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CT enteroclysis: technique and clinical applications

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Abstract CT enteroclysis (CTE) has been gradually evolving with technical developments of spiral and multi-detector row CT technology. It has nowadays become a well-defined imaging modality for the evaluation of various small bowel disorders. Volume challenge of 2L of enteral contrast agent administered to the small bowel via a nasojejunal catheter ensures luminal distension, the prerequisite for the detection of mural abnormalities, also facilitating the accurate visualization of intraluminal lesions. CT acquisition is centered on small bowel loops, reconstructed in thin axial slices and completed by multiplanar views. Image analysis is essentially done in cine-mode on work-stations. CTE is of particular diagnostic value in intermediate or advanced stages of Crohn's disease, including the depiction of extraintestinal complications. It has become the

imaging modality of choice for the localization and characterization of small bowel tumors. The cause and degree of low-grade small bowel obstruction is more readily analyzed with the technique of CTE than conventional CT. Limitations of CTE concern the assessment of pure intestinal motility disorders, superficial mucosal lesions and arteriovenous malformations of the small bowel, which are not consistently visualized. CTE should be selectively used to answer specific questions of the small bowel. It essentially contributes to the diagnostic quality of modern small bowel imaging, and therefore deserves an established, well-defined place among the other available techniques.

Keywords Intestines, CT · Enteroclysis · Crohn's disease · Intestinal neoplasms · Intestines, stenosis or obstruction

Introduction

The investigation of the small bowel nowadays still represents a diagnostic challenge, since it remains the only intestinal organ not fully accessible by endoscopy. CT enteroclysis (CTE) has been defined as small bowel distension by administration of a high volume of contrast medium via a nasojejunal catheter followed by axial CT acquisition [1–6].

Before the advent of spiral CT, conventional double-contrast barium enteroclysis was the widely recognized gold standard for the assessment of small bowel disorders

[7–15]. Spiral CTE now combines the inherent advantages of conventional barium enteroclysis, i.e., homogenous luminal distension resulting from volume challenge [10, 12], with those of cross-sectional imaging, which is the simultaneous detection of intraluminal, mural and extraintestinal pathologies [1–5].

The development of multidetector row technology in 1998 [16] has allowed data acquisition over the entire abdomen in thin slices within one breath-hold, thus reducing peristaltic and breathing artifacts. This shorter acquisition time and better spatial resolution regarding the z-axis has improved the quality of multiplanar reconstruc-

tions, being of particular advantage for the investigation of intestinal pathologies [17]. Therefore, we observe an extension of indications, such as intestinal ischemia with simultaneous CT angiography [18, 19] and multidetector CT enteroclysis [20–23]. There is still a relative paucity of comparative data concerning notably the clinical results of large study populations investigated by CT enteroclysis (CTE). This might partly result from the known low incidence of small bowel disorders [14, 15, 24]. But it might also indicate that CTE has not yet become a successfully adapted and widely used routine modality for small bowel investigation. This review will analyze its diagnostic yield according to the main indications and discuss the technical aspects of CTE as well as alternative, competitive imaging modalities.

Technical aspects of CTE

Patient's preparation

In agreement with other authors [11, 12, 25, 26], we think that fasting for 8–12 h prior to CTE is the adequate patient's preparation. Rollandi et al. stress the need for supplementary rigorous cleansing of the colon [27]. Indeed, a full caecum and ascendant colon might slow the flow of enteral contrast medium through the ileum [28] and therefore prolong the investigation. We have however rarely encountered this delay in our clinical experience and think therefore that overnight fasting is enough. In certain circumstances, for example Crohn's disease, a colonic enema with water might additionally be performed immediately before CT data acquisition, thus improving the detection of disease extension.

Intubation technique

Bypassing the stomach is mandatory for rapid enteral administration of a high volume of liquid, i.e., 2 l of enteral contrast medium, the prerequisite of homogeneous small bowel distension [5, 10, 25, 27, 29]. Patients' tolerance for nasal intubation is generally better than for the oral way [27, 29].

It is definitely the need for nasojejunal intubation that has prevented CTE from becoming a widely accepted and performed technique. Patient's discomfort is related to variable operator experiences in combination with mechanical difficulties in catheter placement. Some recent improvements of material have increased patient's compliance: In our department like in others [23, 25], we use a very thin, small intestinal catheter of 8 F with a plastic olive and Teflon guide (length: 150 cm, 8 French, external/internal diameter: 2.8 mm/2.1 mm, Fresenius Kabi, Bad Homburg, Germany). This small size mostly allows for straightforward insertion and good handling of the probe

inside the stomach, even if performed by less experienced radiologists. Local anesthetics are applied to the patient's nasal and buccal mucosa beforehand; we do not use any oral or intravenous drugs. Other authors stress the increased patient's comfort achieved by intravenous administration of sedatives and analgesics given at a dose that still allows patients to follow commands during nasojejunal intubation [30]. However, these authors use a larger nasojejunal tube (13 F) than our department (8 F), which might be more difficult to swallow and less tolerated by the patients.

An inflatable balloon attached at the catheter's tip is recommended by several authors to prevent gastroduodenal reflux during contrast medium administration, which may cause nausea or vomiting [27, 29]. In our experience, this shortcoming can mostly be avoided by adequate catheter position with the tip well situated distal to the ligament of Treitz. However, whenever the catheter's tip remains placed in the descending duodenum, especially for diagnostic purposes, namely assessment of the duodenal wall, inflation with a 30-ml balloon must then be performed in order to prevent gastric reflux [29].

In patients suspected of having ileus or high-grade small bowel obstruction, Maglint et al. recommend to advance the intestinal tube (three-way with sump valve) into the proximal jejunum and leave it on overnight suction to reduce luminal distension either therapeutically or for subsequent enteroclysis [29].

Enteral contrast medium administration

Whatever enteral contrast medium is used, it should be heated to 37°C before the administration to increase the patient's comfort [25].

At our department, after nasojejunal intubation under fluoroscopy guidance, we routinely transfer the patient to the CT unit. Enteral contrast medium is then administered while the patient is lying on the CT table.

Using the small catheter size described above, a power injector infusion pump is strongly recommended for contrast medium administration [23, 29]. Manual handling of 50-ml syringes filled with contrast agent requires strength from the operator and is a time-consuming procedure. In consensus with other authors [23, 25], we agree on a high enteral injection rate of up to 200 ml/min, which immediately induces a reflex hypotonia of the bowel loops [2, 7]. This contributes to rapid and equal small bowel distension, otherwise obtained by intravenous administration of an antiperistaltic agent. We routinely use 20 mg of scopolaminbutylbromid (Buscopan, Boehringer Ingelheim, Basel, Switzerland) i.v. or, if contraindicated, 1 mg of glucagon (GlucaGen, Novo Nordisk, Bagsvaerd, Denmark), which is ideally injected shortly before data acquisition. In case of suspected or known small bowel strictures, this high flow rate must be reduced. Generally, any significant

patient's discomfort during enteral contrast administration immediately becomes clinically evident, and the injection speed can then be individually adapted followed by early i. v. injection of the antiperistaltic drugs. The overall feasibility of the above-described method of administration has been confirmed by our nearly daily and longstanding use of CTE.

Choice of enteral contrast medium

The choice of the enteral contrast medium mainly depends on the clinical indication: positive (hyperdense) or neutral (hypodense) small bowel opacification. We think that air is routinely not indicated, unlike for the stomach and duodenum [31], because of technical difficulties in administration associated with patient discomfort and late elimination after CTE. Furthermore, the intraluminal air would induce numerous reconstruction artifacts on CT images. However, conventional air double-contrast enteroclysis has occasionally been proven useful for the detection of early Crohn's disease [29].

The inherent advantage of neutral contrast agents is the good delineation of the contrast-enhanced small bowel mucosa contrasting well with the hypodense lumen. It allows detection of very small mural lesions, such as polyps, tumors or vascular malformations, which might be dissimulated by positive enteral contrast agents [25, 32]. Furthermore, opacified mesenteric vessels can thus be exactly analyzed on multiplanar reformations without being obscured by the high-density bowel content. Since various image reconstructions and simultaneous CT angiography have nowadays become part of routine small bowel investigation, neutral small bowel opacification is gaining widespread acceptance [19, 33].

There is a large choice of neutral contrast agents. Pure water is inexpensive and readily available, but is suboptimal since it is absorbed by the intestinal mucosa. Therefore, this method is relatively contraindicated in patients with renal or cardiac failure [5, 19]. Secondly, its capacity for luminal distension is inferior to that of macromolecular substances, such as polyethylenglycol [PEG] [35] or 5% methylcellulose [5, 20, 22, 26, 34].

Neutral luminal opacification is indicated in most cases, such as inflammation and tumors. However, when in search of enteral leakages or fistulae, we consider positive opacification with iodinated hydrosoluble contrast agent and without i.v. contrast medium injection as the technique of choice. Its hyperdense character allows straightforward visualization of even a small volume of extraluminal contrast accumulation. Dilute barium solutions [1, 2, 36], the alternative of positive opacification, are contraindicated if there is any risk of leakage.

In order to increase the attenuation coefficient between hypodense bowel lumen and contrast-enhanced wall, some authors [21, 37] use a paraffin-methylcellulose suspension, which leads to better demarcation of small bowel mucosa than that obtained with watery contrast medium alone. Nevertheless, the risk of aspiration during administration of this large volume of fatty emulsion with subsequent chemical pneumonia should be kept in mind. Phase separation between the fatty contrast medium and intestinal residual liquid might furthermore dissimulate small bowel lesions [21].

Acquisition and reconstruction parameters of CTE

The use of intravenous iodinated contrast medium is mandatory for the detection of inflammatory, neoplastic or vascular small bowel disease. We routinely inject the nonionic contrast medium iopentol (Imagopaque, Nycomed Imaging, Oslo, Norway, 300 mg iodine/ml, volume in milliliters=patient's body weight plus 30 ml) at a rate of 3 ml/s. Higher injection rates up to 5 ml/s are useful for vascular pathologies [18].

Volumetric acquisition parameters depend on the hardware and software equipment available. With 4- to 16-multidetector row CT scanners, a collimation beam of 1.25 mm or thinner is recommended. These data provide the same high spatial resolution of multiplanar reconstructions, which should be done with an overlap of at least 50%. Coronal views are particularly suited to display the physiological course of small bowel loops including the ileocecal valve [20, 22]. They should now routinely be part of small bowel imaging since they have been known to increase the radiologists' diagnostic confidence in image interpretation, even if they generally do not reveal any further abnormalities [17, 19, 20, 23, 33, 37–39]. Multiplanar views are especially well perceived by the referring surgeons, improving preoperative planning. With modern 16- and 64-channel CT scanners allowing for isotropic image acquisition within a few seconds, automatic axial, coronal and sagittal post-processing might become the standard technique of choice.

We routinely use the following acquisition parameters: tube voltage 120 kV, tube current 150 mAs, collimation 16×1.25 mm, pitch 1.75, table feed 70 mm/s and dual phase acquisition with a delay of 30 and 70 s. Dual phase acquisition, routinely performed in most of our patients, increases the chance to visualize all small bowel segments in a distended state since during one of the two phases some loops might be collapsed due to a transitory spasm or a residual peristaltic wave, thus mimicking an organic stenosis [3]. Assessment of Crohn's disease activity is best done in the portal venous phase [37, 40], while the arterial phase allows the possible detection of vascular pathologies, such as arteriovenous malformations of the bowel wall.

Radiation dose

Over the last 10 years, serious concern about the elevated radiation dose of spiral CT or notably multidetector spiral CT has been raised. The mean effective dose equivalent of multidetector CTE in our department, like in others [26], is 6.2 mSv for each acquisition phase, with an additional 0.5–1 mSv for nasojejunal intubation guided by fluoroscopy; this means 13–13.5 mSv altogether using dual-phase acquisition. Some authors report on radiation doses up to 13 mSv for one acquisition by multidetector row CTE depending on the CT manufacturer and patient's gender [37, 40]. A high patient radiation dose had frequently been quoted as one of the disadvantages of conventional barium double-contrast enteroclysis [14]. However, quite important discrepancies of published data exist varying from an average dose of 1.5 mSv [41] to a mean effective dose equivalent of 13.99 ± 7.57 mSv [42]. The major reason for this striking standard variation is the varying fluoroscopy time, reflecting large differences in operator experience, as is also true with fluoroscopy-guided nasojejunal intubation. The radiation dose of CTE is otherwise operator independent; it only depends on the chosen acquisition parameters, mainly varying with the patient's body weight. Furthermore, we observe a more efficient dose profile using the most recent multidetector CT: Due to the relative reduction of penumbra radiation with an increasing number of channels of CT scanners, the radiation dose necessary for the same slice width and with the same image noise decreases [43].

Clinical applications and diagnostic yield

Normal small bowel appearance on CTE

The well-distended and transaxially imaged normal small bowel wall measures 1–2 mm (Fig. 1) [2, 36, 44]. A wall thickness >4 mm in any well-distended segment is abnormal. After i.v. contrast medium bolus injection, homogeneous mural enhancement occurs, even in healthy subjects, predominantly seen at the inner, mucosal side [35, 42]. Pathological small bowel wall attenuation is defined by comparison of its value with those of adjacent, healthy loops. During the portal phase, the average CT density of the normal duodenal, jejunal and ileal wall varies between 107–111 (± 4) Hounsfield units (HU), and between 118–120 (± 5) HU during the arterial phase. However, these values have been calculated on small bowel loops orally opacified with only 500 ml of water, and are therefore less distended than with the enteral administration of 2 l of liquid [45].

Provided that adequate luminal distension had been obtained, the diameter of the small bowel measures between 21–29 mm (Fig. 1) [2], and a diameter >3 cm means dilatation.

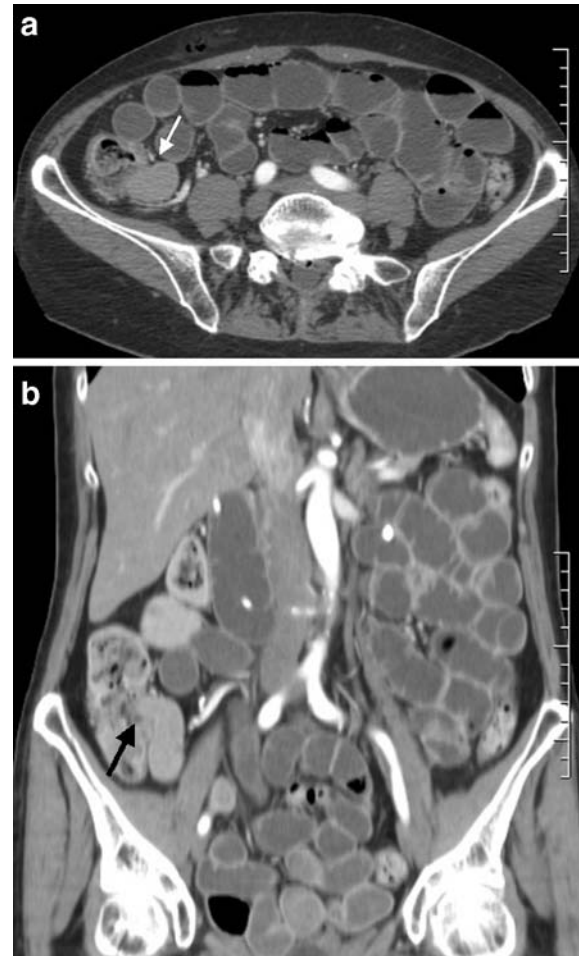


Fig. 1 a Axial and b coronal plane of CTE demonstrates the normal small bowel anatomy, centered on the ileocecal valve (arrow) and the terminal ileum, which is well distended

Crohn's disease

The sensitivity of conventional double-contrast barium enteroclysis for Crohn's disease ranges between 98.2–100%, as was demonstrated on 168 [8] and 143 patients [13], respectively, whereby Maglente et al. had included 43 patients [31%] with early lesions. The diagnostic accuracy of cross-sectional imaging modalities, including CTE, remains controversial for the initial stage of Crohn's disease [36, 40, 46, 47]. Their spatial resolution is still inferior to that of conventional double contrast enteroclysis [13] and does not allow detailed analysis of the small bowel mucosa. Therefore, early mucosal inflammation, histopathologically characterized as aphthoid ulcerations and enlarged lymphoid follicles, is not constantly visualized by CTE, even with the given improvements of multidetector row technology [26, 36].

At intermediate or advanced stages of Crohn's disease, however, the value of CTE is well established [34, 36]. The degree of small bowel wall thickening and intensity of

mucosal contrast enhancement correlate with clinical disease activity at the acute or quiescent phase [36, 48]. Due to homogeneous luminal distension, CTE allows a better analysis of the small bowel wall than conventional CT, and thus a more precise and comprehensive recognition of the different pathological enhancement patterns. Acute inflammation is characterized by mural stratification (Fig. 2), mainly explained by the strongly contrast enhanced mucosa surrounded by the low-density submucosa [5, 36, 48]. Chronic involvement seen during clinical quiescence is associated with diffuse parietal contrast enhancement and mild thickening, indicating irreversible transmural fibrosis [36, 48].

Extraintestinal features of Crohn's disease, such as inflammatory extension into the adjacent mesentery, associated abscesses, enteric fistulae or involvement of other organs, are simultaneously and readily demonstrated by CTE (Fig. 3a), and not by conventional barium studies. The latter only inconstantly show enteric fistulous tracts, which can precisely be demonstrated by multiplanar reformatting views [23]. Finally, the enteral volume challenge of CTE also enables the visualization of even moderate segmentary luminal narrowing due to active Crohn's disease, which might only appear as collapsed or spasmed small bowel loops on traditional CT. The length of these strictures might then be more accurately demonstrated on multiplanar reconstructions, often best appreciated on the coronal plane (Fig. 3b).

Furthermore, CTE features allow accurate classification of Crohn's disease into subtypes that include active inflammatory, fibrostenosing and fistulizing/perforating categories [49]. Its clinical utility and influence on further patient's management is certain: broad antiinflammatory medical treatment is indicated for edematous luminal narrowing due to active Crohn's disease, while fistulous and perforating complications might successfully be managed



Fig. 2 CTE in a 23-year-old woman with acute Crohn's disease: discontinuous parietal thickening involving several distal ileal segments with pathological contrast enhancement characterized by mural stratification (*arrows*) and irregular luminal narrowing

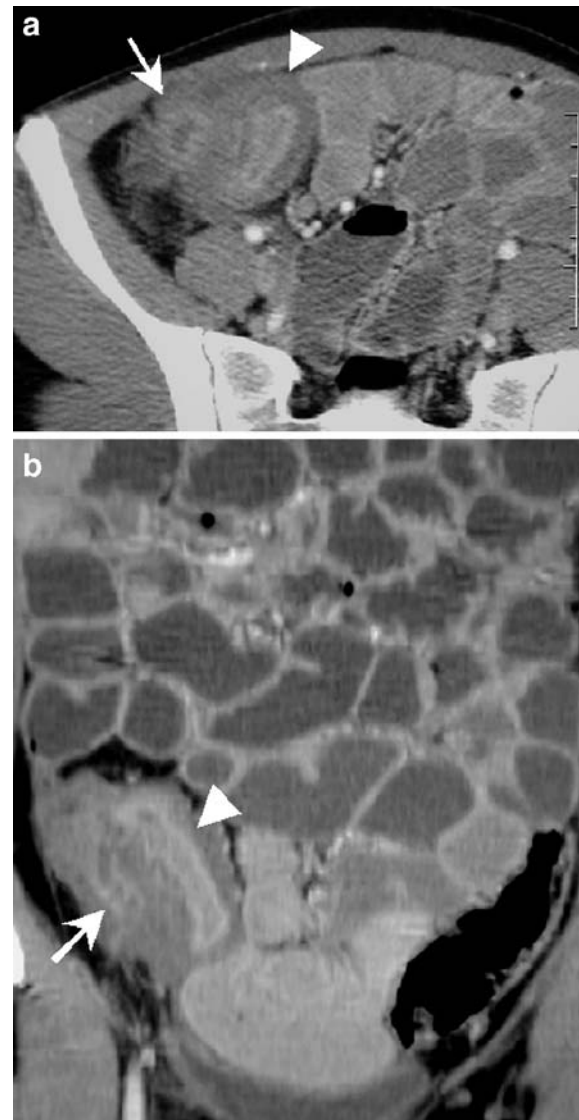


Fig. 3 CTE in a 22-year-old woman with complicated Crohn's disease: diffuse parietal thickening of the distal ileum (*arrowhead*) and surrounding inflammation causes luminal narrowing complicated by an intraperitoneal abscess (*arrow*), both seen on **a** axial and **b** coronal view; however, coronal reconstructions better demonstrate the exact length of segmentary stenosis as well as the anatomical abscess extension

by specific medical treatment (Infliximab). In case of refractory fistulizing disease (Fig. 4), surgical resection is indicated, which might also be the treatment of choice for the symptomatic fibrostenosing subtype whenever minimally invasive procedures, such as stricturoplasty or endoscopic balloon dilatation, fail or are not possible [49].

The unpredictable and insidious character of Crohn's disease might be especially harmful in the acute postoperative period when early complications occur. Patients might present with unexplained persistent inflammatory syndrome or complain of mild intermittent, recurrent abdom-



Fig. 4 A 73-year-old patient with active Crohn's disease (fistulizing subtype): conventional CT **a** with oral and rectal administration of positive contrast medium shows acute inflammation of the ileocaecal region (*arrow*) extending into the mesenteric fat of the right iliac fossa (*arrowhead*), however, without demonstration of the fistulous tract to the iliac muscle, which is only seen on CTE **b** due to its volume challenge and positive enteral opacification

inal pain, however, without evident physical findings or the clear pathological features seen on conventional CT, which is usually the first diagnostic procedure to be performed. In these instances, CTE performed with positive enteral opacification and without i.v. contrast medium is the technique of choice to detect small anastomotic leakages or intestinal fistulae. Due to its enteral volume challenge, CTE is superior to conventional CT in this regard [32]. The fistulous tract is shown by opacification with the positive enterally administered contrast medium (Fig. 5); sometimes it might only become evident on late phase images.

Small bowel neoplasms

Small bowel tumors are very rare, representing less than 2% of all the primary gastrointestinal malignancies, and are often small and generally present with nonspecific abdominal symptoms responsible for a significant diagnostic delay in the past [10, 24].

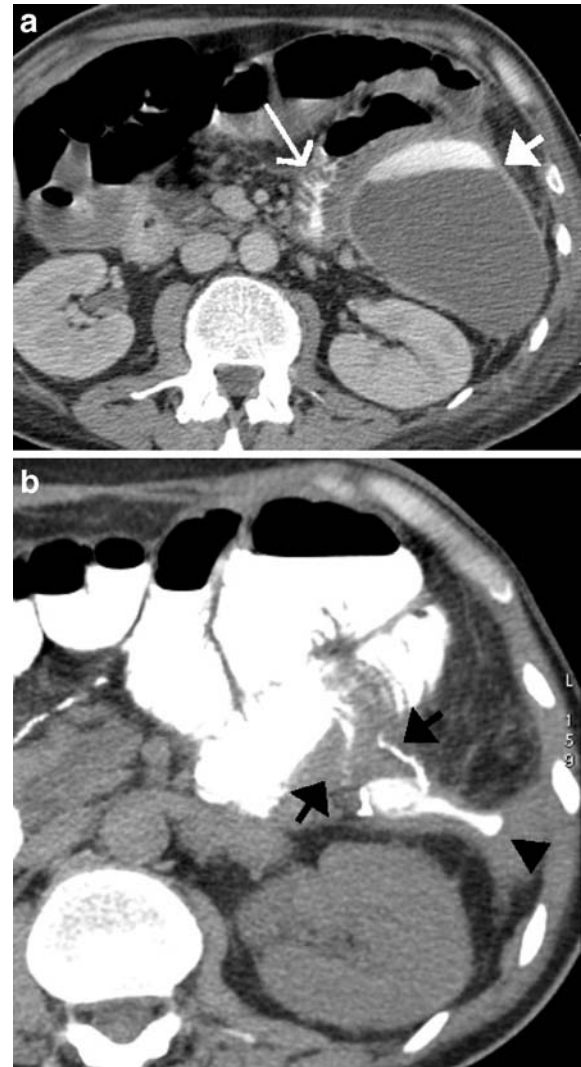


Fig. 5 A 43-year-old patient after colic resection for inflammatory bowel disease and temporary ileostomy. Conventional CT **a** with rectal administration of positive contrast medium was performed during the acute postoperative period for persistent inflammatory syndrome. It shows leakage of the rectal stump with consecutive contrast accumulation within a large abscess formation situated in the left pararenal space (*short white arrow*). The presence of contrast medium in the adjacent jejunal loop (*long, thin, white arrow*) without previous oral contrast administration suggests an underlying fistula. Only CTE **b** performed with positive enteral opacification some days later is able to demonstrate two small fistulous tracts (*short black arrows*) extending from the proximal jejunal loop to the abscess cavity, which has meanwhile been drained. Notice the accumulation of the enteral contrast medium in the former abscess cavity (*black arrowhead*)

The well-distended and i.v. contrast-enhanced small bowel wall provided by CTE with neutral enteral opacification allows detection and differentiation between extra-, intra-mural and luminal lesions, which is of particular importance for neoplastic diseases (Figs. 6, 7, 8). Tumor staging by detecting local extension, adenopathy or distant metastasis is simultaneously realized. [33].

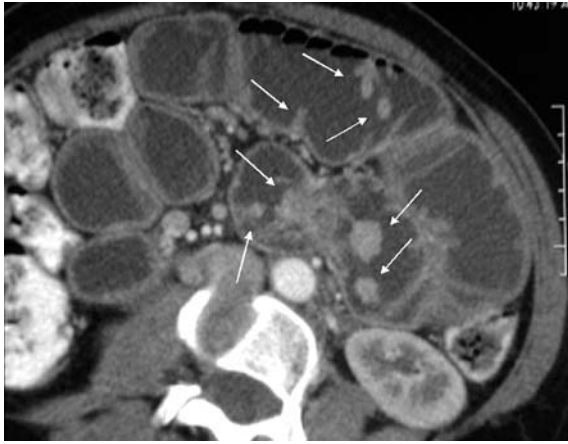


Fig. 6 CTE in a 40-year-old woman with Peutz-Jeghers disease detected after recurrent episodes of intestinal intussusceptions: multiple pedunculated jejunal and ileal hamartomas (*arrows*) are nicely seen within the distended bowel loops, 34 among them were resected

Direct comparison of the technique of conventional enteroclysis, traditional CT and CTE performed on 63 patients revealed 15 cases with neoplastic involvement of the small bowel, whereby CTE provided important supplementary diagnostic features [6].

Orjollet et al. and Boudiaf et al. report on a 100% sensitivity of CTE for the detection of small bowel tumors performed with the monodetector and multidetector row technique, respectively [23, 25]. Using a beam collimation of 5 mm, a pitch of 1 and reconstructed slices of 3 mm, Orjollet et al. revealed 25 small bowel tumors in 48 patients, among them 22 histologically proven, measuring between 0.8 and 6 cm, the mean tumor size being 2.3 cm [25]. Multidetector row CTE performed on 107 patients by Boudiaf et al. (4×2.5-mm collimation and images reconstructed at 3-mm intervals) demonstrated 21 surgically confirmed small intestinal masses of an axial diameter from 5 to 35 mm and a mean diameter of 21 mm [23]. Neutral luminal opacification (2 l) in association with multiplanar reconstructions allowed for confident visualization of even small, centimetric lesions. The diagnostic certitude, however, depends on their degree of hypervascularization and delineation. Detection of little enhancing and sessile adenomas mainly seen in familial intestinal polyposis was considered to be the most difficult [25].

Unfortunately, other comparative studies with traditional CT date back to the incremental mode and thick slices of 8–10 mm [50, 51], reaching a sensitivity of 73% and 80%, respectively, and including 63 and 35 patients, respectively.

In a pictorial essay, Horton et al. highlight the advantages of multidetector-row and 3-dimensional [3D] CT with enteral opacification by oral neutral contrast for imaging of small bowel neoplasms, however without taking into

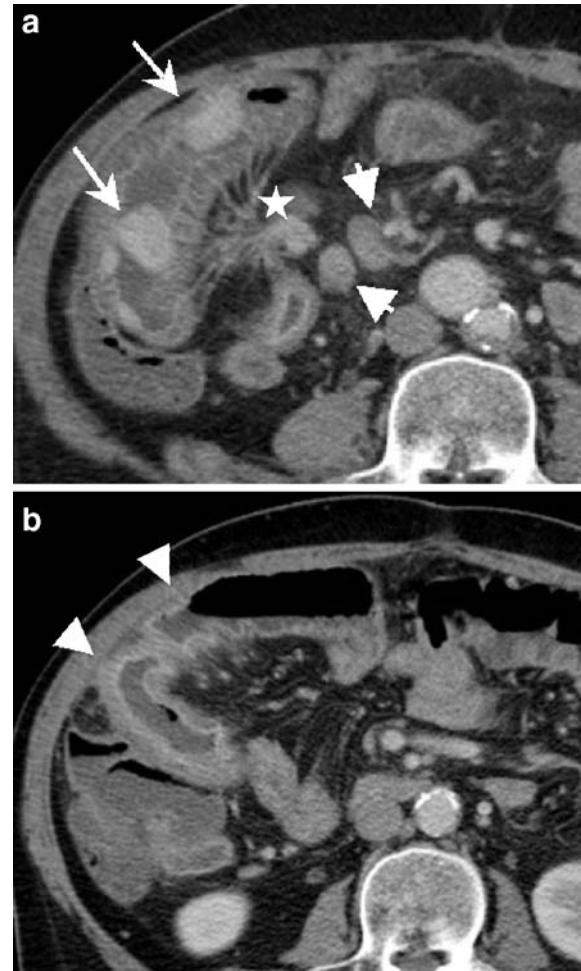


Fig. 7 A 57-year-old man presenting with diarrhea for 3 months (eight times/day): conventional CT (not shown) had only revealed non-specific thickening of the distal ileal wall. CTE shows several intensely i.v. contrast-enhanced nodules **a** situated in a distal ileal loop, the two largest ones measuring 2–2.5 cm (*long arrows*). There is adjacent retractile mesenteric fat stranding (*star*) and associated metastatic lymph nodes (*big, short arrows*). **b** nicely demonstrates tethered appearance of adjacent ileal loops showing angulation and kinking as well as mural thickening with pathological i.v. contrast-enhanced mucosa and submucosal edema (*arrowheads*). Surgical and histopathological findings confirmed the diagnosis of multiple carcinoid tumors of the ileum **a** with desmoplastic reaction of the mesentery and secondary ischemia of the adjacent ileal wall due to perivascular tumor infiltration (**b**)

account the technique of CTE. The added value of 3D imaging of small bowel tumors has not been proven in a prospective trial. It probably does not improve tumor detection itself, but the 3D images are nowadays rapidly generated. They are well received by referring clinicians since they better demonstrate complicated anatomical relationships than 2D slices, thus especially serving for surgical planning [33].

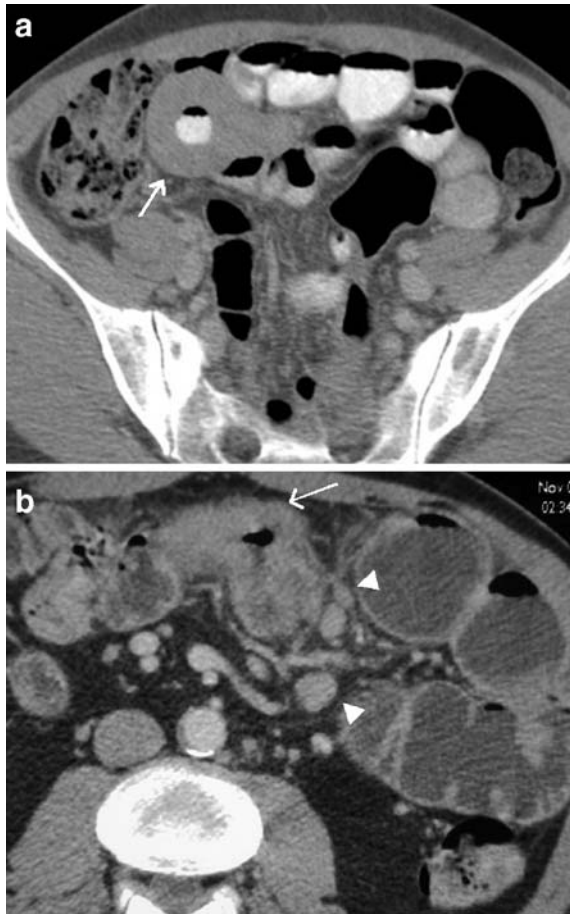


Fig. 8 Two different CTE features of small bowel lymphoma: primary distal ileal lymphoma **a** seen in a 50-year-old woman is characterized by long segmentary and circumferential parietal thickening with aneurysmal luminal dilatation (*arrow*). Secondary lymphomatous transformation of celiac disease **b** in a 60-year-old man is demonstrated as excentric jejunal wall thickening extending to the adjacent mesenteric fat (*arrow*) with multiple associated adenopathies (*arrowheads*). Note diffuse parietal contrast enhancement in both patients without mural stratification in contrast to inflammatory lesions, typically indicating tumoral involvement of the thickened small bowel wall

Chronic obscure GI bleeding

Arteriovenous malformations are the most frequent source of chronic obscure GI bleeding occurring in 39–80% of patients, followed by neoplasms (6–15%) and rare causes, such as jejunal, duodenal or Meckel’s diverticula, segmentary ischemia, Crohn’s’ disease or radiation enteritis [10, 46, 52].

CTE performed for chronic obscure gastrointestinal bleeding or unexplained anemia tends to show a high rate of negative findings similar to conventional enteroclysis, with a reported diagnostic yield as low as 10–20% [52, 53]. Up to now, these figures have been confirmed only by one prospective comparison of CTE with wireless capsule endoscopy (WCE): CTE performed on eight patients

with obscure gastrointestinal bleeding only resulted in one positive finding, which was suspected jejunal angioma. However, this feature was not confirmed by WCE, which revealed five positive findings, such as angiodysplasia and small bowel wall erosions, allowing a final diagnosis in four patients (50%) [26].

Direct visualization of parietal intestinal arteriovenous malformations has otherwise only been described in isolated case reports using traditional CT so far [54, 55]. Published data of spiral CTE prospectively performed on populations with various small bowel disorders, among them 22–50% of patients addressed for unexplained gastrointestinal bleeding or iron deficiency anemia, did not reveal any arteriovenous malformation of the small bowel [22, 23, 25, 26].

Searching for the source of chronic obscure GI bleeding requires “angio CTE,” which is data acquisition in the dual phase after i.v. bolus injection with a flow rate of 4–5 ml/s and neutral enteral opacification (Fig. 9). This technique provides the highest chances for detecting any etiology, either of tumoral, vascular or even congenital origin. Especially underlying Meckel’s diverticula has been reported to be confidently detected by CTE [56].

Mechanical small bowel obstruction (SBO)

Conventional abdominal CT has been shown to be very sensitive for the detection of high-grade SBO [57], including its origin, grade and localization [47, 58–60]. False-negative findings occurring with conventional abdominal CT are mainly due to low-grade, partial occlusion for which a transition zone between dilated proximal and collapsed distal small bowel loops is not clearly individualized



Fig. 9 CTE in a 79-year-old patient presenting with melena of unknown origin: arterial phase nicely demonstrates the intensely contrast-enhanced infracentrimetric polyp situated in a distal jejunal loop (*arrow*), exactly depicted thanks to optimal luminal distension with neutral contrast medium

[47, 61]. Therefore, the value of conventional abdominal CT in the diagnosis of SBO relates to the severity of the obstruction. In a retrospective review including 36 patients, CTE has proven to be more sensitive than traditional CT for low-grade SBO (89 versus 50%), especially in excluding malignant disease [62]. Thanks to the enteral volume challenge provided by CTE, even non-obstructive bowel adhesions might be detected whenever kinking of the well-distended bowel loops is observed. This may be responsible for patients' abdominal pain and can result in future obstructions. CTE prospectively performed on 48 patients showed a sensitivity and specificity of 82.1 and 87.5%, respectively, for the localization and severity of low-grade partial SBO [3]. Therefore, CTE seems to be a valuable tool for any grade of SBO (Figs. 10, 11) combining the advantages of traditional CT and conventional

enteroclysis; the latter has been the imaging modality of choice for low-grade SBO so far [14, 58].

In a recent prospective study, multidetector row CTE revealed a sensitivity of 100% for the site, level and cause of low-grade SBO in 12 out of 31 patients, among them 4 with negative conventional barium follow-through studies [23]. Filmless reading of the whole small bowel in cine-mode and on multiplanar reconstructions provided by the multidetector helical row technique is certainly the decisive advantage of CTE in this regard instead of dealing with

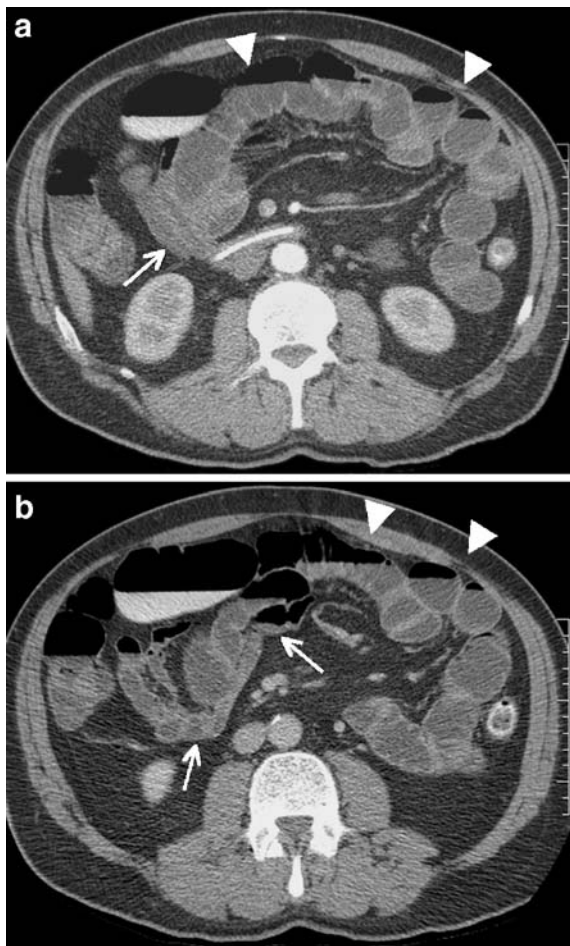


Fig. 10 A 66-year-old man presenting with recurrent episodes of crampy abdominal pain after appendectomy and ileal resection in the past. Conventional CT (not shown) had been normal. CTE shows complete distension of the jejunal loops by the enteral contrast medium methylcellulose (*arrowheads*) while the ileal loops remain collapsed (*long arrows*). This feature strongly suggests a fibrotic adhesion at the jejunio-ileal junction causing low-grade SBO, which was confirmed by surgery

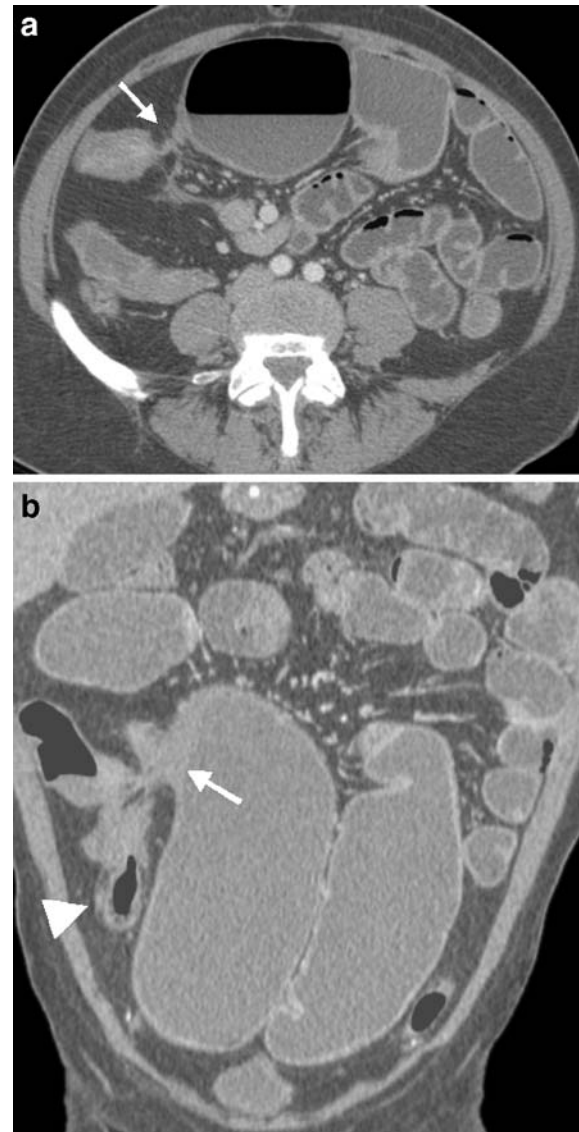


Fig. 11 A 48-year-old woman with long-standing Crohn's disease and high-grade ileal stenosis impossible to overcome by endoscopy: axial image **a** of CTE shows one of two pronounced ileal stenoses (*arrow*) with important prestenotic dilatation (fibrostenosing subtype). However, exact anatomical relationship of the two narrowed ileal loops (*arrow*) with adhesions to the equally involved ascending colon (*arrowhead*) is far better demonstrated on **b** coronal view

overlapping small bowel loops on conventional barium studies.

Furthermore, the patient's immediate operability remains maintained after CTE since the enteral opacification with barium can be avoided, unlike in conventional enteroclysis. However, CTE should not become a substitute for standard CT in the emergency patient presenting with acute SBO [46], but it should be used to investigate low grade partial and intermittent SBO, which is its main advantage over conventional CT [59].

Limitations of CTE in comparison with other diagnostic tools

CTE versus conventional small bowel studies

CTE, as a projection modality, provides precise analysis of anatomical details without superimposition of small bowel loops as often seen at fluoroscopy. Nevertheless, the assessment of motility disorders remains difficult in contrast to conventional small bowel studies. Patients with predominantly functional disorders should therefore continue to be investigated with conventional enteroclysis [7]. However, many functional small bowel disorders will sooner or later also cause organic changes and therefore become evident on CTE, such as prestenotic luminal dilatation when segmentary small bowel narrowing is becoming significant. Furthermore, CTE is much less operator dependent than conventional enteroclysis; therefore, results are far more standardized and reproducible than those of conventional enteroclysis.

Spatial resolution of CTE still remains suboptimal compared to conventional double contrast barium enteroclysis, as it does not provide detailed analysis of the small bowel mucosa [36]; the exclusion of early Crohn's disease in particular is not reliable.

CTE versus "oral CT enterography"

Oral administration of enteral contrast medium before CT, even using a large volume, is always associated with less optimal small bowel distension than obtained after nasojejunal intubation [40]. This drawback might not prevent the detection of many small bowel lesions significantly [40], but it causes diagnostic problems in a small number of difficult cases. Intermittent and low-grade SBO might be impossible to detect [62]. The lack of complete small bowel distention may simulate segmentary mural thickening and mask small intraluminal lesions of the small bowel [36, 44, 45, 64, 65].

According to Wold et al., peroral CT enterography does not show any statistically significant difference concerning the assessment of Crohn's disease activity as compared to CTE. However, the small number of eight patients in-

cluded in the CTE group, among them only four with active inflammation of the terminal ileum, hampers these conclusions [40].

CTE versus MR enteroclysis (MRE)

Thanks to the multiplanar imaging capabilities and the excellent soft tissue contrast resolution inherent in MR imaging, as well as technical progress concerning fast imaging sequences and the absence of ionizing radiation, MRE has become a very promising tool for the evaluation of small bowel disorders [35, 62, 65, 66]. The mural contrast enhancement seen in MRE is far more pronounced than that seen with iodinated contrast medium, and is therefore especially useful for the detection of inflamed bowel segments in Crohn's disease [35, 65, 66] or tumors [66]. Dynamic image acquisition, MR fluoroscopy, is possible, provided that the infusion pump is placed in the MR unit [65], while CTE always reflects a "snapshot" of the small intestine.

Persistent limitations of MRE are the limited availability of MR scanners, and the still long acquisition times associated with a few persistent artifacts due to magnetic susceptibility, chemical shifts or residual peristalsis. The spatial resolution of MR imaging is far inferior to that of CT; small bowel mucosa can therefore not be analyzed in detail like on CTE. The only direct comparison of MRE and multidetector CTE performed on 50 patients resulted in better sensitivity and interobserver agreement of CTE for the detection of various small bowel lesions [22].

CTE versus wireless capsule endoscopy (WCE)

Has the advent of wireless capsule endoscopy (WCE) changed the investigational approach of small bowel disorders? Its clinical value is difficult to evaluate because of the lack of a gold standard despite the proven high sensitivity and good diagnostic yield [26, 67, 68]. The exact localization of lesions can also be difficult with WCE [67]. The high incidence of abnormal findings (33%) classified as "others" among the 49 sources for small bowel hemorrhage revealed by Scarpa et al. shows the problematic interpretation of nonspecific findings and renders treatment options difficult [68]. Up to now, WCE has revealed better sensitivity than barium follow-through [67], conventional enteroclysis, traditional CT [63] and especially CTE [26]. The latter demonstrated fewer positive findings than WCE for obscure gastrointestinal bleeding and Crohn's disease, whereby WCE is contraindicated in case of intestinal stenoses. They should therefore be excluded beforehand, which is done best by CTE. WCE seems therefore an ideal diagnostic modality for early Crohn's disease whenever the localization is beyond the reach of the endoscope and lesions are superficial without associated luminal narrow-

ing. WCE is certainly the method of choice for obscure gastrointestinal bleeding for which CTE is most likely associated with the same low diagnostic performance as conventional double contrast enteroclysis [7, 26].

Conclusion

In summary, CTE represents a problem-solving modality for well-selected patients concerning the detection and characterization of small bowel pathology: It is highly recommended for advanced and complicated Crohn's disease or the preoperative assessment of the inflammatory extent. CTE should be the modality of choice for the detection and localization of small bowel tumors [32] as well as in the clinical setting of recurrent, low-grade obstructive symptoms of SBO, especially to differentiate between malignant and adhesive origin [23, 62]. CTE should not be used as

screening or as the first line investigation, in particular not to search for superficial mucosal alteration due to early inflammatory bowel disease or responsible for obscure gastrointestinal bleeding. It also is not indicated for emergency patients with suspected high-grade SBO. CTE should be selectively used to answer specific questions about the small bowel, and it is usually preceded by another imaging modality [32], which is nowadays often abdominal CT without small bowel preparation.

The successful adoption of CTE by the clinical environment depends on how radiologists can educate surgeons, gastroenterologists and other specialists. Using a very small intestinal catheter can show them that this technique does not only increase patients' discomfort because of the necessary nasojejunal intubation. CTE also essentially contributes to the diagnostic quality of modern small bowel imaging, and therefore deserves an established place among the other available techniques.

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