

Gastrointestinal Imaging

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Index terms:

Colon, CT, 75.12111, 75.12117,
 75.12118
 Colon neoplasms, 75.311
 Colon neoplasms, CT, 75.12111,
 75.12117, 75.12118
 Colonoscopy, 75.1289
 Computed tomography (CT),
 comparative studies, 75.12111,
 75.12117, 75.12118

Published online before print
 10.1148/radiol.2242011382
Radiology 2002; 224:383–392

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Colorectal Neoplasms: Prospective Comparison of Thin-Section Low-Dose Multi-Detector Row CT Colonography and Conventional Colonoscopy for Detection¹

PURPOSE: To prospectively compare thin-section low-dose multi-detector row computed tomographic (CT) colonography with conventional colonoscopy for the detection of colorectal neoplasms.

MATERIALS AND METHODS: One hundred five patients underwent CT colonography immediately before colonoscopy. Supine and prone CT colonographic acquisitions to image the region during a 30-second breath hold were performed. CT colonographic images were prospectively interpreted for the presence, location, size, and morphologic features of polyps. The time of image interpretation was noted. Sensitivity, specificity, and positive and negative predictive values of CT colonography were calculated, with 95% CIs, by using colonoscopic findings as the reference standard. The weighted CT dose index was calculated on the basis of measurements in a standard body phantom. Effective dose was calculated by using commercially available software.

RESULTS: Median CT data interpretation time was 12 minutes. One hundred thirty-two polyps in 59 patients were identified at colonoscopy; no polyps were detected in 46 patients. Sensitivities for detection of polyps smaller than 5 mm, 6–9 mm, and larger than 10 mm in diameter were 12% (11 of 91 polyps), 70% (19 of 27 polyps), and 93% (13 of 14 polyps), respectively. Estimated overall specificity was 97.7% (515 of 527 imaging results). The total weighted CT dose index for combined supine and prone CT colonography was 11.4 mGy. The effective doses for combined CT colonography were 5.0 mSv and 7.8 mSv for men and women, respectively.

CONCLUSION: Low-dose multi-detector row CT colonography has excellent sensitivity and specificity for detection of colorectal neoplasms 10 mm and larger.

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Screening for colorectal cancer reduces the morbidity and mortality associated with this disease by facilitating the depiction and exclusion of precancerous polyps (1–8). However, 50,000 deaths from colon cancer occur in the United States each year. One reason that colorectal carcinoma continues to be so prevalent is patient reluctance to undergo the current screening procedures (9,10). Most authorities agree that full colonic evaluation should be incorporated into the screening program.

Computed tomographic (CT) colonography is a safe noninvasive technique to evaluate the entire colonic surface and detect polyps and/or cancers. Reported sensitivities of CT

colonography performed with single-section CT scanners, a variety of acquisition techniques, and tube current values of 70–150 mAs for the detection of polyps larger than 10 mm in diameter range from 70% to 100% (11–19). The limitations of single-section CT colonography identified in these studies include decreased sensitivity for detection of polyps smaller than 10 mm in diameter, failed depiction of so-called flat lesions, and high false-positive rates due to the inability to differentiate either residual fecal material or bulbous haustral folds from polyps.

Multi-detector row CT enables increased speed (or range) of z-axis coverage with near isotropic z-axis spatial resolution. This combination of factors allows data acquisition with much thinner collimation in the same amount of time. Better voxel profiles over a wider z-axis range are ideal for CT colonography in that they have the potential to yield improved polyp detection and specificity.

A major long-term risk with CT colonography as a potential cancer screening examination is patient exposure to ionizing radiation (20). Adaptation of thin-section acquisition protocols for standard abdominal CT techniques will necessitate an increase in tube current (dose) to compensate for increased noise and possible degradation of image quality. Furthermore, the need to perform supine and prone acquisitions for CT colonography substantially influences the total radiation dose to which the patient is exposed (21). However, because the difference in attenuation (ie, contrast) between the gas-distended colonic lumen and the colonic wall is large, as in the thorax, it seems that the milliamper second setting can be lowered while an adequate contrast-to-noise ratio is maintained.

There are only a few reports (22,23) regarding patient dose and CT colonography in the literature. The purpose of this study was to prospectively compare thin-section low-dose multi-detector row CT colonography with conventional colonoscopy for the detection of colorectal neoplasms.

MATERIALS AND METHODS

Patients

Between September 2000 and June 2001, 105 patients (102 men, three women; age range, 49–79 years; mean age, 58 years) were enrolled in this study. Patients eligible for inclusion were those who

were seen in a gastroenterology clinic and were scheduled for colonoscopic evaluation because of a positive fecal occult blood test, iron deficiency anemia, hematochezia, or a history of polyps. No patient was known to have polyps. All patients underwent CT colonography and colonoscopy within 1 month of the time of recruitment. Eligible patients were informed of the study design and signed an institutional review board-approved consent form on which the procedure and study were explained. CT colonography was performed first, and colonoscopy was performed 3 hours later.

CT Colonography Technique

On the day before the CT colonographic and colonoscopic studies, one of two bowel preparations, as prescribed by the participating gastroenterologist (E.J.B.), was administered to the patient. The preparation consisted of an oral hydration solution that consisted of two 45-mL doses of sodium phosphate (Phospho-soda; Fleet Pharmaceuticals, Lynchburg, Va) or 4 L of polyethylene glycol electrolyte solution (Golytely; Braintree Laboratories, Braintree, Mass). In general, the sodium phosphate preparation was given unless the patient had ascites, renal insufficiency, or congestive heart failure. Because the phospho-soda preparation may result in acute elevation of serum sodium and phosphate concentrations, it is contraindicated in patients with congestive heart failure or renal failure. On site and immediately before undergoing CT colonography, the patient was asked to evacuate any residual fluid from the rectum.

CT colonography was performed with a multidetector CT system (Siemens Plus 4 Volume Zoom; Siemens Medical Systems, Forchheim, Germany). No bowel relaxant was used in this study. An experienced technologist or nurse practitioner inserted a flexible rubber catheter into the rectum and insufflated the colon with room air according to the patient's tolerance (minimum of 40 puffs). The catheter was left in the rectum, and a single supine scout CT image was obtained to verify adequate bowel distention. If adequate bowel distention was present, the CT examination was performed. If adequate bowel distention had not been achieved, additional air was insufflated into the rectum. Following air insufflation, CT colonography was performed first in the supine position in a cephalocaudal direction to image the entire re-

gion of the colon and rectum. The patient was then placed in the prone position. Several additional puffs of air were then administered. Following the acquisition of a second localizing scout image, the process was repeated over the same z-axis range.

CT parameters included 4×1 -mm-section detector collimation, 120 kV, 0.5-second gantry rotation, and effective 50 mAs. Pitch (table feed per gantry rotation/nominal section thickness) varied between 6 and 7 such that the entire region of the abdomen and pelvis could be imaged during a 30-second breath hold. The pitch needed to be varied to account for differences in patient height so that the acquisition could be completed in 30 seconds. This protocol resulted in 12 and 14 mm of coverage per second. CT images were reconstructed as 1.25-mm-thick sections with a 1-mm reconstruction interval.

Radiation Dose Estimation

For estimation of CT radiation dose to the patient, the weighted CT dose index (expressed in milligrays) was used. The weighted CT dose index was based on the kilovolt, effective milliamper second, and section collimation values just described. The effective milliamper second setting depends on the gantry rotation speed, pitch, and tube current. By definition, effective milliamper second = (tube current milliamper second \times rotation time)/beam pitch. The reasoning behind this definition is that rotation time divided by beam pitch is the true radiation exposure time at a certain location along the z axis during a spiral CT acquisition.

The weighted CT dose indexes were calculated on the basis of measurements in a plastic adult body phantom (32-cm CT dose index phantom) of an average-sized man that was made by the CT system manufacturer (Siemens Medical Systems). The weighted CT dose index is the sum of two-thirds of the peripheral CT dose index₁₀₀ plus one-third the central CT dose index₁₀₀ measured in the phantom. CT dose index₁₀₀ is the radiation dose absorbed in air integrated over a 100-mm chamber along the axial direction of the phantom (24).

With use of the described CT protocol, estimations of the effective doses (in millisieverts) for an average-sized male patient and an average-sized female patient were made on the basis of the CT parameters used in the study and the radiation exposure to the entire region of the ab-

domen and pelvis. This calculation was made by using commercially available software (WinDose; Wellhofer Dosimetry, Schwarzenbruck, Germany) that uses estimations of organ-weighting coefficients according to ICRP (International Commission on Radiological Protection) 60 (25). The single supine and prone scout images obtained in each patient were not included in the radiation dose calculations.

CT Colonographic Data Interpretation

All CT colonographic images were interpreted by the same abdominal radiologist (M.M.), who had 4 years of experience in interpreting CT colonographic studies. The radiologist was not informed of any patient's medical history, risk factors, or other demographic information.

The supine and prone reconstructed image data sets were networked to an offline workstation (Vitrea 2; Vital Images, Minneapolis, Minn). The data sets were viewed as continuous 1.25-mm sections in the transverse plane; this was the primary display method. Because the data were acquired with near isotropic voxels, no secondary interpolation was required. For each patient, both prone and supine image data sets were evaluated before assessment of the presence or absence of polyps was performed. When an abnormality was detected on transverse CT colonographic images, coronal and sagittal multiplanar reformatted images, as well as volume-rendered endoluminal CT views (derived from the commercially available software program on the offline workstation), were evaluated to verify the morphologic features of the lesion. If no abnormality was seen at transverse image review, no further image processing was performed.

The presence, location, size, and morphologic features of colorectal polyps in six colonic segments (cecum, ascending colon, transverse colon, descending colon, sigmoid, and rectum) were assessed, and this facilitated polyp-to-polyp mapping. If an abnormality was detected, careful inspection of the internal attenuation—that is, gas bubbles, high-attenuating areas, or homogeneous attenuation—was performed by using a variety of window and level settings. Moreover, to differentiate stool or bulbous folds from polyps, the morphologic features of the abnormalities were evaluated on multiplanar and three-dimensional endoluminal CT views. Lesions with geometric morphologic features (ie, angled

edges) were considered to be residual fecal material. Coronal and endoluminal CT images were used to differentiate linear (ie, fold) from round (ie, polypoid) morphologic features.

The evaluation time was the time during which the networked data sets were reviewed and a statement as to the presence or absence of polyps was made. The presence or absence of polyps or cancers was recorded as a yes or no response. Assessment was made in this fashion because a positive result (polyp or cancer) indicated that follow-up colonoscopy was needed. Findings in each patient were prospectively recorded on the same day that the procedure was performed. These reports were not available to the colonoscopist (E.J.B., A.M.).

Colonoscopy Technique

Colonoscopy was performed, without knowledge of the CT findings, by a board-certified gastroenterologist (E.J.B., A.M.) or a gastroenterology fellow under the direct supervision of the attending gastroenterologist. All polyps identified at colonoscopy were photographed, either resected at biopsy or removed by means of snare polypectomy, and sent for histopathologic analysis. Polyps were measured (in millimeters) by using the open-biopsy forceps technique. The location of each polyp in the same six colonic segments evaluated at CT analysis was mapped.

CT Colonographic and Colonoscopic Data Comparison

Each week the radiologist and the gastroenterologist (E.J.B. or A.M.) reviewed the patient findings from the prior week. For purposes of analysis, a finding was defined as true-positive when CT colonography and conventional colonoscopy depicted a lesion with similar morphologic structure and size in the same anatomic segment. A true-negative finding was considered to be present when both CT colonography and conventional colonoscopy revealed no abnormalities in the same segment. A finding was defined as false-positive when CT colonography depicted an abnormality in a segment but conventional colonoscopy did not depict an abnormality in that segment. A false-negative finding was considered to be present when a lesion was detected in a segment at conventional colonoscopy but a lesion was not detected in the same segment at CT colonography. Therefore, if CT colonography depicted a 10-mm

pedunculated lesion in the sigmoid colon and colonoscopy revealed only a 3-mm sessile polyp in the sigmoid colon in the same patient, the 10-mm lesion was considered a false-positive finding and the 3-mm lesion was considered a false-negative finding at CT colonography. If CT colonography and colonoscopy depicted a lesion with similar morphologic features but slightly different estimated polyp sizes (up to 4 mm) in the same segment, the lesions were considered to be the same polyp. In these cases, the radiologist and gastroenterologist carefully reviewed the images of the polyp to determine the actual size. In cases of incomplete colonoscopy due to obstructing neoplasms or poor bowel preparation, only the segments evaluated at colonoscopy were compared.

Statistical Analysis

Sensitivity, specificity, and positive and negative predictive values were calculated, with 95% CIs, by using the findings at conventional colonoscopy as the reference standard. Calculations were based on segmental findings. A segment can have zero, one, or more than one polyp at either conventional colonoscopy or CT colonography.

Sensitivity was defined as the proportion of polyps detected at CT colonography out of all the polyps detected at conventional colonoscopy—that is, the proportion of true-positive polyps at CT colonography out of all the polyps detected at conventional colonoscopy. Because the sensitivity of CT colonography for polyp detection varies directly according to polyp size, we calculated the sensitivity for the detection of polyps with diameters of 5 mm or less, 6–9 mm, and 10 mm or greater. Specificity was defined as the proportion of negative results at CT colonography out of all the negative results for detection of polyps at conventional colonoscopy—that is, the proportion of true-negative results out of all the negative results at conventional colonoscopy. Positive predictive value was defined as the proportion of true-positive results based on findings at colonoscopy. As with sensitivity, these values were calculated for the detection of polyps with diameters of 5 mm or less, 6–9 mm, and 10 mm or greater. Negative predictive value was defined as the proportion of true-negative CT results based on conventional colonoscopic findings.

The standard approach to calculating the variances of sensitivity, specificity, and positive and negative predictive val-

ues is appropriate only when there is at most one polyp per colon. In the present study, however, each colon was divided into six segments and each segment could have had more than one polyp. In such cases, variance estimations of sensitivity, specificity, and positive and negative predictive values calculated by using the standard approach tend to be too small. An appropriate method for calculating the variance for proportions with correlated binary data and that takes into account the possibility of multiple polyps per colon was used to determine the variances of sensitivity, specificity, and positive and negative predictive values (26).

Histopathologic Analysis

In all cases in which a polyp was detected at colonoscopy, a pathologist reviewed the biopsy material. The pathology report on the biopsy material was reviewed to determine the histopathologic features of all the polyps for which biopsy was performed. Moreover, in all cases in which a polyp larger than 5 mm was detected at colonoscopy but not prospectively at CT colonography, the CT data were retrospectively evaluated by the same radiologist (M.M.) who performed the initial data interpretation to determine the reasons for the initial non-visualization. Finally, when CT colonography depicted a polyp that was not detected at colonoscopy, the CT data were reviewed to determine the reasons for the false-positive finding.

RESULTS

Time Analysis and Adequacy of Data Evaluation

The mean time for CT colonographic data interpretation was 11 minutes (range, 7–20 minutes). The median time for complete supine and prone CT data evaluation was 12 minutes. In general, the images obtained in the patients whose colons did not contain polyps, residual fluid, or fecal material were interpreted in shorter times. The interpretation of images of redundant colons or colons that contained polyps or residual fecal material required longer times. In all 105 patients, the combination of supine and prone CT colonographic imaging enabled the evaluation of each colonic segment.

Colonoscopy to the cecum was complete in 103 (98.1%) of the 105 patients. In the remaining two patients, colonos-

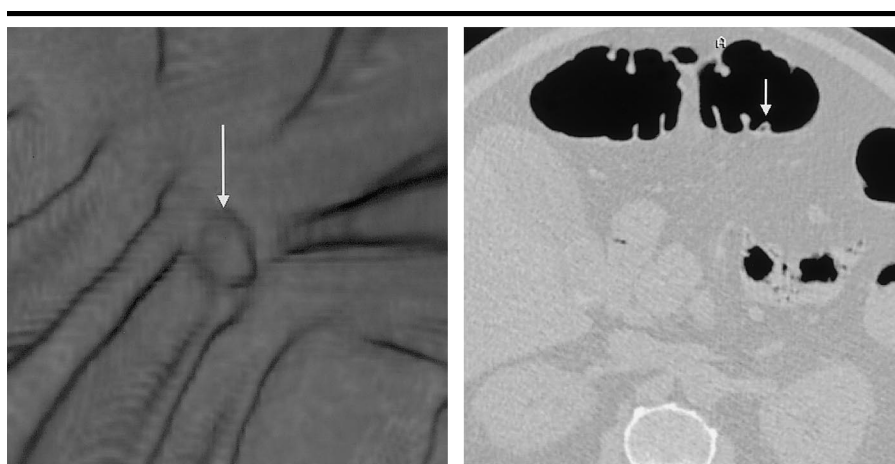


Figure 1. Internal area of hyperlucency in stool of 58-year-old man. **(a)** Three-dimensional volume-rendered endoluminal CT image shows a lobulated mass (arrow) suspected of being a polyp in the transverse colon. **(b)** Transverse CT colonographic image shows a tiny gas bubble in the center of the mass (arrow); this finding confirmed the presence of residual fecal material. No polyp was seen at colonoscopy.

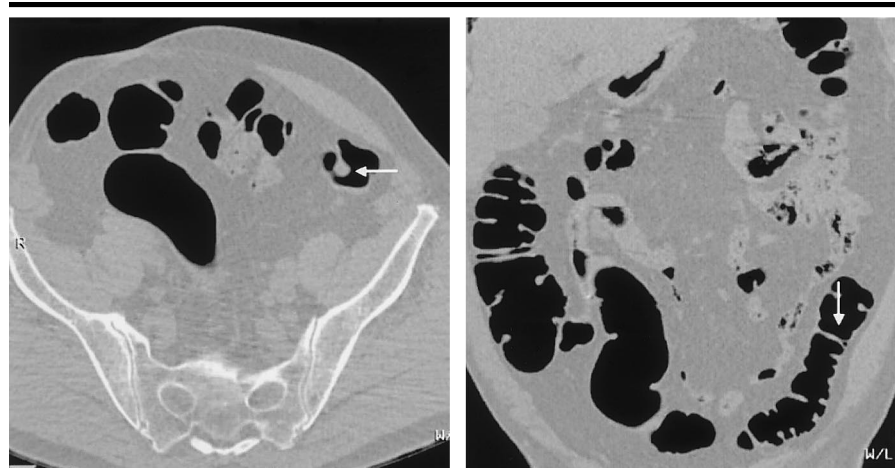
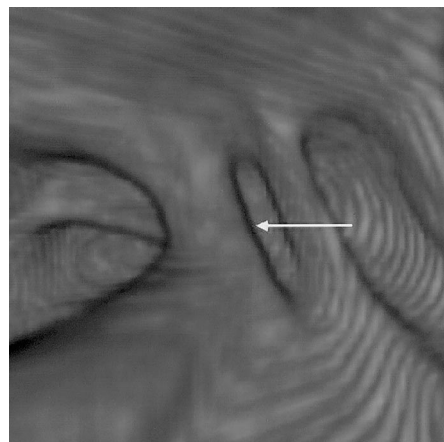


Figure 2. Differentiation of bulbous folds from polyps in 63-year-old man. **(a)** Transverse CT colonographic image shows a 7-mm pedunculated mass (arrow) suspected of being a polyp in the descending colon. **(b)** Coronal CT colonographic image shows that the lesion seen in a actually represents an interhastral fold (arrow) with a linear morphologic structure. **(c)** Three-dimensional endoluminal CT image findings confirm the linear morphologic structure (arrow) of the fold.



copy was incomplete because of residual fecal material and an obstructive neo-

plasm. In the patient with residual fecal material, the combination of supine and prone imaging enabled evaluation of the colon at CT colonography, which depicted no polyps. Follow-up colonoscopy to the cecum in this patient after the administration of a second bowel preparation confirmed the absence of polyps.

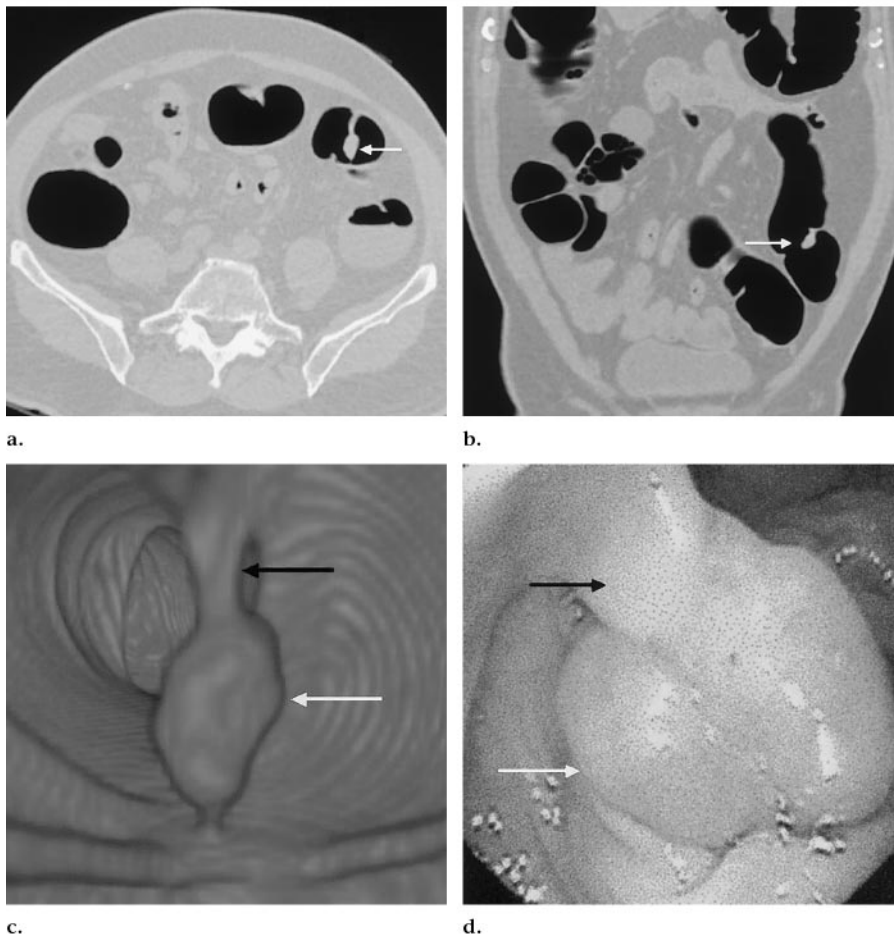


Figure 3. Pedunculated polyp (14 mm) in 74-year-old man. (a) Transverse CT colonographic image shows a lobulated mass (arrow) in the descending colon. (b) Coronal CT colonographic image shows excellent z-axis resolution; the findings confirm the smooth pedunculated morphologic structure of the lesion (arrow). (c) Three-dimensional volume-rendered endoluminal CT image shows the morphologic structure and the stalk (black arrow) and head (white arrow) of the pedunculated polyp. (d) Corresponding colonoscopic image shows the stalk (black arrow) and head (white arrow) of the pedunculated polyp.

Radiation Dose Calculation

With use of the CT parameters described and an effective tube current of 50 mAs, the weighted CT dose index was 5.7 mGy for each acquisition, which resulted in a total weighted CT dose index of 11.4 mGy for the combination of supine and prone CT colonography. With use of the commercially available software (WinDose), the estimated effective dose for full CT colonography would be 5.0 mSv for men and 7.8 mSv for women.

Polyp Detection Rates and Calculations of Sensitivity, Specificity, and Positive and Negative Predictive Values

Forty-six of the 105 patients did not have a polyp at colonoscopy (Figs 1, 2). A total of 132 polyps were present in the

remaining 59 patients (Figs 3–5). At conventional colonoscopy, 24 patients had only one polyp; 15 patients, two polyps; and 20 patients, at least three polyps (Table 1).

The sensitivities of CT colonography for the detection of polyps 5 mm or less, 6–9 mm, and 10 mm or greater in diameter were 12% (11 of 91 polyps; 95% CI: 3.9%, 20.3%), 70% (19 of 27 polyps; 95% CI: 51.6%, 89.2%), and 93% (13 of 14 polyps; 95% CI: 78.6%, 100.0%), respectively. Overall specificity was 97.7% (515 of 527 results; 95% CI: 96.4%, 99.0%) (Table 2). The positive predictive values of CT colonography for the detection of polyps 5 mm or less, 6–9 mm, and 10 mm or greater in diameter were 58% (11 of 19 polyps; 95% CI: 32.4%, 83.4%), 86% (19 of 22 polyps; 95% CI: 69.2%, 100.0%), and 93% (13 of 14 polyps; 95%

CI: 78.6%, 100.0%), respectively. The negative predictive value of CT colonography was 85.3% (515 of 604 results; 95% CI: 81.4%, 89.2%).

Histopathologic Analysis

Of the 91 polyps that were 5 mm in diameter or smaller at CT colonography, one polyp was 1 mm; the colon that contained this lesion was proved to be normal at histopathologic analysis. Twenty-four of the 91 polyps were 2 mm in diameter; at histopathologic analysis, these were one normal colon, 16 hyperplastic polyps, and seven tubular adenomas. Forty-one of the 91 polyps were 3 mm in diameter; at histopathologic analysis, these were seven normal colons, 21 hyperplastic polyps, and 13 tubular adenomas. Eighteen of the 91 polyps were 4 mm in diameter; at histopathologic analysis, these were two normal colons, 10 hyperplastic polyps, five tubular adenomas, and one tubulovillous adenoma. Seven of the 91 polyps were 5 mm in diameter; at histopathologic analysis, these were one normal colon, three hyperplastic polyps, and three tubular adenomas.

On the basis of the morphologic features, sizes, and six-segment polyp-to-polyp comparison between colonoscopy and CT colonography of these 91 polyps, CT colonography depicted three of seven 5-mm polyps, five of 18 4-mm polyps, three of 41 3-mm polyps, and no 1- or 2-mm polyps. Sixty-two (68%) of the 91 5-mm or smaller polyps represented either normal colons or hyperplastic polyps. When failure to depict a 5-mm or smaller polyp at CT colonography was not considered to be a false-negative case, the negative predictive value of CT colonography increased substantially—to 98.5% (595 [515 + 80] of 604 results).

CT colonography depicted 32 (78%) of the 41 polyps larger than 5 mm (Figs 1, 2). CT colonography depicted 19 (70%) of the 27 6–9-mm polyps: eight of 13 6-mm lesions (five hyperplastic polyps, eight tubular adenomas), seven of 10 7-mm lesions (one normal colon, one hyperplastic polyp, seven tubular adenomas, one tubulovillous adenoma), both 8-mm tubular adenomas, and both 9-mm lesions (one hyperplastic polyp, one tubular adenoma).

At imaging of the larger polyps, CT colonography depicted one of two 10-mm polyps (one tubular adenoma, one tubulovillous adenoma), the single 12-mm adenocarcinoma, both 13-mm polyps (one tubulovillous adenoma, one tubular adenoma), both 15-mm tubular adeno-

mas, the single 17-mm tubular adenoma, the single 20-mm adenocarcinoma, the single 27-mm adenocarcinoma, both 40-mm lesions (one juvenile polyp, one adenocarcinoma), and both 50-mm adenocarcinomas.

Reasons for False-Negative CT Colonographic Results

Nine of the 41 colorectal polyps that were larger than 5 mm in diameter at colonoscopy were not prospectively identified at CT colonography. Five of these nine polyps could not be detected at subsequent retrospective CT review. These five polyps included a 10-mm flat lesion in the rectum and a 7-mm flat lesion in the hepatic flexure, neither of which was prospectively identified. These lesions were estimated to be raised approximately 1 mm from the colonic surface at colonoscopy, and despite transverse and three-dimensional evaluation of the area, they could not be visualized—even at retrospective analysis. The three other polyps were 6-mm lesions in the transverse colon that could not be detected in retrospect.

The remaining four lesions that were not detected prospectively at CT colonography—one 7-mm and three 6-mm polyps—could be detected at retrospective CT review. The possible reasons for the failed identification of these polyps prospectively include a lesion in a region of severe sigmoid diverticular disease in one case, a lesion perceived to be mobile in one case, and a lesion perceived to be a fold in two cases.

In addition, a 1.5-cm tubular adenoma at the dentate line was visualized at colonoscopy. This area could not be distended at CT colonography, and, thus, the lesion was not included in our analysis.

Reasons for False-Positive CT Colonographic Results

There were 12 false-positive findings in nine patients at CT colonography: in six patients with normal colons at colonoscopy and in three patients with a polyp at colonoscopy. In the three patients with a polyp at colonoscopy and false-positive findings at CT colonography, the lesion characteristics at CT did not match the location, size, or morphologic features of the lesion seen at colonoscopy. Of the 12 filling defects that were seen at CT colonography but not at colonoscopy, one was 13 mm; three, 6–9 mm; and eight, 5 mm or smaller. In retrospect, the 13-mm filling defect in the splenic flex-

TABLE 1
Polyps Detected in 105 Patients at CT Colonography with Conventional Colonoscopy as the Reference Standard

No. of Polyps Detected at Colonoscopy	No. of Polyps Detected at CT Colonography					Total
	None	One	Two	Three	Four	
None	40	4	2	0	0	46
One	10	14	0	0	0	24
Two	6	6	3	0	0	15
Three	7	4	0	0	0	11
Four	2	2	0	1	1	6
Five	0	0	1	0	0	1
Seven	0	0	1	0	0	1
Nine	0	0	0	0	1	1
Total	65	30	7	1	2	105

Note.—Data are numbers of patients.

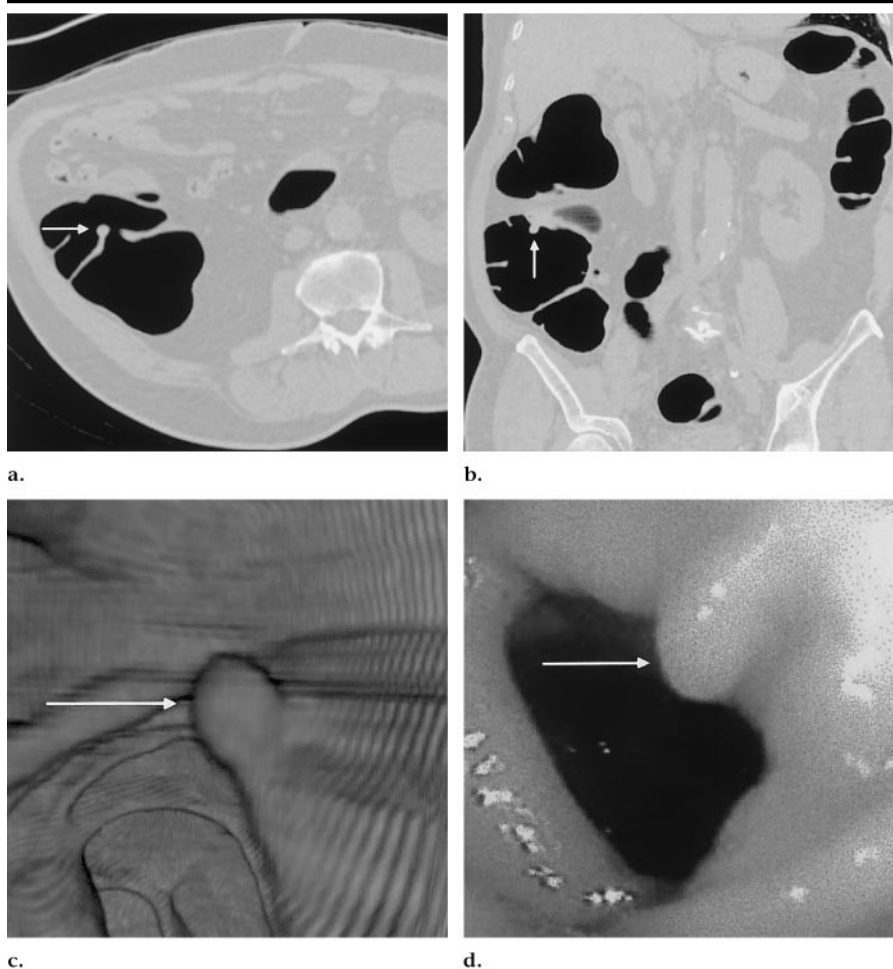


Figure 4. Round polyp (6 mm) in 71-year-old man. (a) Transverse CT colonographic image shows a 6-mm mass (arrow) with smooth round borders on a haustral fold in the ascending colon. (b) Coronal CT colonographic image findings confirm that the mass (arrow) seen in a has a smooth round polypoid morphologic structure. (c) Three-dimensional volume-rendered endoluminal CT image shows the polyp (arrow) to have a round morphologic structure and smooth borders. (d) Corresponding colonoscopic image shows the same round polyp (arrow) with smooth borders.

ure at CT colonography was believed to probably represent a fold. In three other

cases, the 4-, 7-, and 8-mm filling defects at CT colonography were probably re-

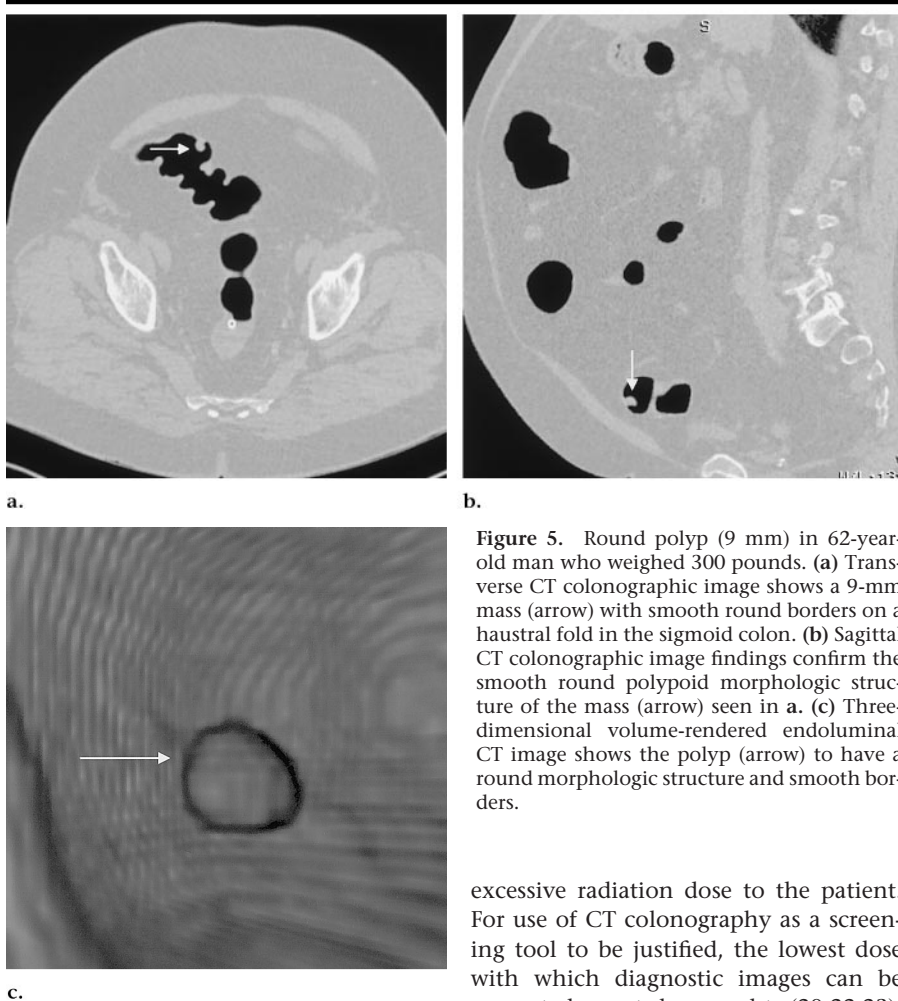


Figure 5. Round polyp (9 mm) in 62-year-old man who weighed 300 pounds. (a) Transverse CT colonographic image shows a 9-mm mass (arrow) with smooth round borders on a haustral fold in the sigmoid colon. (b) Sagittal CT colonographic image findings confirm the smooth round polypoid morphologic structure of the mass (arrow) seen in a. (c) Three-dimensional volume-rendered endoluminal CT image shows the polyp (arrow) to have a round morphologic structure and smooth borders.

lated to adherent stool. In the remaining eight cases, one 6-mm filling defect and seven 5-mm or smaller filling defects with morphologic and attenuation characteristics that were identical to those of polyps were seen at CT (Fig 6).

DISCUSSION

Experiences with single-section CT colonography have been promising (17). For continued improvements in polyp detection, specificity, and patient safety, all aspects of CT colonography have been continuously evolving (10,15,17,27). As in other applications of CT, in CT polyp detection, there is a desire to use the thinnest section collimation possible and to maintain z-axis coverage. The use of thinner section collimation may yield improved polyp detection rates and decreased false-positive findings by facilitating reduced volume averaging and improved z-axis resolution. However, radiologists must also take responsibility to ensure that the acquisition protocol does not result in an

excessive radiation dose to the patient. For use of CT colonography as a screening tool to be justified, the lowest dose with which diagnostic images can be generated must be sought (20,22,23). Therefore, the following dilemma exists: To compensate for the increased noise that results from the decreasing section collimation, tube current—and ultimately radiation dose—must be increased. With current multi-detector row CT technology, this effect is further compounded by the dose inefficiency that is caused by the wide radiation beam relative to the restricted detector use when thin sections are prescribed. The dose inefficiency is most pronounced when the thinnest detector section collimation possible (4×1 mm) is used (21).

The typical tube currents used during abdominal and pelvic CT scanning range from 150 to 250 mAs, and the resulting weighted CT dose index values range from 12 to 34 mGy, depending on the section collimation and pitch values (21). Because of the inherently high contrast between the soft-tissue attenuation of the surface of the colonic wall and the extremely low attenuation of insufflated intraluminal gas, the radiation dose can be reduced without sacrificing CT sensi-

tivity in the detection of large polyps, as demonstrated in our study.

Radiation dose can be decreased at CT by increasing pitch and section collimation or by decreasing kilovolt or milliamperere second values. Although our protocol for CT colonography involves the use of thin-section collimation, we have also used a high-pitch, low effective milliamperere second technique. With use of our protocol for combined supine and prone CT imaging, the effective dose is 5.0 mSv for men and 7.8 mSv for women. The effective dose with use of this technique is similar to the reported dose used with double-contrast barium enema examination (17). Moreover, this dose is comparable to that described in a recent report on the evaluation of multisecton CT colonography with use of 4×5 -mm-thick sections, a pitch of 3, and 40 mAs, in which the effective dose ranged from 4.5 to 6.7 mSv (23).

Multi-detector row CT offers several potential advantages over single-section techniques; these advantages include faster data acquisition, greater anatomic coverage, and comparable coverage times with much thinner section collimation (28). Some of the advantages of performing CT colonography with a multi-detector row scanner have been recently reported (23). These advantages include better bowel distention and fewer respiratory artifacts related to faster data acquisition. Theoretically, these advantages should lead to a greater colorectal polyp detection rate. For our CT colonography protocol, it took 30 seconds to complete each data acquisition, despite the use of 1-mm-section collimation. Although Hara et al (23) took advantage of the rapid acquisition achieved with a section thickness that was similar to that used with single-section data, our protocol favored thinner sections, and the acquisition time was kept slightly less than that with a single-section machine.

The main advantage of performing CT colonography with thin sections (4×1 mm) is that near isotropic voxels are available for data review. Depending on the field of view used, the z-axis pixel dimension (1 mm) is only slightly greater than the x- and y-axis pixel dimensions. Compared with the benefits of having thicker sections, the potential advantages of obtaining near isotropic voxels for CT colonography include improved morphologic analysis of suspicious lesions that are seen on transverse images, much better z-axis resolution for multiplanar reformations and three-dimensional viewing, and better evaluation of the internal

attenuation (ie, gas bubbles, high-attenuating areas, and homogeneous soft-tissue attenuation) in detected filling defects because of improved z-axis resolution. These advantages should lead to improved sensitivity and specificity of CT colonography.

With regard to improved sensitivity, the major reasons for false-negative CT studies are related to colonic segments that are not well distended, perceptible errors, or small polyp size and flat morphologic features (18,19,23). The possibility of decreasing perceptible errors by means of thin-section multi-detector row CT exists. Subtle lesions that might have been detected on only one or two sections with 5-mm-section collimation may be present on 5–10 sections with use of thin-section collimation. In addition, the improved z-axis resolution helps to confirm polypoid morphologic structure. In our study, 13 (93%) of 14 polyps that were 10 mm or larger were prospectively detected at CT colonography. One lesion, a flat adenoma that was 10 mm wide but only 1 mm thick, was not seen. Even in retrospect this lesion could not be detected because of its flat morphologic structure. Flat adenomas are extremely difficult to visualize at CT and will continue to be difficult to visualize with multisection scanning.

Seventy percent of the 6–9-mm polyps were detected at prospective CT review. This percentage is similar to that reported by Fenlon et al (18) and Yee et al (29) for the detection of medium-sized polyps. In our study, the majority of polyps 5 mm or smaller were not depicted at CT colonography. This may have been related to our interpretation technique, with which only the transverse images are reviewed unless a lesion is detected or suspected. Further image processing is performed only when an abnormality is suspected. However, with use of primary axial review as the primary interpretation technique, the median interpretation time was 12 minutes. This included the time to evaluate the colon and to image any abnormalities. By using an interpretation technique such as this, an experienced radiologist can perform CT colonography in a clinically feasible amount of time while maintaining a sensitivity similar to previously reported performance levels.

It is possible and quite likely that smaller polyps can be routinely detected by means of evaluation of three-dimensional endoluminal CT images both antegrade and retrograde. The results of a recent study (29) showed that with use of

TABLE 2
Sensitivity of CT Colonography for Detection of Polyps in 105 Patients

Polyp Size at Colonoscopy	Polyp Size at CT Colonography				Total
	Negative	≤5 mm	6–9 mm	≥10 mm	
Negative	515	8	3	1	527
≤5 mm	80	11	0	0	91
6–9 mm	8	0	19	0	27
≥10 mm	1	0	0	13	14
Total	604	19	22	14	659

Note.—Data are numbers of results. Some segments were depicted at colonoscopy or CT colonography as having more than one polyp. A total of 659 CT colonographic and colonoscopic studies were performed in 630 segments in the 105 patients. Negative was defined as no depiction of abnormalities in the segment.

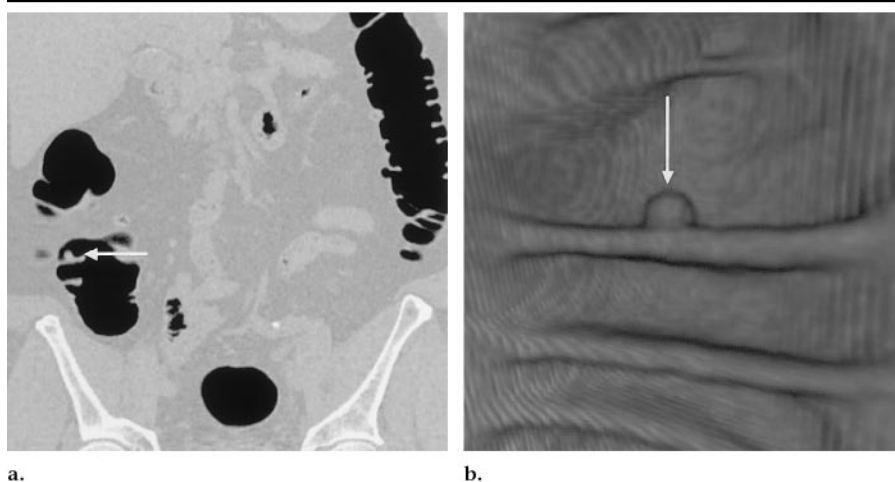


Figure 6. False-positive CT colonographic findings in 55-year-old man. (a) Coronal CT colonographic image shows a smooth round 6-mm mass (arrow) without an internal area of hyperlucency on the fold in the ascending colon. (b) Three-dimensional volume-rendered CT image of the mass seen in a shows a polypoid morphologic structure consistent with a polyp (arrow). At colonoscopy, no lesion was seen. Although we considered this lesion to be a false-positive finding, it is possible that it was a true polyp that was missed at colonoscopy.

transverse images, as well as complete three-dimensional endoluminal navigation in both antegrade and retrograde directions with the patient in the supine and prone positions, the detection of 5-mm or smaller polyps was 59%. In that study, the mean times for data evaluation were 31 and 27 minutes for two separate reviewers. This amount of time for data evaluation may limit the use of virtual colonoscopy in a clinical environment. Moreover, the detection of these diminutive polyps has questionable clinical importance, especially if routine colon screening is to be performed on an interval screening basis (30). In our study the majority of these small polyps (68%) were either hyperplastic or normal colons at histopathologic analysis. In addition, it should be noted that a 15-mm lesion in the anal canal at the dentate

line could not be visualized, even in retrospect, because this area cannot be distended. Given this limitation, a digital rectal examination should be performed in conjunction with CT colonography.

We have found that the major advantage of low-dose thin-section multi-detector row CT has been the reduction of false-positive studies. The majority of false-positive findings at CT colonography are due to poor patient preparation, poor colonic distention, and bulbous haustral folds (19,23,29). A recent report (29) of 300 patients who underwent colonography with single-section CT and 3-mm-section collimation described 185 false-positive findings in 113 of the patients. Twenty-four of the false-positive lesions in that study were 10 mm or larger. A high false-positive rate may decrease the utility of the technique be-

cause many unnecessary colonoscopies will need to be performed. By better depicting the internal heterogeneity and the external morphologic features of the detected filling defects, thin-section multi-detector row CT can yield fewer false-positive findings that result from residual fecal material and folds.

Polyps and small tumors have smooth round borders, whereas residual fecal material often has irregular geometric borders. With use of thin-section CT, the smooth or geometric morphologic structure of a filling defect can be better investigated on both two-dimensional and three-dimensional endoluminal views. Recognition of these features of adherent fecal material should lead to decreased false-positive rates. Because there is less volume averaging in a thin-collimation CT section, as compared with that in thicker sections, the visualization of small gas bubbles or high-attenuating material in detected filling defects is also facilitated. The finding of internal heterogeneities (either high or low attenuating) in the central portion of colonic filling defects is consistent with residual fecal material and not a polyp.

Finally, the improved z-axis resolution achieved with thin-section multi-detector row CT facilitates the differentiation of bulbous folds from polyps. At transverse image review, a bulbous fold may appear to be a pedunculated polyp. Careful inspection of multiplanar and endoluminal images, however, usually enables the differentiation of linear (ie, fold) from true polypoid morphologic structure. In this study, nine of the 105 patients had 12 suspicious filling defects that were depicted at CT colonography but were ultimately proved to be false-positive. Only one of these lesions, which were detected at CT colonography but not at colonoscopy, was larger than 10 mm, and three of them were 6–9 mm. Although the design of our study was such that these lesions were considered to be false-positive CT colonographic findings, it is possible that some of them were true polyps that were not identified at colonoscopy. The rates of false-negative colonoscopic results are widely published (31).

There were some limitations to our study. First, all of the CT colonographic images were interpreted by one experienced reader. There is a steep learning curve for developing CT colonographic image interpretation skills. Moreover, it has been shown that experienced readers may perform quite differently when interpreting CT colonographic studies (19).

Results of a recent study, however, indicate that with proper training, experienced abdominal radiologists can be taught CT colonographic image interpretation skills and thus achieve good interobserver agreement (32). Currently, we are evaluating the performance of less experienced readers in interpreting these studies.

Second, the population that we studied was heterogeneous in that some patients were being evaluated because of symptoms such as rectal bleeding and others were being evaluated for guaiac-positive stools. Moreover, it is likely that there will be differences in polyp detection rates between populations that are totally asymptomatic (ie, screened) and those that have any symptoms. To limit bias, we designed our study so that the radiologist was unaware of the patients' indications for colonoscopy and ages at the time of data evaluation. Moreover, data interpretation was performed by using the same technique in all patients. Further investigation of multisection low-dose CT colonography in a purely screening population is warranted.

Third, although detection of high-contrast structures such as colonic polyps is achieved by using low milliamperage second techniques, low-contrast structures such as hepatic and renal lesions are more difficult to detect and characterize with these methods. Results of studies have shown that incidental findings can be detected at CT colonography (33). This factor should be considered when CT colonographic protocols are being contemplated. As part of our routine protocol, after the colon is evaluated, images of the abdomen and pelvis are routinely reviewed with standard abdominal window and level settings. Although the evaluation of low-contrast structures is limited, if an abnormality is detected it is reported. In our study population, six patients were noted to have kidney stones, one patient had a noncalcified nodule in the left thorax, and one patient with a history of lymphoma had splenomegaly and lymphadenopathy. In addition, in the examination of very large patients, artifacts increase with use of the low-dose technique. However, we have imaged patients who weighed up to 300 pounds without a substantial loss in image quality. It should be remembered that with use of thin-section multi-detector row CT, images can be reconstructed at thicker sections than the nominal section thickness, and this results in decreased noise and potentially in improved low-contrast resolution.

The exact radiation dose to each patient at CT colonography was unknown. Our calculations were based on measurements in a plastic phantom of an average-sized adult patient. However, these phantom models provide a good approximation of patient dose at CT in an average-sized adult. In addition, our efforts in this study were focused on both thin-section CT colonography and dose reduction. With use of thicker (eg, 4.0×2.5 -mm) sections, the CT dose index can be further reduced. However, this would negate the advantage of near isotropic imaging that we believe is important for data analysis.

There are several options for further dose reduction. In thin patients, further reduction of the milliamperage second setting can be attempted; however, this may result in excess noise. In the near future, multi-detector row CT scanners will enable eight and 16 sections to be obtained simultaneously. Compared with four-section scanners, these eight- and 16-section CT scanners, the design of which is based on geometric considerations of the x-ray beam and the detector configuration, may facilitate better dose efficiency and a resultant decrease in patient radiation exposure. The radiation dose implications of lowering the kilovolt peak setting have not been fully explored.

In conclusion, we have found that with thin-section low-dose multi-detector row CT colonography, there is excellent sensitivity and depiction of large colorectal polyps and a median image data interpretation time of 12 minutes per case. In addition, by enabling better evaluation of the morphologic features and heterogeneity of lesions, near isotropic resolution facilitates improved differentiation of adherent residual stool and bulbous folds from colorectal polyps and thus a decreased false-positive rate. Ultimately, low-dose thin-section multi-detector row CT colonography, by facilitating decreased radiation doses and decreased false-positive rates while maintaining excellent sensitivity for detection of large polyps, may lead to increased patient and clinician acceptance of the use of this examination.

Acknowledgments: The authors acknowledge the contributions of the following CT technologists at New York University Medical Center: Emilio Vega, RT, Fiona Feeley, RT, and Bernard Assadourian, RT.

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