Imaging of Large Bowel with Multidetector Row CT

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Abstract

The use of high-resolution multidetector CT (MDCT) has revolutionized evaluation of the large bowel in both the acute emergency room setting and in chronic conditions. The physical exam is often limited and CT can help differentiate between conditions that may mimic each other clinically. Patients often present with vague abdominal symptoms, and CT can help elucidate the etiology and help guide management and treatment. The pathology is vast, and some of the more common acute conditions include appendicitis, diverticulitis, inflammatory bowel disease, and bowel obstruction. More recently, CT has also come

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to play a significant role in the evaluation of acute lower gastrointestinal bleeding. Primary evaluation with CTA has become accepted as an alternative initial screening exam and has been incorporated into the algorithm and work-up of lower gastrointestinal bleeding in many large medical centers. CTA allows for a quick and efficient survey of the abdomen and can triage patients appropriately, ensuring accurate, timely, and safe management.

Considerable improvements have also been made in colorectal cancer screening with CT colonography (CTC, also known as virtual colonoscopy). The American Cancer Society (ACS) and US Preventive Services Task Force (USPSTF) now recognize CTC as an acceptable primary screening option for colorectal cancer, which should pave the way for more widespread usage.

1 Colorectal Cancer

Multidetector CT plays an essential role in the diagnosis, staging, and follow-up treatment of colon cancer. Colorectal cancer is the third most commonly diagnosed cancer and second leading cause of cancer death in the USA with an estimated 4.5% lifetime risk of developing the disease. For the year 2016, the American Cancer Society (ACS) estimates there will be 134,490 new cases of colorectal cancer resulting in approximately 49,190 deaths in the USA. This accounts for 8.0% of all new cancer cases and 8.3% of all cancer-related deaths (SEER Cancer Statistics Review. Available from: https://seer.cancer.gov/data/).

1.1 Colorectal Cancer Pathophysiology

Virtually all colon cancers arise from polyps. Even though there are individuals who are prone to developing polyps such as individuals with a personal or family history of colorectal cancer, those with a history of inflammatory bowel disease or hereditary forms of colorectal cancer, 75–95% of all colon cancers develop in individuals with little or no genetic predisposition for malignancy.

There are two key models or pathways proposed for colorectal cancer development. The vast majority arise from mucosal epithelial cells which undergo a series of mutations according to a well-established adenoma-carcinoma sequence. In this pathway, colorectal cancers arise from precursor lesions known as adenomatous polyps, which undergo a series of stepwise mutational activation of oncogenes and inactivation of tumor suppressor genes ultimately leading to abnormal cell proliferation, apoptosis, and subsequently carcinoma (Bond 2000).

More recently, a serrated neoplastic pathway for colorectal carcinogenesis has also been identified accounting for up to one third of all colorectal cancers (Rex et al. 2012). Serrated lesions are a group of polyps that can be classified pathologically according to the World Health Organization as hyperplastic polyps, sessile serrated adenoma/polyps, or traditional serrated adenomas. While most hyperplastic polyps are typically benign, small subsets, particularly large hyperplastic polyps in the right colon, have been shown to be precursors to sessile serrated adenomas that can ultimately progress to cancer themselves.

1.2 Colorectal Staging

The advent of multidetector CT has played a crucial role in the diagnosis, staging, and treatment of colon cancer. Colon cancer spreads through a variety of patterns including direct infiltration and extension through the serosa, lymphatic drainage to regional lymph nodes, hematogenous spread through the portal venous system to the liver, as well as intraperitoneal seeding. CT has become routine for preoperative staging and surgical planning (Nerad et al. 2016).

Currently, the TNM staging system established by the American Joint Committee on Cancer (AJCC) is the most widely used staging system for colorectal cancer (Fig. 1). This system essentially evaluates three key components in determining staging of the cancer.

T – indicates how invasive the primary tumor is and degree of extension into the wall of the intestine and surrounding structures.

N – indicates the extent of spread to regional lymph nodes.

M – indicates whether the cancer has metastasized to other organ systems.

TNM Colon and Rectum Cancer Staging: Seventh Edition (AJCC)

Primary Tumor (T)

TX Primary tumor cannot be assessed

T0 No evidence of primary tumor

Tis Carcinoma in situ: intraepithelial or invasion of lamina propria

T1 Tumor invades submucosa

T2 Tumor invades muscularis propria

T3 Tumor invades through the muscularis propria into pericolorectal tissues

T4a Tumor penetrates to the surface of the visceral peritoneum

T4b Tumor directly invades or is adherent to other organs or structures

Regional Lymph Nodes (N)

NX Regional lymph nodes cannot be assessed

N0 No regional lymph node metastasis

N1 Metastasis in 1–3 regional lymph nodes

N1a Metastasis in one regional lymph node

N1b Metastasis in 2–3 regional lymph nodes

N1c Tumor deposit(s) in the subserosa, mesentery, or nonperitonealized pericolic or perirectal tissues without regional nodal metastasis

N2 Metastasis in 4 or more regional lymph nodes

N2a Metastasis in 4–6 regional lymph nodes

N2b Metastasis in 7 or more regional lymph nodes

Distant Metastasis (M)

M0 No distant metastasis

M1 Distant metastasis

M1a Metastasis confined to one organ or site (e.g., liver, lung, ovary, nonregional node)

M1b Metastases in more than one organ/site or the peritoneum

The staging of cancer at presentation greatly impacts treatment and survival. Based on the National Cancer Institute's SEER database from 2004 to 2010, the 5-year relative survival rate for individuals with stage I colon cancer was about 92%, 87% for stage IIA, 63% for IIB, 89% for stage IIIA, 69% for IIIB, 53% for stage IIIC, and a dismal 11% for those with stage IV distant metastatic disease.

1.3 Colorectal Screening

The earlier colorectal cancer diagnosis can be made, the better the prognosis. The ACS currently recommends screening for colon cancer beginning at the age of 50 years in asymptomatic men and

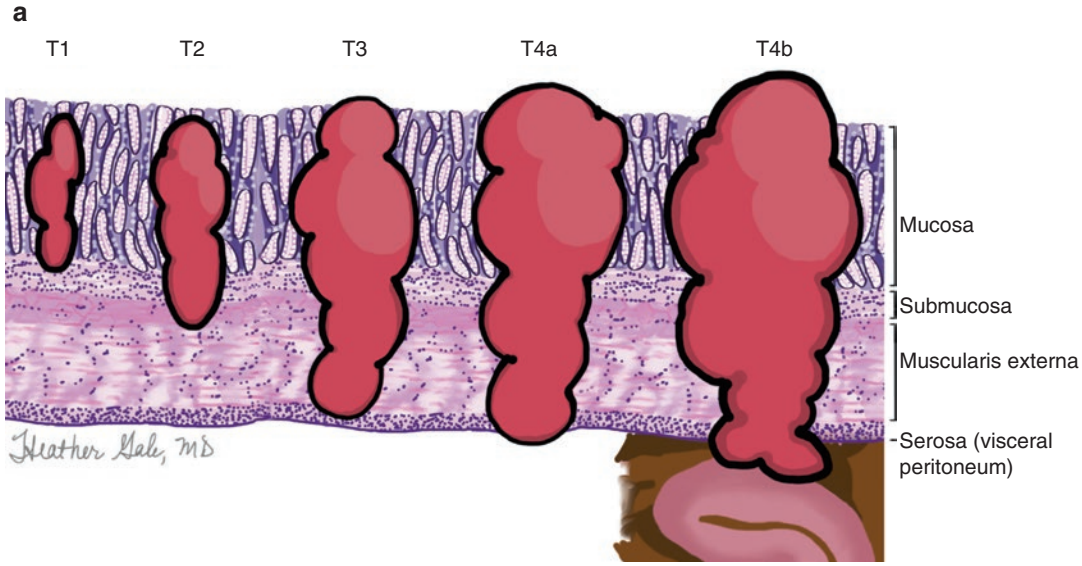
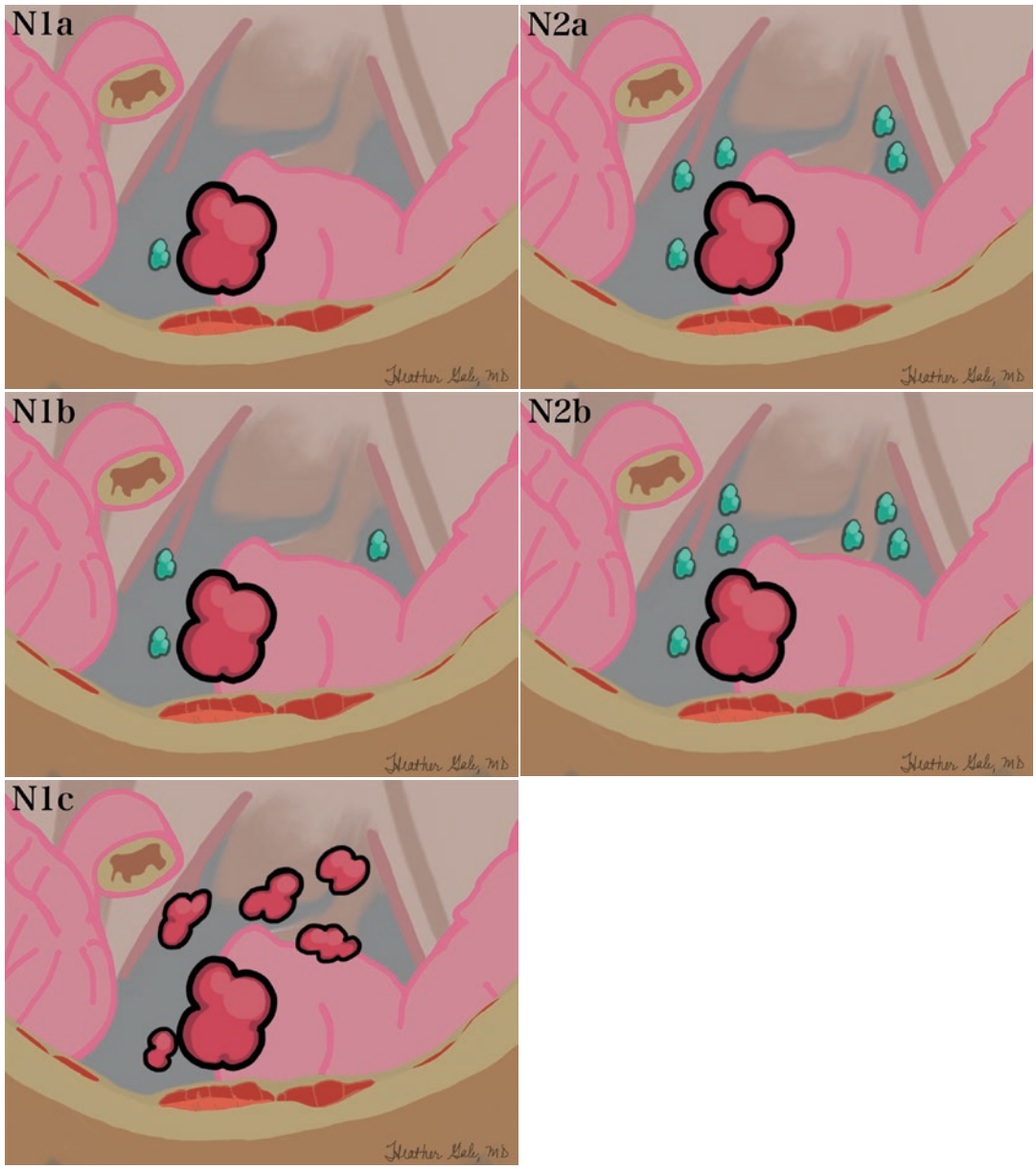


Fig. 1 TNM colon-rectum cancer staging. (**a**) T-staging. (**b**) N-staging. (**c**) M-staging

b



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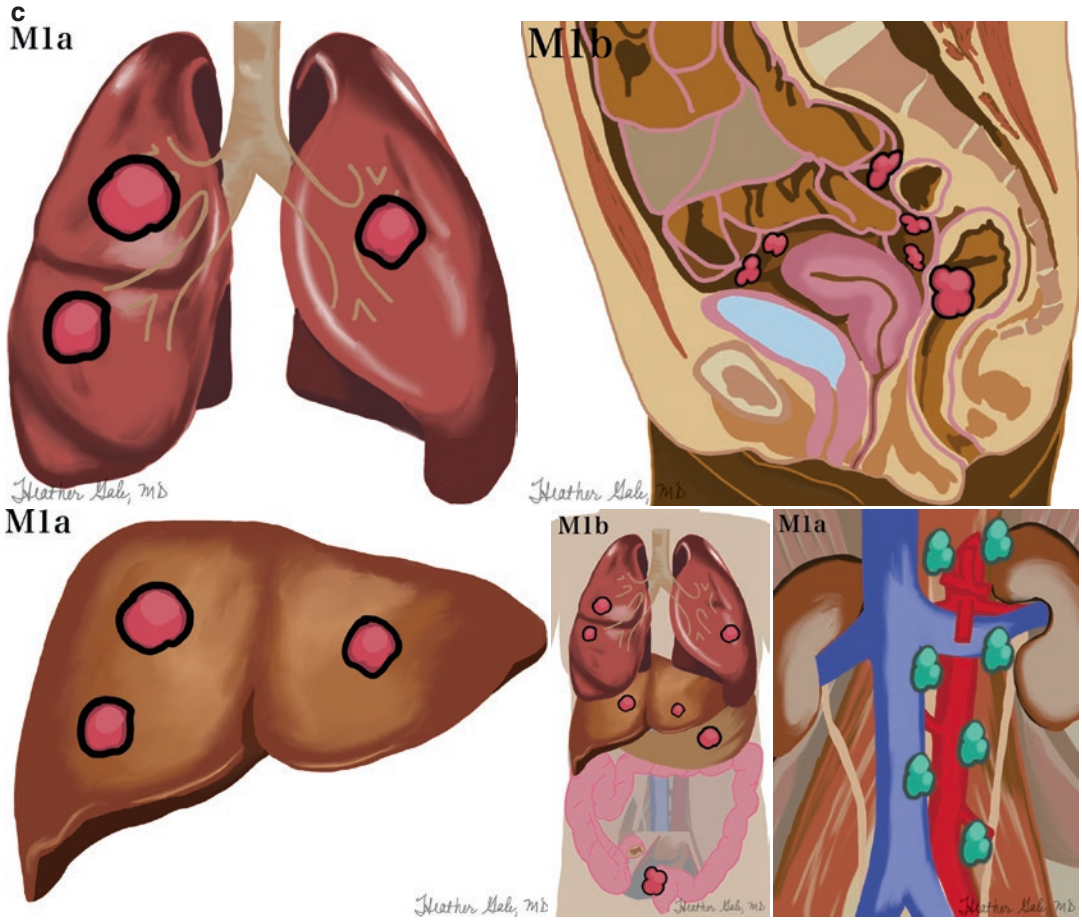

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women at average risk. High-risk patients, such as those with either a personal or family history of prior colonic adenomatous polyps, prior colon cancer, Peutz-Jeghers syndrome, hereditary non-polyposis colorectal cancer (HNPCC), familial adenomatous polyposis (FAP), juvenile polyposis syndrome (JPS), or chronic inflammatory bowel disease, should obtain screening at an earlier stage.

There are a number of colorectal screening tests available and the American Cancer Society endorses a variety of screening regimens based on the examination used. Tests can be divided into cancer prevention and cancer detection. Cancer prevention tests have the potential to image both cancer and polyps, whereas cancer detection tests have lower sensitivity for polyps and typically lower sensitivity for cancer detection (Levin et al. 2008.

Tests that detect polyps and cancer include:

- Colonoscopy – recommended every 10 years
- CT colonography (virtual colonoscopy) – recommended every 5 years
- Flexible sigmoidoscopy – recommended every 5 years
- Double-contrast barium enema – recommended every 5 years

Tests that detect cancer include:

- Guaiac-based fecal occult blood test (gFOBT) – recommended every year
- Fecal immunochemical test (FIT) – recommended every year
- Stool DNA test (sDNA) – recommended every 3 years

1.4 CT Colonography

CT colonography (CTC), also known as virtual colonoscopy, was first described and proposed as an imaging modality for the evaluation of colonic mucosa and colon cancer detection by Vining and Gelfand in 1994. Since then, with the advent of thin-section MDCT, automated insufflation, and oral tagging, CTC screening protocols and technique have been significantly refined.

While optical colonoscopy has traditionally been used as the gold standard for colorectal cancer screening as polypectomy can be performed concurrently, it has several disadvantages. It is invasive and resource intensive and often involves the use of sedation. It is also potentially inconvenient to both the patient and his or her driver requiring significant time spent away from the daily routine. In addition, although small, there is a risk for perforation and bleeding, with an overall complication rate of approximately 0.4% (Nelson et al. 2002). Some feel the complication rate may be significantly underreported with hospital visitation rates as high as 2% within the first week after colonoscopy (Ranasinghe et al. 2016). As a result, CT colonography has emerged as a safe, effective, and efficient alternative means for screening asymptomatic adults.

1.5 CTC Technique

There are four essential components to performing CT colonography.

CT colonography routinely consists of (1) patient preparation, (2) colonic distension, (3) multidetector CT scanning, and (4) interpretation using dedicated CTC 3D rendering software.

The procedure begins with careful bowel preparation. Dietary restrictions generally include maintenance of a clear liquid diet 1–2 days prior to examination. While there are several variations and protocols devised for patient preparation and examination performance, the most crucial aspect of performing high-quality CT colonography involves a thorough colonic cathartic preparation (bowel prep) for at least 1 day. The bowel prep utilized may differ from that used in optical colonoscopy. Instead of a high-volume "wet" prep involving agents such as polyethylene glycol, a "drier" prep can be used which leaves less residual fluid in the colon allowing for better visualization of the colonic wall air-mucosal interface. In general, patients are better able to tolerate these "dry" lower-volume bowel preps than high-volume iso-osmolar preps (typically 2–4 L of fluid). In addition to cleansing with laxatives, fecal and fluid tagging is also important in patient preparation. Many centers use iodinated water-soluble contrast medium for fluid tagging with or without dilute barium (2%) for fecal tagging. This improves polyp detection by raising the inherent CT densities of residual fluid and stool, helping to discriminate these residua from the underlying soft-tissue density of submerged polyps and cancers (Pickhardt and Choi 2003). Although a fully cleansed colon is recommended for patients who can tolerate the preparation, noncathartic or reduced-cathartic CTC preparations are also available, which may reduce patient discomfort at the cost of study sensitivity.

The most crucial technical component of the study lies in adequate gaseous distension of the entire colon. This is usually performed via insertion of a small flexible balloon-tipped rectal catheter through which CO_2 is insufflated (Shinners et al. 2006). Less preferred, although acceptable, is manual insufflation with room air.

In general, a thin-collimation low-radiation dose technique is then employed on a multidetector CT scanner ($\geq$16 slice) in both supine and prone or lateral decubitus positions following scout topogram confirmation of adequate colonic insufflation. A section thickness of 1–1.25 mm with a reconstruction interval of $\leq$1 mm is optimal. Image acquisition is obtained during a single breath hold in end-expiration to limit pressure-related effects of inflated lungs on the transverse colon. The scan is then repeated with the patient in the prone or decubitus position. The data is reformatted into two-dimensional images in axial and other planes as well as reconstructed into three-dimensional endoluminal images that can simulate the view obtained during conventional colonoscopy via commercially available

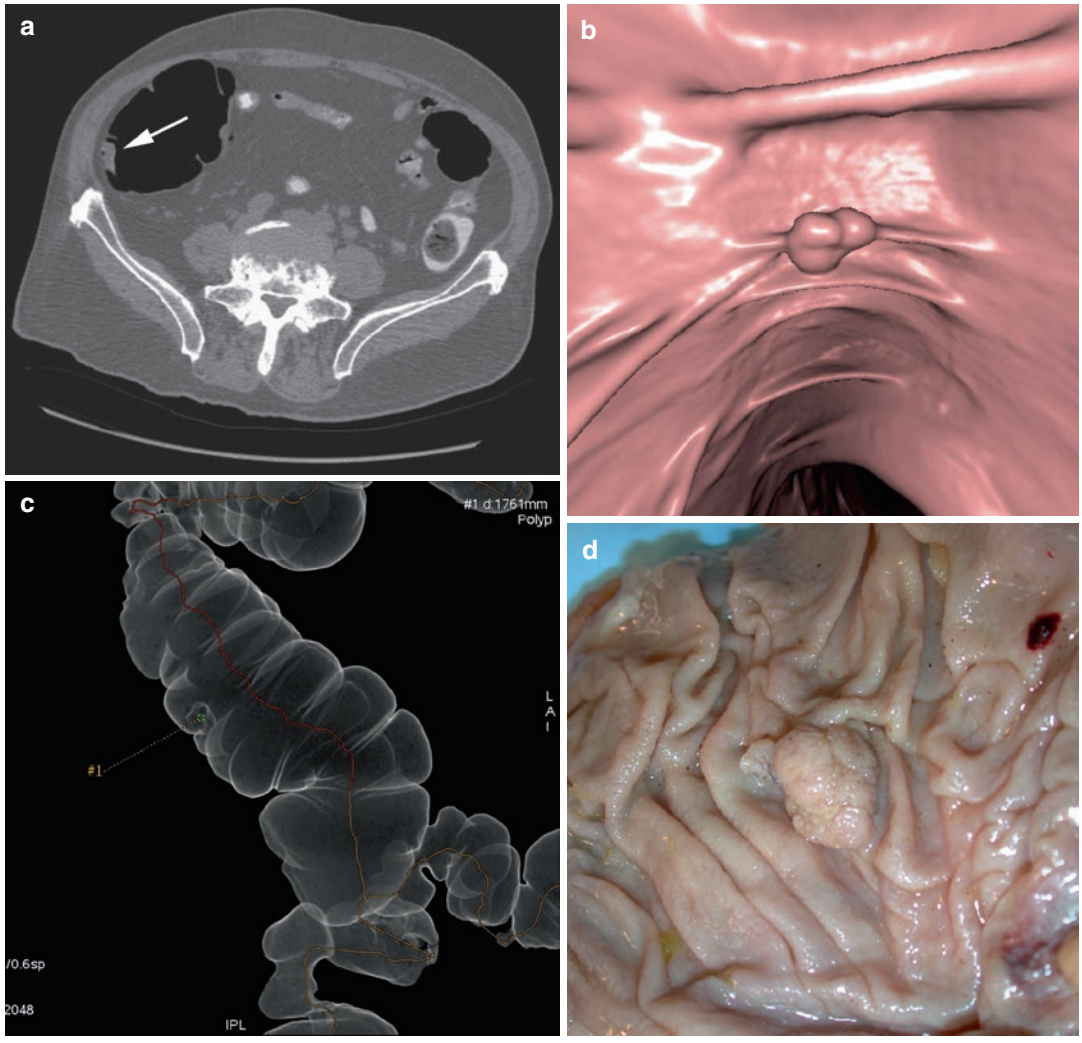

Fig. 2 A 78-year-old man for colorectal screening. (**a**) Axial supine CT shows a lobular pedunculated polyp in the ascending colon (*arrow*). (**b**) 3D endoluminal view confirms the polyp morphology and its location on a haustral fold. (**c**) 3D surface-rendered "colon map" simulates the look of a double-contrast barium enema and guides the colonoscopist or surgeon to the polyp's exact location. Also note the malignant stricture in the sigmoid colon at the bottom of the image. (**d**) Photograph of a portion of the colectomy specimen confirming the lobular appearance of this villous polyp with high-grade dysplasia

software programs (Fig. 2). Many alternative 3D rendering techniques have also been developed including virtual filet, unfolded cubes, and panoramic views (Chang and Soto 2010).

Image interpretation and evaluation of colonic polyps is performed with either a primary 2D or primary 3D approach. The ACRIN trial by Johnson et al. demonstrated no statistical difference in sensitivity between a primary 2D or 3D interpretation (Johnson et al. 2008). However, others such as Pickhardt et al. have suggested there are multiple limitations to a 2D-only approach and advocate the use of a 3D approach for a primary survey of the colon as it may increase sensitivity for polyp detection, followed by a 2D evaluation for confirmation of suspected lesions as it is more specific (Pickhardt 2007). Regardless, both 2D and 3D evaluation should be utilized together for polyp detection. In addition, software for automatic polyp detection

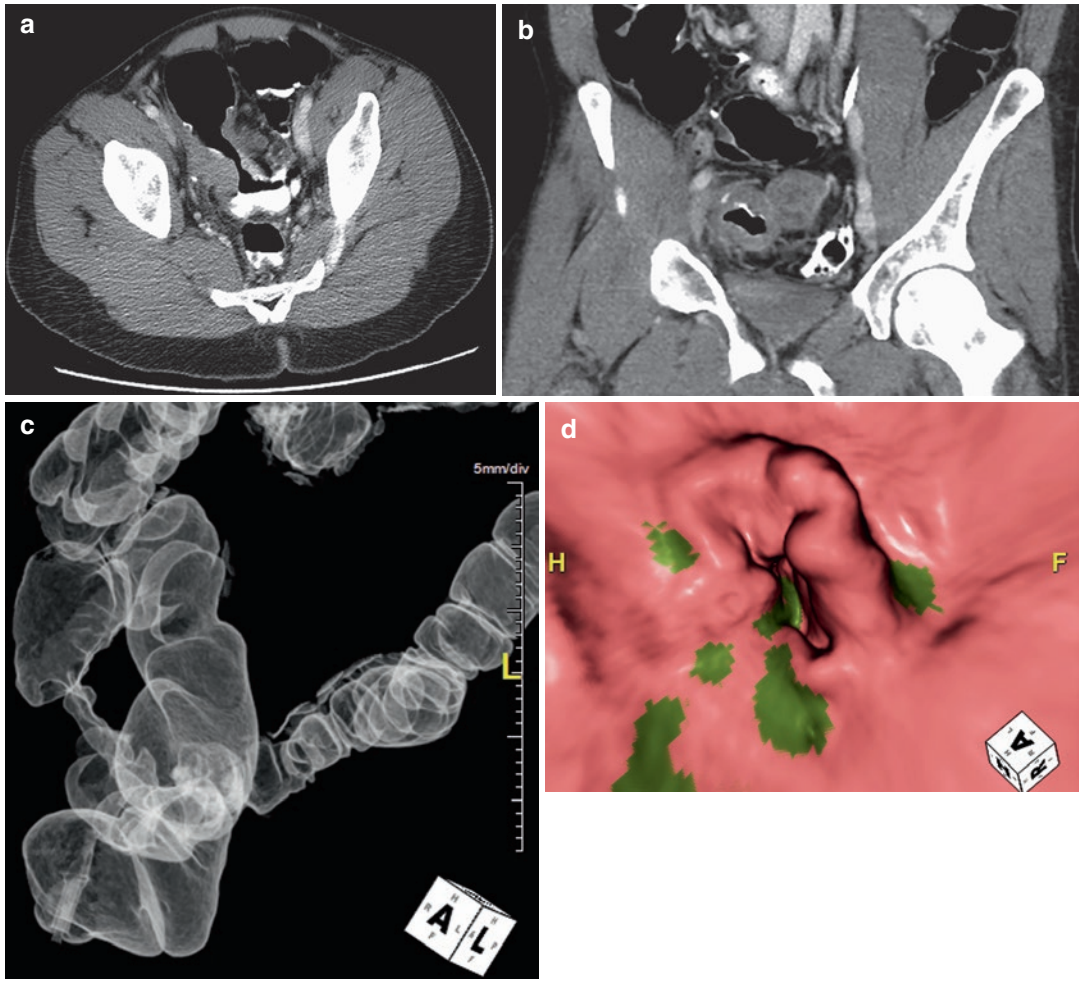

Fig. 3 A 42-year-old male presented for CT colonography due to incomplete colonoscopy to the level of an obstructing sigmoid mass. (**a**) Supine axial CT shows circumferential bowel wall thickening in the sigmoid colon (*arrows*). (**b**) Coronal CT demonstrates a large mass/necrotic lymphadenopathy adjacent to the colon (*arrow*). (**c**) 3D surface-rendered "colon map" shows a typical "apple core" appearance of an annular constricting mass (*arrows*). (**d**) 3D endoluminal view confirms an annular constricting mass in the sigmoid colon highly suspicious for malignancy

(computer-aided detection [CAD]) is also available and helps to reduce interobserver variability and perception errors, especially for readers with limited CTC experience.

1.6 CTC: Polyps and Cancer

Most colon cancers are thought to develop from adenomatous polyps and on CT are generally seen as well-defined oval or round soft-tissue masses which project into the lumen. Frank carcinomas on the other hand appear as larger intraluminal masses with an irregular and/or nodular contour. They may also appear as "apple core" or "saddle" lesions which are annular or semiannular constricting masses with irregular wall thickening and luminal narrowing (Fig. 3). Calcifications within the tumor or metastasis is a finding that can be associated with a mucinous histologic subtype.

Inflammation and stranding of the adjacent fat planes often is a sign of tumor extension through the bowel. Regional lymph nodes >1 cm in size are suspicious for metastatic disease; however,

even small nodes may harbor disease. Distant metastasis is most commonly seen in the liver as the colon has a vast portal venous drainage system. Additional sites of metastasis include the lung, adrenal gland, and peritoneum.

CTC has repeatedly demonstrated sensitivities equivalent to that of optical colonoscopy in the detection of clinically relevant polyps. Polyp detection exceeds 90% for clinically relevant lesions 6 mm or larger, while polyps <5 mm are most likely hyperplastic and clinically insignificant. A large prospective study performed by Pickhardt et al. demonstrated that virtual colonoscopy compares favorably to optical colonoscopy. Sensitivity of virtual colonoscopy for adenomatous polyps was 94% for polyps at least 10 mm in diameter, 94% for polyps at least 8 mm in diameter, and 89% for polyps at least 6 mm in diameter, all similar to that of optical colonoscopy (Pickhardt et al. 2003). In addition, large systematic reviews and meta-analyses have also upheld comparable sensitivities between CT colonography and optical colonoscopy, despite variations in protocols among different institutions (Pickhardt et al. 2011).

1.7 CTC Reporting

In regard to reporting of findings, the CT Colonography Reporting and Data System (C-RADS) has been developed to ensure consistency and clear communication of results between readers of CT colonography. It is a well-established standard for reporting CTC findings and divides findings into colonic and extracolonic categories as described below (Zalis et al. 2005; Yee et al. 2016):

Colonic Findings

C0: Inadequate study/awaiting prior comparisons. Inadequate colonic preparation or insufflation.

C1: Normal colon or benign lesion. No polyp greater than 6 mm. Continue routine screening (every 5 years per American Cancer Society screening guidelines).

C2: Indeterminate polyp or indeterminate lesion. Fewer than three 6–9 mm polyps. Recommend follow-up CTC in 3 years vs. consideration of colonoscopy.

C3: Polyp, possibly advanced adenoma. Three or more polyps 6–9 mm in size or any polyp 10 mm or larger. A follow-up colonoscopy is recommended.

C4: Colonic mass, likely malignant. Surgical consultation is recommended.

Extracolonic Findings

E0: Limited exam. Exam is compromised by an artifact so that evaluation of extracolonic soft tissues is limited.

E1: Normal exam or anatomic variant. No extracolonic abnormalities are visible or there is an anatomic variant.

E2: Clinically unimportant finding. No work-up is indicated.

For example, simple renal or hepatic cysts, cholelithiasis, and vertebral hemangioma

E3: Likely unimportant finding, incompletely characterized. Work-up may be needed, based on practice and patient preference. For example, minimally complex renal cyst

E4: Potentially important finding. Communicate the details to the referring physician.

For example, solid renal mass, lymphadenopathy, aortic aneurysm, and pulmonary nodule >1 cm

Abiding by this reporting system prevents confusion among reports and provides standardized guidelines for the management of various imaging findings.

1.8 CTC Screening

In 2008, the American Cancer Society guideline for colorectal cancer screening was revised jointly with the US Multi-Society Task Force on Colorectal Cancer and the American College of Radiology (ACR) to include CTC every 5 years as an option for screening average-risk individuals.

There are several potential advantages and benefits of CT colonography over optical colonoscopy. Compared to traditional optical

colonoscopy, there is no need for sedation, and patients are able to avoid the cardiopulmonary risks associated with anesthesia. In addition, virtual colonoscopy requires less technical staff as it can be performed without the presence of anesthetists and nurses. It is a quick examination, requiring approximately 10–15 min table time. Most patients tolerate the entire examination without the need for sedation and can thus return to work immediately without the need of a separate driver. CT colonography is also extremely safe with a reported overall perforation rate of 0.009%, significantly lower than that of optical colonoscopy (Pickhardt 2006).

In addition to colonic neoplasia, CTC also allows for the detection of potentially life-threatening extracolonic findings. While not all extracolonic findings are clinically significant, they are important in approximately 10% of patients who require further follow-up (Pickhardt et al. 2008). This includes incidental findings such as extracolonic cancers (most commonly renal, lung, and lymphoma) as well as abdominal aortic aneurysms and adrenal lesions.

1.9 CT Colonography Indications/ Contraindications

According to the ACR Practice Parameters and Technical Standards (the American College of Radiology 2014), the indications for CTC include, but are not limited to, the following: screening individuals who are at average or moderate risk for developing colorectal carcinoma, surveillance examination in patients with prior history of colonic neoplasm, or diagnostic examination in symptomatic patients (Kim et al. 2010; Yee et al. 2010).

CT colonography is also indicated in patients following incomplete screening, surveillance, or diagnostic colonoscopy and for characterization of colorectal lesions indeterminate on optical colonoscopy. Incomplete or failed colonoscopy may be secondary to a variety of factors including colonic tortuosity, nonvisualization of the colon proximal to an obstructive lesion, or colonic spasm. In general, these can be performed the same day as the colonoscopy, unless the reason for failure is inadequate bowel preparation. CT colonography may also be particularly useful in patients who are at increased risk for complications during optical colonoscopy such as patients of advanced age, on anticoagulant therapy, or who have a high sedation risk.

CTC is generally contraindicated in acute abdominal conditions such as acute diverticulitis and acute inflammatory bowel disease due to an increased risk of perforation (Bellini et al. 2014). In addition, CTC is not recommended for routine surveillance imaging of inflammatory bowel disease, evaluation of anal canal disease, or in the pregnant or potentially pregnant patient.

The relative contraindications include symptomatic acute colitis, acute diarrhea, recent diverticulitis, recent colorectal surgery, symptomatic colon-containing abdominal wall hernia, recent deep endoscopic biopsy or polypectomy, colonic perforation, and high-grade small-bowel obstructions.

2 Colonic Lymphoma

Colonic lymphoma is rarer than gastrointestinal lymphoma and much more rare than colonic adenocarcinoma. The most common subtype of colonic lymphoma is diffuse large B-cell lymphoma. The incidence of disease is much more common in patients with acquired immunodeficiency syndrome and inflammatory bowel disease and those who are immunocompromised such as individual posttransplantation. Compared to colon adenocarcinoma, colonic lymphoma presents as marked bowel wall thickening with aneurysmal luminal dilatation rather than stenosis. As a result, bowel obstruction is exceedingly rare. In addition, it tends to affect longer colonic segments than adenocarcinoma. Unlike other tumors, necrosis is also uncommon. The vast majority of large bowel lymphoma occurs in the right colon, whereas colonic adenocarcinoma is most common in the rectosigmoid colon (Quayle and Lowney 2006). Regional and diffuse lymphadenopathy is often an accompanied finding.

3 Colitis

Patients with colitis present with nonspecific abdominal pain, and CT is almost universally the initial study of choice performed for suspected colonic disease, especially in the emergency room setting. Its widespread availability and ease of performance make it an excellent modality for screening patients with nonspecific symptoms. While the subtype of colitis is based on the combination of clinical, laboratory, and pathologic data, CT can help narrow the differential diagnosis by evaluating the extent and distribution of inflammation. The primary hallmark of colitis on CT is bowel wall thickening, mural edema, pericolonic inflammatory stranding, and mucosal enhancement. The evaluation of the colonic wall can be challenging when the colon is not appropriately distended, as a decompressed colon may mimic wall thickening. Notably, the added benefit of performing CT is its ability to accurately evaluate for complications of colitis such as abscess formation and perforation.

3.1 Inflammatory Bowel Disease: Ulcerative Colitis and Crohn's Disease

Ulcerative colitis (UC) is typically a disease of young adults aged 15–40 years; however, a second peak between 50 and 60 years old is also common with slight male predominance (Ekbom et al. 1991; Loftus 2004). It is a disease of colonic inflammation and mucosal ulceration that typically afflicts the rectum and progresses in a retrograde continuous fashion without "skip" lesions (Fig. 4). The hallmark of this condition is colonic wall thickening and luminal narrowing. With the administration of IV contrast, the "halo or target sign" can often be observed in which there is a stratification of the layers of the wall. In acute disease, although nonspecific, there is hyperattenuation and hyperenhancement of the inner mucosa, low water attenuation of submucosal edema, and outer hyperattenuation of the muscularis propria. In chronic disease, there can be a similar halo or target appearance of the wall; however, instead of submucosal water attenuation, there is fatty infiltration (Jones et al. 1986). In addition, with increasing chronicity there is increased perirectal fat and widening of the presacral space. While there is primary involvement of the left colon, the terminal ileum can also be involved via backwash ileitis resulting in a patulous, dilated ileocecal valve.

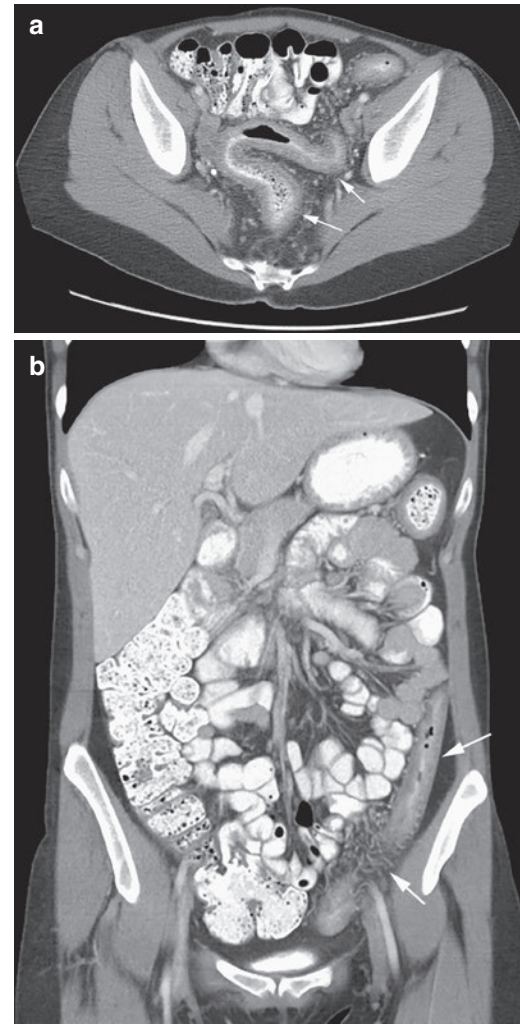

Fig. 4 A 23-year-old with history of ulcerative colitis presents with worsening abdominal pain and diarrhea. (**a**) Axial CT following intravenous and oral contrast administration demonstrates marked contiguous rectosigmoid wall thickening, and (**b**) coronal reformatted images demonstrate continuity to the level of the descending colon with engorgement of mesenteric vessels (*arrows*)

Similar to ulcerative colitis, Crohn's disease typically affects young adults in their twenties;

however, late onset in adulthood has also been observed. While there is considerable overlap in the CT imaging features of Crohn's disease and ulcerative colitis such as mural stratification, mural enhancement, and bowel wall thickening, there are important differences. Crohn's colitis is notorious for transmural inflammation and most commonly affects the terminal ileum and proximal colon. In such cases, there is thick-walled small bowel and proximal colon with narrowed lumen resulting in a so-called string sign (Fig. 5). In addition, in contrast to UC, inflammation often leads to stenosis of the ileocecal valve and proximal dilatation of the terminal ileum. Crohn's disease can also involve "skip lesions" and affect any region in the alimentary tract.

CT enterography (CTE) may be particularly helpful in the evaluation of small-bowel pathology in individuals suspected of having Crohn's disease. CT enterography involves the use of intravenous contrast in combination with large-volume neutral oral contrast agent for luminal distension. Adequate small-bowel distension is necessary as collapsed bowel can pose diagnostic challenges and even mimic small-bowel pathology. Using neutral oral contrast agents such as VoLumen (Bracco Diagnostics, Inc., Monroe Twp, NJ) permits optimal small-bowel distension and improves assessment of mucosal enhancement, mural thickening, and evaluation of strictures. In addition, CT enterography is also useful for evaluating disease activity, and detecting active inflammation as measuring small-bowel mural attenuation has been correlated with disease activity (Bodily et al. 2006). Although non-specific, the presence of engorged mesenteric vessels also suggests active disease and results in a so-called comb sign from hyperemic, congested vessels that are widely spaced (Lee et al. 2002). While CTE is useful in the initial presentation or diagnosis of inflammatory bowel disease, MR enterography (MRE) may be preferred for follow-up surveillance of disease activity, particularly in younger individuals where cumulative lifetime radiation dose from multiple CTs should be minimized.

In the acute setting, CT is helpful not only in diagnosis but also in the assessment of disease complication. Although rare, one of the most feared complications of both types of inflammatory bowel disease is toxic megacolon. CT demonstrates thin-walled, marked colonic dilatation with loss of normal haustral folds and irregular shaggy mucosa. This can ultimately lead to bowel ischemia and perforation. Other complications include phlegmon, which is an ill-defined inflammatory mass without discrete walled-off collection or abscess in which there is a well-defined

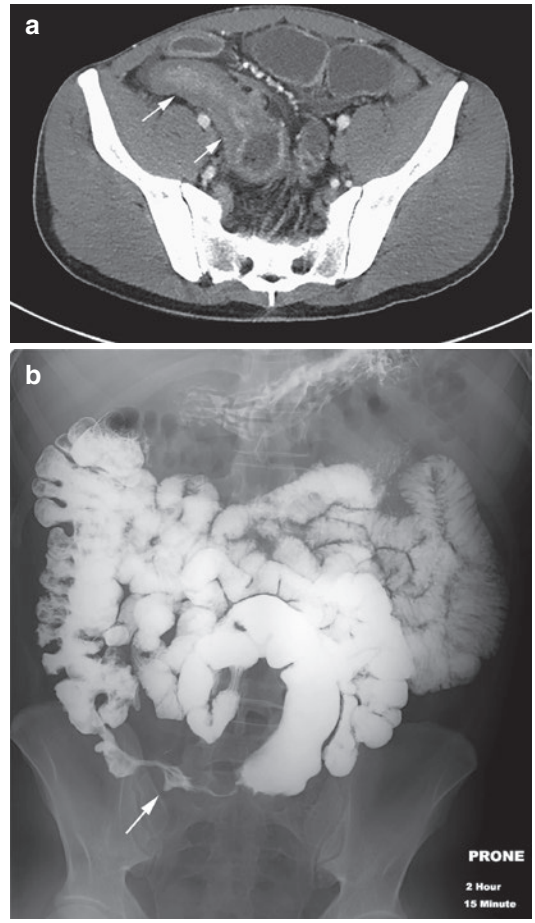

Fig. 5 (**a**) A 45-year-old female with history of Crohn's disease presents with worsening right lower quadrant abdominal pain. Axial CT demonstrates marked mural wall thickening of the terminal ileum and luminal narrowing consistent with terminal ileitis (*arrows*). (**b**) Different patient, 38-year-old with history of Crohn's disease, underwent fluoroscopic small-bowel follow-through series demonstrating marked luminal narrowing and fibrosis of an 8–9 cm segment of terminal ileum consistent with a "string sign"

rim-enhancing wall with central low attenuation. These collections may also contain air-fluid levels, scattered foci of gas, or internal septations. Depending on the size and location of these collections in conjunction with patient's clinical history, findings on CT can help guide treatment whether it is conservative management with antibiotics or, if large and accessible, percutaneous image-guided drainage. Other complications of Crohn's disease include sinus tracts and fistulas, which can be readily visualized on multidetector CT by outlining communicating fluid tracts. Finally, there is also increased risk of colon cancer particularly with long-standing ulcerative colitis, but also Crohn's disease.

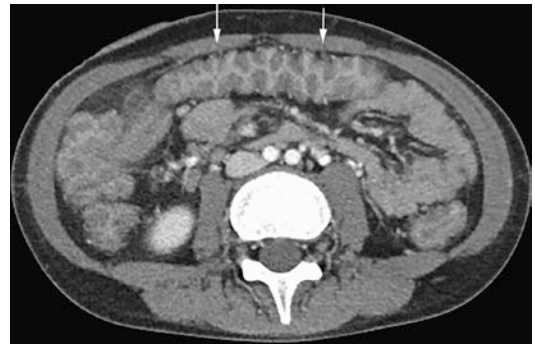

Fig. 6 A 22-year-old male with recent antibiotic use presents with abdominal pain and watery diarrhea and was found to have *C. difficile colitis*. Axial CT image following intravenous contrast administration demonstrates marked intramural edema and transverse colonic wall thickening producing an "accordion"-like appearance (*arrows*)

3.2 Infectious Colitis

Infectious colitis may be caused by a host of different bacteria (*Shigella*, *Salmonella*, *Campylobacter*, *Yersinia*, tuberculosis), fungi, viruses (herpes, *Cytomegalovirus*), and parasites. The imaging findings are generally nonspecific with considerable overlap in the CT findings of different infectious agents. Imaging findings include bowel wall thickening, pericolonic inflammatory stranding, and ascites. While many infectious agents produce diffuse pancolitis such as CMV and *E. coli*, others have a predilection for the right colon including or excluding the ileum such as *Salmonella*, *Yersinia*, tuberculosis, and amebiasis. Others may have predominately left colonic involvement including schistosomiasis, shigellosis, and herpes (Thoeni and Cello 2006).

3.3 Pseudomembranous Colitis

Pseudomembranous colitis is a type of infectious colitis that results from bacterial overgrowth of *Clostridium difficile* within the colon. The bacteria release cytotoxic enterotoxins that produce an exudative inflammatory process within the colonic mucosa. It usually results as a complication of antibiotic use, which disrupts normal gut flora and allows *C. difficile* to colonize the colon. CT findings include bowel wall thickening, a shaggy mucosal outline due to sloughed mucosal cells, and marked submucosal edema resulting in characteristic "accordion sign" (Fig. 6) (Macari et al. 1999). Typically, there is pancolonic involvement; however, it may also manifest as isolated segmental disease. Untreated, *C. difficile* colitis may progress to toxic megacolon and ultimately bowel perforation. Treatment is supportive therapy and antibiotics consisting of metronidazole and oral vancomycin.

3.4 Ischemic Colitis

Ischemic injury of the colon most commonly occurs in the elderly population older than 70 years old. In this age group, ischemic colitis most commonly occurs in the setting of low flow states and decreased cardiac output on a background of extensive atherosclerotic disease. In the younger population, the disease may occur secondary to a vasculitis or hypercoagulable state. Regardless, diminished blood flow leads to colonic ischemia and secondary inflammation. The CT appearance of ischemic colitis will vary depending on the severity; however, the distribution of colonic involvement is crucial in making the diagnosis. Afflicted segments typically follow a vascular distribution and most commonly affect watershed areas including the splenic flexure and rectosigmoid colon. CT will demonstrate wall

thickening and submucosal edema producing a "target" or "halo" sign. In addition, pericolonic inflammation may be present. If necrosis and ulceration develops, this can lead to perforation.

3.5 Typhlitis

Typhlitis is also known as neutropenic enterocolitis and is an infectious colitis usually confined to the cecum and ascending colon in patients that are neutropenic and severely immunocompromised. This includes patients with acquired immunodeficiency syndrome and posttransplantation or on chemotherapy for malignancy. Classically, the disease is associated with patients with leukemia undergoing chemotherapy treatment. CT is the modality of choice for diagnosis, and imaging demonstrates marked circumferential thickening of the cecum and ascending colon with pericolonic inflammatory stranding and edema (Fig. 7). Intramural areas of low attenuation may represent edema or hemorrhage. The disease may also occasionally extend into the terminal ileum. It is important to make the diagnosis in a timely fashion as it can quickly progress to ischemia and necrosis with pneumatosis intestinalis and ultimately bowel perforation.

3.6 Stercoral Colitis

Stercoral colitis is a rare cause of inflammatory colitis that results from ischemic pressure necrosis secondary to chronic fecal impaction. Longstanding fecal impaction results in increased intraluminal pressure, ulceration of the mucosa, and ultimately bowel perforation if not managed appropriately. CT findings of chronic fecal impaction include a distended colon with wall thinning; however, in cases of stercoral ulceration, there may be focal thickening of the colonic wall. In addition, there is pericolonic inflammatory stranding and edema adjacent to the site of fecal impaction, and extraluminal gas may be present suggesting microperforation (Fig. 8) (Heffernan et al. 2005).

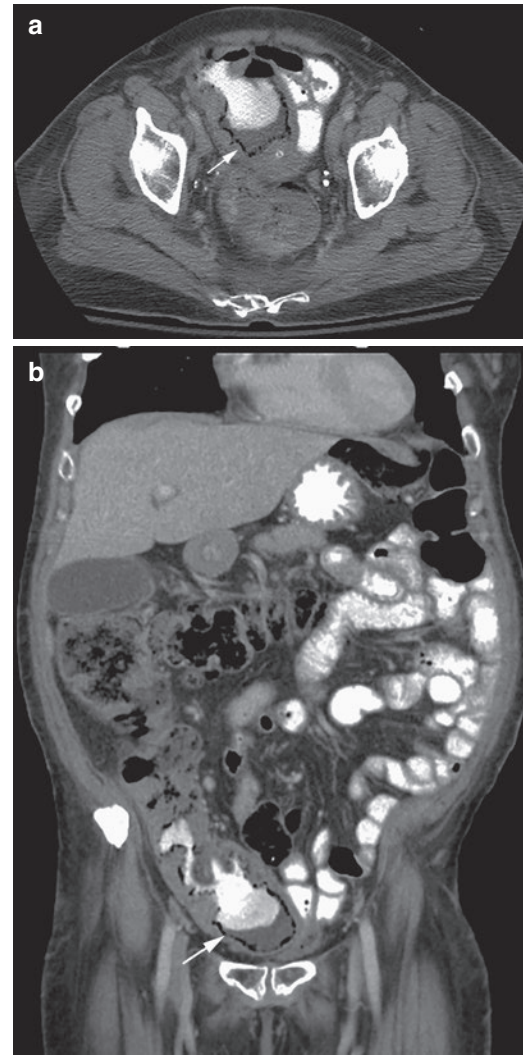

Fig. 7 A 70-year-old female with CLL status post bone marrow transplantation and neutropenia presents with right upper and lower quadrant abdominal pain. (**a**) Axial CT shows marked thickening of the cecal pole with circumferential pneumatosis intestinalis (*arrow*). (**b**) Coronal CT demonstrates cecal and ascending colonic wall thickening and circumferential pneumatosis intestinalis (*arrow*) consistent with typhlitis in this neutropenic patient

4 Acute Diverticulitis

Diverticulitis is a recognized complication of diverticulosis. Diverticula are small sac-like outpouchings of the mucosa and submucosa through areas of weakness and defect in the muscularis,

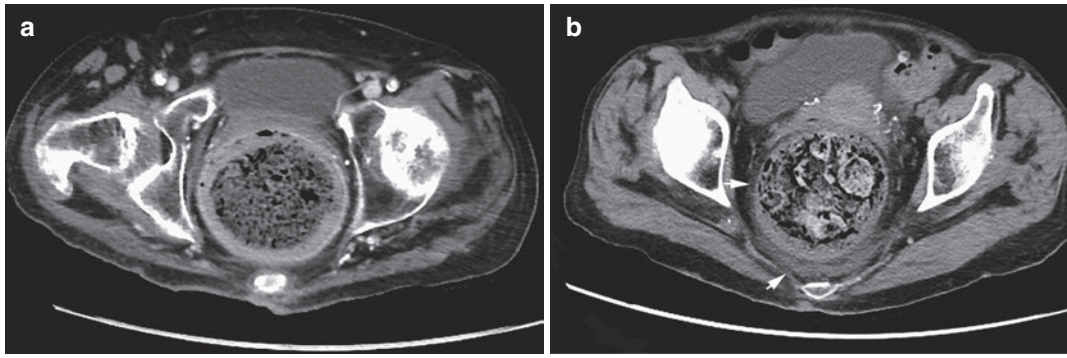

Fig. 8 A 78-year-old female with chronic constipation presents with abdominal pain and was found to have stercoral colitis. (**a**) Axial CT following intravenous contrast administration demonstrates a large stool ball within the rectum with marked rectal distension and wall thickening. (**b**) In addition, there is perirectal edema (*arrow*)

which are still covered by serosa. Since they do not contain all layers of the colonic wall, they are known as "false" or "pulsion diverticula." Most diverticula occur along the mesenteric surface of the colon, typically where the vasa recta penetrate the muscular layer (Meyers et al. 1973). Due to their close proximity to vessels, this also explains their propensity for colonic bleeding. Although the exact prevalence is difficult to determine as many individuals are asymptomatic, there is increased predilection with advanced age, particularly after the age of 50. Colonic diverticula result from increased intraluminal pressure and shortening and thickening of the colon known as myochosis coli. The most common location for diverticula to form is in the sigmoid colon.

Diverticulitis develops when there is inflammation within a diverticulum, usually caused by obstruction of the neck by stool or food particles and is followed by subsequent microperforation. On CT, diverticulitis appears as bowel wall thickening and pericolonic inflammatory stranding centered around a diverticulum (Fig. 9). Complications include diverticular perforation; abscess formation; fistulization to nearby structures including the bladder, bowel, vagina, and skin; as well as bowel obstruction from adhesions. Treatment for mild acute uncomplicated diverticulitis is conservative management with antibiotics and supportive care; however, in the case of complicated or repeated bouts of diverticulitis, surgery may be required.

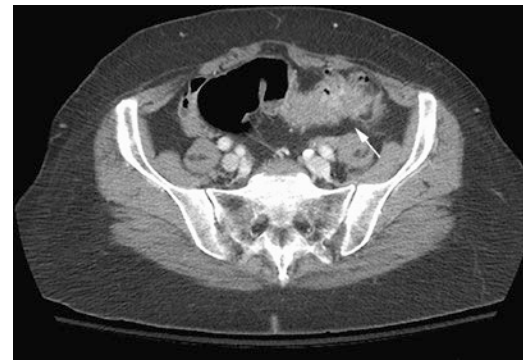

Fig. 9 A 47-year-old male with leukocytosis and acute-onset left lower quadrant abdominal pain. Axial CT following intravenous contrast administration shows sigmoid diverticulosis with wall thickening and adjacent mesenteric inflammatory stranding (*arrow*) consistent with acute uncomplicated diverticulitis

5 Appendix

The normal appendix is a thin-walled blind-ending tubular structure consistently arising between the ileocecal valve and apex of the cecal pole. The length of the appendix and location of the tip are much more variable with roughly one third of cases coursing inferomedial to the cecum and two thirds coursing retrocecal. The normal appendix typically measures 6 mm or less, is surrounded by homogenous mesenteric fat, and maintains a well-defined outer contour.

5.1 Appendicitis

Acute appendicitis is one of the most common causes of acute abdominal pain in children and young adults. The classic presentation consists of periumbilical pain followed by focal tenderness at McBurney's point with associated fever, nausea/vomiting, and leukocytosis.

Appendicitis typically results from obstruction of the tip of the appendix followed by fluid distension, venous engorgement, and ultimately ischemia and perforation. Obstruction is most commonly caused by lymphoid hyperplasia or an appendicolith. CT findings include a fluid-distended appendix >6 mm in diameter, thickened and enhancing wall, and periappendiceal inflammatory fat stranding (Fig. 10). Appendicoliths on CT appear as calcification within the lumen of the appendix; however, if the appendix is ruptured, it may also present adjacent to or within phlegmon or abscess. Appendicitis can also be confined to the distal tip with wall thickening and peri-inflammation isolated to the tip, while the proximal portion appears collapsed or normal in caliber. Complications of perforation include phlegmon, which appears as a soft-tissue inflammatory mass without walled-off collection or abscess, which appears as a discrete peripheral rim-enhancing collection with central low attenuation. While appendectomy has traditionally been the definitive curative treatment for appendicitis, there has been an increasing use of a trial of antibiotics without surgery for the management of less severe cases. In general, phlegmon or small abscess may be treated with antibiotics and interval appendectomy, while larger abscesses may require percutaneous or surgical drainage prior to appendectomy to control the spread of infection.

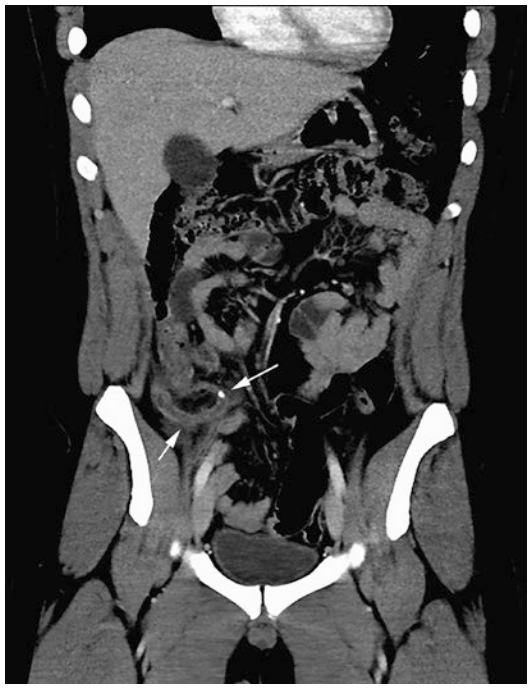

Fig. 10 A 19-year-old febrile with acute right lower quadrant abdominal pain. Coronal contrast-enhanced CT demonstrates a blind-ending tubular structure in the right lower quadrant with fluid distension, mucosal hyperemia, periappendiceal inflammatory stranding (*arrow*), and calcified appendicolith (*arrow*) consistent with acute, uncomplicated appendicitis

5.2 Primary Neoplasms of the Appendix

Primary neoplasms of the appendix are uncommon, found in 0.5–1.0% of all appendectomy specimens (Deans and Spence 1995; Connor et al. 1998; Hananel et al. 1998). Approximately 30–50% of all appendiceal neoplasms manifest clinically with signs and symptoms of acute appendicitis; however, it is important to accurately differentiate the two entities as the surgical approach, and management is quite different, often involving hemicolectomy in the case of appendiceal neoplasm (Carr et al. 1995; Connor et al. 1998; Pickhardt et al. 2002).

5.2.1 Mucinous Epithelial Neoplasm: Mucocele of the Appendix

The majority of epithelial tumors of the appendix are mucin rich with propensity to form mucoceles (Carr et al. 1995) and account for the majority of appendiceal tumors detected at imaging (Pickhardt et al. 2003). The viscous mucous results in chronic obstruction at the neck of the appendix with subsequent dilatation of the lumen. There are both benign and malignant causes of mucoceles, the most common of which are mucinous neoplasms. Causes include

mucosal hyperplasia, mucinous neoplasms (mucinous cystadenoma and mucinous cystadenocarcinoma), appendiceal carcinoid, and adjacent cecal tumor. On CT, mucoceles appear as well-circumscribed blind-ending, thin-walled tubular or spherical cystic masses with central low attenuation arising from the base of the cecum (Fig. 11). Curvilinear mural calcification within the wall is suggestive of the diagnosis, but is seen in less than 50% of patients (Dachman

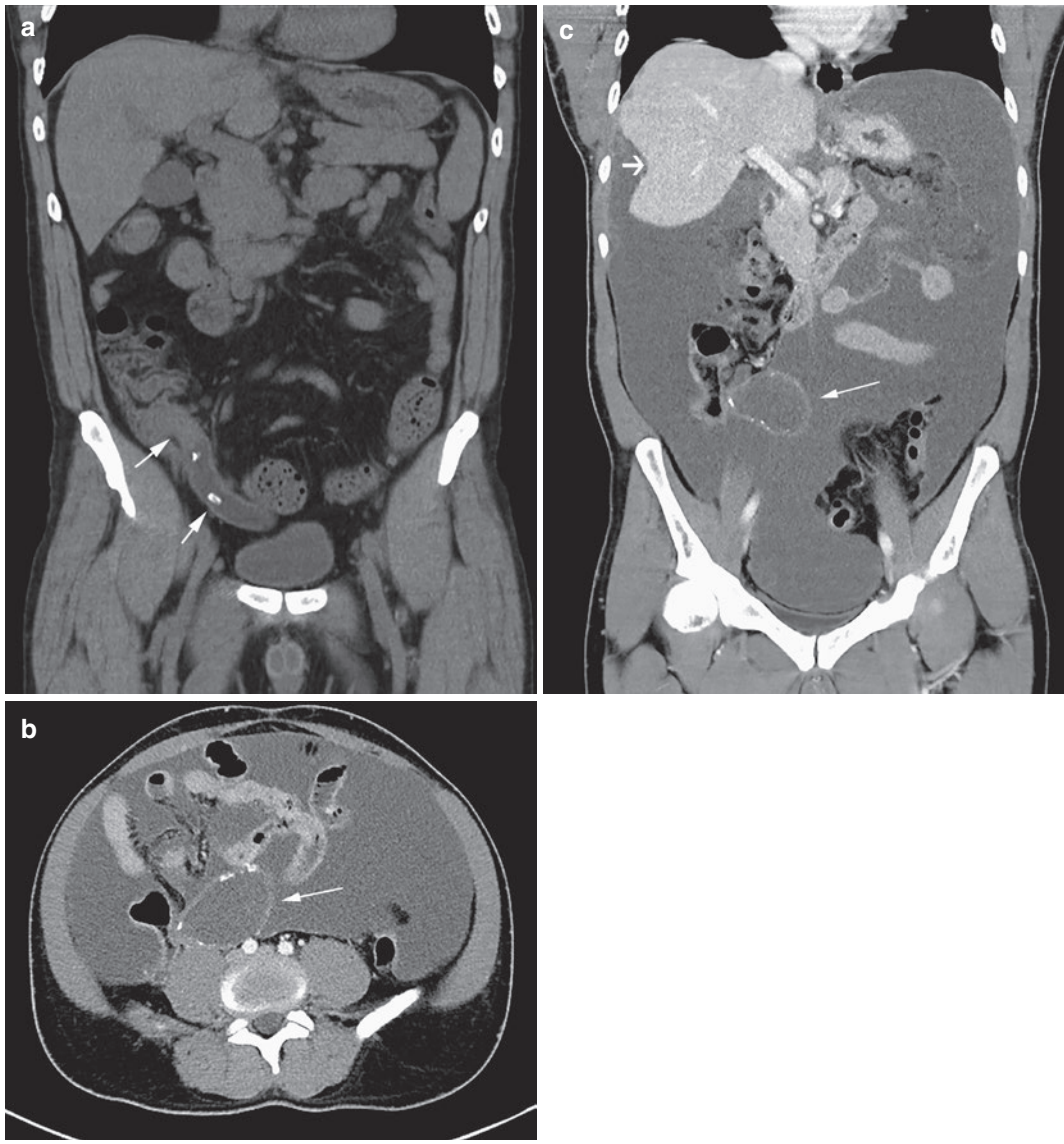

Fig. 11 (**a**) A 42-year-old male with nonspecific abdominal pain. Non-contrast coronal CT depicts a fluid-distended appendix in the right lower quadrant with internal calcifications (*arrow*) and soft-tissue density at the base (*arrow*). Patient subsequently underwent right hemicolectomy with pathology consistent with mucinous adenocarcinoma of the appendix. (**b**) 56-year-old male presented with increasing abdominal distension. Axial CT depicts a markedly dilated fluid-filled appendix with mural calcifications (*arrow*) as well as diffuse ascites. (**c**) Coronal CT shows the blind-ending appendix arising from the colon (*long arrow*) as well as scalloping of the liver surface by gelatinous pseudomyxoma peritonei (*short arrow*), findings consistent with ruptured mucinous neoplasm of the appendix

et al. 1985; Madwed et al. 1992). Mucoceles smaller than 2 cm in diameter are usually caused by nonneoplastic occlusion and result in simple retention cysts, while those larger than 2 cm are usually caused by a mucinous neoplasm (Carr et al. 1995; Carr and Sobin 1996). Reliably differentiating benign and malignant causes of mucoceles is difficult on imaging alone; however, irregularity of the wall and soft-tissue thickening are features suggestive of malignancy (Wang et al. 2013). Due to the ambiguity in imaging diagnosis, the treatment is surgical. Complications include ileocolic intussusception, gastrointestinal bleeding, ureteral obstruction, and superimposed infection, and if neoplastic in origin, appendiceal rupture may lead to diffuse seeding of the peritoneum with accumulation of gelatinous ascites known as pseudomyxoma peritonei (Fig. 11b, c).

5.2.2 Nonmucinous Epithelial Neoplasm

The nonmucinous adenomas and adenocarcinomas are characteristically similar to colorectal neoplasia elsewhere; however, they are exceedingly rare. On CT, these appear as a focal soft-tissue mass involving the appendix without mucocele formation. There may be direct invasion of adjacent organs.

5.2.3 Carcinoid Tumor

Carcinoid tumors of the appendix arise from neuroendocrine cells and, although rare, are the most common of all appendiceal neoplasms, comprising nearly 80% of primary appendiceal neoplasms (Deans and Spence 1995; Sandor and Modlin 1998). Compared to other neoplasms of the appendix, carcinoid tumors tend to occur more often in young adults (Modlin et al. 2003). Carcinoids have a varied appearance and are often barely discernable, incidentally found at appendectomy. On imaging, most are small in size (usually <1 cm) and confined to the distal third of the appendix (Deans and Spence 1995). They can present as a focal soft-tissue mass or diffuse appendiceal thickening (Pickhardt et al. 2003). While most appendiceal carcinoids are benign and do not metastasize, in rare cases they can demonstrate more aggressive behavior and penetrate the appendiceal wall, infiltrate the mesoappendix, spread to mesenteric lymph nodes, and metastasize to the liver.

5.2.4 Other Neoplasms of the Appendix

Primary lymphoma of the appendix is rare and far more common in the gastrointestinal tract. The appendix can become markedly enlarged with aneurysmal dilatation of the lumen, but typically maintains its vermiform appearance (Pickhardt et al. 2002). Patients most often present with clinical signs and symptoms of acute appendicitis.

Other rare neoplasms of the appendix include neuroendocrine tumors such as ganglioneuromas and paragangliomas, smooth muscle tumors such as leiomyoma, as well as neurofibroma, schwannoma, and gastrointestinal stromal tumors (Collins 1955; Hatch et al. 2000; van Eeden et al. 2000; Miettinen and Sobin 2001).

6 Epiploic Appendagitis

Epiploic appendages are pouches of subserosal fat lined by peritoneum that arise from the colonic surface. They are distributed throughout the large bowel along the tenia libera and tenia omentalis and are attached to the colonic serosal surface by a vascular stalk. Epiploic appendagitis results when there is inflammation of one of these appendages, usually caused by torsion or vascular/venous occlusion, which ultimately leads to ischemia, necrosis, and peritoneal inflammation. Although a somewhat rare condition, there is a predilection for occurrence in the obese population (Almeida et al. 2009). Clinically, patients present with acute focal abdominal pain, most often in the left lower quadrant with signs and symptoms that may mimic diverticulitis. When epiploic appendagitis occurs in the cecum or ascending colon, clinical symptoms may also mimic acute appendicitis or omental infarction. In such cases, imaging is very useful and virtually diagnostic. While the diagnosis was once

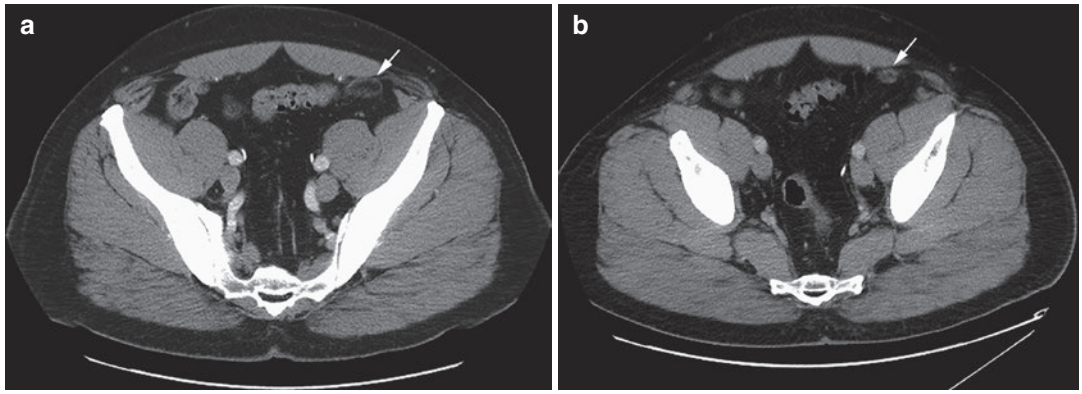

Fig. 12 A 45-year-old with acute-onset left lower quadrant abdominal pain (**a**) demonstrates a fat-containing inflammatory mass within the left lower quadrant adjacent to the sigmoid colon with peripheral ring of hyperdensity compatible with epiploic appendagitis (*arrow*). (**b**) Six months later, the inflammatory mass has involuted, but persists as a focal soft-tissue attenuation scar (*arrow*)

made postoperatively, high-resolution CT has made this previously obscure diagnosis much easier to make. Findings include round or ovoid focal fat density adjacent to the antimesenteric surface of the colon bordered by a hyperattenuating rim and adjacent mesenteric inflammation (Fig. 12). Although not always present, a central focus of hyperattenuation, representing a thrombosed vein, may help with the diagnosis. In addition, there may be thickening of adjacent colon and parietal peritoneum. Occasionally, epiploic appendagitis may also occur within a herniated sac. While the CT features generally resolve by 6 months, in the initial few weeks to months, CT findings range from no change, to decrease in size of the lesion, to residual soft-tissue attenuation in the area of focal inflammation (Rao et al. 1997; Singh et al. 2004). Symptoms are generally self-limiting and treatment is conservative with pain management.

7 Colonic Volvulus

Colonic volvulus results when there is twisting of the mesocolon resulting in bowel obstruction. Clinically, patients present with abdominal pain, nausea, vomiting, and abdominal distension. There are two major categories of large bowel volvulus including sigmoid and cecal volvulus.

7.1 Cecal Volvulus

Cecal volvulus occurs when the cecum twists around its mesentery resulting in large bowel obstruction. It is rare and accounts for only 1% of all causes of intestinal obstruction, but accounts for 25–40% of all cases of colonic volvulus (Peterson et al. 2009; Rosenblat et al. 2010). It generally occurs in a younger population group compared to sigmoid volvulus, typically 30–60 years of age. Risk factors include abnormal congenital peritoneal fixation resulting in a lax, mobile proximal colon as well as abdominal mass, adhesions, or scarring that may serve as a fulcrum for bowel rotation. It is important to make the diagnosis in a timely manner as delay in diagnosis can result in closed-loop obstruction and subsequently vascular compromise, ischemia, and perforation. CT findings include marked cecal dilatation >10 cm, abnormal positioning of the cecum with a gas-filled loop of colon, and cecal apex directed toward the left upper quadrant referred to as a "coffee bean" sign (Fig. 13). Additional findings include distal colonic decompression, proximal small-bowel distension, "whirl sign" with twisting of the mesentery, and "X marks the spot" sign when there are crossing transition points (Rosenblat et al. 2010).

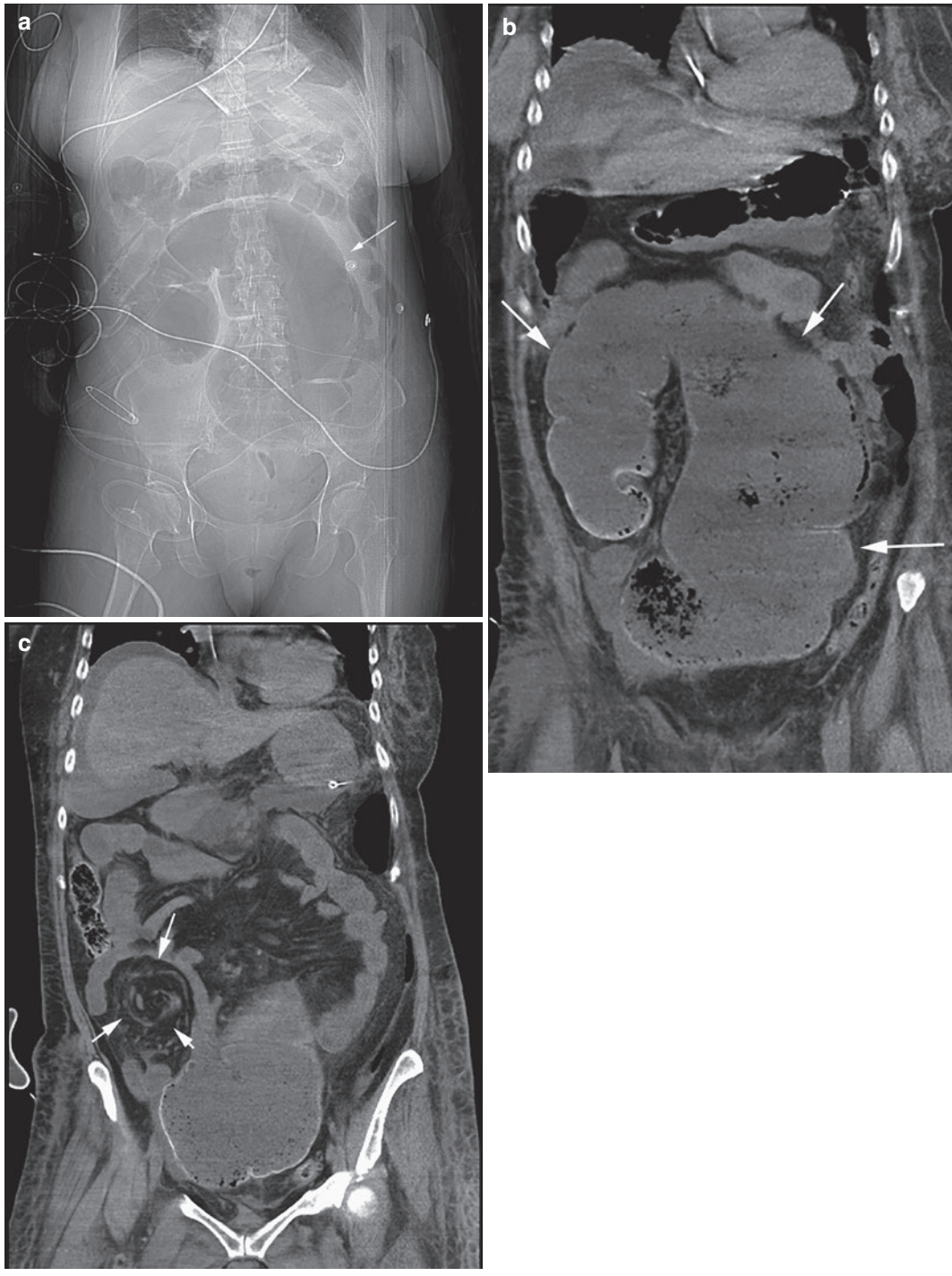

Fig. 13 A 68-year-old presents to the ER with abdominal pain, nausea, and vomiting. (**a**) Scout image from CT demonstrates gaseous distension of a loop of bowel directed toward the left upper quadrant. (**b**) Coronal CT shows the cecum is fluid filled and massively dilated with cecal apex directed toward the left upper quadrant similar to the scout image. Distal colon is also decompressed. (**c**) "Whirl sign" (*arrows*) is noted within the right lower quadrant compatible with twisting of the mesentery and CT findings of cecal volvulus

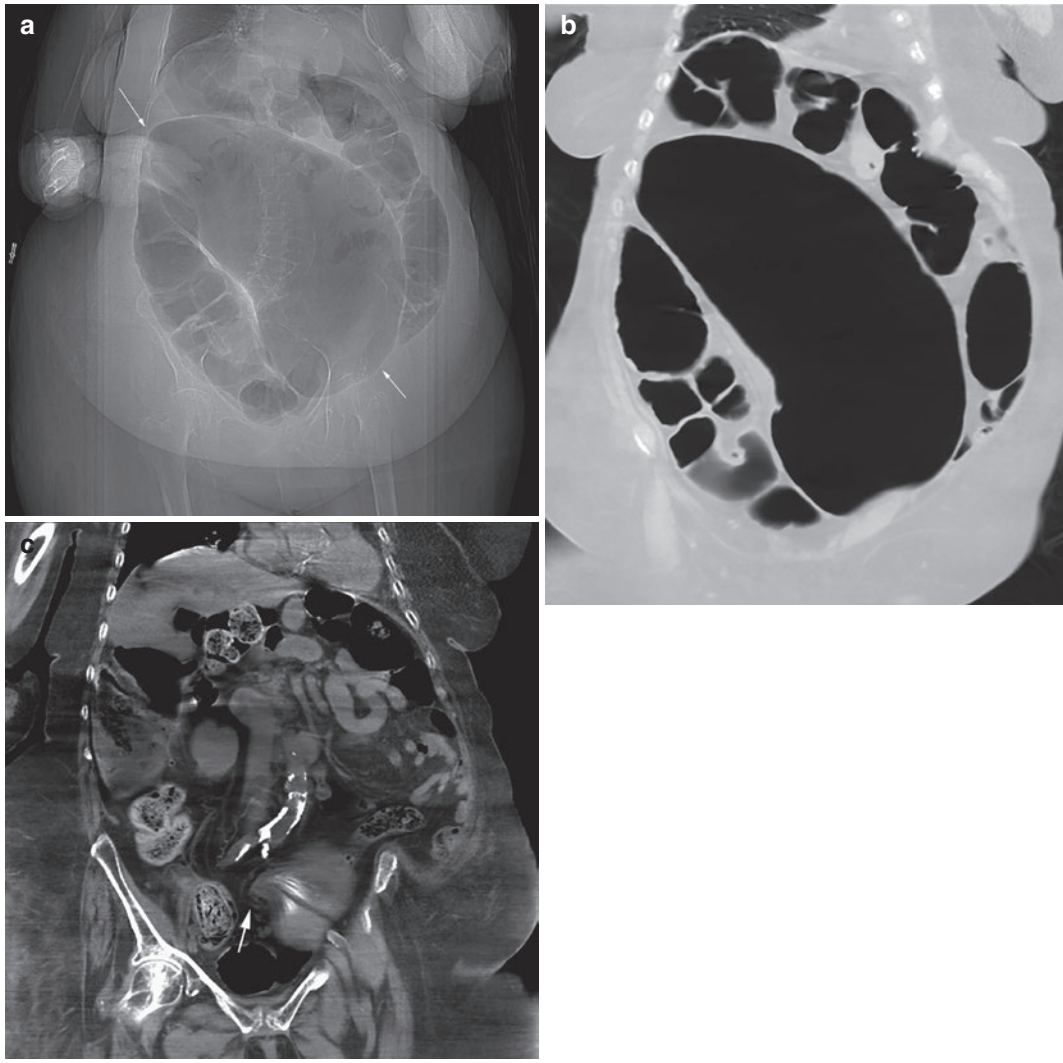

Fig. 14 A 78-year-old female presented with obstipation, nausea, and vomiting. (**a**) Scout image from CT shows marked gaseous distension of sigmoid colon. (**b**) Coronal CT confirms the findings on scout demonstrating a markedly dilated sigmoid colon with apex pointed toward the right upper quadrant, referred to as a "coffee bean" sign. (**c**) Coronal CT demonstrates a "bird's beak" appearance at the point of volvulus (*arrow*)

7.2 Sigmoid Volvulus

Sigmoid volvulus is the most common type of colonic volvulus and accounts for 60–75% of all cases of colonic volvulus (Peterson et al. 2009). The sigmoid colon twists on its mesocolon and results in large bowel obstruction with a large distended loop of bowel directed at the right upper quadrant, also referred to as a "coffee bean" sign (Fig. 14). When this loop of bowel extends cranially from the pelvis beyond the level of the transverse colon, it is referred to as the "northern exposure" sign. Sigmoid volvulus tends to occur more commonly in the elderly population compared to cecal volvulus, and risk factors include chronic constipation, redundant sigmoid colon, and high-fiber diet. Complications include closed-loop obstruction and ultimately bowel ischemia and perforation.

8 Lower Gastrointestinal Bleeding: Role of CTA

While colonoscopy has traditionally been considered the first-line modality for the diagnosis and evaluation of lower gastrointestinal bleeding, it has its limitations. It may not be feasible in the hemodynamically unstable patient and even in patients that undergo colonoscopy; the underlying etiology may be obscured by overwhelming bleeding or inadequate bowel preparation. MDCT with CT angiography offers an alternative modality for the evaluation of patients with lower gastrointestinal bleeding and has gained greater acceptance over the years as an effective first-line alternative. It is particularly useful in the emergency room setting where it is a quick and readily available test. Patients can be triaged in a timely manner and if actively bleeding, management and treatment can be directed appropriately.

In the urgent care setting, evaluation of lower gastrointestinal bleeding with colonoscopy can be very challenging, and some studies suggest the source of bleeding may only be identified in 13% of cases, although a wide range has been reported in the literature (Lee et al. 2011). In fact, a specific cause may not be identified on endoscopy or subsequent work-up in as many as 20% of patients (Whelan et al. 2010). This is at least partially related to the fact that 75–80% of all gastrointestinal bleeding stops spontaneously without intervention (Lee et al. 2011).

High-resolution CT allows for short acquisition times and the ability to image at different time intervals following contrast administration. While exact technical parameters vary between institutions, a three-phase examination is generally performed including non-contrast, arterial, and portal venous phase imaging. Imaging is performed without oral contrast as intraluminal positive contrast can obscure or mask active bleeding. Intravenous contrast is administered via a power injector at a rate of 4 mL/s. Arterial phase imaging can be performed via automated Hounsfield unit triggering when the abdominal aorta reaches 100–150 HU. Portal venous imaging is then performed approximately 70–90 s after initial injection.

The non-contrast study is initially used to evaluate for any pre-existing hyperdense material or substance within the colon that may mimic contrast extravasation or blood products on subsequent post-contrast imaging. Occasionally, clotted blood related to recent hemorrhage may appear hyperdense.

Active bleeding within the colon is identified on CT angiography by the presence of intraluminal contrast extravasation or "blush," which may take on a variety of appearances including jetlike stream, pooling of contrast between folds, or more amorphous high-density material within the lumen (Fig. 15) (Artigas et al. 2013). The diagnosis is made when the extravasation is present on arterial phase imaging and changes in shape, size, or location on delayed imaging.

CT angiography can detect bleeding at a threshold rate of 0.3–0.5 mL/min. In comparison, conventional catheter-directed angiography can detect bleeding at a threshold rate of 0.5 mL/min and nuclear medicine scintigraphy with tagged ^{99}Tc-labeled red blood cells at a rate of 0.1 mL/min (Artigas et al. 2013). Although the nuclear medicine tagged RBC scan is more sensitive, it is more time-consuming and may not always be readily available in the emergency setting. Similarly, catheter-directed angiography is usually reserved for the hemodynamically unstable patient with severe bleeding and is best utilized as a targeted therapeutic procedure. As a result, CTA may be ideally situated to screen and triage patients with lower gastrointestinal bleeding. Many times CTA can also accurately diagnose the underlying etiology, the most common causes of which include diverticulosis, angiodysplasia, ulcers, and malignancy.

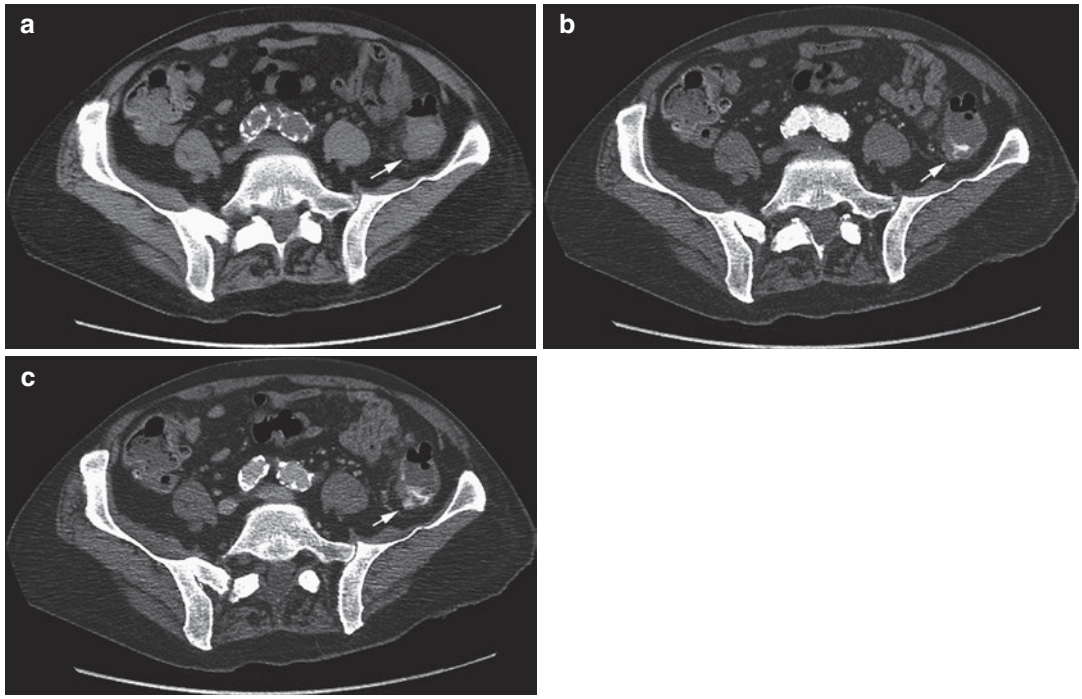

Fig. 15 A 78-year-old presents to the ER with lower gastrointestinal bleeding. (**a**) Axial non-contrast CT shows no acute abnormality. (**b**) Arterial phase shows contrast pooling within the distal descending colon (*arrow*). (**c**) Delayed venous phase shows increased pooling and slight change in morphology consistent with active gastrointestinal bleeding (*arrow*)

Conclusion

The pathology of the large bowel is vast; however, MDCT offers an accurate, efficient, and versatile modality for diagnosis. It can be used in virtually any setting whether it is chronic multisystemic diseases or in the acute emergency room setting. When tailored appropriately, MDCT can aid in the diagnosis, management, and treatment of patients. As discussed, CT enterography can be used to evaluate individuals with inflammatory bowel disease, triple-phase CTA for acute lower gastrointestinal bleeding, MDCT for staging and follow-up surveillance of colorectal cancer, as well as an emerging role for widespread cancer screening with CT colonography.

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