Performance and Interpretation of CTC

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Introduction

It has been almost 30 years since Coin proposed that computed tomography (CT) scanning had the potential to be used as a screening tool for the detection of colonic polyps [1]. Yet it was not until 1994 that Vining and coworkers were able to employ the new technology of spiral/helical CT and modern computer graphics, catalyzing extensive research and clinical efforts that molded the field that we now call CT colonography (CTC) or "virtual colonoscopy." [2] Owing to these efforts, reasonable consensus now exists on the optimal means by which to prepare the patient, acquire the CT data, and interpret the resulting images, though some healthy debates do persist. The goal of this chapter is to describe these technical factors in CTC and to give the reader a perspective on current techniques and alternatives. We review the best evidence for current practices and recommendations. With this information, we hope the reader will have a thorough understanding of what is required to set up a high-quality clinical operation for performance of CTC.

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Bowel Preparation

Background

Technical success in CTC starts with an adequate bowel preparation. A multitude of software tools available on CTC workstations are aimed at minimizing the impact that residual fecal material makes on diagnostic performance. Yet, as any experienced interpreter of CTC will admit, a clean colon makes the job of interpretation immeasurably easier, improves confidence, and ultimately improves performance. This "low-tech" approach will produce results that no presently available computer can replicate.

Adherent stool is the most common cause of false-positives at CTC [3]. It can also lead to false-negative diagnoses, as retained liquid and stool can obscure lesions, especially small ones. Interpretation times are prolonged when a large number of potential lesions must be interrogated and documented [4]. If CTC patients are to be offered same-day optical colonoscopy (OC) for a positive finding, they will have to have completed a full bowel preparation [5]. At this time, CTC bowel cleansing regimens are quite similar to those used at OC.

Diet

Solid food and fiber restriction are as essential as laxatives to an effective bowel preparation regimen.

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Dietary fiber is resistant to enzymatic hydrolysis and to bacterial breakdown [6, 7], and whole seeds and grains can mimic polyps [8]. A low-fiber diet has been proven to improve fecal tagging at CTC [8]. We prescribe a diet free of seeds and nuts for 7 days and a clear liquid diet the entire day before the CTC. Patients are told not to eat or drink anything from midnight until the time of their examination.

Pharmacologic Cathartics

The optimal laxative preparation for CTC has been examined extensively and has been the subject of much debate. Many agents and combinations of agents have been tested, with the goals of balancing strength and safety, with emphasis placed on patient comfort and tolerance [9]. For purposes of discussion, available laxatives have been distinguished as "dry preps" (sodium phosphate and magnesium citrate) and "wet preps" (polyethylene glycol).

The distinction between dry and wet preps is their mechanism of catharsis. Sodium phosphate and magnesium citrate preparations are low-volume, hyperosmotic formulations that induce osmotic catharsis by drawing water into the colonic lumen from the intravascular compartment. Polyethylene glycol (PEG) is a high-volume, isoosmotic, nonabsorbable preparation that causes a washout lavage. It does not cause significant fluid shifts from the intracellular to the extracellular space. These three agents were used in the American College of Radiology Imaging Network (ACRIN) trial [10], of which a recently performed retrospective analysis demonstrated that the sensitivity and specificity for detecting colon polyps ≥6 mm and ≥1 cm did not significantly differ between bowel preparations [5]. Nevertheless, it is pertinent to review their differences.

Sodium Phosphate

Oral sodium phosphate (OSP) products include the prescription Visicol and OsmoPrep [11]. Fleets Phospho-soda® was an over-the-counter sodium phosphate preparation offered without prescription. However, it was recalled in 2009 over concerns phosphate-induced nephropathy, as discussed below [12]. Onset to catharsis was approximately 1 h. Four 10-mg bisacodyl tablets were also typically taken orally in the evening after the sodium phosphate was finished. In 2007, Kim found that a single dose (45 mL) was just as effective as a double dose (90 mL) [13]. Sodium phosphate also comes in pill form, which can be taken with any clear liquid, bypassing the problem of its considerably salty taste [14].

There have been many studies over the years comparing the efficacy of sodium phosphate to PEG. 45 mL of sodium phosphate has been reported in some studies to be superior to PEG in the amount of residual fluid, efficacy of cleansing, patient preference, and compliance [15–19]. Some studies have demonstrated that PEG is better than sodium phosphate [20]. However, in two meta-analyses, the larger of which analyzed 24 studies, there was no significant difference in quality of bowel preparation between sodium phosphate and PEG [16, 21].

More recently, retrospective analysis of the ACRIN trial data showed that sodium phosphate had the best patient compliance, the least residual stool, and highest reader confidence versus PEG for examinations with polyps. It was also the most commonly prescribed cathartic [5]. However, as stated earlier, the sensitivity and specificity for polyp detection did not differ between preparations, illustrating that reader performance does not always correlate with measures of compliance, residual stool, or reader confidence [5].

The routine use of sodium phosphate has come under scrutiny due to its history of causing serious fluid and electrolyte abnormalities [22]. Patients may become dehydrated and develop hypernatremia, hypokalemia, hypophosphatemia, and hypocalcemia [23, 24]. Metabolic acidosis, tetany, and even death have been reported [25, 26]. Additionally, rare cases of acute phosphate nephropathy have been reported. Acute phosphate nephropathy, associated with renal tubular calcium-phosphate crystal deposition, may result in permanent renal insufficiency,

sometimes requiring dialysis [11]. The risk of acute phosphate nephropathy appears to be related to factors such as advanced age, hypovolemia, baseline renal insufficiency, slow bowel transit time, colonic mucosal injury from colitis, or the use of nephrotoxic medications such as diuretics, angiotensin converting enzyme (ACE) inhibitors, and angiotensin receptor blockers (ARBs) [11, 12, 22]. The Food and Drug Administration (FDA) has required the manufacturer of Visicol and OsmoPrep, the two remaining prescription-only OSPs, to add a boxed warning to their labeling [11, 12]. Following that, Fleet recalled its over-the-counter sodium phosphate products.

Some CTC programs have screening questionnaires to triage at-risk patients away from sodium phosphate. However, such systems are imperfect as one study showed that as many as 2% of patients with a contraindication to sodium phosphate could not have been identified, and thus excluded, on the basis of their clinical history alone [27]. Many CTC programs have thus decided to abandon its use. If used, however, the manufacturers have advised that the dose be restricted or split and that the patient drink sufficient liquids [22].

Magnesium Citrate

Magnesium citrate is available over-the-counter in liquid form. The liquid comes in a 10-oz (296-mL) bottle, ready to drink. Like sodium phosphate, magnesium citrate is taken in the late afternoon, and bisacodyl tablets are taken the night before the exam. Time to onset of catharsis is around 1 h. Oral hydration should be maintained to prevent dehydration [12]. Magnesium citrate is preferred to sodium phosphate in patients with underlying medical conditions, given its lower sodium content, decreased incidence of electrolyte disturbances, and higher therapeutic index [9, 12, 28].

There are fewer studies in the literature comparing magnesium citrate to sodium phosphate or PEG than there are comparing the latter two with each other. In a 2005 study by Delegge et al. 506 patients undergoing optical colonoscopy (OC) were randomized to receive either a magnesium citrate (LoSo Prep, containing magnesium citrate, bisacodyl tablets, and a bisacodyl suppository) or sodium phosphate-based prep (double dose sodium phosphate). The group that received magnesium citrate demonstrated superior colon cleansing and the frequency of reported side effects was similar for both groups (59% vs. 58% for sodium phosphate and Neutra prep/LoSo prep, respectively) [9]. A 2010 study comparing sodium phosphate and magnesium citrate showed that residual stool and fluid were comparable, but the attenuation of tagged fluid was closer to optimal with magnesium citrate, potentially increasing lesion conspicuity [29]. Interestingly, although magnesium citrate is classified as a "dry prep," analysis of the ACRIN trial data showed that magnesium citrate was associated with significantly more residual fluid compared with both PEG and sodium phosphate [5]. Our program exclusively uses magnesium citrate, given as a double dose (296 mL×2), except in those patients who require 2-day bowel prep, in whom PEG is added to the regimen.

Polyethylene Glycol

Several formulations of PEG are available by prescription, as well as over-the-counter. Bowel preparation with PEG is usually performed by drinking 4 L of the electrolyte solution, containing 236 g of PEG, on the afternoon before the CTC. Although widely used for OC preparation, PEG has increasingly fallen out of favor for use in CTC. PEG preparation frequently leaves liquid in the colon, which is suctioned at OC without difficulty, but potentially obscures lesions at CTC [17]. It also has the poorest compliance of the preparations, due to its taste and consistency, as well as the daunting volume. At one experienced center, PEG accounts for less than 1% of CTC preparations [30].

Side effects with PEG are not as alarming as with sodium phosphate, since PEG has the benefit of not causing significant fluid shifts and it is safer for those susceptible to such effects [31]. However, it too can potentially lead to electrolyte

disturbances, albeit to a lesser extent. Reported adverse events attributable to oral PEG generally reflect sodium imbalance, gastrointestinal injury caused by vomiting, allergic reactions, and aspiration [22]. Interestingly, three meta-analyses showed that there were no significant differences in adverse events between sodium phosphate and PEG, suggesting that, although the adverse events may be different, PEG may not be any safer [16, 18, 21].

As discussed above, trials examining the relative efficacies of sodium phosphate versus PEG have yielded varying results. A study performed on a population with a high-residue diet showed better colonic cleansing and shorter CTC interpretation times with a PEG-based preparation compared to the sodium phosphate-based preparation [20]. However, most studies have shown that sodium phosphate is superior to PEG in residual fluid, cleansing, patient preference, and compliance [15–19]. Yet, two meta-analyses, the larger of which analyzed 24 studies, found no significant difference in quality of bowel preparation between sodium phosphate and PEG [16, 21]. More recently, retrospective analysis of the ACRIN trial data showed that the sensitivity and specificity for polyp detection did not differ between preparations [5].

The majority of patients experience inconvenience and discomfort, no matter what type of bowel preparation is used [32, 33]. Reduced, limited cathartic, or noncathartic CTC with fecal tagging has the potential to do away with the most burdensome part of the examination.

Special Considerations

For those patients referred to CTC with history of poor bowel preparation, diabetes, or neuromuscular disorders, special attention must be paid to the type of prep prescribed. In this instance, a 2-day prep should be considered. The patient is kept on a low-fiber, clear-liquid diet for 2 days prior to the examination, instead of just the day before. Two days before the examination, the patient drinks 4 L of PEG. The following day, they undergo the standard bowel preparation with magnesium citrate and fecal tagging agents. We do not consider diverticulosis an indication for a 2-day bowel preparation, as this has been shown not to impair good bowel cleansing [34].

Fecal and Fluid Tagging

Background

Fecal tagging is the norm in CTC [32, 33, 35]. High-density oral contrast agents are typically ingested the day before the examination. Any residual feces and fluid mix with the contrast media so that they become homogeneously high in attenuation and are therefore easily differentiated from soft tissue density polyps or masses (Figs. 5.1 and 5.2) [36]. Tagging is thought to help improve the performance of CTC for polyp detection [37, 38]. The optimal tagging density in phantom studies has been shown to be 700 Hounsfield units and greater [39]. Higher attenuation may result in more artifacts and can decrease lesion conspicuity (Fig. 5.3) [29]. Fecal tagging underpins the ability to perform CTC without (or with less) bowel preparation, so-called "reduced cathartic" or "noncathartic" bowel preparation, discussed below. Many different contrast agents and combinations of agents have been used for fecal tagging [33, 40–45]. There are two main classes tagging agents: barium-based and iodine-based (both ionic and nonionic).

Barium

Also used in standard abdominal CT scanning, barium formulations are generally safe and are familiar to radiologists. Various densities of barium-based agents (e.g., Tagitol V 40% W/V; E-Z CAT 2% W/V.; Bracco Diagnostics) have been advocated [33]. Tagging protocols utilizing barium alone have been found to be effective [38, 46, 47]. Lower concentrations of barium, when used alone, may not have high enough attenuation to be helpful. In general barium agents are given in combination with iodinated contrast.

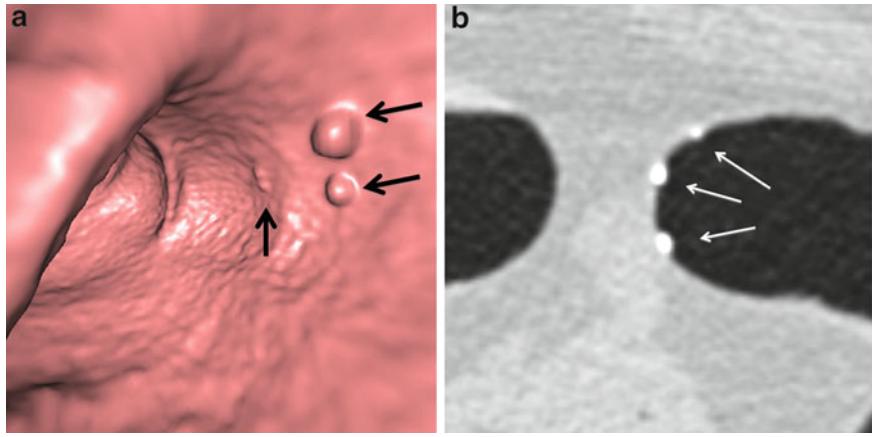

Fig. 5.1 A cluster of densely tagged stool can have the appearance of small polyps. (**a**) 3D endoluminal image of the colon demonstrates a cluster of small polypoid lesions (*arrows*). (**b**) 2D axial image demonstrates that these polypoid lesions correspond to foci of densely tagged stool (*arrows*), and can thus be disregarded

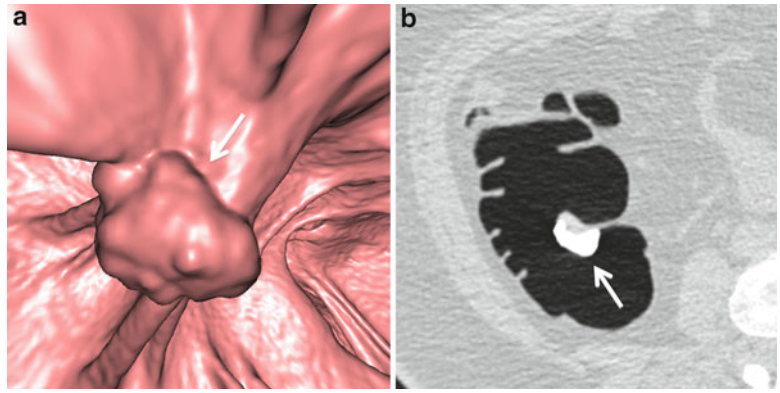

Fig. 5.2 Adherence stool on the ileocecal valve can imitate a mass lesion. (**a**) 3D endoluminal image of the ileocecal valve demonstrates an irregular, mass-like lesion (*arrow*), which appears to originate from the valve. (**b**) Corresponding 2D axial image demonstrates that the "lesion" is actually densely tagged stool (*arrow*) adherent to the valve and can thus be disregarded

Because barium preferentially tags solid stool, not liquid, it can cause inhomogeneous tagging if used alone [37]. Higher concentrations of barium have been described to leave flocculation or a "sticky coat" on the colonic wall, interfering with visualization of the colonic wall and complicating interpretation (Fig. 5.4) [48]. This problem can be solved by giving lower concentrations of barium earlier in the day, before the last dose of cathartic [48]. High-density barium, particularly if heterogeneous, causes problems for electronic cleansing software, discussed below [49]. As a side effect, barium can cause obstipation or even impaction [50]. Interestingly, there is evidence that barium selectively adheres to villous adenomas, a potentially beneficial property [51].

Iodinated Agents

As with barium, iodine-based high-osmolarity oral contrast agents are generally safe and familiar. Iodinated agents are hypertonic, can cause fluid shifts into the bowel lumen, and thus have an additional cathartic effect [52, 53]. Because they act to soften the stool, they mix homogeneously

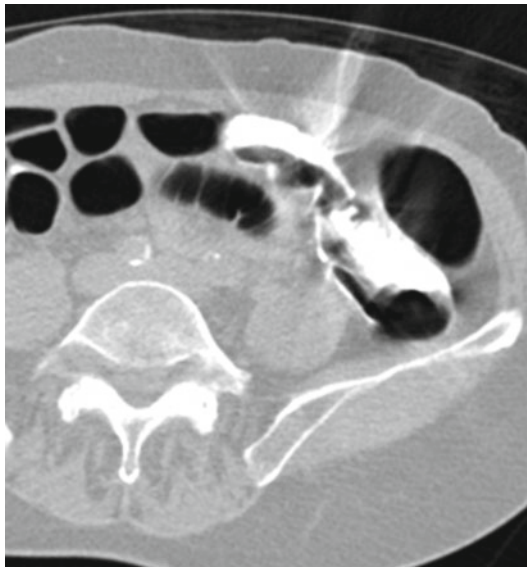

Fig. 5.3 Fecal tagging material is too dense, complicating interpretation. 2D axial image from CTC demonstrates extremely dense tagging material in the sigmoid colon. Streak artifact renders the bowel in the left lower quadrant difficult, if not impossible, to interpret

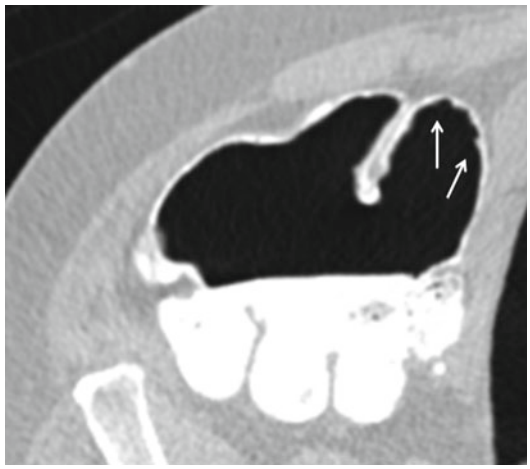

Fig. 5.4 Adherent barium can cause the appearance of a "sticky coat." 2D axial image of the right colon demonstrates circumferential, nodular high-density coating on the colonic mucosal surface, most obvious anteromedially (*arrows*). The patient ingested 40% barium as part of the fecal tagging component of their bowel preparation. Lower concentration barium has been shown to decrease this problem of the "sticky coat" [48]

with colonic contents, which results in more uniform attenuation, improving the ease of interpretation [33, 52, 53]. Iodinated contrast alone may also be used to tag residual material in the colon [40, 41, 53] but in general are used in combination with barium. There are two varieties of iodinated contrast agents, ionic and nonionic.

Ionic Iodinated Agents

The most commonly used agent in the United States is sodium diatrizoate (Gastrografin, Bayer Shering Pharma, Berlin) also commonly used as oral contrast in standard CT examinations [40, 41]. Ionic iodinated contrast is water soluble, a property that lends itself to homogeneous tagging [30]. Although less costly than nonionic agents [33], the taste is unpleasant, especially in large amounts [54]. Despite a generally good safety profile, it can induce diarrhea and dehydration. Rare anaphylactoid reactions have been reported [55]. Sodium diatrizoate is contraindicated in those with iodine allergies, in which case barium alone is substituted. Doses as low as 20 mL have been shown to be adequate for tagging purposes [33], although up to 60 mL is commonly used.

Nonionic Iodinated Agents

As with their ionic cousins, nonionic agents are also water soluble [30]. Nonionic agents (i.e., iopromide, iohexol) have a lower risk for causing diarrhea and dehydration. Unlike sodium diatrizoate, nonionic agents are nearly tasteless and have good patient acceptance [33, 56]. Nonionic agents are less commonly used because they are more expensive than both barium and ionic iodinated contrast [33].

Combined Tagging

Barium and iodine-based tagging agents are commonly used in combination, opacifying residual solids with barium and fluid with iodine. The multicenter ACRIN National CT Colonography Trial successfully used combined tagging [10]. A total volume of 40 mL of 40% weight/volume barium (Tagitol V) was administered orally the day before the CT scan in three divided doses. A total volume of 60 mL of iodinated contrast

material (Gastrografin 37% organically bound iodine) was administered in three aliquots of 20 mL starting the evening before the CT scan.

Following the lead of a large-volume CTC program and after noting that the more dense barium was causing any "sticky coat" to form, our own clinical CTC program has migrated away from using 40% barium. We now exclusively use a combined regimen with 2.1% barium and 37% Gastrografin with excellent results. Although there is no consensus regimen, the European Society of Gastrointestinal and Abdominal Radiology suggests that the choice of tagging agent should be based on local experience, taking into account any history of allergy [35]. A recently described artifact termed the "dense waterfall" is sometimes seen with CTC using fecal tagging. This artifact is caused by gravitational flow of tagged fluid between two colonic levels and appears as arciform streak artifact. It is caused by erroneous image reconstruction brought about by misregistration of moving fluid and is important because it can imitate or obscure pathology [57].

Translucency Rendering

Translucency rendering, or the "translucency view," is a specialized viewing mode in some commercial workstations that may help differentiate high-attenuation tagged stool from the soft tissue density of a true polyp (Fig. 5.5) [12, 58]. This mode is typically activated with the push of a button. The tool, when superimposed on an endoluminal lesion during 3D analysis, assigns different specific color patterns to the lesion based on its attenuation values. In general, densely tagged stool appears white. Polyps have a color signature with a red core and gradual stepwise shift to green, light blue, and dark blue hues more peripherally. Fat density lesions such as the ileocecal valve (Fig. 5.6), lipomas, and impacted diverticula are also well analyzed [59]. In a recent study of 350 patients with 482 colonoscopically verified polyps and 50 pseudopolyps, the overall average sensitivity for polyp characterization by translucency rendering was 96.6% and average overall specificity for pseudopolyp characterization was 91.3% [59].

Reduced, Limited Catharsis, and Noncathartic CTC

Other than improving diagnostic performance, one of the reasons for developing fecal tagging regimens was the desire to improve the patient experience and compliance by decreasing or eliminating the most unpleasant aspect of CTC, the need for a full bowel preparation [60]. This would be of particular benefit to those with limited mobility, the brittle elderly, or those who have a blunted response to laxatives [33]. Additionally, it is thought that by removing the hurdle of a full preparation, patients would undergo screening with CTC more frequently [52, 61].

These types of bowel preparation are termed nonconventional and include reduced catharsis, limited catharsis, or noncathartic preparations. "Reduced catharsis" refers to the use of purgative medications in approximately half of the dose used for conventional preparation. "Limited catharsis" refers to the use of laxatives (senna, bisacodyl, lactulose) to achieve a relatively mild catharsis. "Noncathartic" or "laxative free" refers to a preparation without any purgative or laxative. All of these nonconventional bowel preparations are dependent on excellent fecal tagging [62].

Although patient acceptance is higher with lower doses of iodine and tagging agents, it has been recommended that doses of 50 mL meglumine ioxithalamate be used for optimal tagging quality in noncathartic CTC [63]. It is especially important with noncathartic preparations that good homogeneity and high tagging density be achieved. Low-density tagging increases the difficulty of polyp detection, increases false-positives, and decreases diagnostic accuracy [53].

The literature regarding the diagnostic performance of nonconventional CTC is mixed, with some studies showing favorable [37, 41, 52, 64] and others unfavorable [65–67] results. In general, although results are promising, further study is necessary because study design is inconsistent and data are limited. A systematic review of nine

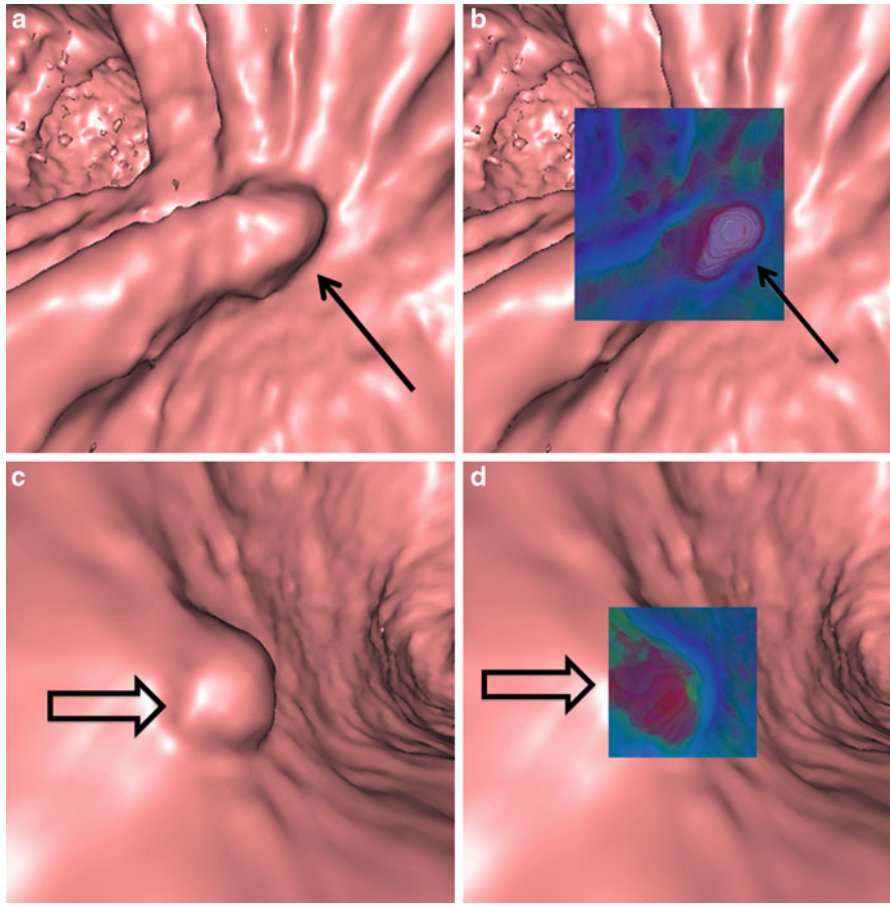

Fig. 5.5 Translucency rendering can be used to differentiate soft tissue polyps from adherent stool. (**a**) 3D endoluminal image shows a 7-mm sessile polypoid lesion on a haustral fold. (**b**) Translucency rendering applied to 3D image in "**a**" shows completely white interior, indicative of contrast material tagging. This appearance excludes a true polyp, so it is not necessary to perform 2D correlation. (**c**) 3D endoluminal image shows 1-cm sessile polyp. (**d**) Translucency rendering applied to 3D image in **c** shows typical color pattern of a soft tissue polyp, consisting of *red core* and gradual uniform shift to *green*, *light blue*, and *dark blue* hues more peripherally

prospective studies of CTC with nonconventional bowel preparation was recently published [62]. In six studies, detection of polyps 10 mm or larger was good [38, 41, 47, 52, 67, 68], with both per-polyp and per-patient sensitivities ranging from 82% [67] to 100% [38, 41, 68]. In the two studies in which electronic cleansing was used, per-patient sensitivity for polyps 10 mm and larger was 100% [68] and 96% [52]. In three studies [64–66], performance was relatively poor for polyps larger than 10 mm, with the per-polyp sensitivity ranging from 0% [65] to 63.3% [66] and per-patient sensitivity ranging from 0% [65] to 75.3% [64]. It should be noted that two of the poor-performing studies [64, 66] used what would be considered suboptimal doses of contrast in one [64] and iodine only in the other [66].

Sensitivity and specificity of smaller lesions is worse. In a 2008 study by Jensch et al., CTC with fecal tagging without stool subtraction and a bisacodyl-only prep was compared with colonoscopy [67]. Sensitivity for lesions 6 mm and greater was 76%. However, despite homogeneous fecal tagging, there were a large number of false-positive findings (specificity 79%) when 6 mm was used as a size threshold. In a 2009 study by Nagata, minimum laxative CTC with fecal tagging demonstrated equally high sensitivity to full

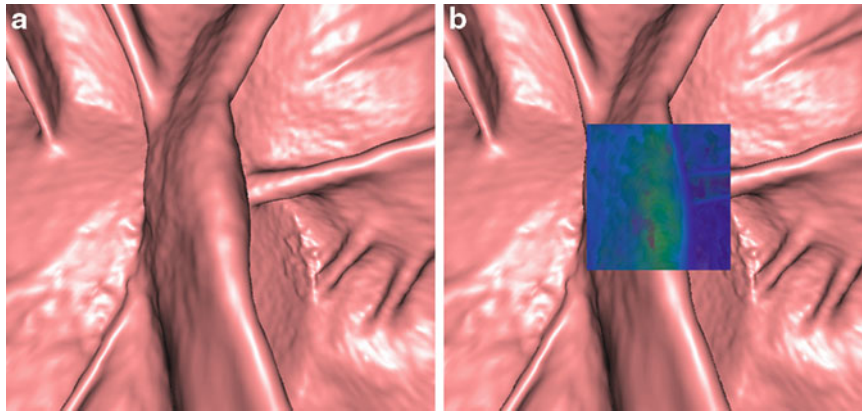

Fig. 5.6 Translucency rendering demonstrates the internal composition of the ileocecal valve. (**a**) 3D endoluminal image of the ileocecal valve demonstrates normal valve morphology with a flat, slit-like opening. (**b**) Translucency rendering applied to the 3D image in "**a**" shows assignment of *green* and *blue shades* to the valve, indicative of fat content

laxative examination [33]. However, the full laxative fecal-tagged CTC yielded a higher specificity. He concluded that it might be desirable to offer patients the option of the full prep for highest accuracy and the ability to perform a same-day colonoscopy, or a minimum laxative CTC for those who are willing to accept an increased risk of false-positives and attendant unnecessary colonoscopy, which not only is inconvenient but also increases risk and costs.

A problem with nonconventional preps is the difficulty of performing a primary 3D interpretation without the ability to perform electronic cleansing. Residual stool and artifacts render the 3D virtual colonoscopic view uninterpretable, as the colonic mucosa is essentially "buried." A large number of filling defects have to be addressed one by one (Fig. 5.7), an "insurmountable task." [52] Even with stool subtraction, optimal fecal tagging would be needed to make 3D interpretation possible [45]. Without the benefit of stool subtraction, a primary 2D method with 3D problem solving must be employed. Primary 2D approaches permit the reader to rapidly examine the internal density of filling defects and decide if they are soft tissue polyps or if they actually contain air or tagging agent consistent with stool [52]. In general, interpretation of noncathartic CTC is a tedious task.

Electronic Subtraction of Tagged Material

"Electronic subtraction," also called "electronic cleansing," refers to post-processing of CTC data to remove interfering high-density tagged liquid and stool, so that theoretically one is left with only the colonic mucosa and any soft tissue abnormalities to interrogate (Fig. 5.8) [49]. Electronic subtraction improves visualization whether the prep is a full prep with fecal tagging or a less rigorous limited or noncathartic one. A number of commercial platforms now feature electronic cleansing algorithms [69].

Presently, cleansing algorithms performed by post-processing software are threshold based, and artifacts often arise that complicate image interpretation. The technique is challenging from a programming aspect, mostly because of the heterogeneity of fecal tagging (Fig. 5.9), variable colonic transit times, and normal desiccation of stool as it progresses through the colon. Additionally, interfaces of air, tissue, and stool are prone to partial volume artifacts [52]. "Oversubtraction," where areas of normal tissue or polyps are subtracted along with the stool, can be a problem and must be avoided. New techniques are being developed to improve electronic cleansing. Spectral electronic cleansing,

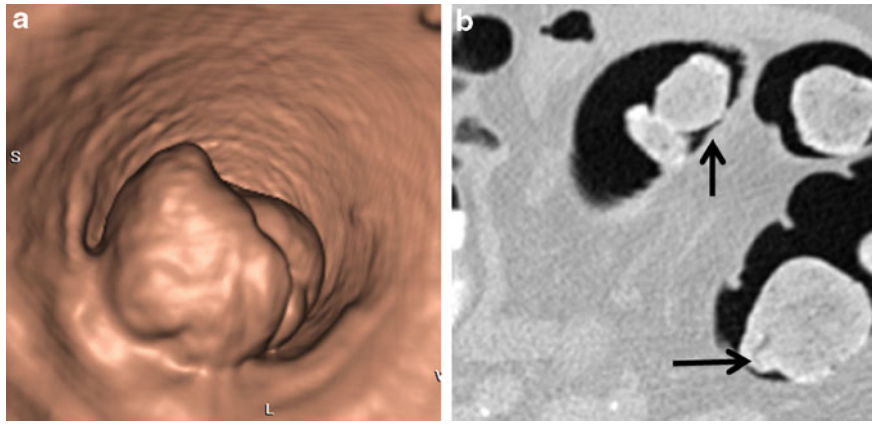

Fig. 5.7 Residual stool can imitate a mass lesion. (**a**) 3D endoluminal image of the sigmoid colon demonstrates an intraluminal lesion, which could represent a large polyp or mass. (**b**) 2D axial image shows multiple stool balls (*arrows*) in this patient who had a very poor bowel preparation. The lesion in question corresponded to one of these stool balls

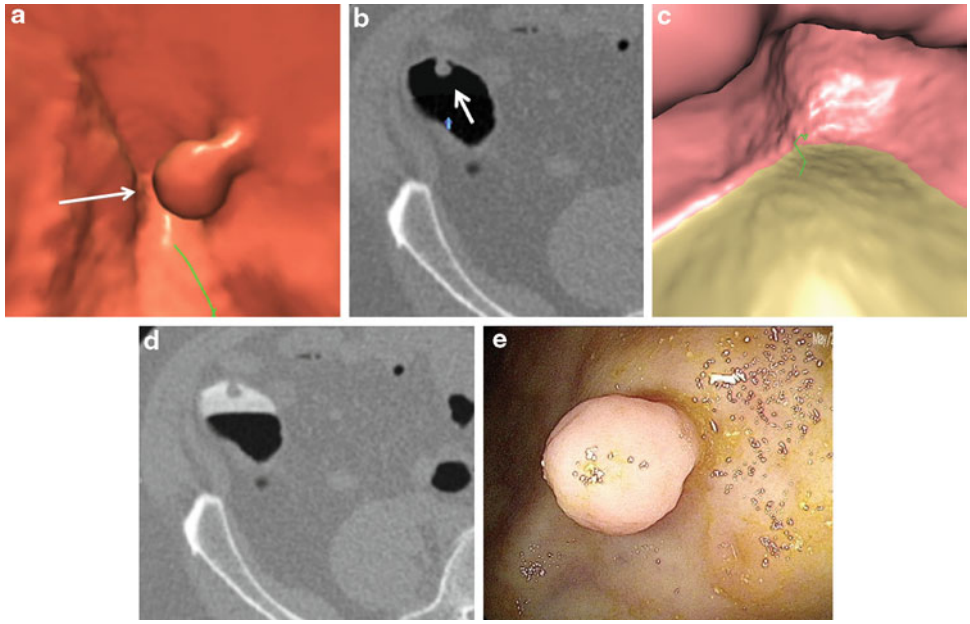

Fig. 5.8 Electronic stool subtraction can be useful to detect lesions submerged in liquid. (**a**) 3D endoluminal image of the base of the cecum demonstrates a 1-cm pedunculated lesion (*arrow*). Electronic stool subtraction was applied to this image. (**b**) Prone 2D axial view of the lesion in **a** (*arrow*) demonstrates that it is soft tissue density, concerning for a polyp. (**c**) Prone 3D endoluminal image generated on a different workstation without stool subtraction using discriminate differential color coding, shows only tagged fluid (assigned a *golden color*) within the lumen. The lesion is submerged under the liquid and is not visible. (**d**) Corresponding prone 2D axial image without stool subtraction applied shows the lesion (*arrow*) is submerged under the tagged fluid. The lesion is still easily appreciable on the 2D view but impossible to see on the unsubtracted 3D endoluminal image. (**e**) Photograph from the optical colonoscopy shows that the cecal lesion has a polypoid morphology, but on close inspection its surface was not characteristic of an adenomatous polyp. The patient had a remote history of appendectomy, and this lesion represents an inverted appendiceal stump, a potential pitfall [183]

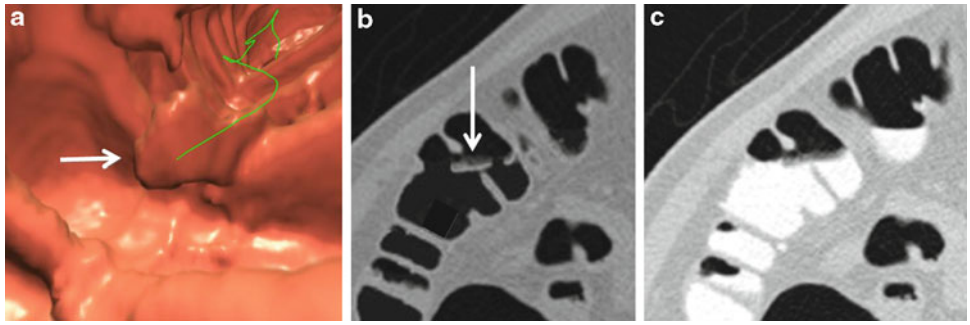

Fig. 5.9 Electronic stool subtraction artifacts can create pseudo-lesions. (**a**) 3D endoluminal image of the transverse colon demonstrates an irregular polypoid protrusion (*arrow*). (**b**) Supine 2D axial image through the area of interest in **a**, using electronic stool subtraction, demonstrates a heterogeneous, linear, soft tissue density (*arrow*). (**c**) Corresponding 2D axial image without stool subtraction applied demonstrates a thin layer of poorly tagged fecal material (*white*) floating on top of radiodense contrast. This material did not meet minimum Hounsfield units to be recognized and subtracted by the computer software and thus remained within the colonic lumen after the higher density liquid was subtracted, creating a distracting pseudo-lesion

based on dual-energy CT, may decrease the number of artifacts and improve image quality. In a 2008 study of a group of patients drawn from the Walter Reed Army Medical Center database, Serlie found that electronic cleansing shortened interpretation time, lowered assessment effort, and had a positive effect on observer confidence [70]. Although stool subtraction has been shown to improve the sensitivity of CTC, studies have also shown that specificity can decrease, especially for the detection of moderate sized polyps [52].

Discriminative Color Coding

An additional technique taking advantage of fecal tagging is discriminative color coding. This is a color enhancement technique available on some workstations that can be used during primary 3D interpretation. When activated, computer software color codes high-attenuation material on the 3D images so that residual liquid and adherent tagged stool can be easily discriminated from soft tissue density polyps, decreasing the need for 2D correlations (Figs. 5.8 and 5.15). This technique has been shown to shorten interpretation times when compared with a standard primary 3D interpretation approach [71].

Performance of CT Colonography

Patient Arrival

Examinations are scheduled first thing in the morning. After checking in to the radiology department, the patient is escorted to a dressing room and instructed to change into a gown. The technologist speaks with the patient and explains what to expect in the CT suite. The nurse requests that the patient attempts to evacuate one last time and inquires about the compliance with the preparation as well as the appearance of the stool. If the patient has not completed the preparation as instructed or continues to have semisolid stools, rather than rescheduling the CTC, more cathartic agents may be administered in the department, schedule permitting. Routine administration of a self-administered phosphate enema before the examination is not indicated, having been shown in a study of noncathartic CTC to not decrease residual stool, to increase retained fluid, and to reduce diagnostic confidence [72].

Insufflation

Ample colonic distention is of fundamental importance for CTC. Collapsed segments can

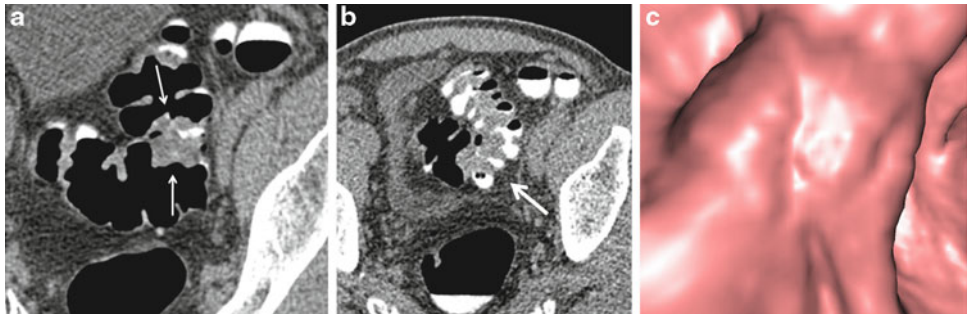

Fig. 5.10 Poor distention of the colon can simulate mass lesions. (**a**) Prone 2D axial image of the sigmoid colon shows a possible mass lesion (between *arrows*) in the sigmoid. This could also represent a pseudo-mass due to under distention. (**b**) Corresponding supine axial 2D image of the sigmoid colon (*arrow*) shows that this area remains poorly distended, limiting evaluation. (**c**) Prone 3D endoluminal view of the area in question demonstrates a possible mass versus a poorly distended complex fold. A decision was made to perform same-day sigmoidoscopy. No mass was found. This was a pseudo-lesion from underdistention, a common cause of false-positives

obscure or mimic pathology (Fig. 5.10), reducing sensitivity and specificity. With inadequate colonic distention, diagnostic confidence can be diminished and interpretation times prolonged [3, 73]. Insufflation can be achieved by administration of either room air or carbon dioxide (CO_2), via a manual pump or electronic insufflator. The most basic technique is room air insufflation using a handheld plastic bulb [74]. This method can even be performed by patients themselves [45]. Of the possible combinations, electronic insufflation of CO_2 is highly favored for reasons given below.

Burling demonstrated that automated CO_2 insufflation significantly improved colonic distention compared to manual carbon dioxide insufflation, particularly the left colon in the supine position and the transverse colon when both supine and prone scans were combined [74]. Slow, continuous, low-pressure administration of CO_2 can only be achieved with the electronic insufflator. This helps alleviate colonic spasm, especially in segments with diverticular disease [30]. CO_2 has superior lipid solubility and higher partial pressure gradient than room air and is thus more rapidly absorbed from the colon into the blood stream and exhaled with respiration [75]. Post-procedural gaseous discomfort is less than with room air [12, 76], and patients often feel back to normal by the time they get off the CT table.

Electronic CO_2 insufflation also improves the safety of the examination. The perforation risk with electronic CO_2 insufflation is negligible in the screening population. Close to all of the reported perforations from CTC have involved staff-controlled manual insufflation of room air [77]. In two large series, the risk of colonic perforation at CTC was approximately 0.06% [78, 79]. In a review of 11,870 CTCs, seven perforations occurred, all of which involved manual insufflation of room air [79]. Risk factors for perforation include advanced age, recent colonoscopy, diverticular disease, recent colonic biopsy (Fig. 5.11), inguinal hernia, and obstructive carcinoma [78, 79].

In patients who have undergone incomplete OC and are referred for same-day CTC, it is important to inquire whether a biopsy or polypectomy was performed. Patients who have undergone deep cold forceps biopsy, hot snare polypectomy, or endoscopic mucosal resection should wait at least 1 week before undergoing CTC. In patients who have had an incomplete OC, even if they have not undergone shallow cold forceps biopsy, we obtain CT images of the abdomen and pelvis before insufflation of intra-rectal air. This is done as a safety precaution, to exclude the possibility of perforation.

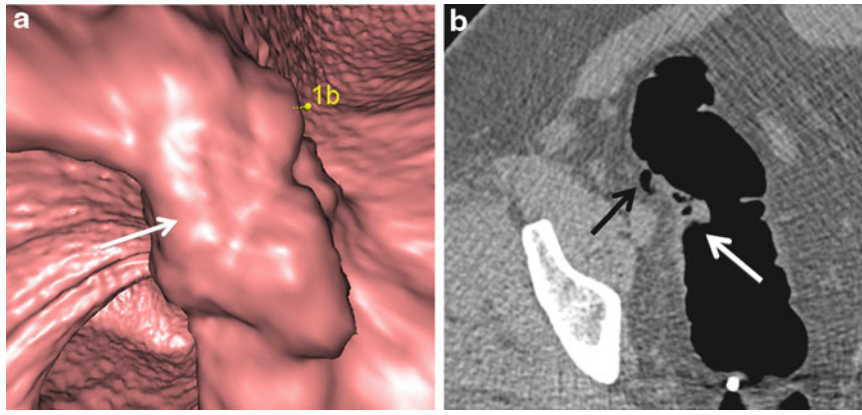

Fig. 5.11 Deep biopsy or polypectomy is a risk factor for perforation during CT colonography. (**a**) 3D endoluminal view of the sigmoid colon demonstrates a large, irregular, nearly obstructing mass lesion. This lesion had undergone biopsy earlier in the day, and the scan was ordered to clear the proximal colon of synchronous lesions. (**b**) Corresponding 2D axial supine image demonstrates the mass (*white arrow*) along the right wall of the sigmoid colon. Foci of gas can be seen in the lesion post biopsy. Additionally, there is extracolonic gas (*black arrow*). Because a scan was not performed before CO_2 insufflation, it is unknown whether this small perforation was due to the biopsy or CO_2 insufflation. The patient was asymptomatic

Patient Positioning

Insufflation techniques vary between centers [12, 30], but it is agreed that both supine and prone images are necessary. The rationale of dual positioning is to redistribute residual fluid, as well as to help redistribute air. A segment of colon may distend well on one view, but not another (Fig. 5.12) [80]. Polyp detection sensitivity has been shown to improve when both supine and prone acquisitions are performed [73, 80].

The exam is often started with the patient in the right side down decubitus position in order to facilitate rectosigmoid and descending colon distention. At our institution, with the patient on their right side on the CT table, a radiology tech or nurse inserts a thin, flexible rectal catheter. This is connected to the electronic CO_2 insufflator (PROTOCO$_2$L, Bracco). For comfort, we avoid using larger catheters, such as those used at barium enema, unless the patient needs help retaining the CO_2. A target pressure of 25 mmHg is programmed, and the CO_2 is administered, titrating to pressure and patient comfort. It is important to acquire the CT images during active replacement of CO_2 at equilibrium pressures [30]. Because of differences in colonic anatomy, patient tolerance, small bowel reflux, and anal incontinence, the total volume of gas delivery can vary widely and thus has little significance [74]. Anywhere from 3 to 10 L may be needed for sufficient distention [12, 30]. Patient cooperation with gas retention is essential.

After insufflation of approximately 1.5 L, insufflation is continued in the supine position until the patient reports fullness in the right side of the abdomen, usually indicating cecal distention. One must always be aware of patient comfort, as well as the displayed pressure reading. When ready for scan acquisition, the patient exhales and then holds their breath, elevating the diaphragm, expanding the abdominal cavity, and allowing more room for the splenic flexure and transverse colon [30]. A CT scout image is used to assess colonic distention (Fig. 5.13). If distention is adequate, a supine CT scan is performed.

Unfortunately, the scout is at times unreliable for evaluation of distention. For this reason, technologists or research assistants are sometimes trained to assess the adequacy of distention by reviewing the CT images on the scanner console. This allows for problem solving in real time and reduces the need for callbacks. At our institution the interpreting radiologist or the body-imaging

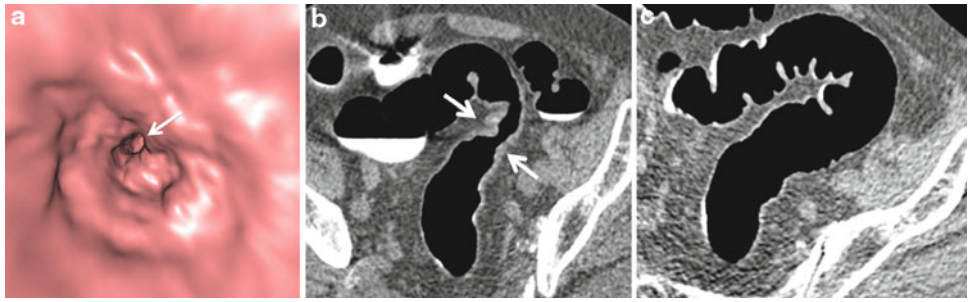

Fig. 5.12 Dual positioning may eliminate pseudo-lesions. (**a**) 3D endoluminal view of the sigmoid colon demonstrates apparent severe narrowing with only a pinpoint lumen (*arrow*) visible. (**b**) Corresponding supine 2D axial image demonstrates apparent wall thickening and luminal narrowing at the area in question (between *arrows*). This is concerning for an apple-core lesion. (**c**) 2D axial image obtained in the right lateral decubitus position demonstrates better sigmoid distention, without evidence of a mass lesion. This demonstrates the value of dual positioning

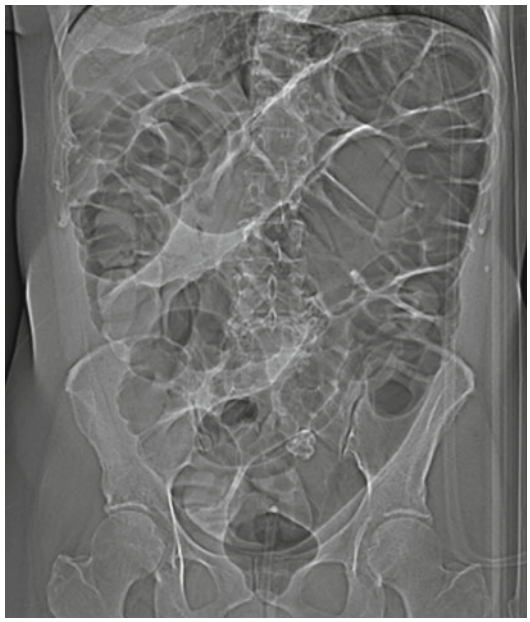

Fig. 5.13 The scout image is used to check for adequate distention before scanning. Supine scout view of CTC during CO_2 insufflation shows good distention of the entire colon, without significant small bowel reflux

fellow are involved with scan acquisition from start to finish. However, in a busy CT practice, assigning quality assurance responsibility to the CT technologist is an important goal that necessitates continued training and feedback [81]. After supine acquisition, the patient is turned prone. Elevating the torso and hips with pillows can be helpful, especially in overweight patients. External abdominal compression in the prone position can cause poor colonic distention, especially in the transverse colon [12, 82]. Once prone, the scout is repeated. Equilibrium CO_2 pressures are maintained at 25 mmHg. At that point, axial prone images are obtained.

If, after acquisition of prone and supine data sets, a portion of the colon is not visualized well on either position, a decision can be made to obtain a third set of images, most commonly a right lateral decubitus (Fig. 5.14). To limit radiation exposure and improve efficiency, programs should limit a third series as much as possible without sacrificing diagnostic performance [81]. Most commonly, the sigmoid and/or the descending colon is the offending segment [30], and the patient in that instance would be placed in the right lateral decubitus position to facilitate distention of the nondependent sigmoid colon. As expected, the rate of obtaining a right lateral decubitus series in a diagnostic cohort is higher than that of a screening, likely because many of the reasons for failed OC (diverticulosis, redundancy, tortuosity, and obstructing masses) can lead to challenges with luminal distention at CTC [81]. Advanced diverticular disease of the sigmoid colon is a recognized cause of luminal nondistention [83]. At times, because of circular muscular hypertrophy and poor distensibility [84], the sigmoid will not be well visualized in any position. In these instances, a decision to perform unsedated flexible sigmoidoscopy may be

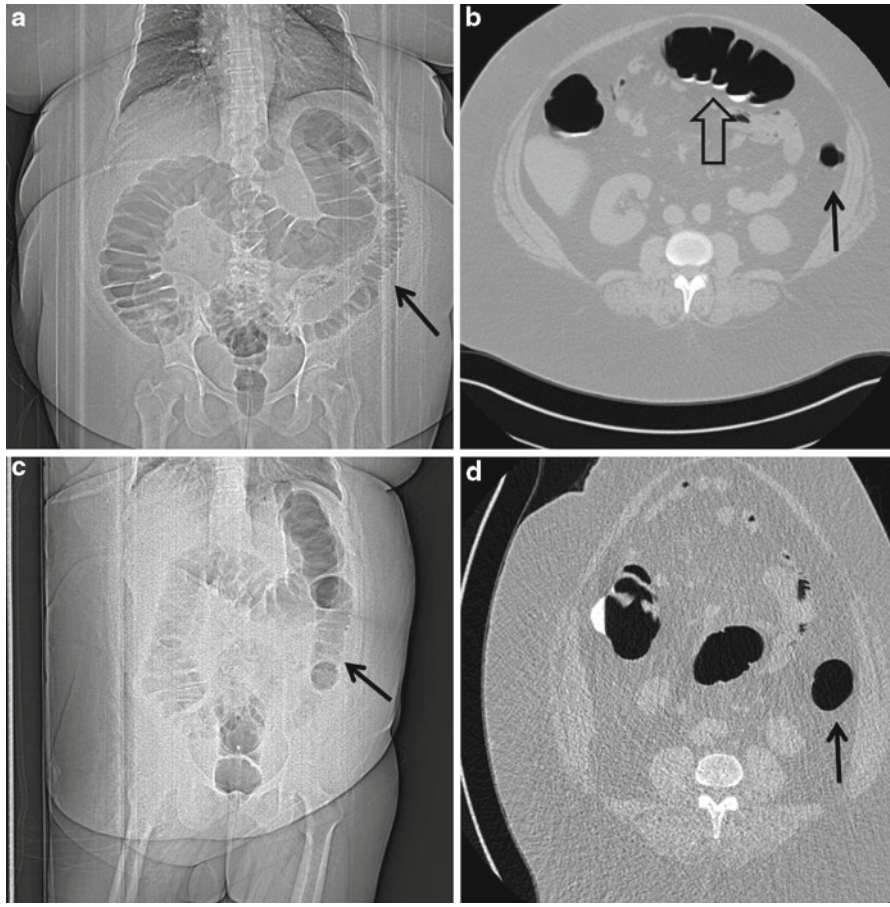

Fig. 5.14 Right lateral decubitus views may be useful when a particular segment is collapsed on both supine and prone images. (**a**) Scout supine image of the abdomen demonstrates that the descending colon (*arrow*) is suboptimally distended. (**b**) Supine 2D axial image shows that, compared with the transverse colon (*open arrow*), the descending colon (*arrow*) is suboptimally distended. Prone positioning (not shown) did not improve distention. (**c**) Scout image in the right lateral decubitus (*right-side-down*) position demonstrates somewhat improved distention of the descending colon (*arrow*). (**d**) Right lateral decubitus 2D axial images confirm better distention of the descending colon (*arrow*)

considered [83]. An additional consideration in positioning relates to patients with limited mobility, in whom supine and right lateral decubitus may be sufficient, obviating the difficult task of turning these patients prone.

Spasmolytics

Spasmolytic agents such as glucagon have been investigated with the goals of lessening patient discomfort and reducing peristalsis and resultant motion artifact. Part of the rationale for using glucagon arises from its role as an antiperistaltic in barium enema studies [85]. A placebo-controlled study of glucagon in double-contrast barium enemas demonstrated that glucagon lessened patient discomfort. However, the onset of maximum effect was after 8 min post administration [86]. Given that image acquisition with multidetector row CT (MDCT) is so fast, if given glucagon immediately before the exam, patients will have already completed the CTC before glucagon achieves its maximum effect [87]. The alternative,

waiting for glucagon to take effect, increases total duration of the examination [76] and decreases efficiency. Glucagon is also costly (wholesale cost is US$48–66 per 1-mg vial). It requires an IV or intramuscular injection, increasing discomfort [87]. It also carries a risk of side effects, such as nausea and vomiting [76].

Most importantly, studies of glucagon in CTC have shown no objective beneficial effects. In a blinded, non-randomized study of 60 patients undergoing CTC, the 33 patients who received glucagon did not show any difference in segmental or overall colonic distention [88]. Morrin studied 74 patients who were administered glucagon before CTC and found that distention scores for the glucagon and non-glucagon patients were similar [87]. Its lack of proven effectiveness in CTC is not surprising physiologically, given that the colon is recognized as the least responsive part of the bowel to the antiperistaltic effects [89].

Though not available in the USA, the spasmolytic Buscopan is available in Europe and has been suggested to be more effective than glucagon as an antiperistaltic agent [90]. However, despite improved colonic distension in certain segments, Buscopan did not necessarily translate into improved polyp detection, and thus it is not routinely used in CTC. Based on the literature, there does not appear to be justification for routine use of spasmolytics in CTC. At the same time, a small percentage of patients may have cramping and pain that significantly limits tolerance of bowel insufflation, and in these selected cases, administration of glucagon may be worthwhile [12].

CT Data Acquisition

Since the introduction of spiral or helical CT in the early 1990s, CT scanning has sped up by a factor of at least 500, such that the CT acquisition portion of the exam is not at all rate limiting. Modern scanners can acquire the CT data in 10–15 s, which is well within the breath holding capability of almost all patients. There remain, however, important considerations related to slice thickness, reconstruction interval, and radiation dose that we elaborate further here.

Imaging Parameters

Careful setting of the scan parameters is needed to balance image quality (spatial and contrast resolution, and slice thickness) and radiation dose. Now, with MDCT, data can be acquired much faster, even with thinner slices. In a 2005 meta-analysis, seven studies that used multidetector scanners had higher sensitivity than nine studies in which a single-detector scanner was used (95% versus 82%) [91]. The entire abdomen and pelvis can be now scanned within a single breath hold, which decreases both respiratory and peristalsis motion artifacts.

Initial work with single-detector CTC usually used 3–5-mm-thick sections with a high degree of image overlap for data acquisition [92–94]. However, we now realize that the acquisition of thin sections is essential for the performance of CTC because they decrease partial volume averaging and improve quality of the multiplanar reconstruction (MPR) and endoluminal reformats [12, 95]. Moreover, thinner slices improve sensitivity for polyps and improve specificity, as shown in a 2005 meta-analysis [91]. The same meta-analysis evaluated data from 19 studies and suggested that every 1-mm increase in collimation width decreases sensitivity by 4.9% [91]. There is a trade-off, of course, between slice thickness and radiation dose.

As with any type of CT exam, each time the slice thickness is reduced by half, the radiation dose must be doubled to maintain image noise constant [96]. Increasing collimation or decreasing tube current (mAs) or voltage (kVp) will decrease radiation dose but at the expense of increased noise. Because image noise increases as dose is decreased, image noise can, at a certain point, degrade image quality and may decrease diagnostic performance, especially for smaller polyps [97]. It may be more difficult to differentiate stool from polyps because the attenuation of polyps becomes more heterogeneous as noise increases.

Another advantage of MDCT is that images can be reconstructed at thicknesses larger than the collimator width, for example at 2.5 or 5 mm thickness, if desired by the radiologist.

This enables efficient interpretation of extracolonic structures [12]. The ACRIN Trial sites used a minimal detector collimation of 0.5–1.0 mm, a slice thickness of 1–1.25 mm, and a reconstruction index of 0.8 mm [10]. The 2009 ACR practice guidelines for CTC recommend that CTC be performed using an MDCT with ≥4 detector rows, a slice thickness of ≤3 mm, and a reconstruction interval of ≤2 mm [98]. We review our extracolonic structures using 5-mm slices.

Radiation Dose

Every effort should be made to maintain radiation exposure *as low as reasonably achievable (ALARA)*, especially for screening examinations, where the benefit/risk ratio must be favorable [99]. As CTC becomes increasingly employed for colon cancer screening, we must consider any possible radiation risk to the population of these potential millions of scans [99]. Concern over radiation exposure, real or imaginary, was one of the reasons given why Medicare declined reimbursement of screening CTC in 2009.

Fortunately, because of the large difference in the attenuation between bowel wall and intraluminal air, as well as the lack of need for detailed evaluation of extracolonic structures, there is potential for dose reduction. The dose/noise trade-off can be heavily weighted toward low-dose, higher-noise images, while still maintaining sensitivity and specificity, at least for polyps > 10 mm in diameter [93, 99–101]. Brenner, in a widely cited study, estimated the combined prone and supine radiation dose for CTC at around 13 mSv [102]. However, this study used data from older generation 8 and 16 row machines. In comparison, the ACRIN trial used newer MDCT scanners with low-dose technique and was able to limit dose to approximately 5 mSv per exam [10]. This is very close to the 4.5-mSv annual background exposure at high altitude [4]. Additionally, a 2008 study by Liedenbaum surveyed CTC providers about their equipment and dose parameters. He found that 62% of his questionnaire respondents were using 64 row scanners and 50% used dose modulation. The average dose of his respondents was 5.7 mSv [103].

Ultralow-dose scans have been shown to be able to deliver an effective radiation dose of 1.8 mSv for males and 2.4 mSv for females while preserving excellent sensitivity (100% for polyps greater than 10 mm and 100% for cancers) [104]. In a 2004 feasibility study, van Gelder studied 15 patients with doses ranging from 0.05 to 12 mSv. Overall sensitivity for polyps 5 mm or larger decreased at lower doses but was 74% or higher down to 1.6 mAs (0.2 mSv) [97]. Noise-related artifacts affect image quality for 3D more than 2D [97], a potential concern for primary 3D readers. However, a recent study of low-dose CTC showed that, although cobblestone artifacts and irregularly delineated folds were significantly higher with low dose compared with standard dose, most of the artifacts were mild and no significant difference in sensitivity was found between dose levels for polyps greater than or equal to 6 mm in diameter [105].

Despite these encouraging performance data, the use of ultralow-dose scans has yet to catch on, possibly because radiologists are unwilling to sacrifice image quality and further compromise evaluation of extracolonic organs [106]. New techniques, such as adaptive statistical iterative reconstruction (ASIR) and prior image constrained compressed sensing algorithm (PICCS), have the potential to improve image quality at lower radiation doses. A 2010 study demonstrated that the standard radiation dose for CTC could be reduced 50% when ASIR was used, without significantly affecting image quality [107]. As expected, image quality scores were best in thin patients, with worse image quality and noise in larger patients. PICCS, when applied to standard FBP with low-dose multidetector CT images, results in considerable noise reduction and improved image quality [108]. Further dose reductions can be achieved with automatic tube current modulation, a standard technique on newer scanners that adjusts tube current, and thus the radiation dose, to the patient's body density in order to decrease variation in image quality. This enables a significant decrease in radiation exposure without decrease

in image quality in CTC [109]. It has been shown that an additional dose reduction of 20% can be accomplished with attenuation-based tube current modulation [105].

The 2009 ACR practice guidelines for CTC specify that the recommended dose level for screening CTC should be ≤50% of the CT dose index by volume (CTDI) for routine CT of the abdomen and pelvis, which is set at an upper limit of 25 mGy [110]. Thus, for CTC, a CTDI of 6.25 mGy per position or 12.5 mGy for the entire examination is the upper limit [111].

Interpretation

Background

Depending on scan parameters, a CTC study can contain between 600 and 2,000 images. An ever-growing number of techniques for 2D and 3D reconstructions provide even more images for review. Also, advanced adenomas are relatively uncommon in a screening population, with an incidence of approximately 4% [10]. Therefore, the expectation is that the bulk of CTC studies will be "negative." This "needle in a haystack" issue, as well as the fact that CTC is difficult and time intensive, can make interpretation intimidating. It is also an issue that considerably motivates research into how to most accurately and efficiently interpret CTC, which is the focus of this section.

Training

Before interpretation can begin, one must undergo training. It is well documented that the detection of carcinoma and polyps improves with practice [112–115]. Data from the ACRIN trial shows that the odds of identifying patients with disease increase 1.5-fold for every 50-case increase in reader experience or formal training [113]. Although CTC interpretation can be challenging, even well-trained nonphysicians can achieve respectable performance [112, 116]. Multiple professional organizations, including the American College of Radiology (ACR), the American Gastroenterological Association (AGA) Institute, and the International Collaboration for CT Colonography Standards recommend dedicated training for CTC [111, 117, 118]. The only consistently recommended format for training is the educational workshop, where attendees receive face-to-face, hands-on training using colonoscopically proven cases [119]. Despite these recommendations, many interpreters of CTC do not meet minimum recommended standards. According to a recent survey of attendees at a CTC training workshop, only 24% of those already interpreting CTC had interpreted more than 50 cases [119]. Interestingly, despite evidence that non-radiologists desire to interpret CTC [120], the great majority (97%) of those attending the workshop were radiologists [119].

Training should encompass anatomy, colorectal cancer pathogenesis, examination technique, and pitfalls. It should also include appropriateness criteria, risks and benefits, problem solving (e.g., the use of IV contrast and decubitus imaging), technologist training, facility requirements, quality control, documentation [111], and standardized reporting of intra- and extracolonic findings (C-RADS/E-RADS) [113, 121]. Although training methods may vary, a minimum of 50–75 OC-validated CTC practice cases should be reviewed [122]. That said, even this may be insufficient, as a recent study demonstrated that it required on average 164 CTC studies for novices to achieve performance equal to that of experienced interpreters [122].

Clearly, one of the major goals of training is to reduce errors. Therefore, it is necessary to be cognizant of the types of errors that degrade performance. Liedenbaum describes three types of errors: errors of search (the radiologist's gaze completely misses the abnormality), errors of detection (the eyes of the radiologist pass over the abnormality, but not long enough for it to be recognized), and errors of decision (the abnormality is not correctly characterized) [122]. One can conclude that to reduce errors, competent, trained readers must read CTC with concentration, at a reasonable speed.

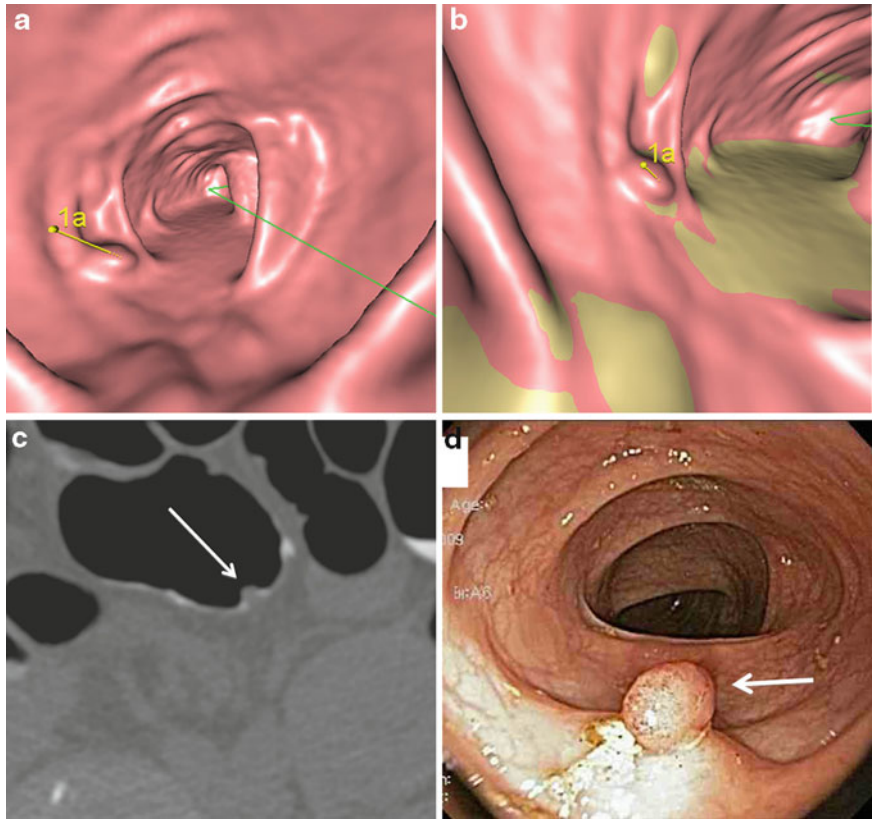

Fig. 5.15 Polyps are usually soft tissue attenuation and round in shape. (**a**) 3D endoluminal view of the sigmoid colon shows a polypoid filling defect (labeled 1a). (**b**) Application of discriminative color coding shows that high-density tagged fluid and stool is labeled a *golden color*. The lesion is not color-coded, indicating that it is soft tissue density. (**c**) Supine 2D axial image demonstrates that the lesion is indeed soft tissue, suspicious for a polyp (*arrow*). (**d**) Photograph from optical colonoscopy demonstrates snare retrieval of the polyp (*arrow*) found on CTC

Polyp Identification

The goal of CTC is to identify adenomatous polyps before they have time to turn into cancer. Polyps may develop anywhere along the mucosal lining, including on haustral folds or the ileocecal valve. The typical polyp on CTC is homogeneous soft tissue in attenuation and ovoid or round in shape (Fig. 5.15). Lesions may be sessile, pedunculated (Fig. 5.16), or flat (Fig. 5.17). Sessile lesions should not change position with respect to the colonic wall between supine and prone repositioning. In contrast, residual stool, the main source of false-positives, is often heterogeneous in attenuation and may contain air (Figs. 5.18 and 5.19). Stool can be irregular in shape and tends to change position between supine and prone scans (Fig. 5.20).

Interpretive pitfalls are abundant, a point that underscores the importance of systematic training and experience. Stool may at times be homogeneous in density. Pedunculated polyps may trap air and appear heterogeneous in attenuation [12]. Pedunculated polyps may be mistaken for pseudo-lesions (false-positives) when, because they are on a stalk, they move between supine and prone data sets. Additionally, colonic rotation may cause interpretive confusion. The ascending colon may have a deficient mesocolon [123] and may rotate from supine to prone positions, resulting in a change in the radial polyp position of as much as 79°, causing it to

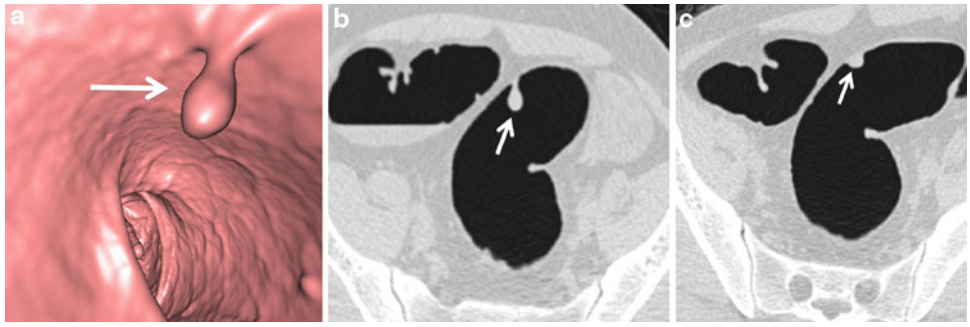

Fig. 5.16 Pedunculated polyps can change their appearance with dual positioning. (**a**) Supine 3D endoluminal view of the sigmoid colon demonstrates a 1-cm pedunculated polyp dangling into the colonic lumen (*arrow*). (**b**) Corresponding 2D supine axial image demonstrates the same polyp (*arrow*). (**c**) 2D prone axial image demonstrates that the polyp (*arrow*) has assumed a different configuration because it is now lying dependently along the anterior colonic wall. The stalk is no longer evident

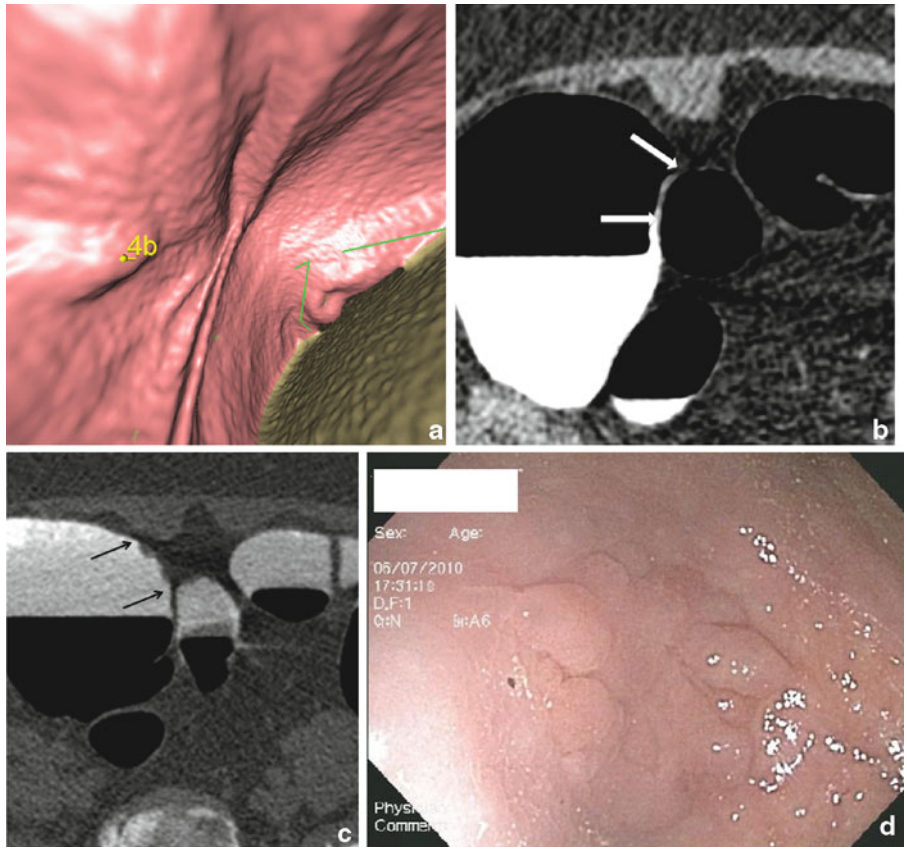

Fig. 5.17 Flat lesions can be difficult to visualize. (**a**) 3D endoluminal view of the cecum demonstrates a contour abnormality (labeled 4b) along the medial wall. This image is taken from the base of the cecum-looking Retrograde. The ileocecal valve is seen in the background (between *green lines*). The tagged fluid in the cecum is color-coded *gold*. (**b**) Corresponding supine 2D axial view of the cecum demonstrates a subtle sessile lesion arising from the medial wall (between *white arrows*). (**c**) Corresponding prone 2D axial view of the cecum demonstrates the sessile lesion (between *black arrows*) is entirely submerged by contrast, thus masking it on the 3D endoluminal reformats (not shown). (**d**) Photograph from optical colonoscopy shows a 3-cm lobulated flat lesion within the cecum. Biopsies were performed, and histology was consistent with tubular adenoma

falsely appear mobile [124]. Characteristics of difficult-to-detect polyps include flat morphology, undulating surface contour, visibility on only one view, location on a fold, or morphology that imitates a bulbous fold (Fig. 5.21) [113, 125]. On 2D images, thickened or complex folds, real or artifactual, may also be mistaken for polyps or masses (Fig. 5.22).

While the debate about the relevance of flat, superficially elevated, or "non-polypoid" lesions [126, 127] is beyond the scope of this chapter, awareness of their presence and appearance is important. These lesions are defined as having a height less than or equal to 3 mm [126]. While less conspicuous than polypoid lesions, they are still detectable with meticulous technique. Of note, this 3-mm definition does not include "carpet lesions."

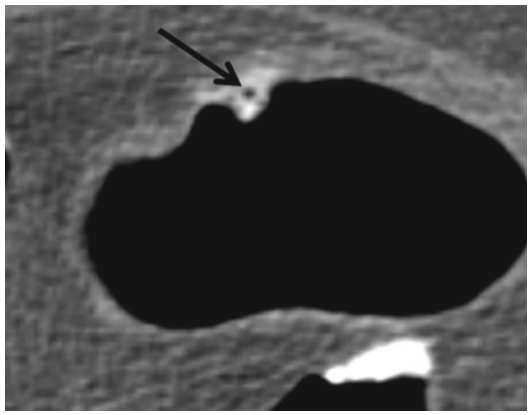

Fig. 5.18 Stool is often irregular in morphology and contains gas. Prone 2D axial image demonstrates a polypoid lesion within the colonic lumen. This can be confidently diagnosed as stool because it contains a focus of air (*arrow*) and has an irregular morphology. It is also higher attenuation than soft tissue due to fecal tagging

Differential Diagnosis

Differential diagnosis of mucosal lesions includes not only neoplastic entities such as adenomas (tubular, tubulovillous, or villous in histology) and adenocarcinoma (Fig. 5.23), but also nonneoplastic lesion such as hyperplastic, juvenile, inflammatory, or hamartomatous polyps. These are impossible to distinguish on CTC, although it is postulated that hamartomatous polyps are flatter because they are soft and compress easily with insufflation [128]. Submucosal lesion such as lipomas, carcinoids, gastrointestinal stromal tumors, and hematogenous metastases can also imitate polyps (Fig. 5.24). Extrinsic lesions, such as impression from extracolonic structures (Fig. 5.25), appendiceal lesions (Fig. 5.26), and intussusception can also cause interpretive difficulties. Diverticula, especially when impacted,

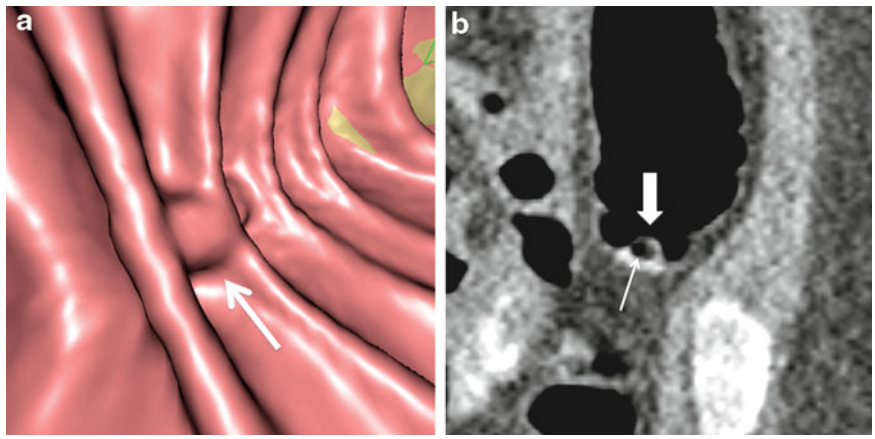

Fig. 5.19 Stool may be round in morphology. In this case, intralesional gas helps exclude a true lesion. (**a**) 3D endoluminal view of the descending colon demonstrates a polypoid lesion (*arrow*) between two haustral folds. (**b**) 2D supine axial image demonstrates that the lesion (*larger arrow*) is heterogeneous and contains a focus of gas (*smaller arrow*), confirming that it is residual fecal material

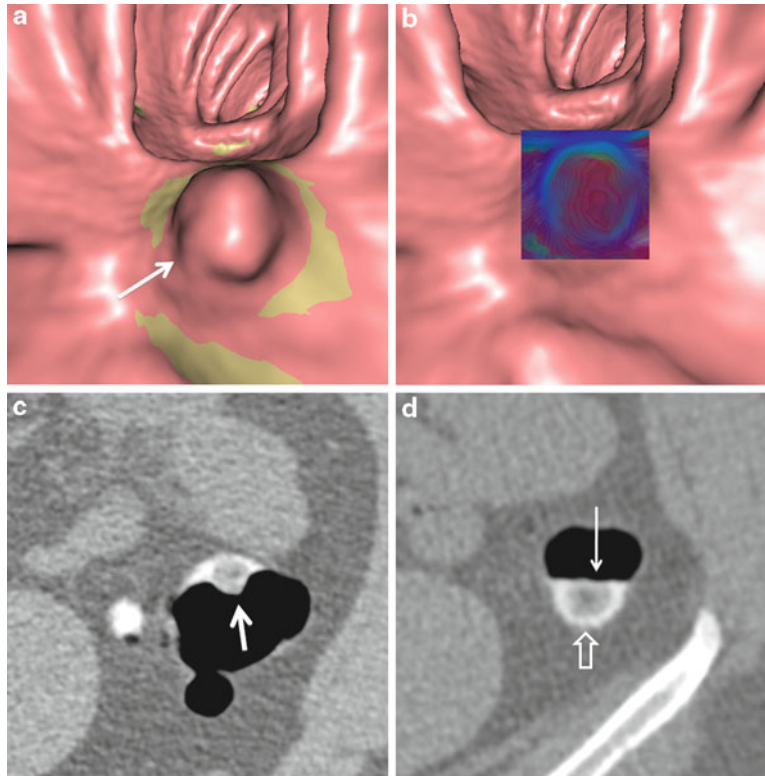

Fig. 5.20 Stool usually changes position between supine and prone scans. In this example, dual positioning was critical because the stool was homogeneous soft tissue density. (**a**) 3D endoluminal view of the left colon demonstrates a polypoid luminal protrusion. Note that the discriminative color coding (*golden colored*) did not identify the lesion as tagged stool. (**b**) Application of the translucency views demonstrates that the core of the lesion is *red*, corresponding to soft tissue density. This appearance is highly suspicious for a true polyp. (**c**) 2D axial prone view demonstrates that the lesion (*arrow*) layers dependently. (**d**) 2D supine axial image shows that the lesion again layers dependently, changing position. This lesion is consistent with residual stool. Note that high-density tagging material (*open arrow*) outlines and undercuts the lesion

can imitate disease (Fig. 5.27). Anorectal lesions such as hemorrhoids or hypertrophied anal papilla can simulate polyps or cancers.

Workstation Selection

Alongside advancements in MDCT, computer graphics technology has also evolved, such that there are now on the order of ten FDA-approved commercial workstations with CTC interpretation software. Some are thin-client web based, some are stand-alone workstations, and others are integrated into PACS. While they share many features in common, there is substantial variability in capabilities and user-friendliness. Basic features include the ability to perform MPR and 3D endoluminal reconstructions as well as length and volume measurements (Fig. 5.28). Additional features may include wide-angle or panoramic views, "virtual dissection" or "filet" views, translucency rendering, stool labeling or color coding, electronic stool subtraction, "missed region" identification, and computer-aided detection (CAD) among others. All of these features are designed to improve diagnostic performance, as well as increase reader confidence and efficiency. Because one "optimal" means of CTC interpretation does not fit all readers, there is considerable debate about the best approach to use.

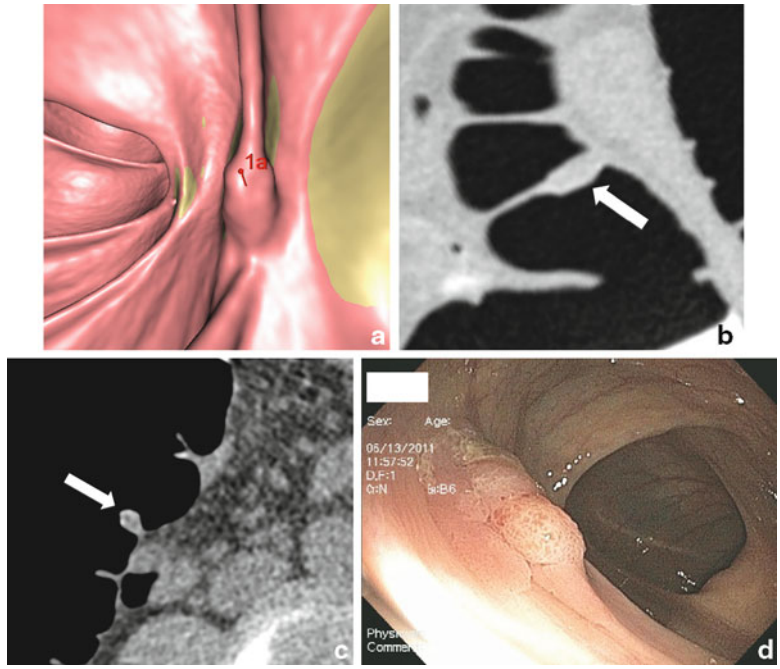

Fig. 5.21 Polyps can be mistaken for bulbous haustral folds. (**a**) 3D endoluminal view of the ascending colon demonstrates a polypoid contour abnormality of the base of a haustral fold (labeled 1a). (**b**) Corresponding supine 2D axial image demonstrates asymmetric fold thickening along the medial wall (*arrow*). (**c**) Prone axial view of the area in question demonstrates a thickened fold along the medial wall. (**d**) Photograph from optical colonoscopy shows a lobulated, sessile polyp that was subsequently removed. The lesion was a tubular adenoma

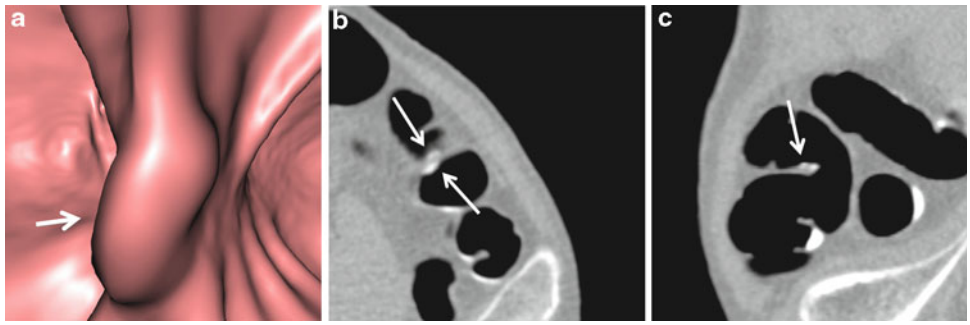

Fig. 5.22 Pseudo-fold thickening can be mistaken for a pedunculated polyp. (**a**) 3D endoluminal view of the left colon demonstrates a possible pedunculated polyp (*arrow*). (**b**) 2D axial image of the area in question demonstrates that the bulbous component of the lesion actually consists of labeled stool on both sides of a non-thickened fold (between *arrows*). (**c**) Corresponding 2D sagittal MPR confirms that the fold is not thickened and that the bulbous component is composed of tagged stool

2D Versus 3D Interpretation

Without a doubt, comprehensive assessment of CTC data requires interrogation of both 2D and 3D views. That said, upon opening a case at the workstation, one can choose to begin the primary search for polyps with either 2D or 3D projections. The 2D data set is the standard grayscale display, optimized for polyp detection by employing high contrast window settings (width = 1,400,

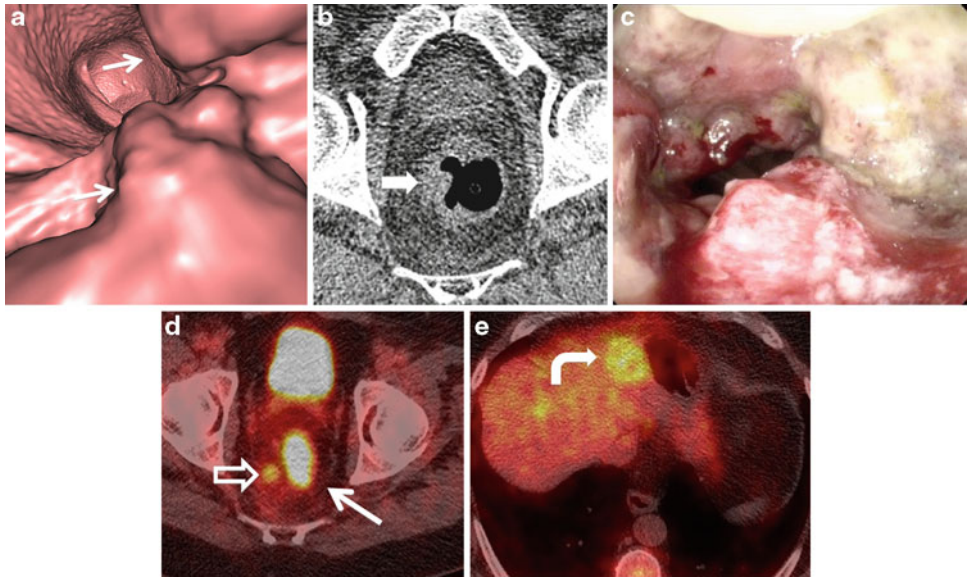

Fig. 5.23 The differential diagnosis of mucosal lesions includes adenocarcinoma. (**a**) 3D endoluminal view of the rectum demonstrates a large, irregular, nearly circumferential mass lesion (*arrows*) in the low rectum. (**b**) Corresponding prone 2D axial image of the lower rectum demonstrates the mucosal mass lesion (*arrow*) extending from approximately the 4:00 to the 2:00 position. (**c**) Photograph from optical colonoscopy demonstrates a friable, ulcerated, annular mass in the low rectum. Pathology was consistent with adenocarcinoma. (**d**) Single axial image from staging PET/CT demonstrates the hypermetabolic primary mass (*arrow*), as well as a hypermetabolic perirectal lymph node (*open arrow*). (**e**) The same PET/CT at the level of the liver demonstrates a hypermetabolic liver metastasis (*curved arrow*)

level = −350) [12]. Multiplanar reformats such as coronal and sagittal views fall under the umbrella of 2D. The 3D data set refers to other data reconstructions, most commonly virtual endoluminal views. A "primary 2D reader" first reviews the data in the axial plane with interrogation and problem solving of suspected lesions using 3D reformations [129]. A "primary 3D reader" does the opposite, examining the colon with the 3D endoluminal view and using the 2D data to investigate suspected findings.

It has been known for some time that endoluminal viewing improves the sensitivity for polyp detection at CTC above that achievable with 2D alone [45, 130]. Before 2003, most CTC readers used a primary 2D technique, reflecting the majority opinion that this was the optimal method of data interpretation [131, 132]. This technique was also more comfortable and familiar than the endoluminal fly-throughs. As technology has improved and CTC software systems have become capable of time-efficient 3D review, attitudes have begun to change [133]. As evidence of its superiority accumulates, there has been a more recent migration toward primary 3D interpretation [134, 135].

To date, there have been five major CTC trials evaluating cohorts of patients with a low prevalence of disease. The Department of Defense (DOD) CTC screening trial [45] used a primary 3D approach and demonstrated that the sensitivity of CTC for clinically relevant polyps was comparable to that of OC. In contrast, three other trials restricted readers to a primary 2D approach, and results were inferior [136–138]. The most recent of the trials, the ACRIN trial, randomized readers to interpret in primary 2D or 3D. It demonstrated the there was no difference in performance between the two techniques [10]. Confounding the results, however, the majority of ACRIN sites used a cumbersome software platform, which at the time, could not really support

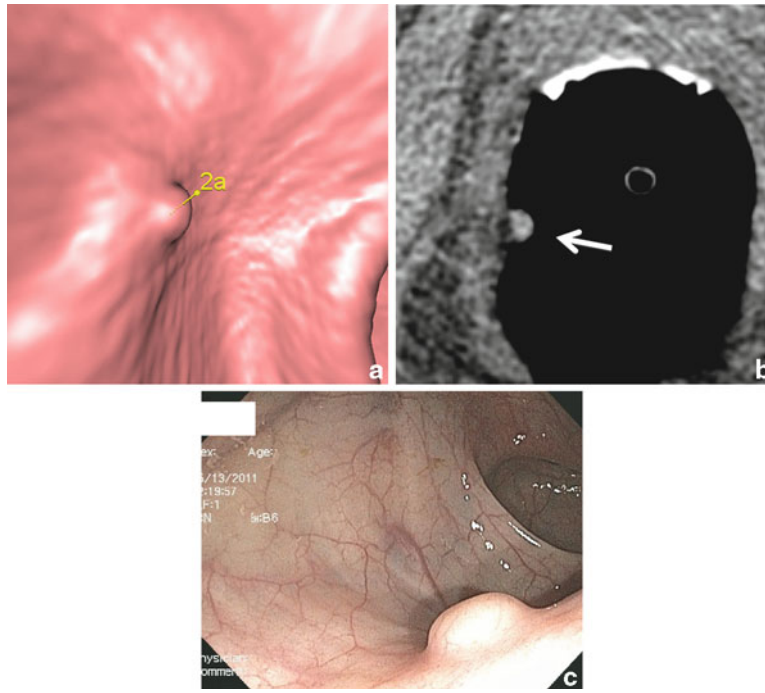

Fig. 5.24 Submucosal lesions can be mistaken for polyps. (**a**) 3D endoluminal view of the rectum demonstrates a 7-mm polypoid protuberance (labeled 2a). (**b**) Corresponding 2D axial image confirms that the lesion in question is homogeneous soft tissue density (*arrow*), concerning for a polyp. (**c**) Photograph from optical colonoscopy shows that the lesion is actually submucosal. Endoscopic mucosal resection was performed, the pathology of which revealed a low-grade neuroendocrine tumor. Small submucosal lesions are difficult to discriminate from mucosal lesions at CTC

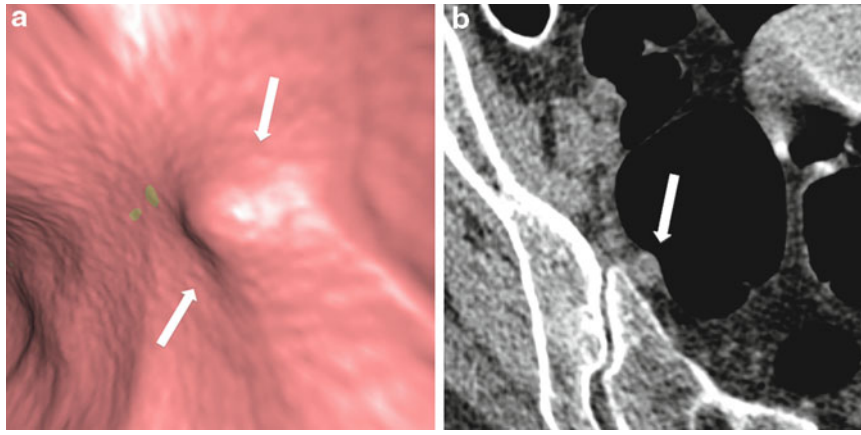

Fig. 5.25 Impression from extracolonic structures can imitate lesions. (**a**) 3D endoluminal view of the colon demonstrates a contour abnormality along the lateral wall (between the *arrows*). (**b**) Corresponding supine 2D axial image demonstrates that this contour abnormality is due to the impression from the normal right internal iliac artery (*arrow*)

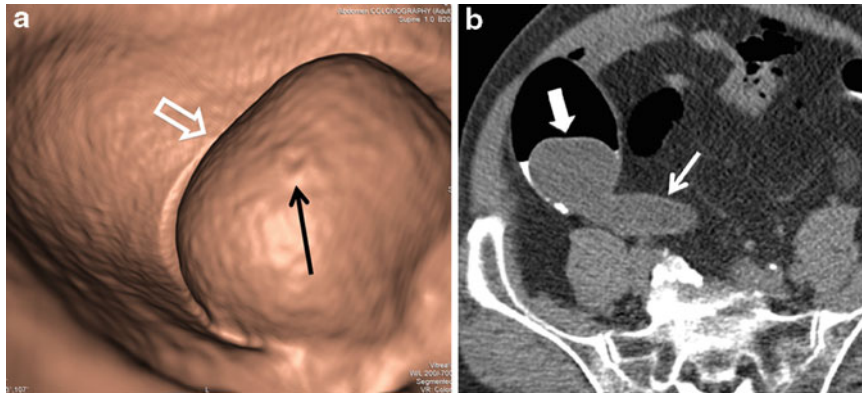

Fig. 5.26 Appendiceal lesions can cause interpretive difficulties. (**a**) 3D endoluminal view of the cecum demonstrates a round mass lesion (*open arrow*), which is inverting the appendiceal orifice (*arrow*). (**b**) Corresponding supine 2D axial image demonstrates that the appendix (*arrow*) is severely distended, and there is a low-density round lesion (*open arrow*) projecting from the appendiceal lumen into the cecum. The patient underwent surgery and was found to have a mucinous cystadenoma of the appendix

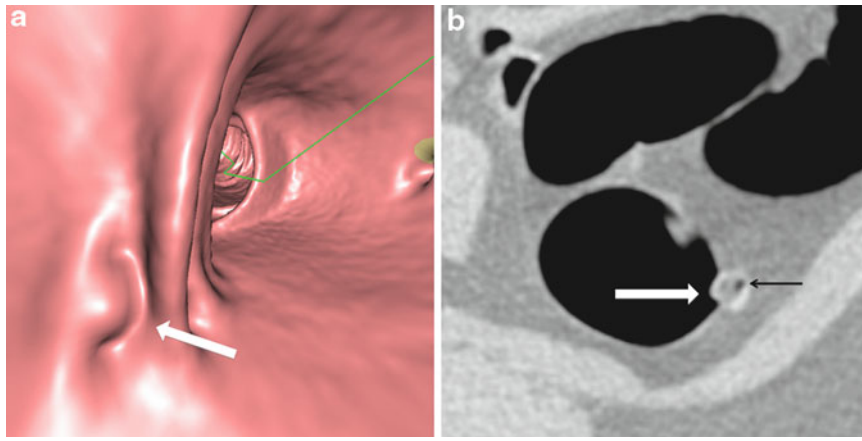

Fig. 5.27 Impacted diverticula are a known pitfall at CTC. (**a**) 3D endoluminal view demonstrates a polypoid protrusion (*arrow*) within the colon, adjacent to a fold, suggestive of a small polyp. (**b**) Corresponding 2D axial image demonstrates that this lesion is actually an impacted diverticulum (*arrow*), a diverticulum with heterogeneous inspissated contents that project intraluminally. Note the focus of gas (*thin black arrow*)

a true primary 3D approach. It is likely, therefore, that 3D performance in this trial was underestimated [133]. Pickhardt, in an ingenious 2007 study, retrospectively reinterpreted CTC cases from the DOD trial (initially read in primary 3D) using a primary 2D approach. Results showed that, despite the fact that his reviewers were significantly more experienced than those for the original trial, the sensitivity for adenomas ≥10 mm dropped from 92.2 to 75% [133].

Whatever the method of primary interpretation, there are inherent advantages and disadvantages to each method. Some pitfalls are lessened using primary 3D technique. For example, small polyps in particular are more easily separated from haustral folds. Complex folds are less likely to be misinterpreted as polyps. Primary 3D is often easier for inexperienced readers, with a shorter learning curve [139]. Interobserver variability is lower with 3D technique [45, 136].

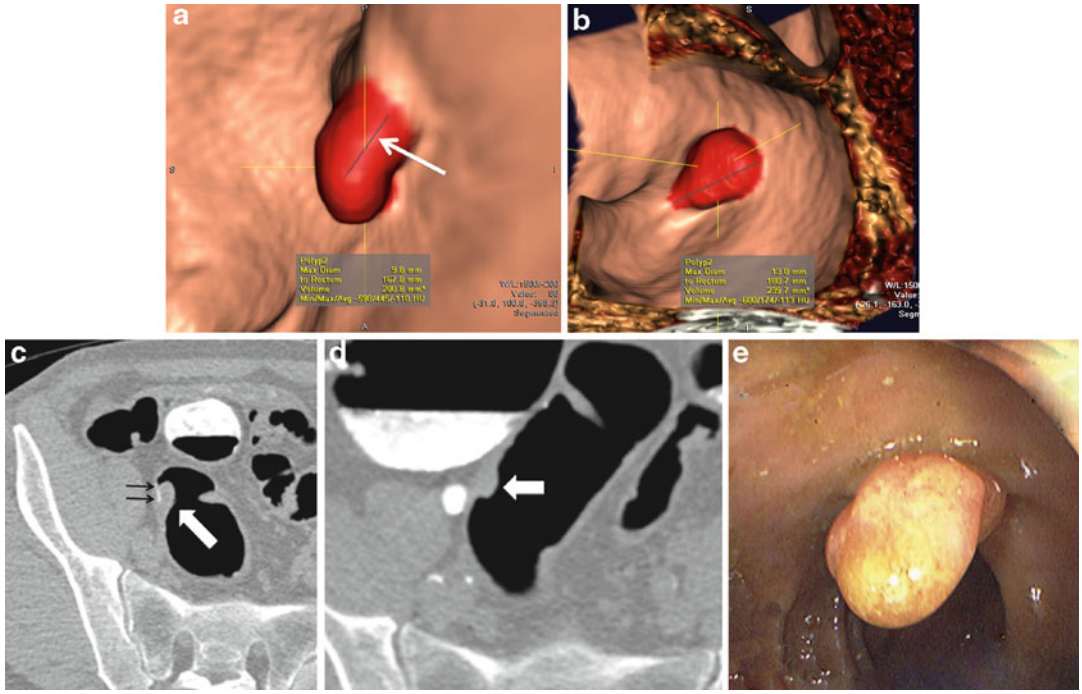

Fig. 5.28 Length and volume measurements are a basic feature of any CTC software package. (**a**) Prone 3D endoluminal view of the sigmoid colon demonstrates a pedunculated polyp. This software has an automated measurement feature. The user clicks on the suspected abnormality. The software then labels it *red*, creating a bookmark. Maximum diameter, distance to rectum, and volume measurements are displayed. Note that in this instance, the length of the automatic measurement caliper (*arrow*) has likely under-measured the polyp diameter (shown in *red*). (**b**) Supine 3D endoluminal "cube view" shows the same polyp. Its pedunculated morphology is less apparent than on the prone view. The cutaway of the cube view allows the area of interest to be rotated and viewed from different angles, removing the voxels, which interfere with the desired viewing angle. Note that in this view, the automated measurement calipers are placed more accurately. (**c**) Corresponding prone 2D axial image demonstrates a soft tissue polyp (*large white arrow*) in the sigmoid colon. Note that tagged liquid (*small black arrows*) undercuts the lesion, demonstrating its pedunculated morphology. (**d**) Corresponding supine 2D axial image demonstrates the polyp (*large white arrow*) in the sigmoid colon. Just as with the 3D endoluminal view, its pedunculated morphology is not well appreciated. (**e**) Photograph from optical colonoscopy shows a pedunculated polyp in the sigmoid colon. Pathology revealed a tubular adenoma

Referring gastroenterologists tend to appreciate 3D endoluminal views because they simulate colonoscopy.

Advantages of primary 2D interpretation include the ability to readily determine the density of filling defects. 2D evaluation is particularly helpful in cases with poor bowel preparation and adherent stool or in segments with luminal collapse [133]. The bowel wall integrity and fold contour are also more readily assessed with 2D evaluation [129, 140, 141]. An often-cited advantage of primary 2D over 3D is faster interpretation time [10, 45]. For example, the mean interpretation times in the DOD study were 6.7 min for 2D versus 19.6 min for 3D [45]. In the ACRIN trial, they were 19.4 min versus 25.3 min, respectively [10]. Longer interpretation times for 3D are due to the necessity of performing a total of four fly-throughs, two in each direction in both the supine and prone positions [142]. This is done in order to avoid "blind areas," parts of the mucosa hidden behind colonic folds or simply out of the field of view of the virtual colonoscope. It should be noted that even bidirectional review does not eliminate all blind spots, and some 3D workstations can display sequential

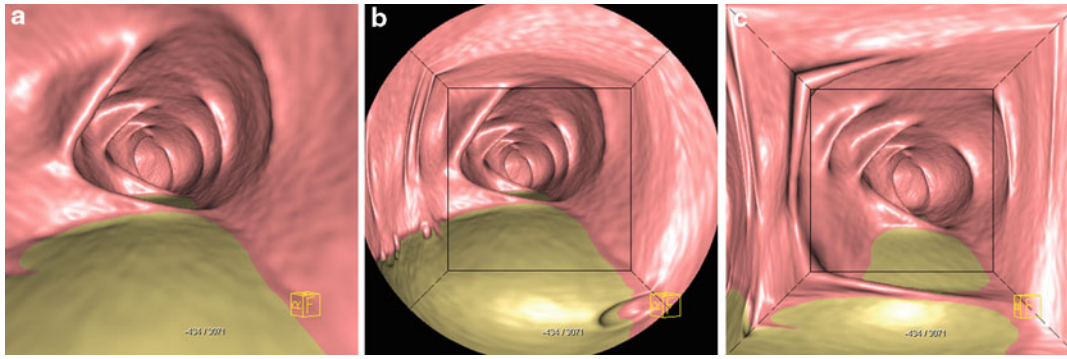

Fig. 5.29 Panoramic 3D displays widen the field of view, increasing mucosal visualization. (**a**) Standard 3D endoluminal view of the sigmoid colon demonstrates color-coded liquid layering dependently (*golden color*). (**b**) Panoramic wide-angle view of the same region demonstrates how the frontal view is mapped into a square, and the other 4 faces are mapped around it into a disk. This widens the field of view. A luminal protrusion is seen in the lower right-hand corner (*arrow*). (**c**) This panoramic view shows an even wider field of view. The filling defect is seen in the lower left-hand corner (*arrow*). Notice the distortion that thins and elongates the abnormality

blind spots until 100% of the mucosa has been displayed [143].

As both hardware and software have improved, the speed of 3D rendering has improved substantially [133]. As such, the advantage that a primary 2D viewer has in terms of speed is likely being eroded. Speed also improves with experience. At one high-volume center, interpretation times with a primary 3D approach are under 10 min for an average case [30]. Newer techniques such as panoramic views and virtual dissection were designed to reduce the need to do both antegrade and retrograde navigation, thus shortening interpretation times.

Panoramic View

Panoramic 3D display was designed to improve the visualized surface area in CTC by increasing the field of view from 90 to 120°. It is constructed by mapping the frontal view into a square, while the other four faces are mapped around it into a disk [143]. This not only widens the field of view but also essentially "stretches open" or unfolds the colon, revealing the spaces between and behind folds (Fig. 5.29). Thus, only unidirectional navigation is needed to evaluate the entire mucosa, increasing speed because theoretically there are no unseen areas. [132, 143, 144] One criticism of this technique is mucosal distortion and its potential effect on polyp conspicuity [135]. However, this does not appear to influence performance, as shown in several studies. A 2011 retrospective study of 150 OC-validated CTC data sets was performed comparing a standard, bidirectional primary 3D approach with a unidirectional 3D panoramic view. Overall sensitivity was not significantly different, but mean interpretation times decreased from 14.6 to 7.5 min using the panoramic view [145]. These results are consistent with several other studies demonstrating improved efficiency without degraded performance. [132, 143, 144]

Virtual Dissection

The "virtual dissection" or "filet" view grew out of laboratory work demonstrating the efficacy of the panoramic view in virtual endoscopy [146]. The software was designed to allow overview of the entire colonic mucosa at once. To do this, the software "slices" along the long axis of the colonic 3D model, "fileting" it open and displaying what was once a cylindrical object as a flattened rectangular image (Fig. 5.30) [147–149]. The appearance is similar to that of a pathologic

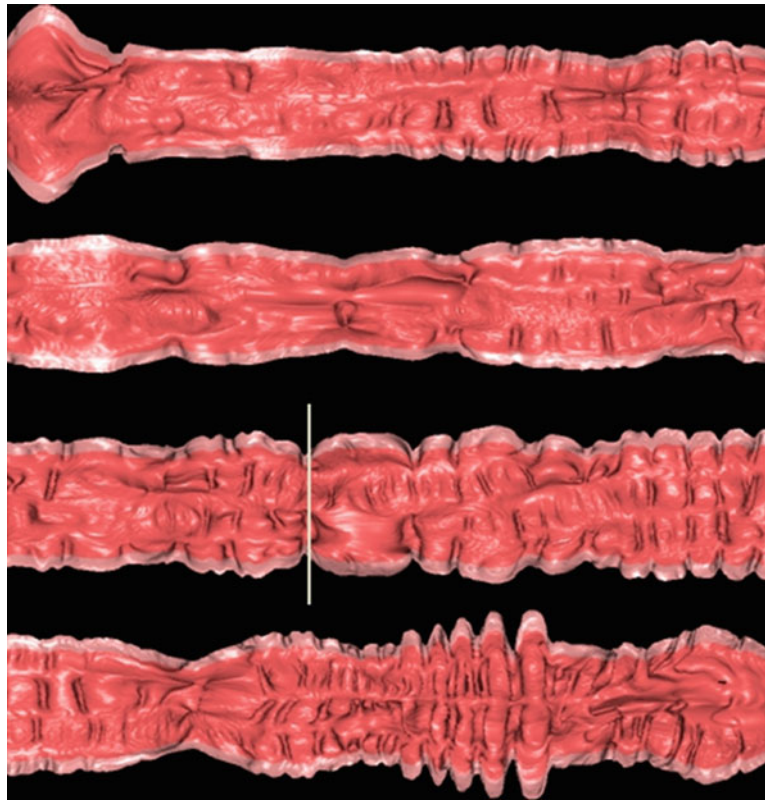

Fig. 5.30 The virtual dissection technique enables simultaneous visualization of the entire colonic mucosal surface. 3D filet view of the colon demonstrates how it is virtually straightened along the centerline and "sliced" open as if it were a pathologic specimen

specimen, thus the name "virtual dissection." The advantages of the virtual dissection view include shorter interpretation times, reduced blind spots, and elimination of the need to perform both anterograde and retrograde fly-throughs [135, 140]. The virtual dissection view has been criticized for the anatomic distortion that occurs, especially at flexures. Polyp shape and size can be misrepresented so that even some large polyps may be unrecognizable due to distortion [144]. Conversely, normal folds can take on the appearance of polyps. That said, this distortion is fairly predictable [147]. Another criticism of virtual dissection is that it must be correlated with the standard 2D and 3D views [146, 150]. However, the need for 2D problem solving is not unique to the virtual dissection view but applies to all 3D techniques [151]. An additional problem is that collapsed segments or annular masses can cause skip areas where the lesion is not displayed at all [148]. The learning curve for virtual dissection has been voiced as a concern, which could further diminish performance for this method [144].

Performance characteristics of virtual dissection are lower than those achievable with the standard 3D interpretation [140, 152, 153]. They are comparable to 2D in detection rates for both experienced [135, 140, 152] and inexperienced [154] readers. In a 2007 study, Johnson showed that interpretation times for virtual dissection were 28% faster than with the conventional 2D method (10.4 min vs. 14.5 min, respectively) [140]. Additionally, he demonstrated that double review using both conventional and virtual dissection could compensate for poorer-performing reviewers, decreasing interobserver variability,

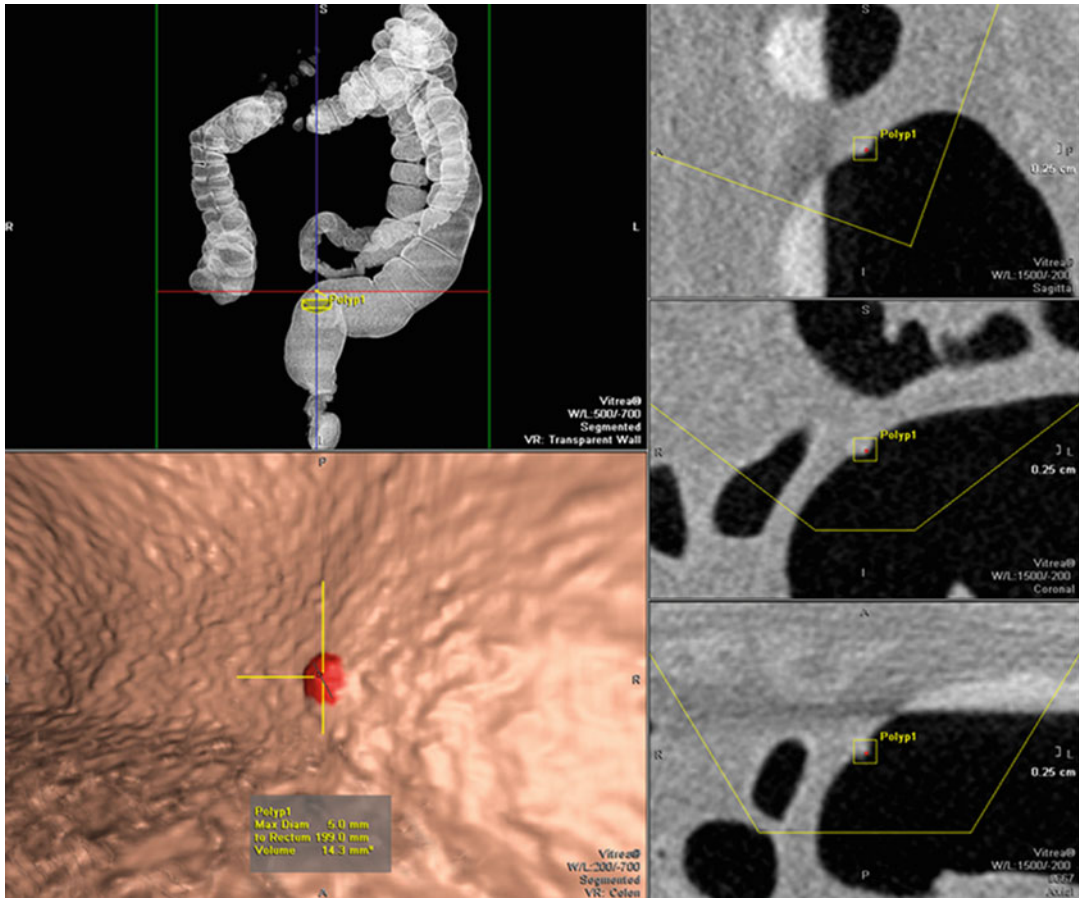

Fig. 5.31 Computer-aided detection (CAD) software can help detect and mark lesions suspicious for polyps. Screenshot from a 3D CTC workstation demonstrates a luminal protrusion detected by computer-aided detection (CAD). In the *lower left-hand corner*, the lesion is shown coded *red*, with diameter, volume, and distance from the rectum displayed. The *top left* shows a virtual barium enema view with a marker at the location of the polyp. The 3 panels on the *right* are standard 2D MPR's with the polyp marked with a *red dot*

and improving sensitivity, surpassing even the sensitivity of OC for adenomatous lesions ≥ 1 cm [140]. At this time, the filet view is not commonly used as a primary means of interpretation, but rather as a useful adjunct.

Computer-Aided Detection

Computer-aided detection refers to analysis of the 3D CTC data set by a computer software algorithm to detect and flag lesions that are likely to be polyps (Fig. 5.31). This has been proposed as a way to help readers achieve better performance. In the majority of studies, investigators have found that CAD does improve readers' performance, particularly those with less experience [155–159]. One consistent criticism of CAD is that it typically generates a number of findings, most of which are false-positives that nevertheless have to be interrogated. This has the potential to decrease specificity, although the majority can be quickly dismissed. According to one recent study, the three most common causes of false-positive findings were the ileocecal valve (Fig. 5.32), haustral folds, and poorly tagged stool [160]. CAD can be used either concurrently with the human interpreter or used as a second reader.

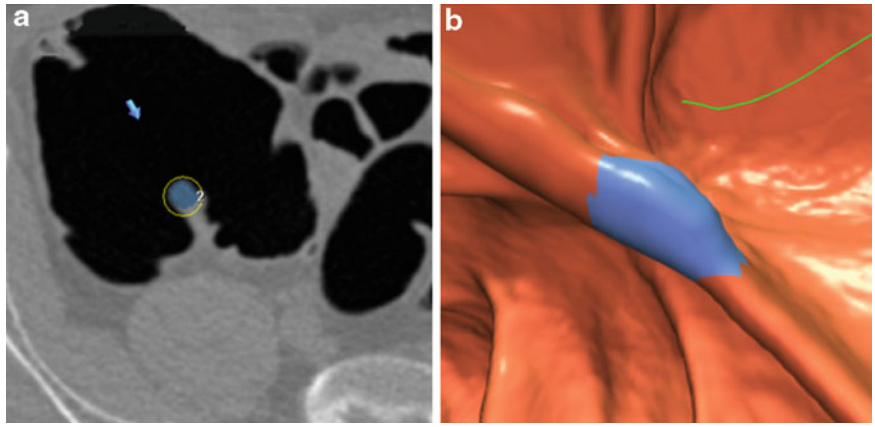

Fig. 5.32 The ileocecal valve is a common cause of false-positive findings at CTC with CAD. (**a**) Prone 2D axial image of the right colon demonstrate that CAD has marked a possible lesion (*blue color* with a *yellow circle* around it). (**b**) Corresponding 3D endoluminal view of the cecum demonstrates that the lesion marked *blue* by CAD is actually the normal ileocecal valve

A recent study by Halligan showed that second-read CAD significantly improved per-patient polyp detection without a clinically unacceptable decrease in specificity, whereas use of concurrent CAD was less effective [161].

It is remarkable that stand-alone CAD is often more sensitive than a reader assisted by CAD. This may be due to the radiologist sometimes incorrectly dismissing lesions that are correctly detected by CAD [155, 157, 162]. A study by Taylor in 2009 identified factors that lead radiologists to incorrectly dismiss lesions [163]. Interestingly, the larger the polyp and the more irregular its contour, the more likely it was to be thought to be a false-positive [163]. Thus, although CAD may generate a large number of targets and most of these may be quickly and easily dismissed, it is important to realize a potential bias against large or irregular lesions.

Measurements, Reporting, and Triage

Background

The size of an adenomatous polyp directly correlates with its cancerous potential. For this reason, accurate measurement is essential for proper patient management [164]. A difference of a millimeter can change patient disposition. As an example, a polyp ≤ 5 mm need not be reported under the 2009 ACR guidelines and thus a patient with such a lesion will not be offered surveillance. A consensus of three national medical societies, including the ACR, recommends immediate colonoscopy with polypectomy for both small (6–9 mm) and large (≥10 mm) polyps [165]. The C-RADS reporting system (discussed below) discriminates between small and large polyps. A CTC that depicts only one or two polyps 6–9 mm in size is reported as "C2," whereas one that demonstrates a polyp 10 mm or more in size is categorized as "C3." The recommended management in this system is surveillance or colonoscopy for C2 and colonoscopy for C3. Thus, the accuracy of polyp measurement in the 5–10 mm range is especially important [166].

Polyp Measurements

Both CTC and OC have inherent limitations in measurement capability and accuracy [167, 168]. The most accurate method of polyp measurement is debatable, as the data are mixed. Some studies demonstrate underestimation [168–172] of polyp size on CTC and others demonstrate overestimation [170, 173]. In general, polyp size measured

at CTC tends to lay between measurements at OC and pathologic evaluation and may be the most accurate method compared to the in vivo size [174]. This is substantiated by a 2007 direct comparison of CTC and OC in the measurement of 86 simulated polyps in pig colonic specimens where CTC was shown to be superior in both accuracy and reliability [168].

There are several possible ways of measuring a polyp found on CTC, including the 2D axial images, 2D MPR's, "optimized" MPR's, or 3D endoluminal images, each of which has been demonstrated to give differing measurements, as does the window-level setting used to view the images [169, 175]. Additional factors affecting size include spatial resolution, partial volume averaging, motion artifacts, noise, rendering thresholds, the effects of fecal tagging agents, and unsurprisingly, observer variability [174]. This issue has been studied, and it is of practical interest to understand which methods are most effective.

A 2006 retrospective study by Yeshwant et al. [176] demonstrated that measurements from 3D images best approximate polyp size at OC. Bethea validated this in a 2009 study [166]. In his 2007 simulated polyp study, Park demonstrated that 2D measurements in an "optimized" MPR plane, an oblique plane in which the polyp has the largest diameter, were found to be the most accurate [168]. 3D measurements were the second most accurate, followed by 2D orthogonal MPR's. He concluded that the speed and ease of 3D measurements make up for any degree of the inaccuracy and are preferred over the optimized MPR method in practice [36]. It should be noted that 3D measurements in this case do not apply to nontraditional 3D techniques such as "virtual dissection," that are prone to distortion.

Many software platforms have an automated measuring tool that measures the polyp diameter and volume simply by clicking on it with the mouse (Fig. 5.33). Automated measurements tend to either overshade or under-shade the area being used for length and volume computation and no tool may be available to manually correct the errors. It has been noted that this problem is particularly exacerbated for polyps with irregular, nonspherical morphologic features. This tool should be used with caution, paying attention to the accuracy of what the software determines to be the borders of the lesion (Fig. 5.28) [166].

Polyp Location

Accurate localization of a polyp on CTC is of paramount importance so that the endoscopist can easily and efficiently find and remove the lesion at OC. Absolute distance values from the anus cannot be used to locate polyps found on CTC at OC. This is because CTC software calculates the colonic length at almost double that at OC [177]. These differences in colon length are due mostly to procedural factors that occur during OC, such as telescoping and foreshortening. Simply communicating polyp location by the colonic segment of interest is also not useful because the endoscopist is not often able to accurately determine his location during OC.

More accurate localization can be provided by computing the normalized distance along the colon centerline of a polyp found at CTC. By using this technique, the location of a polyp at OC can be predicted to within 10 cm for the majority of lesions [177]. The normalized distance at CTC is computed by dividing the distance of the polyp from the anorectal junction along the colonic centerline by the length of the entire colon. The predicted polyp location at OC is then computed by multiplying this normalized distance by the length of the entire colon at OC. For example, a polyp is identified on CTC at 50 cm from the rectum. The length of the colon is measured at 200 cm. Normalized distance is calculated as $50/200 = 0.25$. The clinician then performs OC and measures the distance from the anorectal junction to the cecum as 150 cm. Therefore, he will search for the polyp at 38 cm (0.25×150). Duncan, based on a study of 383 patients with 437 polyps, proposed standardized conversion factors for determining anus-to-polyp distance at OC from CTC measurements [178]. Conversion factors of 0.59 for right-sided or 0.78 for left-sided CTC anus-to-polyp measurements may substitute for calculating the normalized distance. He also mentioned that details about the lesions' relationship to an anatomical

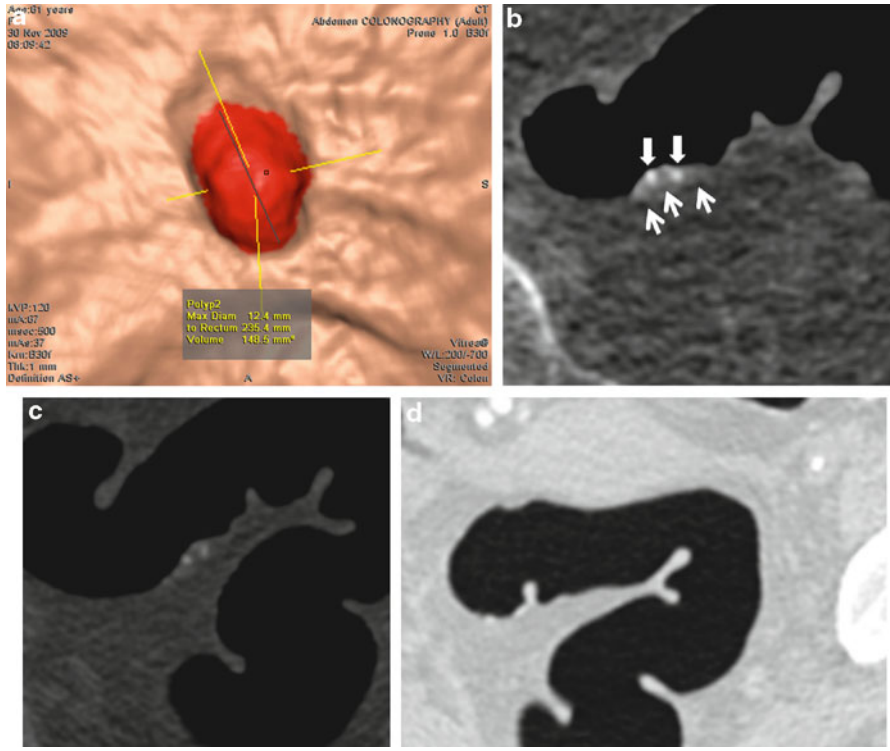

Fig. 5.33 CTC workstations have automated polyp measuring tools as a standard feature. The tools cannot help discriminate polyps from pseudo-lesions. (**a**) Prone 3D endoluminal view shows a 1.2-cm lesion in the sigmoid colon suspicious for a polyp. The lesion was slightly under-measured by the automated measurement calipers. (**b**) Corresponding prone 2D axial image shows a heterogeneous lesion arising from the posterior wall. The lesion has an irregular surface (*small arrows*) superficially coated with high-density tagging material (*larger arrows*). (**c**) Supine 2D axial image shows the lesion is nonmobile. Barium can selectively adhere to villous lesions, raising our suspicions. Because the patient was anticoagulated for severe pulmonary hypertension, rather than performing colonoscopy, the patient was followed up 1 month later. (**d**) Repeat supine 2D axial image demonstrates that the area in question is free of disease. The lesion seen on the original examination was therefore a pseudo-lesion from thickly adherent stool

reference point such as the ileocecal valve, appendiceal orifice, or a particular fold can be helpful to the endoscopist [178]. We routinely provide distance to the polyp from the anorectal junction, the colonic segment, as well as any nearby landmarks.

Systematic Reporting

A system for structured reporting of CTC studies has been proposed by a panel of experts, with the aim of replicating the benefits of the BI-RADS system used in mammography. The C-RADS system [121] captures information about preparation quality, polyp presence and size, and extracolonic findings, and places the overall study into one of five categories including recommendations for follow-up. Such a system will be very useful for large-scale research, both for epidemiological and cost-effectiveness purposes.

Same-Day Service

Same-Day OC

In a model setting, patients with positive CTC examinations would proceed directly to same day OC, thereby avoiding treatment delay and a second

bowel cleansing. Arranging this workflow requires close coordination with the endoscopy department at each particular institution. Patients who undergo CTC with the option of same-day OC must adhere to guidelines intended for OC patients, who are prepared for potential polypectomy. This includes stopping anticoagulants, aspirin and NSAIDs, requiring coordination with the referring physician.

The issue of patient preparation must also be addressed by consensus. The cathartics and fecal tagging agents for CTC must be acceptable to the endoscopist for OC. Unlike residual solid material, residual fluid is not a problem at OC because it can easily be suctioned during the exam [48]. Noncathartic or limited cathartic bowel preparations are obviously not appropriate for same-day OC. If less aggressive catharsis is employed, additional bowel preparation before OC has been advocated [38].

Patients should undergo CTC in the early morning while their colon remains well prepared. For proper triage, CTC studies should be interpreted in as close to real time as possible, while the patient stays NPO and awaits results and instructions. We communicate both positive and negative findings directly to the patient. Positive cases are discussed immediately with the endoscopist, who decides together with the radiologist whether same day OC is indicated. Information such as polyp size, location, and distance from the rectum is essential. The images of the CTC should be available to the endoscopist in a format that is intuitive and informative. 3D endoluminal views as well as the "virtual barium enema" are excellent views to include (Fig. 5.34).

Some flexibility in the OC schedule is needed so that add-on patients can be accommodated when necessary. The amount of flexibility is determined by the CTC program workflow as well as the referral rate. The referral rate depends on the agreed-upon size threshold for referral. For reference, a positive CTC can be expected in approximately 13% of normal risk adults using a size threshold of 6 mm [10]. If the size threshold were 1 cm, the referral rate would of course be lower.

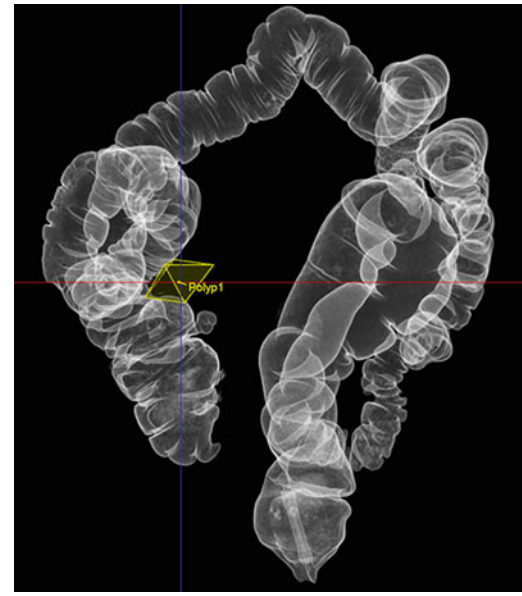

Fig. 5.34 Virtual barium enema views are easy to interpret for non-radiologists. "Virtual barium enema" 3D reconstruction of the colon demonstrates that the location of polyps can be labeled as an aid to the gastroenterologist who will be performing the subsequent colonoscopy. "Polyp 1" is seen in the ascending colon

Same-Day CTC Service

Some have postulated that if patients are offered the option of "same-day CTC," general rates of screening compliance and patient satisfaction will likely be higher [48]. Just as our endoscopy colleagues have committed to perform OC on our CTC patients with polyps, so have we agreed to perform same day CTC. We make every effort to accommodate patients who have undergone incomplete OC earlier in the day. Rates of incomplete OC range in the literature from 2 to 40%, although 5% is a commonly cited number [179]. Reasons for incomplete OC include tortuosity, redundancy, stricture, and obstructing lesions, among others. CTC is of particular use in those with obstructing neoplasms, as it can identify synchronous proximal polyps and cancers preoperatively [180, 181]. Incomplete OC is our most common indication for referral, although many are still not in the habit of referring for same-day CTC service.

In practice, the endoscopist calls us immediately after the incomplete OC. We instruct the patient, after recovery from sedation, to take 60 cc of Gastrografin 2 h before CTC. This technique has been shown to result in satisfactory opacification of the colon, especially proximal segments not seen during OC, in most patients [182]. If the OC is late in the day, the patient is administered the Gastrografin, kept on clear liquids overnight, and scanned first thing in the morning. Patients who have undergone deep biopsy or polypectomy are not candidates for same-day CTC because of the risk of perforation. Regardless of whether polypectomy was performed, we perform a thick slice low-dose scan before insufflation to check for the presence of an asymptomatic perforation.

Summary

CTC has several inherent technical components—preparation, insufflation, CT data acquisition, interpretation, and reporting—all of which must be optimized to enable a high-quality screening or diagnostic clinical practice. This field is a very good example of successful collaborative research between radiologists, basic scientists, and endoscopists. These efforts have been repeatedly validated and matured an important clinical imaging examination that, with widespread application, could significantly reduce the morbidity and mortality of a common disease.

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