CT colonography for screening of patients at increased risk for colorectal cancer: accuracy, patient acceptance and radiation issues
van Gelder, R.E.

Citation for published version (APA):
van Gelder, R. E. (2005). CT colonography for screening of patients at increased risk for colorectal cancer: accuracy, patient acceptance and radiation issues
CT Colonography at Different Radiation Dose Levels: Feasibility of Dose Reduction

Rogier E. van Gelder¹, MD, Henk W. Venema¹,², PhD, Iwo W.O. Serlie³, MSc, C. Yung Nio¹, MD, Rogier M. Determann¹, Corinne A. Tipker¹, MSc, Frans M. Vos¹,³, PhD, Afina Glas⁴, MD, Joep F.W. Bartelsman⁵, MD, Patrick M.M. Bossuyt⁴, PhD, Johan S. Laméris¹, MD, PhD, Jaap Stoker¹, MD, PhD

Departments of Radiology¹, Medical Physics², Clinical Epidemiology and Biostatistics⁴ and Gastroenterology⁵ of the Academic Medical Center, University of Amsterdam, the Netherlands and the Pattern Recognition Group³, Department of Applied Physics, Technical University of Delft, the Netherlands.

Radiology 2002; 224:25-33
Abstract

Purpose: To investigate the sensitivity and specificity of polyp detection and the image quality of computed tomographic (CT) colonography at different radiation dose levels and to study effective doses reported in literature on CT colonography.

Materials and Methods: CT colonography and colonoscopy were performed with 100 mAs in 50 consecutive patients at high risk for colorectal cancer; 50- and 30-mAs CT colonographic examinations were simulated with controlled addition of noise to raw transmission measurements. One radiologist randomly evaluated all original and simulated images for the presence of polyps and scored image quality. Differences in image quality were assessed with the Wilcoxon rank test. Scan protocols from the literature and recent (unpublished) updates were collected.

Results: In nine of 10 patients with polyps 5 mm in diameter or larger (sensitivity, 90%) and in seven of 17 patients with polyps smaller than 5 mm, polyps were correctly identified with CT colonography at all dose levels. Specificity for patients without polyps 5 mm or larger was 53%–60% at all dose levels and for patients without any polyps was 26% (at 100 and 50 mAs) and 48% (at 30 mAs). Image quality decreased significantly as the dose level decreased. The median effective doses (supine and prone positions) calculated from protocols reported in the literature and updates were 7.8 and 8.8 mSv, respectively.

Conclusion: Although image quality decreases significantly at 30 mAs (3.6 mSv), polyp detection remains unimpaired. The median dose for CT colonography at institutions that perform CT colonographic research is currently 8.8 mSv.
Introduction

Several investigators have demonstrated that computed tomographic (CT) colonography is an accurate and reproducible method for detecting colonic polyps larger than 5 mm in diameter (1–12). Because of its minimally invasive character, CT colonography is expected to receive better patient acceptance than have current screening methods (13). CT colonography is therefore considered to be a candidate technique for colorectal cancer screening (14,15).

The exposure of the patient to ionizing radiation is a drawback of CT colonography that hampers implementation for colorectal cancer screening. When repeated investigations are required in large numbers of patients, the accumulated radiation dose may have harmful effects on public health (16).

It has been suggested that CT colonography with low-dose CT is sufficiently accurate (17). On CT images, a large contrast is present between the bowel wall and the air or carbon dioxide that is insufflated to distend the colon. Therefore, a reduction of dose, while increasing the noise level, may still result in an acceptable image quality. During the past few years, clinical studies have been performed (1–12,18–20) to investigate the diagnostic accuracy of CT colonography with different types of CT scanners and varying scan parameters (eg, kilovolts, milliamperes seconds, and collimation), resulting in a considerable range of radiation exposures. To our knowledge, no study has been performed to systematically investigate the influence of radiation dose on the accuracy of CT colonography.

The objective of our study was to investigate the sensitivity and specificity of polyp detection and the image quality of CT colonography at different dose levels and to study effective doses reported in literature on CT colonography.

Materials and Methods

Patient Population Fifty consecutive patients (a) with a previous polyp and/or previous colorectal cancer or (b) with a first- and/or second-degree relative(s) with a polyp and/or colorectal cancer were included in this study between March and November 2000. Pregnancy and inability to give written informed consent were the exclusion criteria. The mean age of the 50 patients was 59 years (range, 20–86 years). Twenty-two patients were women. The Medical Ethics Committee of the Academic Medical Center approved this study. Every patient gave written informed consent.
**Bowel Preparation** All patients orally ingested 4–6 L of macrogol solution (KleanPrep; Helsinn Birex Pharmaceuticals, Dublin, Ireland) for bowel preparation on the day before the investigation and/or on the day of the investigation.

**Three-dimensional CT Colonography** Spiral CT scans were obtained of the air-distended colon with a multisection CT scanner (Mx8000; Marconi, Cleveland, Ohio). Each patient was examined in the supine and prone positions after intravenous administration of 20 mg of butylscopolamine (Buscopan; Boehringer Ingelheim, Germany). The air used for bowel distention was enriched with carbon dioxide (13.4% volume) to enhance air resorption and reduce patient discomfort. The CT scans were obtained within 2 hours prior to conventional colonoscopy.

The scan parameters for CT colonography were the following: 120 kV; 167 mA; rotation time, 0.75 second; collimation, 4 x 2.5 mm; pitch, 1.25; standard reconstruction filter; and a 180° interpolation algorithm. In the present study, we used milliamperes per section (as used by Marconi and Siemens), which is defined as the tube current multiplied by rotation time and then divided by the pitch, as an indicator of the amount of radiation. Accordingly, we used 100 mAs per section in the present study. The effective section width was 3.2 mm, and a 1.6-mm reconstruction interval was used.

**Conventional Colonoscopy** After CT image acquisition, patients underwent colonoscopic examination with a standard endoscope (model CF-140L; Olympus, Tokyo, Japan), which was performed by experienced gastroenterologists who were blinded to the CT colonographic results. During this examination, 44 of the 50 patients received 5 mg of midazolam (Dormicum; Roche, Basel, Switzerland) and 0.05 mg of fentanyl (Fentanyl-Janssen; Janssen Pharmaceuticals, Beerse, Belgium) intravenously. A research fellow (R.E.v.G.) who was not involved in CT colonographic data evaluation was present and recorded the examination on videotape. Polyps, if present, were scored with respect to size, morphology (flat, sessile, or pedunculated), and the segment in which they were located. Polyp size was estimated by the gastroenterologist who performed the colonoscopy on the basis of comparison with an open biopsy forceps of known size.

**Simulation of Lower-Dose CT Scans** Lower-dose CT scans were simulated by modifying the raw transmission data of each spiral CT scan by using a simulation technique (21). The raw transmission measurements were extracted from the Mx8000 scanner and transferred to a personal computer equipped with a 600-MHz processor.
(Pentium Pro Processor; Intel, Santa Clara, Calif). The raw data were modified by adding a random number to each transmission measurement from a normal distribution with zero mean and a variance according to the desired simulated dose setting. A simulated 50-mAs scan, for example, was obtained from the 100-mAs scan by adding a random number with the same variance as the raw transmission measurement. The relationship between the magnitude and the variance of the transmission measurements was determined experimentally by analyzing the transmission data from scans of a rectangular water-filled phantom made of polymerized methyl methacrylate.

Depending on the length of the spiral CT scan, the raw data sets consisted of 200-250 x 10⁶ transmission measurements. The modification of each data set took about 30 minutes. The modified raw data set was imported into the Mx8000 computer and reconstructed with standard reconstruction software.

**Validation of Lower-Dose Simulations** The purpose of adding noise to the raw data of the 100-mAs spiral CT scans was to simulate scans obtained at 50 and 30 mAs (ie, with 50% and 30% of the original number of photons). As to a good approximation, the noise on a CT image is inversely proportional to the square root of the number of photons used in the measurements of the raw data, so the image noise in the simulated 50- and 30-mAs CT images can be expected to be a factor of 1.41 and 1.83 higher, respectively.

In 12 patients, the physicist (H.W.V.) measured the image noise in a circular region of interest placed in the descending aorta, both in the 100- and the simulated 50- and 30-mAs images. Since the blood in the aorta can be considered to be homogeneous with respect to x-ray attenuation, the SD of the CT numbers within the region of interest can be attributed to image noise. The 12 patients were chosen according to measured waist circumference to have representative samples of slim, medium, and large patients. The diameter of the region of interest was approximately two-thirds of the diameter of the aorta. The measurements were obtained from the uppermost section downward to the region of the waist, if possible. Obvious artifacts and calcifications were excluded from the measurements.

**Data Evaluation** One senior abdominal radiologist (C.Y.N., 10 years of experience) trained in the evaluation of CT colonographic images (having evaluated >50 cases before the start of this study) evaluated the CT colonographic data sets. He was blinded to patient name, dose level of the data set, and findings at conventional colonoscopy. All original and simulated low-dose CT data were displayed by means of volume-rendered
(threshold, -750 HU) three-dimensional (3D) cubic projections (Fig 1) by using EasyScil 4.3 software (Philips Medical Systems, Best, the Netherlands).

With this software, endoscopic views consisting of preprocessed 3D cineloops were reviewed for the presence of polyps. The interface enables one to directly obtain additional information on suspected lesions by using two-dimensional multiplanar reformatted images. Thus, the final judgment on the authenticity of each suspected lesion was made by using the information from both 3D and two-dimensional images. This display method has been validated previously (22). Each lesion surmised to be a polyp was scored with respect to size, morphology (flat, sessile, or pedunculated), and location in a segment. To characterize the location, the colon was divided into the following segments: cecum, ascending colon, hepatic flexure, transverse colon, splenic flexure, descending colon, sigmoid colon, and rectum. At the same session, the image quality was evaluated by using a five-point Likert scale (excellent = 4, good = 3, sufficient = 2, poor = 1, and unreadable = 0). For each patient, the original 100- and simulated 50- and 30-mAs data were reviewed in random order, with a mean interval of 8 weeks ± 5 (SD) (median, 7 weeks; range, 3–43 weeks) between two subsequent readings of the

![Figure 1. Unfolded cubic CT colonographic projection of a polyp.](image)
CT scans obtained at different dose levels in the same patient. The reading time of all cases was measured by the radiologist (C.Y.N.).

**Measurement of Waist Circumference** Noise on CT images is an important factor in the subjective image quality of images obtained with low-dose CT. Noise is related to the number of photons transmitted through the body. This number depends on the CT technique used in the examination and on the thickness of the patient. For constant scan parameters, the dimensions of the patient cross section determine to a large extent the amount of noise on the CT images and, hence, the subjective image quality.

To assess the influence of patient dimensions on subjective image quality, we quantified the size of each patient. A common measure to use for this purpose is patient weight (23,24). In the present study, we preferred to use a more direct measure—the waist circumference of each patient (25)—which is measured midway between the lowest rib and the iliac crest, as determined from the CT images. For that purpose, a threshold of -500 HU was applied to the source images. The circumference was determined by measuring around the perimeter by using pixels at a distance of 1 cm. Both the lowest section containing the ribs and the upper section containing the iliac crest were selected automatically. The waist circumference used in the data analysis was the average of the circumference of seven contiguous sections in the middle of the waist. Waist measurement was performed by the physicist (H.W.V.).

**Statistical Analysis** Validation of lower-dose simulations. — For each patient, the mean ratio of the SD in the aorta in the 100- and simulated 50-mAs images was determined, as well as in the 100- and simulated 30-mAs images. The statistical difference of these measured ratios from the expected values (1.414 and 1.826, respectively) was assessed by using a sign test.

To check whether the measured ratio of the SD depended on the girth of the patient, the correlation coefficient \( r \) of the ratio of the SD and waist circumference was determined and tested for significance.

*Polyp detection.*—Sensitivity and specificity at 100- and simulated 50- and 30-mAs CT colonography were determined, with conventional colonoscopy as the reference standard. All polyps detected during colonoscopy were categorized as either "medium to large" for polyps 5 mm or larger or "small" for polyps smaller than 5 mm.

A research fellow (R.E.v.G.) not involved in the evaluation of CT colonographic data
compared all lesions detected at CT colonography with polyps found at videotaped colonoscopy.

A lesion detected during CT colonography was considered to be true-positive if it matched colonoscopic findings recorded on videotape with regard to size, morphology, the segment in which the lesion was located, and the anatomic interrelation with haustral folds. A false-positive finding at CT colonography was defined as a finding that was not detected during conventional colonoscopy or that did not match a colonoscopic finding as recorded on videotape. Thus, if a polyp was found at both CT colonography and colonoscopy but the findings did not match, then it was considered false-positive.

Correct identification of a patient with polyps by means of CT colonography was defined as the detection of at least one true-positive polyp in the patient. Patients without polyps at colonoscopy were identified correctly if polyps were absent at CT colonography, as well. The per-patient sensitivity was calculated as the proportion of correctly identified patients with polyps at CT colonography out of all patients with a polyp found at colonoscopy. The specificity was calculated as the proportion of patients correctly identified as having no polyps at CT colonography out of all patients without polyps at colonoscopy. Similar definitions were used in the analysis, in which only medium to large polyps were taken into account and small polyps were disregarded.

Image quality and reading time.—For purposes of image quality analysis at the 100- and simulated 50- and 30-mAs levels, the average of subjective image quality of each data set (of images obtained with patients in the prone and supine positions) was used. Differences in median image quality between data sets obtained with different dose levels were assessed by means of the Wilcoxon rank test.

Differences in mean reading time between data sets obtained with different dose levels were assessed with a paired-samples t test.

For all statistical analyses, a P value of less than .05 was considered to indicate a statistically significant difference.

Survey of CT Colonography Scan Protocols To investigate the effective dose used for CT colonography in the recent past, the research fellow (R.E.v.G.) performed a literature search of Medline. He selected articles in the English language that addressed the diagnostic accuracy of CT colonography in humans and supplied the required specifications to calculate effective dose. Several authors published more than one article. In these cases, the earliest study was chosen. Scan parameter
Radiation dose reduction in CT colonography, part 1

information was collected from the selected articles. To update this information, the research fellow (R.E.v.G.) e-mailed all authors and requested that they provide their most recent scan protocol. Also, investigators who were known to perform research on the diagnostic accuracy of CT colonography in human subjects and who were present at the Second International Symposium on Virtual Colonoscopy (Boston, Mass, October 2000) were requested to provide us with this information. Those who did not respond were reminded once. A comparison of published and most recent (unpublished) scan protocols enabled us to monitor possible changes in the protocols used.

Effective radiation doses resulting from these different scan protocols were calculated by means of the ImPACT CT Patient Dosimetry Calculator version 0.99 g (London, England). We estimated the relative accuracy of effective dose values (by comparing the dose from one scanner to the next and from one protocol to the next) to be approximately 10%–20%. Since the effective dose values were determined by using an androgynous mathematic phantom, they were calculated as mean values for both men and women. The significance of the differences between effective doses ensuing from published and recent (unpublished) scan protocols was determined by using the Wilcoxon rank test.

Results

Waist Circumference The waist circumference of the 50 patients ranged from 72 to 118 cm (mean, 98 cm ± 11). On the basis of this range, the patients were divided into three categories: large (>102.5 cm; n = 18), medium (87.5–102.5 cm; n = 21), and slim (<87.5 cm; n = 11). The mean circumference of patients with and those without polyps was 98 cm ± 11 and 97 cm ± 12, respectively.

Colonoscopy Colonoscopy was successful in all patients. Sixty-two polyps were detected in 27 (54%) patients. In 10 of these patients, at least one medium to large polyp was detected. In the other 17 patients, only small polyps were present. Of the 62 polyps, 13 (21%) were medium to large (median, 8 mm; range, 5–20 mm) and 49 (79%) were small (median, 2 mm; range, 1–4 mm).

3D CT Colonography Validation of lower-dose simulations.—The mean ratio of the SD in the aorta on the 100- and simulated 50-mAs scans in the 12 patients was 1.393 ± 0.010 (range, 1.374–1.408). For the 100- and simulated 30-mAs scans, the mean SD ratio was 1.789 ± 0.017 (range, 1.761–1.817). These mean ratios differed only slightly, albeit
significantly, from the expected values of 1.414 and 1.826, respectively ($P < .01$). No significant correlation between the ratio of the SD in the aorta and waist circumference was found.

**Polyp detection.**—Table 1 lists the number of patients with and without polyps that were correctly identified with CT colonography at 100 mAs and simulated 50 and 30 mAs. No difference was found in the identification of patients with polyps at the three dose levels. In 90% (nine of 10) of patients with medium to large polyps and in 41% (seven of 17) of patients with only small polyps, at least one polyp was correctly identified. Thus, sensitivity with regard to identification of patients with a polyp of any size was 59% (16 of 27) at all dose levels.

Concerning specificity, 26% (six of 23) of patients without polyps were correctly identified with 100-mAs and simulated 50-mAs CT colonography, while 48% (11 of 23) of these patients were correctly identified with simulated 30-mAs CT colonography.

**Table 1.** Sensitivity and specificity of CT colonography for identification of patients with or without polyps.

<table>
<thead>
<tr>
<th>Patients:</th>
<th>Colonoscopy (n)</th>
<th>100 mAs (%)</th>
<th>50 mAs (%)</th>
<th>30 mAs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>with polyps</td>
<td>27</td>
<td>59 (16/27)</td>
<td>59 (16/27)</td>
<td>59 (16/27)</td>
</tr>
<tr>
<td>with polyps ≥ 5mm</td>
<td>10</td>
<td>90 (9/10)</td>
<td>90 (9/10)</td>
<td>90 (9/10)</td>
</tr>
<tr>
<td>Specificity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without polyps ≥ 5mm</td>
<td>40</td>
<td>55 (22/40)</td>
<td>53 (21/40)</td>
<td>53 (21/40)</td>
</tr>
</tbody>
</table>

Note. — Numbers in parentheses are raw data.

**Figure 2.** Sensitivity and specificity at different cutoff values for 100- and simulated 50- and 30-mAs CT colonography for the identification of patients with and those without polyps. Sensitivity was equal at all dose levels, whereas specificity was better at the simulated 30-mAs level. Solid line with + indicates sensitivity with 100- and simulated 50- and 30-mAs CT colonography. Dashed line with X indicates specificity with 100-mAs CT colonography. Dashed line with Δ indicates specificity with 50-mAs CT colonography. Dashed line with □ indicates specificity with 30-mAs CT colonography.
Of the 40 patients without medium to large polyps, 55% (22 of 40), 53% (21 of 40), and 60% (24 of 40) of patients were correctly identified at 100, 50, and 30 mAs, respectively. Figure 2 demonstrates the sensitivity and specificity for different cutoff values for CT colonography at 100, 50, and 30 mAs.

Table 2 displays the performance of CT colonography in detecting polyps of different sizes. For all three dose settings, nearly all medium to large polyps were detected, while only a quarter of small polyps were detected, regardless of dose level.

Table 2. Sensitivity on a per-polyp basis.

<table>
<thead>
<tr>
<th>Polyp group</th>
<th>Polyps (n)</th>
<th>100 mAs (%)</th>
<th>50 mAs (%)</th>
<th>30 mAs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyps &lt; 5mm</td>
<td>49</td>
<td>24 (12/49)</td>
<td>27 (13/49)</td>
<td>24 (12/49)</td>
</tr>
<tr>
<td>Polyps ≥ 5mm</td>
<td>13</td>
<td>85 (11/13)</td>
<td>92 (12/13)</td>
<td>85 (11/13)</td>
</tr>
</tbody>
</table>

Note. — Numbers in parentheses are raw data

Image quality and reading time.—Table 3 lists the subjective image quality for CT colonography at different dose levels for all patients according to their waist circumference and the results of the Wilcoxon rank test to assess differences in image quality between different dose levels. Median image quality was the highest at the 100 mAs level and decreased with decreasing dose level. When analyzed according to waist circumference, image quality was judged to be better in the slimmer patients, and the subjective image quality decreased when the waist circumference increased at all dose levels. The image quality was poor for 30-mAs CT colonography in patients with a large waist circumference.

The mean reading times for the 100- and simulated 50- and 30-mAs examinations were 19 minutes and 48 seconds, 16 minutes and 51 seconds, and 16 minutes and 0 seconds, respectively. Differences in reading time between the 100- and simulated 50-mAs examinations and 100- and simulated 30-mAs examinations were significant (P ≤ 0.01), while the difference between simulated 50- and 30-mAs examinations was not significant (P = .09).

Table 3. Median and range of the subjective image quality.

<table>
<thead>
<tr>
<th>Waist circumference (cm)</th>
<th>100 mAs</th>
<th>50 mAs</th>
<th>30 mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>3.0 (2.0-4.0)</td>
<td>2.75 (1.0-4.0)*</td>
<td>2.0 (1.0-4.0) **</td>
</tr>
<tr>
<td>&lt; 87.5</td>
<td>3.5 (2.0-4.0)</td>
<td>3.0 (2.0-4.0)</td>
<td>2.5 (1.0-4.0)*</td>
</tr>
<tr>
<td>87.5 - 102.5</td>
<td>3.0 (2.0-4.0)</td>
<td>2.5 (1.5-4.0)</td>
<td>2.0 (1.0-4.0)*</td>
</tr>
<tr>
<td>≥ 102.5</td>
<td>3.0 (2.0-3.5)</td>
<td>2.5 (1.0-3.5)*</td>
<td>1.5 (0-3.0) **</td>
</tr>
</tbody>
</table>

Significant differences in image quality between 50 and 100 mAs, and 30 and 100 mAs, are indicated with * (P<0.05) or ** (P<0.001).
Figure 3 shows a 5-mm polyp detected by using 100- and simulated 50- and 30-mAs CT colonography and demonstrates the increased noise in the simulated 50- and 30-mAs source images and virtual endoscopic images.

CT Colonography Scan Protocols In 13 articles on CT colonography published from October 1997 until June 2001 (1–9,12,18–20), the estimated effective dose was in the range of 1.7–9.2 mSv, with a median of 3.9 mSv. The increase in effective dose that resulted from overlapping scan regions in some of the earlier protocols, which consisted of multiple scans, was disregarded. Updated (unpublished) CT colonography scan protocols used at the time this article was written were obtained from 12 of 19 institutions that received a request to provide this information. Table 4 lists the scan protocols and the effective doses for these protocols for one CT examination, together with the effective dose of the present study at 100, 50, and 30 mAs. The effective doses at the 12 other centers range from 1.9 to 5.9 mSv, with a median of 4.4 mSv. No statistically significant differences were observed between the published and updated (unpublished) effective doses. Because patients are scanned in two positions in most institutions, the above effective doses have to be doubled for complete CT colonography.
Table 4. Scan protocols of 13 centers that perform CT colonography.

<table>
<thead>
<tr>
<th>Center:</th>
<th>kV</th>
<th>Eff dose (mSv/mAs)</th>
<th>mA</th>
<th>t(sec)</th>
<th>pitch</th>
<th>mAs/slice</th>
<th>collimation</th>
<th>multipl. Eff dose factor (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picker PQ 5000:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Göteborg</td>
<td>110</td>
<td>0.047</td>
<td>125</td>
<td>1</td>
<td>1.25</td>
<td>100</td>
<td>1 x 5</td>
<td>1</td>
</tr>
<tr>
<td>2. Boston</td>
<td>140</td>
<td>0.092</td>
<td>100</td>
<td>1</td>
<td>1.50</td>
<td>67</td>
<td>1 x 5</td>
<td>1</td>
</tr>
<tr>
<td>GE Lightspeed QX/I (Mayo b): Lightspeed Plus):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Harvard</td>
<td>120</td>
<td>0.070</td>
<td>50</td>
<td>0.8</td>
<td>1.50</td>
<td>27</td>
<td>4 x 2.5</td>
<td>1</td>
</tr>
<tr>
<td>4. Chicago</td>
<td>120</td>
<td>0.070</td>
<td>60</td>
<td>0.8</td>
<td>1.50</td>
<td>32</td>
<td>4 x 2.5</td>
<td>1</td>
</tr>
<tr>
<td>5. Lausanne</td>
<td>120</td>
<td>0.070</td>
<td>70</td>
<td>0.8</td>
<td>1.50</td>
<td>37</td>
<td>4 x 5</td>
<td>0.88</td>
</tr>
<tr>
<td>6. Mayo Clinic [a]</td>
<td>120</td>
<td>0.070</td>
<td>50</td>
<td>0.8</td>
<td>0.75</td>
<td>53</td>
<td>4 x 5</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>[b]</td>
<td></td>
<td>80</td>
<td>0.5</td>
<td>0.75</td>
<td>53</td>
<td>4 x 5</td>
<td>0.88</td>
</tr>
<tr>
<td>7. Stanford [a]</td>
<td>120</td>
<td>0.070</td>
<td>60</td>
<td>0.8</td>
<td>0.75</td>
<td>64</td>
<td>4 x 2.5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>[b]</td>
<td></td>
<td>120</td>
<td>0.8</td>
<td>1.50</td>
<td>64</td>
<td>4 x 2.5</td>
<td>1</td>
</tr>
<tr>
<td>8. Yale</td>
<td>120</td>
<td>0.070</td>
<td>100</td>
<td>0.8</td>
<td>1.50</td>
<td>53</td>
<td>4 x 1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>Toshiba Aquilion:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Berlin</td>
<td>120</td>
<td>0.085</td>
<td>100</td>
<td>0.5</td>
<td>1.38</td>
<td>36</td>
<td>4 x 1</td>
<td>1.36</td>
</tr>
<tr>
<td>Siemens Volume Zoom:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. New York [a]</td>
<td>120</td>
<td>0.056</td>
<td>150</td>
<td>0.5</td>
<td>1.50</td>
<td>50</td>
<td>4 x 1</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>[b]</td>
<td></td>
<td>200</td>
<td>0.5</td>
<td>2.00</td>
<td>50</td>
<td>4 x 1</td>
<td>1.18</td>
</tr>
<tr>
<td>11. Dublin</td>
<td>120</td>
<td>0.056</td>
<td>250</td>
<td>0.5</td>
<td>1.25</td>
<td>100</td>
<td>4 x 2.5</td>
<td>1</td>
</tr>
<tr>
<td>Marconi Mx8000:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Aarhus</td>
<td>120</td>
<td>0.059</td>
<td>250</td>
<td>0.5</td>
<td>1.25</td>
<td>100</td>
<td>4 x 2.5</td>
<td>1</td>
</tr>
<tr>
<td>13. Amsterdam</td>
<td>120</td>
<td>0.059</td>
<td>167</td>
<td>0.75</td>
<td>1.25</td>
<td>100</td>
<td>4 x 2.5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>0.059</td>
<td>83</td>
<td>0.75</td>
<td>1.25</td>
<td>50</td>
<td>4 x 2.5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>0.059</td>
<td>50</td>
<td>0.75</td>
<td>1.25</td>
<td>30</td>
<td>4 x 2.5</td>
<td>1</td>
</tr>
</tbody>
</table>

Note.—At some institutions, higher doses are used for obese patients; in this Table, the lowest milliampere values are listed throughout. The effective dose is for an examination with a 10-mm collimation and was estimated by using the ImPACT Patient Dosimetry Calculator. Correction factors for other collimations are given in the column with multiplication factors. For single-section scanners, we assumed the correction factor to be 1. The listed centers are Sahlgrenska University Hospital, Göteborg, Sweden; Boston Medical Center, Mass; Beth Deaconess Medical Center, Harvard Medical School, Boston, Mass; University of Chicago, Ill; University Hospital Center CHUV, Lausanne, Switzerland; Mayo Clinic, Rochester, Minn; Stanford University Medical School, Palo Alto, Calif; Yale University Medical School, New Haven, Conn; Charité Hospital, Berlin, Germany; Tisch Hospital, New York University Medical Center, NY; Mater Misericordiae Hospital, Dublin, Ireland; Aarhus University Hospital, Denmark; and Academic Medical Center, Amsterdam, the Netherlands.

Figure 4 demonstrates the effective dose, resulting as a function of the milliamperes per section value for all protocols used in the past and at present at different institutions. The relationship of milliamperes per section and effective dose differs for different CT scanner manufacturers and types, depending on geometry and the x-ray filter used. For fixed CT scanner and dose values, the effective dose also depends on the kilovolts and collimation. Most centers used (or still use) 120 kV; four centers, 110 kV; and one center, 140 kV. For narrow collimation (1.00 or 1.25 mm), which is used in multisection CT scanners only, the effective dose is approximately 20%-35% higher.
Figure 4. Graph shows effective dose for one CT examination of the abdomen (for one position) for the 13 published CT colonographic scan protocols (□) and for those used at present (●). Overlap of scans in multiple-scan protocols was disregarded. The relationship between dose per section and effective dose for the Mx8000 multisectison CT scanner used in the present study is indicated with a solid line. In all protocols except five, 120 kV was used. In four protocols, 110 kV was used (indicated with an X), and in one protocol, 140 kV was used (indicated with a +).

Discussion

The effective dose resulting from CT colonography as performed up to the time this article was written ranges from 4 to 18 mSv for CT colonography in two (supine and prone) positions. Although the risks of using radiation doses of this magnitude are uncertain because they are based on extrapolated data, they are expected to be harmful (16). For CT colonography to become a screening method for colorectal cancer, radiologists must aim for the lowest effective dose possible to perform this examination. The results of the present study demonstrate that although subjective image quality decreases as dose level decreases, polyp detection by means of CT colonography remains equal at the 100- and simulated 50- and 30-mAs levels. The sensitivity with regard to identification of patients with medium to large polyps was 90% (nine of 10). When patients with only small polyps were regarded, the sensitivity dropped to 41% (seven of 17). The sensitivity for the detection of medium to large polyps was 85%–92% (11–12 of 13), and for small polyps it was 24%–27% (12–13 of 49).

The sensitivity with regard to identification of patients with at least one medium to large polyp or with only one or more small polyps is comparable with values reported in the literature: 65%–94% for patients with medium to large polyps and 25%–82% for patients with only small polyps (1–12,18,19). The sensitivity with regard to the detection of medium to large polyps is at the upper range reported in the literature, namely 22%–94% (1–12,18,19). The poor sensitivity for detection of small polyps in the present study is in concordance with that in current literature (11%–59%) and confirms the poor results of CT colonography for polyps smaller than 5 mm (1–12,18,19).
The accuracy of the identification of patients without medium to large polyps is equal at 100- and simulated 50- and 30-mAs CT colonography. However, identification of patients without any polyps appears to be better at the 30-mAs level. This can probably be explained by the decreased image quality at the 30-mAs level, which may restrain the radiologist to consider small (3-mm) structures to be true polyps. Therefore, this may account for the lower number of false-positive findings in this size range at the 30-mAs level. This assumption is concordant with the finding that 100-mAs examinations, with a generally better image quality, have a significantly longer evaluation time, as smaller details will be regarded as potential lesions.

Specificity for identification of patients without polyps (26%–48%) and patients without medium to large polyps (53%–60%) is low compared with values reported in the literature, which are in the range of 62%–93% and 58%–96%, respectively (1–12,18,19). However, when 8- or 10-mm thresholds are used, the specificity results of the current study (87%–89% [39–40 of 45 patients without polyps 8 mm or larger] and 91%–96% [43–45 of 47 patients without polyps 10 mm or larger], respectively; Fig 2) are in the upper range of published values (74%–96%) (1–12,18,19). In practice, use of a cutoff value of 5–6 mm would have resulted in a considerable number of false-positive findings, and, therefore, in unnecessary colonoscopies. However, colorectal cancer screening will most likely be aimed at polyps larger than 10 mm, and the above results indicate that at this threshold, the specificity will exceed 90%.

The relatively low sensitivity and specificity with regard to the detection of small polyps may result from the strict definitions of true- and false-positive findings that we used. In the present study, CT colonographic findings were compared with the colonoscopic video with regard to anatomic interrelation to haustral folds, anatomic segment, size, and morphology. In most articles, a less strict criterion concerning location was employed: A result was considered to be true-positive if the lesion was found in the same colonic segment at both colonoscopy and CT colonography. Since a colonic segment is between 15 and 40 cm long, this may cause erroneous interpretation of CT colonographic findings to be true-positive when in fact they are false-positive, because they match with other lesions in the colonic segment or are in fact residual stool. Thus, in our opinion, this strategy may cause overestimation of the number of true-positive results and underestimation of the number of false-positive results of CT colonography.

Another explanation for the high rate of false-positive findings is the fact that 27% of small polyps (<5 mm) are missed at colonoscopy (26). Therefore, some small lesions detected during CT colonography may in fact be true-positive findings. At any rate, the
benefit of the detection of lesions smaller than 5 mm in a screening setting is dubious, since small polyps are known to rarely contain malignant tissue (27).

A limitation of the present study is that only one abdominal radiologist reviewed the CT colonographic results, and as a result, interobserver analysis could not be performed. The noise level on CT images depends on the accuracy of the transmission measurements used in the reconstruction of the images, which in turn depends primarily on the number of transmitted photons. This number is proportional to the dose used for the CT scan and also depends strongly on the dimensions of the patient, which we have quantified by means of waist circumference. With regard to image quality, noise level appears to be an important factor, since the subjective image quality depends on both the dose and the waist circumference (Table 3). As could be expected, subjective image quality is worst at the lowest dose level in patients with the largest circumference. The decrease in image quality as a result of dose reduction is more marked in large patients. This observation, in combination with the comparable values of the sensitivity and specificity for polyp detection at 30 and 100 mAs, suggests that for slim to medium patients, 30 mAs may be sufficient for CT colonography. In fact, the data presented here emphasize the desirability to tailor the doses used in CT colonography to the girth of the patient. Low-dose high-noise imaging may be less effective in regions with an intrinsically high noise level, such as the pelvic region, due to the presence of bony structures and the relatively large cross section. This is an issue that needs further consideration. Because of the limited amount of data in the present study, we are not able to draw any firm conclusions on this point.

The validation of the simulation procedure consisted of measuring the SD of noise in regions of interest in the descending aorta on simulated 50- and 30-mAs scans. This revealed a small disparity between the measured and expected noise values. The simulated doses were therefore 52 and 31 mAs instead of 50 and 30 mAs. This discrepancy was most likely caused by a small inaccuracy in the calibration method and possibly also by slight inhomogeneities in the regions of interest used in the validation procedure. Notably, on real 30-mAs CT scans of large patients, the actual noise will be slightly higher than theoretically expected (depending on the type of CT scanner) as a result of the electronic noise in the preamplifiers of the detectors, which under these circumstances cannot be completely neglected.

Effective Dose of CT Colonographic Examinations In this study, we have made an inventory of the CT scanners and technical protocols that are used in the institutions
that perform CT colonographic research.

Important technical factors that influence the effective dose of an examination are the construction of the scanner (geometry, collimation, filtration), tube voltage, tube current, rotation time, and pitch.

Three of these factors—tube current, rotation time, and pitch—can be combined in the milliamperes per section value ((tube current x rotation time)/pitch). When different CT scanners are compared, it appears that the milliamperes per section value alone is not a sufficient indicator of the effective dose of a CT examination, even when the kilovolts and section collimation are the same, because of differences in the construction of the CT scanners. We used the ImPACT CT dose calculator to estimate the effective dose for all CT scanners in our inventory.

A comparison of published effective dose values with those used at the present time indicates that in some research centers, high dose values were used initially but that at the time this article was written, all effective doses (for one examination) were approximately 2–6 mSv, which is also the range of effective doses covered by the dose per section levels of the present study. Although there is a trend to lower the dose used in the examinations, no significant differences are present between the effective doses used in the (recent) past and at present. This is mainly due to the fact that, at the present time, most examinations are performed with multisection CT scanners, which tend to have a higher effective dose level for the same dose as single-section CT scanners (28). Another reason is that at present, some centers use narrower collimations (1.0 or 1.25 mm instead of 2.5 or 5.0 mm), which also lead to an increase in effective dose.

Some centers indicated that they use higher milliamperes for obese patients, in line with the tailoring of milliamperes to the size of the patient (as mentioned above). In case more dose values were reported, we used the lowest value to determine the effective dose, because the dose estimated with the ImPACT CT dose calculator is for an average patient. Since the relationship between dose and effective dose depends on the size of a patient (29), the effective dose for a particular dose value will be lower in obese patients.

**Screening for Colorectal Cancer with Low-Dose CT Colonography** The possible future role of CT colonography as a screening method to prevent colorectal cancer is open to discussion because of the required bowel preparation and the use of ionizing radiation in the examination. The first issue is being addressed by several institutions. Current research indicates that strict bowel preparation, as performed in
the current study, may be redundant in the near future (20). This is expected to dramatically increase patient acceptance of CT colonography, since bowel preparation appears to be one of the main drawbacks of present colonic examinations. Use of high-attenuation contrast material (such as iodine or barium) within the colon, however, will have a tendency to increase noise and streak artifacts and may complicate use of low-dose CT scans. Further research is required to investigate this point.

The results of the current study indicate that use of low-dose CT does not impair the performance of CT colonography in patients who received bowel preparation. The reduction of the amount of ionizing radiation used to perform CT colonography is important, since it will reduce risk in a proportional fashion. In the population as a whole, the lifetime risk of developing fatal cancer as a result of ionizing radiation exposure is estimated by the International Commission on Radiological Protection, or ICRP, to be approximately 5% per sievert (16). However, the risk is highest for children and decreases considerably with increasing age. The targeted population for colorectal cancer screening is probably 50 years of age and older. The ICRP data indicate that the probability of inducing fatal cancer in a 50-year-old individual is approximately 2.5% per sievert, and at the age of 70, the risk is half this value. As a consequence, one can estimate the risk of inducing cancer by means of CT colonography with an effective dose of 8.8 mSv (which is the median effective dose used in present examinations) to be approximately 0.02% in a 50-year-old individual and lower for older people. For a lower-dose setting (eg, the lowest dose considered in this study), the risks are about half these values.

In conclusion, the results of this study indicate that although subjective image quality is worse at low-dose CT colonography, the sensitivity and specificity remain unimpaired. This finding may be an important argument in the discussion of the possible screening role of CT colonography. A considerable range in effective dose is present in CT colonographic examinations performed at different institutions. At the present time, the median effective dose for a complete examination is approximately 8.8 mSv. Such an examination may result in a risk of up to 0.02% for inducing cancer in the population over 50 years of age who are currently considered for colorectal cancer screening (16). The present study indicates that the same accuracy can be obtained at an effective dose level of approximately 3.6 mSv, resulting in a substantial decrease of lifetime risk of developing fatal CT-induced cancer.
Acknowledgements

The authors thank Maria Svensson, MD, Joel G. Fletcher, MD, Chris Beaulieu, MD, MPH, and the other contact persons at the radiology departments who provided information used in this article.

References


