15.3.3 Radiology of the gastrointestinal tract 274

15.3.3 Radiology of the gastrointestinal tract 2748

section 15 Gastroenterological disorders 2748 FURTHER READING Allison MC, et al. (2009). Antibiotic prophylaxis in gastrointestinal endoscopy. Gut, 58, 869–80. ASGE Standards of Practice Committee, et al. (2012). Adverse events of upper GI endoscopy. Gastrointest Endosc, 76, 707–18. Dumonceau JM, et al. (2014). Prophylaxis of post-ERCP pancrea- titis: European Society of Gastrointestinal Endoscopy (ESGE) Guideline. Endoscopy, 46, 799–815. Veitch AM, et al. (2015). Optimizing early upper gastrointestinal cancer detection at endoscopy. Nat Rev Gastroenterol Hepatol, 12, 660–7. 15.3.3 Radiology of the gastrointestinal tract Fiachra Moloney and Michael Maher ESSENTIALS The widespread introduction of endoscopic techniques has reduced the need for radiological examination of the intestinal tract and has almost completely rendered imaging of the stomach obsolete. There remains, however, a substantial role for radiological imaging in the investigation of the small and large bowel in the diagnosis of abdom- inal and gastrointestinal disease. The small intestine may be examined by a number of radio- logical techniques, including plain films, barium contrast studies, ultrasonography, CT, MRI, and nuclear medicine. Barium studies (follow-through or small-bowel enema) provide good morpho- logical detail of the mucosal surface of the bowel; cross-sectional imaging (usually CT or MRI) is required for disease involving the wall of the bowel or outside it. CT is increasingly used as the pri- mary investigation in suspected bowel obstruction. Nuclear medi- cine studies have a role in the examination of the small bowel for the presence of inflammatory conditions, and for demonstration of potential bleeding sources. Colonoscopy has revolutionized imaging approaches to the colon because of its proven diagnostic efficacy and the added facility for biopsy of diffuse mucosal pathology and focal mucosal lesions, but is associated with a small risk of perforation. The use of barium enema continues to decline steadily. The advent of multidetector CT that allows three-dimensional reconstruction has led to a large number of new applications, including virtual colonoscopy or colonography, use of which is steadily increasing and is particularly valuable in the setting of unsuccessful or incomplete optical colonoscopy, although it is disadvantaged by inability to perform biopsy. Introduction Traditionally, barium studies were the mainstay of gastrointestinal tract imaging. However, barium techniques are labour intensive, time-consuming, sometimes technically demanding and unpleasant for the patient, and do not provide adequate extraluminal

infor- mation and have thus largely been superseded by cross-sectional imaging techniques, namely computed tomography (CT) and mag- netic resonance imaging (MRI). CT and MRI usually provide sat- isfactory luminal and mural information as well as detecting the presence of extraintestinal disease. Furthermore, there have been many technological advances in these imaging techniques in recent years including the development of enteric contrast agents that dis- tend the bowel, multiplanar and three-dimensional imaging, and advanced imaging applications such as motility imaging, and radi- ation dose reduction techniques. An exception to the trend in the declining use of barium studies is the barium swallow. This technique is still commonly used in pa- tients intolerant of endoscopy and in the assessment of oesophageal function and motility (Fig. 15.3.3.1). Barium studies also have an important role in the evaluation of patients following gastrointes- tinal surgery to detect postoperative complications. Upper gastrointestinal endoscopy has effectively replaced radio- logical studies for imaging the stomach. Radiology continues to play a pivotal role in the investigation of small-bowel pathology, as the small bowel is much less amenable to conventional endoscopy due to its length and tortuosity. The barium enema is the fluoroscopic procedure that has undergone the greatest decline in use with the emergence of CT colonography. This technique has a higher diagnostic accuracy than barium enema and may be used in patients intolerant of colonos- copy or as a screening tool. Fig. 15.3.3.1 Upright double-contrast view of the oesophagus shows tapered, beak-like narrowing of the distal oesophagus (arrow) due to incomplete opening of the lower oesophageal sphincter, with a standing column of barium proximally and slow emptying of barium into the stomach. There was no primary peristalsis in the body of the oesophagus at fluoroscopy. This constellation of findings is characteristic of achalasia. From Levy AD, Mortele KJ, Yeh BM (eds) (2015). Gastrointestinal imaging. By permission of Oxford University Press.

15.3.3 Radiology of the gastrointestinal tract 2749 Capsule endoscopy is a commonly used imaging technique that involves the ingestion of a pill camera that acquires high-definition colour views of the bowel lumen. Although the technique provides excellent mucosal detail, it has a relatively high false-positive rate (14%) due to mucosal breaks and erosions. In addition, it does not provide extraluminal information and its use is contraindicated in bowel obstruction and in patients with a history of bowel stric- tures. Many authorities advocate reserving capsule endoscopy for selected cases in which the suspicion of small-bowel disease re- mains high despite negative evaluations with endoscopy and radio- logical studies. The small bowel Small-bowel imaging techniques CT enterography and enteroclysis CT enterography and enteroclysis can be used to image a spectrum of small-bowel disorders including inflammatory bowel disease, coeliac disease, small-bowel tumours, and bowel obstruction. Both techniques combine an enteral volume challenge with the advan- tages of modern multidetector CT scanners, which offer multiplanar and three-dimensional reformatting capabilities with reduction in motion artefacts. CT enterography involves the oral administration of a neutral oral contrast agent approximately 1 hour prior to an abdominopel- vic CT examination. Patients are fasted for 8 to 12 hours prior to the study and drink 1.5 to 2 litres of oral solution. Neutral enteric contrast agents have similar attenuation properties to water (10–20 Hounsfield units) and may include polyethylene glycol, mannitol, water–methylcellulose solution, and milk, with polyethylene glycol being marginally favoured at many institutions. Reported side ef- fects include diarrhoea, vomiting, and abdominal cramps. CT enteroclysis involves inserting a nasojejunal tube under fluoroscopic guidance and infusing an enteral contrast agent at a controlled rate using an enteroclysis pump to a total volume of ap- proximately 2 litres. Postprocessing options with both techniques include multiplanar reformations and maximum intensity projections,

which are useful to assess the mesenteric vasculature and highlight enhancing path- ology on coronal reconstructions. Although superior small-bowel distension is routinely obtained with the enteroclysis technique, CT enterography has been found to be comparable in terms of diagnostic accuracy. Furthermore, given the invasive nature of the enteroclysis technique and the additional radiation exposure incurred during nasojejunal tube placement, CT enterography has become the preferred technique for the investiga- tion of suspected small-bowel disease. CT lacks the mucosal detail of small-bowel barium studies but pro- vides excellent depiction of the bowel wall and extraintestinal tissues. Other limitations include the need to administer intravenous contrast, possible poor toleration of the enteral contrast agent, and exposure to relatively high levels of ionizing radiation (up to 15 millisievert com- pared to 2 millisievert for a small-bowel follow-through). Exposure to ionizing radiation is a key consideration when decid- ing on the most appropriate imaging modality to investigate poten- tial small-bowel disease. This is especially true in young patients and patients with chronic conditions such as Crohn's disease that are at risk of high cumulative radiation doses from diagnostic imag- ing. Imaging modalities that do not involve exposure to ionizing ra- diation such as MRI and US should be used where possible in the first instance. However, CT is an appropriate technique when used judiciously in the correct clinical setting with consideration of the potential radiation dose to the patient and possible use of dose re-duction strategies to keep the dose as low as reasonably practical. Dose optimization strategies include limiting the number of imag- ing phases acquired, omitting unnecessary images at the peripheries of acquired series that do not contribute to diagnosis, and the use of modern image reconstruction techniques such as iterative recon- struction that reduce radiation dose while still acquiring diagnostic quality images (Fig. 15.3.3.2). Magnetic resonance enterography and enteroclysis MRI has many advantages that make it well suited for imaging the gastrointestinal tract: excellent tissue contrast, absence of ionizing radiation, and ultrafast sequences that facilitate the acquisition of real-time cine sequences which can evaluate small-bowel motility. The two imaging techniques most commonly used to achieve small-bowel distension are magnetic resonance enterography with oral contrast administration and magnetic resonance enteroclysis with infusion of the contrast solution through a nasojejunal tube. Enteric agents are classified as being positive (gadolinium, manga- nese ions), negative (super-paramagnetic iron oxides), or biphasic (water, polyethylene glycol) according to the signal intensity pro- duced on T1- and T2-weighted images. Biphasic agents are the most commonly used and produce low signal on T1-weighted images, which contrasts well to hyperenhancing inflammatory or neoplastic tissue on postgadolinium sequences (Fig. 15.3.3.3). As with CT en- teral contrast solutions, these agents may cause diarrhoea, vomiting, and abdominal pain. A routine MRI examination of the small bowel includes multiplanar T1- and T2-weighted sequences, often supplemented by dynamic contrast-enhanced sequences. Several new advanced imaging applications have been developed and investigated for small-bowel imaging in recent years including diffusion-weighted imaging, perfusion imaging, and motility imaging. Both diffusion and perfusion imaging have been shown to accurately discriminate normal from abnormal bowel, especially in inflammatory bowel dis- ease. Motility imaging, whereby real-time short cine loops of bowel motility are acquired, are facilitated by several properties of MRI including a rapid acquisition time and absence of ionizing radiation (Fig. 15.3.3.4). Both MRI and CT frequently serve as a 'one-stop shop' for imaging the small bowel offering satisfactory imaging of the bowel wall as well as the extraintestinal tissues. Compared with CT, MRI has su- perior contrast resolution and does not involve exposure to ionizing radiation, thus small-bowel loops of interest can be reimaged sev- eral times until satisfactory assessment is achieved. Conversely, CT is more widely available and is less prone to motion artefact. A major

disadvantage of CT, however, is that due to the limitation of radi- ation exposure, a single imaging acquisition can only be taken and thus distinction of small-bowel stricture from normal peristalsis can sometimes be difficult. The choice of modality should be tailored to the individual patient with consideration of current guidelines. Both modalities are comparable in terms of diagnostic accuracy but given

section 15 Gastroenterological disorders 2750 the radiation dose incurred during a CT examination of the small bowel, MRI is recommended by most authorities as the preferred initial investigation. However, in the acute setting CT is frequently more appropriate. Barium studies There are two barium techniques that are utilized to image the small bowel: the barium follow-through and the small-bowel enema. The barium follow-through involves the oral administration of a barium suspension followed by the acquisition of prone films every 20 to 30 min until barium reaches the terminal ileum. Fluoroscopic com- pression views of the terminal ileum to separate overlying small-bowel loops are then performed. For the small-bowel enema technique, a nasojejunal tube is inserted and the barium suspension is infused to give better bowel distension. Patients are fasted prior to both procedures. Small-bowel barium studies offer excellent mucosal detail at a lower radiation dose than CT. However, they provide very limited extraluminal information and patients often need to undergo fur- ther imaging with a cross-sectional technique. Ultrasonography Ultrasonography offers many advantages when imaging the small bowel: absence of ionizing radiation, low cost, and the dynamic real- time nature of the technique provides high temporal resolution. The technique generally involves systematic scanning of the abdomen with the use of graded compression to displace air and overlying bowel loops with a low- to medium-frequency ultrasound probe. Thickened, dilated bowel loops can often be identified but patient factors such as Fig. 15.3.3.2 Coronal reformatted images from a CT enterography in a 25-year-old female patient with Crohn’s disease. The left panel is from a conventional-dose CT with standard reconstruction. The right panel is from a contemporaneously acquired low-dose study performed at 18% of the conventional radiation dose study and reconstructed with pure model-based iterative reconstruction. Both images demonstrate thickening of distal ileal loops with associated mucosal hyperenhancement and mesenteric fat stranding (arrows). An extraluminal abscess is clearly seen on both studies (arrowheads). Courtesy of Cork University Hospital, Cork, Ireland. Fig. 15.3.3.3 Coronal T1 fat-saturation post-contrast magnetic resonance enterography in a 32-year-old male patient with Peutz– Jeghers syndrome demonstrates an ileoileal intussusception (arrow) secondary to an enhancing 4-cm polyp (arrowheads); another polyp is also shown (arrowhead). Courtesy of Cork University Hospital, Cork, Ireland.

15.3.3 Radiology of the gastrointestinal tract 2751 obesity, guarding, and shadowing gas often limit complete evaluation. Furthermore, ultrasonography is operator dependent and may fail to identify disease in bowel loops located deep within the abdomen and pelvis and to detect complications such as fistulas and strictures. Contrast-enhanced ultrasonography involving the intravenous injection of microbubbles and hydrosonography, whereby the small bowel is distended with oral contrast, are two additional ultrasound techniques that are gaining in popularity. Ultrasound elastography is a novel technique that exploits the fact that pathological processes have altered elastic properties. This change in elasticity is detected and im- aged using ultrasound elastography; this technique is currently under evaluation and may play a future role in small-bowel imaging. Nuclear medicine The more commonly used nuclear medicine techniques in small- bowel assessment include labelled red and white cell studies, Meckel’s diverticulum scintigraphy, and

position emission tomog- raphy (PET). Many of these play a role in patient assessment when the results of other modalities have been negative or equivocal. Scintigraphy with red blood cells involves labelling red blood cells with a radioactive substance that can be detected on a gamma camera to identify occult sites of gastrointestinal bleeding. This may be done in vivo, whereby the patient is administered 99mTc-pertechnetate following an agent that reduces the radioisotope within the red blood cells or in vitro, whereby the binding process is performed after blood is taken from the patient and then reinjected. Bleeding rates of up to 0.1 ml/min can be detected compared to 1 ml/min for conventional angiography. Extravasated red blood cells within the small bowel lumen are identi- fied as a focus of activity that increases in intensity over time and moves along the expected anatomical course of the small bowel (Fig. 15.3.3.5). Labelled white cell scanning is another nuclear medicine tech- nique occasionally used in small-bowel imaging to detect sites of inflammation. The labelling can be completed in vivo or in vitro and a number of agents including 99mTc-pertechnetate and indium may be used. Meckel's scintigraphy is performed to localize gastric mucosa in a Meckel's diverticulum as a potential source of unexplained gastrointestinal bleeding. The technique involves the administra- tion of 99mTc-pertechnetate with any radioactivity appearing at the same time as orthotopic gastric mucosa. Detection rates are often increased by the administration of pentagastrin, glucagon, or a H2 blocker around the time of the procedure. PET or hybrid PET-CT with 18F-FDG (fluorodeoxyglucose) may be used to detect the enhanced glucose metabolism associated with Fig. 15.3.3.4 Three consecutive images from a cine sequence acquired using a fast T2-weighted steady-state free procession imaging sequence in a 29-year-old male patient with Crohn's disease. An apparent stricture (arrowheads) is seen to resolve (left panel to right panel) as it represents an area of peristalsis. Courtesy of Cork University Hospital, Cork, Ireland. Fig. 15.3.3.5 Fused images of a technetium red blood cell scan obtained by single-photon emission CT show bleeding (arrows) in the right lower abdomen surgically proven to stem from within a Meckel's diverticulum. From Levy AD, Mortele KJ, Yeh BM (eds) (2015). Gastrointestinal imaging. By permission of Oxford University Press.

section 15 Gastroenterological disorders 2752 inflammation, especially in patients with fever of unknown origin. 18F-FDG can localize at sites of small-bowel inflammation over the course of a few minutes. Radiological findings in small-bowel disease Obstruction CT is the best investigation to diagnose the presence of small-bowel obstruction and determine its cause, the key issue being to locate a transition point from distended (obstructed) bowel proximally to bowel that is normal or collapsed distally (Figs. 15.3.3.6 and 15.3.3.7). Crohn's disease Crohn's disease is a chronic, noncaseating granulomatous disease characterized by a chronic relapsing and remitting clinical course. Crohn's disease may affect any part of the gastrointestinal tract from mouth to anus but in the majority of cases the small bowel is involved, especially the terminal ileum. Small-bowel involve- ment is typically transmural with skip lesions being a character- istic feature. Imaging features of active Crohn's disease include mural thick- ening (>3 mm), mucosal hyperenhancement, mesenteric inflam- matory fat stranding, strictures with proximal bowel dilatation, and prominence of the vasa recta (comb sign) (Fig. 15.3.3.8). Mural stratification is another feature on CT or MRI whereby hyperenhancement of the inner mucosal and outer serosal layers following intravenous contrast administration are separated by an interposed layer of lower attenuation/signal intensity submucosa which facilitates visualization of the bowel wall layers. The inter- vening submucosa may be of lower attenuation/signal intensity due to the presence of oedema in acute disease, fat in chronic dis- ease, or an inflammatory infiltrate. Ulceration is identified by clefts in the thickened bowel wall, which may penetrate the wall forming an abscess.

Other extraenteric complications include bowel obstruction, bowel stricture, and sinus tract and fistula formation. Fistulas may Fig. 15.3.3.6 Small-bowel obstruction from an adhesion. Intravenous contrast-enhanced CT showing a small-bowel obstruction with a transition point in the distal jejunum and abrupt change in calibre (arrow). To the left of the arrow the bowel is dilated; to the right, decompressed small bowel is seen. This was due to an adhesion. From Levy AD, Mortele KJ, Yeh BM (eds) (2015). Gastrointestinal imaging. By permission of Oxford University Press.
Fig. 15.3.3.7 Small-bowel obstruction from primary adenocarcinoma. Intravenous contrast-enhanced CT showing a small-bowel obstruction transition point that is abrupt, with no mass or distortion (arrow), but with circumferential rather than eccentric margins. This appearance is very nonspecific and could be due to an inflammatory or ischaemic stricture, nonsteroidal anti-inflammatory drug diaphragm-like stricture, or metastatic disease. In this case, it was due to a primary adenocarcinoma. From Levy AD, Mortele KJ, Yeh BM (eds) (2015). Gastrointestinal imaging. By permission of Oxford University Press. Fig. 15.3.3.8 Coronal T1 fat-saturation post-contrast MR enterography image in a 23-year-old female patient with Crohn's disease shows thickening with associated transmural enhancement of a long contiguous segment (20 cm) of the distal ileum (arrowheads) consistent with active inflammation. Courtesy of Cork University Hospital, Cork, Ireland.

15.3.3 Radiology of the gastrointestinal tract 2753 form between adjacent bowel segments, the anterior abdominal wall, vagina, and genitourinary tract. Features of chronic disease include fibrotic strictures, pseudosac culation, and submucosal fat deposition. Transmural extension of inflammation into the mesentery of the affected bowel segment in the acute phase resulting in asymmetric inflammation and fibrosis with pseudosacculation of the antimesenteric border is a hallmark feature. With long-standing Crohn's disease, there may be separ- ation of bowel loops due to fibrofatty proliferation of the perienteric and colonic fat. Findings in acute and chronic disease as well as extraenteric complications can be readily identified on both CT and MRI. Other associated conditions such as gallstones, sclerosing cholangitis, renal calculi, sacroiliitis, and adenocarcinoma may also be detected. Barium studies may demonstrate fold thickening, coarsening of the villous pattern, and aphthous ulceration, particularly along the mesenteric border. The gastrointestinal 'string sign' where luminal narrowing occurs secondary to fold thickening, oedema, spasm, and inflammation may also be seen. Tumours of the small bowel Small-bowel tumours account for less than 5% of all gastrointestinal tract tumours. They may be classified as benign or malignant and often produce nonspecific clinical symptoms and signs resulting in delayed diagnosis. Benign These include benign gastrointestinal tumour (GISTs), hamar- tomas, and benign neuroendocrine tumours and adenomas and may present with bleeding or intussusception. A number of syn- dromes are associated with multiple small-bowel polyps including Peutz–Jeghers syndrome (multiple hamartomas) and Gardner's syndrome (multiple adenomas). Malignant These include carcinoid, adenocarcinoma, lymphoma, gastrointes- tinal stromal tumours (GISTs), and metastatic disease. Presentation may be with bleeding, bowel obstruction, intussusception, and rarely perforation. • Carcinoid is the most common primary malignant small-bowel tumour. Carcinoid tumours occur most frequently in the ileum and are typically intensely enhancing luminal polyps or enhanc- ing carpet lesions with mesenteric metastases being characteristic. The mesenteric disease incites a desmoplastic reaction producing a spiculated mass-like appearance, which may calcify. • Adenocarcinoma has a predilection for the duodenum but also occur with decreasing frequency in the jejunum and ileum, and may appear as a focal area of annular narrowing, a tumour mass, or an ulcerated plaque (Fig. 15.3.3.9). • Lymphoma does not have a particular predilection for any small-

bowel territory. The imaging appearances are protean ranging from a solitary polypoid mass to segmental mural thickening with aneurysmal dilatation due to destruction of the myenteric plexus with associated adjacent lymphadenopathy (Fig. 15.3.3.10). • GISTs are typically extraluminal occurring most commonly in the stomach followed by the small bowel. It is often difficult to distinguish benign from malignant GISTs on imaging but cer- tain findings favour malignant disease including lesion size greater than 5 cm, heterogeneous enhancement, gastric location, necrotic components, and associated metastases. • Metastatic disease to the small bowel is encountered more frequently than primary tumours. Transcoelomic spread may occur from colonic, gastric, or ovarian malignancies while haematogenous metastasis may occur from breast, lung, or melanoma primaries (Fig. 15.3.3.11). Fig. 15.3.3.9 Coronal contrast-enhanced CT following positive oral contrast administration shows a large soft tissue mass (arrowheads) centred in the proximal ileum with associated luminal narrowing. Biopsy confirmed adenocarcinoma of the small bowel. Courtesy of Cork University Hospital, Cork, Ireland. Fig. 15.3.3.10 Axial contrast-enhanced CT enterography in a 39-year- old male patient demonstrates segmental mural thickening within a loop of jejunum with aneurysmal luminal dilatation (arrowheads). Histology confirmed a diagnosis of small-bowel lymphoma. Courtesy of Cork University Hospital, Cork, Ireland.

section 15 Gastroenterological disorders 2754 Immune-mediated enteritis Coeliac disease Coeliac disease is a gluten-related, immune-mediated enteropathy occurring in susceptible individuals. The most common imaging finding is moderately dilated fluid-filled loops of small bowel. The classic finding of jejunal fold atrophy with secondary hypertrophy of the ileal folds (jejunoileal fold reversal) is uncommonly encoun- tered. Characteristic findings on barium examinations occurring due to an excess of luminal fluid include air–fluid levels and ag- gregation of coarse clumps of disintegrated barium, termed floc- culation. Other imaging features include transient small-bowel intussusceptions and splenic atrophy. The primary role of imaging is the detection of enteropathy-associated T-cell lymphoma, espe- cially in patients with refractory disease. Findings vary from mul- tiple enhancing mural nodules to aneurysmal luminal dilatation due to destruction of the muscle wall and myenteric plexus. Patients with coeliac disease are also at an increased risk of developing small-bowel adenocarcinoma. Another entity that has been described in coeliac disease is cavi- tating mesenteric lymph node syndrome. This consists of enlarged, rim-enhancing, necrotic mesenteric lymph nodes in association with an ulcerative jejunoileitis, predominantly affecting the je- junum. On MRI, the centres of these lymph nodes may be bright on T2-weighted images, in keeping with central cavitation within the lymph nodes. Ulcerative jejunoileitis results in diffuse mucosal ulceration and the appearances may closely simulate lymphoma or Crohn’s disease. Graft-versus-host disease (GVHD) Acute GVHD disease involves the small bowel in 75 to 100% of cases. The typical imaging findings are mild bowel wall thickening with dilatation, marked mucosal hyperenhancement, and mural stratification. Small-bowel GVHD differs in appearance from other inflammatory pathologies in that the bowel wall thickening is gener- ally mild and disease involves a long segment often extending from the duodenum to the rectum. Eosinophilic gastroenteritis Eosinophilic gastroenteritis is a rare condition with over 50% of cases occurring in patients with atopy. The disease most commonly affects the small bowel and stomach with imaging findings of fold thickening, polyps, mucosal ulcers, stricture formation, ascites, omental thickening, and lymphadenopathy. Patients often respond well to an initial course of corticosteroids. Vascular diseases of the small bowel Small-bowel ischaemia Small-bowel ischaemia may result from arterial occlusion, venous occlusion, or low-flow states such as cardiac failure or hypovol- aemia, with superior mesenteric artery occlusion accounting for over 50% of cases. The imaging manifestations

vary according to the degree of vascular insufficiency. Occlusive arterial disease may re- sult in acute transmural infarction with absence of enhancement, mural thinning, and bowel dilatation. Pneumatosis intestinalis and portal venous gas are less commonly seen (Fig. 15.3.3.12). Conversely, nonocclusive disease may result in mural thickening and mucosal hyperenhancement related to reactive hyperaemia due to reperfusion injury. Venous occlusion, the least common cause of small-bowel ischaemia, presents with marked mural thickening with hyperenhancement and associated vascular engorgement and mesenteric stranding. CT is the imaging modality of choice for the detection of acute mesenteric ischaemia with a reported high sensitivity (93%) and specificity (96%). CT also facilitates evaluation of the mesen- teric vessels detecting potential causes of ischaemia and guiding management. Systemic vasculitis may present with small-bowel ischaemia. This should be suspected in young patients with recurrent symptoms, disease involving atypical sites such as the duodenum, and when additional findings such as aneurysms and solid visceral infarcts are present. Small-bowel bleeding Angiodysplasia is the most common cause of occult gastrointestinal tract bleeding. It typically manifests on CT as an avidly enhanc- ing nodule or plaque during the arterial phase that fades during the delayed phase. Other potential causes of small-bowel bleeding include tumours, other vascular malformations, and Meckel's di- verticulum. Multiphase contrast-enhanced CT has been shown to be effective in the detection of occult small-bowel bleeding sites. Furthermore, it may guide interventional management by identi- fying the bleeding vessel facilitating selective catheterization and embolization. Capsule endoscopy may also be complementary in patients with suspected small-bowel bleeding but is limited by long reporting times. Fig. 15.3.3.11 Coronal contrast-enhanced CT following positive oral contrast administration shows a large soft tissue mass centred in the distal ileum (arrow). Biopsy at laparoscopy confirmed melanoma of the small bowel. Courtesy of Cork University Hospital, Cork, Ireland.

15.3.3 Radiology of the gastrointestinal tract 2755 The colon Radiological techniques to image the colon CT colonography CT colonography or virtual colonoscopy is gaining in popularity as an alternative or complementary investigation to conventional colo- nography for diagnosis and screening for colorectal carcinoma. Bowel preparation with dietary restriction and laxatives is re-commended in a similar fashion to colonoscopy. Additional faecal tagging with an oral enteric contrast agent is often performed. A rectal tube is inserted and room air or carbon dioxide is insuf-flated into the colon under controlled injection until satisfactory colonic distension is achieved. Patients are then scanned in the prone and supine positions with additional imaging being per-formed as required to ensure complete colonic imaging. Images undergo postprocessing on an integrated computer system to gen- erate three-dimensional endoluminal or 'fly-through' series from the two-dimensional images. Disadvantages of the technique include the prerequisite exposure to ionizing radiation and in the event of a lesion being found, the pa- tient may need a second bowel preparation to undergo colonoscopy to perform biopsy or further treatment. However, the risk of bowel preparation is lower than with colonoscopy. Barium enema Although use of the barium enema has declined significantly in recent years with the advent of CT colonography, it may still be of use in selected patients to investigate altered bowel habit, inflam- matory bowel disease, and colorectal carcinoma. Patients undergo bowel preparation as for CT colonography. High-density barium (100% w/v) is administered per rectum via a rectal tube. This is then drained and air is administered followed by double-contrast spot films of each colonic segment. The barium serves to coat the mucosa and absorb residual fluid in the colon. Before acquiring a spot image, barium is allowed to pass over the mucosal surface, the patient is turned to displace the barium

pool, and air is insuf- flated. The volume of barium retained by the patient is important as excessive barium will obscure colonic lesions and a paucity of barium will result in poor mucosal coating. Incomplete filling of the right colon may also occur, resulting in the inability to exclude disease of the proximal colon. The technique may be poorly toler- ated by some patients due to abdominal cramps despite the use of an antispasmodic agent and/or lax anal sphincter. Glucagon 1 mg or Buscopan 20 mg intravenously may be used to induce colonic hypotonia. MRI colonography Dark-lumen magnetic resonance colonography is a rapidly evolv- ing, almost noninvasive method currently under evaluation for the assessment of colonic disease. The technique combines an aqueous enema with the intravenous administration of a gadolinium-based contrast agent. This discriminates colonic pathology, which appears bright on T1-weighted images post contrast, from the bowel lumen, which is rendered totally dark by the aqueous solution. Residual stool and air bubbles, which may mimic bowel pathology, also re- main dark. Patients undergo bowel preparation in a similar manner to colonoscopy. Approximately 2500 ml of warm tap water is instilled into the colon via a rectal enema tube following which scanning is performed in the prone position to reduce breathing artefacts. Multiplanar reformations are generated from pre- and post-contrast three-dimensional data sets and virtual endoscopic fly-through may be performed on a postprocessing workstation. Both antegrade and retrograde visual fly-through is performed to ensure visualization of both sides of the haustral folds. Pathology of the colon Colorectal cancer CT colonography is the imaging modality of choice to detect colo- rectal cancer with a reported sensitivity of 96% and specificity of greater than 90%. CT can identify the tumour site, lesion length, de- gree of extension through the wall and into the mesentery, as well as the presence of nodal and distal metastatic disease in a single examination. The primary lesion may appear as a focal intraluminal mass, an area of asymmetric wall thickening, or an annular constriction of
Fig. 15.3.3.12 Acute arterial occlusive mesenteric ischaemia. CT images during intravenous contrast in early arterial phase in a patient with proximal thrombotic occlusion of the superior mesenteric artery show portal venous gas (arrow on left image), mesenteric venous gas (arrows on right image), pneumatosis intestinalis, and a diffuse lack of bowel wall enhancement in keeping with bowel infarction. From Levy AD, Mortele KJ, Yeh BM (eds) (2015). Gastrointestinal imaging. By permission of Oxford University Press.

 the colon. If the lesion causes a stricture, patients may present with large-bowel obstruction. Extracolonic spread is detected by loss of the fat planes between the colon and surrounding tissue. Tumours may invade the mesentery, abdominal wall, retroperitoneum, or ad- jacent organs such as the stomach and liver. Inflammatory bowel disease The two main inflammatory bowel diseases are ulcerative colitis and Crohn’s disease. Although both can be readily diagnosed on barium studies due to its excellent mucosal detail, CT and MRI have become the imaging modalities of choice in suspected and known inflammatory bowel disease, especially for the detection of complications. There are imaging features specific to each disease that may help to distinguish them. Ulcerative colitis generally involves the rectum and extends proximally without skip lesions to in- volve the entire colon whereas Crohn’s disease tends to involve the right colon and small bowel. On CT, both conditions show mural thickening greater than 3 mm, submucosal oedema, mes- enteric hypervascularity, and fibrofatty proliferation of the ad- jacent pericolonic fat. Wall thickening in Crohn’s disease tends to be greater and is more often asymmetric involving the mes- enteric border predominantly, resulting in the formation of pseudodiverticula along the antimesenteric border. The wall also tends to enhance homogeneously. Wall thickening in ulcerative colitis tends to be diffuse and symmetric. In addition, a low- attenuation ring of submucosal fat (halo sign) is more commonly seen in ulcerative colitis.

Complications of inflammatory bowel disease, which are more common in Crohn’s disease, that can be readily detected on CT and MRI include abscess, sinus tract, and fistula. Enterovesical, enterocutaneous, perianal, and rectovaginal fistulas may be detected with CT by the presence of enteric contrast within the fistula tract or adjacent organs. MRI is the investigation of choice for the de- tection and characterization of perianal fistula formation in Crohn’s disease. The differential diagnosis for inflammatory bowel disease of the colon includes pseudomembranous colitis, ischaemic colitis, infectious colitis, and radiation colitis. Ischaemic colitis The causes of colonic ischaemia are the same as small-bowel is- chaemia. However, there are certain watershed areas that are par- ticularly susceptible to ischaemia from hypovolaemia including the splenic flexure (watershed between the superior and inferior mesenteric arteries) and rectosigmoid (watershed between the inferior mesenteric artery and superior rectal artery). These are regions of poor perfusion at the peripheries of major ar- terial territories with a poor collateral supply. Ischaemic colitis typically involves the left colon in the elderly patient with hypop- erfusion and the right colon in young patients with haemorrhagic shock. Findings on CT include symmetrical wall thickening, haustral fold enlargement, mural stratification, mesenteric in- flammation, pneumatosis coli, and portal venous gas. High at- tenuation within the wall indicates intramural haemorrhage. Pneumatosis coli is not specific to bowel ischaemia and may be seen in a wide range of nonischaemic conditions such as infection, inflammation, malignancy, respiratory disease, and also following endoscopic procedures. Thrombus may be identified within the splanchnic vessels in cases of occlusive arterial disease. Mural scarring and stricture formation may be seen in cases of chronic ischaemic colitis. Radiation colitis Findings of acute radiation colitis are nonspecific including bowel wall thickening and pericolic inflammatory change. However, the clinical history will help to make the diagnosis. The rectum and sigmoid are the most common sites of disease in patients who have undergone radiation therapy for prostate and cervical cancer. Chronic radiation colitis occurring secondary to radiation-induced endarteritis generally presents more than 6 months following treat- ment. Findings on CT and MRI include bowel wall thickening, in- creased pelvic fat stranding, and thickening of the pericolic fibrous tissues. Strictures and fistulas are potential complications. Diverticular disease Diverticula are outpouchings of the colonic mucosa and sub- mucosa at the point where the vessels pierce the muscularis be- tween the mesenteric and antimesenteric taenia (Fig. 15.3.3.13). Diverticulosis appears on CT as multiple, small, air-filled out- pouchings of the colonic wall, most prevalent in the sigmoid colon. The wall of the colon is often thickened due to circular muscle hypertrophy. Acute diverticulitis occurs when the neck of a diverticulum is occluded by stool leading to microperforation of the diverticulum and inflammation. CT is the imaging modality of choice to detect acute diverticulitis and its associated compli- cations. Imaging findings include segmental wall thickening, peri- colic inflammatory fat stranding, and injection of the mesenteric vessels. As acute diverticulitis occurs most commonly in the sig- moid colon, positive contrast material may be given per rectum to aid diagnosis. Potential complications include perforation, abscess (Fig. 15.3.3.14), and colovesical fistula formation. A colovesi- cal fistula may be identified by the presence of air in the bladder, Fig. 15.3.3.13 A pelvic CT scan of mild diverticulitis showing mural thickening of the sigmoid colon, diverticula, and fluid in the combined interfascial plane (arrows). From Levy AD, Mortele KJ, Yeh BM (eds) (2015). Gastrointestinal imaging. By permission of Oxford University Press.

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