REVIEW ARTICLE

CT enterography: review of technique and practical tips

¹R ILANGO VAN, ¹D BURLING, ¹A GEORGE, ¹A GUPTA, ¹M MARSHALL and ²S A TAYLOR

¹Intestinal Imaging Centre, St Mark's Hospital, Harrow, UK, and ²Department of Medical Imaging, University College London, London, UK

ABSTRACT. CT enterography is a new non-invasive imaging technique that offers superior small bowel visualisation compared with standard abdomino-pelvic CT, and provides complementary diagnostic information to capsule endoscopy and MRI enterography. CT enterography is well tolerated by patients and enables accurate, efficient assessment of pathology arising from the small bowel wall or surrounding organs. This article reviews the clinical role of CT enterography, and offers practical tips for optimising technique and accurate interpretation.

Received 7 September 2011
Revised 1 December 2011
Accepted 6 December 2011

DOI: 10.1259/bjr/27973476

© 2012 The British Institute of Radiology

Until recently, diagnosis of small bowel pathology had relied primarily on radiological techniques, in part due to the relative inaccessibility of the small bowel to conventional endoscopy. However, new endoscopic developments—notably the recent introduction of capsule endoscopy and double balloon enteroscopy—are challenging this position. Capsule endoscopy, for example, is now generally accepted as first-line investigation for occult gastrointestinal haemorrhage, and increasingly advocated for diagnosis of early Crohn's disease. However, the radiological community has not stood still. In parallel with the development of new endoscopic techniques, rapid progress has been made in cross-sectional imaging technologies, harnessing the power of multidetector row CT (MDCT), MRI and ultrasound, facilitating rapid, accurate and minimally invasive investigation of the small bowel and adjacent tissues.

CT enterography was first introduced by Raptopoulos et al [1] in 1997 as a modification to "standard" abdomino-pelvic CT examination to specifically examine the small bowel in detail, notably to assess the extent and severity of Crohn's disease [1, 2]. They combined neutral (low-density) oral contrast with "enteric phase" CT to optimise contrast resolution between mucosa and lumen, thereby maximising conspicuity of abnormalities arising from the small bowel wall.

Several authors have subsequently described similar techniques, which are broadly categorised into CT enterography (where patients drink oral contrast) and CT enteroclysis (luminal contrast is introduced via a nasojejunal tube placed fluoroscopically prior to CT examination). Although superior jejunal distension is attained using enteroclysis, the convenience, efficiency and superior patient experience achieved with CT enterography make it the preferred technique at the authors' institutions, and therefore the focus of this review.

This paper will critically review the CT enterography technique and provide practical tips on interpretation to assist radiologists and help them avoid common interpretative pitfalls. We will also examine its role relative to other complementary non-ionising radiation radiological tests.

Technique

The technique of CT enterography combines small bowel distension with a neutral or low-density oral contrast mixture and abdomino-pelvic CT examination during the enteric phase following administration of intravenous contrast. Patients drink approximately 1.5–2 l of oral contrast over 45–60 min. Patient compliance is central to the success of CT enterography, and supervision and encouragement during the drinking phase is recommended. Akin to CT colonography, optimising luminal distension will facilitate rapid and efficient luminal navigation, enabling accurate detection and characterisation of abnormalities.

Luminal contrast and distension

Neutral or low-density oral contrast media are a prerequisite for good-quality CT enterography [3–5] because they maximise contrast between the lumen and enhancing small bowel wall, facilitating assessment of mucosal thickening and wall stratification/enhancement patterns [1–8]. Water–methylcellulose solution, polyethylene glycol, commercially available low-density barium, 0.1% Volumen (Bracco, Milan, Italy) and milk are examples of neutral oral contrast agents with CT attenuation properties similar to that of water. Water alone usually results in inadequate distension due to rapid reabsorption, although some authors advocate its use [9].

Use of Volumen has been shown to improve the quality of bowel distension compared with water alone [4, 10–12], but it remains unlicensed for use in the UK

Address correspondence to: Dr David Burling, Intestinal Imaging Centre, Level 4V, St Mark's Hospital, Watford Road, Harrow HA1 3UJ, UK. E-mail: david.burling@nwlh.nhs.uk

and therefore is not available. Milk was shown to give similar results as Volumen [13], but although less expensive and freely available in Europe, it may be deemed unpalatable by many patients when drunk in large volumes. Kuehle et al [14] reported that good small bowel distension could be achieved when using a 1-l solution of 2.5% mannitol/0.2% locust bean gum prior to MR enterography, with relatively minimal side effects. However, they found increased side effects such as diarrhoea, vomiting and spasms with increasing volumes (1200 and 1500 ml), without any significant improvement in small bowel distension.

Various studies have investigated the optimal volume of oral contrast that should be ingested, balancing the need for good distension with patient compliance and side effect profile. Maglinte [9] stated that a volume of <1.5 l is unlikely to be sufficient to adequately distend the small bowel without active inflammation, and a subcentimetre mass could be missed; although, in the authors' experience, good-quality examinations can be achieved with smaller volumes. Other authors have used contrast volumes of 1000–2500 ml, with variable results. Boudiaf et al [6] used <2 l of water in all the 107 patients who underwent CT enteroclysis. Boudiaf et al classified small bowel distension using a grading system based on diameters of jejunum and ileum graded 0–3 (where 0 was for no distension and 3 was optimal distension). They observed poor distension in only 2 of the 107 patients [6].

Positive oral contrast agents (containing iodine or barium) are not routinely used for CT enterography because they obscure mucosal enhancement, intraluminal haemorrhage and assessment of subtle mural disease [15, 16]. Use of positive oral contrast should particularly be avoided in obscure gastrointestinal bleeding because the contrast can obscure the bleeding site. However, positive contrast can occasionally help establish fistula patency or the exact site of mechanical obstruction, because it will track the flow of luminal contents [16]. With this in mind, choice of standard abdomino-pelvic CT or CT enterography will be determined by the target of investigation, individualised according to clinical scenario. As discussed below, use of CT should be restricted in younger patients, particularly when not presenting acutely.

Recommended protocol

Table 1 provides a summary of the technique used in our institution, which has evolved over 4 years and 500 CT enterography examinations.

Table 1. Summary of technique

Avoid solid foods (clear liquids only) for 4 h
20 ml (5 mg 5 ml ⁻¹) of oral metoclopramide is given at the start of the oral contrast agent (Rosemont Pharmaceuticals Ltd, Leeds, UK)
1500–2000 ml of neutral contrast (see main text) orally over 45 min
20 mg Buscopan administered intravenously immediately prior to scanning (20 mg ml ⁻¹ of hyoscine butylbromide; Boehringer Ingelheim Ltd, Bracknell, UK)
150 ml of Iohexol (Omnipaque 300; Amersham Health, Amersham, UK) administered intravenously at 4 ml s ⁻¹ via an 18-gauge cannula.
Supine single phase images acquired at 50 s post-intravenous contrast administration
64-slice CT scanner (Brilliance CT; Philips Medical Systems, Best, the Netherlands)
Slice thickness of 2 mm with reconstruction interval of 0.75 mm
Automated 2-mm axial and coronal reformats generated and archived to picture archiving and communication system (PACS)

Patients are requested to avoid solid food for at least 4 h prior to examination to decrease the possibility of mischaracterising solid food residue as true luminal pathology. Patients can liberally drink clear fluids to maintain hydration prior to examination. Outside the scanner room, patients are then encouraged to drink up to 2 l of oral contrast—2.5% mannitol (Baxter Health Care Ltd, Thetford, UK) containing 0.2% bulk fibre solution (Instant Carobel; Cow & Gate, Trowbridge, UK)—at a steady rate (approximately 150 ml every 5 min). In small patients and patients with history of previous small bowel resection, smaller volumes of oral contrast may be sufficient, judged mainly by patient tolerance. In the authors' experience it is difficult to predict the degree of distension achieved in any one individual, but, perhaps unsurprisingly, distension is usually better if there is partially obstructing small bowel pathology, such as stricture. Adequate jejunal distension is a recurrent challenge, but anecdotally this does not seem to have impaired diagnostic performance in our centre.

Actively supervising and encouraging the patients to adhere to the oral contrast regimen while awaiting the scan in the radiology department can undoubtedly improve the quality of small bowel distension. The patient is then transferred to the scanner table, drinking the last cup on the table. Then, assuming no contraindication, 20 mg Buscopan (Boehringer Ingelheim Ltd, Bracknell, UK) is administered intravenously immediately prior to scanning to decrease small bowel peristalsis. The remainder of the technique is summarised in Table 1. Maximal small bowel enhancement on MDCT has been reported by Schindera et al [17] to be 50 s after administration of intravenous contrast or 14 s after aortic peak enhancement. We therefore administer contrast intravenously during this enteric phase. The enteric phase is similar to the pancreatic phase; therefore, CT enterography also optimises demonstration of most pancreatic neoplasms. This is particularly relevant for clinicians, given that symptoms of pancreatic tumour can mimic luminal disease. In the authors' experience, lack of portal venous phase imaging is rarely a problem for patients undergoing CT enterography because subtle liver metastases are rarely the target of imaging in this patient group. To avoid intravenous contrast-induced nephropathy, we limit the use of CT enterography in frail and diabetic patients. If utilised in higher-risk groups, consider reducing the volume of intravenous contrast, ensure patients are well hydrated before the examination and monitor renal function closely afterwards. A large

volume of oral contrast is contraindicated in patients who are fluid-restricted owing to clinical conditions such as renal or heart failure.

Following CT enterography examination, patients are encouraged to remain in our department for approximately 45 min because they reasonably frequently experience severe, albeit short-lived, diarrhoea.

Variations to the basic protocol-multiphase scan

In patients where active gastrointestinal bleeding is suspected (and endoscopic work-up is negative) a multiphase scan protocol can be used to identify sites of occult gastrointestinal bleeding. This protocol would frequently include pre-contrast, arterial and delayed-phase CT examinations of the abdomen and pelvis. Rarely, this can be used in emergency situations to identify the site of bleeding. However, the radiation burden is approximately three times higher, and therefore potential radiation risks should be balanced against patient benefit.

CT enterography interpretation: how to review and avoid pitfalls

Reading technique

Accurate detection of small bowel pathology requires careful luminal navigation from the gastro-oesophageal junction to the anus, or vice versa. This will frequently take several minutes (up to 15 min in some patients) and can be thwarted by poor luminal distension or collapse, particularly when there is minimal intra-abdominal fat separating loops. Anecdotally, we have noted a significant learning curve for this technique, and therefore advocate additional interpretation time to ensure complete luminal navigation and thorough assessment of all bowel segments and the adjacent mesentery.

Use of a multiplanar review will improve accuracy of both luminal navigation and interpretation [2]. It is important to first distinguish abnormal from normal segments. As discussed below, differential contrast enhancement is a cardinal sign of many small bowel pathologies. Indeed, an abnormal segment will often be initially perceived owing to the presence of a hyper-enhancing mass or focus of wall thickening. However, it is important to be aware that during the enteric phase of enhancement the jejunum enhances more than the ileum (Figure 1) [2, 18]. This should not be mistaken for pathology. Furthermore, collapsed bowel loops appear to enhance more than the distended loops in the same segment (Figure 2) [2, 18, 19]. In the non-distended loops, other signs of disease must be used to diagnose pathological processes, including associated changes in the adjacent small bowel mesentery such as hypervascularity, fat stranding or lymphadenopathy. Subtle mucosal pathology and/or mucosal enhancement can also be difficult to perceive.

Focal small bowel spasm is frequently encountered, despite the use of Buscopan, and can mimic short strictures. Identification of similar areas of spasm, lack of mucosal hyperenhancement and absence of mesenteric

abnormality helps to distinguish spasm from true pathology (Figure 3). Repeat scanning through the section of interest is often useful to distinguish stricture from a collapsed loop, but clearly the dose of ionising radiation imparted by CT makes this less applicable than during MRI enterography. As noted above, multiplanar reformatting when reporting CT enterography has been shown to increase diagnostic confidence and sensitivity.

The stomach and colon are frequently well distended and merit careful evaluation for associated pathology. However, it is important to recognise the limitations of colonic review in the absence of formal laxative preparation and dual patient positioning. Key tips and pitfalls are summarised in Table 2.

Characterisation of small bowel pathology

General principles

The differential diagnosis for abnormal small bowel is wide. A more detailed description of the commoner small bowel diseases is provided below. However, when interpreting CT enterography, it is important to be aware of the more general diagnostic principles, which govern the correct interpretation of small bowel abnormalities.

Macari et al [16] described several criteria to help to characterise abnormal small bowel segments, including pattern of contrast enhancement, length of involvement, degree and symmetry of wall thickening, location in proximal/distal jejunum/ileum, location of pathology within the small bowel wall (mucosal/submucosal/serosal) and associated abnormality in the adjacent mesentery or vessels.

Enhancement pattern

Small bowel wall enhancement patterns have been divided into a "target" appearance, homogeneous, heterogeneous and diminished.

Target appearance with stratification of the layers of the small bowel wall (mural stratification) is generally found with benign conditions—for example, vasculitis, Crohn's disease, venous thrombosis with associated bowel oedema or ischaemia and intramural haemorrhage. If wall enhancement is homogeneous and mild (*i.e.* similar to muscle), chronic inflammatory conditions should be considered, particularly those producing fibrosis within the small bowel wall (for example Crohn's disease, ischaemia and radiation) [16, 20, 21].

Homogeneous hyperenhancement is commonly seen with active Crohn's disease, and is frequently associated with increased density in the surrounding mesenteric fat. Indeed, it has been proposed by Bodily et al [22] that a cut off of 109 HU can be used with reasonable accuracy to diagnose activity in Crohn's-afflicted small bowels.

Heterogeneous enhancement is seen in small bowel neoplasms, including gastrointestinal stromal tumours, adenocarcinomas, metastases and peritoneal deposits. Decreased enhancement is typical of bowel ischaemia [16, 23–25], and usually precedes the development of intramural gas and subsequent perforation.

Figure 1. Normal CT enterography. Coronal CT enterography image showing normal jejunal (short arrows) and ileal (long arrows) loops. Note the prominent mucosal pattern in the proximal jejunal loops.

Figure 2. Collapsed small bowel. Axial CT enterography image showing a collapsed small bowel mimicking pathology (long arrow) compared with a normal fluid-filled loop (short arrow). Note the absence of any associated changes.

Figure 3. Small bowel spasm. Axial CT enterography image showing two areas of focal small bowel spasm mimicking pathology (arrows). Note the absence of any associated changes.

Length of small bowel involvement

For the purpose of differential diagnosis, the length of small bowel involvement can be divided into three: focal (<5 cm), segmental (6–40 cm) and diffuse (>40 cm) [2, 16]. Focal small bowel wall thickening is generally found with neoplasms, endometriosis, small bowel diverticulitis, foreign body perforations, small bowel ulcers (secondary to non-steroidal anti-inflammatory drugs) and occasionally granulomatous processes like tuberculosis and Crohn's disease [16, 26–30]. Segmental involvement is found with intramural haemorrhage, Crohn's disease, lymphoma, infectious enteritis and ischaemia, particularly due to superior mesenteric artery (SMA) embolus or superior mesenteric vein (SMV) thrombosis [16, 22, 31–34]. In a patient with previous malignancy and segmental involvement, previous radiotherapy should be considered [16, 35]. Diffuse involvement of the small bowel is commonly a result of hypoalbuminaemia, low-flow intestinal ischaemia, vasculitis, graft *vs* host disease and infectious enteritis [16, 22, 30, 36–38].

Mural thickening and symmetry

The site, degree and symmetry of mural thickening can also help in the characterisation of small bowel pathology. Tables 3–5 summarise mural thickening [16, 22, 30, 31, 39–41], symmetry of small bowel thickening [16, 31, 42] and sites of abnormality in the small bowel [16, 41], respectively. Identification of the layer of the small bowel wall that is predominantly affected also helps in reaching a diagnosis (Table 6). The mucosa is seen to be predominantly affected in inflammatory conditions like Crohn's disease, tuberculosis and neoplasms such as adenocarcinoma. Although mucosa is affected predominantly in infectious conditions and vasculitides, mucosal disruption is not evident on MDCT in these conditions [16]. The predominant abnormality is seen in the submucosa in

Table 2. Key tips

Improve bowel distension by active supervision and encouragement of oral contrast intake
Carefully navigate the lumen
Use a multiplanar review
Differential contrast enhancement of the bowel is a cardinal sign
The jejunum enhances more than the ileum
Collapsed bowel loops and focal small bowel spasm can mimic pathology the; look for associated changes

conditions like intramural haemorrhage, vasculitis, ischaemia, hypoalbuminaemia and angio-oedema. In conditions where there is thickening of the submucosa, the equivalent barium follow-through appearance is classically described as stacked coin- or picket fence-like. The serosa is predominantly involved in metastases, endometriosis, carcinoid and other inflammatory conditions in the peritoneum.

Extraluminal findings

One of the major advantages of CT and other cross-sectional techniques is their ability to visualise the extraluminal soft tissues. It is therefore important to carefully evaluate the structures beyond the bowel wall. Patency or otherwise of mesenteric blood vessels should be assessed to exclude a vascular pathology such as arterial embolus or venous thrombosis. Lymphadenopathy in the mesentery can give an important clue to the presence of underlying disease, both benign and malignant. In

intestinal tuberculosis, for example, the lymph nodes have a central low attenuation, while in lymphoma and Crohn's disease the nodes are usually of soft tissue density. Presence of other extraluminal findings such as mesenteric oedema, fluid, fibro-fatty proliferation, abscess and fistula should also be carefully assessed. A list of common indications for CT enterography is given in Table 7.

The commoner small bowel diseases

Crohn's disease

CT enterography provides a highly accurate method for diagnosis and assessment of Crohn's disease in adults. Initial diagnosis (in combination with endoscopic biopsy where possible) or exclusion of all but subtle or early disease can often be made with high reader confidence. In addition, a single examination can assess severity, extent and location of disease, coupled with extraluminal manifestations and complications. The

Table 3. Characterisation of mural thickening

Mild (3–4 mm)	Moderate (5–9 mm)	Severe (>10 mm)
Hypoalbuminaemia, infectious enteritis and occasionally ischaemia or mild Crohn's disease	Crohn's disease, intestinal ischaemia, intramural haemorrhage, angio-oedema, vasculitis, early adenocarcinoma and lymphoma	Neoplasm including lymphoma, vasculitis, Crohn's disease, intramural haemorrhage and, rarely, in infectious colitis; most cases of thickening >20 mm are due to neoplasms or intramural haemorrhage

Table 4. Symmetry of small bowel thickening

Symmetrical	Asymmetrical
Benign conditions and some cases of lymphoma	Crohn's disease, tuberculosis, adenocarcinomas and gastrointestinal stromal tumours

Table 5. Site of abnormality in the small bowel

Proximal	Distal
Adenocarcinoma and coeliac disease	Lymphoma and carcinoid tumours, Crohn's disease (most commonly affects the terminal ileum with skip lesions elsewhere)

Table 6. Affected layer of the small bowel

Mucosa	Submucosa	Serosa
Crohn's disease, tuberculosis and neoplasms (i.e. adenocarcinoma, infectious conditions and vasculitides)	Intramural haemorrhage, vasculitis, ischaemia, hypoalbuminaemia and angio-oedema	Metastases, endometriosis, carcinoid and other inflammatory conditions in the peritoneum

Table 7. Specific indications for CT enterography

Small bowel disorder	Indication	Advantage	Disadvantage
Crohn's disease	Assessment of extent, severity and luminal/extraluminal complications	Allows simultaneous diagnosis of extraluminal disease and complication Preferred examination in suspected small bowel stricture	Less sensitive in detecting early mucosal abnormalities than capsule endoscopy Radiation concerns preclude use of CT enterography in paediatric patients; repeated examination in young adults, ultrasound or MR enterography are preferred in these situations
Small bowel tumour	Detection, characterisation and staging	Allows simultaneous detection and staging	Less sensitive than capsule study for detection of small mucosal lesions
Occult gastrointestinal bleeding	Detect and characterise vascular/neoplastic origin	Improved visualisation of lesions compared with conventional CT and fluoroscopy, enabling improved lesion-directed planning	Unlike nuclear medicine techniques, CT enterography does not allow prolonged imaging times, which are necessary for detection of intermittent bleeding Pre-existing high-attenuation material within the bowel may limit the detection of active bleeding
Partial small bowel obstruction	Locate site and detect cause	Improved visualisation of mucosal lesions compared with conventional CT	Conventional barium follow through study is more sensitive in the assessment of adhesional obstruction than CT enterography
Coeliac disease	Assessment of complications, particularly lymphoma	CT enterography may show typical mucosal pattern and lymph node involvement	Unlike endoscopic techniques, does not depict subtle mucosal changes
Ulcerative colitis	Exclude small bowel inflammation (Crohn's disease) and extraluminal complications	CT enterography allows simultaneous assessment of the small and large bowel, and extraluminal disease	CT enterography usually underestimates the disease extent and severity

radiation exposure associated with CT is discussed in greater detail below. However, with increasingly robust MR enterography and ultrasound techniques available, it is the responsibility of radiologists and clinicians alike to ensure that cumulative radiation dose is strongly considered when selecting the optimal imaging modality for assessment of Crohn's disease. Consideration must be made as to the age of the patient, their past diagnostic history, previous imaging and endoscopic examinations and general well-being, as well as the specific clinical question and availability of imaging platforms and interpretative radiological expertise. A recent survey of use of small bowel imaging of Crohn's disease within National Health Service radiological practice showed that although CT is relatively infrequently used as a first-line test in younger patients without a prior diagnosis, it is commonly performed in those with suspected extra-intestinal complications [43].

Radiological findings of Crohn's disease at CT enterography include mucosal hyperenhancement, mural thickening and stratification, transmural ulceration, mesenteric inflammation, engorgement of vasa recta and strictures associated with upstream dilatation (Figure 4).

Mucosal hyperenhancement refers to the increase in attenuation of mucosa relative to adjacent normal loops, and correlates well with the activity of Crohn's disease [2, 19]. Mural stratification describes the visible layers of the inflamed small bowel wall demonstrated following administration of intravenous contrast in the enteric phase. The mucosa and serosa enhance avidly, but the intervening bowel wall enhances to a varying degree, either due to intramural oedema (isodense with water), indicating active

disease [2], or intramural fat, indicating chronic inflammation. Intramural soft tissue attenuation may also indicate an inflammatory infiltrate (Figure 5). Transmural ulceration is detected by discontinuity of the mucosa, associated with "clefts" in the thickened wall. Such ulcers may penetrate through the wall, forming a small periluminal abscess (indicating localised perforation).

Crohn's disease predominantly involves the mesenteric border of the small bowel, frequently leading to asymmetric inflammation and fibrosis, with pseudosaccululation of the antimesenteric border. Pre-stenotic dilatation helps define, locate and assess the functional significance of a stricture. Active inflammation is associated with enlargement and engorgement of the mesenteric vessels (vasa recta), which penetrate the bowel wall perpendicular to the bowel lumen, creating the so-called "comb sign" (Figure 4b). The usefulness of this sign in day-to-day clinical practice is debatable, however. For example, in a study using MRI by Koh et al [44], increase in mesenteric vascularity was shown to have a sensitivity of 78% and specificity of 57% in diagnosing active Crohn's disease.

Fibro-fatty proliferation of mesentery adjacent to diseased segments occurs, and usually persists into clinically inactive phases of the disease [2, 44]. This mesenteric fat change, which manifests as abnormal loop separation on contrast examination, is easily appreciated at CT enterography (Figure 4c).

Complications of Crohn's disease may be due to transmural ulceration (as noted above), resulting in abscesses, or formation of fistulae between bowel segments and other organs (commonly the anterior abdominal wall, vagina or renal tract; Figure 6).

Figure 4. Spectrum of findings in active Crohn's disease. (a) Active distal ileal Crohn's disease in a 36-year-old male. Coronal CT enterography image showing mural thickening and mucosal hyperenhancement (long arrows). Compare the normal enhancement of the unaffected small bowel (short arrow). (b) Enlarged vasa recta involving the actively inflamed neoterminal ileum producing a comb sign (arrows). Note the presence of enlarged mesenteric lymph nodes. (c) Axial CT enterography image in a 40-year-old female with a 7-year history of Crohn's disease showing perienteric fibro-fatty proliferation resulting in loop separation (arrows).

Metabolic changes are associated with the formation of gallstones and renal calculi, and less commonly CT enterography may reveal complicating tumours (lymphoma, adenocarcinoma), sacroilitis or sequelae of sclerosing cholangitis.

Small bowel tumours

Small bowel neoplasms account for <5% of gastrointestinal tumours [42]. The high spatial resolution of CT enterography, together with its relative insensitivity to motion and breathing artefacts, arguably make it more suitable for the detection of small bowel tumours than MR enterography. Pilleul et al [45], for example, reported a sensitivity of 84.7% and a specificity of 96.9% for detection of small bowel tumours using CT enterography. Table 8 lists the commoner small bowel tumours, and provides information on incidence and imaging characteristics.

In the authors' experience, small bowel tumours are most commonly detected in patients with:

- occult gastrointestinal haemorrhage or iron deficiency anaemia following negative conventional and capsule endoscopy (Figure 7)
- small submucosal abnormality noted by endoscopy for further investigation in cases of "tip of iceberg" or metastatic disease
- endoscopy-negative patients with symptoms of luminal obstruction and/or weight loss.

Alternatively they may be an incidental finding.

Gastrointestinal bleeding

Again, the usual high image quality of CT enterography makes it superior to MRI enterography for the

investigation of chronic blood loss. Importantly, there are data suggesting that CT may be complimentary to capsule endoscopy. For example, in a study of 22 patients with occult gastrointestinal bleeding, MDCT was positive in 10/22 (45%) patients [46]. Eight of these patients were confirmed to have positive findings on capsule endoscopy or subsequent clinical diagnosis, and CT enterography identified three lesions, which were undetected on capsule endoscopy [47]. As noted above, multiphase CT scanning may increase the diagnostic yield in those with occult gastrointestinal bleeding, but consideration must be given to the increased radiation dose, particularly in the non-acute setting. In older patients, the risk-to-benefit ratio is decreased significantly and therefore multiphase CT enterography may be appropriate in the non-emergency situation where active bleeding is suspected. Finally, CT enterography has a definite role in the localisation of symptomatic (bleeding)—for example, in Meckel's diverticulum (Figure 8), which tends to present in younger patients. Meckel's diverticulum is present in 2–3% of the population, with similar prevalence in both sexes. However, when symptomatic, it is more often in male patients. Clinical symptoms arise from complications of Meckel's diverticulum, such as peptic ulceration with haemorrhage, diverticulitis, intestinal obstruction from diverticular inversion, volvulus, intussusception, inclusion of diverticulum in a hernia, formation of enteroliths and development of neoplasia within the diverticulum.

Technetium 99 pertechnetate scintigraphy is the modality of choice for investigating paediatric patients with gastrointestinal haemorrhage and a suspected Meckel's diverticulum, with a sensitivity of 85%, a specificity of 95% and an accuracy of 90% [47–49]. However, the sensitivity and accuracy drop in adults to 63% and 46%, respectively, owing to lack of heterotopic gastric mucosa.

Figure 5. Different types of mural stratification. (a) Soft tissue density mural thickening of the terminal ileum representing inflammatory infiltrate in a 34-year-old male with newly diagnosed active Crohn's disease. (b) Fluid density mural thickening of the distal ileum representing submucosal oedema in a 62-year-old female with recurrent Crohn's disease. (c) Fat density mural thickening of the terminal ileum in a 62-year-old female, representing chronic active inflammation.

Comparing CT enterography with other modalities

CT enterography has several advantages over small bowel follow-through and conventional enteroclysis [1, 15]. It can demonstrate extraluminal pathology in addition to luminal disease; the entire small bowel can be inspected, unhindered by overlapping loops; and use of multiplanar reconstructions are routine, increasing diagnostic accuracy and confidence [2]. As a result, a

Figure 6. Complications of Crohn's disease: complex ileo-colonic Crohn's disease in a 62-year-old female. Axial CT enterographic image demonstrating the presence of a retroperitoneal abscess (long arrow) and a sinus tract (short arrow) connecting the abscess and the inflamed distal ileum.

single CT enterography may eliminate the need for multiple radiological tests, thus improving diagnostic (and cost) efficiency, improving patient compliance and ultimately reducing radiation dose [1]. Fluoroscopic small bowel studies still hold advantages over cross-sectional techniques when assessing small bowel motility and patency of sinus or fistula tracts.

There are limited published data comparing CT enteroclysis and CT enterography, but quality of luminal distension and patient experience are major considerations. In 2007, Mazzeo et al [50] reported that in over 20% of patients CT enterography was inadequate owing to poor distension. However, a smaller study performed by Wold et al [8] showed no significant difference in distension between CT enteroclysis and enterography. Boudiaf et al [6] reported that 106/107 patients tolerated CT enteroclysis well, and reported suboptimal distension in just 2 patients. Intuitively, it would seem the quality of distension is linked to diagnostic accuracy, although there is no good evidence for this. CT enterography is more efficient, and probably preferred by patients (owing to the absence of a nasoduodenal tube and shorter examination times), but further studies will help compare differences in examination quality, patient experience and diagnostic impact.

Compared with MRI enterography, the authors of this article have found that CT enterography images frequently provide greater diagnostic confidence for exclusion of both small bowel and extraluminal pathology. CT has superior spatial and temporal resolution, and fast single breath-hold examinations facilitate luminal navigation. CT is also cheaper and more available than MRI

Table 8. Primary malignant small bowel tumours

Tumours	Location	Imaging characteristics
Adenocarcinoma (at least 25%)	Generally in the proximal small bowel especially near the ampulla	Variety of shapes; soft tissue mass with heterogeneous attenuation; duodenal ones can be papillary or polypoid; more distal ones are likely to be annular
Carcinoid tumour (25–41%)	Often in the ileum	Polypoid or carpet-like with mesenteric desmoplastic reaction; may have calcified deposits in mesentery; may have hypervascular or necrotic liver metastases
Lymphoma	Can occur at multiple sites, commonly in the ileum	Exoenteric mass with adjacent lymphadenopathy and aneurysmal dilatation
Gastrointestinal stromal tumour (can be benign or malignant)	Commonly in the ileum or jejunum	Pedunculated or exoenteric; usually homogeneous, but large tumours can have necrotic areas

enterography, and patients benefit from shorter examination times and avoid MRI-associated claustrophobia. However, MRI has superior contrast resolution and may demonstrate fistulae better than CT [51]. Gadolinium-based intravenous contrast used for MR examination may also be safer in adults than the iodinated contrast used for CT. Nevertheless, a meta-analysis by Horsthuis et al [52] and a study by Siddiki et al [53] showed that small bowel CT and MRI had similar diagnostic performance. Of course, the radiation exposure with CT is a disadvantage compared with MRI.

Capsule endoscopy provides exquisite demonstration of the small bowel mucosa and is the preferred first-line

test for “conventional endoscopy-negative” gastrointestinal haemorrhage [54]. In addition, capsule endoscopy may be superior to radiological tests for diagnosis of early Crohn’s disease and small bowel neoplasms. Indeed, in circumstances where there is a high suspicion of underlying small bowel mucosal disease, capsule endoscopy provides an excellent complementary role [55]. However, capsule endoscopy is unable to assess the extramucosal manifestations or complications of disorders affecting the small bowel; for example, small bowel Crohn’s disease is well recognised as a disease of both mucosa and mesentery, with variable involvement of both components. In addition, mucosal visualisation is frequently incomplete at capsule endoscopy and potentially adverse complications of capsule retention or, rarely, capsule endoscope aspiration can occur [55]. Radiological investigations are therefore preferred in patients with suspected small bowel stricture or established Crohn’s disease.

Radiation exposure

Unlike MR enterography or capsule endoscopy, CT enterography utilises ionising radiation. Brenner and Hall [55] predicted that 1.5–2% of all cancers in the USA may be caused by radiation exposure. The BEIR VII risk model predicts that 0.7% of cohorts’ lifetime cancers may be caused by CT. Recently published data on the risk of carcinogenesis in adult patients due to CT quote significantly lower-risk percentages of 0.02–0.04% [56] (average effective dose of abdomino pelvic CT examination is around 15 mSv [57], and the average dose for CT enterography at our institution is also 15 mSv). The effective dose will be higher in paediatric patients [58] and, because younger patients are more likely to require more scans during their lifetime, serious consideration should be given to the use of small bowel MRI in younger patients over CT. The authors believe that CT enterography is an appropriate technique when used judiciously in the right patient groups. Recent development of innovative techniques such as the adaptive statistical iterative reconstruction algorithm are promising and will probably provide diagnostic-quality CT images at significantly reduced radiation doses in the near future [58].

Figure 7. Small bowel tumour: jejunal gastrointestinal stromal tumours in a 77-year-old male with gastrointestinal bleeding (multiple endoscopies including capsule endoscopy examinations were negative). Coronal CT enterography image demonstrates an exoenteric gastrointestinal stromal tumour of the jejunum (arrow).

Figure 8. Meckel's diverticulum with ectopic gastric mucosa in a 31-year-old male with gastrointestinal bleeding. Coronal CT enterography image showing a blind-ending gas-filled tubular structure with thickened, hyperenhancing mucosa in the left lateral margin (arrows, with nodule identified by shorter arrow).

Conclusion

CT enterography is a valuable and complementary addition to MR enterography/enteroclysis and capsule endoscopy in the diagnostic armamentarium of small bowel disorders. Wide availability of multidetector row CT platforms and examination efficiency with good patient tolerance will ensure a significant role for CT enterography, but this must be tempered with careful monitoring of the cumulative radiation dose.

References

1. Raptopoulos V, Schwartz RK, McNicholas MM, Movson J, Pearlman J, Joffe N. Multiplanar helical CT enterography in patients with Crohn's disease. *AJR Am J Roentgenol* 1997;169:1545–50.
2. Paulsen SR, Huprich JE, Fletcher JG, Booya F, Young BM, Fidler JL, et al. CT enterography as a diagnostic tool in evaluating small bowel disorders: review of clinical experience with over 700 cases. *Radiographics* 2006;26:641–62.
3. Hara AK, Leighton JA, Sharma VK, Heigh RI, Fleischer DE. Imaging of small bowel disease: comparison of capsule endoscopy, standard endoscopy, barium examination and CT. *Radiographics* 2005;25:697–718.
4. Megibow AJ, Babb JS, Hecht EM, Cho JJ, Houston C, Boruch MM, et al. Evaluation of bowel distention and bowel wall appearance by using neutral oral contrast agent for multi-detector row CT. *Radiology* 2006;238:87–95.
5. Arslan H, Etlik O, Kayan M, Harman M, Tuncer Y, Temizöz O. Peroral CT enterography with lactulose solution: preliminary observations. *AJR Am J Roentgenol* 2005;185:1173–9.
6. Boudiaf M, Jaff A, Soyer P, Bouhnik Y, Hamzi L, Rymer R. Small-bowel diseases: prospective evaluation of multidetector helical CT enteroclysis in 107 consecutive patients. *Radiology* 2004;233:338–44.
7. Reittner P, Goritschnig T, Petritsch W, Doerfler O, Preidler KW, Hinterleitner T, et al. Multiplanar spiral CT enterography in patients with Crohn's disease using a negative oral contrast material: initial results of a noninvasive imaging approach. *Eur Radiol* 2002;9:2253–7.
8. Wold P, Fletcher J, Johnson C, Sandborn W. Assessment of small bowel Crohn disease: noninvasive peroral CT enterography compared with other imaging methods and endoscopy—feasibility study. *Radiology* 2003;229:275–81.
9. Maglinte D. Invited commentary. *Radiographics* 2006;26:657–62.
10. Maglinte D, Sandrasegaran K, Lappas J, Chiorean M. CT enteroclysis. *Radiology* 2007;245:661–71.
11. Al-Hawary M, Platt J, Francis I. Comparison of adequacy of oral contrast bowel preparation with two different low attenuation agents for CT enterography (CTE) in patients with known or suspected inflammatory bowel disease. Radiological Society of North America scientific assembly and annual meeting program. Oak Brook, IL: Radiological Society of North America; 2005. p. 377.
12. Oliva M, Erturk S, Ichikawa T, Ros P, Silverman S, Morteale K. Abdominal MDCT with neutral oral contrast media (VOLUMEN®): comparison with positive oral contrast media (ReadCat®) and water [abstr]. Radiological Society of North America scientific assembly and annual meeting program. Oak Brook, IL: Radiological Society of North America; 2005. p. 378.
13. Koo C, Shah-Patel L, Baer J, Frager D. Cost-effectiveness and patient tolerance of low-attenuation oral contrast material: milk versus VoLumen. *AJR Am J Roentgenol* 2008;190:1307–13.
14. Kuehle CA, Ajaj W, Ladd SC, Massing S, Barkhausen J, Lauenstein TC. Hydro-MRI of the small bowel: effect of contrast volume, timing of contrast administration, and data acquisition on bowel distention. *AJR Am J Roentgenol* 2006;187:W375–85.
15. Hong SS, Kim AY, Byun JH, Won HJ, Kim PN, Lee MG, et al. MDCT of small-bowel disease: value of 3D imaging. *AJR Am J Roentgenol* 2006;187:1212–21.
16. Macari M, Megibow A, Balthazar E. A pattern approach to the abnormal small bowel: observations at MDCT and CT enterography. *AJR Am J Roentgenol* 2007;188:1344–55.
17. Schindera ST, Nelson RC, DeLong DM, Jaffe TA, Merkle EM, Paulson EK, et al. Multi-detector row CT of the small bowel: peak enhancement temporal window—initial experience. *Radiology* 2007;243:438–44.
18. Booya F, Fletcher J, Huprich J. Active Crohn disease: CT findings and interobserver agreement for enteric phase CT enterography. *Radiology* 2006;241:787–95.
19. Booya F, Fletcher J, Johnson C, Fidler F, Huprich J, Solem C, et al. Conspicuity of small bowel inflammation at CT enterography: "enteric" vs. "hepatic" phase imaging. Radiological Society of North America scientific assembly and annual meeting program. Oak Brook, IL: Radiological Society of North America; 2004. p. 611.
20. Macari M, Balthazar EJ. CT of bowel wall thickening: significance and pitfalls of interpretation. *AJR Am J Roentgenol* 2001;176:1105–16.
21. Gore R, Balthazar E, Ghahremani G, Miller F. CT features of ulcerative colitis and Crohn's disease. *AJR Am J Roentgenol* 1996;167:3–15.
22. Bodily KD, Fletcher JG, Solem CA, Johnson CD, Fidler JL, Barlow JM, et al. Crohn disease: mural attenuation and thickness at contrast-enhanced CT enterography—correlation

- with endoscopic and histologic findings of inflammation. *Radiology* 2006;238:505–16.
23. Macari M, Chandarana H, Balthazar E, Babb J. Intestinal ischemia versus intramural hemorrhage: CT evaluation. *AJR Am J Roentgenol* 2003;180:177–84.
 24. Wiesner W, Khurana B, Ji H, Ros P. CT of acute bowel ischemia. *Radiology* 2003;226:635–50.
 25. Chou C, Wu R, Mak C, Lin M. Clinical significance of poor CT enhancement of the thickened small-bowel wall in patients with acute abdominal pain. *AJR Am J Roentgenol* 2006;186:491–8.
 26. Levy A, Remotti H, Thompson W, Sobin L, Miettinen M. Gastrointestinal stromal tumors: radiologic features with pathologic correlation. *Radiographics* 2003;23:283–304.
 27. Horton K, Kamel I, Hofmann L, Fishman E. Carcinoid tumors of the small bowel: a multitechnique imaging approach. *AJR Am J Roentgenol* 2004;182:559–67.
 28. Bennett G, Birnbaum B, Balthazar E. CT of Meckel's diverticulitis in 11 patients. *AJR Am J Roentgenol* 2004;182:625–29.
 29. Macari M, Balthazar E, Cao H, Krinsky G. CT diagnosis of ileal diverticulitis. *Clin Imaging* 1998;22:243–5.
 30. Balthazar E, Gordon R, Hulnick D. Ileocecal tuberculosis: CT and radiologic evaluation. *AJR Am J Roentgenol* 1990;154:499–503.
 31. Wiesner W, Khurana B, Ji H, Ros P. CT of acute bowel ischemia. *Radiology* 2003;226:635–50.
 32. Balthazar E, Noordhoorn M, Megibow A, Gordon R. CT of small-bowel lymphoma in immunocompetent patients and patients with AIDS: comparison of findings. *AJR Am J Roentgenol* 1997;168:675–80.
 33. Kumar S, Sarr M, Kamath P. Mesenteric venous thrombosis. *N Engl J Med* 2001;345:1683–8.
 34. Horton K, Corl F, Fishman E. CT evaluation of nonneoplastic diseases of the small bowel: spectrum of disease. *J Comput Assist Tomogr* 1999;23:417–28.
 35. Iyer R, Jhingran A, Sawaf H, Libshitz H. Imaging findings after radiotherapy to the pelvis. *AJR Am J Roentgenol* 2001;177:1083–9.
 36. Ha HK, Lee SH, Rha SE, Kim JH, Byun JY, Lim HK, et al. Radiologic features of vasculitis involving the gastrointestinal tract. *Radiographics* 2000;20:779–94.
 37. Kalantari BN, Mortelé KJ, Cantisani V, Ondategui S, Glickman JN, Gogate A, et al. CT features with pathologic correlation of acute gastrointestinal graft-versus-host disease after bone marrow transplantation in adults. *AJR Am J Roentgenol* 2003;181:1621–5.
 38. Jones B, Kramer SS, Saral R, Beschoner WE, Yolken RH, Townsend TR, et al. Gastrointestinal inflammation after bone marrow transplantation: graft-versus-host disease or opportunistic infection? *AJR Am J Roentgenol* 1988;150:277–81.
 39. Kirkpatrick I, Kroeker M, Greenberg H. Biphasic CT with mesenteric CT angiography in the evaluation of acute mesenteric ischemia: initial experience. *Radiology* 2003;229:91–8.
 40. Puylaert J. Mesenteric adenitis and acute terminal ileitis: US evaluation using graded compression. *Radiology* 1986;161:691–5.
 41. Rao P, Rhea J, Novelline R. CT diagnosis of mesenteric adenitis. *Radiology* 1997;202:145–9.
 42. Buckley J, Fishman E. CT evaluation of small bowel neoplasms: spectrum of disease. *Radiographics* 1998;18:379–92.
 43. Hafeez R, Greenhalgh R, Rajan J, Bloom S, McCartney S, Halligan S, et al. Use of small bowel imaging for the diagnosis and staging of Crohn's disease—a survey of current UK practice. *Br J Radiol* 2011;84:508–17.
 44. Koh DM, Miao Y, Chinn RJS, Amin Z, Zeegen R, Westaby, et al. MR imaging evaluation of the activity of Crohn's disease. *AJR Am J Roentgenol* 2001;177:1325–32.
 45. Pilleul F, Penigaud M, Milot L, Saurin JC, Chayvialle JA, Valette PJ. Possible small bowel neoplasms: contrast-enhanced and water-enhanced multidetector CT enteroclysis. *Radiology* 2006;241:796–801.
 46. Huprich JE, Fletcher JG, Alexander JA, Fidler JL, Burton SS, McCullough CH, et al. Obscure gastrointestinal bleeding: evaluation with 64-section multiphase CT enterography—initial experience. *Radiology* 2008;246:562–71.
 47. Levy A, Hobbs C. Meckel diverticulum: radiologic features with pathologic correlation. *Radiographics* 2004;24:565–87.
 48. Cooney DR, Duszynski DO, Camboa E, Karp MP, Jewett TC Jr. The abdominal technetium scan (a decade of experience). *J Pediatr Surg* 1982;17:611–19.
 49. Sfakianakis G, Conway J. Detection of ectopic gastric mucosa in Meckel's diverticulum and in other aberrations by scintigraphy: Indications and methods: a 10-year experience. *J Nucl Med* 1981;22:732–7.
 50. Mazzeo S, Caramella D, Belcari A, Melai L, Cappelli C, Fontana F, et al. Multidetector CT of the small bowel: evaluation after oral hyperhydration with isotonic solution. *Radiol Med* 2005;109:516–26.
 51. Fidler J, Guimaraes L, Einstein D. MR imaging of the small bowel. *Radiographics* 2009;29:1811–25.
 52. Horsthuis K, Bipat S, Bennink R, Stoker J. Inflammatory bowel disease diagnosed with US, MR, scintigraphy, and CT: meta-analysis of prospective studies. *Radiology* 2008;247:64–79.
 53. Siddiki H, Fidler J, Fletcher J. Prospective comparison of state-of-the-art MR enterography and CT enterography in small-bowel Crohn's disease. *AJR Am J Roentgenol* 2009;193:113–21.
 54. Maglinte D, Sandrasegaran K, Chiorean M, et al. Radiologic investigations complement and add diagnostic information to capsule endoscopy of small-bowel diseases. *AJR Am J Roentgenol* 2007;189:306–12.
 55. Brenner D, Hall E. Computed tomography: an increasing source of radiation exposure. *N Engl J Med* 2007;357:2277–84.
 56. Meer A, Basu P, Baker L, Atlas S. Exposure to ionizing radiation and estimate of secondary cancers in the era of high speed CT scanning. Scientific Formal (Paper) Presentation: CODE: SSK08-04: RSNA: 1 December 2010.
 57. Sodickson A, Baeyens PF, Andriole KP, Prevedello LM, Nawfel RD, Hanson R, et al. Recurrent CT, Cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. *Radiology* 2009;251:175–84.
 58. Ware D, Huda W, Mergo P, Litwiller A. Radiation effective doses to patients undergoing abdominal CT examinations. *Radiology* 1999;210:645–50.