CT Colonography (Virtual Colonoscopy): Technique, Indications and Performance

Arye Blachar a  Jacob Sosna b

a Departments of Radiology, Tel Aviv Sourasky Medical Center, Tel Aviv, Israel, and University of Pittsburgh Medical Center, Pittsburgh, Pa., USA; b Departments of Radiology, Hadassah Hebrew University Medical Center, Jerusalem, Israel, and Beth Israel Deaconess Medical Center, Boston, Mass., USA

Key Words
Colorectal cancer · Colonoscopy · CT colonography · Colorectal polyps · Electronic bowel cleansing

Abstract
Worldwide, colorectal cancer is the third most frequent cancer occurring in both sexes. Screening programs for early detection enable detection of tumors at an earlier stage and have been shown to reduce death rate. Currently, colonoscopy is the investigation of choice for colorectal cancer screening and for investigation of patients with suspected colorectal cancer. However, colonoscopy remains an invasive technique requiring anesthesia, with a risk of perforation and bleeding. In addition, even experienced colonoscopists may be unable to complete the colonoscopy due to multiple reasons such as severe diverticulosis, stricture, obstructing mass, or fixation of colonic loops. CT colonography, also known as virtual colonoscopy, is a relatively new technique that is becoming increasingly popular. The technical aspects, indications, advantages and diagnostic performance of this technique are briefly reviewed.

CT Colonography, Background and Rationale
Colorectal cancer is the second leading cause of cancer mortality in the United States accounting for approximately 10% of all cancer deaths in both men and women combined [1, 2]. The adenoma carcinoma sequence refers to the process of transformation of small adenomas into large adenomas, then into noninvasive carcinoma and finally into invasive carcinoma, through a series of genetic mutations. Colorectal cancer is a curable disease if detected early and may be prevented if precursor adenomas are detected and removed.

Regular colon cancer screening has been recommended by the medical community for all individuals over 50 years of age and for individuals over 40 years of age with a significant family history of colorectal cancer or other risk factors. Screening programs using fecal occult blood test, flexible sigmoidoscopy, conventional colonoscopy and double-contrast barium enema have reduced the mortality from colorectal cancer [3]. The goal of these programs is to interrupt the adenoma–carcinoma progression by identifying and removing small polyps before they become malignant as most carcinomas arise from pre-existing adenomas [3]. Mortality is reduced in screening populations thanks to early detection of malignant lesions and identification and removal of premalignant lesions. Screening for colorectal cancer is cost-effective, but a single optimal strategy has not yet been determined [4].
Until recent years, only conventional colonoscopy and double-contrast barium enema have been used for evaluation of the whole colon [5]. Conventional colonoscopy is considered to be highly sensitive and specific for the detection of colonic neoplasia, but it is not perfect and some lesions may be missed. In the study of Rex et al. [6], the miss rates were 6% for adenomas 10 mm and larger in diameter, 13% for adenomas 6–9 mm in diameter and 27% for adenomas 5 mm and smaller in diameter. In addition, conventional colonoscopy may be associated with serious complications when used as a screening tool in an average-risk population, limiting its acceptance as a broad-based screening test [3]. The aim of colonoscopy is to completely evaluate the colon and to reach the cecum, but this is not always possible. Even experienced colonoscopists may be unable to complete the colonoscopy due to multiple reasons such as severe diverticulosis, stricture, obstructing mass, or fixation of colonic loops due to adhesions after surgery. In addition, performing colonoscopy requires discontinuation of oral anticoagulation treatment that may not be advisable to some patients. The need for sedation coupled with substantial costs associated with conventional colonoscopy may make this method of screening less attractive in the large average-risk population above the age of 50. Recent studies show that double-contrast barium enema has a poor sensitivity with detection rates as low as 48% for polyps and adenomas larger than 1.0 cm [7].

CT Colonography (Virtual Colonoscopy)

CT colonography (CTC), also known as virtual colonoscopy, is a technique that uses data generated from CT imaging of the fully prepared and gas-distended colon to generate two-dimensional (2D) and three-dimensional (3D) images of the colon. It was first reported by Vining and Gelfand in 1994 [8] as a rapid, noninvasive imaging method to investigate the colon and rectum. With the advent of multi-detector CT and CT software, volumetric data of the entire colon are acquired in a few seconds of CT scanning with a total of 10–20 min of examination time. Assessment of the colon requires assessment of the 2D (axial and coronal planes) and 3D images which also includes endoluminal navigation of the colon. Since the advent of CTC, it has been regarded as a potential alternative technique to conventional colonoscopy for the detection of colorectal polyps and cancers.

Current Indications for CTC

Failed or Incomplete Colonoscopy

CTC can be performed following incomplete colonoscopy [9–12] that occurs in 5–15% of studies due to obstructing colorectal lesions or technical reasons such as a long and tortuous colon, or patient’s discomfort [13]. CTC has the ability to complete the colon evaluation as well as identify the cause of endoscopic failure in a large percentage of cases [9]. In cases of occlusive carcinoma, CTC can detect synchronous carcinomas [9, 10], which occur in about 5% of cases [14]. In a very recent article [10], CTC depicted 88 endoscopically nonvisualized lesions of 6 mm or larger, including 12 masses greater than 20 mm. Intravenous contrast can add information about local tumor invasion and regarding metastatic spread [15].

Contraindication to Endoscopic Colonoscopy

Some patients that require colonoscopy can not have the procedure due to various reasons such as: severe comorbidity, advanced age, bleeding disorders, very tortuous colon, prior allergic reaction to sedation, etc. These patients may benefit from CTC.

Patients’ Refusal to Colonoscopy

Some patients that require colonoscopy refuse to have the procedure due to lack of information or fear and may agree to have CTC.

Extrinsic Compression of the Colon on Colonoscopy

A patient that underwent a complete colonoscopy that demonstrated suspected extrinsic compression on the colon may undergo CTC. The reason for the extrinsic compression (adjacent spleen, liver impression or distended bowel loops) may be demonstrated on the 2D images.

Screening for Colorectal Cancer

Although CTC is a promising technique, it has not yet been approved for colorectal screening in large-scale populations. In the near future, it may provide a rapid safe and effective screening test to screen the colon for neoplasia.

Patient Preparation for CTC Examination

Thorough bowel preparation is mandatory for an accurate CTC examination, since residual stool and large amounts of residual fluid may obscure small polyps and...
adherent stool may mimic a polyp or mass. Contrary to endoscopic colonoscopy, residual feces and fluid cannot be aspirated. A well-prepared, well-distended colon reduces interpretation time as well as false-positive findings. Patients undergo bowel preparation for 24–48 h prior to the procedure using various products available on the market consisting of either a common barium enema preparation (magnesium citrate, bisacodyl tablets, cleansing enemas or suppositories) or a balanced polyethylene glycol (GoLYTELY; Braintree Laboratories, Braintree, Mass., USA) solution. A phospho-soda preparation is more commonly used since it is reported to result in significantly less residual fluid than a polyethylene glycol electrolyte solution preparation and is therefore less likely to obscure small polyps [16]. The use of spasmolytic agents such as glucagon to prevent collapse and spasm of the colon is controversial and usually avoided since it has been reported by some authors [17] to have no beneficial effect and may also lead to unwanted reflux of air into the ileum through the ileocecal valve.

Fecal and fluid tagging is a promising technique that is becoming more popular. It may be performed with or without electronic bowel cleansing. The patient ingests small amounts of barium or iodinated oral contrast with meals prior to CTC. The high attenuation contrast incorporates within the residual stool facilitating differentiation from polyps. When electronic bowel cleansing techniques are used (‘digital cleansing’), a prep-less CTC examination may be performed. The high-attenuation-tagged stool is segmented from the data leaving only the colonic mucosa and filling defects attributed to polyps and cancerous masses [18]. Barium suspension given six to seven times over the course of 48 h prior to CTC has been reported to tag 80–100% of the stool and demonstrated good results for polyp detection without bowel cleansing [19]. In a recent study, the sensitivity and specificity of fecal-tagged CTC for the detection of colorectal polyps 10 mm and larger was reported to be 100% [20]. However, fecal tagging may sometimes obscure colorectal lesions, especially if large amounts of fecal residue are present and no electronic cleansing techniques are available [21].

It is clear that there is tremendous potential for using CTC as a screening study if limited bowel preparation is used, reducing patient discomfort associated with traditional cleansing techniques and resulting in an improved perception of the screening study [20]. However, currently, fecal tagging is used as an addition to the standard preparation and prep-less CTC is not commercially performed.

**CTC Examination Technique**

Patients are placed in the right lateral decubitus position on the CT table, a small catheter is inserted into the rectum and using a plastic bulb connected to the rectal catheter, room air, or CO₂, is gently insufflated into the colon. The amount of air or CO₂ that is insufflated is determined by patient tolerance, or by pressure-sensitive insufflator monitors that stop the insufflation once threshold pressure has been achieved (PROTO₂L, E-Z-EM, Inc., Westbury, N.Y., USA). Although many centers use room air since colonic distension is easily and reliably achieved with atmospheric air, carbon dioxide is becoming increasingly popular and is considered to be more comfortable, due to the more rapid absorption of CO₂ through the colon wall and blood causing less cramping after the procedure [22–24]. Adequate distension is crucial for accurate assessment of the colon as polyps may be obscured in collapsed bowel segments.

After the colon is insufflated, a CT scout image is obtained in the supine position to assess the degree of colonic distension. The patient is scanned in the supine position and then turned onto the prone position. A CT scout image is again obtained to assure that colonic distension is still adequate and the study is then completed. Dual positioning has been shown to improve colonic distension allowing confirmation of suspected findings [25] and to increase detection of colonic polyps ≥5 mm by approximately 15% compared with supine positioning alone [23, 26].

**CTC Technical Aspects**

CTC can be performed using a single or multi-detector CT scanner with the acquisition of volumetric data from the entire colon. The new multi-detector CT scanners allow 4–64 sections to be obtained in a single rotation of the X-ray tube enabling fast scanning, and shorter acquisition time, resulting in less motion artifacts due to breathing and bowel peristalsis and significantly improved demonstration of the colon compared with single-detector row CT [27]. Using the multi-detector scanners, the colon is usually scanned using a section thickness of 1–2 mm compared to 5 mm or more using single-detector CT scanners. Thinner scanning results in near isotropic data (data with equal resolution in all imaging planes), allowing excellent coronal, sagittal and endoluminal images. No significant differences in the detection of polyps larger than 10 mm has been demon-
strated between single- and multi-detector row CT [27]; however, evaluation of thinner slices improves diagnostic performance. Thicker slices were found to be inadequate for the evaluation of small polyps [28].

Intravenous contrast is not routinely used, although it has been shown to significantly improve readers’ confidence, colonic wall conspicuity, and depiction of subcentimeter colorectal polyps [29]. However, the added value of administration of intravenous contrast material in colonic depiction has been modest. Intravenous administration of contrast material may rarely be associated with serious allergic reactions, but minor reactions are not uncommon (3–4% of patients). In addition, there is an associated increase in cost and substantial increase in examination time. Intravenous contrast is therefore mostly used for problem solving in selected groups of patients, including those who have suboptimally prepped colon seen during initial scanning in the supine position. It is also used in patients who have colonic masses, for assessment of pericolic spread, lymphadenopathy and distant metastases.

**CTC and Radiation**

The lifetime risk of developing fatal cancer as a result of ionizing radiation exposure is estimated by the International Commission on Radiological Protection, or ICRP, to be approximately 5% per Sievert [30]. Because of the long latency period, radiation-induced cancer death becomes less probable the older the radiated person is. The targeted population for CTC is 50 years of age and older. The ICRP data indicate that the probability of inducing fatal cancer in this age group is approximately 2.5% per Sievert, and at the age of 70, the risk is half this value. The effective dose of CTC is estimated at about 8.8 mSv (range 4–12 mSv) and carries a risk of 0.02% in a 50-year-old individual and is lower for older patients [31]. In order to minimize the dose, efforts have been made to adapt the tube current to the minimum accepted dose while not diminishing study performance. No change was reported in the diagnostic efficacy when lowering the tube current from 140 to 70 mA using single-detector CT [32] and multidetector CT [31]. Low-dose CTC was shown to have excellent sensitivity and specificity for detection of colorectal neoplasms 10 mm and larger [33]. The performance of CTC using an ultra-low radiation dose of 10 mAs has been shown to compare favorably with conventional colonoscopy in the detection of polyps larger than 6 mm with markedly decreased performance for small polyps of 5 mm or smaller [34]. The reduction in tube current has been shown to result in more noise with degradation of image quality. However, it has recently been shown [35] that combined x-, y- and z-axis tube current modulation leads to significant reduction of radiation exposure without loss of image quality.

**Interpretation of CTC Examinations**

Acquired CT data are transferred onto a dedicated postprocessing workstation, equipped with navigator software, permitting the radiologist to obtain multiplanar reformations (MPR, 2D), as well as to construct an endoluminal model of the air-distended colon (3D model). The endoluminal model allows fly through capabilities in the distended colon enabling viewing of the distended colonic lumen, in both the antegrade and retrograde directions. Some navigator software also allows ‘virtual dissection’, or ‘filet mode evaluation’ of the colon, where the colon is divided along its long axis and is opened for display, giving a panoramic view of the details of the colonic lumen (fig. 1, 2). This feature gives CTC an important advantage over endoscopic colonoscopy, overcoming the presence of blind areas due to haustral folds in both forward and reverse views, thereby reducing the chances of missing polyps. We find this feature to be extremely useful. Most workstations allow simultaneous viewing of the 3D and 2D images and also provide a 3D map of the colon, indicating the position along the colon of the area being viewed. There is usually an option that enables locating a suspected pathology simultaneously, on all views and reconstructions.

There are two primary techniques for data interpretation: a primary 2D approach and a primary 3D approach, where the 2D or 3D images, respectively, are evaluated primarily with the alternative views used as a problem-solving tool [36, 37]. In 2D imaging, the colon is ‘tracked’ from the rectum to the cecum using the supine and prone axial images that can usually be displayed adjacent to each other. Images are viewed in suitable windows for viewing the colonic wall and polyps and then in abdominal windows for evaluation of flat polyps, circumferential colonic masses and extra-colonic findings in the abdominal and pelvic organs. In 3D viewing, the radiologist ‘flies through’ the colon using the reconstructed 3D model.

Residual fecal material may simulate polyps. Three signs may allow distinction of fecal material from polyps: mobility, lesion morphology and internal attenuation.
Fecal material is usually mobile, although this sign must be interpreted with caution since the colon segments are mobile and pedunculated polyps may also be mobile. Polyps may be sessile pedunculated or flat, and are usually visualized as round, oval or bilobed lesions with well-delineated contour. Fecal material exhibits commonly a geometric form with irregular sides that change between the two scans. Internal attenuation of polyps is usually homogeneous, lacking internal gas or areas of high attenuation typical of fecal material.

A typical CTC study produces 700–1,200 axial CT images as well as multi-planar reconstructions and 3D views. The evaluation of this large data requires considerable time and effort. Computer-aided detection of polyps...
may reduce radiologists’ interpretation time, as well as increase the diagnostic accuracy of polyp detection. Current methods of computer-aided detection generally rely upon shape-based algorithms to localize potential polyps [38, 39]. One of the drawbacks of this technique is the possible large number of false-positive lesions. Additional filters can be applied to minimize their number to an acceptable level of 2.5 false-positive findings per patient [39], and it is likely that better results will be obtained in the future.

**CTC Performance: How Good Is It?**

Multiple studies have documented the ability of CTC to detect patients with polyps greater than 10 mm in size with sensitivities ranging from 50 to 100% [10, 21, 23, 27, 40–50]. The wide range in sensitivity for the detection of polyps may be explained by significant differences in the techniques used in data acquisition and analysis [51–53] and by the readers’ expertise. The sensitivities for polyps 6–9 mm are lower reaching 60–70%. The performance of CTC for small polyps less than 6 mm in size is poor, but from a clinical perspective these are the least important lesions. Based on available results, CTC seems to have an excellent specificity record (false-positive results of up to 10%) with specificity for polyps larger than 10 mm of 90–95% [40–50]. Recent meta-analyses [54, 55] showed a pooled per patient (finding a patient with polyps irrespective of the number of polyps found) sensitivity and specificity for polyps 10 mm or larger of 88 and 95, and 84 and 65% pooled per patient sensitivity for polyps 6–9 mm and 5 mm or smaller, respectively. Another recent meta-analysis [56] evaluating 4,181 patients showed an even higher per patient sensitivity and specificity for polyps 10 mm and larger of 93 and 97%, respectively. The sensitivity and specificity decreased to 86% when medium-sized polyps were included. The sensitivity for detection of cancer was 96% with 144 of 150 tumors detected. It is clear that the performance of CTC in detection of polyps is improving as the technology and experience of radiologists’ progress.

The pitfalls of CTC are beyond the scope of this review. It is important to realize that although CTC is a powerful tool for colonic polyp and tumor detection, there are many pitfalls for misdiagnosis. These include: (1) technical errors: due to suboptimal patient preparation with a large amount of residual stool or fluid, under distension or spasm of the colon, respiratory and metallic artifacts, image noise; (2) pitfalls related to evaluation technique such as incorrect window settings, 3D threshold values; (3) pitfalls related to reading such as failure to detect lesions and misinterpretation of findings [57].

When considering the performance of CTC as a possible screening technique for colorectal cancer [58], it must be remembered that most reported clinical studies comparing CTC to conventional colonoscopy have included high-risk patients. This may result in an increased positive predictive value due to the higher prevalence associated with this population in comparison with a screening population where the prevalence of disease is lower. It must also be remembered that conventional colonoscopy is not perfect as 6% of polyps can be missed [59]. Therefore the comparison of CTC is not with another perfect technique but rather with one that is about 95% sensitive for polyps larger than 10 mm. The new developments in data acquisition, as well as faster and more accurate image interpretation and better residual stool and fluid tagging techniques, will likely improve results, reduce cost and provide a rapid, safe, reasonably convenient method for colon cancer screening.

An important advantage of CTC over conventional colonoscopy is the ability of CTC to evaluate extra-colonic structures such as the lung bases, the abdomen and the pelvis. The frequency of extracolonic findings at CTC varies between 11 and 15% [60, 61], but only 3–5% of these findings are clinically important. It is therefore important for the radiologist to make an assessment of the importance of these findings and to avoid excessive caution and ambiguity when describing findings that are almost certainly benign. Hara et al. [61] found that in 7% of patients further examinations were performed and nearly 2% of patients had abnormalities requiring surgical intervention.

**Complications**

Until recently, it was thought that the only complications of CTC were mild to moderate abdominal discomfort due to the colonic insufflation and radiation exposure. Two articles published recently [62, 63] that evaluated large patient cohorts of 11,870 and 17,067 patients, respectively, reported a risk of colonic perforation during CTC of 0.06–0.08%. Older age and underlying concomitant colonic disease such as inguinal hernia containing the colon, severe diverticulitis and obstructing colonic mass were present in most patients with perforation [62].
Conclusion

CTC is a fast, safe, rapidly evolving examination that is accurate in detecting clinically significant colorectal polyps. The specificity and sensitivity of CTC are improving with time and are excellent for detection of colorectal tumors and polyps larger than 10 mm. Further improvement of this newly emerged technique may be expected with the introduction of techniques undergoing development, including computer-aided diagnosis, as well as better fecal tagging with electronic cleansing of the bowel, eliminating bowel preparation.

Disclosure Statement

None.

References

32 Har A, Johnson CD, Reed JE, et al: Reducing data size and radiation dose for CT colo

40 Digestion 2007;76:34–41

Blachar/Sosna


