CT Enterography

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Overview

CT enterography (CTE) has become a key component for the diagnosis and management of small intestinal diseases and lesions. As a radiologic modality designed to optimize visualization of the small bowel and surrounding structures, it can be utilized for an extremely diverse set of indications. CTE in adult and pediatric Crohn's disease patients can detect active inflammation, stricturing disease, and penetrating complications, and assess response to medical therapy. It can also demonstrate extraintestinal inflammatory bowel disease manifestations and alternate etiologies for a patient's symptoms of abdominal pain or diarrhea. Additional CTE applications include the diagnosis of small bowel tumors and vascular lesions in patients with obscure gastrointestinal bleeding. These features have made CTE a vital tool in the clinician's small bowel imaging armamentarium.

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Introduction

CTE has gained widespread acceptance in abdominal imaging and gastroenterology as a powerful technique to visualize small bowel inflammation and masses and to guide therapeutic decision making. Its adoption was initially aided by recognition that small bowel fluoroscopy is limited in its visualization of mucosal detail compared to modern endoscopic techniques [1, 2]. The past decade has provided evidence for the complementarity and uniqueness of CTE findings compared to capsule and balloon-assisted endoscopy, e.g., intramural and perienteric findings that provide important adjunctive information not provided by direct luminal visualization [3–5]. For example, many small bowel tumors can arise within the small bowel wall with intact, overlying mucosa, and many complications of Crohn's disease (such as perienteric fistula or mesenteric venous thromboses) can directly affect management of care and are usually not that visualized at endoscopy. While vascular lesions are directly visualized with endoscopic techniques, CTE can provide important information relating to size and arteriovenous shunting that may influence treatment [6]. In this chapter, we highlight the imaging findings at CTE, with an emphasis on differential diagnosis, summarize indications and evidence for use of CTE, as well as review technical adaptations that maximize patient benefit while

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minimizing risk. Finally, we suggest a perspective for incorporating CTE into multimodality adult and pediatric GI practices.

General Principles and Patient Preparation

Prior to reviewing imaging findings, a basic understanding of CTE patient preparation is necessary. CTE is an abdominopelvic CT in which patient preparation and image acquisition and reconstruction methods have been adapted to maximize visualization of the small bowel lumen, wall, and perienteric mesentery. Patient preparation requires ingestion of a relatively large volume of enteric contrast (900–1,800 cc) administered over 45–60 min prior to CT examination to distend the small bowel lumen [7–9]. The enteric contrast agent is selected based on potential pathologies and the patient's ability to ingest different agents, but most small bowel pathologies are best visualized with the use of neutral enteric contrast, which possesses CT attenuation similar to water. Hyperenhancing masses and inflammation and vascular structures are conspicuous when juxtaposed against low-attenuation perienteric fat and a neutral enteric contrast agent [10, 11]. Most neutral contrast agents contain sugar alcohols or similar substances, which retard water absorption along the small bowel to result in better luminal distension [9]. Owing to the need for patient ingestion, CTE is generally performed as an outpatient procedure; when performed in the emergency room or hospital, it is often performed only with water. CTE is usually performed as a single acquisition, usually in the "enteric phase" of contrast enhancement, approximately 50 s after the start of intravenous injection, as this is the time period of maximal small bowel enhancement [12]. When synchronous imaging of other organs, such as the liver, is required, hepatic phase imaging can also be performed without demonstrable loss in performance for identification and staging of Crohn's disease [13]. For patients with potential pancreatic or small bowel pathology, the timing of the "pancreatic phase" of enhancement is identical to the enteric phase. Multiphase CTE is reserved for detection and characterization of causes of obscure gastrointestinal bleeding, as multiphasic exams are required to confidently diagnose active bleeding (as demonstrated by extravasation of intravenous contrast into the bowel lumen) and vascular lesions [14]. Patient preparation, image acquisition, and reconstruction parameters are tailored to meet the individual needs of each patient and their indication for imaging, or diagnostic task (see later section: Adaptations).

Imaging Findings

Visual review of CTE findings can be classified according to the small bowel segment (i.e., duodenum, jejunum, or ileum); mural thickening and enhancement, symmetry, and location within the bowel wall (i.e., intramural, luminal, or related to diverticula); and perienteric findings. The distribution and enhancing nature of the lesions will further aid in differential diagnosis and guide subsequent imaging and treatment options.

The Normal Small Bowel

Radiologists and gastroenterologists should be familiar with the appearance of the normal bowel at CTE. The jejunum demonstrates numerous feathery folds, the valvulae conniventes. The jejunal and ileal wall thickness should be 3 mm or less when the small bowel is distended, but can be thicker when collapsed or in peristalsis. Owing to the feathery valvulae conniventes, the jejunum wall is often falsely interpreted as having mural thickening when the lumen is only collapsed and the folds are coapting with each other (Fig. 4.1). The duodenum has a similar appearance to the jejunum, with the transverse portion crossing underneath the SMA to enter the left upper quadrant. The proximal jejunum may be located in the left upper quadrant or may cross into the right lower quadrant. Both the duodenum and jejunum will enhance to a substantially greater degree than the ileum during the enteric phase, with

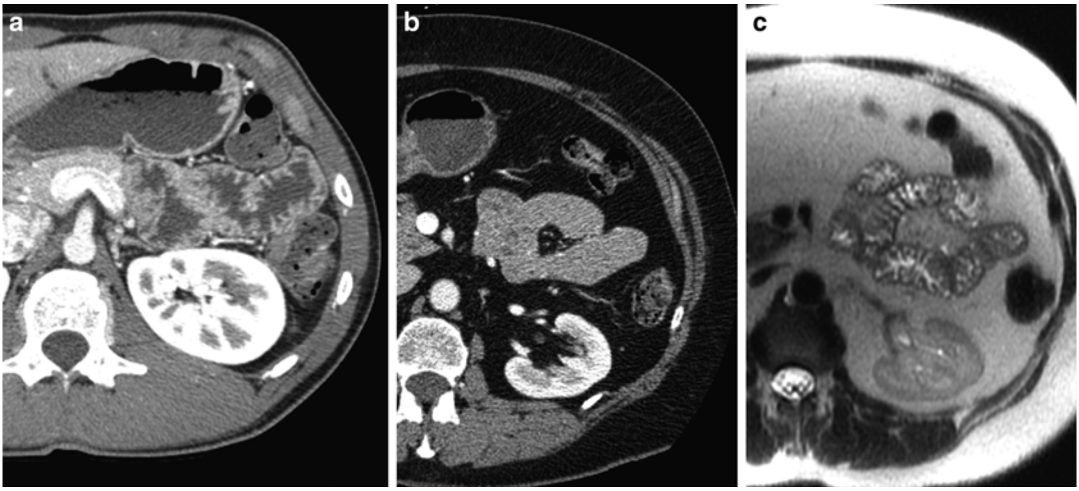

Fig. 4.1 Normal appearance of jejunum at CT enterography. Note thin and regularly spaced valvulae conniventes in distended jejunum (**a**). Collapsed jejunum in another patient at CT enterography (**b**) shows normal appearance as lumen collapses and jejunal folds coapt together. Forty minutes after CT in (**b**), patient underwent MR enterography showing normal jejunal loops and folds (**c**)

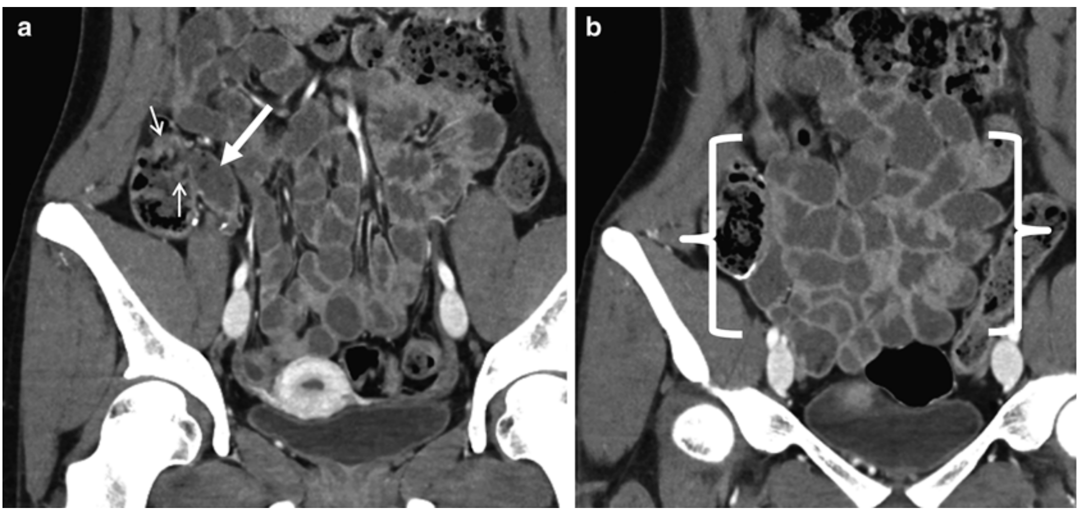

Fig. 4.2 Coronal CT enterography images showing normal appearance of terminal (**a**, *arrow*) and distal (**b**, *between brackets*) ileum. Note paucity of folds, thin wall, and slightly decreased mural enhancement. *Small arrows* (**a**) show ileocecal valve, which is located within a haustral fold in the cecum

enhancement becoming more similar across the length of the small bowel in later phases of enhancement [15]. The terminal ileum enters the cecum at the ileocecal valve, which has a "fish-mouth" shape and is located within a cecal fold (Fig. 4.2). It is normal for the terminal ileum to contain intramural fat, and this should not be regarded as a sign of chronic inflammation within the terminal ileum, as it is in other enteric locations [16]. The small bowel vasculature should be carefully evaluated along with the small bowel. The mesenteric arteries are best evaluated on the sagittal view; the mesenteric veins are best appreciated on coronal images.

Mural Findings

Mural hyperenhancement is generally seen in the presence of mural thickening, and it is a nonspecific sign of inflammation or altered perfusion. The combination of segmental mural hyperenhancement and mural thickening is specific for Crohn's disease when the enhancement and mural thickening are asymmetric with respect to the bowel lumen—for example, worse along the mesenteric border (Fig. 4.3). Similar to findings at small bowel follow-through where the mesenteric border linear ulcers are pathopneumonic for Crohn's disease, inflammation as represented by CT findings of hyperenhancement and mural thickening are seen most prominently along the mesenteric border, often with pseudosacculation along the anti-mesenteric border, with prominent vasa recta that supply the inflamed bowel segment. Jejunal Crohn's involvement occurs in about 15 % of Crohn's patients, is associated with an increased incidence of stricturoplasty and hospitalizations [17], and is frequently overlooked by novice radiologists and gastroenterologists (Figs. 4.4 and 4.5). While there are a number of other causes of segmental jejunal hyperenhancement and mural thickening, including infection (often giardia), ulcerative jejunitis in sprue, vasculitis, and systemic infiltrating diseases, only Crohn's disease typically involves the bowel in an asymmetric fashion (whether proximal or distal). Segmental hyperenhancement without wall thickening can be seen in early Crohn's disease, as well as other causes of hyperenhancement, and generally reflects more mild degrees of inflammation. Radiation enteritis and NSAID-related diaphragm disease also demonstrate segmental hyperenhancement in conjunction with focal strictures in the mid to distal small bowel. Both types of strictures are short (often 1–2 cm) and symmetric with respect to the bowel lumen

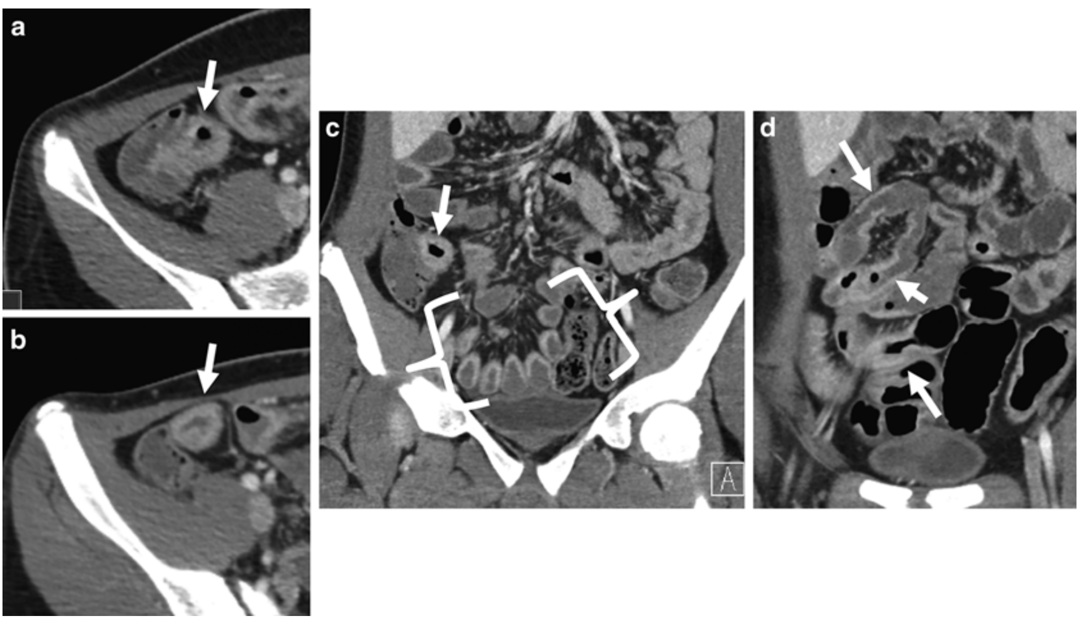

Fig. 4.3 Typical appearance of Crohn's ileitis at CT enterography in patient with erythematous mucosa at ileoscopy. Note mural thickening and hyperenhancement of terminal ileum on axial and coronal images (**a**–**c**, *arrows*). In distal ileal loops, inflammation as demonstrated by hyperenhancement and wall thickening is more prominent along the mesenteric border (**c**, *between brackets*), so is asymmetric with respect to bowel lumen. Multiple skip lesions (**d**, *arrow*) are present in the mid-ileum. Findings demonstrate the complementarity of CT enterography with endoscopic assessment. Biopsy at ileoscopy showed active and chronic ileitis

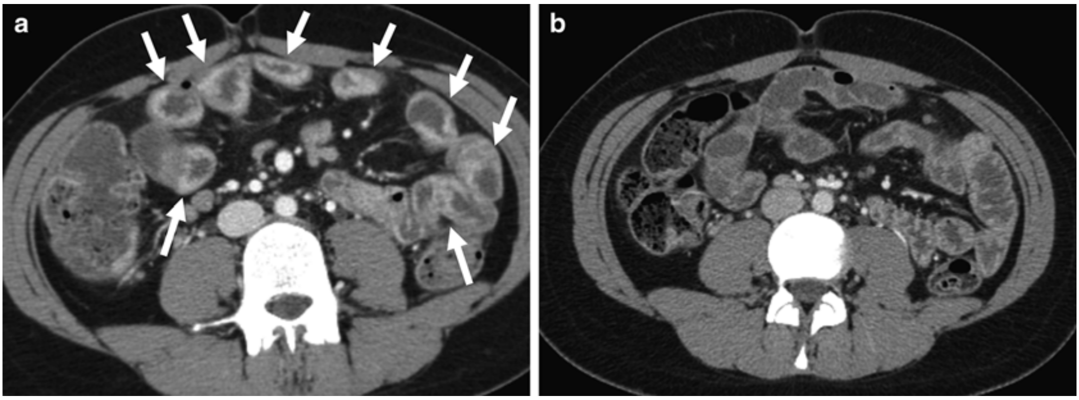

Fig. 4.4 Typical findings of jejunal Crohn's disease in 18-year-old Crohn's patient with asymmetric thickening and hyperenhancement of multiple loops (**a**, *arrows*). After combination therapy (infliximab combined with azathioprine), CT enterography 2 years later demonstrates normal appearance to the previously inflamed jejunal loops (**b**)

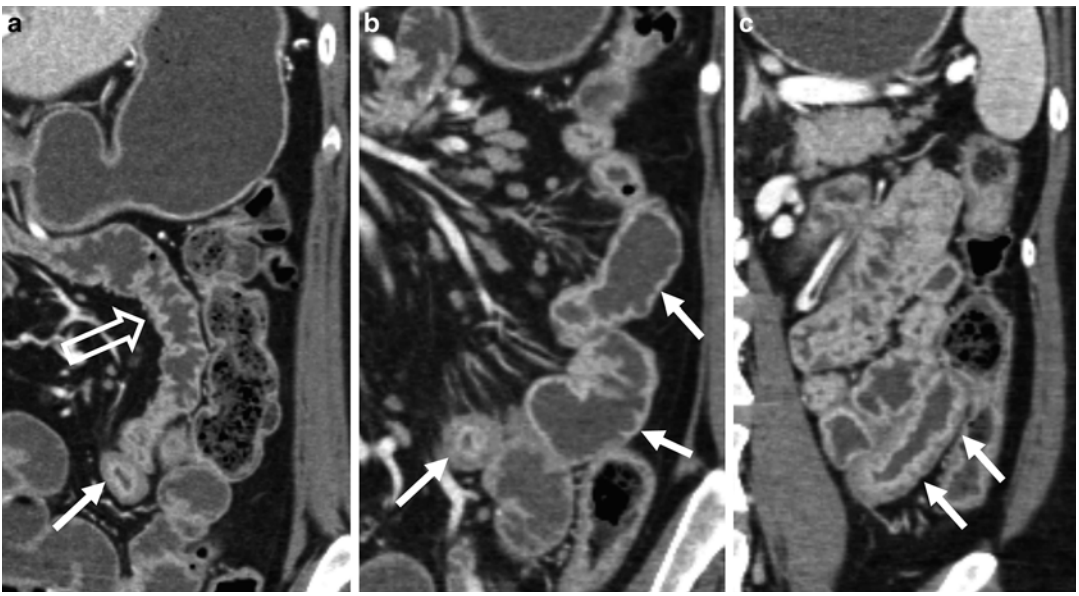

Fig. 4.5 CT enterography images from another patient with jejunal Crohn's disease show normal-appearing jejunum (*open arrow*, **a**) superior to inflamed jejunum (**a**, *solid white arrow*). Note prominent vasa recta along mesenteric border of other jejunal loops (**b**, *arrows*), in addition to disruption of fold pattern and asymmetric enhancement. Some inflamed loops have a layered or stratified appearance to the thickened bowel wall (**a**–**c**, *arrow*)

[18, 19]. Strictures in the setting of radiation enteritis occur in small bowel with abnormal enhancement, while those in diaphragm disease have variable (often mild) hyperenhancement with intervening regions of normal-appearing bowel. Celiac sprue typically manifests as normally enhancing jejunal loops that have lost valvulae conniventes due to villous atrophy, usually with fold reversal (or increased number of folds) in the ileum (Fig. 4.6). Hypoenhancing bowel can be a worrisome finding for ischemia, and when pneumatosis is present, infarction is often present. As ischemia generally frequently occurs in the setting of high-grade small bowel

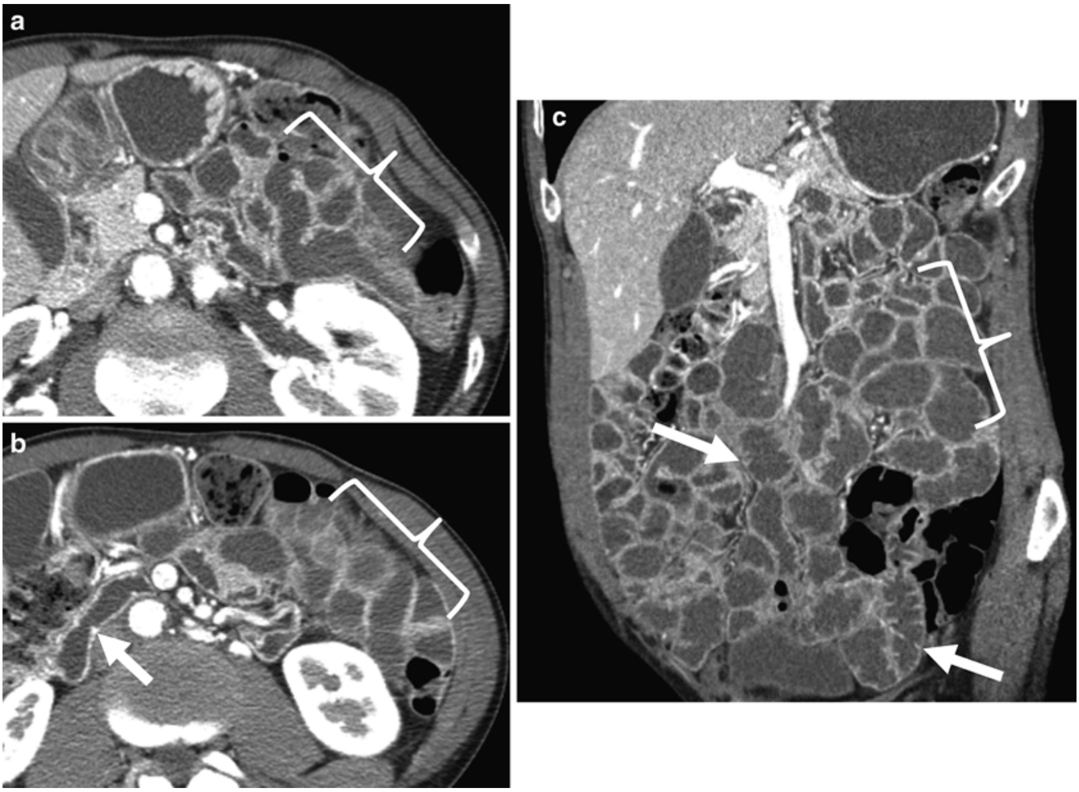

Fig. 4.6 CT enterography images demonstrating typical findings of celiac sprue, including normally enhancing jejunal loops with loss of folds (**a**–**c**, *brackets*). Note featureless duodenum (**b**, *arrows*) and increased number of folds in the ileum (fold reversal; **c**, *arrows*)

obstruction or vascular occlusion, pneumatosis cystoides coli and benign pneumatosis are not infrequently observed in outpatient CTE (Fig. 4.7). Focal regions of wall thickening with hypo- or isoenhancement may also represent intramural hemorrhage or lymphoma (described later) [20].

Mural thickening is generally considered to be present when greater than 3 mm in a distended bowel segment. When segmental mural thickening is combined with segmental hyperenhancement, findings usually reflect inflammatory or infectious etiologies. Symmetrical involvement in the proximal small bowel can be seen in ulcerative jejunitis and/or infectious jejunitis, such as neutropenic enteritis or giardia. For ulcerative jejunitis, other findings such as relative loss of valvulae conniventes are helpful. Symmetrical mural thickening combined with straightened and dilated bowel loop is often seen in ACE-related angioedema, venous compromise (such as from SMV thrombosis or carcinoid tumor), or pancreatitis. ACE-related angioedema is usually seen in women and may or may not be associated with first exposure to an ACE inhibitor. It is manifest by general bowel wall edema, and segmental luminal dilation, often with localized ascites and mesenteric edema [21]. Hyperenhancement of affected loops is normal or relatively mild with symmetric bowel wall edema present. SMV thrombosis, and segmental hemorrhage in anticoagulated patients, can also present with long segment mural thickening with or without hyperenhancement, and correlative findings in the SMV or solid organs should be searched for. Infiltrating diseases such as systemic IgG-related

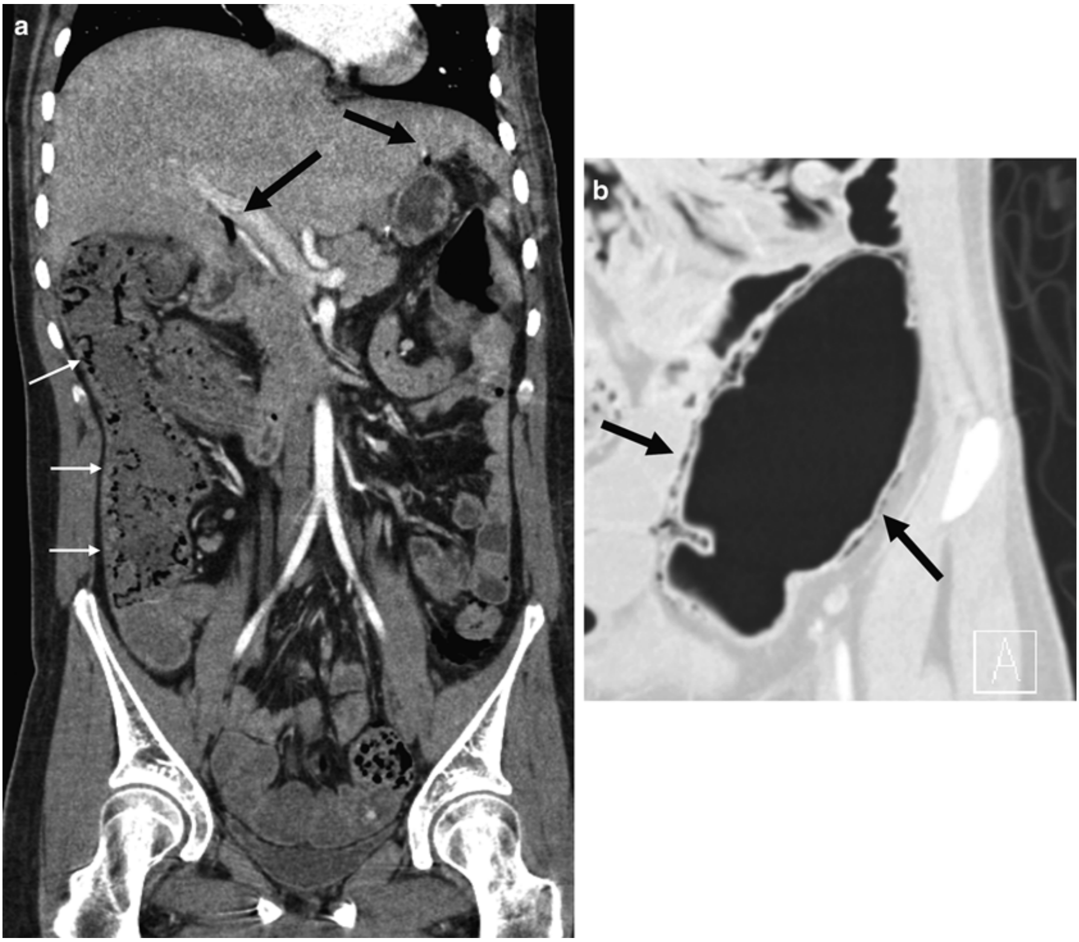

Fig. 4.7 Pneumatosis is observed throughout the ascending colon (**a**, *small white arrows*), with a small amount of free air underneath the liver (**a**, *black arrows*) on CT enterography performed for anemia. Coronal image of sigmoid colon also shows pneumatosis (**b**, *black arrows*). Patient was observed in hospital without treatment without deterioration. Imaging findings felt to represent benign pneumatosis potentially due to pseudo-obstruction or multiple prior enteroenteric anastomoses

disease, mastocytosis, and amyloidosis are rarely seen, but they can also cause segmental bowel wall thickening (Fig. 4.8). In general, for inflammatory, vascular, and infiltrative diseases, the bowel wall thickening will be less than 1.5 cm in diameter; neoplasm should be considered for focal regions of bowel wall thickening of greater degree [22]. Diffuse small bowel thickening can be seen in cirrhosis, graft-versus-host disease, and shock bowel, where correlation with patient history and other imaging findings usually suggests the diagnosis. Diffuse hyperenhancement of the bowel with mild and symmetric wall thickening is seen in conjunction with CT signs of hypotension (e.g., flat IVC) in patients with trauma-induced shock bowel, but similar findings are seen in other conditions such as septic shock and cardiac arrest that cause hypotension [23].

Focal mural findings in the small bowel are generally neoplastic or vascular, whereas luminal findings include active bleeding and polyps or neoplasia. While adenocarcinoma is generally considered one of the more common small bowel neoplasms, carcinoid (neuroendocrine) tumors,

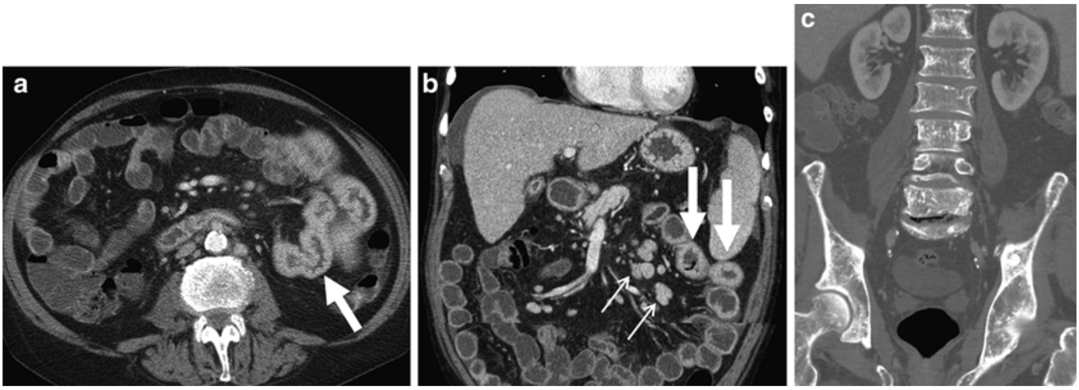

Fig. 4.8 Diffuse and continuous jejunal mural thickening and enhancement (**a** and **b**, *arrows*) due to mastocytosis. Note mesenteric adenopathy (*small white arrow*, **b**), small amount of ascites (**b**), and diffuse sclerotic lesions in the bones (**c**)

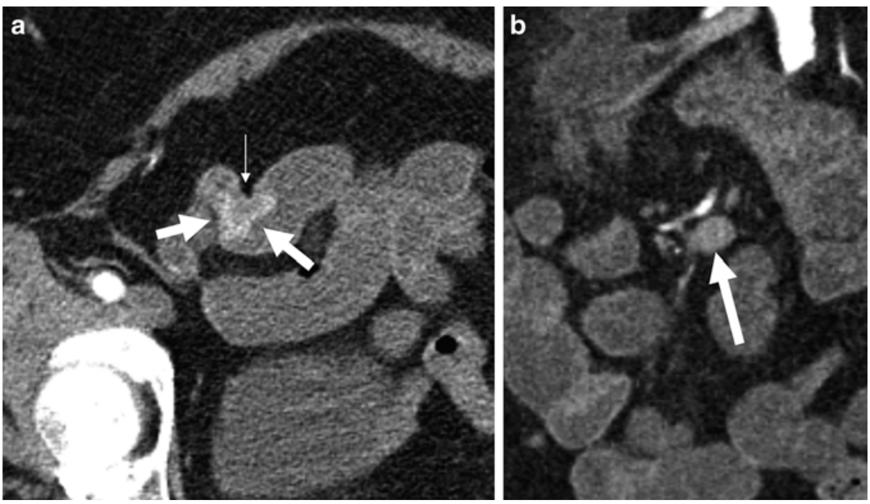

Fig. 4.9 Multiphase CT enterography performed for obscure GI bleeding demonstrates an enhancing ileal tumor (**a**, *arrows*). The mass demonstrates intense enhancement and serosal puckering (*small white arrow*), which is indicative of carcinoid tumors. Nodal metastases from carcinoid tumors typically occur close to mesenteric vessels (**b**, *arrows*)

gastrointestinal stromal tumors (GIST), and lymphoma are much more frequently seen at cross-sectional enterography. Now that multiphase CTE is often performed to evaluate for obscure GI bleeding, the unique morphologies of many of these tumors are being better appreciated.

Carcinoid tumors can appear as small hyperenhancing polyps, which grow within the bowel wall and over time will often become flat or plaque-like masses, often with luminal shouldering and serosal puckering or retraction (Figs. 4.9 and 4.10) [24]. Multifocal neuroendocrine tumors are frequently seen and are clustered within a small bowel (usually ileal) segment. As the tumor infiltrates through the vessel wall, typical patterns of metastatic lymphadenopathy are seen (Fig. 4.10). Neuroendocrine mesenteric and nodal metastases will often cluster along the regional mesenteric vessels and eventually cause vascular compromise. Eventually, liver metastases will develop.

GIST tumors are generally hyperenhancing tumors, often with an exoenteric component,

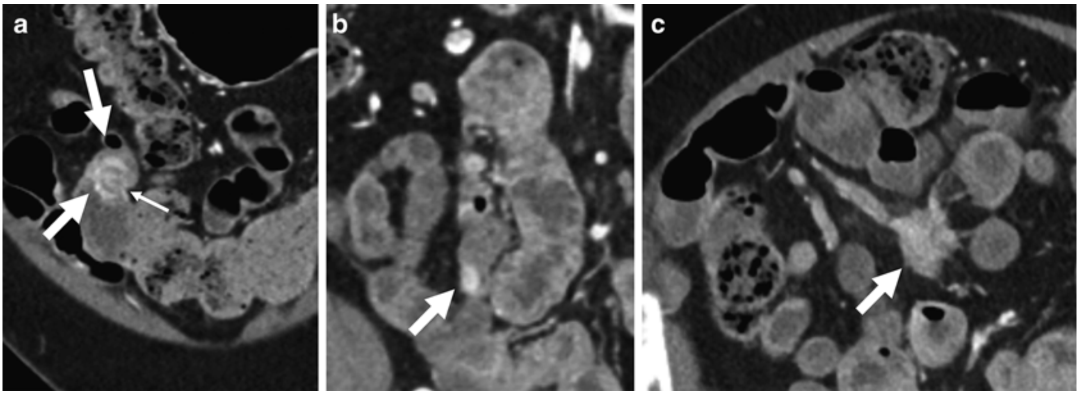

Fig. 4.10 CT enterography performed for abdominal pain shows multiple enhancing ileal masses (**a** and **b**, *arrows*), one with characteristic serosal puckering (**a**, *small arrow*), indicating multifocal ileal carcinoid tumors. Mesenteric nodal metastasis (**c**, *arrow*) demonstrates typical findings of enhancing mesenteric mass with radiating strands of desmoplasia to nearby small bowel loops and engorged mesenteric veins (due to obstruction)

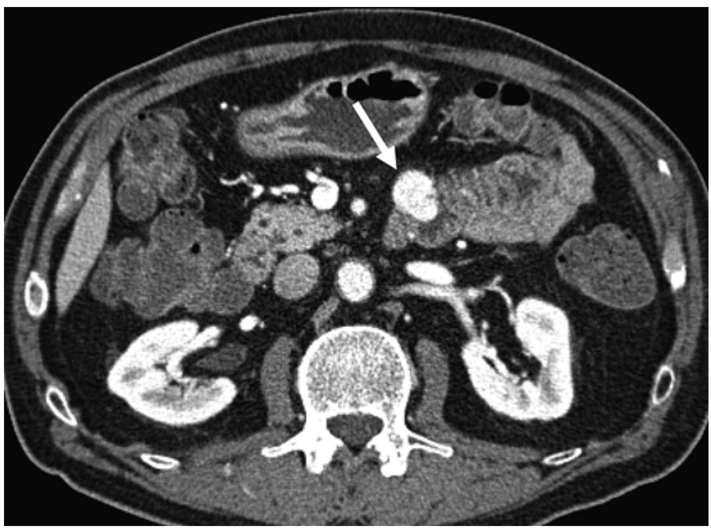

Fig. 4.11 Typical appearance of small bowel gastrointestinal stromal tumor (GIST; *arrow*) at CT enterography. Axial image shows 2 cm hypervascular mass with intraluminal and exoenteric components

and may or may not show surface ulceration (Fig. 4.11). In contradistinction, some GIST tumors can be isoenhancing and intraluminal. Frequently, as the GISTs enlarge, they ulcerate and may lose typical hyperenhancement patterns. It may be useful to characterize the morphology of these masses with positive enteric contrast when needed. Occasionally, ectopic pancreas can mimic the appearance of GIST tumors in the proximal small bowel, as the ectopic tissue will also be exoenteric with respect to the bowel lumen.

Small bowel lymphomas occur as singular or multiple areas of focal bowel wall thickening. Unlike carcinoid or GIST tumors and Crohn's disease, lymphomas typically are iso- or hypoenhancing compared to the adjacent bowel wall. The classic pattern for lymphoma is that of "aneurysmal ulceration," meaning that the lumen of the small bowel tumor is markedly enlarged with thickening of the surrounding wall (Fig. 4.12) [25]. There will often be adjacent lymphadenopathy. Adenocarcinoma can be seen

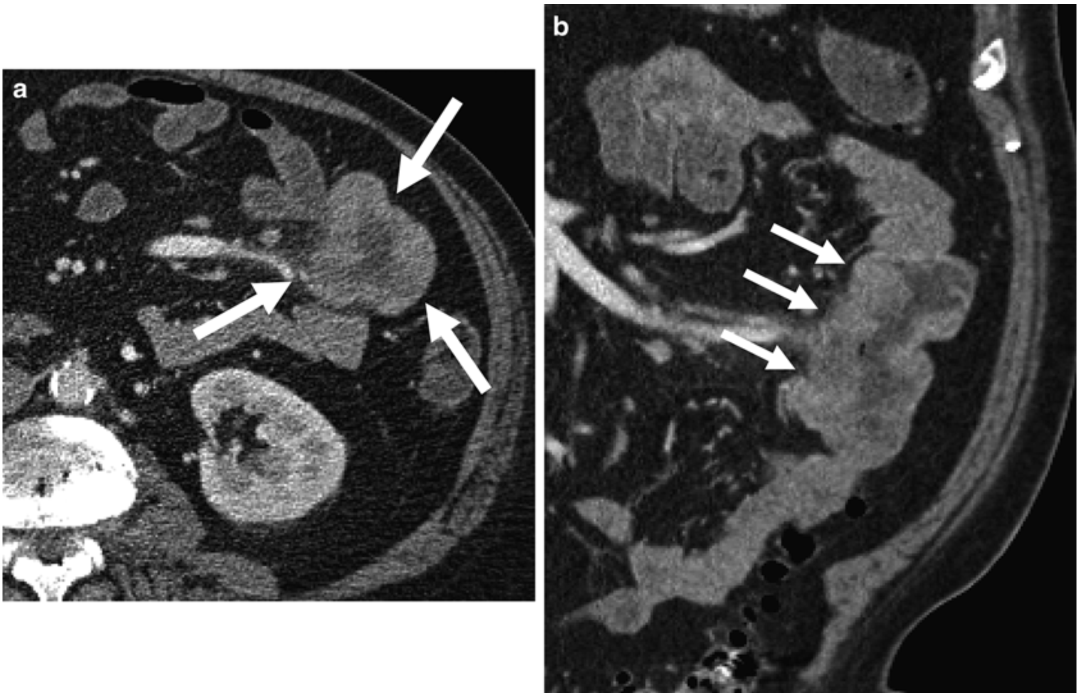

Fig. 4.12 Small bowel lymphoma (**a** and **b**, *arrows*) with marked wall thickening caused by iso- or hypo-attenuating tumor and enlargement of the bowel lumen (referred to as "aneurysmal ulceration")

Fig. 4.13 Adenocarcinoma (*arrows*) arising in setting Crohn's disease in a patient with multiple strictures. Note high-grade partial obstruction and nodularity to the extraluminal margin

in isolation or in the setting of Crohn's disease, where it can appear as a focal stricture with mural nodularity (Fig. 4.13) [26]. Adenocarcinomas are infrequently detected at CTE and do not demonstrate a characteristic morphology.

Active bleeding at multiphase CTE is demonstrated by progressive accumulation of intraluminal contrast over subsequent phases of enhancement (Figs. 4.14 and 4.15). Active bleeding may be associated with a neoplasm or vascular etiology, but in the case of a Dieulafoy lesion or focal ulcer, no other abnormality will be appreciated. Several studies have shown that bleeding rates detectable at CT angiography and

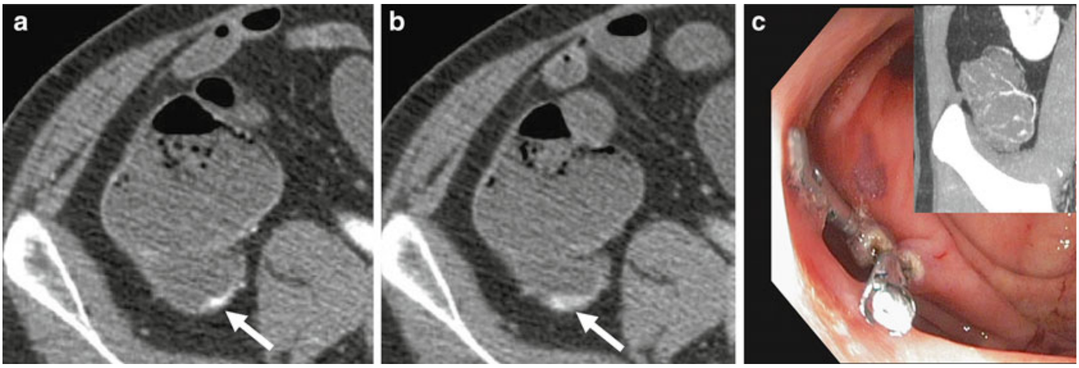

Fig. 4.14 Axial enteric and delayed-phase images (**a** and **b**, respectively) demonstrate progressive accumulation of intravenous contrast dependently within the cecum, indicating active bleeding (**a** and **b**, *arrows*). Coronal maximum intensity projection images (**c**, *inset*) show nodular tufts of vessels in the wall of the cecum. Patient was treated with argon plasma coagulation and hemoclips

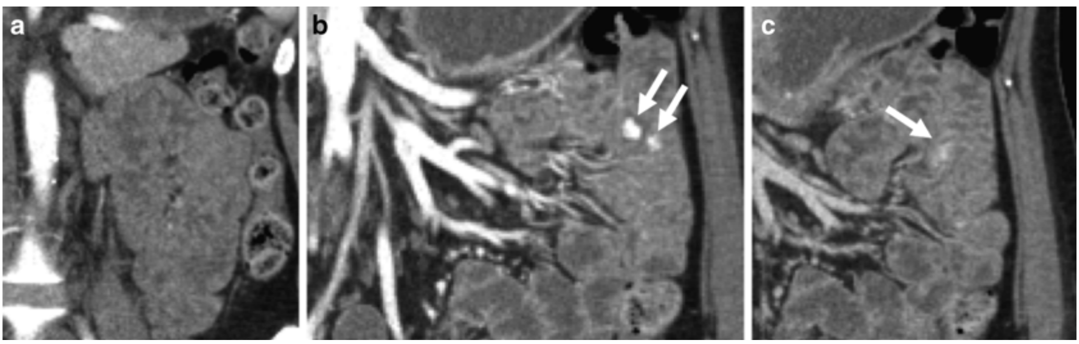

Fig. 4.15 Coronal arterial-, enteric-, and delayed-phase images (**a**, **b**, and **c**, respectively) from a multiphase CT enterography demonstrate progressive accumulation of intravenous contrast within the jejunal lumen between the arterial and enteric phases (**b**, *arrows*). Delayed-phase images show movement and dilution of intraluminal contrast (**c**, *arrow*). Findings indicate active jejunal bleeding. Small bowel enteroscopy identified a Dieulafoy lesion at this location, which was treated with argon plasma coagulation

multiphase CTE are comparable to catheter angiography [14]. Medication and radiopaque debris will also be bright at multiphase CTE, and will be unchanged in appearance between phases when slight movement of luminal contents due to peristalsis is taken into account.

Vascular lesions at CTE are generally classified according to the method of Huprich and Yano as angioectasias, arterial lesions, and venous lesions [6]. Angioectasias are frequently multiple and seen in elderly patients. They appear as small or round intramural lesions, usually best seen in the enteric phase of enhancement. They are frequently multiple and are generally underestimated by CT compared to endoscopy. They are thought to arise from mesenteric veins that lack an internal elastic layer, with arteriovenous communication developing as the precapillary sphincter becomes incompetent [6]. Angioectasias and arterial lesions are also seen in the cecum and ascending colon with some regularity at multiphase CTE exam, and in this location, they are generally associated with arterial shunting and an enlarged draining vein. Arterial lesions are best seen in the arterial phase and may or may not have an enlarged draining vein. Because of avid

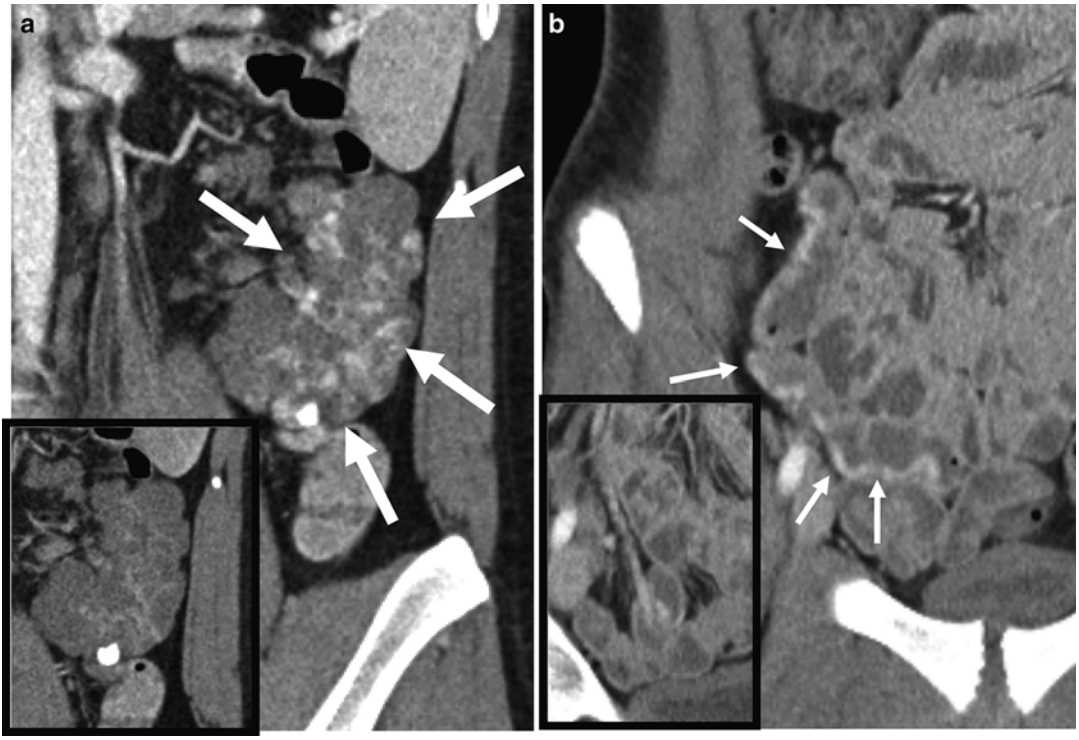

Fig. 4.16 Large jejunal vascular malformation with phleboliths on precontrast imaging (**a**, *inset*), and blood-filled spaces that enhanced slowly with time after contrast (**a**, *arrows*), in patient with presumed Klippel-Trenaunay-Weber. Another patient with an ileal vascular malformation with dilated intramural vessels (**b**, *arrows*) and a large draining vein (**b**, *inset*)

arterial enhancement, there is the potential for large amounts of bleeding. Arterial lesions include angioectasias with arterial shunting, Dieulafoy lesions, and arteriovenous fistulas. Venous lesions are a heterogeneous group of disorders, with varices frequently seen in patients with cirrhosis or chronic mesenteric venous thrombosis from Crohn's disease. Younger patients often have large congenital vascular malformations, often in conjunction with other known vascular lesions, e.g., Klippel-Trenaunay-Weber syndrome (Fig. 4.16).

CTE surveillance for polyps and masses can be performed in addition to magnetic resonance (MR) enterography or enteroclysis in patients with polyposis syndromes. In these patients, polyps and neoplasia occur within the lumen, so positive enteric contrast is often used. Because of the high attenuation differences between positive contrast and the filling defects of polyps, radiation doses can be markedly reduced to levels used for CT colonography (Fig. 4.17).

Morphologic abnormalities constitute a heterogeneous group of disorders, including malrotation, small bowel diverticulosis, Meckel's diverticulum, and postoperative anastomoses. Intestinal malrotation predisposes to midgut volvulus. Findings of small bowel nonrotation include ascending colon and cecum in the midline, redundant duodenum with ligament of Treitz in the right upper quadrant, and rounding of the uncinate process of the pancreas [27]. Patients with non-rotation and intermittent small bowel volvulus often present for outpatient imaging when the small bowel volvulus has resolved. They should be informed of findings so that they can present to the ER if acute, unrelenting pain occurs as prompt surgical treatment may be required.

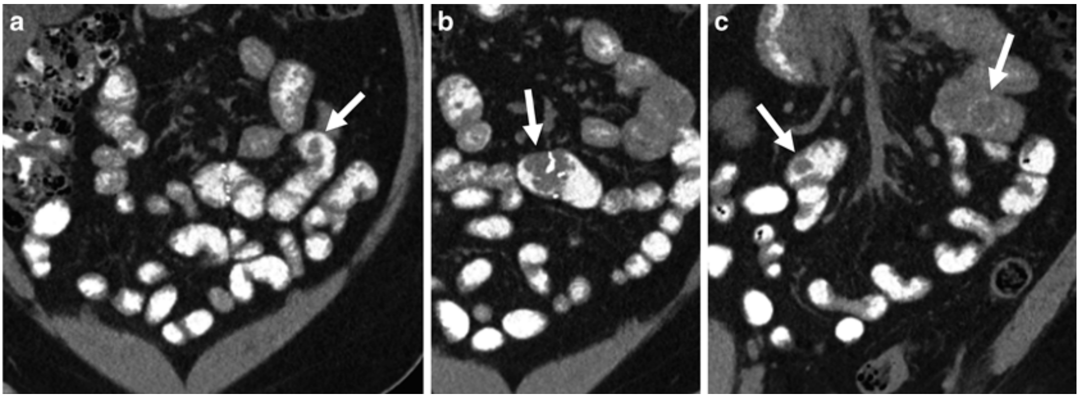

Fig. 4.17 Single-phase CT enterography with positive oral contrast demonstrates multiple polyps (**b–c**, *arrows*), including a recurrent polyp (**b**, *arrow*). Positive contrast enteroclysis or enterography can be performed at low radiation doses because suspected pathology is known to be located in the small bowel lumen, as opposed to the wall or perienteric tissues

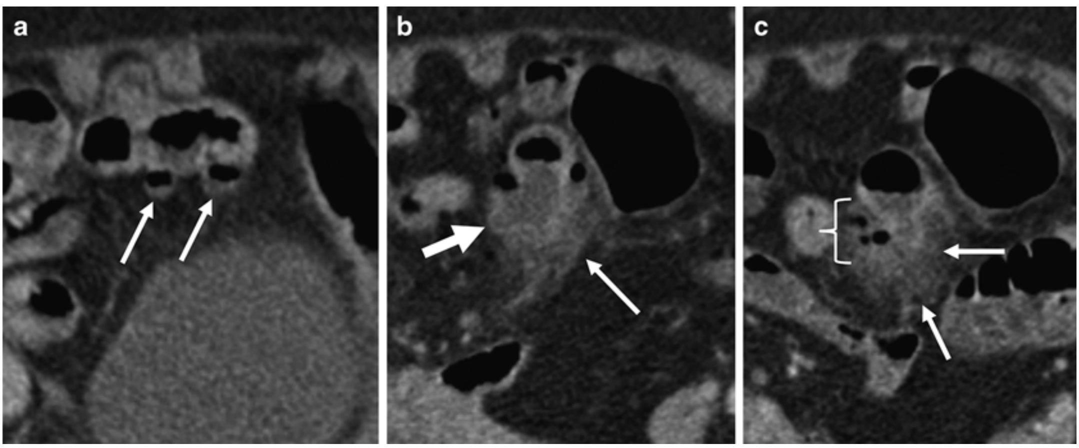

Fig. 4.18 Just superior to two ileal diverticula (**a**, *small arrows*), a large ileal diverticulum is seen (**b**, *arrow*) with stranding in the surrounding perienteric fat (**b** and **c**, *small arrows*) and localized perienteric air (**c**, *brackets*), indicating perforated ileal diverticulitis

Small bowel diverticula can be mistaken for a small bowel loop on a single cross-sectional image. In volumetric datasets from CT and MR enterography, the findings are unmistakable, but they are often overlooked. The lumen of the jejunum will have valvulae conniventes, whereas diverticula will not. Jejunal or ileal diverticulitis can occur when a diverticulum becomes inflamed or perforated (Fig. 4.18). Meckel's diverticulum is a frequent cause of obscure gastrointestinal bleeding in young and middle-aged patients. Bleeding from Meckel's can occur due to ulcer, inflammation, neoplasm, or ectopic gastric mucosa within the diverticulum. Often, the diverticulum will be large and may contain a focal area of hyperenhancement or luminal defect corresponding to one of these abnormalities.

Extraenteric Findings

Extraenteric findings can often be an important clue to inflammatory bowel disease or its complications (Fig. 4.19). Penetrating Crohn's

Fig. 4.19 Patient with history of indeterminate colitis underwent CT enterography showing pancolitis with patulous ileocecal valve (**a**), characteristic of ulcerative colitis. Coronal liver images show mild intrahepatic biliary dilation (**b**, *large arrow*) extending inferiorly into the right lobe (**b**, *small arrow*) with periductal perfusion abnormalities (**b**, *oval*), suggesting cholangitis. Patient underwent ERCP (**c**) demonstrating a localized stricture at the bifurcation of the intrahepatic ducts and mild changes of intrahepatic primary sclerosing cholangitis

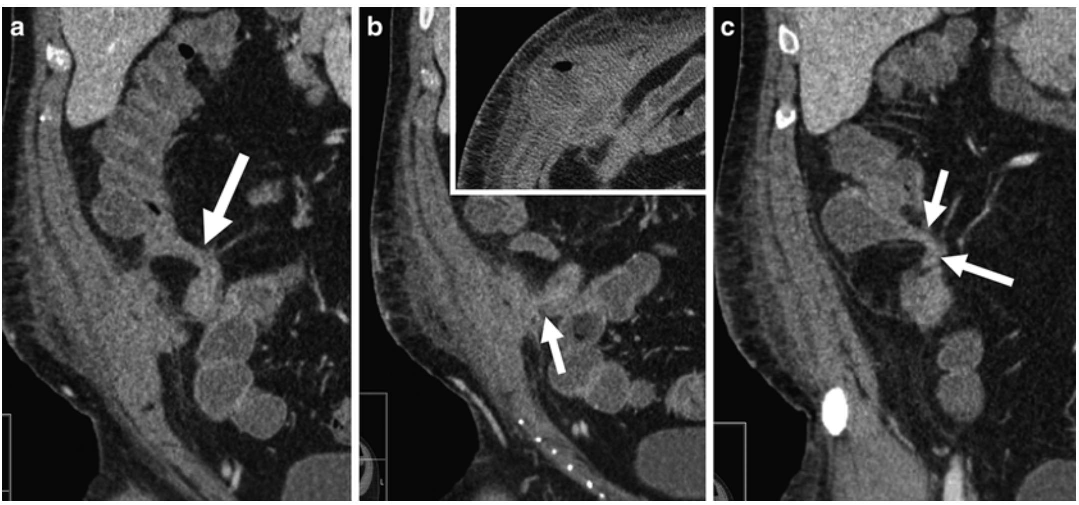

Fig. 4.20 CT enterography images from anterior to posterior demonstrate complex, penetrating ileocolic Crohn's disease. Fistulas appear as extraenteric tracts with tethering of affected bowel loops (enteroenteric fistula, **a**—*large arrow*; ileocecal fistula, **c**—*arrows*). *Middle image* shows fistula to abdominal wall (**b**, *arrow*) that has resulted in abdominal wall abscess (**b**, *inset*)

disease is manifest by sinus tracts, fistulae, inflammatory mass, and abscess. Small bowel fistulas (e.g., enterocolic fistula or entercutaneous fistulas) appear as enhancing, extraenteric tracts that arise from inflamed small bowel loops, and often distort or tether loops from which they arise [28]. Complex, branching fistulas will form asterisk-shaped fistulae complexes that will involve multiple small bowel loops (Figs. 4.20 and 4.21). Fistulas that extend to the retroperitoneum will often form abscesses along the iliopsoas muscle. Perianal fistulae

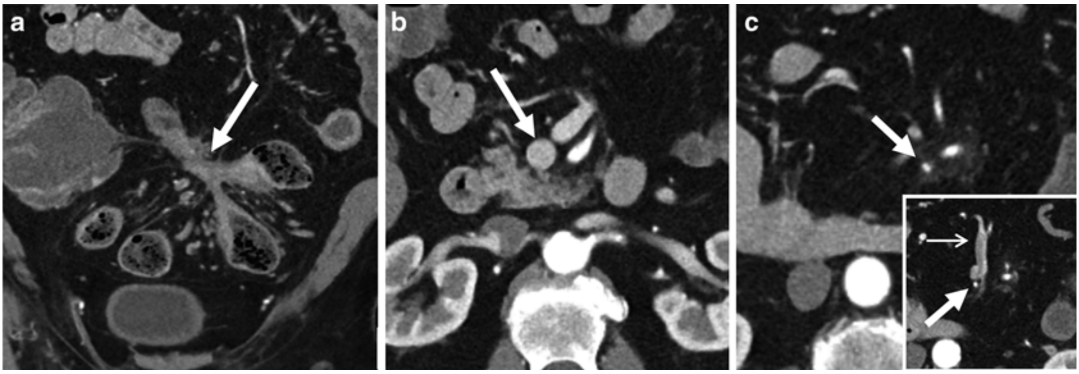

Fig. 4.21 Chronic superior mesenteric vein thrombosis in a patient with asterisk-shaped enteroenteric and enterocolic fistulae complex (**a**, *arrows*). Axial images demonstrate normal caliber superior mesenteric vein at the level of pancreatic head (**b**, *arrow*) that becomes diminutive inferiorly at the level of transverse duodenum (**c**, *arrow*). Even more inferiorly, enlarged peripheral mesenteric venous collaterals are seen (**c**, *inset*)

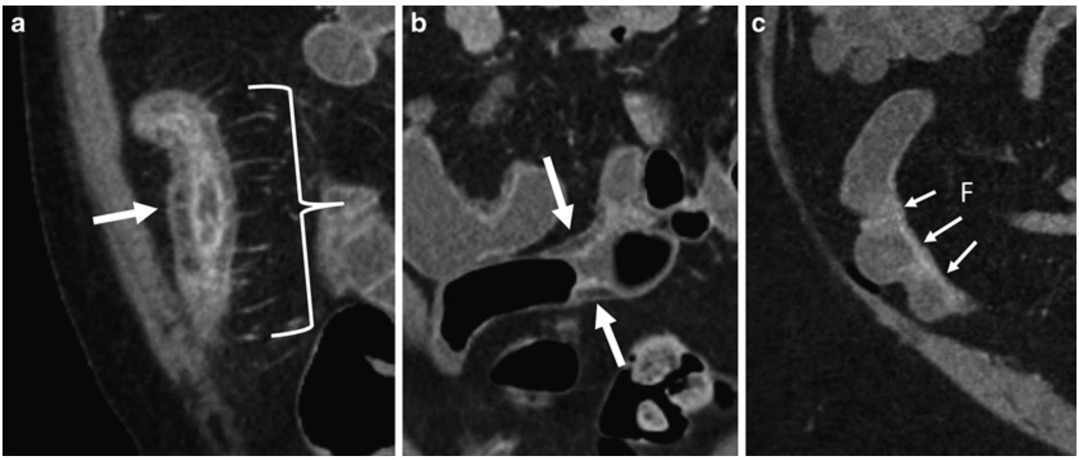

Fig. 4.22 Perienteric and acute and chronic Crohn's inflammation. Acute and chronic Crohn's inflammation is evidenced in small bowel loops with mural stratification with synchronous findings of submucosal fat (prior inflammation) and inner wall hyperenhancement (current inflammation; **a** and **b**, *arrows*). The "comb sign" (**a**, *brackets*) refers to engorged vasa that enter the small bowel or colon at a right angle (**a**, *bracket*). This imaging finding is associated with moderate to severe active inflammation. Mesenteric border inflammation (evidenced by mural hyperenhancement and wall thickening; *small arrows*, **c**) in a third patient is also indicative of Crohn's enteric inflammation, and is associated with antimesenteric sacculation and fibrofatty proliferation ("F")

suggest Crohn's disease as the etiology in patients with inflammatory colitis without small bowel involvement. While perianal fistulas and abscesses are often detected at CTE, they are poorly characterized in terms of their anatomic location compared to dedicated perineal MR imaging. Low-kV imaging techniques generally increase the conspicuity of perianal fistulas. Chronic perianal fistulas and anovaginal fistulas are often not seen at CTE.

Vascular and mesenteric findings are often associated with Crohn's disease. The "comb sign" represents engorged vasa recta that supply inflamed bowel segments (Fig. 4.22) and are associated with increased rates of hospitalization and TNF response [29]. Fibrofatty proliferation is often associated with mesenteric border inflammation, and displaces bowel loops (Fig. 4.22). Mesenteric venous thrombosis can be located centrally in the superior mesenteric vein and portal vein, or in smaller, peripheral mesenteric veins. Central mesenteric thromboses frequently completely recanalize, while peripheral ones often result in lasting venous narrowing (i.e., chronic peripheral mesenteric vein thrombosis), and result in collateral vessel formation, including the development of varices (Fig. 4.21) [30].

Reactive lymph nodes are a hallmark of Crohn's disease, where they are often numerous. For colorectal Crohn's disease, reactive lymph nodes are characteristically located in the pericolonic fat between the engorged vasa recta, whereas reactive mesenteric lymph nodes for small bowel Crohn's are usually located within the central mesentery. Lymph nodes greater than 1.5 cm are considered by some to be abnormal. As mentioned, metastatic lymphadenopathy from small bowel neuroendocrine tumors has a characteristic appearance. It clusters along lymph nodes, and owing to the serotonin release, often creates radiating strands of desmoplasia to adjacent small bowel loops, often with characteristic punctate calcification.

Indications and Evidence

Crohn's Disease

Natural History

The natural history of Crohn's disease in individual patients is varied. Different initial presentations of the disease, age at disease onset, and extent and location of disease involvement have been shown to suggest different phenotypes with different disease courses and complications. Therefore, the optimal imaging modality and timing will vary from patient to patient. Pigneur et al. showed that disease onset in childhood versus adulthood portends more active disease requiring more immunosuppressive therapy [31]. These patients require more frequent imaging specifically assessing for active inflammation and response to treatment changes. Cosnes et al. showed that the initial location of disease can predict the development of subsequent stricturing or penetrating complications [32]. Given the frequent asymptomatic nature of these complications in many patients [28, 33], cross-sectional radiologic surveillance to guide medical management is often helpful. And finally, Crohn's disease is a chronic disease process requiring ongoing imaging monitoring, with 70–80 % of patients requiring surgery at 20 years and many patients experiencing disease recurrence requiring reoperation within several years [34].

Mucosal Reference Versus Integrated Reference, and Endoscopic Skipping of the Terminal Ileum

Early studies of CTE compared CT findings to fluoroscopic small bowel follow-through, which is an inadequate reference standard for mucosal inflammation when compared to optical techniques. Consequently, early CTE studies compared results to endoscopy in the terminal ileum in patients that could be assessed at ileocolonoscopy [35]. Subsequent studies have suggested that the ileal mucosa can appear normal at ileocolonoscopy in the presence of synchronous intramural and proximal ileal inflammation [3, 36]. Indeed, in just over 50 % of Crohn's patients with normal findings in the terminal ileum at endoscopy [5], small bowel inflammation will be unequivocally present, either intramurally within terminal ileum or in the proximal small bowel. This phenomenon may occur in an even higher percentage of pediatric patients than adults [37, 38] and may herald aggressive disease. CTE is complementary to endoscopy in the assessment of small bowel involvement, as it readily shows disease involvement in segments of bowel not accessible by endoscope, as well as disease limited to the wall of the bowel and mesentery. Consequently, current reference standards for CTE studies usually include combined assessment using endoscopy or surgery, serum markers, and other confirmatory, cross-sectional imaging methods [3].

Clinical Benefit: Adult IBD

Several observational studies have demonstrated the benefit of CTE in making clinical decisions in the inpatient and outpatient settings. Higgins et al. showed that enterography imaging findings change the impression of steroid benefit in the majority of patients [39]. Bruining et al. prospectively assessed the clinical benefit of CTE in more than 250 patients with either established or suspected Crohn's disease [40]. After gastroenterologists examined the patient and obtained the clinical history, they were asked to detail their pre-imaging clinical management plan and level of confidence. After the CTE was performed, gastroenterologists were again asked for their management plan and level of confidence. Bruining et al. found that in approximately half of patients with either established or suspected Crohn's disease, CTE resulted in clinical management changes, and in 70 %, CTE findings substantially improved clinician level of confidence.

Two studies have examined the benefit of CT in the ER. Israeli et al. found that in a series of Crohn's patients presenting to the ER (80 % with abdominal pain), over 25 % had a small bowel obstruction and 8 % had penetrating disease, with management changes occurring on the basis of abdominal CT in over 80 % of patients (including 12 % of patients going to surgery) [41]. In a larger retrospective study of 648 Crohn's patients over an 8-year time frame, Kerner et al. found that the rate of penetrating disease, obstruction, or abscess was about 29 % and that about 35 % of patients had an abdominopelvic CT finding that necessitated treatment [42]. They concluded that "these numbers reflect the fact that patients with Crohn's disease are at high risk for complications given the nature of their disease and the risks of immunosuppression … Although radiation exposure in patients with Crohn's disease is a concern, clinicians must also weigh the risk of missing a potential urgent diagnosis when they forgo CT" [42].

Clinical Benefit: Pediatrics

Pediatric patients pose unique considerations for the imaging diagnosis and monitoring of inflammatory bowel disease and many factors need to be considered when determining the appropriate imaging modality to be used.

CTE is often used in conjunction with ileocolonoscopy as one of the first imaging studies to establish a diagnosis of inflammatory bowel disease and distinguish between ulcerative colitis and Crohn's disease. CT offers superior spatial resolution and ability to assess all segments of bowel [43]. In addition, CT is often used in patients with known inflammatory bowel disease in the setting of acute abdominal pain with fever, leukocytosis, obstructive symptoms, or suspicion of penetrating complications or perforation, due to its wide availability, rapid performance, and good tolerability. In this scenario, positive oral contrast or water is often used in place of neutral enteric agents even though this may decrease sensitivity for identifying Crohn's small bowel inflammation. Finally, CTE is often used for procedure planning when invasive intervention, such as stricturoplasty, surgical resection, abscess drainage, or colectomy, is being considered. The most significant drawback of CTE is that because Crohn's disease has a chronic remitting course requiring lifelong imaging for acute complications often requiring medical and surgical intervention, the cumulative radiation dose of multiple CT exams can be substantial [44]. Therefore, in pediatric patients, medical justification rests on the perceived medical benefit for each exam (e.g., identification of abscess for antibiotic treatment, or obstruction evaluation for potential surgery).

MR enterography (MRE) is utilized most often for monitoring of disease activity and response to treatment, offering global assessment of the bowel wall and extraluminal disease manifestations like CTE. Because no ionizing radiation is utilized, MRE is the preferred imaging modality when evaluating asymptomatic patients [45]. MRE has been shown to be equally sensitive to CTE for the detection of bowel inflammation [36, 46], and is felt to be superior to CTE in the detection and characterization of perianal fistulizing disease and detection of fibrosis [47]. MRE can, however, suffer from various artifacts, such as air in the bowel lumen and motion. MRE also has the drawbacks of being a lengthy exam, which may not be well tolerated in very young patients, symptomatic patients, and claustrophobic patients, and is more costly compared to CTE. Some institutions routinely sedate younger patients for MRE to improve tolerance of the exam; others do not, citing potential risk of aspiration in anesthetized patients after oral contrast.

Both CTE and MRE require the ingestion of a large amount of enteric contrast, which can be poorly tolerated by pediatric patients. Ultrasound is emerging as a viable alternative for monitoring of Crohn's disease, with its application being particularly suitable to children and adolescents due to smaller body habitus and frequent lack of need for oral contrast. Ultrasound has the added benefit of interactive, real-time imaging, which allows the sonographer and radiologist to get feedback about symptom location and to assess for persistence of bowel wall thickening, narrowing, and dilatation. Real-time assessment can increase confidence that findings are not artifactual, e.g., by observing and distensibility in a potentially stenotic segment. Contrast-enhanced ultrasound using microbubbles has been shown to improve detection and confidence in active inflammation of the bowel wall over thickening alone [48]. Analysis of the bowel wall vascularity pattern after administration of microbubbles has also been shown to assist in the differentiation of inflammatory versus fibrotic strictures [49], and used to evaluate the response to treatment as manifested by wall enhancement and vascularity patterns [50–52]. Ultrasound may suffer from poor visualization of deeper bowel loops and decreased accuracy for global bowel assessment, particularly if enteric contrast is not utilized. Ultrasound is also heavily operator dependent, requiring experienced sonographers and radiologists for performance and interpretation.

Clinical Benefit: Obscure Gastrointestinal Bleeding (Adult)

Early capsule endoscopy studies showed that traditional radiologic imaging with small bowel follow-through and routine abdominal pelvic CT was ineffectual in detecting causes of obscure gastrointestinal bleeding [53]. Moreover, capsule endoscopy has a very high yield of positive findings in large series, particularly in patients with active bleeding [54–56]. However, as CTE and balloon-assisted endoscopy techniques have developed, it is also clear that capsule endoscopy fails to identify many small bowel tumors, owing largely to their intermural or submucosal location. Compared to double-balloon endoscopy, capsule endoscopy may only identify about one-third of mass lesions [57]. In a retrospective study of 103 post-bulbar tumors, CTE found 91 % versus 30 % for capsule endoscopy, and in the subset of patients undergoing both studies, CTE found 2–3 times as many tumors [58]. Finally, Huprich et al. performed prospective and retrospective studies examining the role of multiphasic CTE in identification of small bowel bleeding sources in patients with obscure gastrointestinal bleeding [4, 59]. In a prospective study of 58 patients, capsule endoscopy demonstrated significant findings in 25 % of patients versus 44–48 % for CTE. In nine confirmed small bowel masses, CTE found 100 % versus 33 % for capsule endoscopy. The ASGE's 2011 practice guidelines recommend consideration of multiphase CTE after repeat endoscopy. Shin et al. additionally found that positive multiphase CTE findings occur more often in overt rather than occult obscure gastrointestinal bleeding, and that positive CTE findings are associated with specific treatments and diminished rates of rebleeding [60]. Additionally, multiphase CTE may be particularly helpful in patients with nondiagnostic capsule findings, such as nonspecific blood in the small intestine or lesions without bleeding [61, 62]. Based on these and other studies, multiphase CTE is considered complementary with capsule endoscopy in defining the site and cause of obscure gastrointestinal bleeding, particularly when nondiagnostic or questionable findings are seen at capsule endoscopy(e.g., due to stricture, motility, or dysphasia). Finally, multiphase CTE can be performed and interpreted on the same day to quickly guide diagnostic workup in these patients, and to select patients for surgery or therapeutic angiography in the case of small bowel tumors and active bleeding, or as an aid to visualization and treatment at subsequent balloon-assisted endoscopy.

Clinical Benefit: Obscure Gastrointestinal Bleeding (Pediatric)

Gastrointestinal bleeding in the pediatric population can be caused by a variety of conditions. Bleeding can be obscure and life threatening. Pediatric patients can experience obscure gastrointestinal bleeding secondary to the same etiologies as adults. In addition, some etiologies tend to present more commonly with gastrointestinal bleeding in children, such as Meckel's diverticulum, Crohn's disease, congenital vascular malformations, and polyps. After upper and lower endoscopy fail to reveal a cause, and capsule endoscopy is negative, radiologic workup is often initiated including nuclear medicine Meckel's scan, conventional CT and CTE, and catheter angiography.

The use of CTE for obscure gastrointestinal bleeding in the pediatric population has not been studied as extensively as in the adult population. In fact, only one case series was found in the literature reporting the use of CTE for this indication. Davis et al. reported a series of six patients with prior negative imaging studies such as ultrasound and Meckel's scan who underwent CTE [63]. In this cohort of patients, CTE was able to prospectively diagnose solitary polyps in two cases, multiple polyps in one case, a Meckel's diverticulum in two cases, and an inflamed duplication cyst in one case. No cases of vascular anomalies of the bowel wall were found in these patients. Diagnostic yield remains unknown as the cases with negative CTE were not reported.

Meckel's diverticulum in particular often poses a challenging clinical and radiologic diagnosis. Nuclear medicine Meckel's scan with Tc-99m pertechnetate is the first-line test ordered when a Meckel's diverticulum is suspected, with sensitivity and specificity reported to be 94 and 97 % in the literature [64]. However, false negatives do occur, and Meckel's without ectopic gastric mucosa are not diagnosed. CTE can potentially give the diagnosis in these cases.

The instance of vascular anomalies including hemangiomas and vascular malformations in the pediatric gastrointestinal tract is rare. These can be diffuse and associated with syndromes such as Klippel-Trenaunay, Osler-Weber-Rendu, and blue rubber bleb nevus syndrome. The most common symptom is gastrointestinal bleeding [65, 66]. The use of multiphase CTE exams in children has not been studied, and due to the concern of radiation exposure in young patients and the need to adhere to the principles of ALARA in the pediatric population, until further dose reduction techniques and supportive data are established, use of these exams should be confined to pediatric patients with ongoing blood loss and negative endoscopic assessment.

Diarrhea and Abdominal Pain

Because CTE is often performed in patients with diarrhea, CTE may suggest noninflammatory bowel disease causes such as pancreatic insufficiency or mass, celiac disease, other causes of malabsorption, or bacterial overgrowth, due to motility disorder or small bowel diverticulosis. In these settings, CTE performed at routine abdominopelvic radiation dose settings can easily evaluate for pancreatic tumors and causes of diarrhea other than inflammatory bowel disease.

Adaptations of CTE Technique

CTE technique is adapted for patients of different sizes, ages, and clinical indications (called diagnostic tasks in the radiology literature). Obviously, single-phase CTE (in either the enteric/pancreatic or portal phase of enhancement) is performed for most indications. Multiphase examinations are performed for patients with obscure gastrointestinal bleeding, or patients with suspected pancreatic or neuroendocrine tumors. CTE is not performed for acute gastrointestinal bleeding, where enteric contrast is not needed [14]. Radiation dose is tailored to patient size and diagnostic task through use of the automatic exposure control on modern multidetector CT systems. Automatic exposure control modulates the X-ray tube current as the X-ray tube rotates around the patient as the patient passes through the CT gantry, and is designed to produce a constant level of image quality regardless of patient attenuation (e.g., with lower levels of tube current for projections going anterior to posterior in thin patients). It reduces radiation exposure by about 30 % over large numbers of patients. Newer CT systems also use tube energy (or kVp) to simultaneously minimize radiation exposure and increase iodine contrast to noise, which can increase conspicuity of inflamed bowel segments [67]. Lower tube energies and decreasing tube currents reduce radiation dose but increase CT image noise. Multiple studies have demonstrated that radiologists can perform quite well in diagnosing and staging Crohn's disease, even with lower dose CT images [68–70], but currently, multiple CT noise reduction methods exist, such as iterative reconstruction, and are available in most radiology departments [71, 72]. It is imperative that gastroenterologists and radiologists work together to make these lower dose technologies available to Crohn's patients who are young, who will incur greater lifetime radiation doses due to the recurrent nature of Crohn's complications [44]. In patients with renal insufficiency, contrast-enhanced CTE using half the routine amount of iodinated contrast can be performed by combining bolus-tracking, low kVp techniques, and iterative reconstruction. Positive enteric contrast can be used for polyposis patients, as mentioned earlier, and will permit exams to be performed without intravenous contrast at substantial dose reduction (Fig. 4.17).

CTE is often performed using a low-concentration barium solution containing sorbitol to promote gastric peristalsis and water retention within the bowel lumen. A variety of other commercially available products, as well as water, have been evaluated in a head-to-head comparison [9], but the low-concentration barium solution demonstrated the best lumen distension with fewer side effects. Studies have been performed looking for the optimal concentration, amount, and timing of enteric contrast [7, 9, 73]. Side effects are common, but are generally minor and time limited, including abdominal cramping, diarrhea, and nausea. Some patients have difficulty ingesting the required volume of enteric contrast, especially young patients or those with obstructive symptoms. In such cases the ingestion protocol is generally altered, such as giving less enteric contrast or having the patient switch to water ingestion. Administering the enteric contrast via enteric tube is an alternative available at some institutions due to patient preference.

Conclusion

CTE is an accepted cross-sectional imaging modality optimized for small bowel assessments, with CTE technique guided by both patient size and indication. Applications are numerous in patients with inflammatory bowel disease and obscure gastrointestinal bleeding as well as those with other gastrointestinal diseases. CTE can detect both intestinal and extraintestinal disease processes. Dose reduction techniques can be utilized to limit exposure, particularly in young patients.

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