cm scout view was first obtained at 120 kVp and 35 mA, followed by a first helical scan with 4 x 2.5-mm collimation at 120 kVp and 30 effective mAs. A second helical scan with the same CT parameters, but with 120 effective mAs, was then acquired and combined with intravenous injection of 120 ml of iodine contrast (Iobitridol – Xenetix 350®, 350mg%, Guerbet, Aulnay-sous-Bois, France) at 2 milliliter per second and a start delay of 70 seconds. As defined by Manesh et al. (16), ‘effective mAs’ corresponds to mAs divided by the pitch, whereby pitch is defined by Silverman et al. (17) as the ratio between the table feed per rotation and the x-ray beam
width. Pitch factor was 1.5 and the table feed by scanner rotation 15 mm. The tube current was automatically modulated by an on-line tube current control (Care Dose®, Siemens, Forchheim, Germany) during all acquisitions. All examinations were performed from the upper surface of the liver to the symphysis pubis. From the raw data of both acquisitions, 3 mm-thick axial images were reconstructed with a 2 mm increment. From each data set of 3 mm slices, we reconstructed 60 multiplanar reformations each with a 5 mm thickness in a coronal oblique orientation parallel to the lower abdominal wall.

**Effective Dose Calculation**

The effective dose was computer simulated with commercially available software installed on a personal computer (CT-Expo®, Medizinische Hochschule, Hannover, Germany). This software does not require phantom measurements. CT acquisition parameters, patient gender, and the scanned region as represented on a graph of the Monte-Carlo phantom model, were entered into the program. For each acquisition, milliampere-second values given to the program corresponded to the ones displayed on the CT images after tube current modulation, whereby this modulation was independent to body habitus and the mAs presets (18). The program calculated effective doses, taking into account scanner parameters as reported by Nagel et al. (19) and conversion factors as reported by Zankl et al. (20, 21). The calculated effective doses are expressed according to IRCP60 recommendations (22).

**Image Analysis**

Native and multiplanar images were stored on compact disks and read on a clinical workstation with 3D functionalities (Wizard®, Siemens Medical Systems, Forchheim, Germany). These images were read independently by four readers: a general radiologist (OA) with more than 20 years experience in reading body CT scans (Reader 1); a gastrointestinal radiologist (SS) with more than ten years experience in reading abdominal CT scans (Reader 2); a second-year radiology resident (PB) (Reader 3); and a gastroenterologist (IP) with 12 years of clinical experience, but without any specific education in CT imaging (Reader 4). Readers were unaware of the definite diagnoses, but knew that the patient presented acute or sub-acute left iliac fossa pain for less than two weeks.

Readings were conducted in the following manner. Reconstructions from low-dose scans were read twice in two separate reading sessions, with a two-week minimum interval between readings. Scans were presented to readers in the same patient order. One month later, reconstructions from standard-dose scans were read once by each reader. For all readings, readers were asked to record the presence or absence of colon diverticula, colon wall thickening (by comparison to adjacent colonic segments), retroperitoneal fat stranding, and/or abscess (air and fluid collection) in the peritoneum and/or the retroperitoneum. In addition of these items, readers were asked to give an overall diagnosis of colon diverticulitis, to grade its severity as low or high, and to suggest alternative diagnosis, if any. As defined by Horton et al. (23) and Ambrosetti et al. (24), low grade diverticulitis consisted of segmental wall thickening with inflammatory changes in the pericolic fat, whereas high grade diverticulitis consisted of the same accompanied by abscess formation, gaseous collection within the peritoneum and/or the retroperitoneum, and/or fistula to adjacent organs (23, 24). Exemplative images of low-grade diverticulitis are shown in Figure 1.
Definite diagnosis

By considering scans from enhanced standard-dose CT and all available clinical data from medical charts, a separate panel comprised of two radiologists, one with 15 years (DT) and one with 20 years experience in reading abdominal CT, and one gastroenterologist with 25 years of clinical experience. These panellists established the definite diagnosis by consensus. They were not involved in scoring the low-dose and the standard-dose scans. The panel was also asked to grade the severity of diverticulitis as low or high, and to suggest an alternative diagnosis, if any. Clinical data available from medical charts (in all patients) consisted of colonoscopy (in 55 patients) and surgical findings (in 19 patients) – both with pathology examination (in 74 patients), and the serum C-reactive protein with a normal upper limit in our laboratory at 0.5mg/100 ml (in 89 patients). A serum C-reactive protein lower than this threshold value associated with the relief of pain without antibiotic excluded the diagnosis of diverticulitis.

Statistical Analysis

Intra-reader and inter-reader agreements were investigated by calculating Cohen’s $\kappa$ statistics with their asymptotic standard error (ASE) (25). Inter-reader agreements were assessed for both reading sessions. All $\kappa$ values were interpreted as proposed in the literature (26): a $\kappa$ value lower than 0.20 indicates poor agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, good agreement; and 0.81-1.00, excellent agreement.

Sensitivity and specificity of each CT sign, the overall diagnosis of diverticulitis or alternative disease, and the CT assessment of the disease severity, were calculated for each radiation dose, each reader, and each reading session at low-dose. Differences in sensitivity and specificity between readers, radiation doses, and reading sessions at low-dose were investigated. All proportions were compared with the Pearson’s exact test.

Logistic regressions were used to modelise the probability of correctly diagnosing diverticulitis as a function of the following CT signs: presence of colon diverticula, colon wall thickening, retroperitoneal fat stranding, and abscess. These logistic regressions were performed at low-dose (first reading) and then at standard-dose for each of the two best reproducible readers. For each of these four regressions, a stepwise method was used to determine the successive signs useful for best predicting that probability.

Statistical significance for all tests was set at a $P$-value less than 0.05. The statistical software used were SPSS for Windows (release 11.5, SPSS, Chicago, IL) and StatXact (release 5.0.3, Citel Software Corporation, Cambridge, MA)

RESULTS

Definite diagnosis

Thirty-nine patients (18 men and 21 women) were classified as definitely having an acute diverticulitis. All of them had an elevated serum C-reactive protein that normalized after specific treatment. Thirty-seven patients had a positive colonoscopy and 14 patients who were treated by surgery had a pathology diagnosis of acute diverticulitis. Among these 39 patients, 22 and 17 patients were respectively classified as having low and high grade of severity. Within those having a high graded diverticulitis, 14 had an abscess, three a gaseous collection within the peritoneum and/or the retroperitoneum, and no patient had a fistula to adjacent organs.
Seventy-one patients (23 men and 48 women) were classified as definitely having no acute diverticulitis. Forty-nine of them had a normal serum C-reactive protein and relief of pain without antibiotics. In these 71 patients, colonoscopy was normal in eight and demonstrated an alternative colonic disease in seven. Five patients were operated and visual inspection by the surgeon, as well as pathologic examination revealed the absence of diverticulitis but the presence of an alternative disease (colon cancer in three patients, and colon ischemia in two patients). Twenty-two of the 71 patients had an alternative disease that was confirmed by favorable response to a specific medical or surgical treatment, and/or by further diagnostic tests. Alternative diagnoses consisted of ureteric stone in five patients, ovarian cyst in three patients, inflammatory bowel disease in three patients, colon cancer in two patients, sigmoid volvulus in two patients, small bowel obstruction in two patients, colonic ischemia in two patients, abdominal wall muscle hematoma complicating coagulation disorders in two patients, and acute pancreatitis in one patient.

**Intra-reader and inter-reader agreements**

Frequency of each sign, overall diagnosis of diverticulitis or alternative disease, and high grade diverticulitis are listed in Table 1.

The $\kappa$ values (± ASE) for intra-reader and inter-reader agreements for each sign, for the overall diagnosis of diverticulitis or alternative disease, and for grading the severity of diverticulitis are shown in Figures 2, 3 and 4. Inter-reader agreements for the overall diagnosis of diverticulitis were excellent among radiologists (i.e. Readers 1, 2, and 3), but agreements between a radiologist and the gastroenterologist (Reader 4) were only good.

**Diagnosis performance**

Results for sensitivity and specificity of each CT sign, of the overall diagnosis of diverticulitis or alternative disease, and of the disease severity calculated for each radiation dose, each reader, and each reading session at low-dose are listed in Table 2 and 3. Comparisons of these values within readers, radiation doses, and reading sessions at low-dose are summarized in these tables.

For signs that had significant overall differences in sensitivity or specificity, we looked for further differences according to the dose, the reader, and the reading session. Between doses, no statistically significant difference was observed in sensitivity ($P$ ranging from 0.081 to >0.99) or in specificity ($P$ ranging from 0.326 to >0.99) for any sign by all readers, except wall thickening that had a higher specificity at low-dose than at standard-dose for reader 3 ($P = 0.025$).

Results of comparisons of sensitivity and specificity between readers at low-dose and standard dose are listed in Table 4. Between reading sessions at low-dose, no statistically significant difference in sensitivity ($P$ ranging from 0.125 to >0.99) or in specificity ($P$ ranging from 0.292 to >0.99) by all readers for any sign but wall thickening by reader 3 ($P = 0.025$ and 0.002, respectively for sensitivity and specificity) was detected.

Logistic regression models were applied to the results from the two readers who had the highest rate of correct classifications of acute diverticulitis (Readers 2 and 3), as compared to the method of reference. At both radiation doses, the most predictive sign was the retroperitoneal fat stranding ($P < 0.001$), followed by the presence of colon diverticula ($P < 0.001$).
**Misclassifications as compared to the definite diagnosis of diverticulitis**

Two of the four readers (Reader 2 and 3) correctly diagnosed all 39 patients with an acute diverticulitis from scans from both low and standard dose MDCT. Among these 39 patients, there were significant differences in number of misclassifications between Reader 1 and Readers 2 ($P = 0.025$) and 3 ($P = 0.025$) at 30 mAs, but not at 120 mAs ($P = 0.067$).

Among the other 71 patients (i.e. without a definite diagnosis of acute diverticulitis), there were significant differences in number of misclassifications between Reader 2 and Reader 4 ($P = 0.028$) at standard dose, but not at low dose ($P = 0.096$).

For each reader individually, there was no significant difference detected between low and standard dose ($P$ ranging from 0.481 to >0.99).

**Misclassifications as compared to the definite diagnosis of alternative diseases**

The frequency of each alternative diseases from each reader at standard-dose and low-dose CT are listed in Table 5. Among patients with definite diagnosis of alternative disease, there were significant differences in number of misclassifications between Reader 1 and Reader 4 ($P = 0.021$). Among patients without definite diagnosis of alternative disease, there was no significant difference between readers, regardless of the dose ($P >0.99$).

For each reader individually, no significant difference was detected between doses ($P$ ranging from 0.183 to >0.99).

**Effective radiation dose**

The mean height of scanned region was 38 cm in men and 33 cm in women. The mean effective dose was 1.2 mSv in men and 1.6 mSv in women.

**DISCUSSION**

This present study shows that for patients with suspected acute colon diverticulitis: (i) sensitivity and specificity were similar, regardless of dose, (ii) predictive values of all signs considered were not affected by dose, and (iii) inter-observer agreements ranged from good to excellent, regardless of dose, (iv) potential of CT to detect alternative disease. This was achieved without IV injection of iodinated contrast medium and with an effective radiation dose corresponding to a radiographic plain film examination of the abdomen with three views (9, 11, 15). The low-dose technique results in a dose reduction of 75 to 90% as compared to an abdominal standard-dose multidetector-row CT (8, 9, 11, 15).

Several aspects of the current investigation deserve further discussion. In previous studies, fat stranding has already been reported as the most predictive one for the diagnosis of acute appendicitis at both standard and low-dose MDCT (15), and of acute colon diverticulitis at standard dose CT (27, 28). In our study, this sign was also the most predictive indicator for acute colon diverticulitis, at low as well as at standard radiation doses. In the present study, colon wall thickening is not predictive of acute diverticulitis, probably because this sign is also present in colon diverticulosis and reflects the muscular layer thickening (29).

Secondly, dose reduction does not affect ability to grade severity. This study reveals that low-dose MDCT enabled one to correctly assess the presence of abscess and air collections distant to the colon — the two most predictive signs of recurrence (30).
Thirdly, in the present study as well as in previous ones (11-13), the lower dose was not responsible for any significant loss in diagnostic performance regarding acute colon diverticulitis and alternative diseases. This was observed for both experienced radiologists and less experienced readers such as a second-year radiology resident and an experienced gastroenterologist but without any specific education in CT imaging.

And lastly, this study shows that the diagnosis of acute left colon diverticulitis may be achieved without contrast enema. Although enema is generally considered to be a safe procedure (5, 23), it is not completely without complications such as colon perforation as recently reported by Gayer et al. (31). In addition, enema leads to a longer duration of the CT procedure and additional costs.

The present study might have some limitations. Firstly, the study addressed two simultaneous variables. The influence of dose reduction was not investigated without the use of contrast material. In order to separate these two items, two additional MDCT scans should have been acquired: one at standard-dose without contrast material and one at low-dose MDCT with iodine injection. However, to have done this, the radiation dose per patient would have been ethically unacceptable. Consequently, it was our consensus that both issues could be investigated together without impairing the clinical implications of this study, thus sparing unnecessary radiation exposure. Further, a protocol with four CT acquisitions would have resulted in a huge increase in the number of images to read and may have influenced reviewer’s performances. However, as we did not detect any significant difference between standard dose MDCT with contrast material and low-dose MDCT without contrast material, there is no reason to believe that differences between enhanced and unenhanced low-dose CT or between enhanced and unenhanced standard dose CT might have reached statistical significance separately.

A second limitation was the low proportion of patients with BMI > 35 reached (only 8%). There was also an absence of extremely obese patients (i.e. BMI > 40). In such patients, image noise may be of huge importance, and, as suggested by Katz et al. (32), low-dose images with acceptable noise may be obtained with 60 mAs. Since the effective dose in larger patients is lower than that in smaller ones - absorption of X-rays is divided by two while abdominal diameter increases by 4 cm, the use of 60 mAs presets may not correspond to higher effective radiation doses than 30 mAs presets in normal and underweight patients (33).

Third, we included patients with suspected acute colon diverticulitis, independently of age-related risk for radiation-induced cancer. Even if low-dose MDCT delivers one-tenth of the radiation dose delivered by a standard MDCT examination, elderly patients will not benefit from dose reduction as radiation accumulation from repeated exposure is not likely to happen on account of their additional life expectancy (34). Rather, these patients may receive much more benefit from absence of iodine contrast injections and enema than dose reduction.

In conclusion, the present study suggests that, in patients with suspected acute colon diverticulitis, low-dose unenhanced MDCT has a diagnostic performance that is similar to enhanced standard-dose MDCT.
REFERENCES


LEGENDS TO FIGURES

**Figure 1**
41-year-old man (BMI = 26.7 Kg/m²) with acute colon diverticulitis. Multidetector CT scans obtained with 4 x 2.5 mm collimation at 120 kVp. All readers interpreted low-dose and standard dose MDCT scans as low grade acute diverticulitis of sigmoid colon.

**Figure 1A**
Unenhanced axial low-dose MDCT scan acquired at 30 mAs preset at the level of the sigmoid colon showing fat stranding around the colon.

**Figure 1B**
Enhanced axial standard-dose CT scan acquired at 120 mAs preset at the level of the sigmoid colon showing fat stranding around the colon.

**Figure 2**
Graph showing intra-reader agreements (Kappa ±ASE) at low-dose unenhanced MDCT for signs of diverticulitis, overall diagnosis of diverticulitis, alternative diagnoses, and for diverticulitis severity grading. Black circles correspond to agreements by Reader 1, white circles to agreements by Reader 2, black triangles to agreements by Reader 3, and white triangles to agreements by Reader 4.

**Figure 3**
Graph showing inter-reader agreements (Kappa ±ASE) at low-dose unenhanced MDCT for signs of diverticulitis, overall diagnosis of diverticulitis, alternative diagnoses, and for diverticulitis severity grading. Black circles correspond to agreements between Reader 1 and 2, white circles to agreements between Reader 1 and 3, black triangles to agreements between Reader 1 and 4, white triangles to agreements between Reader 2 and 3, black squares to agreements between Reader 2 and 4, and white squares to agreements between Reader 3 and Reader 4.

**Figure 4**
Graph showing inter-reader agreements (Kappa ±ASE) at standard dose enhanced MDCT for signs of diverticulitis, overall diagnosis of diverticulitis, alternative diagnoses, and for diverticulitis severity grading. Black circles correspond to agreements between Reader 1 and 2, white circles to agreements between Reader 1 and 3, black triangles to agreements between Reader 1 and 4, white triangles to agreements between Reader 2 and 3, black squares to agreements between Reader 2 and 4, and white squares to agreements between Reader 3 and Reader 4.
Table 1 Frequency of signs, overall diagnosis of acute diverticulitis, alternative disease and high grade diverticulitis

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Table 2 Sensitivity of signs of diverticulitis, overall diagnosis of diverticulitis, alternative diseases, high grade diverticulitis, and comparison among readers, radiation doses and reading sessions at low-dose.

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<tr>
<td>Diverticula</td>
<td>36/39 (92)</td>
<td>38/39 (97)</td>
<td>37/39 (95)</td>
<td>39/39 (100)</td>
<td>39/39 (100)</td>
</tr>
<tr>
<td>Colon Wall Thickening</td>
<td>34/39 (87)</td>
<td>37/39 (95)</td>
<td>37/39 (95)</td>
<td>37/39 (94)</td>
<td>33/39 (85)</td>
</tr>
<tr>
<td>Fat Stranding</td>
<td>34/39 (87)</td>
<td>38/39 (95)</td>
<td>39/39 (100)</td>
<td>39/39 (100)</td>
<td>37/39 (95)</td>
</tr>
<tr>
<td>Overall Diagnosis of</td>
<td>33/39 (85)</td>
<td>36/39 (92)</td>
<td>39/39 (100)</td>
<td>39/39 (100)</td>
<td>39/39 (100)</td>
</tr>
<tr>
<td>Diverticulitis</td>
<td>14/39 (36)</td>
<td>15/39 (38)</td>
<td>20/39 (51)</td>
<td>19/39 (49)</td>
<td>11/39 (28)</td>
</tr>
<tr>
<td>Abscess</td>
<td>17/17 (100)</td>
<td>17/17 (100)</td>
<td>17/17 (100)</td>
<td>17/17 (100)</td>
<td>17/17 (100)</td>
</tr>
<tr>
<td>Alternative Diseases</td>
<td>22/22 (100)</td>
<td>22/22 (100)</td>
<td>21/22 (96)</td>
<td>21/22 (96)</td>
<td>20/22 (91)</td>
</tr>
</tbody>
</table>

Note: Numbers in parentheses are percentages
Table 3 Specificity of signs of diverticulitis, overall diagnosis of diverticulitis, alternative diseases, high grade diverticulitis, and comparison among readers, radiation doses and reading sessions at low-dose.

<table>
<thead>
<tr>
<th></th>
<th>Reader 1</th>
<th>Reader 2</th>
<th>Reader 3</th>
<th>Reader 4</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 mAs</td>
<td>120 mAs</td>
<td>30 mAs</td>
<td>120 mAs</td>
<td></td>
</tr>
<tr>
<td>Diverticula</td>
<td>37/71 (52)</td>
<td>38/71 (54)</td>
<td>26/71 (37)</td>
<td>26/71 (37)</td>
<td>21/71 (30)</td>
</tr>
<tr>
<td>Colon Wall Thickening</td>
<td>62/71 (87)</td>
<td>64/71 (90)</td>
<td>64/71 (90)</td>
<td>65/71 (92)</td>
<td>50/71 (70)</td>
</tr>
<tr>
<td>Fat Stranding</td>
<td>64/71 (90)</td>
<td>66/71 (93)</td>
<td>62/71 (87)</td>
<td>64/71 (90)</td>
<td>60/71 (85)</td>
</tr>
<tr>
<td>Overall Diagnosis of Diverticulitis</td>
<td>68/71 (96)</td>
<td>70/71 (99)</td>
<td>70/71 (99)</td>
<td>71/71 (100)</td>
<td>70/71 (99)</td>
</tr>
<tr>
<td>Abscess</td>
<td>71/71 (100)</td>
<td>69/71 (97)</td>
<td>67/71 (94)</td>
<td>66/71 (93)</td>
<td>70/71 (90)</td>
</tr>
<tr>
<td>High Grade Diverticulitis</td>
<td>19/22 (86)</td>
<td>20/22 (91)</td>
<td>21/22 (96)</td>
<td>21/22 (96)</td>
<td>21/22 (96)</td>
</tr>
<tr>
<td>Alternative Diseases</td>
<td>87/88 (99)</td>
<td>87/88 (99)</td>
<td>88/88 (100)</td>
<td>88/88 (100)</td>
<td>88/88 (100)</td>
</tr>
</tbody>
</table>

Note: Numbers in parentheses are percentages
Table 4 Comparison of sensitivity and specificity between readers at low-dose and standard dose (P values after exact tests).

<table>
<thead>
<tr>
<th></th>
<th>Low-dose</th>
<th></th>
<th>Standard-dose</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sensitivity</td>
<td>Specificity</td>
<td>Sensitivity</td>
<td>Specificity</td>
</tr>
<tr>
<td>Diverticula</td>
<td>0.007</td>
<td>0.001</td>
<td>0.004</td>
<td>0.001</td>
</tr>
<tr>
<td>Colon Wall Thickening</td>
<td>0.491</td>
<td>0.009</td>
<td>0.632</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Fat Stranding</td>
<td>0.107</td>
<td>0.750</td>
<td>0.157</td>
<td>0.590</td>
</tr>
<tr>
<td>Overall Diagnosis of Diverticulitis</td>
<td>0.012</td>
<td>0.096</td>
<td>0.067</td>
<td>0.015</td>
</tr>
<tr>
<td>Abscess</td>
<td>0.198</td>
<td>0.015</td>
<td>0.573</td>
<td>0.223</td>
</tr>
<tr>
<td>Severity grading</td>
<td>1.000</td>
<td>0.155</td>
<td>1.000</td>
<td>0.161</td>
</tr>
<tr>
<td>Alternative Diseases</td>
<td>0.025</td>
<td>1.000</td>
<td>0.183</td>
<td>&gt; 0.99</td>
</tr>
</tbody>
</table>
Table 5 Number of misclassifications in assessing the overall diagnosis of diverticulitis, and alternative diseases

<table>
<thead>
<tr>
<th>Overall Diagnosis of Diverticulitis</th>
<th>Alternate Diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Reference 30 mAs 120 mAs</td>
<td>Positive Reference 30 mAs 120 mAs</td>
</tr>
<tr>
<td>Negative Reference 30 mAs 120 mAs</td>
<td>Negative Reference 30 mAs 120 mAs</td>
</tr>
</tbody>
</table>

Reader 1: 6 3 3 1 0 0 1 1

Reader 2: 0 0 1 0 1 1 0 0

Reader 3: 0 0 1 1 2 3 0 0

Reader 4: 4 4 6 6 6 4 0 0

Note: Only the first reading session at low-dose multidetector-row CT is considered.
Table 6 Frequency of alternative diagnosis from each reader at standard-dose and low-dose multi-detector row CT

<table>
<thead>
<tr>
<th>Alternative diagnosis (Number of cases)</th>
<th>Diagnostic modality</th>
<th>Reader 1</th>
<th>Reader 2</th>
<th>Reader 3</th>
<th>Reader 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left sided ureteral stone (5)</td>
<td>Stone excretion or retrieval.</td>
<td>5 (30 mAs)</td>
<td>5 (120 mAs)</td>
<td>5 (30 mAs)</td>
<td>5 (120 mAs)</td>
</tr>
<tr>
<td>Ovarian cyst (3)</td>
<td>US, relief of pain, and normal control US after treatment.</td>
<td>3 (30 mAs)</td>
<td>3 (120 mAs)</td>
<td>3 (30 mAs)</td>
<td>3 (120 mAs)</td>
</tr>
<tr>
<td>Inflammatory bowel disease (3)</td>
<td>Coloscopy and pathology.</td>
<td>3 (30 mAs)</td>
<td>3 (120 mAs)</td>
<td>3 (30 mAs)</td>
<td>3 (120 mAs)</td>
</tr>
<tr>
<td>Colorectal cancer (2)</td>
<td>Coloscopy, surgery and pathology.</td>
<td>2 (30 mAs)</td>
<td>2 (120 mAs)</td>
<td>2 (30 mAs)</td>
<td>2 (120 mAs)</td>
</tr>
<tr>
<td>Small bowel obstruction (2)</td>
<td>Surgery</td>
<td>2 (30 mAs)</td>
<td>2 (120 mAs)</td>
<td>2 (30 mAs)</td>
<td>2 (120 mAs)</td>
</tr>
<tr>
<td>Colon ischemia (2)</td>
<td>Coloscopy and surgery</td>
<td>2 (30 mAs)</td>
<td>2 (120 mAs)</td>
<td>1 (30 mAs)</td>
<td>1 (120 mAs)</td>
</tr>
<tr>
<td>Abdominal wall muscle hematoma (2)</td>
<td>Follow-up sonography. Relief of pain.</td>
<td>2 (30 mAs)</td>
<td>2 (120 mAs)</td>
<td>1 (30 mAs)</td>
<td>1 (120 mAs)</td>
</tr>
<tr>
<td>Sigmoid colon volvulus (2)</td>
<td>Barium enema, coloscopy or surgery.</td>
<td>2 (30 mAs)</td>
<td>2 (120 mAs)</td>
<td>2 (30 mAs)</td>
<td>2 (120 mAs)</td>
</tr>
<tr>
<td>Acute Pancreatitis (1)</td>
<td>Biology and follow-up CT.</td>
<td>1 (30 mAs)</td>
<td>1 (120 mAs)</td>
<td>1 (30 mAs)</td>
<td>1 (120 mAs)</td>
</tr>
</tbody>
</table>

Note: – Data represent the number of each alternative diagnosis from each reader and at each dose. Numbers in parentheses are the number of each definite diagnosis based on diagnostic modalities used as methods of reference.
FIGURE 2

Kappa

0.0 0.2 0.4 0.6 0.8 1.0

Diverticula Colon wall thickening Fat stranding Overall diagnosis of diverticulitis Abscess Severity grading Alternative diagnoses

Kappa
FIGURE 3

Kappa values for different conditions and diagnoses.

- Diverticula
- Colon wall thickening
- Fat stranding
- Overall diagnosis of diverticulitis
- Abscess
- Severity grading
- Alternative diagnoses

Kappa range: 0.0 to 1.0

Severity grading and alternative diagnoses show higher Kappa values compared to the other conditions.
FIGURE 4

Kappa values for various diagnostic criteria:

- Diverticula
- Colon wall thickening
- Fat stranding
- Overall diagnosis of diverticulitis
- Abscess
- Severity grading
- Alternative diagnoses

The graph shows the distribution of Kappa values across these criteria, with confidence intervals indicated by error bars.
OBJECTIVE. This study was designed to quantify the radiation dose saved by attenuation-based online tube current modulation applied to multidetector CT (MDCT) of the adult trunk as a function of effective milliampere-second (mAs) presets, sex, and body habitus.

SUBJECTS AND METHODS. One hundred twenty patients underwent MDCT of the trunk (60 thoracic, 60 abdominal) with an attenuation-based online tube current modulation. Consecutive acquisitions at standard and two lower effective mAs presets were obtained in each patient. Mean percentage effective mAs reductions were compared for each effective mAs preset, taking into account sex and body mass index.

RESULTS. Mean effective mAs reduction was 16.9% and 20.0% for the chest and the abdomen, respectively. Mean percentage effective mAs reductions were found to be significantly different for sex (chest, \( p = 0.003 \); abdomen, \( p = 0.002 \)) but not significantly different for the different effective mAs presets or body mass index.

CONCLUSION. Attenuation-based online tube current modulation used with MDCT should be considered as a secondary tool of radiation dose reduction because it saves as much as 20% of the radiation dose on the adult trunk, regardless of initial mAs preset. However, initial decreases of mAs presets by the physician should be considered the primary tool for radiation dose reduction.
medical charts. For the entire study group, the mean BMI was 26.2 kg/m².

CT Examinations

CT scans were obtained using a commercially available helical scanner (Somatom Plus Volume Zoom, Siemens Medical Systems, Forchheim, Germany) with four rows of detectors. Patients were examined while in the supine position. A 52-cm scout view was first obtained at 80 kV and 50 mA, followed by three acquisitions at different effective mAs presets that are summarized in Table 1. As defined by Silverman et al. [12], effective mAs corresponds to mAs divided by the pitch, whereas the pitch is defined by Silverman et al. [13] as the ratio between the table feed per rotation and the X-ray beam width.

For the three consecutive acquisitions, the scanned region ranged from the pulmonary apex to the costodiaphragmatic salci for the chest and from the top of the liver to the symphysis pubis for the abdomen. The effective mAs presets were chosen to reach a total absorbed dose—expressed in weighted CT dose index—not higher than the reference doses recommended by the European Guidelines on Quality Criteria for Computed Tomography [14] and not exceeding 15.7 and 17.0 mGy for thoracic and abdominal examinations, respectively. The weighted CT dose index used in this study has already been corrected for the pitch in helical and axial scanning. It is equivalent to the new volume CT dose index, as recently introduced by the International Electrotechnical Commission [15].

Results

Effective mAs values and mean percentage effective mAs reductions obtained using the attenuation-based online tube current modulation are listed in Tables 2 and 3 for thoracic and abdominal examinations, respectively. The only statistically significant different mean percentage effective mAs reductions were obtained for sex (chest, p = 0.003; abdomen, p = 0.002) but not for the BMI (chest, p = 0.105; abdomen, p = 0.432) or the effective mAs preset (chest, p = 0.308; abdomen, p = 0.405).

When we compared the sex of patients, mean percentage effective mAs reductions were significantly higher in men than in women for the three effective mAs presets applied to the chest (p = 0.018, 0.001, and 0.004 for 20, 40, and 80 effective mAs presets, respectively) and

Noise in CT scans varies proportionately to the square root of the applied dose—that is, proportionately to the square root of the mAs product if the tube current is kept constant. Noise in CT scans is dominated by those projections in which attenuation is the highest. For a homogeneous object with a circular cross section, attenuation is constant over all projections, and all measured values contribute equally. However, for a nonhomogeneous object with a noncircular cross section, attenuation varies strongly—sometimes by more than three orders of magnitude [6, 10]. Noise in the data measured from high-attenuation projections (i.e., lateral direction) greatly influences noise level in the CT scans. This means that the dose for projections with relatively low attenuation (i.e., anteroposterior direction) can be reduced substantially without a measurable increase in image noise [6, 10]. The tube current should thus be decreased as a function of rotation angle whenever attenuation is low.

The commercially available current modulation software (Care Dose, Siemens Medical Systems) used during all acquisitions in this study is characterized by online monitoring of the attenuation and subsequent tuning of the tube current as a function of the projection angle with a delay of 360°. For projections with low attenuation, the maximal reduction of the tube current is 90%. For each acquisition, the CT unit calculates the arithmetic average effective mAs throughout the duration of the exposure. The mean effective mAs, as displayed on the CT scans, was recorded for further calculations.

Statistical Analysis

Mean percentage effective mAs reductions were compared for the three effective mAs presets taking into account sex and BMI for the thoracic and abdominal examinations, respectively. Analyses of variance for repeated measures, corresponding to each of the three different effective mAs presets, were performed with sex as the intersubjects factor and BMI as the covariate. The two-way interactions between dose, sex, and BMI were also investigated. Statistical significance for all tests was set at a p value of less than 0.05.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Acquisition Parameters of Multidetector CT of the Trunk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chest</td>
</tr>
<tr>
<td>Collimation (mm)</td>
<td>4.0 × 1.0</td>
</tr>
<tr>
<td>kV</td>
<td>120</td>
</tr>
<tr>
<td>Pitch</td>
<td>2.0</td>
</tr>
<tr>
<td>z-Direction</td>
<td>Caudocranial</td>
</tr>
<tr>
<td>Acquisition height (cm)</td>
<td>30</td>
</tr>
<tr>
<td>Effective mAs presets</td>
<td>80, 40, 20</td>
</tr>
<tr>
<td>Tube current (mA)</td>
<td>320, 160, 80</td>
</tr>
<tr>
<td>Weighted CT dose index (mSv)</td>
<td>8.96, 4.48, 2.24</td>
</tr>
</tbody>
</table>

Note.—Pitch is defined by Silverman et al. [13] as the ratio between the table feed per rotation and the width of the X-ray beam. Weighted CT dose index is equivalent in this study to the volume of CT dose index defined by the International Electrotechnical Commission [15].
were significantly lower in men than in women for the three mAs presets applied to the abdomen (p = 0.001, 0.001, and 0.004 for 30, 50, and 100 effective mAs presets, respectively).

This difference according to sex was found to be dependent on BMI for the chest (p = 0.001, 0.015, and 0.004 for 20, 40, and 80 effective mAs presets, respectively) but not for the abdomen (p = 0.388, 0.171, and 0.259 for 30, 50, and 100 effective mAs presets, respectively). The difference according to sex in thoracic examinations reached high statistical significance in the normal BMI subgroup of patients only (p = 0.001, < 0.001, and < 0.001 for 20, 40, and 80 effective mAs presets, respectively).

Discussion

Our study shows that attenuation-based online tube current modulation applied to standard-dose MDCT reduces total effective mAs by 15–20%. Because Schmidt et al. [16] have shown in phantom studies that the reduction in effective mAs underestimates the real reduction in radiation dose by approximately 20%, the percentage of effective mAs reduction provided by the online tube current modulation represents the minimum dose saving. The mAs reduction obtained with MDCT is approximately 5% lower than that reported with single-detector CT [7–9]. With single-detector CT, the mAs reduction obtained with attenuation-based online tube current modulation ranges from 19% to 27% and from 11% to 24% for scans obtained through the whole chest and the upper abdomen, respectively [8]. Because only MDCT was used in the present study protocol, we could not compare the efficacy of online tube current modulation used with single-detector CT on the same patients. Nor were we able to verify whether this apparent 5% difference between the two modalities would have been statistically significant.

In our study, we considered 80 and 100 effective mAs as standard presets [17–19], corresponding to mAs values of 160 and 150 mAs and to tube currents of 320 and 300 mA for the chest and the abdomen, respectively. These presets were set at levels in which no degradation of image quality had been observed in comparison with doubled values of mAs presets as shown by Ravenel et al. [17] in the chest and by Kalra et al. [18] in the abdomen. The lowest effective mAs presets tested in our study are the ones currently used in screening programs [20, 21]. We have also considered the middle effective mAs preset used in our study as a possible low-dose preset suitable for patients who are overweight.

The effective mAs reduction obtained with attenuation-based online tube current modulation is independent of the effective mAs preset. Because this modulation saves up to only 20% of the dose, it cannot by itself save up to 90% of the dose as the so-called “low-dose” CT protocols do by lowering the effective mAs preset [4, 5, 19–21]. Nevertheless, when applied to low-dose presets, the attenuation-based online tube current modulation provides a 15–20% supplementary dose reduction [5, 20, 21].

The effective mAs reduction obtained with attenuation-based online tube current modulation is independent of BMI, indicating that normal weight and obese patients have similar ratios in attenuation between anteroposterior and lateral projections. In fact, tube current modulation does not adapt effective mAs settings to the body’s diameter nor to the total absorption of X-rays by the patient’s body. If CT parameters are maintained constant, independently of body size, the energy delivered to small individuals is
lower than that delivered to larger individuals, but the effective dose delivered to sensitive organs is higher in smaller individuals [22, 23]. As suggested by Kalra et al. [18], the effective mAs preset should thus be adapted to the patient’s body size (i.e., BMI) before applying attenuation-based online tube current modulation. This recommendation applies to pediatric patients as well.

The effective mAs reduction obtained with attenuation-based online tube current modulation varies also with sex. The mAs reduction was found to be 2% higher in men than in women for the chest and 3% higher in women than in men for the abdomen. However, even if statistically significant, these differences are clinically small. They indicate that men and women have subtle differences in attenuation between anteroposterior and lateral projections. In the chest CT only, this difference is related to BMI, probably as a result of a woman’s breasts. Interestingly, sex differences (because of breasts) were seen only in patients of normal weight.

The software release used in our study to modulate online tube current was designed only as a function of the projection angle with a delay of 360°. It was not designed to tune the mAs as a function of the table position (z-axis). Therefore, the tube current was not modulated according to differences in absorption along the scanned region. Because Itoh et al. [24] have reported that the detection of lung nodules requires a tube current that may vary by 50% from the shoulders to the mid lung zones, the attenuation-based online tube current modulation along the cephalocaudal axis could be a technical advance able to reduce the radiation dose more adequately [25].

In conclusion, attenuation-based online tube current modulation used with MDCT reduces radiation dose by 15–20% in all patients, regardless of the initial effective mAs preset. As a consequence, attenuation-based online tube current modulation does not replace the reduction in mAs presets but should be considered as a supplementary tool to decrease the radiation dose.

References

1. Golding SJ, Shrimpton PC. Radiation dose in CT: are we meeting the challenge? Br J Radiol 2002;75:1–4