Abdominal Imaging


Published online: 31 January 2015

Abdom Imaging (2015) 40:938–952
DOI: 10.1007/s00261-015-0357-4

# CT enterography for Crohn's disease: optimal technique and imaging issues

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## Abstract

CT enterography (CTE) is a common examination for patients with Crohn's disease. In order to achieve high quality, diagnostic images, proper technique is required. The purpose of this treatise is to review the processes and techniques that can optimize CTE for patients with suspected or known Crohn's disease. We will review the following: (1) how to start a CT enterography program; (2) workflow issues, including patient and ordering physician education and preparation; (3) oral contrast media options and administration regimens; (4) intravenous contrast media injection for uniphasic and multiphasic studies; (5) CTE radiation dose reduction strategies and the use of iterative reconstruction in lower dose examinations; (6) image reconstruction and interpretation; (7) imaging Crohn's patients in the acute or emergency department setting; (8) limitations of CTE as well as alternatives such as MRE or barium fluoroscopic examinations; and (9) dictation templates and a common nomenclature for reporting findings of CTE in Crohn's disease. Many of the issues discussed are summarized in the Abdominal Radiology Society Consensus MDCT Enterography Acquisition Protocol for Crohn's Disease

**Key words:** CT Enterography—Technique and issues

In 1987, both Raptopoulous et al and Thoeni and Filson described the use of neutral enteric oral contrast media in abdominal CT (whole milk and polyethylene glycol, respectively) in abdominal and pelvic CT [1, 2]. Later, Raptopoulos and co-workers introduced the term CT enterography when describing a technique utilizing large volumes (1–1.5 L) of a 2% barium-based or 2%–2.5% water soluble iodine-based oral contrast media [3, 4]. A subsequent investigation describe the use of an isotonic oral agent [5]. With the evolution of multidetector CT (MDCT) and volume scanning and reconstruction as well as commercially available neutral oral contrast agents, CT enterography (CTE) was subsequently refined and developed worldwide. In the last decade, CTE has become one of, if not the most common imaging examination in patients with suspected or known Crohn's disease, especially in the United States.

In order to achieve a high level of efficacy, optimal technique is critical, especially in evaluating patients with obscure gastrointestinal bleeding [6–22]. Further, because CT is now the greatest, single source of non-background ionizing radiation in the United States [23] (exposure from medical sources of ionizing radiation in 2006 accounted for 48% of the total exposure as opposed to 50% from background; CT contributes 49% of the medical exposure), dose reduction techniques should be utilized, especially in Crohn's patients, given the chronicity of their disease and the likelihood that they will have repeated examinations in their lifetime.

The purpose of this treatise is to review the processes and techniques that can optimize CTE for patients with suspected or known Crohn's disease. We will review the following: (1) how to start a CT enterography program; (2) workflow issues, including patient and ordering physician education and preparation; (3) oral contrast media options and administration regimens; (4) intravenous contrast media injection for uniphasic and multiphasic studies; (5) CTE radiation dose reduction strategies and the use of iterative reconstruction in lower dose examinations; (6) image reconstruction and inter-

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pretation; (7) imaging Crohn's patients in the acute or emergency department setting; (8) limitations of CTE as well as alternatives such as MRE or barium fluoroscopic examinations; and (9) dictation templates and a common nomenclature for reporting findings of CTE in Crohn's disease. Many of the issues discussed are summarized in the Abdominal Radiology Society Consensus MDCT Enterography Acquisition Protocol for Crohn's Disease (Table 1).

## How to start a CT enterography program

For an effective CTE program to function, several important key elements must be in place. First, on the imaging side, there must be a champion radiologist, technologist, and nurse that will drive the process and focus on patients, process, and interpretation of the examination. The radiologist must be well versed in small bowel disease, especially in the findings and treatment of Crohn's disease, and have a good reputation with referring gastroenterologists, colorectal, and general surgeons. This individual should have spent time reading the CTE and Crohn's disease literature as well as attend meetings and seminars, learning the techniques of interpreting CTE (for several years, the Society of Abdominal Radiology has provided a one-day course focusing on CTE interpretation). A 16-row MDCT scanner is the minimum requirement for producing 2–3 mm reconstructed slices in multiple planes. It is best to start the program in one scanner location, focusing on the people and process of CTE. Either a nurse or technologist must be assigned the task of instructing and then supervising the patient, while ingesting the oral contrast agent. This individual must understand the importance of continuous oral contrast ingestion and can often serve as a cheerleader, positively encouraging the patient to appropriately ingest the oral agent. A physical area should be reserved for patients to drink the contrast; an area easily monitored by the responsible technologist or nurse.

Once the imaging elements are in place, marketing a small, focused individual or individuals in the gastroenterology or surgical side of medicine is the next step. Many of these physicians will have already heard about CTE at national meetings such as the Digestive Disease Week and the Advances in Inflammatory Bowel Diseases held by the Crohn's and Colitis Foundation. In fact, many gastroenterologists and surgeons cannot get CTE performed in their community and want this examination for their patients. Starting with a small, interested group will enhance the success of the examination as these individuals are already fully invested in making the process happen. Further, success on a small scale will breed success on a large scale. When discussing the examination with this small group, it is important to stress the patient requirements for a successful examination (see below vis-à-vis oral contrast media ingestion).

Once the "kinks" have been worked out of the system, and well performed, interpretable exams are being produced, the market can be widened by advertising the examination to a larger number of ordering physicians. The imaging group will likely find that by focusing first on a small number of interested users and providing them an excellent service and product that when satisfied these users will then become their own marketers of the service. Lastly, once a core group of images has mastered the process, they should consider expanding the examination location to several sites. However, this core group should train the off-site personnel. Further, careful, and ongoing assessment of the quality and interpretation of these examinations should be performed. As the examination becomes geographically disseminated, it is easy to allow the quality of the exam and its interpretation to deteriorate.

## Patient/ordering physician education and preparation

Over the last 15–20 years, given marked improvements in CT image quality and speed, distinguishing bowel from other structures without oral contrast opacification in adults is much easier than in the early days of CT. As a result, many radiologists have become complacent about bowel opacification and distension with oral contrast media. With CTE, however, this is not the case where opacifying and distending the small bowel is critical. It is therefore important to first educate the ordering clinician that a CTE is distinctly different than a routine abdomen and pelvis CT using positive oral contrast, requiring that the patient ingest at least 900–1500 cc of oral agent in approximately one hour. It is also imperative that the ordering clinician, CT nurse and/or technologist stress to the patient that such an effort is essential for a well-performed study. If the patient arrives without this knowledge, encouraging them to ingest the oral agent is much more difficult. If patients have difficulty ingesting the required volume of oral contrast, they should be given the option of having a small feeding tube placed in their stomach to administer the oral contrast. Surprisingly, many patients prefer this method of oral agent administration.

In practices where enteroclysis expertise is available, some patients have preferred this method with conscious sedation over CTE that requires ingesting a large volume of oral agent either per mouth or via feeding tube [24].

## Workflow set-up and patient supervision

Ideally, a separate waiting area should be designated for patients who are about to have a CTE. This area should

**Table 1.** 2014 Society of Abdominal Radiology consensus statement on CT enterography acquisition protocol for children and adults with Crohn's disease

| |
|---|
| MDCT scanner with a minimum of 16-detector rows |
| Oral contrast: >900 cc neutral enteric contrast administered in regularly divided doses 45–60 min prior to scanning |
| For children, 20 cc/kg of oral agent |
| Intravenous contrast: 300 mg/mL iodine; injection rate 3–4 cc/s |
| For children, 2 cc/kg for children up to 120 cc |
| Timing of image acquisition: enteric to portal phase imaging (50–70 s after beginning of injection) |
| Radiation dose Level: CTDIvol <15 mGy for most patients (<220 pounds) |
| Protocol adapted for individual patient size |
| Encouraged to adapt to patient size using kV selection, automated exposure control, mAs selection, and noise reduction methods (image-based or raw data-based iterative reconstruction) |
| Planes of reconstruction: axial, coronal, & sagittal (optional based upon purpose of examination and subsequent findings) |
| Slice thickness: axial (2–3 mm); coronal (2–3 mm) and sagittal (2–3 mm) |
| Alternatives if iodinated intravenous contrast cannot or should not be used |
| Contrast-enhanced MRE |
| Non-contrast-enhanced MRE if severe CKD |
| Addition of diffusion weighted imaging (see SAR Consensus MR Enterography Acquisition Protocol) |
| If CT is used, large volumes of positive enteric contrast should be administered (this method is considered inferior to a non-contrast-enhanced MRE) |
| Dedicated small bowel examination utilizing barium and regular, dedicated fluoroscopic techniques by an experienced imager (rotation and palpation) |

be easily visible to a supervising technologist or nurse. The supervising health care provider should take ownership in the process and is responsible for determining if the patients are complying with the schedule of drinking the oral contrast agent. If the patient is not or cannot comply with the schedule, and does not respond to gentle encouragement, the supervising technologist or nurse should inform the radiologist. At that time, a determination should be made as to whether a small nasogastric or feeding tube be placed in the stomach, by which the agent can be administered. There are some patients who either cannot or will not ingest the minimum amount of oral agent and refuse any sort of oral or nasogastric tube. Some of these patients are too sick to ingest the large volume of agent. In these cases, we will then perform the examination after the patient has ingested 500–800 cc of oral agent. Surprisingly, we often find that there is already a sufficient amount of intrinsic succus entericus for a diagnostic examination.

Before starting the oral contrast ingestion, we have found that the IV cannula should be placed first. If difficulties arise from placing an IV, and the patient has already started to ingest the oral agent, there will be a delay in initiating the scan. Delay in placing the IV can result in diarrhea (most oral agents other than water are cathartics) and poor opacification of the small bowel.

Various regimens/schedules exist for the administration of oral contrast (Table 1). In general, most centers require the patient ingest at least 900 cc of oral contrast agent. Most require the patient to continuously sip the oral agent. It is better for the patient to sip rather than gulp down the agent in large aliquots. Most regimens require that the patient must ingest approximately 450 cc of liquid every 15 min, over 45 min. This results in the patient ingesting 1350 cc of liquid. In a study from Essen, investigators found that a volume of 1350 cc was preferable for optimal small bowel distension; ingestion of 1800 cc led to a significantly higher rate of cramping and diarrhea; 900 cc yielded sufficient duodenal distension, if imaged soon after ingestion, but led to less jejunal and ileal distension [25]. In this investigation, the subjects were timed with a stopwatch and ingested the oral agents at a rate of 40 mL/min, an extremely regimented protocol and likely not clinically achievable! After one hour, some sites scan their patients; while at other sites, an additional 250–500 cc of water is administered. In these later sites, the patient is scanned at 70 min after the start of oral contrast ingestion.

Special considerations should be given to patients with end ileostomies, ileal-anal pouches, and patients with ileal-sigmoid or ileal-rectal anastomoses. First, these patients do not have or have a short segment of colon. Thus, the neutral contrast will reach the conduit end much faster than in patients with a normal length colon. For ileostomy patients, we scan the patients when contrast reaches the ileostomy bag. Often these patients will ingest less than the 900–1350 cc of oral agent. For patients with either ileal pouches or a short segment of remaining colon, we scan the patients when they have their first watery bowel movement.

## Oral contrast agent choice

Investigations in the late 1980's and 90's were the first to explore the use of low attenuation (<25–30 H.U.), non-barium, or iodine-containing oral agents in abdominal CT [7, 25–35]. Strongly influenced by Alec Megibow, the development of CTE was further motivated by the formulation of VoLumen© by E–Z–EM (now owned by Bracco) [7]. Over the last 10 years, a variety of oral agents have been used for CTE. These include water, methylcellulose mixtures with water, VoLumen© (Bracco), polyethylene glycol, lactulose, and milk. Water is a very acceptable agent for the very proximal bowel

(stomach, duodenum and proximal jejunum). However, because water is normally absorbed in the more distal small bowel, it is ineffective in luminal opacification and distention [32]. Thus, higher osmolality agents or agents that retain fluid, such as those containing methylcellulose, polyethylene glycol, or sugars such as sorbitol and lactulose, and even milk, are more effective in maintaining small bowel opacification and distension.

In a comparison of 2 L of water, methylcellulose, polyethylene glycol, or 1.35 L of low concentration barium (LCB, i.e., VoLumen©) followed by 0.5 L of water, PEG, and LCB distended the small bowel loops more than water or methylcellulose [33]. Optimal terminal ileal distention time after start of ingestion was 51–72 min. Water and methylcellulose had fewer side effects; water was the most preferred agent and PEG the least. Gas and/or diarrhea are the most common side effects.

In the previously mentioned study from Essen, water, locust bean gum with 5% mannitol, and VoLumen with 1.4% sorbitol and 2% sorbitol were ingested [25]. Regardless of the agent, volumes of up to 1350 mL were associated with no or only mild side effects or objections. However, 1800 mL of contrast agent led to a significantly higher rate of diarrhea and cramps, higher for the sorbitol containing agents. All agents but water yielded equivalent levels of small bowel distension.

## Consistent bowel opacification

Regardless of techniques utilized, most if not all radiologists encounter examinations with inconsistent bowel lumen opacification and distention (Figs. 1, 2). The jejunum is the most difficult segment of bowel to opacify. In the standard small bowel series, overhead films are routinely obtained to determine the level of stomach opacification and the location of the barium column in the small bowel. If the stomach is collapsed, it is easy to have the patient ingest more barium, as keeping the stomach full, promotes continued small bowel peristalsis. Unfortunately, we do not have the ability to periodically assess the level of gastric distention with oral contrast agents nor determine the location of the contrast in the small bowel. This is why the consistent and almost continuous sipping of contrast is helpful in maintaining uniform small bowel opacification and distention.

Prone imaging, employed by many centers in MRE, may promote jejunal opacification and distention. Some centers utilize anti-spasmolytics, such as glucagon and Levsin, in order to promote small bowel opacification.

Lastly, it is important to recognize that at least with Crohn's disease, most active disease will be detected even when the bowel opacification and distention is inconsistent. Because of depressed peristalsis, virtually all segments of affected bowel will have some fluid present upstream to the disease site. Further, virtually all segments of disease, small bowel will have important other findings of wall thickening (>3 mm) and hyperenhancement (either mural stratification or homogeneous hyperenhancement) [5, 8]. Extra-mural findings such as distended vasa recta, fibrofatty proliferation, sinus tract or fistulae, and abscess may also be present. In other words, luminal narrowing is not the only sign of abnormal bowel. These additional signs are all important methods of distinguishing a segment of small bowel with Crohn's disease from a segment that is collapsed or contracting.

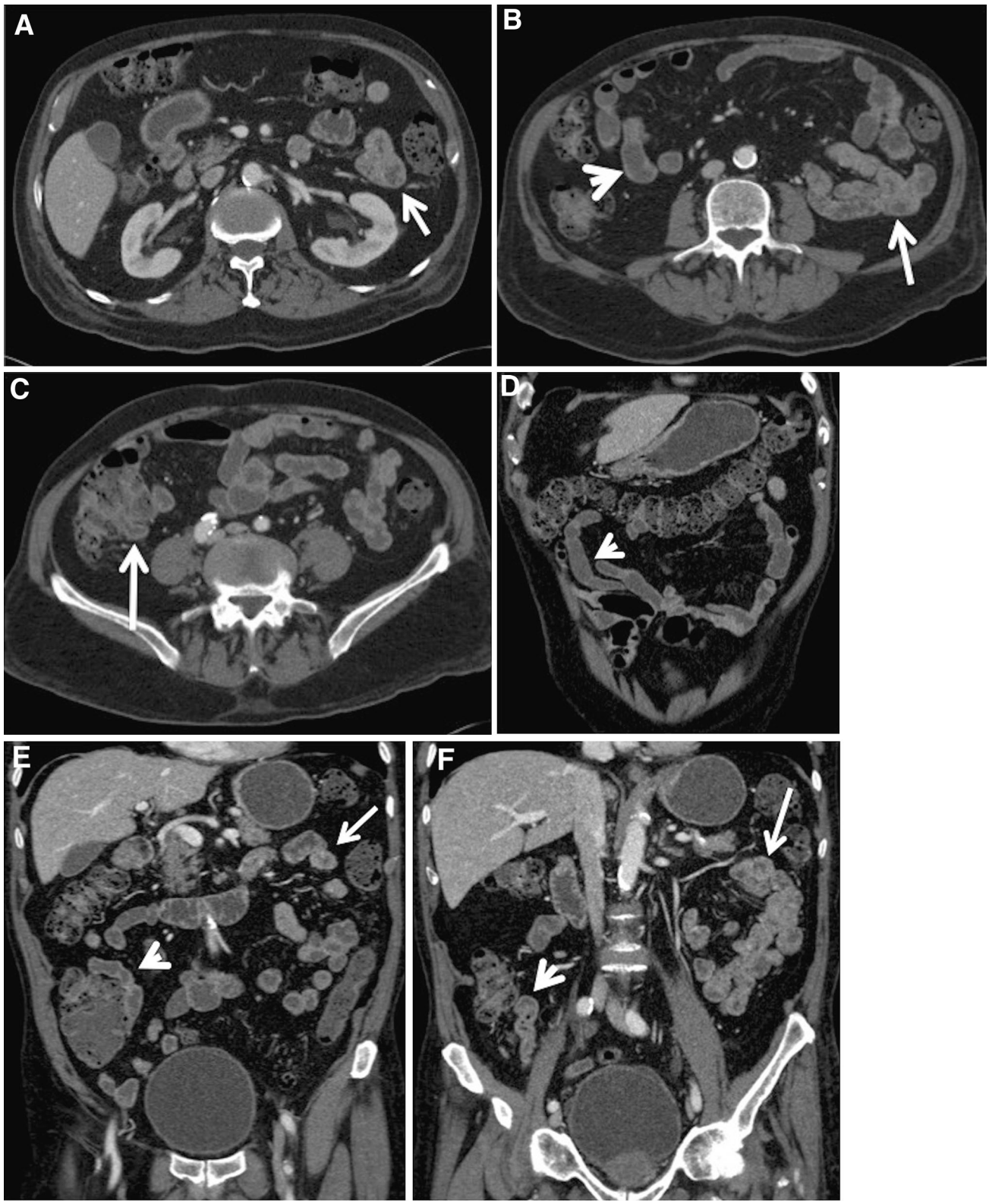
**Fig. 1.** Normal CTE with suboptimal small bowel distension. ▶ **A** shows collapsed jejunum (*long arrow*) on the axial image in the upper abdomen. **B** shows relatively collapsed jejunum (*long arrow*) and ileum (*short arrow*) on the axial image in the mid abdomen. **C** shows a small amount of contrast in the terminal ileum (*long arrow*) on the axial image in the pelvis. **D** shows contrast-filled ileum (note no folds) (*short arrow*) on the coronal view in the anterior abdomen. **E** shows collapsed jejunum (*long arrow*) in the left upper quadrant and contrast in a relatively non-distended loop of ileum (*short arrow*) in the right mid abdomen on the coronal view in the mid abdomen. **F** shows relatively collapsed jejunum (*long arrow*) and small amount of contrast in the terminal ileum (*short arrow*) on the coronal view in the posterior abdomen.

## Intravenous contrast enhancement

Iodinated contrast media enhancement is essential in detecting active inflammatory small bowel Crohn's disease as well as penetrating disease. In Crohn's disease, if the patient cannot receive iodinated contrast media because of a severe contrast allergy or CKD, one should consider an MRE. In cases of severe CKD, when gadolinium cannot or should not be administered due to the possibility of systemic nephrogenic fibrosis, the alternatives include a fluoroscopic small bowel barium study or an unenhanced MRE, relying on the heavily weighted T2-weighted and diffusion weighted pulse sequences. In practices where expertise is available, in instances where gadolinium cannot be administered, an alternative is CT enteroclysis with positive enteral contrast.

In routine, uniphasic scanning, most institutions use contrast media that contain 300 mg/mL of organic iodine. In most cases, at least 120–150 cc of contrast media is injected, with dose adjustment based on patient's weight when patients weigh <100–125 pounds.

For multiphasic scanning, many institutions use contrast media that contains more organic iodine, from 350–370 mg/mL. For more concentrated iodine-containing contrast media, the volume of contrast media is adjusted downward so that the patient does not receive more than a total of 60–70 g of organic iodine. The rate




of contrast media injection depends upon the size of the catheter used, the viscosity of the contrast media, and the location of the vein used. In general, for uniphasic scanning, most institutions inject the contrast media at a rate of 3 cc/s, with some institutions attempting to inject at a rate of 4 cc/s. For multiphasic scanning, the arterial phase is best achieved by injecting the contrast media at a rate of 4–6 cc/s.

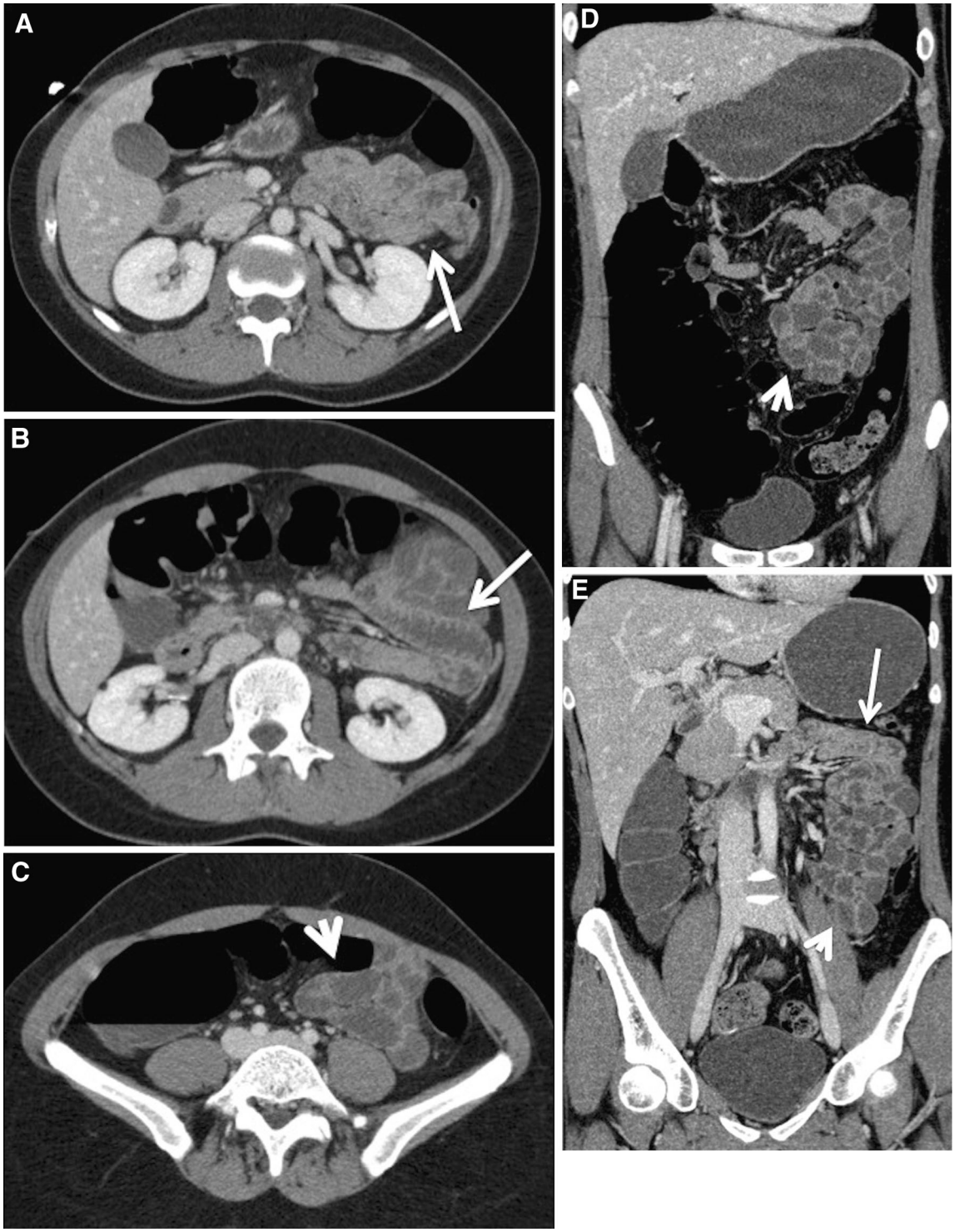



**Fig. 2.** Normal CTE with optimally distended mid to distal jejunum, with proximal jejunum still not distended. This is a very common result as it is very difficult, if not impossible to scan when the proximal jejunum is distended with the neutral oral contrast agent. **A** shows collapsed loops of jejunum (*long arrow*) on the axial image in the upper abdomen. **B** shows more contrast-filled jejunal loops (note folds) (*long arrow*) on the axial image in the upper abdomen. **C** shows contrast-filled ileal loops (*short arrow*) on the axial image in the lower abdomen. **D** shows fluid-filled distal jejunum or proximal ileum (fewer folds present) (*short arrow*) on the coronal view in the mid abdomen. **E** shows collapsed jejunal folds (*long arrow*) and more contrast-filled ileum (*short arrow*) on the coronal view in the mid to posterior abdomen.

## Scanner timing vis-à-vis contrast median injection (uniphasic and multiphasic)

### *Uniphasic examinations: primary use for known or suspected Crohn's disease*

For Crohn's disease, CTE employs MDCT with narrow section thickness and reconstruction interval, intravenous contrast material, and large volumes of neutral contrast agent to distend the lumen in an effort to improve the detection of small bowel inflammation and extracolonic complications. CTE can be performed during the enteric phase (45–50 s after injection) [36] and the portal venous phase (70 s after injection). Maximum peak small bowel wall enhancement occurs during the enteric phase (50 s post-contrast media injection) [36]. As a result, many centers scan at 50 s. However, this investigation did not take into account the location of small bowel. Subsequent work has shown that jejunal attenuation is greater than ileal attenuation, and collapsed bowel loops demonstrate greater attenuation than distended bowel loops [13]. Another investigation showed that there is no significant difference in detecting Crohn's disease when the enteric phase is compared to the portal venous phase [37]. Lastly, there is also some MR data that suggest more delayed imaging, up to 5–7 min, may detect more disease [38]. At the Cleveland Clinic, using the 128 MDCT scanners, because the scanners are very fast and scanning often occurs during the later arterial phase, our portal venous phases have been adjusted to start at 90 s rather than 70 s.

### *Multiphasic examinations for suspected mesenteric ischemia or obscure gastrointestinal bleeding*

Multiphasic examinations after the administration of intravenous contrast media are rarely used in patients with known or suspected Crohn's disease. These examinations are reserved for patients with obscure or acute gastrointestinal tract bleeding and Soto et al describe the technique in the article in this issue.

### *Dose reduction strategies and iterative reconstruction*

Every effort should be made to limit the radiation exposure from CT in all patients, especially, in patients with Crohn's disease. Several studies have shown that some Crohn's patients can receive large cumulative doses (over 100 mSv) over the course of their disease, and often are examined with CT two to three times a year [39–45]. In one series, encompassing a 15-year period of time, the mean ionizing radiation dose was 36.1 mSv [41]. Over the entire study period, there was an increasing use of CT, and while CT accounted for only 16.2% of all imaging studies, it accounted for 77.2% of the radiation dose. Further in that study, the total ionizing radiation exceeded 75 mSv in 15.5% of the patients. Patients who received higher doses had disease onset before 17 years of age, upper gastrointestinal tract or penetrating disease, required intravenous steroids or infliximab or had multiple surgeries. There is recent evidence that radiation exposure from CT scans in children results in an increased risk of brain tumors and leukemia [46, 47]. Most pediatric centers almost exclusively use MR or ultrasound as a means of evaluating younger patients.

Efforts to reduce the dose from CT are ongoing and include alterations in kVp and mAs vis-à-vis body habitus, lateral body width, weight, and BMI, altering the scan pitch as well as applying new reconstruction techniques to lower dose examinations, generally termed iterative reconstruction. Dose reductions from CTDIvol of 15–20 to $<10$ mGy and even below 5 mGy have been achieved [48–56]. However, the most substantial reductions in dose have been in smaller patients who weigh less than 160–180 pounds (Fig. 3).

A growing concern among radiologists is what data are lost with lower dose examinations. All the known iterative reconstruction techniques lower the noise level on these lower dose exams; often below "full" dose noise level examinations reconstructed with standard filtered back projection techniques. However, there is growing evidence that these iterative reconstruction techniques cannot overcome low-contrast object detection loss due to noise [57–65]. Small, low-contrast objects (a lower attenuation mass in an enhanced liver for instance) are much more difficult to detect by the human eye when compared to higher contrast objects [59]. Further, to date, low-contrast object detection (an object of lower attenuation vis-à-vis background) is lost with lower dose MDCT, even with any of the known iterative reconstruction techniques, including model-based iterative reconstruction, which processes only raw data rather than the faster, hybrid forms of IR. To summarize, unlike weighted filtered back projection, spatial resolution is contrast-dependent for IR (i.e., no loss of spatial resolution for high-contrast objects). However, using IR, there is often loss of low-contrast resolution.

Crohn's disease identification is a high-contrast issue with CT (i.e., identifying a process with a higher attenuation vis-à-vis background). Studies using lower dose techniques have shown that reducing exposure does not result in a reduction in diagnostic efficacy of small bowel Crohn's disease. However, we do not know how much we can reduce the dose without losing this efficacy. If lower dose CTE is utilized in a patient with Crohn's disease, radiologists may have to accept a lower sensitivity in detecting low attenuation lesions in the liver, the low-contrast objects that are most readily present in a

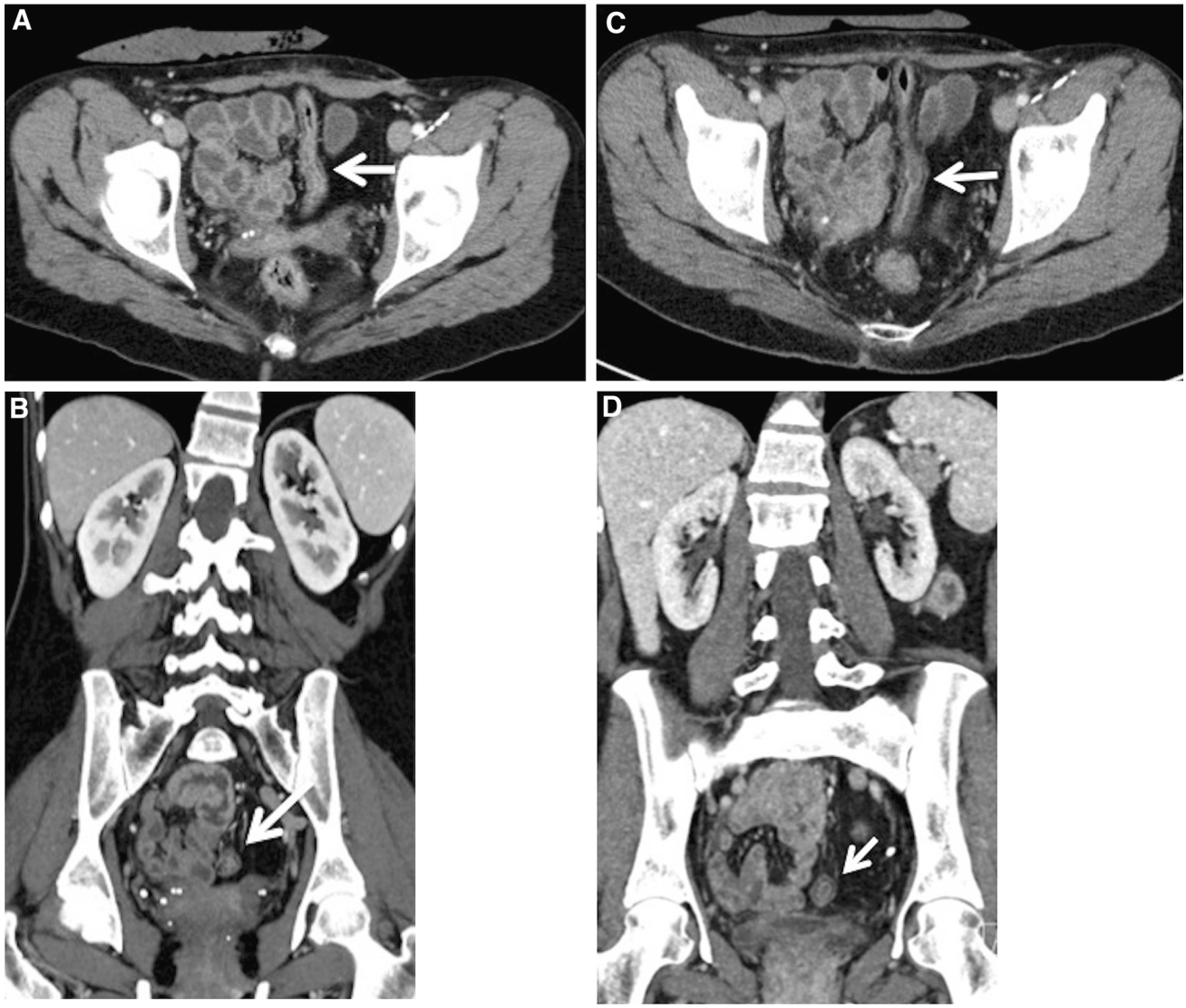



**Fig. 3.** Patient with Crohn's colitis s/p colectomy with rectal remnant scanned in 2006 before any changes in CT enterography protocol and in 2014 with new protocol. **A**, **B** are axial and coronal images, respectively, from the 2006 exam showing the diseased rectosigmoid remnant (*arrow*). In 2006, the patient weighed 114 pounds. The technique used was 120 kVp with a quality reference mAs of 200. The resulting CTDIvol was 9.59 mGy. **C**, **D** are axial and coronal images, respectively, from the 2014 exam showing the diseased rectosigmoid (*arrow*). In 2014, the patient weighed 113 pounds. In 2014, CARE kV was used with a quality reference mAs of 113 (the tube voltage selected was 100 kVp). The resulting CTDIvol was 5.12 mGy. On all sets of images, the stratified enhancement pattern of active colonic Crohn's disease is easily identifiable (*arrows*).

patient population. Fortunately, identifying smaller, low-contrast hepatic lesions are much less important in patients with Crohn's disease than in patients with a primary malignancy.

At the Cleveland Clinic, we routinely employ an attenuation-based automated tube voltage selection tool for all of our CTE examinations (CARE kV, Siemens Healthcare). In patients less than 200–200 pounds, the tool almost always utilizes 100 kVp, and, thus, lowers the dose (it is vitally important to ensure that the patient is centered in the CT gantry in order for this tool to be effective). If the patient is not centered, inappropriate assumptions will be made by the software, often resulting in the use of either 120 or 140 kVp, markedly increasing the patient's dose). We also use a weight-based approach to setting the quality reference tube current–exposure time product (mAs) (qmAs = 1 mAs* patient weight (lbs) (up to 220 pounds) [66, 67]. In the near future, we will likely reduce the qmAs to ½ mAs*patient weight (lbs) and apply iterative reconstruction. In a recently presented, multi-reader, objective, and subjective investigation at Cleveland Clinic using CARE kV and a

weight-based mAs, half-dose imaging was statistically non-inferior to full dose imaging in detecting active inflammatory terminal ileal Crohn's disease, using both filtered back projection and iterative reconstruction (sonogram-affirmed iterative reconstruction) (CTDIvol ½ dose mean = 6.55 mGy, median = 3.68 mGy, range-181–22.25 mGy; population mean weight = 165 pounds (range = 94–315 pounds) (median weight = 143 pounds; population mean BMI = 25.68 (range = 16.6–54) (median = 22.33) (mean ROC curve areas = 0.908–0.935 for all doses & reconstructions) (Figs. 4, 5) [68]. Interestingly, more of the half-dose images, regardless of reconstruction were subjectively deemed suboptimal or non-diagnostic than those at full dose reconstructed with filtered back projection. However, regardless of this subjective assessment by the readers, their accuracy in distinguishing active inflammatory Crohn's disease from normal was not affected. Given these findings, it is very likely we can reduce the dose to a third of our original, already lower dose scans in patients with suspected or known Crohn's disease.

## Reconstruction strategies

Using a modern PACS and workstation, theoretically, a radiologist does not need to reconstruct the scan data in multiple planes. However, the referring clinicians, often gastroenterologists and surgeons, want and need to review the examination themselves. We have found that multi-planar reconstructions in orthogonal planes are essential in the evaluation of Crohn's disease and in patients with obscure gastrointestinal bleeding. In Crohn's disease, a fistula or sinus tract may not be visualized in one plane and obvious in another. The most common

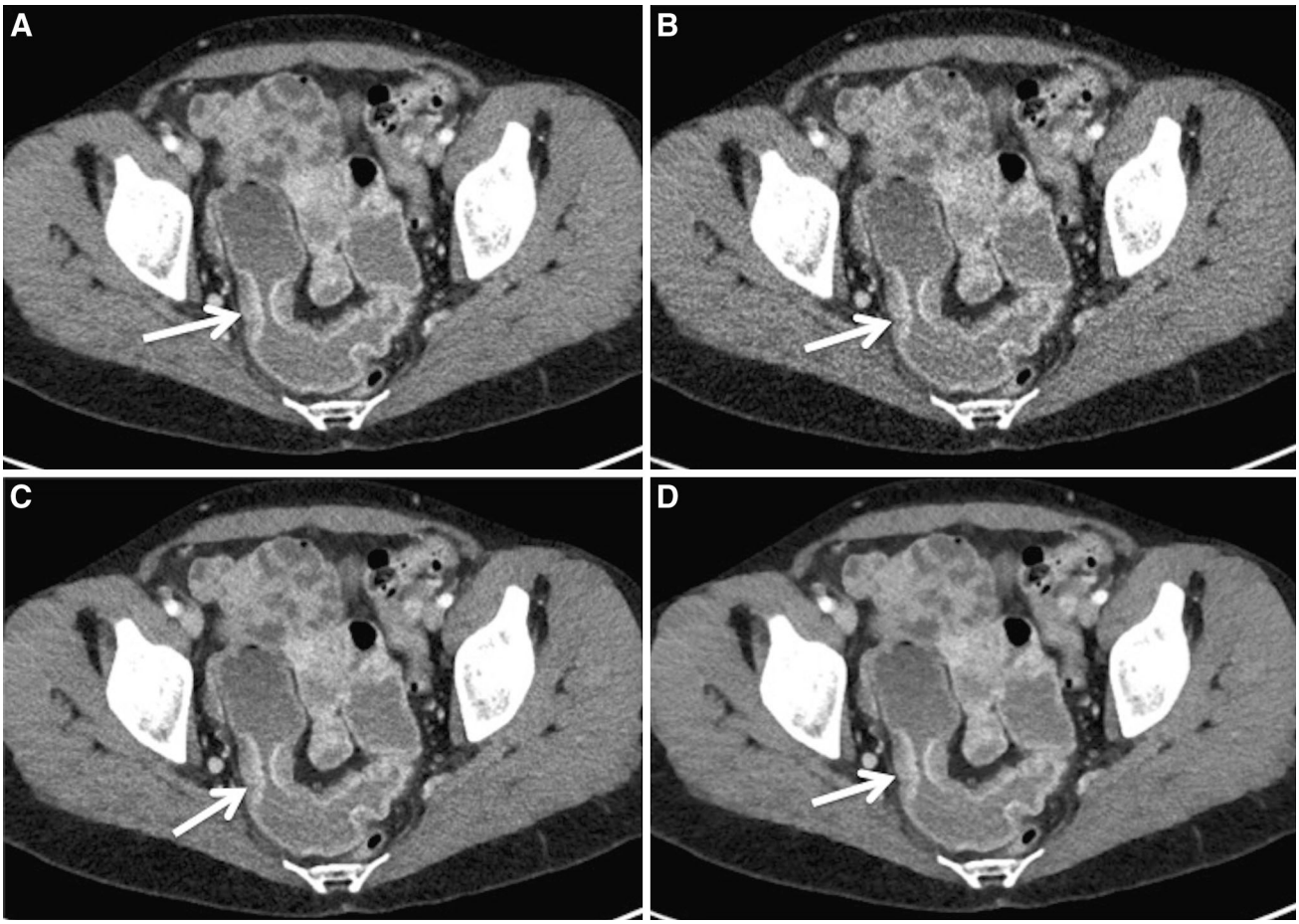



**Fig. 4.** Patient weighing 108 pounds with mixed stenotic and active inflammatory small bowel Crohn's disease of the ileum scanned using CARE kV at full and half-dose, and reconstructed with filtered back projection (FBP) and iterative reconstruction (sonogram-affirmed iterative reconstruction or SAFIRE). Images at full dose (**A**), half-dose reconstructed with FBP (**B**), half-dose reconstructed with SAFIRE, strength 3 (**C**), and half-dose reconstructed with SAFIRE strength 4 (**D**). Tube voltage selected was 100 kVp; quality reference mAs was 108. The CTDIvol at full dose was 4.86 mGy (half-dose = 2.43 mGy) (SSDE = 7.4 mGy full dose; half-dose = 3.7 mGy). The ileal disease (*arrow*) is easily identified on all the scans, including the half-dose images reconstructed with filtered back projection. The disease is mixed stenotic and active inflammatory for the following reasons: stratified enhancement pattern, luminal narrowing, and upstream dilation. The half-dose images were obtained by extracting the scan data from one tube, operating at 50% output, from a dual-source CT scanner.

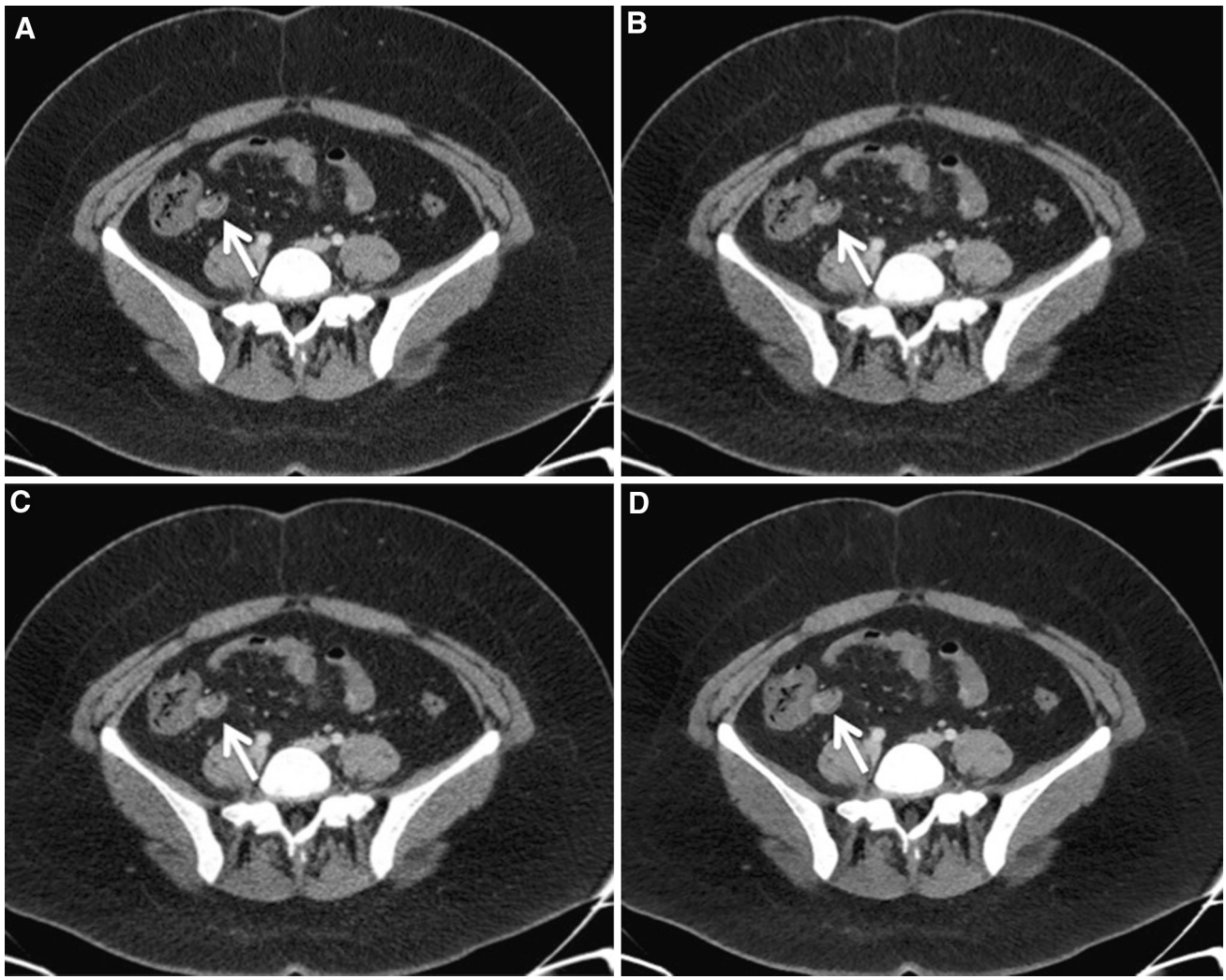



**Fig. 5.** Patient weighing 255 pounds with subtle, active inflammatory neo-terminal ileal disease without luminal narrowing using CARE kV at full and half-dose, and reconstructed with filtered back projection (FBP) and iterative reconstruction (sonogram-affirmed iterative reconstruction or SAFIRE). Images at full dose (**A**), half-dose reconstructed with FBP (**B**), half-dose reconstructed with sonogram-affirmed SAFIRE, strength 3 (**C**), and half-dose reconstructed with SAFIRE, strength 4 (**D**). Tube voltage selected was 120 kVp; quality reference mAs was 220. The CTDIvol at full dose was 38.27 mGy (half-dose = 19.13 mGy) (SSDE full dose = 34.2 mGy; half-dose = 17.1 mGy). The ileal disease is identifiable on all the scans (*arrow*), but more difficult on the half-dose image reconstructed with FBP (**B**) where there is more noise. In obese patients, more subtle disease could be obscured with doses lower than used here, unless the data is reconstructed with some form of iterative reconstruction. Using the dictation format, the impression on this patient should be active inflammatory small bowel Crohn's disease without luminal narrowing. The half-dose images were obtained by extracting the scan data from one tube, operating at 50% output, from a dual-source CT scanner.

would be an entero-vesicular fistula, often not visualized axially, but easily identified in the coronal or sagittal plane. In general, only the axial and coronal planes are reconstructed, with sagittal reconstruction reserved for cases of suspected mesenteric ischemia or where the plane adds information to the axial and coronal images.

## Interpretation techniques

Using a workstation, radiologists should page through the examination specifically assessing the bowel in a continuous fashion. This is the surrogate for rotation and palpation used in the fluoroscopic examination of the small bowel. In the axial plane, this paging results in a cephalad, caudad, etc., approach. In the coronal plane, this paging results in an anterior, posterior, anterior, etc., approach. Altering the window and level as the interpretation process continues is essential. Some of us assess the bowel using narrow windows, much like liver windows, in order to detect the high attenuation, hyperenhancing patterns of Crohn's disease and hyperenhancing small bowel tumors such as carcinoids. However, it is

also important to view the image dataset using soft tissue and even wider windows, as some tumors are not hyperenhancing and may be subtly similar to the water to near water attenuation oral contrast.

Even though the findings on a static CTE are not identical to the findings of a fluoroscopic study, there are surrogates on CTE than can assist the radiologist in identifying disease. The small bowel is attached to a mesentery that extends diagonally from the left upper quadrant to the right lower quadrant, assuming no rotational variation. In a virgin belly, the bowel undulates and moves with peristalsis in a curving, rotating manner. Thus, the border of the small bowel is curved or rounded, not angulated or "fixed". The bowel loops should not look tethered or drawn toward other loops or structures. There should not be any linear strands between the small bowel loops. Further, given the amount of mesenteric fat, the space between the small bowel loops is generally consistent, without asymmetric deposition of fat around some loops and not others. The radiologist must be attuned to alterations in the small bowel border to determine if the bowel is "fixed," angulated, and "tethered." Additionally, as previously stated, in Crohn's disease, affected segments almost always have other findings accompanying the mural findings, such as mural stratification and/or hyperenhancement.

For patients with ileal pouches, the radiologist should remember that without a colon, the distal small bowel proximal to the pouch always dilates. Thus, in these patients, a small bowel obstruction should not be diagnosed unless there is an unequivocal transition point. If a possible small bowel obstruction is suspected in a patient with an ileal pouch, a contrast enema is often a better method of evaluation.

## Imaging acutely ill Crohn's patients

An acutely ill patient with Crohn's disease may have a small bowel obstruction, an acute exacerbation of the disease, new or unsuspected penetrating disease, and/or an abscess or infectious phlegmon. Studies have shown that CTE substantially changes clinical management and improves physician confidence level in a large number of patients with Crohn's disease [69–74]. The postoperative patient (within 2–3 weeks), most often presents with signs of infection.

We approach the acutely ill and postoperative Crohn's patient almost always with a CT rather than an MRE or fluoroscopic study as the examination can be performed almost immediately and rapidly. However, we separate the acutely ill, non-surgical patients from the patients in the perioperative period. Patients who are not post-surgical receive neutral oral contrast media; patients in the perioperative period receive positive oral and rectal (if there is a colonic anastomosis) contrast media. In the non-surgical patient, we have not found that the use of neutral oral contrast media limits the ability to detect an abscess even though abscesses have similar attenuation as neutral contrast-filled bowel [73]. Careful scrutiny of the images should allow the observer to distinguish the two. However, in post-surgical patients, the possibility of an anastomotic leak is relatively high. The use of neutral contrast media will not detect anastomotic dehiscence. Thus, we use positive oral and/or rectal contrast media in these patients.

Performing a CTE on a hospitalized patient is particularly challenging. Many of these patients have some level of a bowel obstruction. These patients may not be able to ingest any oral contrast media. However, most already have bowel filled if not dilated with neutral succus entericus and do not need to ingest any oral agent. Many of hospitalized patients have nausea, even without a bowel obstruction or are unable to ingest large amounts of contrast media. The use of a naso- or orogastric tube or feeding tube facilitates the process of bowel opacification. In all instances, however, no hospitalized patient should be allowed to ingest the oral agent on the floor. We require that all inpatients come to the department, where radiology personnel can monitor oral contrast media ingestion. Clinical information is critical in deciding how more oral agent should be ingested before scanning.

## Imaging Crohn's patients in the emergency department

Institutions should have a specific Emergency Department approach in dealing with acute ill Crohn's patients. First, MRE is generally not a practical imaging alternative for emergency department patients. Recent investigations have shown that CT imaging in the emergency setting is very efficacious in identifying important complications of Crohn's disease [71, 72, 74]. However, before contemplating a CT, risk stratification should be performed by the ordering physician. This should be based on history and physical findings. In one analysis, a prior history of intestinal obstruction or intraabdominal abscess, current hematochezia, and leukocytosis (WBC count $>12{,}000$ μL) were independent predictors of urgent findings on a subsequent CT (abscess, perforation, obstruction, or new or worsening non-Crohn's disease findings) [74]. If the patient presentation warrants immediate imaging, then a CT should be performed. As previously stated, if the patient is not postoperative, then neutral oral contrast media should be administered. If the patient is postoperative, then positive oral contrast media should be administered. Additionally, as in all MDCTE, low dose techniques should be employed.

## Limitations of CTE- when to image with MRE and/or dedicated small bowel series or enteroclysis

There are clinical scenarios where CTE may not or is not an appropriate examination. First, there is no evidence

**Table 2.** CTE report template (preliminary Society of Abdominal Radiology consensus statement on nomenclature and reporting of CTE/MRE; a similar reporting template is also discussed by Al-Hawary et al. [79]

| |
|---|
| Title: CTE (abdomen and pelvis CT with intravenous contrast) |
| History: |
| Technique: standard, single-phase (multi-phase) CT enterography |
| Contrast: |
| Oral: type and volume consumed |
| IV: type and volume of iodinated contrast media injected |
| Other medications: if applicable (i.e., glucagon, Levsin, etc.) |
| Radiation dose: DLP (mGy/cm), CTDIvol (mGy) or SSDE (mGy) |
| Comparison: |
| Result or findings: |
| Disease location |
| Stomach |
| Small bowel |
| Duodenum, jejunal, and/or ileal |
| Colon |
| Enhancement pattern |
| Stratified or homogeneous |
| Bowel wall thickening |
| Site, location, and length of disease |
| Stricture |
| Small bowel luminal narrowing |
| Without upstream dilation |
| With upstream dilation |
| Penetrating disease |
| Sinus tract |
| Fistula |
| Simple |
| Complex |
| Mesenteric findings (perienteric findings) |
| Stranding |
| Fibrofatty proliferation |
| Vasa recta distension |
| Fluid collection |
| Not amenable to drainage (<3 cm; generally, catheter deployment in a cavity <3 cm difficult or impossible) |
| Amenable to drainage (>3 cm and accessible to intervention) |
| Extra-intestinal findings |
| Cholelithiasis, nephrolithiasis, PSC, sacroiliitis, perianal disease, and AVN of femoral heads |
| Abdomen: other findings not otherwise mentioned |
| Pelvis: other findings not otherwise mentioned |
| Impressions: |
| Active inflammatory small bowel Crohn's disease |
| Without luminal narrowing |
| With luminal narrowing |
| Mixed stenotic and active inflammatory small bowel Crohn's disease (the term fibrostenosis is controversial to some physicians caring for Crohn's disease patients; they believe that some degree of fibrosis can be effectively treated medically) (this term should only be used when both luminal narrowing and upstream bowel dilation >3 cm are present) |
| Penetrating Crohn's disease (added to either active inflammatory or mixed disease) (almost always only present with mixed stenotic and active inflammatory small bowel Crohn's disease) |
| Quiescent or inactive small bowel Crohn's disease |
| Fibrostenotic small bowel Crohn's disease |

that a CTE will adequately evaluate patients who have recurrent small bowel obstructions, presumably due to adhesive disease. In these patients, an enteroclysis likely with CT rather than fluoroscopic remains the best test available [75]. Second, as previously stated, patients with Crohn's disease, who are not postoperative and not thought to have an abscess, and in whom a previous CTE has been performed, are best followed with an MRE rather than a CTE. The liberal use of MRE should reduce the cumulative dose from CT that they may receive. Lastly, there are some patients who cannot receive either intravenous iodinated contrast media or gadolinium due to chronic kidney disease. In these cases, an unenhanced MRE or a dedicated fluoroscopic small bowel series are the best alternatives. While to our knowledge there are no data, an unenhanced MRE, relying on the heavily weighted T2 sequences and diffusion weighted imaging should detect active inflammatory disease and penetrating disease. A reasonable alternative is a barium-based, fluoroscopic examination. However, only a radiologist trained in the fluoroscopic techniques of rotation and palpation should perform this examination. Unfortunately, these skills are not taught in residency programs, due to the lack of patients (one downside of the proliferation of CT and MR enterography). Some highly specialized centers use ultrasound, especially in pediatric and thin adult patients. In isolated centers, an enteroclysis is considered a better examination. However, unless conscious sedation is used, the patient generally will
refuse to tolerate more than one of these examinations. Further, conscious sedation requires nursing support for administration and monitoring, increasing the costs of care.

## Reporting CTE

As health care is evolving, radiologists must recognize that proper reporting and nomenclature will play an increasing role in measuring outcomes. Imaging in Crohn's disease is increasingly used to determine therapy and measure its affect (e.g., Lemann score) [76–78]. Endoscopy is limited in that it is invasive, cannot assess the entire bowel, or the extraluminal structures. CTE and MRE are increasingly used to determine the therapy, both medical and surgical as well as follow therapy. By reporting appropriately and consistently, radiologists will demonstrate "meaningful use," a process now mandated by the federal government.

Many if not most departments now have voice recognition dictation systems. The user can modify these systems to contain report templates. These templates can be modified to prompt the user to include important information both for billing and communication.

From the perspective of the ordering physician, it is important to title the examination as a uniphasic or multiphasic CT enterography. Without this title, the clinician may not know that an enterography was performed. Adjacent to this title, one can for billing purposes state that the examination is an abdomen and pelvis CT with intravenous contrast enhancement. This alerts the referring physician that an enterography was performed.

Next, information related to quality and safety, sometimes mandated by CMS and/or state regulations,

must be reported. In our institutions this includes history or reason for the examination; technique used; contrast media administered and/or ingested (type and volume specified); amount and type of anti-peristaltic agent administered; and, in many cases, documenting the "dose" received by the patient [dose length product (DLP) and/or CTDIvol]. As with any radiology report, comparison examinations should be mentioned. The results or findings then must be documented. Lastly, an impression should synthesize the findings into an understandable and clinically relevant fashion.

The Society of Abdominal Radiology Crohn's Disease Focus Group has made initial attempts to define the necessary elements of a CTE report and the nomenclature that should be utilized including how to synthesize the findings into an appropriate impression (Table 2). This is an ongoing, international process that includes collaboration with gastrointestinal and colorectal societies.

*Acknowledgments.* We would like to thank the many other members of the Crohn's Disease Focus Group of the Society of Abdominal Radiology who contributed thoughts and ideas that are incorporated in this document: Mahmoud Al-Hawary, Suhda Anupindi, David Bruining, Kassa Darge, Jonathan Dillman, David Einstein, Jeff Fidler, Michael Gee, Flavius Gugliemo, Tracy Jaffe, Seong Ho Park, Daniel Podberesky, Jordi Rimola, Dushyant Sahani, Jorge Soto, Stuart Taylor, and last but not least Alec Megibow, whose foresight and leadership helped propel small bowel imaging into the 21st Century.

*Conflict of interest.* Dr. Baker receives support from Siemens Healthcare in the form of salary support, software, and hardware to investigate radiation dose reduction in CT and has informal consultations with Bracco. Dr. Fletcher receives support from Siemens Healthcare in the form of grant support. Dr. Maglinte is a consultant for Cook Inc. Drs. Hara and Platt has no conflicts of interest.

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