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Abbreviations:

DCBE = double-contrast barium enema
3D = three-dimensional
2D = two-dimensional

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CT Colonography: Where Have We Been and Where Are We Going?¹

Over the past decade, computed tomographic (CT) colonography (also known as virtual colonoscopy) has been used to investigate the colon for colorectal neoplasia. Numerous clinical and technical advances have allowed CT colonography to advance slowly from a research tool to a viable option for colorectal cancer screening. However, substantial controversy remains among radiologists, gastroenterologists, and other clinicians with regard to the current role of CT colonography in clinical practice. On the one hand, all agree there is much excitement about a noninvasive imaging examination that can reliably depict clinically important colorectal lesions. However, this is tempered by results from several recent studies that show the sensitivity of CT colonography may not be as great when performed and the images interpreted by radiologists without expertise and training. The potential to miss important lesions exists; moreover, if polyps cannot be differentiated from folds and residual fecal matter, unnecessary colonoscopy will be performed. In this review, current issues will be discussed regarding colon cancer and the established and reimbursed strategies to screen for it and the past, current, and potential future role of CT colonography.

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On the one hand, all agree there is tremendous excitement about a noninvasive imaging examination that can help reliably detect clinically important colorectal lesions. However, this is tempered by several recent studies that have shown that the sensitivity of CT colonography may not be as great when performed and the results interpreted by radiologists without expertise and training. The potential to miss important lesions exists even among experts; moreover, if polyps cannot be differentiated from folds and residual fecal matter, unnecessary colonoscopy will be performed. This article will review current issues regarding colon cancer; the established and reimbursed strategies to screen for it; and the past, current, and future role of CT colonography.

COLON CANCER

Incidence and Risk Factors

Colon cancer is the second leading cause of cancer death in the United States and accounts for approximately 10% of all cancer deaths in both men and women combined (1,2). Approximately 150 000 new cases and 50 000 deaths result from colon cancer every year in the United States (1). In recent years, the incidence and mortality of colorectal cancer have declined. This is attributable to the increased use of colonoscopy and the removal of premalignant polyps (3). However, the cumulative lifetime risk for the development of colorectal cancer is still approximately 5% (3).

There are several conditions that are known to increase the risk of the development of colon cancer. These conditions include (a) a first-degree relative in whom colon cancer or a large adenomatous polyp was diagnosed before the age of 60 years, (b) inflammatory

ESSENTIALS

- *CT colonography is an imaging technique that has been used for more than 10 years in evaluation of the colon.*
- *Techniques for preparation of patients, acquisition of data, and interpretation of data continue to evolve.*
- *The current role of CT colonography in clinical practice remains controversial.*
- *Reimbursement and radiologist training remain obstacles to more widespread use of CT colonography.*

bowel disease, (c) a history of familial adenomatous polyposis or hereditary non-polyposis colorectal cancer syndromes, and (d) prior adenomatous polyps or colon cancers (1,3). Although there are specific conditions that predispose to the disease, approximately 75% of all cases of colon cancer occur in patients without specific risk factors (3).

The Adenoma-Carcinoma Sequence

Numerous studies have shown that most colorectal cancers progress from small adenomas through a process known as the adenoma-carcinoma sequence (4–6). Through a series of genetic mutations, small adenomas (<5 mm) are transformed into large adenomas (>10 mm), then into noninvasive carcinoma, and finally into invasive carcinoma. Up to 80%–90% of all colorectal cancers likely develop through this series of genetic alterations (4,7). Analysis of data from the National Polyp Study shows that an average of 5.5 years is required for the transformation of a large (>10-mm) adenomatous polyp into cancer (3). Moreover, an average of 10–15 years is required for most small adenomas to develop these genetic alterations to become cancer (4).

Clinical Importance of Small Lesions

While most carcinomas progress from adenomas, the majority never acquire the genetic mutations to undergo this process (3,4). This assertion is based on autopsy observations that up to 60% of men and 40% of women have colonic adenomas (3). A surveillance study showed that many small polypoid lesions detected but not removed at endoscopy

were not present at follow-up endoscopic examinations (8). These lesions presumably regressed. In addition, it has been shown that the majority of diminutive polyps, those measuring 5 mm or smaller, are not adenomas (9,10). More often, these small lesions represent hyperplastic polyps or normal mucosal tags at histologic assessment (Fig 1). These lesions have no clinical potential to become cancer (3), but their removal could lead to potential complications and increased costs.

Since many small polypoid lesions in the colon are not adenomas and since those that are undergo mutation into invasive cancer slowly, there is controversy about when to consider a colorectal polyp clinically relevant on the basis of size alone (11–13). This controversy arises from the fact that there are additional financial costs associated with polyp excision and analysis. Moreover, there are associated patient risks, including bleeding and colonic perforation after polypectomy, when compared with diagnostic colonoscopy (Fig 2).

This issue of polyp size is critical if CT colonography is to be used for colon screening. First, CT colonography does not routinely demonstrate diminutive (≤ 5 -mm) lesions (9,14,15). Moreover, if CT colonography was able to depict a substantial portion of these diminutive lesions, it could prompt many unnecessary colonoscopies, since most of these small lesions will not be adenomas. As a result, screening CT colonography would not be cost-effective. For CT colonography to be accepted as a screening procedure, diminutive lesions will need to be ignored or, if detected, followed at an appropriate surveillance interval (9,10) (Fig 3).

What are the data on diminutive polyps? In a study of 1048 colorectal polyps measuring up to 6 mm, Waye et al (13) found that 61% were adenomas, and the remainder were hyperplastic polyps or normal colonic mucosa. In the cohort of patients with polyps, the prevalence of carcinoma was extremely low (0.1%). Nevertheless, the authors recommended that all diminutive polyps be resected, since the majority were adenomas. As a result of that study, polypectomy became a routine part of any endoscopic procedure, regardless of polyp size.

Authors of other studies (5,16,17) in which the relevance of small colorectal polyps was evaluated have reached different conclusions. The authors of those studies have confirmed that most small polyps are not adenomas and that cancer

in small polyps is extremely rare. In one study (17) in which over 20 000 polyps were evaluated, invasive carcinoma was not present in any of the 5027 small (≤ 5 -mm) adenomas. It is estimated that fewer than 1% of adenomas 1 cm or smaller contain cancer (3). As a result of these observations and the understanding that the adenoma-carcinoma sequence requires time, it has been suggested that attention should be shifted away from identification and removal of all diminutive polyps and toward strategies that will allow reliable detection of the less common, but more dangerous, advanced adenomas (12).

Current Screening Techniques

The majority of cases of colon cancer develop in patients without specific risk factors. The current recommendation for colon cancer screening in asymptomatic patients at average risk for colorectal cancer is that it should begin at age 50 years (1). There are several criteria that make a screening test effective: The disease needs to be common, screening tests need to demonstrate early-stage disease, the test needs to be acceptable to patients, and the benefits should outweigh the costs (3). Since colon cancer is the second leading cause of cancer death, screening examinations can demonstrate precancerous polyps, and screening can be cost-effective, it would appear that colon cancer screening fulfills three of these criteria (3,18). With proper education, colon cancer screening is also acceptable to most patients.

Moreover, current colon cancer screening techniques have been shown to lead to decreases in the morbidity and mortality associated with colon cancer by allowing detection and leading to the removal of premalignant adenomatous polyps (1–3,18–23). As a result, there is consensus among health care providers and policy makers that screening for colorectal cancer is justified (1,3,19). The current reimbursable options available for colorectal carcinoma screening include fecal occult blood testing, sigmoidoscopy, double-contrast barium enema (DCBE) examination, colonoscopy, and combinations of these tests (23).

Despite consensus on the need and efficacy of screening, colon cancer remains a major cause of cancer mortality (2). There are many potential reasons for the continued high incidence of colorectal cancer, including limitations of current screening options, confusion about when and how to perform screening, patient reluctance to

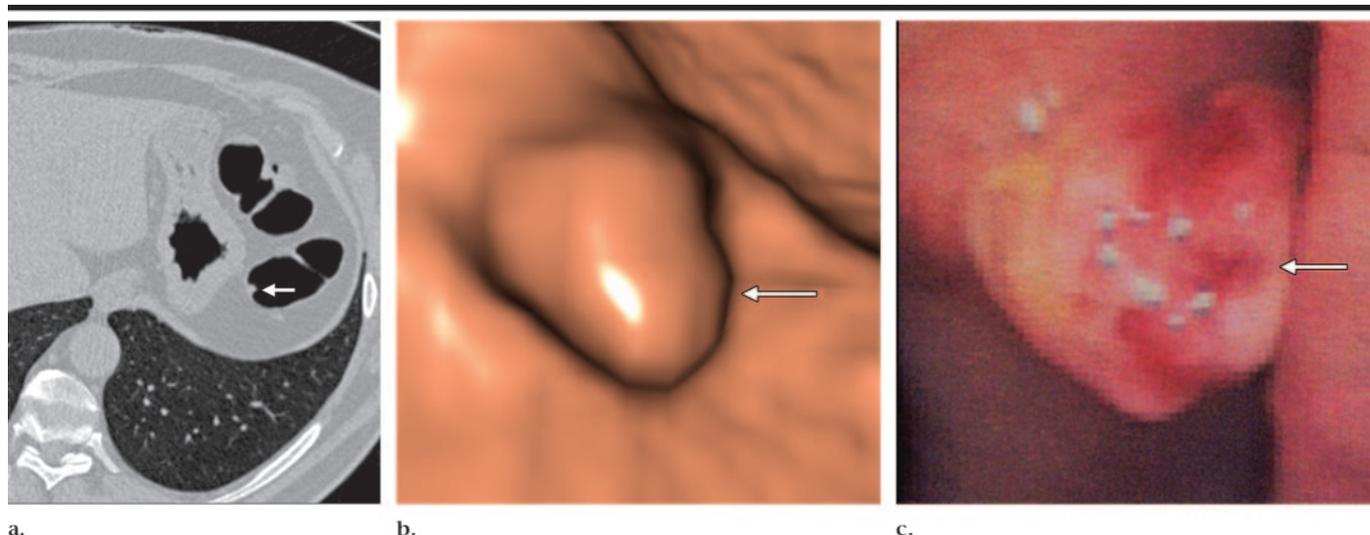


Figure 1. A 4.5-mm splenic flexure polyp in a 53-year-old man. (a) Transverse CT image obtained with patient in prone position shows small polypoid lesion (arrow) in the splenic flexure. (b) Endoluminal CT colonographic image shows polypoid morphology (arrow) of the lesion. (c) Image from conventional colonoscopy performed 1 week later shows identical morphology (arrow). Histologic evaluation indicated an inflammatory polyp.

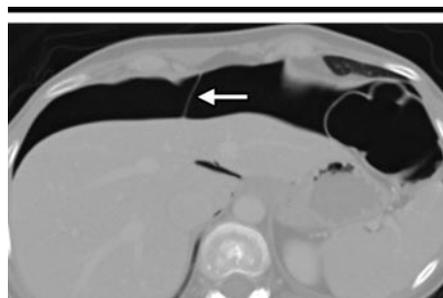


Figure 2. Colon perforation after endoscopic polypectomy in a 62-year-old man. Transverse CT image shows intraperitoneal air 4 hours after endoscopy with polypectomy. Note falciiform ligament (arrow). At surgery, sigmoid perforation was found at the site of polypectomy.

undergo screening, or reluctance if there is a need for bowel cleansing when sigmoidoscopy, DCBE, or colonoscopy is performed. With regard to patient reluctance to comply with current screening options, a survey in 1992 found that only 17.3% of patients over the age of 50 years had undergone fecal occult blood testing within the previous year and, only 9.4% had undergone sigmoidoscopy within the previous 3 years (3).

Each current colon screening option has important limitations. While the performance of yearly fecal occult blood testing has demonstrated a reduction in mortality due to colorectal cancer, fecal occult blood testing is not a direct evaluation of the colonic mucosa (24). Many large adenomatous polyps do not bleed, and occasionally cancers will not bleed.

In addition, there are many false-positive fecal occult blood test results for colon cancer, which can lead to further testing and expense. A study (25) demonstrated that in more than 50% of occult hemipositive stool examinations, the source was the upper gastrointestinal tract.

Screening sigmoidoscopy has been shown to decrease the mortality due to colorectal cancer (26). However, sigmoidoscopy is not an evaluation of the entire colon, and, therefore, complete colon screening is not achieved (27,28). Authors of two studies (27,28) evaluating sigmoidoscopy and colonoscopy found that if sigmoidoscopy alone were performed for colon screening in an asymptomatic population, many advanced proximal colon lesions would be missed. This takes into account the fact that a distal adenomatous polyp would prompt a complete colonoscopic evaluation. Moreover, it appears that the combination of fecal occult blood testing and sigmoidoscopy does not result in a substantial improvement in the effectiveness of screening (29).

There are currently two reimbursable options available for full colonic evaluation: colonoscopy and DCBE. Norfleet et al (30) determined that the sensitivity of DCBE was 26% for detection of polyps larger than 5 mm, compared with a sensitivity of single-contrast barium enema examination of 13%. A study (31) comparing DCBE with colonoscopy for the detection of polyps in patients who had undergone prior polypectomy (surveillance evaluation) demonstrated poor

sensitivity for DCBE. In that study, DCBE did not depict over 50% of polyps larger than 1 cm. Another study (32) comparing patient preferences regarding DCBE and colonoscopy found that patients experience less discomfort with colonoscopy and were significantly more willing to undergo follow-up screening with colonoscopy than with DCBE. While DCBE may be cost-effective in colon cancer screening given its relatively low cost, it is being performed with decreasing frequency.

Complete colonoscopy allows the most thorough evaluation of the colon, with the added benefit of the ability to perform biopsy or excision of suspicious lesions. Colonoscopy is considered the reference standard for colonic evaluation (1,33). However, there are several important limitations to the widespread use of screening colonoscopy, including the need for sedation, the potential risk of perforation and bleeding (0.1%–0.3% of cases), the costs of the procedure (including the need for sedation), a failure to complete the examination in 5%–10% of patients, and an insufficient workforce of trained endoscopists to meet the increased demand (34,35). For these reasons, CT colonography is being investigated and used clinically to evaluate the colon for polyps and cancers.

CT COLONOGRAPHY

CT colonography is an evolving noninvasive imaging technique that relies on

the performance of thin-section CT of the colon and evaluation of the data by using both two-dimensional (2D) and three-dimensional (3D) images (36–54). Clinical evaluation of CT colonography has shown promise for the detection of polyps and cancers of the colon and rectum, with per-polyp sensitivity values ranging from 75% to 100% for polyps 10 mm and larger (14). For thin-section multi-detector row CT, the per-patient specificity for lesions 10 mm and larger is greater than 95% (10,50).

Recently, there have been conflicting data published on the sensitivity of CT colonography for the detection of colorectal polyps. Two recent studies (9,10) showed CT colonography to be as effective as conventional colonoscopy for the detection of polyps 10 mm and larger. In fact, in one study (10), the sensitivity of CT colonography for detection of adenomas 10 mm and larger was superior to that of conventional colonoscopy (93.8% vs 87.5%). As previously stated, the ability of CT colonography to depict smaller lesions has consistently been shown to be inferior to that of conventional colonoscopy. A recent multi-institutional study (15) showed that the performance of CT colonography was inferior to that of conventional colonoscopy for the demonstration of polyps that were at least 10 mm in size. In that study, the sensitivity of CT colonography for detection of such polyps was only 55%. There were several limitations to that study, including the training and experience of some of the radiologists involved. As with most imaging techniques, there is a learning curve, and with greater experience improved results are expected (55). A study by Spinzi et al (55) with 99 patients showed that the sensitivity of CT colonography increased from 31.8% for the first 25 cases interpreted to 91.6% for the last 20 cases. Despite these conflicting results, it is hoped that CT colonography may improve colorectal screening. CT colonography may improve colorectal screening by facilitating detection of clinically important colorectal polyps with the use of a relatively noninvasive safe examination, thereby increasing patient and clinician acceptance of colon cancer screening (14,15).

Patient Preparation

There are several techniques that may be used for bowel preparation, and controversy remains as to how to optimize

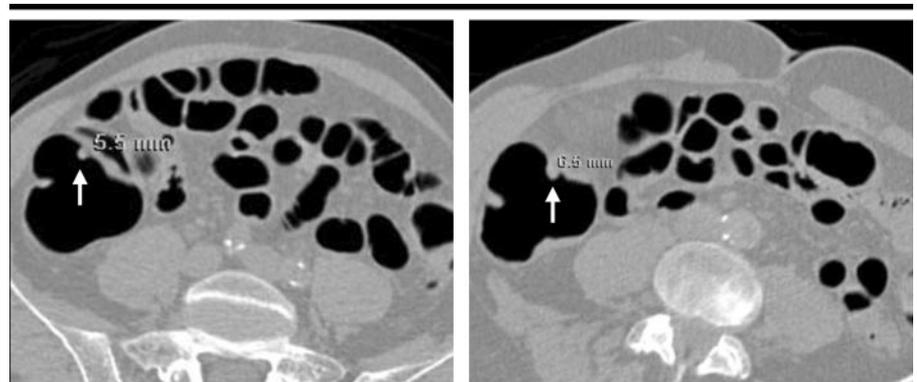


Figure 3. Surveillance CT colonography in a 65-year-old man with a 5.5-mm polyp. (a) Transverse CT image obtained in August 2001 with patient in supine position shows small polypoid lesion (arrow) in ascending colon. Because of severe pulmonary disease, which increased the risk associated with endoscopy, endoscopy was deferred and the lesion was followed. (b) Transverse CT image obtained in December 2002 shows same lesion now measuring 6.5 mm (arrow). Discrepancy in measurement was likely technical. The lesion is currently stable after 3 years. Many small adenomas will never progress to carcinoma, and those that do will progress slowly.

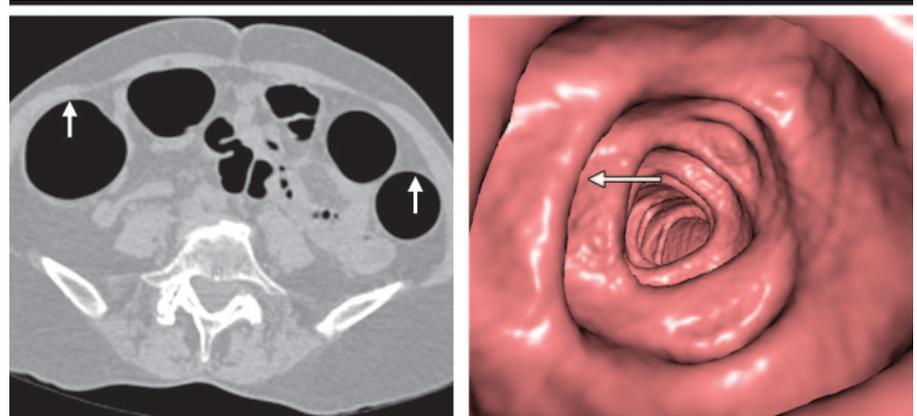


Figure 4. Optimized colonic distention and cleansing in a 56-year-old man. (a) Transverse CT image shows well-distended clean colon (arrows). (b) Endoluminal CT colonographic view shows normal haustral fold (arrow) without evidence of lesion.

patient preparation. The goal is to have a well-prepared, well-distended colon that will facilitate polyp detection and minimize false-positive findings (Fig 4). Most investigators currently believe the colon needs to be thoroughly cleansed for accurate interpretation to proceed (14,51–53,56,57). A clean well-distended colon facilitates detection of colorectal abnormalities, whether 2D or 3D techniques are used for data interpretation. More important, it often maximizes our ability to differentiate polyps, folds, and residual fecal matter in the colon (45). While a clean colon currently appears to be essential for colorectal polyp detection, many patients find bowel preparation to be the most onerous part of the examination (32,58).

There are three commercially available bowel preparations; these include cathartics such as magnesium citrate and phosphosoda and colonic lavage solutions such as polyethylene glycol. In our experience, the polyethylene glycol preparation frequently leaves a large amount of residual fluid in the colon (57). While this preparation is adequate for colonoscopy, large amounts of residual fluid will limit CT colonography. At conventional colonoscopy, residual fluid can be endoscopically aspirated from the colon. With CT colonography, the examination is typically limited to only two acquisitions, one with the patient supine and one prone. While supine and prone imaging allow for fluid redistribution, this does not ensure full mucosal evaluation

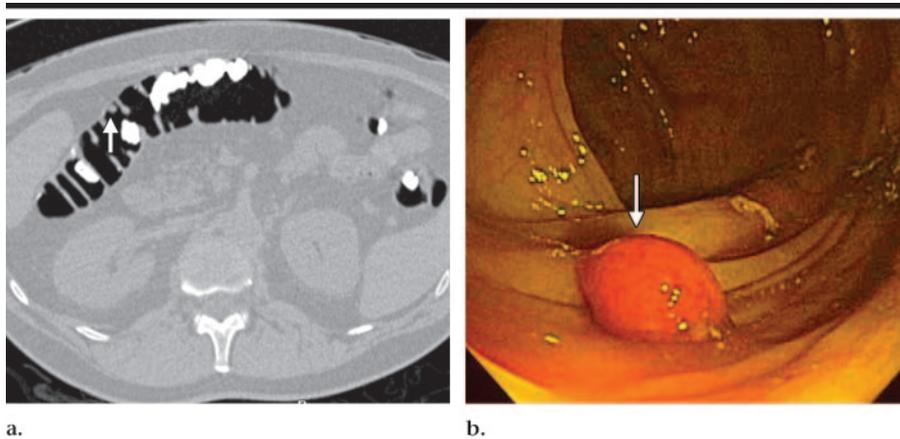


Figure 5. Fecal tagging and polyp in a 62-year-old man. (a) Transverse CT image shows small 5.6-mm polypoid lesion (arrow) in the hepatic flexure. Note high-attenuation fecal material. (b) Conventional colonoscopic image in same patient shows polyp (arrow). Histologic evaluation showed tubular adenoma.

if a large amount of fluid is present. Therefore, for CT colonography, the preparation that provides the least amount of residual fluid will theoretically allow evaluation of the most mucosal surface.

Some investigators have found that the use of intravenous contrast material may facilitate colorectal polyp detection when a large amount of fluid is present (59). On occasion, polyps will be obscured by residual fluid. After intravenous administration of contrast material, a polyp will enhance and may become visible despite being submerged in the fluid. The downside of the routine administration of contrast material includes the cost, the need for intravenous access, and the risk of allergy to iodinated contrast material. In the setting of a known colorectal lesion, the use of intravenous contrast material may be justified since better delineation of the colonic abnormality, as well as improved detection of liver metastases, is possible. Most investigators do not routinely administer intravenous contrast material for screening CT colonography studies.

Our preference for bowel preparation for CT colonography is to use commercial preparation kits for bowel cleansing. The instructions are easy for the patient to follow, and the kits are inexpensive and available at pharmacies. The two commercial preparation kits that we use are the 24-hour Fleet 1 Preparation (Fleet Pharmaceuticals, Lynchburg, Va) or the LoSo Preparation (EZ-Em, Westbury, NY). The Fleet Kit consists of a clear fluid diet the day before the examination, as well as a single 45-mL dose of phosphosoda and four bisacodyl tablets the day before

the examination. In addition, patients receive a bisacodyl suppository the morning of the examination. The LoSo Preparation consists of magnesium citrate and four bisacodyl tablets the day before the examination and a bisacodyl suppository the morning of the examination. Our reason for using these preparations is that they provided adequate bowel preparation for the majority of patients undergoing DCBE. However, we have found that with these kits, approximately 3%–5% of patients will have inadequate bowel cleansing for complete interpretation. In these cases, fecal tagging or repreparation with polyethylene glycol may be necessary.

Polyethylene glycol preparations should be used in all patients with substantial cardiac or renal insufficiencies. The polyethylene glycol preparation results in no fluid shifts and no electrolyte imbalances. Therefore, it is safe to use in these patients. In addition, many gastroenterologists use two 45-mL doses of phosphosoda for bowel preparation. Administration is performed the evening before and the morning of the examination. We have found that this combination results in excellent bowel cleansing (9). In a large multi-institutional study (10), two 45 mL doses of phosphosoda were used, and excellent results were obtained for polyp detection. In that study, several other factors may have contributed to the excellent results, including fecal and fluid tagging and segmentation of the tagged material. However, caution is required since it is not recommended that more than 45 mL of phosphosoda be administered within a 24-hour period.

Fecal and Fluid Tagging

Given the limitations of bowel preparation, including poor patient compliance and reluctance, as well as residual fecal material that can make interpretation difficult, the possibility of fecal and fluid tagging for CT colonography is being investigated (10,60–62). Fecal tagging is achieved by having the patient ingest small amounts of barium or iodine with their meals prior to imaging. The high-attenuation contrast material will be incorporated within residual fecal matter, facilitating differentiation from polyps (Fig 5). Fecal tagging has been advocated by some researchers because tagged fecal matter should allow improved differentiation of residual stool from colorectal polyps (10,61). However, tagged fecal material can occasionally obscure other colorectal lesions. Moreover, if large amounts of tagged fecal material are present and electronic cleansing techniques are not available, 3D interpretation techniques may not allow evaluation of the luminal surface. If fecal tagging is used in conjunction with a good cathartic, a primary 3D interpretation may still be possible. Whether bowel cleansing is performed with or without tagging, careful analysis of all filling defects in the colon needs to be performed.

Several studies have recently evaluated the use of fecal tagging. One showed 100% sensitivity and specificity for colorectal polyps 10 mm and larger (61). A study of over 1200 patients who underwent CT colonography with fecal and fluid tagging prior to colonoscopy was recently performed (10). In that study, the detection of polyps measuring 10 mm or larger was the same as that for conventional colonoscopy. In both studies, however, the use of either magnesium citrate or phosphosoda remains a major limitation to patient acceptance of colon cancer screening.

Fecal tagging without bowel cleansing relies on the patient ingesting small amounts of iodine or dilute barium with a low-fat and low-fiber diet beginning 1 to several days before the examination. When CT colonography data are acquired, residual fecal material that is tagged will show high attenuation. One study (60) demonstrated very good preliminary results for polyp detection with the use of fecal tagging without bowel cleansing. In theory, when computer-generated electronic-cleansing techniques are used, the high-attenuation tagged fecal material can be segmented from the data, leaving only the colonic mucosa and fill-

ing defects attributable to a colorectal neoplasm or polyp (62). If CT colonography could be performed without the need for bowel cleansing and yet still maintain excellent sensitivity for polyps 10 mm and larger, it could become the screening test of choice (37).

Colonic Distention

Once the colon has been prepared, the examination is ready to be performed. Colonic distention should be performed entirely by a trained technologist or nurse. A radiologist does not need to be present for high-quality data acquisition to proceed. The presence of an experienced technologist or nurse thus minimizes the radiologist time needed for data acquisition.

Immediately before data acquisition, the patient should evacuate any residual fluid from the rectum. Therefore, easy access to a nearby bathroom is essential. For colonic insufflation, either room air or carbon dioxide (CO₂) can be used. The use of room air is easy, clean, and inexpensive. Proponents of CO₂ use argue that because it is readily absorbed from the colon it causes less cramping after the procedure than does room air insufflation (63). While initial discomfort is usually present with either CO₂ or room air, delayed cramping appears to be less of a problem with CO₂.

A small rubber catheter can be used to insufflate the colon. These catheters are much smaller than a traditional barium enema rectal catheter, and a balloon is not used. Patients generally do not feel these small caliber catheters being inserted. Patients are encouraged to keep the gas (room air or CO₂) in and to let as much gas in as possible. Optimal colonic distention is a prerequisite to CT colonographic data interpretation. The patient is asked to let the technologist know when they begin to feel uncomfortable. Generally this signals that the colon is well distended. Approximately 40 puffs with a hand-held bulb syringe is usually sufficient to distend the colon with room air. However, we do not use a strict number of insufflations, since the length of an individual colon is variable. In addition, if the ileocecal valve is incompetent, more gas will be required for optimal distention. The use of a mechanical CO₂ insufflator works very well for colonic distention. With mechanical CO₂ insufflation, approximately 2.0–2.0 L is slowly instilled into the rectum. Authors of a recent study (10) used manual insufflation of the colon with CO₂ performed by

the patient. In that study, excellent distention was achieved. However, the study population appeared to be a very motivated group of patients, and whether manual insufflation results will be reproducible is unclear.

The use of a bowel relaxant is controversial. Previous data have shown minimal benefit to the routine use of intravenous or intramuscular administration of glucagon (53). At our institution, a bowel relaxant is not routinely used. This minimizes cost and patient anxiety because no needles are used. Excellent results in achieving colonic distention without a bowel relaxant have been obtained. The authors of a report from England (64) showed that hyoscine butylbromide improved colonic insufflation, and they suggested that it should be routinely administered when available. This product is not approved by the Food and Drug Administration and is not available for use in the United States.

After insufflation, the catheter is left in the rectum, and a single scout CT image is obtained with the patient in the supine position to verify adequate bowel distention. If adequate bowel distention is present, the CT examination is performed (Fig 6). If adequate bowel distention is not achieved, as determined by examining the scout image, additional gas is insufflated into the rectum. After insufflation, CT colonography is performed first with the patient in the supine position and proceeds in a cephalocaudal direction to encompass the entire colon and rectum. The patient is then placed in the prone position. Several additional puffs of air are then administered, or CO₂ is continuously administered. If CO₂ is not continuously administered, it will be resorbed and colonic distention will be inadequate. After a second scout localizing image is obtained, the process is repeated over the same z-axis range. Supine and prone imaging doubles the radiation dose but is essential to allow optimal bowel distention, redistribution of residual fluid, and differentiation of fecal material from polyps because visualization of mobility of a filling defect implies residual fecal material. It has been shown that many colonic segments will be submerged under fluid if only one acquisition is performed (52). Moreover, polyp detection rates are increased if both supine and prone acquisitions are obtained (51).

Data Acquisition

Over the past decade, three important advances have occurred in the acquisition of CT colonographic data. These in-



Figure 6. Scout radiograph shows optimal colonic distention in a 62-year-old man. Excellent distention was achievable even though patient had undergone prior rectosigmoid resection for colon cancer. Arrows = surgical clips.

clude reduction in radiation exposure, improved CT section profile, and shorter acquisition times (9,65–67). These advances have been facilitated by the development and installation of multi-detector row CT scanners. These scanners allow four to 64 sections to be obtained in a single rotation of the x-ray tube (9,68,69). Moreover, gantry rotation times have decreased so that most CT scanners now allow a tube rotation time of 0.5 second or less. Multi-detector row CT scanners allow large volumes of near-isotropic data to be acquired in a single breath hold.

For CT colonography with a single-section scanner, data were usually acquired with 5-mm-thick sections and a pitch of 2. The resulting effective section thickness is 6.4 mm owing to section broadening with the high pitch value (70). To scan the abdomen and pelvis typically requires 35–40 seconds with this protocol. By using a 16-section CT scanner with 0.75-mm collimation and a pitch of 1.5, the same z-axis coverage can be obtained in 15–20 seconds. Data can be reconstructed as 1-mm-thick sections overlapped every 0.75 mm. With a 64-detector row CT scanner, acquisition times are routinely less than 10 seconds.

There are enormous differences in the CT colonographic data that result from single- versus multi-detector row scanners. First, motion artifacts from respiration and peristalsis are decreased or eliminated with multi-detector row CT. Moreover, data interpretation is not lim-



Figure 7. Ovarian carcinomatosis incidentally discovered during CT colonography in a 67-year-old woman. Coronal reformatted image shows extensive omental carcinomatosis (arrows).

ited to evaluation of transverse images only. Near-isotropic image data are now available, which allow coronal, sagittal, and endoluminal images to be obtained from the single transverse acquisition, thus facilitating differentiation of polyps, bulbous folds, and residual fecal material (9,45,65,66,71).

The optimal section profile for CT colonography has not been determined, but it is likely that data acquired with thin (approximately 1-mm) sections will improve sensitivity for small polyps and improve specificity. When using a four-row scanner, a 1–1.25-mm detector configuration is recommended (9,65,66). Others have advocated 2.5-mm detector configuration with a four-row scanner (72). There are two benefits to the 2.5-mm detector configuration. First, the milliampereseconds setting can be lowered, and there is an inherent decrease in radiation exposure at 2.5 mm when compared with that at 1-mm collimation and a four-detector row system (68,72). In addition, there are fewer images that need to be acquired. However, the radiation dose penalty can be substantially decreased at CT colonography, and there are several important strategies for CT radiation dose optimization that may be applied (73) (see next section). Moreover, with faster computer processors and greater data storage capacity, large data sets pose less of a problem with current workstations. Finally, by acquiring data at 2.5 mm, the sections need to be recon-

structed as 3-mm-thick sections. By scanning with thicker section width, the improved specificity of thin-section CT colonography is lost (71).

Radiation Dose

When considering an imaging examination that uses ionizing radiation for screening, exposure is a serious concern. In addition to CT colonography, other screening examinations use ionizing radiation, including mammography and DCBE. The benefits of a particular imaging examination for early detection need to be assessed in terms of potential risks, including those associated with radiation exposure (74). Preliminary studies (40,56,75,76) in which CT colonography with single-section scanners were evaluated used values ranging from 110 to 300 mAs. A resulting effective dose of up to 18 mSv from a protocol with a high milliampereseconds level may be incurred, given that two acquisitions are necessary (51,77,78). When a multi-detector row scanner and thin collimation are used, the resulting exposure would be even greater because there is a penumbra effect of radiation that is delivered to the patient but that does not contribute to the image (68).

Radiation dose can be decreased at CT by increasing pitch and collimation or by decreasing the peak voltage or milliampereseconds level (73). Absorbed dose and milliampereseconds values are directly proportional. Since there is extremely high tissue contrast between insufflated gas and the colonic wall, substantial reductions in milliampereseconds values can be achieved without sacrificing polyp detectability. The increased noise resulting from acquisitions acquired with low-milliampereseconds techniques does not appear to affect polyp detection. In 2002, a study (50) in which CT colonography was compared with colonoscopy in 105 patients showed that the sensitivity of CT colonography for the detection of 10-mm or larger polyps was greater than 90% when an effective value of 50 mAs was used. The resultant effective dose to the patient for both supine and prone imaging was 5.0 mSv for men and 7.8 mSv for women. The effective dose with this technique is similar to the dose reported for DCBE (14).

Since that publication (50), several investigators have shown that milliampereseconds values can be decreased even further (72,77,78). For example, in one study (72) 140 kVp and 10 mAs (effective) with a four-row, 2.5-mm detector configuration were used and showed

100% sensitivity for polyps larger than 10 mm. The resulting effective dose was 1.8 mSv in men and 2.4 mSv in women. Recent advances in automatic tube current exposure and dose modulation allow even further reduction in patient exposure (67). By using these dose-reduction techniques, the effective dose from a CT colonography examination becomes close to or even less than that from yearly background radiation (78).

An obvious way to decrease patient exposure and dose is to perform only one acquisition (supine or prone). However, unless adequate colonic distention can be achieved with a single supine or prone acquisition, the second acquisition will be necessary. The authors of one study (81) showed that up to 16% of colorectal polyps will be detected on images from only one of the two acquisitions. If residual fluid and fecal matter are tagged, segmentation techniques may help to facilitate a single acquisition. Close patient monitoring by a physician will be required if a single acquisition is to be considered. This could negate the potential advantage of not requiring a radiologist to be on site during data acquisition. If adequate distention is not achieved or there is a large amount of residual fluid, the second acquisition will be necessary.

When performing CT colonography, there is the opportunity to evaluate more than just the colon (Fig 7). Since all of the CT data are present, extracolonic structures in the abdomen and pelvis should be evaluated. Incidental extracolonic findings may be detected (79,80). We have found that low-dose CT colonography can depict highly important extracolonic lesions (80). In one study, 136 extracolonic findings were detected in 83 (33.2%) of 250 patients undergoing CT colonography. Of these 136 findings, 17 (12.5%) were highly important, 53 (39.0%) were moderately important, and 66 (48.5%) were of low importance (80). The most common highly important lesions were solitary lung nodules in three patients, mesenteric lymphadenopathy in three, adrenal masses in two, low-attenuation liver lesions consistent with metastases in two, and bone metastases in two. Fourteen (82.4%) of the 17 highly important findings were new findings, and 11 of the extracolonic abnormalities resulted in further diagnostic testing. In that study, none of the patients with lesions of moderate or low importance underwent further testing.

Incidental lesions are more difficult to detect and, importantly, difficult to characterize at CT colonography because a

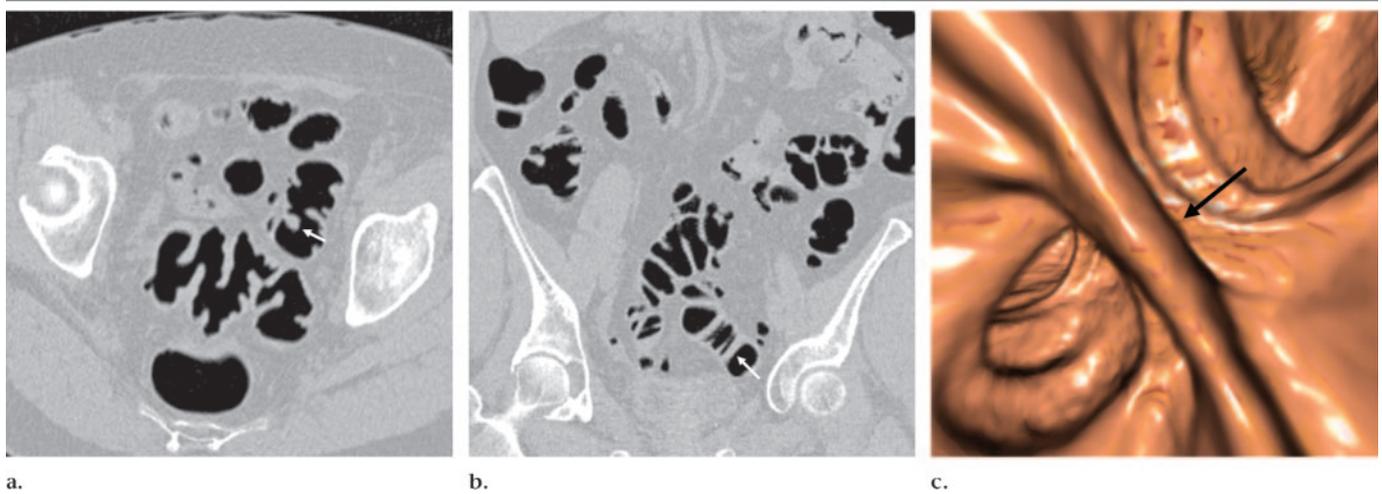


Figure 8. Questionable lesion at 2D review of CT images in a 57-year-old man. (a) Transverse CT image shows lobulated lesion (arrow) measuring 7 mm in sigmoid colon. (b) Coronal reformatted image of same area shows linear morphology (arrow), consistent with a fold. (c) Endoluminal CT colonographic view confirms haustral morphology (arrow). A combination of 2D and 3D views were essential for optimal interpretation.

low-radiation-dose technique is used. Moreover, patients do not routinely receive intravenous or oral contrast material for CT colonography. Therefore, careful inspection is warranted because unnecessary further testing and expense may be incurred.

DATA INTERPRETATION

Once the colon has been cleansed, distended, and scanned, the data need to be interpreted. There are two primary techniques for data interpretation: a primary 2D or a primary 3D approach. In either case, the alternative viewing technique needs to be available for problem solving and to aid in differentiating folds, fecal matter, and polyps.

Interpretation of 2D Data

Traditionally, most investigators have relied on a primary 2D technique for data interpretation (9,14,38,40,43,44). With a primary 2D technique, the entire colon is evaluated by using the transverse source images. This is accomplished at a specialized workstation, and the colon is "tracked" from the rectum to the cecum by using the supine images. This is facilitated by cine scrolling of images through the entire colon. If an abnormality is detected; coronal, sagittal, and endoluminal reformatted images are used to help determine whether the abnormality is a polyp, fold, or fecal matter (Fig 8). If an abnormality is seen during the supine review, prone images may be helpful to determine if a lesion is mobile (81). The

process is the repeated for the prone acquisition.

There are three criteria to use with 2D and 3D imaging that help distinguish residual fecal material from polyps. First, the presence of internal gas or areas of high attenuation suggest that a lesion is residual fecal material, since colorectal polyps are homogeneous in attenuation (82,83). It is necessary to evaluate a lesion with multiple window and level settings during CT colonography. This facilitates identification of gas, high-attenuation material, and adipose tissue (Fig 9).

The second criterion is morphology. Morphologically, polyps and small cancers have rounded or lobulated smooth borders. Residual fecal material may have a similar morphology. However, if a lesion shows geometric or irregularly angled borders, it almost always represents residual fecal material (44). Recognition of morphology is best performed by using thin-section CT colonographic data and 3D endoluminal images.

Mobility of a lesion is the third criterion that has been reported to facilitate differentiation of residual fecal material from polyps. Stool tends to move to the dependent surface of the colonic mucosa when a patient is turned from the supine to the prone position (83,84). Polyps maintain their position with respect to the bowel surface (ventral or dorsal) regardless of the patient's position. However, caution is required since pedunculated polyps and sessile polyps in segments of the colon with a long mesentery may appear to be mobile (81).

There are two primary reasons to con-

sider a 2D data interpretation algorithm. The first is that with this approach, in theory 100% of the colonic mucosa can be visualized with one pass. Polyps will not be hidden behind folds, which may occur with a conventional colonoscopic or a primary 3D CT data interpretation technique. A second rationale for interpreting CT colonographic data by using a primary 2D approach is time. For CT colonography to be a clinically viable tool in everyday radiology practice, the examination needs to be performed and interpreted in a time-efficient manner. While technologists can be trained to perform colonic insufflation (saving the radiologist time), the potential to spend a large amount of time interpreting data exists, especially with thin-section multi-detector row CT, where up to 1000 images may be obtained per patient. The authors of one study (56) evaluated a large cohort of patients by using both 2D and 3D imaging with both antegrade and retrograde 3D colon navigation in both the supine and the prone position. They showed that the median interpretation time for two radiologists was 31 minutes. In that study, the sensitivity of CT for polyps 10 mm and larger was over 90%. However, results reported in that study were based on a consensus interpretation, and after factoring in the time for consensus, a substantial amount of radiologist time was used in evaluating these data sets.

In 1998, Dachman et al (43), using 2D imaging as the primary imaging technique with 3D imaging for problem solving, reported findings in 44 patients. In

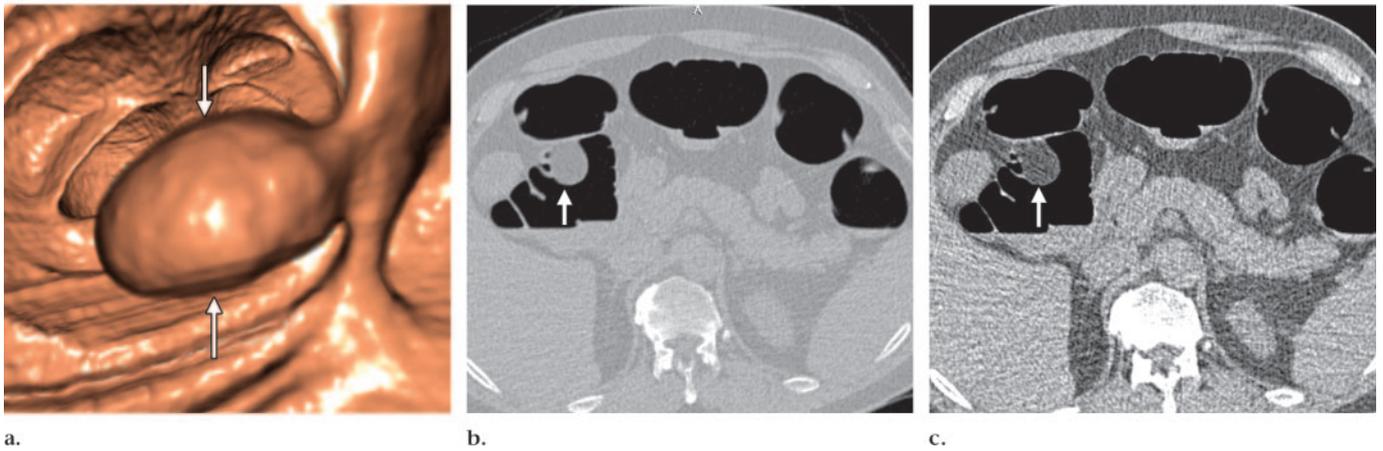


Figure 9. Hepatic flexure lesion in a 67-year-old man. (a) Endoluminal CT colonographic view shows 24-mm lobulated mass (arrow) in hepatic flexure. (b) Transverse CT image (window, 1500 HU; level, -200 HU) shows homogeneous attenuation of lesion (arrow). (c) Transverse CT image (window, 400 HU; level, 40 HU) clearly shows homogeneous low attenuation, similar to that of intraperitoneal fat. Lesion (arrow) was a lipoma.

that study of two radiologists, the sensitivity for polyps larger than 8 mm was 83% and the specificity was 100% for both observers. The average amount of time spent on interpretation was 28 minutes 30 seconds. Similar results were reported in 2000 by Macari et al (44), who used a primary 2D transverse imaging technique, with 3D and multiplanar reformation only for problem solving. In that study, the mean interpretation time with a primary 2D approach was 16 minutes. A more recent study (50) in which 2D imaging was used as the primary imaging technique showed a mean time for data interpretation of 11 minutes. The use of 2D images as the primary interpretation technique should allow CT colonographic data to be interpreted within 15 minutes.

Interpretation of 3D Data

When acquiring CT colonographic data by using a single-section CT scanner or a multisection scanner with collimation of more than 3 mm, the ability to interpret CT colonographic data by using 3D imaging is limited because of the poor z-axis resolution. With a 512×512 matrix, the typical pixel size in the x and y planes is 0.5–0.7 mm, depending on the field of view. If 5-mm-thick sections are used to acquire data, z-axis blurring occurs when images are reconstructed as endoluminal or coronal reformatted data. Moreover, there is substantial volume averaging within a voxel, which may limit the ability to differentiate fecal material and polyps (71).

With thin-section multi-detector row CT and improved 3D workstations, however, the ability to perform a primary 3D

endoluminal interpretation is now possible. A recent study (10) with 1233 asymptomatic patients and the use of a primary 3D endoluminal interpretation technique showed 93.8% sensitivity for colorectal adenomas measuring 10 mm or larger. In addition, as workstations have improved, interpretation times have decreased for endoluminal imaging. It is possible that as computer technology continues to improve, a 3D interpretation algorithm may become the interpretation technique of choice. In order to rely on a primary endoluminal interpretation technique, familiarity with 2D interpretation tools and the ability to interact with 2D images is necessary for problem solving.

Primary reliance on 3D virtual colonoscopic techniques has the appeal of a true simulation of conventional colonoscopy. Several workstation vendors are incorporating software to enable a computer-generated centerline path that will automatically allow endoluminal navigation of the colon to traverse this path. With improvements in software, one can then navigate through the colon and evaluate suspicious abnormalities.

Despite the optimism associated with a primary 3D review, however, there are several potential limitations of this imaging technique. First, there are blind spots in the colon when 3D endoluminal views are used (85). This is true even if antegrade and retrograde interrogations of the colon are performed. To optimize data interpretation, the colon needs to be evaluated with four fly-through passes: supine and prone, antegrade and retrograde. This increases interpretation time.

Several workstations currently have the capacity to display these blind areas to the reviewer after the 3D navigation is performed, which should allow a more complete visualization of the colon when a primary 3D interpretation technique is used. Moreover, improved 3D panoramic display techniques are being developed that should enable complete visualization of the undersurface of interhastral folds, which will improve polyp visualization and, at the same time, decrease interpretation time (85). Although it is hoped that these panoramic techniques—or “virtual pathologic examination” or “virtual dissection” techniques—which “unfold and dissect” the colon, will allow a rapid and accurate interpretation, an initial evaluation (86) of the virtual dissection technique did not show improved lesion detection when compared with 2D interpretation. For polyps 10 mm or larger, the sensitivities of two readers were 67% and 89% for virtual colon dissection and 89% and 100% for transverse image interpretation (86). The average time for reconstruction and analysis of a colonic virtual dissection display was 36.8 minutes, versus 29.2 minutes for transverse images.

A second limitation of 3D endoluminal fly-through imaging is that the centerline cannot be generated when segments of the colon are not well distended. In such cases, endoluminal navigation is impossible. Third, in overdistended segments the centerline may jump to an adjacent distended loop. Finally, it has been suggested that flat or annular lesions are best seen at transverse 2D review of images displayed with abdomen window and level settings of 400

and 40 HU, respectively (45). Therefore, whether a primary 2D or 3D review is performed, it is important to scroll through the data by using 2D transverse images with abdomen window and level settings to allow optimal detection of flat and annular types of lesions.

Given these limitations, however, it is possible—and quite likely—that with interrogation of 3D endoluminal images in both antegrade and retrograde directions, smaller polyps (<5 mm) can be routinely detected (10). Moreover, it is possible that polyps in the 6–9-mm range may also be better detected at 3D imaging (10). Authors of a study published in 2001 (56) found that the use of transverse images, as well as complete 3D endoluminal navigation in antegrade and retrograde directions in both supine and prone positions, allowed detection of 59% of polyps 5 mm or smaller. This result compares favorably with that of a study (44) where 2D images alone were used as the primary data interpretation technique and in which fewer than 20% of the diminutive polyps were visualized. In a relatively recent study (87), improved detection was shown for diminutive lesions in an ideally prepared and distended pig colon by using 3D and multiplanar reformation views, when compared with transverse images alone. However, the ability of endoluminal imaging to depict these diminutive filling defects in human subjects may lead to decreased specificity as a result of the demonstration of small adherent bits of residual fecal material that can be difficult to differentiate from small polyps. Moreover, the detection of true diminutive polyps with 3D imaging is of questionable clinical relevance, especially if routine colon screening is to be performed on an interval basis (9).

In summary, optimal evaluation of CT colonographic data are facilitated by easy access to supine and prone images and 2D and 3D images. Most workstations allow the transverse supine and prone images to be displayed adjacent to each other. Easy access to both data sets ensures that segments of the colon that are filled with fluid or incompletely distended on one data set are free of fluid and well distended on the other. At this time, a clear consensus on a primary 2D or 3D approach is not established.

POTENTIAL CLINICAL INDICATIONS

Currently, there are several clinical situations where CT colonography may play

an important role in patient care. These include evaluation of the colon after an incomplete conventional colonoscopic examination or evaluation of the colon proximal to an obstructing neoplasm (88–90). Another potential indication for CT colonography is evaluation in patients who are clinically unfit to undergo conventional colonoscopy, such as those with severe cardiac or pulmonary disease, those with a bleeding diathesis, those being treated with warfarin, and those with a prior allergic reaction to sedation. Finally, CT colonography may contribute to colorectal screening by providing a safe, effective, and rapid examination that can be used to evaluate the entire colon for clinically relevant lesions.

Failed Colonoscopy

An incomplete colonoscopic examination may occur in approximately 5% of cases and may be due to patient discomfort, colon tortuosity, postoperative adhesions, or hernia. Traditionally, DCBE has been used to evaluate the proximal colon in this setting. After incomplete colonoscopy, however, DCBE may be difficult to perform owing to air blockage from gas present due to the recently performed colonoscopy. In addition, because of residual fluid from a polyethylene glycol preparation, optimal coating of the colonic wall with barium may not be achieved. Two studies (88,89) have demonstrated the utility of CT colonography after an incomplete colonoscopic examination. CT colonography performed on the same day as incomplete colonoscopy takes advantage of the single bowel preparation and the fact that the colon is often well distended from previous gas insufflation for colonoscopy, thus necessitating only a small amount of additional insufflation. In this setting, CT colonography is clearly better tolerated than DCBE (88).

Evaluation of Colon Proximal to an Obstructing Lesion

Synchronous colon cancers occur in approximately 5% of cases of colorectal cancer, and synchronous polyps are common (90). On occasion, an obstructing carcinoma may prevent proximal endoscopic evaluation. In this setting, CT colonography has been shown to be useful for the evaluation of the more proximal colon for synchronous lesions (90). In addition to obstructive cancers, strictures from prior irradiation may prevent complete colonoscopic evaluation of the

colon. In a study with 61 patients (91), CT colonography was shown to allow a high-quality imaging study to be obtained in this setting. A potential limitation of CT colonography when there is near-total colonic obstruction is in achieving a clean enough colon proximal to the tumor or stricture to allow optimum evaluation. Careful clinical evaluation of the patient is necessary to exclude total obstruction, which would be a contraindication to bowel cleansing.

Patients with Contraindications to Colonoscopy or Who Refuse Other Screening Options

For a variety of reasons, a gastroenterologist may be unwilling to perform conventional colonoscopy in a patient in whom there is a high suspicion, based on clinical symptoms (bleeding, change in bowel habits, etc), of a colonic lesion. Reluctance to perform colonoscopy may be related to advanced patient age, severe comorbid disease, bleeding diathesis, or prior allergic reaction to sedation during colonoscopy (Fig 10). In these cases, CT colonography can be safely performed to exclude neoplastic disease.

Moreover, for a variety of reasons (anxiety, fear, embarrassment) people who should undergo screening are often reluctant to do so. Although conventional colonoscopy is the current reference standard for pancolonic evaluation, it is not a useful examination if the patient is unwilling to have the procedure performed. The concept of a relatively painless examination (CT colonography) that can image the colon and depict important lesions is appealing to many patients. Once a suspicious lesion is detected, a patient will be more willing to undergo conventional colonoscopy and polypectomy.

While CT colonography is a relatively painless procedure it is not entirely without discomfort. Most studies in which patient preferences were evaluated for conventional colonoscopy and CT colonography have shown CT colonography to be the preferred test (32,46–48). One study (47) with patients undergoing CT colonography followed by conventional colonoscopy showed that 82% of those who had an opinion favored CT colonography. Another study (32) with 696 patients who underwent CT colonography and colonoscopy showed that patients preferred CT colonography to colonoscopy 72.3% to 5.1%. However, another study (48) showed that 63.7% of patients preferred

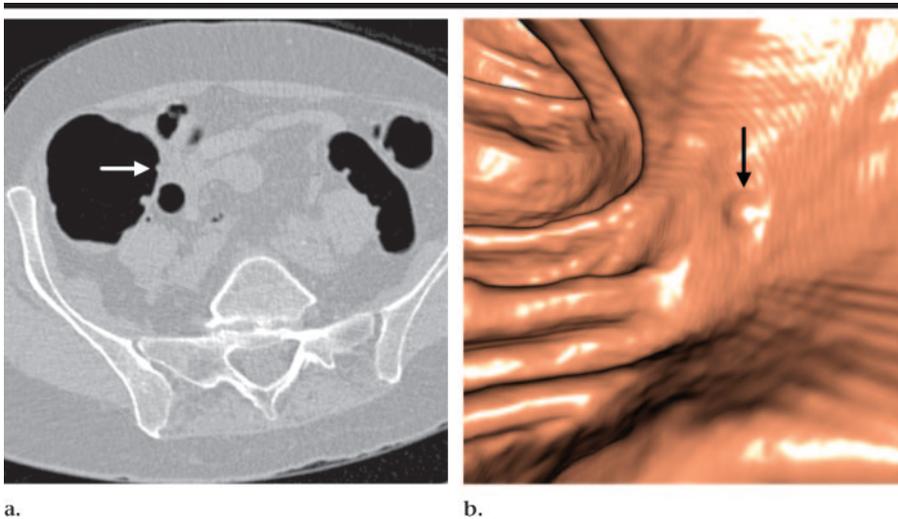


Figure 10. Factor V clotting deficiency in a 54-year-old man. (a) Transverse CT image shows small (4-mm) homogeneously attenuating polypoid lesion (arrow) in the ascending colon. (b) Endoluminal CT colonographic view confirms polypoid morphology (arrow). Given the small size and no other colorectal lesion, observation was recommended with follow-up CT colonography in 3–5 years.

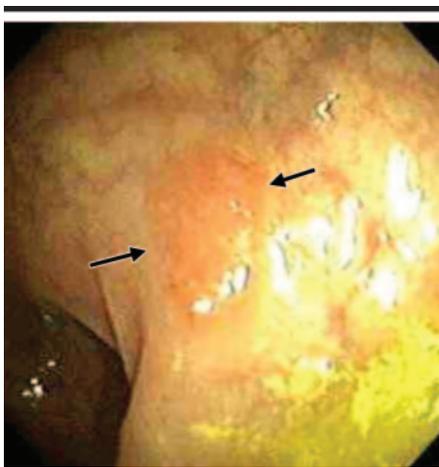


Figure 11. Flat adenoma in the rectum in a 60-year-old man. Conventional colonoscopic image shows slightly discolored flat lesion (arrows) raised not more than 1 mm from the background colonic mucosa. This lesion was not visible, even in retrospect, at CT colonography.

conventional colonoscopy to CT colonography. Our own data (49) on patient preferences for CT colonography and conventional colonoscopy demonstrated that 70.5% of patients preferred CT colonography, while 29.5% chose conventional colonoscopy.

How can these differences be explained? One potential explanation is that different CT techniques were used. Patient comfort and privacy need to be maximized during CT colonography. We do not use venous catheters or needles for the procedure, while others may use bowel relaxants re-

quiring venous access. Another important aspect is that CT colonography may be performed with a small rubber catheter. Finally, when questionnaires regarding the two procedures are given to patients, it is important to address outcomes as well as the therapeutic effect of conventional colonoscopy in allowing polyp removal in addition to depiction. A patient may prefer CT colonography over conventional colonoscopy, but if the patient knows something can be done to remove a detected abnormality at colonoscopy, it may increase the patient's acceptance of conventional colonoscopy.

SCREENING

Ultimately, CT colonography may be of assistance for other current options by enabling widespread pancolonic screening to be performed. In the gastroenterology community, there are differing opinions as to the current role of CT colonography. It has been suggested that while CT colonography is an exciting imaging technique that has promise, it is not yet ready to be recommended for general screening (12,37). What are the data comparing CT and conventional colonoscopy?

Initial investigations to evaluate CT colonography and conventional colonoscopy, including those performed by Vining et al (36), Hara et al (41), and Dachman et al (43), showed promising results regarding the ability of CT to demonstrate colorectal polyps and cancers. Many single-in-

stitution clinical studies evaluating CT colonography have demonstrated a sensitivity of over 90% for the detection of colorectal polyps measuring 10 mm or larger, when correlated with findings from conventional colonoscopy (14). These results compare favorably with studies that have evaluated DCBE and colonoscopy in the detection of lesions of this size (31). However, most of these CT colonography studies were performed in patients with specific colorectal symptoms.

A study published in 1999 (75) with 100 patients who underwent back-to-back CT and conventional colonoscopy showed a sensitivity for CT of 100% for colorectal carcinoma, 91% for polyps 10 mm or larger, and 82% for polyps 6–9 mm. Not all studies have demonstrated a similar sensitivity for detection of 10-mm or larger polyps. In a cohort of 180 patients, Fletcher et al (51) showed a sensitivity of 85% for polyps measuring 10 mm or larger. In 1997, Hara et al (39) showed 75% sensitivity for polyps 10 mm or larger. In 2001, a follow-up study by Hara et al (69) showed improved sensitivity, which ranged from 80% to 89% for polyps 10 mm or larger. These data suggest that there is a learning curve associated with CT colonography (55,69). This was also shown in a recent multi-institutional study (15) in which multi-detector row CT colonography and conventional colonoscopy were evaluated. In that study, the overall detection rate for CT colonography for colorectal polyps 10 mm or larger was only 55%. However, analysis of results from those centers that had the most prior experience with CT colonography showed excellent sensitivity (approaching 90%) for 10-mm or larger polyps. For small polyps (≤ 5 mm), the sensitivity was lower.

Perhaps of more concern than the small raised polyp is the truly flat adenoma, which is very difficult—and in some cases almost impossible—to detect at CT colonography (Fig 11) (76). The definition of a flat polyp is a lesion with a height of less than 50% of the lesion width (92). While most flat lesions are 2 mm in height or less, they may occasionally be up to 5 mm in height. Therefore, many slightly raised flat lesions are visible at CT colonography (Fig 12). Authors of a recent study (10) in the United States found the prevalence of flat lesions to be extremely low. While flat lesions have traditionally been thought to be rare in Western populations, they may in fact be more common than was previously believed (92). Authors of one study (92) of 1000 colonoscopic examinations per-

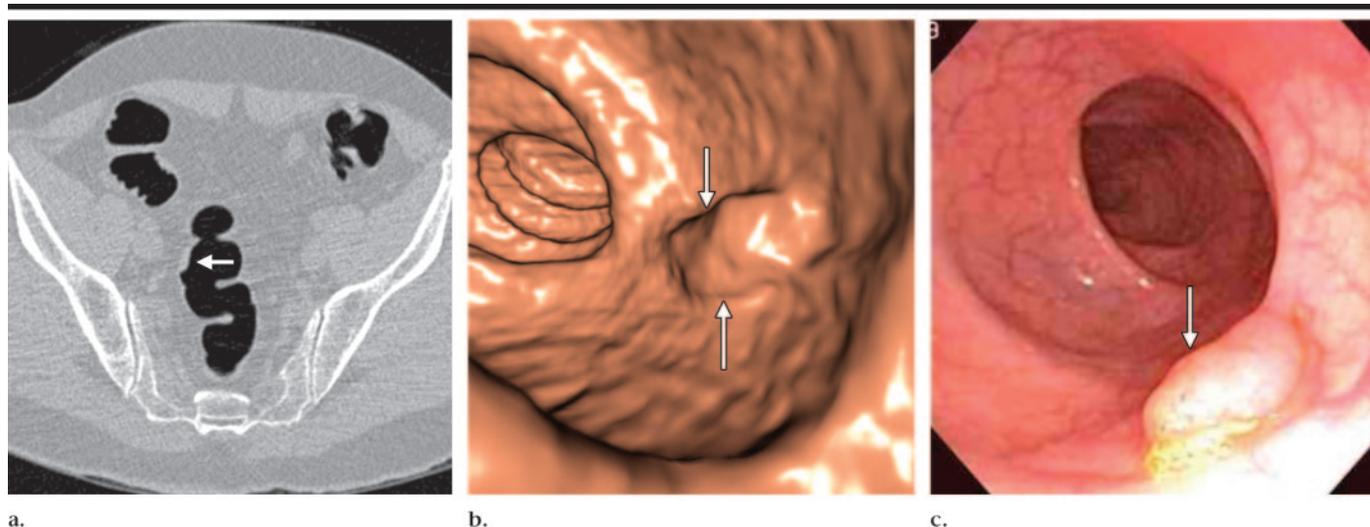


Figure 12. Tubular adenoma with flat morphology in the sigmoid colon in a 64-year-old man. (a) Transverse CT image shows barely perceptible raised lesion (arrow) in sigmoid colon. Lesion measured 2 mm in height and 12 mm in width. (b) Endoluminal CT colonographic view confirms flat morphology (arrows) of lesion. (c) At conventional colonoscopy, the lesion was interpreted as flat and shows morphology (arrow) similar to that in b. Histologic evaluation demonstrated tubular adenoma.

formed from 1995 to 1999 in the United Kingdom evaluated the prevalence of flat adenomas. They found that 36% of adenomas were flat, and the majority of those lesions appeared to be in the proximal colon.

There is some controversy about the clinical importance of flat lesions compared with that of sessile or pedunculated lesions (92,93). However, authors of a recent review (93) of flat lesions (ie, thickness ≤ 1.3 mm) that used data from the National Polyp Study suggested that flat lesions are not more aggressive than sessile or pedunculated adenomas. The results of that study showed that flat lesions, which made up 27% of all baseline adenomas, were no more likely than sessile or pedunculated adenomas to exhibit high-grade dysplasia. Moreover, there was no increased risk of advanced adenomas at surveillance endoscopy in patients whose initial adenomas were flat (93). The ability of CT colonography to depict the majority of clinically important lesions is still relevant. It should be pointed out that conventional colonoscopy also has limitations in its ability to depict all colorectal polyps (10,94).

With regard to screening, there have been several published series (10,76,95,96) in which CT colonography and conventional colonoscopy were evaluated. In a series of 67 asymptomatic patients who underwent screening CT colonography and conventional colonoscopy, three (100%) of three polyps 10 mm or larger were detected at CT (95). Rex et al (76) reported on 46 patients who underwent

screening CT colonography and colonoscopy; they demonstrated a low sensitivity for CT colonography not only for the detection of small polyps (11% for polyps ≤ 5 mm) but also for larger flat lesions. In that study, only one of four flat adenomas measuring more than 2 cm in width that were present at conventional colonoscopy were detected at CT colonography. The results of that study seem to suggest that CT colonography may not be an accurate screening test for colorectal polyps. However, as pointed out in an associated editorial (97) about that series of patients, it is too early to pass judgment on CT colonography on the basis of a single report. Of importance, CT colonography in that screening study was performed with single- or dual-section helical CT scanners with 5-mm collimation (76).

Two large studies have recently been published in which CT colonography was evaluated in an asymptomatic population. The first study (10) included 1233 average-risk asymptomatic patients and is the largest study to date in which CT colonography and conventional colonoscopy were evaluated. The sensitivity of CT colonography for the detection of 10-mm or larger polyps was over 90% and was, in fact, greater than that of conventional colonoscopy. In that study, determination of true-positive lesions was based on sequential unblinding of the colonoscopist to the CT colonography results as the colonoscope was removed. This served as an improved standard for the presence or absence of polyps. Moreover, of those polyps that were missed at CT colonography,

most were hyperplastic polyps, not adenomas (98). Hyperplastic polyps may be more compressible when the colon is insufflated. Missing these polyps at CT colonography clearly has no effect on patient survival.

However, a second recently published large study (96) was an evaluation of CT colonography and colonoscopy performed on the same day in 703 asymptomatic but higher-than-average-risk patients. In that study, three experienced readers detected 34%, 32%, and 73% of all polyps measuring 10 mm or larger. With double reading of the cases, 63% of these polyps were prospectively observed, and there was high interobserver variability in polyp detection. The conclusion of the study was that in a low-prevalence population, the polyp detection rates are much lower at CT colonography than at colonoscopy.

While there is obviously a training issue and a learning curve for CT colonography, these do not explain the discrepant results between the two studies (10,96). In the second study (96), three experienced readers showed relatively poor sensitivity for clinically relevant lesions. Some of the differences may be explained by the choice of collimation, workstation, and interpretation techniques. These factors need to continue to be explored.

THE FUTURE

While most studies to date have been focused on the ability of CT colonogra-

phy to depict colorectal polyps, the real measure of this screening test will be to decrease the morbidity and mortality associated with colorectal cancer. The future of CT colonography is promising. Training of radiologists in CT colonography interpretation techniques and access to reimbursement for the performance of CT colonography remain challenges for the radiology community. Continued hypothesis-driven research will be focused on elimination of or improvement in bowel preparation, improvement in software for polyp visualization and detection, and further development and implementation of computer-assisted detection for colorectal polyps (85,99–101).

Training and Implementation

A major limitation of conventional colonoscopy is that there are not enough trained endoscopists to perform routine screening in all eligible subjects (37). Likewise, there currently are not enough trained radiologists to influence colon cancer screening with CT colonography. If CT colonography is going to affect colon cancer screening, training of radiologists to interpret CT colonographic studies will be critical.

In the United States, several medical centers are offering hands-on training in CT colonographic data interpretation. These courses usually run for 2 days and comprise a mixture of didactic lectures and review of colonoscopy-proved cases. Participants have the use of a workstation and learn skills that enable polyp detection and differentiation from residual fecal material and bulbous folds. Moreover, training modules are being developed that will allow radiologists to undergo independent training with a mixture of cases that demonstrate different pathologic conditions (102). Ultimately, CT colonographic interpretation will need to be incorporated into radiology residency training programs if sufficient numbers of radiologists are ever to have the expertise to contribute to colon cancer screening.

Reimbursement

CT colonography is not listed as a colon cancer screening study that Medicare will reimburse. As of July 1, 2004, two new Current Procedural Terminology (CPT) codes were created by the CPT editorial panel for CT colonography. The codes are 0066T for examinations performed for screening and 0067T for examinations performed for diagnostic purposes (eg, obstructive cancer, bleeding).

These are category III codes, meaning that they are not valued through the Relative Value Update Committee process. As such, the Centers for Medicare and Medicaid Services and individual insurance carriers decide on a code-by-code basis if coverage will be provided. Thus, payment is variable; however, this usually means that there is no coverage provided.

Category I codes specifically require that a device or drug be approved by the Food and Drug Administration, the procedure be performed at multiple locations and by multiple physicians, and that the clinical efficacy be well established and documented (103). The new CPT category III codes replace the three previously used codes that were routinely used to bill for CT colonography (71450, abdominal CT without contrast material; 72192, pelvic CT without contrast material; and 76375, tomographic reconstruction). Radiologists must now use these new category III codes for tracking purposes, and the use of the category I codes is now inappropriate. The American College of Radiology is working to obtain reimbursement for these procedures, but payment is currently neither universal nor uniform.

At present, several private insurers, including Physicians Plus Insurance in Madison, Wis, are reimbursing for screening CT colonography. The reason given by these insurance carriers for reimbursing for screening CT colonography is that screening with high-quality CT colonography will be cost-effective relative to conventional colonoscopy, given all of the associated costs incurred with conventional colonoscopy. For most payers, however, CT colonography is currently not a reimbursable procedure. As such, if a patient wants to undergo CT colonography or a physician refers a patient for the procedure, payment will ultimately come from the patient. Radiology practices, therefore, need to decide on a fee for the procedure. Since CT colonographic examinations extensively evaluate the colon with two acquisitions, as well as the remainder of the abdomen and pelvis for incidental findings, an inappropriately low fee has been discouraged, and it has been suggested that the charges should be at least the same as those for routine CT of the abdomen and pelvis, and possibly more.

CT Colonography without Bowel Preparation and Computer-assisted Detection of Polyps

There are two major areas of intense CT colonography research being per-

formed by both radiologists and software manufacturers: (a) the clinical performance of CT colonography without bowel cleansing and (b) efforts to enhance polyp visualization. CT colonography without colon cleansing was discussed earlier (see Patient Preparation section). However, it should be pointed out that a recent study (104) evaluated the performance of CT colonography in 200 patients in whom dilute iodinated contrast material was used. The contrast material was ingested in small aliquots over five low-fat and low-fiber meals and without any other bowel catharsis. In that study, the sensitivity for polyps 8 mm or larger was 95%. Continued evaluation of such "preless" CT colonography by using both iodine and barium is underway.

Polyp enhanced visualization or computer-assisted detection of polyps are software programs that detect colorectal lesions that have morphologies suggestive of a polyp. Various strategies have been used by software and workstation manufacturers to enable detection of polyps; however, geometric and morphologic characteristics of polyp candidates appear to be the most important (101).

Most of these systems are being designed to act as a second reader for polyp detection. Most computer-assisted detection systems operate on the premise that a primary review will be performed by the radiologist. Either simultaneously, or in the background, the computer analyzes the data and displays potential polyps to the reviewer. The reviewer can then evaluate these lesions and determine, on the basis of morphologic and attenuation characteristics, whether the presented lesion is indeed a polyp or a false-positive finding (fecal material, fold, ileocecal valve). Polyp enhanced visualization will soon be available on workstations, and, it is hoped, will enable improved polyp detection rates, especially for polyps measuring 6 mm and larger.

CONCLUSION

CT colonography is currently a viable alternative imaging tool for colorectal polyp detection. At centers where there is expertise in data acquisition and interpretation, CT colonography is being offered as a routine imaging examination. Radiologists who perform CT colonography should be familiar with current colon cancer screening techniques and how CT colonography can be incorporated

into clinical practice. Moreover, techniques of bowel preparation, colonic insufflation, and CT colonographic data interpretation need to be learned by sufficient numbers of radiologists if this exciting technology is to have a substantial influence on colon cancer screening.

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