Effect of Altering Automatic Exposure Control Settings and Quality Reference mAs on Radiation Dose, Image Quality, and Diagnostic Efficacy in MDCT Enterography of Active Inflammatory Crohn’s Disease

**OBJECTIVE.** The purpose of our study was to determine whether the MDCT enterography dose can be reduced by changing automatic exposure control (AEC) setting and quality reference milliampere-seconds (mAs) without altering subjective image quality or efficacy in active inflammatory Crohn’s disease.

**SUBJECTS AND METHODS.** This is a prospective study of 2,310 MDCT enterography procedures performed using 16- and 64-MDCT in three cohorts (original, intermediate, and final dose levels). For 16-MDCT, the original and intermediate dose level quality reference mAs was 200, and weight-based (1 pound [0.45 kg] = 1 mAs) for the final dose level. For 64-MDCT, the original dose level quality reference mAs was 260; the mAs was 220 for intermediate and weight-based for the final dose level. For the intermediate and final dose levels, AEC was changed from strong to weak increase for obese and weak to strong decrease for slim patients. Demographic data and volume CT dose index (CTDIvol) were analyzed. Three readers evaluated the cases for image quality and efficacy differentiating normal from active inflammatory Crohn’s disease.

**RESULTS.** For 16-MDCT, CTDIvol decreased from 12.82 to 10.14 mGy and 10.14 to 8.7 mGy between original to intermediate and intermediate to final dose levels. For 64-MDCT, the CTDIvol decreased from 15.72 to 11.42 mGy and 11.42 to 9.25 mGy between original to intermediate and intermediate to final dose levels. Images were rated suboptimal or nondiagnostic more often in the intermediate dose level ($p < 0.05$) but not in the final. There was no reduction in diagnostic efficacy as measured by area under the ROC curve ($p > 0.1443$ except for one comparison with one reader).

**CONCLUSION.** Substantial dose reduction can be achieved using weight-based quality reference mAs and altering AEC settings without affecting diagnostic efficacy in active inflammatory Crohn’s disease of the terminal ileum. However, subjective image quality can be compromised at these dose settings, depending on radiologist preference.

Crohn’s disease is an idiopathic, chronic inflammatory disease of the gastrointestinal tract that affects between 400,000 and 600,000 patients in North America [1]. CT enterography, performed with low-Hounsfield-value enteric contrast administration, is accurate in the diagnosis of small-bowel Crohn’s disease and complications [2–10].

Over the past 15 years, there has been a significant increase in the number of CT examinations in the evaluation of Crohn’s disease, with an associated decrease in barium–fluoroscopic studies [11]. Recent investigation has found that CT accounted for 16.2% of imaging studies and 77.2% of diagnostic radiation exposure in Crohn’s patients, and that the effective dose may be up to five times higher with MDCT than with small-bowel follow-through examinations [11, 12].

Exposure to low-level ionizing radiation may be associated with an increased risk of cancer, and some suggest that the increasing use of CT is a significant contributor to low-level ionizing radiation exposure, possibly leading to more neoplasms [13]. Dose reduction strategies in MDCT are numerous [14–17]. One strategy is automatic tube current modulation, which maintains constant image quality regardless of patient size and shape [18–21]. In pediatric CT, dose reduction has been achieved using a weight-based approach to tube current [22, 23]. A weight-based dose reduction approach has also been proposed for adults weighing up to 180 pounds (81.8 kg) [24].
Dose modulation settings with Siemens MDCT (CARE Dose4D) are based on automatic exposure control (AEC). According to the 2D attenuation profile obtained from the topogram, CARE Dose4D adapts the mean tube current per rotation to an overall patient size and the attenuation change along the patient length (z-axis). In addition, tube current modulation in the gantry plane (xyz-plane) is performed “on the fly” during each tube rotation according to the real-time measurements of the patient’s angular attenuation profile. Thus, tube current modulation is performed in all three dimensions [21, 25]. From the topogram, the scanner determines whether the patient is slim or obese compared with an ideal reference patient. For adults, this is an idealized 30–33 cm in diameter individual, weighing approximately 70 kg. If the software detects that the body part is larger, or obese, compared with this idealized reference patient, the scanner prescribes an increase in tube output (mAs) above the user set quality reference mAs using one of three curves preselected by the user (strong increase, average increase, and weak increase). Likewise, if the software detects that the body part is smaller, or slim, compared with this idealized reference patient, the scanner prescribes a decrease in tube output below the user set quality reference mAs using one of three curves (weak decrease, average decrease, and strong decrease). For the slim, strong decrease, setting, the tube output is decreased less than constant noise would require. For the obese, strong increase, setting, the tube output is increased less than constant noise would require [25] (Fig. 1).

An anecdotal review of patients undergoing MDCT enterography at our institution suggested that the resultant dose was consistently more than 10 mSv, higher than we thought reasonable, given the relatively young population scanned. Specifically, our review of the quality reference mAs suggested that it might be too high for 64-MDCT, yielding doses higher than 15 mSv in most patients, and that the AEC setting for both 16-MDCT and 64-MDCT might not be appropriate. We then altered these settings in an attempt to reduce the dose. Therefore, the purpose of this investigation was to determine if MDCT enterography dose can be reduced by changing AEC settings and quality reference mAs without adversely impacting subjective image quality and diagnostic efficacy in active inflammatory Crohn’s disease.

Subjects and Methods

All CT enterography examinations performed at our institution are entered into an institutional...
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TABLE 1: CARE Dose4D Automatic Exposure Control (AEC) Settings and Quality Reference mAs Settings for Each Scanner Type for Original, Intermediate, and Final Dose Levels

<table>
<thead>
<tr>
<th>Dose Level</th>
<th>AEC Setting Obese</th>
<th>AEC Setting Slim</th>
<th>Quality Reference mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-MDCT enterography</td>
<td>Strong increase</td>
<td>Weak decrease</td>
<td>200</td>
</tr>
<tr>
<td>64-MDCT enterography</td>
<td>Strong increase</td>
<td>Weak decrease</td>
<td>260</td>
</tr>
<tr>
<td>Intermediate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-MDCT enterography</td>
<td>Weak increase</td>
<td>Strong decrease</td>
<td>200</td>
</tr>
<tr>
<td>64-MDCT enterography</td>
<td>Weak increase</td>
<td>Strong decrease</td>
<td>220</td>
</tr>
<tr>
<td>Final</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-MDCT enterography</td>
<td>Weak increase</td>
<td>Strong decrease</td>
<td>Weight-based</td>
</tr>
<tr>
<td>64-MDCT enterography</td>
<td>Weak increase</td>
<td>Strong decrease</td>
<td>1 mAs/1 pound (0.45 kg)</td>
</tr>
</tbody>
</table>

Note—CARE Dose4D is manufactured by Siemens Healthcare.

review board approved, HIPAA compliant database. Written informed consent was waived. This database contains only the date of the scan and the patient’s medical record number. Therefore, a separate institutional review board–approved, HIPAA-compliant chart review was approved to record patient demographics, as well as endoscopic, surgical, pathologic, and clinical findings for all patients in this study. Written informed consent was waived.

Patient Population

For this study we used a prospective cohort study design. A total of 2,310 MDCT enterography examinations were performed between December 1, 2006, and December 31, 2008 (Fig. 2). We included all patients imaged during this time frame. These examinations were separated by scanner type (16- and 64-MDCT). Patient age, sex, height, and weight were recorded from this data, the patient body mass index (BMI) was calculated. Scanning parameters including effective mAs, quality reference mAs, volume CT dose index (CTDItotal), and dose–length product (DLP) were recorded. For each scan, the indication was recorded.

After exclusions (detailed later), for 16-MDCT examinations, there were 703 women and 454 men with a mean age of 44.1 years (range, 18–89 years). For the 64-MDCT examinations, there were 436 women and 289 men with a mean age of 45.5 years (range, 18–89 years). Indications for CT enterography included patients with known Crohn’s disease (41.5%, 781/1,882), suspected Crohn’s disease (7.5%, 141/1,882), known ulcerative colitis (6.7%, 126/1,882), nonspecific abdominal pain (28.8%, 542/1,882), chronic diarrhea (10.1%, 190/1,882), and nausea and vomiting (5.4%, 102/1,882). Using the electronic medical record, optical colonoscopy with ileoscopy, surgical, pathologic, and clinical reports, and pathologic reports were reviewed and results were recorded.

The study population was divided into three cohorts, consecutively collected. The first cohort was labeled original dose level, the second was labeled intermediate dose level, and the last was labeled final dose level.

Original Dose Level and Automatic Exposure Control

Over a 7-month period (December 1, 2006–June 29, 2007), 801 CT enterography examinations were performed at our institution. In this population, the CARE Dose4D AEC was set to a strong increase for obese and weak decrease for slim patients. The quality reference mAs was set to 200 for 16-MDCT and 260 for 64-MDCT. Exclusion criteria included unavailable CT dose data (n = 61), multiphasic CT enterography (n = 46), patients less than 18 years old (n = 31), unavailable demographic data (n = 22), and no images archived (n = 1). In all, 640 patients were included in this cohort: 476 patients scanned with 16-MDCT and 164 patients scanned with 64-MDCT (Fig. 2).

Intermediate Dose Level and Automatic Exposure Control

Over a 6-month period (January 15, 2008–June 30, 2008), 722 CT enterography examinations were performed at our institution. For these patients, the AEC settings were set to a weak increase for obese and a strong decrease for slim patients (opposite settings compared with the original dose level). The quality reference mAs was again set to 200 for 16-MDCT but decreased from 260 to 220 for 64-MDCT. Exclusion criteria included multiphasic CT enterography (n = 37), unavailable demographic data in the electronic medical record (n = 31), patients less than 18 years old (n = 23), and unavailable CT dose data (n = 12). In all, 619 patients were included in this cohort: 356 patients scanned with 16-MDCT and 263 patients scanned with 64-MDCT (Fig. 2).

Final Dose Level and Automatic Exposure Control

Over a 6-month period (July 1, 2008–December 31, 2008), 787 CT enterography examinations were performed at our institution. AEC settings were unchanged from the intermediate dose level. For both 16- and 64-MDCT, the quality reference mAs was set to the patient’s weight in pounds for patients weighing less than 200 pounds (90.9 kg) and adjusted by weight for the two types of scanners (Table 1). We adjusted the quality reference mAs upward for patient’s above 200 pounds (90.9 kg) because of concern that the AEC setting would not adequately increase the tube output. Exclusion criteria included wrong quality reference mAs (i.e., not the patients’ weight in pounds) (n = 57), multiphasic CT enterography (n = 56), unavailable demographic data (n = 33), and unavailable CT dose data (n = 18). In all, 623 patients were included in this cohort: 325 patients scanned with 16-MDCT and 298 patients scanned on 64-MDCT (Fig. 2).

CT Enterography Protocol, Equipment, and Settings

All CT enterography examinations at our institution are performed on MDCT scanners (Sensation 16, Sensation 64, or Definition, all Siemens Healthcare). The choice of scanner was entirely at the discretion of the technologist in charge of CT utilization that day and was dependent on scanner availability vis-à-vis patient readiness. For all scans throughout the study period, the kilovoltage (kVp) was set to 120. All images were reconstructed with the same reconstruction kernel (B31f). For both MDCT scanners, the examinations were performed using 500-millisecond gantry rotations, with images reconstructed with contiguous axial 3-mm slices and contiguous coronal 3-mm slices reformatted from a separate set of 1-mm axial slices reconstructed every 0.8 mm. For the 16-MDCT units, the examinations were performed using 0.75-mm collimation, and for the 64-MDCT units the examinations were performed using 0.6-mm collimation.

Before the examination, patients ingest a total of 1,350 mL of low-Hounsfield-unit enteric contrast material (VoLumen [0.1% barium suspension], Bracco Imaging) over a 60-minute period. After 40 minutes, a nurse establishes IV access. At 60 minutes, patients are given 225 mL of water to ingest over 5 to 10 minutes, and patients are scanned 70 minutes after starting ingestion of enteric contrast material.
IV contrast enhancement is achieved with iopromide (Ultravist 300, Bayer HealthCare), 150 mL injected at 3 mL/s. Scanning begins 70 seconds after the start of contrast injection and is performed using a single breath-hold, with a scan duration of 18–22 seconds.

Statistical Analysis: Quantitative Data

A generalized linear model was built to measure the effect of altering quality reference mAs and AEC settings on radiation dose reduction, while accounting for other covariates. Separate models were created for CTDIvol and DLP for each scanner type. The dependent variables in the models were CTDIvol and DLP, and the independent variables were age, sex, indication for CT, height, weight, BMI, and AEC setting.

Image Quality and Diagnostic Efficacy Assessment

Because it was unreasonable to ask three radiologists to grade image quality on such a large sample, cases were randomly selected from each cohort. We determined the sample size needed to detect 5% or higher suboptimal or nondiagnostic image quality using three readers. We assumed that the frequency of nondiagnostic or suboptimal image quality for the final dose level parameters would be 2% or less and that the correlation between the readers would be high ($r = 0.75$). With three readers and 70 patients, an upper bound for the 95% CI would not contain values greater than 5%. Cases were randomly selected by image finding within modulation setting and scanner type.

A stratified random sampling plan was used (Fig. 3). First, an equal number of cases (35) was randomly selected for each modulation setting and scanner-type combination (for the original and intermediate dose levels). These were roughly split in two on the basis of imaging finding (half with active Crohn’s disease, and definitely Crohn’s disease, and probably Crohn’s disease, respectively). The readers were not told the proportion of normal and abnormal examinations.

Next, a stratified random sample of 70 final dose level cases was selected using the same sampling scheme as described above (Fig. 3). The same three staff abdominal imagers were each given 140 cases (70 final, 33 intermediate, and 37 original dose level), matched for BMI and weight, to read. Using the same method as outlined earlier, the imagers assessed image quality and confidence in detecting active inflammatory Crohn’s disease. Only the assessments of the 70 final dose level cases were used from this analysis. The original and intermediate dose level cases were included to mask the readers to the dose modulation setting. In the end, there were 210 cases used in the quality and accuracy analysis, 70 each for original, intermediate, and final dose levels.

Reference Standard for Diagnostic Efficacy Evaluation

Confirmation of the presence or absence of active inflammatory Crohn’s disease of the terminal ileum using a 5-point scale (definitely normal, probably normal, possibly Crohn’s disease, probably Crohn’s disease, and definitely Crohn’s disease). The readers were not told the proportion of normal and abnormal examinations.

The frequency of nondiagnostic or suboptimal image quality using three readers. We assumed that the frequency of nondiagnostic or suboptimal image quality for the final dose level parameters would be 2% or less and that the correlation between the readers would be high ($r = 0.75$). With three readers and 70 patients, an upper bound for the 95% CI would not contain values greater than 5%. Cases were randomly selected by image finding within modulation setting and scanner type.

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Reference Standard for Diagnostic Efficacy Evaluation

Confirmation of the presence or absence of active inflammatory Crohn’s disease of the terminal ileum was based on ileocolonoscopy, without or with biopsy–laparoscopy–laparotomy without or with biopsy within 6 months of the CT enterography. In the original dose level, 114 patients had a confirmed normal terminal ileum ($n = 80$ for 16-MDCT and $n = 34$ for 64-MDCT). In the intermediate dose level, 95 patients had a confirmed normal terminal ileum ($n = 48$ for 16-MDCT and $n = 47$ for 64-MDCT). For the final dose level, 180 patients had a confirmed normal terminal ileum ($n = 95$ for 16-MDCT and $n = 85$ for 64-MDCT). In the original dose level, 131 patients had confirmed active inflammatory terminal ileal Crohn’s disease ($n = 89$ for 16-MDCT and $n = 42$ for 64-MDCT). In the intermediate dose level, 89 patients had confirmed active inflammatory terminal ileal Crohn’s disease ($n = 40$ for 16-MDCT and $n = 49$ for 64-MDCT). In the final dose level, 67 patients had confirmed active inflammatory terminal ileal Crohn’s disease ($n = 35$ for 16-MDCT and $n = 32$ for 64-MDCT) (Fig. 3).

Statistical Analysis: Image Quality and Diagnostic Efficacy

Nondiagnostic and suboptimal categories were combined to identify the proportion of all cases that were of low quality for each of the three dose levels (original, intermediate, and final). For each reader and over all readers, 95% CIs were constructed using methods for clustered binary data [26].

The difference in the quality of images under each of the dose level settings was evaluated through a logistic regression analysis. This allowed direct comparison between the original and intermediate dose levels as well as between the original and final dose levels. Generalized estimating equations were used to account for each case being rated by multiple readers, and a significance level of 0.05 was applied. Interobserver variability was examined by evaluating the kappa statistic for each pair of readers. The kappa statistic provides a measure of agreement accounting for chance and takes on values between 0 (no agreement) and 1 (total agreement).

After the initial analysis, we wondered whether obese patients had a greater proportion of nondiagnostic or suboptimal cases than nonobese patients, particularly in the intermediate and final dose levels. To address this question, a logistic regression model was built with nondiagnostic or suboptimal (yes or no) as the dependent variable and BMI as the independent variable. BMI was categorized to look at multiple cut-points. Other independent variables included AEC setting and reader. Because of
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TABLE 2: Mean Dose and Dose Reductions in the Three Dose Levels for MDCT Enterography

<table>
<thead>
<tr>
<th>Dose Level</th>
<th>AEC Setting Change</th>
<th>Quality Reference mAs</th>
<th>Mean CTDI\textsubscript{vol} (95% CI) (mGy)</th>
<th>AEC Setting Change</th>
<th>Quality Reference mAs</th>
<th>Mean CTDI\textsubscript{vol} (95% CI) (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>Obese strong ↑, slim weak ↓</td>
<td>200</td>
<td>12.82 (12.67–12.96)</td>
<td>Obese strong ↑, slim weak ↓</td>
<td>260</td>
<td>15.72 (15.32–16.10)</td>
</tr>
<tr>
<td>Original to intermediate</td>
<td>↓ 2.68</td>
<td></td>
<td></td>
<td></td>
<td>↓ 4.30</td>
<td></td>
</tr>
<tr>
<td>Final</td>
<td>Obese weak ↑, slim strong ↓</td>
<td>1 mAs/pound (0.45 kg)</td>
<td>8.74 (8.56–8.92)</td>
<td>Obese weak ↑, slim strong ↓</td>
<td>1 mAs/pound (0.45 kg)</td>
<td>9.25 (8.96–9.53)</td>
</tr>
<tr>
<td>Original to final</td>
<td></td>
<td>↓ 4.08</td>
<td></td>
<td></td>
<td>↓ 6.47</td>
<td></td>
</tr>
</tbody>
</table>

Note—AEC = automatic exposure control, CTDI\textsubscript{vol} = volume CT dose index.

the limited number of nondiagnostic or suboptimal cases available, cases from both 16- and 64-MDCT scanners were combined. Therefore, scanner type was also included as an independent variable. All two-way interactions were considered as well. To account for each case being read by multiple readers, generalized estimating equations were used. The proportion of patients having nondiagnostic or suboptimal scans was estimated from the models by AEC setting within scanner type. Obese patients were then compared with nonobese patients. All percentages were derived from the models. Analysis was done using SAS statistical software (SAS Institute). All tests for significance were conducted at the 5% level (i.e., \( \alpha = 0.05 \)).

After reviewing multiple cut-points, differences in trend were noted at BMI values of 25 and 35. As a result, the multicode BMI categorical variable used in the model was defined with three levels: BMI ≤ 25, 26–35, and > 35. The percent of cases found nondiagnostic or suboptimal varied across the different cut-points. No two-way interactions were found to be significant, and, therefore, they were not included in the final model.

For each reader, the diagnostic accuracy in distinguishing Crohn’s disease patients from healthy patients was estimated by the area under the ROC curve (AUC). Parametric estimates of the AUC were obtained using ROCFIT (Metz CE, University of Chicago) [27]. A two-tailed Wald’s test was used to compare accuracies between original and intermediate dose levels and between original and final dose levels. A significance level of 0.05 was applied. Because accuracy was rated on a 5-point Likert scale, interobserver variability was measured using the weighted kappa statistic, which assigns less weight to categories further apart. Cicchetti-Allison weights were used in deriving this estimate.

**Results**

**Quantitative Analysis**

Dose reductions occurred by changing the AEC settings and reducing the quality reference mAs for 16- and 64-MDCT enterography (Table 2). Additionally, the use of a weight-based quality reference mAs over a fixed quality reference mAs led to a further reduction in dose between the intermediate and final dose levels. For 16-MDCT, CTDI\textsubscript{vol} decreased from 12.82 to 10.14 mGy and 10.14 to 8.74 mGy between original to intermediate and intermediate to final dose levels (32% overall dose reduction) (Table 2). When patients were grouped into 20-pound increments, we again found a much more pronounced decrease in CTDI\textsubscript{vol} with thinner patients than for patients closer to 200 pounds (90.9 kg) (\( p < 0.0001 \)) (Fig. 4).

**Image Quality**

For both 16- and 64-MDCT enterography, when comparing original dose level to intermediate dose level, the mean frequency of examinations rated as either nondiagnostic or suboptimal increased from 5.7% to 14.3% (\( p = 0.0341 \)) and 10.5% to 22.9% (\( p = 0.0216 \)), respectively (Table 3). One of the readers rated a very high proportion of intermediate exami-
nations as nondiagnostic or suboptimal (37.1% compared with 0.0% and 5.7% for the other two readers for the 16-MDCT enterography and 51.4% compared with 5.7% and 11.4% for the other two readers for the 64-MDCT enterography). When comparing original dose level to final dose level, the mean frequency of examinations rated as either nondiagnostic or suboptimal increased from 5.7% to 12.4% for the 16-MDCT enterography, but this did not reach statistical significance ($p = 0.1356$) (Table 3 and Fig. 6). When comparing original dose level to final dose level, the mean frequency of examinations rated nondiagnostic or suboptimal increased from 10.5% to 22.9% for the 64-MDCT enterography, but this also did not reach statistical significance ($p = 0.0593$) (Table 3 and Fig. 7).

Obese patients (BMI $> 35$) were estimated to have a higher proportion of nondiagnostic or suboptimal scans than nonobese patients (BMI $\leq 35$) ($p = 0.0101$) across all parameter settings (Fig. 8). Patients with BMI $\leq 25$ were not found to be significantly different from patients with BMI $> 25$ ($p = 0.5587$), but they were found to be different from patients with BMI values between 25 and 35 ($p = 0.0124$). Interestingly, patients with BMI $\leq 25$ had a greater percentage of nondiagnostic or suboptimal scans compared with patients with BMI between 25 and 35 (Fig. 9).

As inferred by the mean differences in quality assessment, there was slight to fair agreement between the readers. For readers one and two, the kappa statistic was 0.343 for 16-MDCT enterography and 0.193 for 64-MDCT enterography. For readers one and three, the kappa statistic was 0.130 for 16-MDCT enterography and 0.155 for 64-MDCT enterography. For readers two and three, the kappa statistic for 16-MDCT enterography was 0.145 and 0.395 for 64-MDCT enterography.

**Diagnostic Efficacy**

For both 16- and 64-MDCT enterography, regardless of the parameters used and resulting dose levels, the diagnostic accuracy of MDCT enterography for active inflammatory Crohn’s disease was very high (Table 4). None of the three readers showed a drop in diagnostic efficacy reflected by the area under the ROC curve as the dose was reduced between dose levels ($p$ values ranged from 0.1443 to 0.8787 for all readers and all comparisons except for one reader with one comparison; for this reader, there was a significant improvement in diagnostic efficacy for the intermediate dose level compared with the original dose level for 16-MDCT enterography ($p = 0.0249$)).

There was strong interobserver agreement in diagnostic efficacy. For readers one and two, the weighted kappa statistic was 0.795 for 16-MDCT enterography and 0.777 for 64-MDCT enterography. For readers one and three, the weighted kappa statistic was 0.766 for 16-MDCT enterography and 0.839 for 64-MDCT enterography. For readers two and three, the weighted kappa statistic for 16-MDCT enterography was 0.795 and for 64-MDCT enterography was 0.848.

**Discussion**

Most patients with Crohn’s disease have a chronic, intermittent clinical course, and a small percentage have unremitting disease [1]. Risk factors for high cumulative dose from diagnostic imaging include pa-

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**TABLE 3: Number of Nondiagnostic and Suboptimal MDCT Enterography Examinations as Judged by Three Separate, Independent Readers**

<table>
<thead>
<tr>
<th>Dose Level</th>
<th>16-MDCT</th>
<th>64-MDCT</th>
<th>16-MDCT</th>
<th>64-MDCT</th>
<th>16-MDCT</th>
<th>64-MDCT</th>
<th>16-MDCT</th>
<th>64-MDCT</th>
<th>Mean</th>
<th>16-MDCT</th>
<th>64-MDCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original (nondiagnostic + suboptimal)</td>
<td>0/35 (0)</td>
<td>0/35 (0)</td>
<td>3/35 (8.6)</td>
<td>5/35 (14.3)</td>
<td>3/35 (8.6)</td>
<td>6/35 (17.1)</td>
<td>6/105 (5.7)</td>
<td>11/105 (10.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate (nondiagnostic + suboptimal)</td>
<td>0/35 (0)</td>
<td>2/35 (5.7)</td>
<td>2/35 (5.7)</td>
<td>4/35 (11.4)</td>
<td>13/35 (37.1)</td>
<td>18/35 (51.4)</td>
<td>15/105 (14.3)</td>
<td>p = 0.0341</td>
<td>24/105 (22.9)</td>
<td>p = 0.0216</td>
<td></td>
</tr>
<tr>
<td>Final (nondiagnostic + suboptimal)</td>
<td>2/35 (5.7)</td>
<td>4/35 (11.4)</td>
<td>4/35 (11.4)</td>
<td>8/35 (22.9)</td>
<td>7/35 (20.0)</td>
<td>12/35 (34.3)</td>
<td>12/105 (11.4)</td>
<td>p = 0.1356</td>
<td>24/105 (22.9)</td>
<td>p = 0.0593</td>
<td></td>
</tr>
</tbody>
</table>

Note—Data are number with percentage in parentheses.
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Patients who are diagnosed before the age of 17 years, upper gastrointestinal tract disease, penetrative disease, and IV steroids or infliximab [11]. Regardless of the time of diagnosis, limiting the dose per study is essential in these patients. Numerous dose reduction strategies have been used in CT, but reducing the tube current, kVp, or both and AEC are the most commonly used strategies [17.

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**Fig. 6**—16-MDCT enterography in 37-year-old man with Crohn’s disease using original, intermediate, and final dose levels.

A–F, MDCT enterography images at similar levels through midliver show noise levels at original (A), intermediate (C), and final (E) dose levels. B shows active inflammatory Crohn’s disease of distal ileum (arrow) using original quality reference mAs of 200 and strong increase for obese and weak decrease for slim automatic exposure control (AEC) setting. Volume CT dose index (CTDI\text{vol}) for this examination was 13.65 mGy. D shows active inflammatory Crohn’s disease of distal ileum (arrow) using intermediate parameters: quality reference mAs of 200 and weak increase for obese and strong decrease for slim AEC setting. CTDI\text{vol} for this examination was 9.10 mGy. F shows active inflammatory Crohn’s disease of distal ileum (arrow) using final, weight-based quality reference mAs of 145 (patient weighed 145 pounds [65.9 kg]), weak increase for obese and strong decrease for slim AEC setting. CTDI\text{vol} for this examination was 6.45 mGy.
A reduction in tube current, kVp, or both results in dose reduction; however, this dose reduction is associated with an increase in image noise, which has the potential to degrade image quality [14]. In most instances, kVp should be adjusted to maximize image contrast, taking into account patient size.

For adult CT, a setting of 120 kVp historically has been accepted as reasonable. Thus, for most adult CT, tube current is the primary method of adjusting patient dose, with large...
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In our current investigation, we first used a simple strategy of changing the AEC setting strength and, in the case of the 64-MDCT, additionally reducing the fixed quality reference mAs. As a result, we were able to decrease the dose substantially. When stratified by patient weight, we saw a much more substantial reduction with our thinner patients with the addition of the weight-based parameters.

Fig. 8—64-MDCT enterography (final dose level) in 21-year-old woman with body mass index of 59 and normal terminal ileum. Three readers qualitatively rated images as diagnostic, suboptimal, and suboptimal. Confidence level for all three readers was probably normal. 

A and B, Image through midliver (A) shows noise level. Image at level of terminal ileum (B) shows normal structure (arrow). Quality reference mAs was set at 270, weak increase for obese and strong decrease for slim automatic exposure control setting, and resultant volume CT dose index was 40.38 mGy.

Fig. 9—64-MDCT enterography (final dose level) in 33-year-old woman with body mass index of 19.5 and active inflammatory Crohn’s disease of terminal ileum. Three readers qualitatively rated images as suboptimal, suboptimal, and nondiagnostic. Their confidence level for diagnosis was probable Crohn’s disease, probable Crohn’s disease, and possible Crohn’s disease of terminal ileum, respectively.

A and B, Image through midliver (A) shows noise level. Image at level of terminal ileum (B) shows active inflammatory Crohn’s disease (arrow). Quality reference mAs was 110 (patient weighted 110 pounds [49.9 kg]), weak increase for obese and strong decrease for slim automatic exposure control setting, and resultant volume CT dose index was 3.17 mGy.
Our data suggest that current AEC inadequately decreases the dose for slim patients even with the strong decrease setting (Fig. 1). But, even if the AEC did adequately decrease the dose, this scheme is not thought to be ideal in clinical practice. Wilting et al. [29] used phantoms of increasing diameter (i.e., a homogeneous object) and proposed a mathematical formula for determining kVp and mAs to maintain constant image noise. Nyman et al. [30] reduced their techniques from 140 kVp and 225 mAs to 120 kVp and 175 mAs regardless of height, weight, diameter, and circumference in 19 patients and assessed noise and image quality, correlating patient diameter and circumference with measured noise. They determined the maximum circumference for which the setting of 120 kVp and 175 mAs was sufficient and defined that as the reference patient circumference. They then investigated whether they could achieve constant image noise by adjusting the dose on the basis of circumference. Not surprisingly, image noise increased with patient circumference using a fixed protocol.

In our study, we were not attempting to maintain constant noise and, in fact, hypothesized that image noise would increase. Second, patients are not homogeneous, both in terms of attenuation as well as diameter and circumference. In many ways, we may have replicated the work of Wilting et al. [29] by substituting patient weight for diameter. One of the problems with using patient diameter and circumference is which to choose for a patient with vast differences in these parameters between the upper abdomen and pelvis. It is not clear from the work of Wilting et al. and Nyman et al. [30] how they chose the patient’s diameter when it varied in the z-axis.

There are two major concerns when CT dose is reduced: image quality and diagnostic efficacy. Most radiologists assume that there is a direct relationship between image quality and diagnostic efficacy. Unfortunately, image quality is often in the eye of the beholder (as shown by the differences in subjective image quality between our three readers). There is little objective data to support the notion that better image quality improves diagnostic efficacy. Although there is a point at which image noise will affect diagnostic efficacy, especially with low-contrast detectability, most radiologists have spent little time and effort in determining the least dose necessary while maintaining diagnostic efficacy. We have shown that although some radiologists may perceive that the images are suboptimal or nondiagnostic, it may not affect their ability to detect disease.

We have continued the techniques used for the final dose level (AEC strong decrease for thin and weak increase for obese; quality reference mAs, 1 mAs/1 pound [0.45 kg]) for CT enterography clinically in patients up to 199 pounds (90.3 kg). In fact, we have started to use these techniques for all standard single-phase abdomen and pelvis CT. Between 200 and 249 pounds (90.7 and 112.9 kg), we keep the quality reference mAs for the 16-MDCT fixed at 200 and for the 64-MDCT at 220, use the identical AEC settings, and continue to reconstruct axial images at 3 mm. Between 250 and 349 pounds (113.4 and 158.3 kg), we keep the quality reference mAs for the 16-MDCT fixed at 200 and for the 64-MDCT at 220, use the identical AEC settings, and increase the collimation for the 16-MDCT from 0.75 to 1.5 mm and for the 64-MDCT, from 0.6 to 1.2 mm, with axial images reconstructed at 3 mm. Above 350 pounds (158.8 kg), we keep the quality reference mAs for the 16-MDCT, do not use AEC, and reconstruct axial images at 5 mm rather than 3 mm. This approach causes no significant workflow issues because the patient weight is readily available in the hospital information system.

We continue to use AEC for patients up to 350 pounds (158.8 kg) because we believe that there is added dose reduction benefit. This approach is supported by our data. We do not use AEC in patients above 350 pounds (158.8 kg) because we have some anecdotal evidence that it increases the dose inordinately. All the abdomen section members in our department (n = 15) are comfortable with this strategy. Additionally, we have received no complaints from our clinicians.

In our investigation, subjective image quality was judged suboptimal and nondiagnostic for both dose reduction strategies when compared with our original dose level. One reader judged more than 50% of the intermediate dose level 64-MDCT examinations and more than 30% of the final dose level 64-MDCT examinations as unacceptable. Both other readers were much less critical of the image quality. This shows the potentially vast differences between radiologists’ preferences. Nonetheless, despite the reduction in subjective image quality, our diagnostic efficacy differentiating normal from active inflammatory terminal ileal Crohn’s disease was not significantly changed.

Of interest is the analysis of suboptimal and nondiagnostic scans vis-à-vis body habitus. Not only were obese patients, BMI > 35, judged to have significantly more undesirable scans, but thin patients, BMI < 25, also had significantly more undesirable scans when compared with those patients with BMI between 25 and 35 (Figs. 8 and 9). This suggests that the lower dose strategy for the thin patients creates as undesirable a level of noise for radiologists as does a higher dose strategy for obese patients.

We do not know why more images from the intermediate dose level were rated nondiagnostic or suboptimal compared with the final group. Two different image quality and diagnostic efficacy evaluations were performed. The first compared the original and intermediate dose levels. In the second evaluation, although the readers evaluated cases from the original, intermediate, and final dose levels, only the results from the final dose level were used. These results were then compared with the original and intermediate dose levels from the first evaluation. We changed the CT enterography pro-

### TABLE 4: Diagnostic Efficacy of Three Independent Readers in Differentiating Normal From Active Inflammatory Crohn’s Disease of the Terminal Ileum at Three MDCT Enterography Dose Parameters

<table>
<thead>
<tr>
<th>Dose Parameters</th>
<th>Reader 1</th>
<th>Reader 2</th>
<th>Reader 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-MDCT (AUC)</td>
<td>0.905</td>
<td>0.975</td>
<td>0.911</td>
</tr>
<tr>
<td>64-MDCT (AUC)</td>
<td>0.849</td>
<td>0.933</td>
<td>0.902</td>
</tr>
<tr>
<td>16-MDCT (AUC)</td>
<td>0.984</td>
<td>0.903</td>
<td>0.975</td>
</tr>
<tr>
<td>64-MDCT (AUC)</td>
<td>0.969</td>
<td>0.988</td>
<td>0.915</td>
</tr>
<tr>
<td>16-MDCT (AUC)</td>
<td>0.929</td>
<td>0.941</td>
<td>0.959</td>
</tr>
<tr>
<td>64-MDCT (AUC)</td>
<td>0.297</td>
<td>0.579</td>
<td>0.835</td>
</tr>
<tr>
<td>16-MDCT (AUC)</td>
<td>0.945</td>
<td>0.982</td>
<td>0.955</td>
</tr>
<tr>
<td>64-MDCT (AUC)</td>
<td>0.738</td>
<td>0.301</td>
<td>0.495</td>
</tr>
</tbody>
</table>

Note—AUC = area under the receiver operating characteristic curve.

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We also only assessed the efficacy of detecting active inflammatory disease of the terminal ileum. We did not look at complications of Crohn's disease, such as fistulae and sinus tracts and did not assess how the diagnosis was affected in other organs such as the liver, where low contrast detectability can be significantly affected by increases in noise, and in the pelvis, often the site of greatest patient attenuation and therefore noise. But, we had no other consistent reference standard. Also, the terminal ileum is often in the pelvis; yet, efficacy of detecting active inflammatory disease was not affected. Lastly, although weight-based quality reference mAs may be used with all vendors' scanners, the AEC settings we used are specific to Siemens Healthcare MDCT.

Our study raises several important issues. To date, for adults, radiologists do not have substantial guidance in how to rationally choose a quality reference mAs for MDCT. We have shown that a weight-based approach to choosing the quality reference mAs, primarily for patients between 100 and 200 pounds (45.3 and 90.7 kg), does not alter efficacy in differentiating normal from active inflammatory Crohn's disease of the terminal ileum. However, given the marked differences in body habitus in adults, using a quality reference mAs per unit of weight strategy may not always lead to diagnostic MDCT images. Could there be a better way to initially choose the quality reference mAs, such as maximum patient girth? Second, if the automatic exposure settings are truly effective, why did the setting used not lead to the same decrease in dose as did weight-based quality reference mAs? It may be that the current settings for the scanners used in this investigation do not adequately alter tube output to reduce patient dose and that new settings should be created and implemented. The current AEC curves never increase or decrease the tube output to achieve constant noise (Fig. 1).

In conclusion, we were able to significantly reduce patient radiation dose using simple methods: altering AEC settings and using a weight-based quality reference mAs. Further, despite a significant reduction in perceived image quality, diagnostic efficacy in detecting active inflammatory Crohn's disease of the terminal ileum was not significantly reduced by the dose reduction methods.

References

15. Verduen FR, Gutierrez D, Schneider P, Aroua A,
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For Your Information

The reader’s attention is directed to the commentary by Leng et al., which accompanies this article and appears on the preceding pages.