

Update on CT colonography

The American Society for Gastrointestinal Endoscopy (ASGE) Technology Committee provides reviews of existing, new, or emerging endoscopic technologies that have an impact on the practice of GI endoscopy. Evidence-based methodology is used with a MEDLINE literature search to identify pertinent clinical studies on the topic and a MAUDE (Food and Drug Administration Center for Devices and Radiological Health) database search to identify the reported complications of a given technology. Both searches are supplemented by accessing the "related articles" feature of PubMed and by scrutinizing pertinent references cited by the identified studies. Controlled clinical trials are emphasized, but, in many cases, data from randomized controlled trials are lacking. In such cases, large case series, preliminary clinical studies, and expert opinions are used. Technical data are gathered from traditional and Web-based publications, proprietary publications, and informal communications with pertinent vendors.

Technology Status Evaluation Reports are drafted by 1 or 2 members of the ASGE Technology Committee, reviewed and edited by the committee as a whole, and approved by the governing board of the ASGE. When financial guidance is indicated, the most recent coding data and list prices at the time of publication are provided. For this review, the MEDLINE database was searched through September 2008 for articles related to CT colonography by using the keywords "CT colonography," "virtual colonoscopy," "screening," and "cancer."

Technology Status Evaluation Reports are scientific reviews provided solely for educational and informational purposes. Technology Status Evaluation Reports are not rules and should not be construed as establishing a legal standard of care or as encouraging, advocating, requiring, or discouraging any particular treatment or payment for such treatment.

BACKGROUND

The term CT colonography (CTC) refers to using helical-CT scanning and computers to produce high-resolution 2-dimensional (2D) and 3-dimensional (3D) imaging

of the colon.¹ Other terms used to describe these techniques include virtual colonoscopy and CT colography. This technique of virtual imaging of the colon can also be accomplished with magnetic resonance imaging,² but this review focuses on the CT technique.

TECHNICAL CONSIDERATIONS

The technique for CTC involves the following steps: (1) bowel cleansing and stool labeling, (2) colon insufflation, (3) image acquisition, and (4) image processing and interpretation.

Bowel cleansing

Current techniques require meticulous bowel preparation analogous to that required for endoscopic colonoscopy. Retained intraluminal fluid or stool can result in visual artifacts. For CTC, osmotically active preparations, such as oral sodium phosphate laxatives, offer low fluid residual compared with polyethylene-glycol-based preparations.^{3,4} Recently reported series used combined bowel cleansing and contrast labeling of residual stool with barium and residual liquids with water-soluble contrast medium (diatrizoate meglumine and diatrizoate sodium, Gastrografin [Bracco Diagnostics, Princeton, NJ], or MD-Gastroview [Mallinckrodt Inc, St Louis, Mo]) in the colonic lumen have yielded improved accuracy.⁵⁻⁷ Feasibility studies are being performed to evaluate the potential to identify polyps without a colon preparation.⁸ The term "prep-less" CTC is a misnomer, because oral labeling of the stool is required as is per rectal colon insufflation with air or carbon dioxide. Another potential drawback to "prep-less" CTC is the inability to have same-day colonoscopy should CTC document an abnormality.⁹

Colon insufflation

Colon insufflation distends the lumen to facilitate mucosal imaging. Failure to adequately distend the colon may obscure lesions or yield false-positive findings. The colon is distended with air or carbon dioxide via a rectal tube. A scout film is obtained to assess for satisfactory colon distention. Carbon dioxide given by an automated low-pressure delivery system has replaced manual insufflation with air.¹⁰⁻¹² Rapid resorption of carbon dioxide through the colonic wall may account for decreased discomfort after the procedure and has become the standard means of

distention. Glucagon as an antispasmodic agent has not been consistently shown to improve distension of the colon and adds complexity to the procedure.¹³⁻¹⁵

Image acquisition

Helical CT technology has unique advantages over conventional CT scanning for virtual image rendering. Conventional CT examinations take sequential static cross-sectional images that require longer image acquisition times and multiple breath holds, which result in imaging gaps and artifacts. Helical CT moves the patient continuously through a rotating x-ray beam during a single breath hold, which limits image gaps and motion artifact. With the development of multidetector CT scanners, narrow x-ray collimation (1.0-1.5 mm) and shortened image acquisition times (15-20 seconds) have further reduced artifacts. Patients are scanned in the prone and supine position, and more than 500 potential image slices for colon reconstruction are obtained. IV contrast is not required in CTC.

Image processing and interpretation

The images are processed by means of commercially available software packages that simultaneously display 2D axial, coronal, and sagittal images of a given point designated by the radiologist. In addition, the software will simultaneously display a 3D endoluminal view that simulates colonoscopic imaging. Several software programs allow automatic luminal centering, multidirectional viewing (eg, to see both sides of colonic folds), color enhancement of the wall to indicate abnormalities, reporting of a lesion's location, calculation of unseen surface area, and simulated gross anatomic reconstruction of the colon laid open for an en face inspection.¹⁶ Initial reports primarily used 2D imaging, with 3D review of uncertain regions and lesions. More recent studies used both 2D and 3D views. Data from the American College of Radiology Imaging Network (ACRIN) trial demonstrated that 2D and 3D reconstructions with sophisticated software yielded equal efficacy.¹⁷ Automated polyp detection software is pending U.S. Food and Drug Administration clearance.

INDICATIONS

CTC is used in patients with obstructing colon cancer, which allows simultaneous preoperative tumor staging and inspection of the proximal colon for synchronous lesions.^{18,19} CTC may be used adjunctively in patients who have had incomplete colonoscopy²⁰ and is preferred over barium enema.²¹ There are not enough data to support the use of CTC in the primary evaluation of patients with symptoms related to the lower digestive tract. Although earlier guidelines indicated that there were insufficient data to support the use of CTC for colorectal cancer screening,²²⁻²⁶ the 2008 updated screening recom-

mendations from the American Cancer Society, the U.S. Multi-Society Task Force on Colorectal Cancer, and the American College of Radiology included CTC as a screening option for the early detection of colorectal cancer and adenomatous polyps for asymptomatic adults aged 50 years and older.²⁷ It was recommended that screening of average-risk individuals commence at age 50 years. The group recommended that colonoscopy be offered to all patients whose largest polyp is 6 mm or larger. The interval for repeated CTC is uncertain but a repeated examination was recommended at 5-year intervals until additional data become available. A 2008 updated systematic review on colorectal cancer screening by the U.S. Preventive Services Task Force (USPSTF) determined that CTC appeared as likely as colonoscopy to detect lesions 10 mm or larger but may be less sensitive for smaller adenomas. Given the potential radiation-related harms, the indeterminate downstream health effects of extracolonic findings, and the uncertain fidelity of test performance of CTC in community settings, the USPSTF concluded that the evidence was insufficient to assess the benefits and harms of CTC as a screening modality for colorectal cancer.²⁸

EFFICACY

CTC imaging has been compared with colonoscopy in multiple studies. The reported sensitivity and specificity to detect all polyps range widely and decrease with decreasing polyp size. Earlier studies that used 2D imaging but did not include stool and fluid tagging demonstrated a low sensitivity and specificity for the detection of polyps.^{5,29-31} A study of 1233 asymptomatic adults that used experienced radiologists, stool and fluid tagging, and 2D and 3D imaging reported a sensitivity and specificity of 94% and 96%, respectively, for polyps at least 10 mm in diameter and 89% and 80%, respectively, for polyps at least 6 mm in diameter.⁷ The negative predictive value of CTC was more than 99% for adenomatous polyps that measured 8 mm or more in diameter. In a nonrandomized study of patients undergoing either colonoscopy (3120 patients) or CTC (3163 patients), the rate of detection of advanced neoplasms was similar in the CTC group (3.2%) and the colonoscopy group (3.4%). Patients with only 1 or 2 polyps 6 to 9 mm in size were offered CTC surveillance in 3 years or colonoscopy, whereas, polyps smaller than 5 mm were not reported. In the CTC group, 561 polyps were removed in contrast to 2434 in the colonoscopy group. The referral rate for colonoscopy in the primary CTC screening group was 7.9% (246/3120 patients). The perforation rate in the colonoscopy group (7/3163) was much higher than reported in the literature. In the ACRIN 6664 trial, 2531 study participants at 15 institutions each had a CTC followed by a colonoscopy on the same day.¹⁷ This study demonstrated a 90% sensitivity and 86% specificity for identifying patients with adenomas 10 mm or

larger and a 78% sensitivity and 88% specificity for lesions 6 mm or larger. The per patient positive predictive value was 23%, and the negative predictive value was 99% for polyps 10 mm or larger. The per patient sensitivity for adenomas that were 6 mm or more in diameter was 78%. In this screening population, the prevalence of neoplastic lesions \geq 6 mm was low at 8.3%. In this study, 17% of patients would be referred for colonoscopy for a lesion 5 mm or larger versus 12% if the threshold was 6 mm or larger. The radiologists in this study were experts who had interpreted 500 CTC examinations or had participated in a specialized 1.5-day training session. Several studies suggested that the detection of flat adenomas by CTC is poor.³²⁻³⁴

Extracolonic findings are identified in 6% to 8% of asymptomatic individuals and add to the cost of CTC.³⁵⁻³⁷ In the ACRIN study, 16% of patients had extracolonic findings that required further evaluation.¹⁷ Defining what is an important extracolonic lesion that requires follow-up is controversial. Potentially important lesions include extracolonic cancers; abdominal aortic aneurysms; adrenal adenomas; lung nodules; and renal, ovarian, hepatic, and splenic cysts. Kim et al³⁸ identified 241 extracolonic findings in 3120 asymptomatic patients (7.7%) screened with CTC, which resulted in a recommendation for an additional test or procedure. There were 8 extracolonic cancers identified (0.3%).

The Computed Tomographic Colonography Reporting and Data System was developed to standardize findings on CTC.³⁹ These include a classification scheme for extracolonic abnormalities. The categories are E1 (normal or anatomical variant), E2 (clinically unimportant finding), E3 (probably unimportant, incompletely characterized), or E4 (potentially important finding).

EASE OF USE AND LIMITATIONS

After patient preparation and colon insufflation, CTC requires a scan time of no longer than 15 seconds per acquisition (supine and prone), with the patient spending 1 to 2 minutes in the scanner. Typically, the entire procedure on the CT table takes approximately 10 minutes.²⁷ Sedation is not used. Image generation may be as short as 10 minutes. Radiologist interpretation time is variable. In the ACRIN study, the radiology interpretation ranged from 19 to 25 minutes (19 minutes for primary 2D image review and 25 minutes for primary 3D image review).¹⁷ As described above, a rigorous training program was instituted and required for all radiologists who participated in the study. Endoscopists who perform colonoscopy are well equipped to discuss with the patient the implications of diminutive polyps and to perform a therapeutic colonoscopy. A position paper that described the training process for gastroenterologists to read the intraluminal findings has been published.⁴⁰

Patient acceptance of CTC and colonoscopy are favorable and comparable, with no consistent preference.⁴¹⁻⁴³

It is not known if the availability of CTC would prompt unscreened patients to elect to be screened. In addition, there is uncertainty of how dissemination of CTC would impact existing screening modalities, for example, colonoscopy. In April 2004, 3 private health plans in Wisconsin initiated coverage for CTC screening to be performed at the University of Wisconsin. In the first 33 months of this program, there was no change in the number of screening colonoscopies or therapeutic (polypectomy) procedures performed.⁴⁴ Because CTC does not require sedation, those associated costs and risks are avoided.

CTC is more accurate for lesion localization than colonoscopy. Because synchronous cross-sectional imaging is performed, CTC has the potential to detect extracolonic abnormalities that may or may not benefit the asymptomatic patient. CTC does not offer the potential for tissue sampling or polypectomy. Patients with polyps detected on CTC, both true and false positives, will require colonoscopy.

SAFETY

There are rare reported complications from CTC. Potential complications include those related to colonic preparation, colon insufflation,⁴⁵ and radiation exposure.^{46,47} Colonic perforation is rare and more common in symptomatic patients who undergo manual air insufflation as opposed to automated low-pressure carbon dioxide insufflation. Burling et al⁴⁸ reported 9 perforations in 17,067 CTC examinations (0.08%) at 50 institutions in the United Kingdom. In another study, of 11,870 cases performed at 11 institutions, there were 7 perforations (0.06%).⁴⁹ The vast majority of perforations were in patients being evaluated because of symptoms. The International Working Group on Virtual Colonoscopy reported no perforations in more than 11,000 screening CTC examinations and one perforation in 22,000 screening and diagnostic CTC examinations (0.005%).⁴⁵

Radiation exposure is of concern, especially in patients who are obese and in those patients undergoing repeated examinations to follow-up small polyps left in situ. The radiation dosage is comparable with a barium enema examination.⁵⁰ In one model that uses "typical" current scanner techniques, an approximately 0.14% increased lifetime cancer risk was calculated for a 50-year-old patient undergoing a single CTC.⁴⁶ It was further suggested that these values could probably be reduced by a factor of 5 or 10 with optimized CTC protocols. Imaging with lower-dose radiation would be an advance and is currently under study.^{51,52}

The safety of not removing polyps 6 to 9 mm in size or not reporting polyps 5 mm or smaller is controversial. Radiologists consider a screening CTC positive if a lesion 6 mm or larger is encountered.⁵³ A radiology consensus proposal suggests a 3-year follow-up interval for CTC

surveillance of 1 or 2 small polyps.³⁹ Although the risk of advanced neoplasia in these polyps is low,⁵⁴ it has been proposed that patients with any polyp ≥ 6 mm in size or 3 polyps of any size should be offered colonoscopy and polypectomy.⁵⁵ Furthermore, the findings of 1 or 2 polyps < 5 mm with moderate to high confidence should be reported, and, if patients are not offered polypectomy, then they should be informed of the findings. In the 2008 consensus colorectal cancer screening guidelines, the panel concluded that colonoscopy and polypectomy should be recommended if patients have one or more polyps 6 mm or larger.²⁷

FINANCIAL CONSIDERATION

Category III Current Procedural Terminology (CPT)* codes for diagnostic (0067T) and screening (0066T) CTC were published in the 2005 CPT, and, subsequently, many Medicare contractors published local coverage policies that allow for payment for diagnostic CTC in circumstances in which colonoscopy was incomplete because of anatomic issues (eg, obstructing cancer).⁵⁶ Payment rates and allowable ICD-9 codes vary by contractor (these can be found on the Centers for Medicare and Medicaid Services [CMS] Local Coverage Determination Web site at cms.hhs.gov/mcd); private payers are generally less likely to cover CTC, even in limited circumstances. After the release of colorectal cancer screening guidelines by the American Cancer Society and the U.S. Multi-society Task Force,²⁷ CMS initiated a national coverage analysis for the use of CT for colorectal cancer screening, expected to be concluded in 2009. CMS has the option of providing screening benefits for CTC. With the publication of the ACRIN study,¹⁷ it is expected that CPT Category I code proposals will move forward (for publication in 2010 if adopted by February 2009) and that CMS may well allow for use of screening applications of CTC. It is unsettled whether gastroenterologists will legally be able to work with radiologists to share professional reading fees and how coverage of extracolonic findings will emerge.

Several cost-effectiveness models were developed for screening applications of CTC.⁵⁷⁻⁶⁰ The cost-effectiveness of CTC versus other screening strategies is sensitive to the performance characteristics of CTC, the cost of CTC, and the threshold to refer patients for colonoscopy. In one model, managing smaller polyps detected on a screening CTC with another CTC examination 3 years later will likely result in more deaths and cancers than immediate colonoscopy and polypectomy,⁵⁷ whereas in another

model, CTC with nonreporting of diminutive lesions was found to be the most cost effective and safest screening option.^{58,59} False-positive and incidental extracolonic findings on CTC lead to additional investigation and cost. CTC-directed colonoscopy for diminutive polyps may decrease efficiency in the endoscopy unit, because additional time is spent trying to identify polyps, both true and false positives, seen on CTC.⁶¹

AREAS OF FUTURE RESEARCH

To further define the optimal role of CTC, particularly in the realm of colorectal cancer screening, several issues need to be clarified with future studies. Further evidence-based studies are needed to define the optimal screening interval of CTC and the surveillance interval for diminutive polyps. Further cost-effectiveness studies of this technology, incorporating the life years gained or lost with an evaluation of extracolonic findings, various thresholds for colonoscopy referral, and morbidity of radiation exposure, are warranted. Most importantly performance of CTC in community-based medical practices remains uncertain. Training guidelines to promote high-quality screening needs to be defined, along with metrics to confirm the quality in the performance of CTC.⁶² The impact of patient education on the decision to have CTC versus colonoscopy and whether or not to have colonoscopy after a small lesion is identified on CTC needs to be determined.

CONCLUSIONS

CTC is a radiologic method to examine the colon. The accuracy for detection of polyps improves with increasing polyp size and is comparable with colonoscopy for polyps 10 mm or larger by using multidetector scanners, stool and fluid tagging, 2D and 3D imaging, and interpretation by experts with appropriate training. However, the detection of polyps smaller than 10 mm and flat polyps is inferior to colonoscopy, and this should be considered by providers and patients when considering screening options. CTC is preferred to a barium enema for evaluation of the colon proximal to an obstructing lesion and in patients with an incomplete colonoscopy. Several outstanding issues, including reporting of polyps 5 mm or smaller, the threshold polyp size for colonoscopy referral, intervals for repeated examinations, training, and radiation exposure must be thoroughly addressed before the optimal role of CTC in colorectal cancer screening is defined.

Abbreviations: 2D, 2-dimensional; 3D, 3-dimensional; ACRIN, American College of Radiology Imaging Network; ASGE, American Society for Gastrointestinal Endoscopy; CMS, Centers for Medicare and Medicaid Services; CPT, Current Procedural Terminology; CTC, CT colonography; USPSTF, U.S. Preventive Services Task Force.

* Current Procedural Terminology (CPT®) is copyright 2008 American Medical Association. All Rights Reserved. No fee schedules, basic units, relative values, or related listings are included in CPT. The AMA assumes no liability for the data contained herein. Applicable FARS/DFARS restrictions apply to government use.

REFERENCES

1. Royster AP, Gupta AK, Fenlon HM, et al. Virtual colonoscopy: current status and future implications. *Acad Radiol* 1998;5:282-8.
2. Kinner S, Lauenstein TC. MR colonography. *Radiol Clin North Am* 2007; 45:377-87.
3. Kim DH, Pickhardt PJ, Hinshaw JL, et al. Prospective blinded trial comparing 45-mL and 90-mL doses of oral sodium phosphate for bowel preparation before computed tomographic colonography. *J Comput Assist Tomogr* 2007;31:53-8.
4. Ginnerup Pedersen B, Moller Christiansen TE, Viborg Mortensen F, et al. Bowel cleansing methods prior to CT colonography. *Acta Radiol* 2002;43:306-11.
5. Cotton PB, Durkalski VL, Pineau BC, et al. Computed tomographic colonography (virtual colonoscopy): a multicenter comparison with standard colonoscopy for detection of colorectal neoplasia. *JAMA* 2004; 291:1713-9.
6. Kim DH, Pickhardt PJ, Hoff G, et al. Computed tomographic colonography for colorectal screening. *Endoscopy* 2007;39:545-9.
7. Pickhardt PJ, Choi JR, Hwang I, et al. Computed tomographic virtual colonoscopy to screen for colorectal neoplasia in asymptomatic adults. *N Engl J Med* 2003;349:2191-200.
8. Iannaccone R, Laghi A, Catalano C, et al. Computed tomographic colonography without cathartic preparation for the detection of colorectal polyps. *Gastroenterology* 2004;127:1300-11.
9. Pickhardt PJ. Colonic preparation for computed tomographic colonography: understanding the relative advantages and disadvantages of a noncathartic approach. *Mayo Clin Proc* 2007;82:659-61.
10. Shinnars TJ, Pickhardt PJ, Taylor AJ, et al. Patient-controlled room air insufflation versus automated carbon dioxide delivery for CT colonography. *AJR Am J Roentgenol* 2006;186:1491-6.
11. Dachman AH. Advice for optimizing colonic distention and minimizing risk of perforation during CT colonography. *Radiology* 2006;239: 317-21.
12. Tolan DJ, Armstrong EM, Burling D, et al. Optimization of CT colonography technique: a practical guide. *Clin Radiol* 2007;62:819-27.
13. Yee J, Hung RK, Akerkar GA, et al. The usefulness of glucagon hydrochloride for colonic distention in CT colonography. *AJR Am J Roentgenol* 1999;173:169-72.
14. Morrin MM, Farrell RJ, Keogan MT, et al. CT colonography: colonic distention improved by dual positioning but not intravenous glucagon. *Eur Radiol* 2002;12:525-30.
15. Rogalla P, Lembcke A, Ruckert JC, et al. Spasmolysis at CT colonography: butyl scopolamine versus glucagon. *Radiology* 2005;236:184-8.
16. Kim SH, Lee JM, Eun HW, et al. Two- versus three-dimensional colon evaluation with recently developed virtual dissection software for CT colonography. *Radiology* 2007;244:852-64.
17. Johnson CD, Chen MH, Toledano AY, et al. Accuracy of CT colonography for detection of large adenomas and cancers. *N Engl J Med* 2008; 359:1207-17.
18. Fenlon HM, McAneeny DB, Nunes DP, et al. Occlusive colon carcinoma: virtual colonoscopy in the preoperative evaluation of the proximal colon. *Radiology* 1999;210:423-8.
19. Morrin MM, Farrell RJ, Raptopoulos V, et al. Role of virtual computed tomographic colonography in patients with colorectal cancers and obstructing colorectal lesions. *Dis Colon Rectum* 2000;43:303-11.
20. Copel L, Sosna J, Kruskal JB, et al. CT colonography in 546 patients with incomplete colonoscopy. *Radiology* 2007;244:471-8.
21. Rockey DC, Paulson E, Niedzwiecki D, et al. Analysis of air contrast barium enema, computed tomographic colonography, and colonoscopy: prospective comparison. *Lancet* 2005;365:305-11.
22. Winawer S, Fletcher R, Rex D, et al. Colorectal cancer screening and surveillance: clinical guidelines and rationale: update based on new evidence. *Gastroenterology* 2003;124:544-60.
23. Pignone M, Rich M, Teutsch SM, et al. Screening for colorectal cancer in adults at average risk: a summary of the evidence for the U.S. Preventive Services Task Force. *Ann Intern Med* 2002;137:132-41.
24. Berg AO, Allan JD, Frame PS, et al. Screening for colorectal cancer: recommendation and rationale. *Ann Intern Med* 2002;137:129-31.
25. Levin B, Brooks D, Smith RA, et al. Emerging technologies in screening for colorectal cancer: CT colonography, immunochemical fecal occult blood tests, and stool screening using molecular markers. *CA Cancer J Clin* 2003;53:44-55.
26. Smith RA, von Eschenbach AC, Wender R, et al. American Cancer Society guidelines for the early detection of cancer: update of early detection guidelines for prostate, colorectal, and endometrial cancers. Also: update 2001: testing for early lung cancer detection. *CA Cancer J Clin* 2001;51:38-75; quiz 77-80.
27. Levin B, Lieberman DA, McFarland B, et al. Screening and surveillance for the early detection of colorectal cancer and adenomatous polyps, 2008: a joint guideline from the American Cancer Society, the US Multi-Society Task Force on Colorectal Cancer, and the American College of Radiology. *CA Cancer J Clin* 2008;58:130-60.
28. Whitlock EP, Lin JS, Liles E, et al. Screening for colorectal cancer: a targeted, updated systematic review for the U.S. Preventive Services Task Force. *Ann Intern Med* 2008;149:638-58.
29. Gluecker T, Dorta G, Keller W, et al. Performance of multidetector computed tomography colonography compared with conventional colonoscopy. *Gut* 2002;51:207-11.
30. Pineau BC, Paskett ED, Chen GJ, et al. Virtual colonoscopy using oral contrast compared with colonoscopy for the detection of patients with colorectal polyps. *Gastroenterology* 2003;125:304-10.
31. Johnson CD, Toledano AY, Herman BA, et al. Computerized tomographic colonography: performance evaluation in a retrospective multicenter setting. *Gastroenterology* 2003;125:688-95.
32. Fidler JL, Johnson CD, MacCarty RL, et al. Detection of flat lesions in the colon with CT colonography. *Abdom Imaging* 2002;27:292-300.
33. Pickhardt PJ, Nugent PA, Choi JR, et al. Flat colorectal lesions in asymptomatic adults: implications for screening with CT virtual colonoscopy. *AJR Am J Roentgenol* 2004;183:1343-7.
34. Park SH, Lee SS, Choi EK, et al. Flat colorectal neoplasms: definition, importance, and visualization on CT colonography. *AJR Am J Roentgenol* 2007;188:953-9.
35. Pickhardt PJ, Taylor AJ. Extracolonic findings identified in asymptomatic adults at screening CT colonography. *AJR Am J Roentgenol* 2006; 186:718-28.
36. Kim YS, Kim N, Kim SY, et al. Extracolonic findings in an asymptomatic screening population undergoing intravenous contrast-enhanced computed tomography colonography. *J Gastroenterol Hepatol* 2008; 23:e49-57.
37. Pickhardt PJ, Kim DH, Taylor AJ, et al. Extracolonic tumors of the gastrointestinal tract detected incidentally at screening CT colonography. *Dis Colon Rectum* 2007;50:56-63.
38. Kim DH, Pickhardt PJ, Taylor AJ, et al. CT colonography versus colonoscopy for the detection of advanced neoplasia. *N Engl J Med* 2007;357: 1403-12.
39. Zalis ME, Barish MA, Choi JR, et al. CT colonography reporting and data system: a consensus proposal. *Radiology* 2005;236:3-9.
40. Rockey DC, Barish M, Brill JV, et al. Standards for gastroenterologists for performing and interpreting diagnostic computed tomographic colonography. *Gastroenterology* 2007;133:1005-24.
41. Akerkar GA, Yee J, Hung R, et al. Patient experience and preferences toward colon cancer screening: a comparison of virtual colonoscopy and conventional colonoscopy. *Gastrointest Endosc* 2001; 54:310-5.
42. Bosworth HB, Rockey DC, Paulson EK, et al. Prospective comparison of patient experience with colon imaging tests. *Am J Med* 2006;119:791-9.
43. Svensson MH, Svensson E, Lasson A, et al. Patient acceptance of CT colonography and conventional colonoscopy: prospective comparative study in patients with or suspected of having colorectal disease. *Radiology* 2002;222:337-45.
44. Schwartz DC, Dasher KJ, Said A, et al. Impact of a CT colonography screening program on endoscopic colonoscopy in clinical practice. *Am J Gastroenterol* 2008;103:346-51.

45. Pickhardt PJ. Incidence of colonic perforation at CT colonography: review of existing data and implications for screening of asymptomatic adults. *Radiology* 2006;239:313-6.
46. Brenner DJ, Georgsson MA. Mass screening with CT colonography: should the radiation exposure be of concern? *Gastroenterology* 2005;129:328-37.
47. Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. *N Engl J Med* 2007;357:2277-84.
48. Burling D, Halligan S, Slater A, et al. Potentially serious adverse events at CT colonography in symptomatic patients: national survey of the United Kingdom. *Radiology* 2006;239:464-71.
49. Sosna J, Blachar A, Amitai M, et al. Colonic perforation at CT colonography: assessment of risk in a multicenter large cohort. *Radiology* 2006;239:457-63.
50. Hara AK, Johnson CD, Reed JE, et al. Reducing data size and radiation dose for CT colonography. *AJR Am J Roentgenol* 1997;168:1181-4.
51. Iannaccone R, Laghi A, Catalano C, et al. Feasibility of ultra-low-dose multislice CT colonography for the detection of colorectal lesions: preliminary experience. *Eur Radiol* 2003;13:1297-302.
52. Vogt C, Cohnen M, Beck A, et al. Detection of colorectal polyps by multislice CT colonography with ultra-low-dose technique: comparison with high-resolution videocolonoscopy. *Gastrointest Endosc* 2004;60:201-9.
53. Pickhardt PJ. Screening CT colonography: how I do it. *AJR Am J Roentgenol* 2007;189:290-8.
54. Butterly LF, Chase MP, Pohl H, et al. Prevalence of clinically important histology in small adenomas. *Clin Gastroenterol Hepatol* 2006;4:343-8.
55. Rex DK, Lieberman D. ACG colorectal cancer prevention action plan: update on CT-colonography. *Am J Gastroenterol* 2006;101:1410-3.
56. Knechtges PM, McFarland BG, Keysor KJ, et al. National and local trends in CT colonography reimbursement: past, present, and future. *J Am Coll Radiol* 2007;4:776-99.
57. Hur C, Chung DC, Schoen RE, et al. The management of small polyps found by virtual colonoscopy: results of a decision analysis. *Clin Gastroenterol Hepatol* 2007;5:237-44.
58. Pickhardt PJ, Hassan C, Laghi A, et al. Small and diminutive polyps detected at screening CT colonography: a decision analysis for referral to colonoscopy. *AJR Am J Roentgenol* 2008;190:136-44.
59. Pickhardt PJ, Hassan C, Laghi A, et al. Cost-effectiveness of colorectal cancer screening with computed tomography colonography: the impact of not reporting diminutive lesions. *Cancer* 2007;109:2213-21.
60. Vijan S, Hwang I, Inadomi J, et al. The cost-effectiveness of CT colonography in screening for colorectal neoplasia. *Am J Gastroenterol* 2007;102:380-90.
61. Hur C, Gazelle GS, Hsu EH, et al. The effect of prior colonic imaging on endoscopic productivity: potential impact of computed tomographic colonography. *Clin Gastroenterol Hepatol* 2005;3:1124-7.
62. American College of Radiology. ACR practice guidelines for performing and interpreting diagnostic computed tomography. Reston (Va): American College of Radiology; 2006.

Prepared by:
ASGE TECHNOLOGY COMMITTEE
Francis A. Farraye, MD, MSc
Douglas G. Adler, MD
Bipan Chand, MD
Jason D. Conway, MD
David L. Diehl, MD
Sergey V. Kantsevov, MD
Richard S. Kwon, MD
Petar Mamula, MD, NASPGHAN representative
Sarah A. Rodriguez, MD
Raj J. Shah, MD
Louis Michel Wong Kee Song, MD
William M. Tierney, MD, Committee Chair

This document is a product of the ASGE Technology Committee. This document was reviewed and approved by the governing board of the American Society for Gastrointestinal Endoscopy.
