CT enterography: Principles, technique and utility in Crohn's disease

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ABSTRACT

CT enterography is a modification of conventional CT technique optimized for the evaluation of small bowel. This technique utilizes multidetector scanners with high spatial and temporal resolution; multiplanar reconstructions; and large volumes of enteric contrast to provide bowel distension. This article discusses the essential principles of the exam and its use in the evaluation of Crohn’s disease of the small bowel.

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1. Introduction

Imaging patients with suspected small bowel disease has always been challenging. Because of its length and location between the stomach and colon, the small bowel has, until recently, been beyond the endoscope’s reach. Before the introduction of capsule endoscopy and advanced endoscopic techniques, barium examination of the luminal surfaces of the small bowel was the only noninvasive method available for small bowel evaluation. As a result of the proven superiority of capsule endoscopy and double balloon endoscopy over barium studies for mucosal assessment, these techniques have threatened to minimize the role of the radiologist in caring for patients with small bowel disease.

Limitations in spatial and temporal resolution of early single-slice CT scanners made this technology largely unsuitable for the evaluation of the small bowel. The development of multi-slice CT technology, with faster scanning times and isotropic spatial resolution combined with the development of new enteric contrast media, has reestablished an important role for radiologists in evaluating small bowel disease. In the following pages we will discuss the essential elements of a successful CT enterography exam and the application of this robust technique in evaluating patients with Crohn’s disease.

2. Positive vs. neutral enteric contrast

Positive enteric contrast agents, containing iodine or barium compounds, are of higher attenuation than soft tissue. Because of the high attenuation compared to soft tissue and perienteric fat, these agents provide an excellent background for the detection of intraluminal filling defects such as polyps. The use of these agents also facilitates the tracking of the bowel lumen through the abdomen, and therefore, it may also assist in estimating the location of pathology within the small bowel. On the other hand, the high attenuation of positive enteric contrast may prevent detection of pathological bowel wall enhancement (Fig. 1). By comparison, neutral enteric contrast agents are near water-density and, because of the large attenuation difference between the lower-density luminal contrast and the higher-density enhancing bowel wall, the detection of pathologic bowel wall enhancement and bleeding is facilitated. On the other hand, the smaller attenuation difference between a neutral agent and soft tissue can hinder the detection of non-enhancing polypoid lesions. In a prospective, randomized comparison of high- vs. low-attenuation enteric contrast media in 90 consecutive patients without small bowel disease, Erturk et al. [1], concluded that low-attenuation (neutral) oral contrast media provided equal or superior distension and bowel wall visualization compared to the high-attenuation contrast medium. For these reasons, neutral enteric contrast agents are preferred when performing routine CT enterography. Certain clinical situations dictate the use of positive rather than neutral contrast and these will be discussed later.

3. Which neutral enteric contrast?

The optimal neutral enteric contrast agent must not only allow detection of enhancing bowel wall abnormalities, it must also provide good luminal distension and be well tolerated by patients. Young et al. [2] compared bowel wall distension among groups of volunteers ingesting water, polyethylene glycol (PEG), methylcellulose and low-concentration barium solution containing sorbitol (VoLumen®, E-ZEM, Inc., Westbury, NY, 0.1% weight/volume bar
32-Year-old male with active Crohn’s disease underwent routine contrast-enhanced CT (A) and 2 weeks before undergoing CT enterography with neutral enteric contrast (B). Both images demonstrate bowel wall thickening (arrows) but intense mucosal hyperenhancement is obscured by the positive enteric contrast on conventional CT.

1350 cm³ was initially given followed by 500 cm³ water. In a similar study, Kuehle et al. compared bowel distension among four neutral contrast agents (locust bean gum with mannitol, VoLumen® containing 2.0% and 1.4% sorbitol and water) [3]. A total of 1350 cm³ of contrast was given orally at a constant rate of 40 cm³/min. Both studies concluded that water provided the poorest luminal distension because of rapid resorption over the length of the small bowel, and that VoLumen® provided the best distension. None of the agents provided consistently good distension of the jejunum (Fig. 2). Patients in Young’s study preferred VoLumen® over polyethylene glycol solution, even though both produced equally good distension. Megibow et al. comparing VoLumen® with methylcellulose solution also confirmed the advantages of the former [4]. These studies support the use of low-concentration barium/sorbitol solution as the preferred neutral enteric contrast for CT enterography.

4. Oral administration vs. enteroclysis

Enteroclysis examinations produce distension of the small bowel by rapidly infusing enteric contrast through a nasojejunal catheter. The injection is usually made using a mechanical injector so that contrast is delivered at a constant rate. As described by Maglinte et al. [5], this technique produces superior distension of the entire small bowel, including the jejunum, thus overcoming one of the disadvantages of oral administration. However, fluoroscopic placement of the enteric catheter for enteroclysis requires technical skill and exposes the patient and physician to additional radiation. In addition, because of the patient’s discomfort associated with nasoenteric intubation and the time-consuming nature of the study, there is underutilization of this technique due to...
poor patient acceptance and less efficient utilization of the imaging suite.

In 2001 Mazzeo et al. evaluated the ability of oral administered PEG to produce adequate small bowel distension in 33 patients with suspected small bowel Crohn's disease and 10 normal subjects. In all patients there was satisfactory distension of ileal loops. The jejunum distended partially or completely in all of the Crohn's patients but only in 69% of the normal subjects [6]. Wold et al. compared CT enterography in a group of patients ingesting 1800 cm3 of water over 75 min with a similar group of patients undergoing CT enteroclysis. In a small cohort of patients with known or suspected inflammatory bowel disease, they found that the proportion of distended small bowel loops was not significantly different between the two groups [7]. Based upon studies such as these, as well as our own clinical experience, we prefer the use of per-oral administration of contrast during routine CT enterography, especially those with Crohn's disease.

5. Technique

Patients undergoing CT enterography are kept NPO for 4 h prior to scanning. Low-concentration barium sulfate with sorbitol is our preferred oral contrast agent. Our current regimen uses 1350 cm3 Volumen® followed by 500 cm3 of water administered orally according to the following schedule:

- 450 cm3 Volumen® 60 min before scanning.
- 450 cm3 Volumen® 40 min before scanning.
- 450 cm3 Volumen® 20 min before scanning.
- 500 cm3 of water 10 min before scanning.

Single-phase CT enterography images are acquired after an appropriate delay following IV contrast injection to optimize visualization of bowel wall abnormalities. Schindera et al. recently examined the attenuation of the small bowel wall and aorta at 5 s intervals following the injection of intravenous contrast at 5 cm3/s. They found that peak small bowel wall enhancement occurs at 50 s after the beginning of contrast injection [8]. Whether mural enhancement in Crohn's disease occurs at the same time is uncertain. Vandenbroucke et al. concluded that there was very little difference in the appreciation of mural enhancement in Crohn's disease in images acquired at 45 or 70 s after injection [9].

Our protocol calls for injection rates of 4–5 cm3/s of 150 cm3 of iohexol (300 mg/ml; Omnipaque; Amersham Health, Inc., Princeton, NJ) Scanning is performed on 8–64 channel MDCT scanners beginning 50 s after the initiation of contrast injection. Slices are acquired using a narrow slice thickness (2.5–3.0 mm) and reconstruction interval (1.0–2.0 mm). Automatic coronal reformats using similar parameters are generated on our 64-channel CT system. For other scanners, coronal reformats are generated using the minimal collimation available to produce high quality multiplanar images. Because of the potential presence of peripheral fistulizing Crohn's disease, which can be clinically occult, technologists should routinely scan through the perineum when performing CT enterography (Table 1).

6. CT enterography in Crohn's disease

Crohn's disease is one of the two major subtypes of inflammatory bowel disease and is characterized pathologically by a transmural granulomatous inflammatory process. It affects over 600,000 of the U.S. population and nearly one million Europeans [10]. The disease may affect any portion of the tubular GI tract but most commonly affects the small bowel. Symptoms are often non-specific, leading to frequent delays in diagnosis. No single test can provide an unequivocal diagnosis or a complete depiction of biologic activity; therefore, a variety of modalities are usually necessary to confidently diagnose the disease.

The recent introduction of new medical therapeutic agents has resulted in dramatic improvements in the care of Crohn's patients. Chief among these agents are the anti-TNFα antibodies—infliximab, adalimumab and certolizumab. These medications have been successful in the treatment of moderate to severe small bowel and colonic disease and fistulizing Crohn's disease. Early studies have shown that 81% of patients with moderate to severe Crohn's disease responded favorably after a single infusion of infliximab [11]. In patients with fistulizing disease, over one-half demonstrated signs of healing after treatment with infliximab [12]. These agents are not without disadvantages, however. Treatment is costly—approximately $25k annually. In addition, their use is associated with a slightly increased incidence of opportunistic infections, lymphoma and drug-induced immune disease [13]. Therefore treatment with these agents is not initiated unless (1) the presence of Crohn's disease is confirmed; (2) the disease severity and extent have been defined; (3) associated penetrating disease has been delineated; (4) there is a clear understanding of the benefit/risk ratio compared to other therapies.

The CT enterography findings in Crohn's small bowel disease have been well described previously [14–16]. CT enterography findings of active Crohn's disease include mural hyperenhancement, bowel wall thickening, and stratification. Mural hyperenhancement is segmental attenuation greater than adjacent normal small bowel loops and is the most sensitive CT finding for active disease [16]. Although segmental mural enhancement is a non-specific finding and is present in other inflammatory conditions, the presence of asymmetrical mural enhancement and thickening is a characteristic finding in Crohn's disease (Fig. 3). Mural thickening is present when the bowel wall is greater than 3 mm in thickness in a well-distended segment. Similar to mural enhancement, mural thickening is often asymmetric, usually more prominent along the mesenteric border. Mural stratification refers to a laminated appearance of the thickened bowel wall—a finding indicating more advanced Crohn's disease (Fig. 4).

Because Crohn's disease is a transmural inflammatory process changes may occur in the adjacent perienteric fat and small bowel mesentery. Increased density in the perienteric fat results from extension of the inflammatory process outside the bowel wall and is associated with an elevated serum C-reactive protein. Fibrofatty proliferation refers to the surgical and imaging findings of increased fat deposition along the mesenteric border of the bowel. This fatty tissue in Crohn's disease contains metabolic factors which may actively participate in the inflammatory process [17].

Table 1

<table>
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<tr>
<th>Technique: recommended CT parameters for single-phase CT enterography.</th>
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<tr>
<td>kv 120 kV</td>
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<tr>
<td>mAs Selected to yield CTDIvol of &lt;12 mGy</td>
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<tr>
<td>Minimal detector configuration &lt;1 mm</td>
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<tr>
<td>Axial slice thickness &lt;2.5–3 mm</td>
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<tr>
<td>Axial reconstruction interval &lt;2 mm</td>
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<tr>
<td>Coronal slice thickness* 2–3 mm</td>
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<tr>
<td>Coronal reconstruction interval 1–1.25 mm</td>
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<tr>
<td>IV contrast 150 cm3 Omnipaque 300 at 4–5 cm3/s</td>
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<tr>
<td>Enteric contrast 1350 cm3 Volumen® followed by 500 cm3 water</td>
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<td>Scan delay 50 s after beginning of IV injection</td>
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* Coronal images should be generated either directly or on the scanner console using minimum detector configuration, or from axial data employing slice thickness of 1–1.5 mm and reconstruction interval of 0.5–0.8 mm.
Fig. 3. Reconstructed coronal image in a patient with active Crohn’s disease demonstrating asymmetrical segmental mucosal enhancement (arrows), virtually pathognomonic of inflammation due to Crohn’s disease.

Fig. 4. Axial image from CT enterography showing mural stratification in a patient with a long-standing Crohn’s disease. Trilaminar appearance of the thickened ileal bowel wall with mucosal hyperenhancement (arrowhead) surrounded by fatty infiltration of the bowel wall (arrows) contained within the serosal boundary.

Fig. 5. Comb sign. Reconstructed coronal image from a CT enterography in a patient with active Crohn’s disease demonstrating dilation of the vasa recta (arrows) resembling the teeth of a comb.

Fig. 6. Axial image from CT enterography in a patient with active Crohn’s disease. An enterocutaneous fistula is visualized as an extra-enteric enhancing tract (large arrows) adjacent to the ileostomy (small arrow).

resemble the teeth of a comb (Fig. 5). The presence of a comb sign on CT enterography indicates active disease and correlates with C-reactive protein and length of hospital stay during Crohn’s flares [18].

Penetrating disease refers to the presence of fistulas, sinus tracts, phlegmons, and abscesses and occurs in up to 20% of Crohn’s patients [19]. Penetrating disease is frequently unsuspected, especially entero-enteric and entero-colic fistulas. The majority of fistulas appear as extra-enteric enhancing tracts on CT (Fig. 6), which may not contain air or fluid. In a group of 56 patients with penetrating disease reported by Booya et al. [20], penetrating disease was unsuspected in 50% of patients. In this cohort, 34 patients (61%) required a change in medical therapy and another 10 patients (18%) underwent an interventional procedure based upon the CT enterography findings.

Many early studies compared the performance of CT enterography with surgical and fluoroscopic findings. In more recent studies comparing CT enterography with an endoscopic reference standard, CT enterography demonstrated a sensitivity for active Crohn’s disease in the range of 80–90% [20–22] with some reports showing sensitivity around 60% [23,24]. Solem et al., in a head-to-head comparison of CT enterography, capsule endoscopy, ileocolonoscopy,
and small bowel follow-through in 42 patients with suspected or known Crohn's disease, showed that the sensitivity of capsule endoscopy and CT enterography was almost identical (83% and 82%, respectively). However, the specificity of CT was significantly higher (89% vs. 53%). Even though patients with clinical signs of obstruction were excluded, 17% had asymptomatic strictures at CT enterography, which precluded capsule endoscopy. By contrast, Voderholzer et al. demonstrated a significantly lower sensitivity for CT enteroclysis compared to capsule endoscopy in a group of 41 patients. However, in their study capsule endoscopy was not performed in 27% of patients because of small bowel strictures found at enteroclysis and the capsule failed to reach the colon in 25% of patients [21]. We have recently found that cross-sectional enterography is complementary to direct mucosal assessment in the identification of Crohn's-related inflammation. In a recent series of 30 patients undergoing CT and MR enterography and ileoscopy, 24% were found to have a normal-appearing ileal mucosa at ileoscopy but had evidence of intramural inflammation at enterography and by a clinical reference standard [22].

There is emerging evidence that CT enterography has a large impact on clinical management decisions in patients with known and suspected Crohn's disease. In a retrospective study, Higgins et al. had gastroenterologists review the pre-CT enteroclysis clinical assessment of patients with Crohn's disease and give their impression of the presence of strictures and the potential benefit of steroids [23]. The gastroenterologists were then shown CTE results and asked for their post-CTE clinical assessment. CTE changed gastroenterologists' impression of steroid benefit in 61% of patients and excluded stricture disease in about half the patients with clinically suspected partial small bowel obstruction. Bruining et al. has recently validated the benefit of CTE in a large prospective clinically suspected partial small bowel obstruction. In a recent series of 30 patients undergoing CT and MR enteroclysis and ileoscopy, 24% were found to have a normal-appearing ileal mucosa at ileoscopy but had evidence of intramural inflammation at enterography and by a clinical reference standard [22].

At our institution the initial diagnostic workup of patients with suspected Crohn's disease includes ileocolonoscopy with random biopsy and CT enterography. Additional examinations may be performed to assess the response to therapy or to evaluate for clinically suspected complications such as bowel obstruction or penetrating disease. Patients undergoing additional CT enterography exams are exposed to additional radiation, and the small risk of radiation-induced disease must be weighed against the benefits of accurate diagnosis. To minimize radiation exposure we adjust our tube speed and tube current to yield a CTDIvol of 12 mSv for routine examinations. Additionally, in patients less than 40 years old, we prefer to use MR enterography for follow-up imaging unless the clinical symptomatology warrants CT enterography. Because of its superior spatial resolution, we prefer to use CT rather than MR for the detection and mapping of fistulas, regardless of patient age.

7. Conclusion

The benefit of CT enterography is recognized at many institutions where it has become a primary diagnostic tool in Crohn's disease. The application of the principles outlined herein will hopefully encourage more widespread use of this robust technique in the clinical evaluation of small bowel disease.

References