Radiology

Consensus Recommendations for Evaluation, Interpretation, and Utilization of Computed Tomography and Magnetic Resonance Enterography in Patients With Small Bowel Crohn's Disease[1]

David H. Bruining
Ellen M. Zimmermann
Edward V. Loftus Jr
William J. Sandborn
Cary G. Sauer
Scott A. Strong
Society of Abdominal Radiology Crohn's Disease-Focused Panel

Computed tomography and magnetic resonance enterography have become routine small bowel imaging tests to evaluate patients with established or suspected Crohn's disease, but the interpretation and use of these imaging modalities can vary widely. A shared understanding of imaging findings, nomenclature, and utilization will improve the utility of these imaging techniques to guide treatment options, as well as assess for treatment response and complications. Representatives from the Society of Abdominal Radiology Crohn's Disease-Focused Panel, the Society of Pediatric Radiology, the American Gastroenterological Association, and other experts, systematically evaluated evidence for imaging findings associated with small bowel Crohn's disease enteric inflammation and established recommendations for the evaluation, interpretation, and use of computed tomography and magnetic resonance enterography in small bowel Crohn's disease. This work makes recommendations for imaging findings that indicate small bowel Crohn's disease, how inflammatory small bowel Crohn's disease and its complications should be described, elucidates potential extra-enteric findings that may be seen at imaging, and recommends that cross-sectional enterography should be performed at diagnosis of Crohn's disease and considered for small bowel Crohn's disease monitoring paradigms. A useful morphologic construct describing how imaging findings evolve with disease progression and response is described, and standard impressions for radiologic reports that convey meaningful information to gastroenterologists and surgeons are presented.

This article is being published jointly in *Radiology* and *Gastroenterology*.

[1]From the Division of Gastroenterology and Hepatology, Mayo Clinic, Rochester, Minn (D.H.B., E.V.L); Department of Gastroenterology, University of Florida, Gainesville, Fla (E.M.Z.); Division of Gastroenterology, University of California San Diego, San Diego, Calif (W.J.S); Division of Pediatric Gastroenterology, Emory University, Children's Healthcare of Atlanta, Ga (C.G.S); and Division of GI Surgery, Northwestern Medicine, Chicago, Ill (S.A.S). **Address correspondence to** Joel G. Fletcher, MD, Department of Radiology, Mayo Clinic 200 First Street SW, Rochester, MN 55905 (e-mail: *fletcher.joel@mayo.edu*).

Computed tomography enterography (CTE) and magnetic resonance enterography (MRE) have emerged as the most effective methods for imaging the small bowel in patients with Crohn's disease (1,2). Cross-sectional enterography techniques complement ileocolonoscopy and can visualize intramural or proximal small bowel inflammation in approximately 50% of Crohn's disease patients who have endoscopically normal examinations (3–5). CTE and MRE are useful tools for Crohn's disease diagnosis, determining distribution of disease involvement, and detecting complications of the disease (1,2). Recent data suggest that cross-sectional imaging may be useful in determining response to therapy, assessing bowel healing, and monitoring disease progression (6). The Society of Abdominal Radiology (SAR) formed a Crohn's Disease-Focused Panel, which has established standards for the technical performance of these examinations (Appendix 1) (7–9). CTE and MRE are now performed across a range of institutions, with the radiologic literature focusing on the technical aspects of diagnosis and identification of mural inflammation or penetrating complications, such as fistula and abscess, using various acquisition methods and imaging findings. Important prior consensus statements, including those of the European Crohn's and Colitis Organization and European Society of Gastrointestinal and Abdominal Radiology and SAR recommendations for the performance of CTE and MRE establish critical and necessary rationale for when and how imaging of inflammatory bowel disease patients should be performed, respectively (2,7,8). To date, however, there are no agreed-upon expectations for structures that should be evaluated at cross-sectional enterography, no standardized nomenclature for describing imaging findings in Crohn's disease, no guidance for how to describe severity and burden of different Crohn's disease imaging findings to best guide medical and surgical management, and no consensus between US gastroenterology and radiology societies on when these tests should be performed. The purpose of this work is to establish a common system for mapping specific imaging findings to clinically useful impressions and for description of Crohn's disease phenotypes that can guide gastroenterologists and surgeons in making important treatment decisions for Crohn's disease patients. The standardization will both advance patient care through improved understanding of the communicated imaging findings and improve comparison of reported research in the field.

Because CTE and MRE findings change patient management in a substantial proportion of symptomatic patients (10,11), systematic review of CTE and MRE images is essential to maximize patient benefit. A motivating example for how a systematic review of imaging findings and standard nomenclature might improve patient care can be found in the standard reporting template for pancreatic cancer: an interdisciplinary group of radiologists, medical oncologists, pancreatologists, and pancreatic surgeons recommended a systematized reporting template for pancreatic carcinoma, designed to capture objective imaging findings to guide and improve therapeutic decisions (12). In Crohn's disease, the use of imaging is evolving over time. Cross-sectional imaging was initially used to detect and stage Crohn's disease (5), but it is increasingly being used to gauge therapeutic response (4,13), providing objective measures to guide treatment decisions that can potentially alter the natural history of the disease (14). Mucosal healing as detected by colonoscopy in Crohn's disease results in improved outcome (15–18); however, more recently, cross-sectional imaging, primarily MRE, has demonstrated a high correlation between mucosal healing at endoscopy and transmural healing at cross-sectional imaging, with improved outcomes when detected (19–21). Thus, there needs to be a shared understanding of the goals of imaging between referring clinicians and radiologists: while numerous investigators have consequently examined the relationship between objective and subjective imaging findings and the severity of endoscopic and histologic inflammation (4,22–25), others have described the extent of intestinal damage using cross-sectional findings (26). Information conveying length of involvement, severity of inflammation or bowel dilation, and surgical resections are required when assessing for therapeutic response.

While the existing Montreal classification (and pediatric Paris classification) sub-classify phenotypes of Crohn's disease, including nonstricturing and nonpenetrating inflammatory disease; stricturing disease; penetrating complications; and perianal fistula (27,28), they do not describe the length and severity of inflammatory involvement or the anatomic relationship of coexisting phenotypes that are necessary to make important surgical and medical management decisions. More specifically, the Montreal/Paris classifications do not take into account the dynamic continuum of the disease, the overlap or co-existence of stricturing and penetrating disease (2 separate types of disease complications occurring from disease progression) (29,30), or the fact that active inflammation is most often present in stricturing complications (22,29,31). Both CTE and MRE can detect the morphologic continuum and co-existing "complications" with regularity, thus prompting the need for radiologists to reliably define and

https://doi.org/10.1148/radiol.2018171737

Content code: GI

Radiology 2018; 286:776–799

Abbreviations:
AGA = American Gastroenterological Association
CTE = computed tomography enterography
MRE = magnetic resonance enterography
SAR = Society for Abdominal Radiology

Conflicts of interest are listed at the end of this article.

This article is being published jointly in *Radiology* and *Gastroenterology*.

Table 1

Imaging Findings Associated With Small Bowel Crohn's Disease Inflammation

Imaging findings	Description/definition	DDX considerations/comments	Conclusions (level of evidence)
Segmental mural hyperenhancement	Increased attenuation/signal intensity on contrast-enhanced scan in noncontracted segment in comparison to nearby normal small bowel segments	Predictive but nonspecific sign (36,41) Causes include Crohn's disease-related mural inflammation, backwash ileitis, infectious enteritis, mucositis, graft-vs-host disease, contraction or underdistension, radiation enteritis, NSAID enteropathy, angioedema, vasculitis, and ischemia Altered enhancement in Crohn's disease can also reflect processes other than inflammation, such as fibrosis or chronic mesenteric venous occlusion More likely indicates Crohn's disease when asymmetric and combined with other mural and mesenteric findings below Contrast-enhanced imaging is performed in enteric to portal phases of enhancement (7,8)	1. Segmental mural hyperenhancement and wall thickening have a moderately high sensitivity and specificity for small bowel Crohn's disease at CTE or MRE (37–40).(Moderate) 2. Mural hyperenhancement without wall thickening is a nonspecific imaging sign, and may reflect inflammation or other processes (24,37,40,41). (Moderate) 3. CTE and MRE may detect small bowel inflammation not seen at ileocolonoscopy (3,5,75). (Moderate) 4. CTE and MRE with only oral contrast will not detect or stage colonic inflammation as well as ileocolonoscopy (75–77). (Moderate) 5. Hyperintense T2-weighted signal and restricted diffusion at MR enterography is correlated with moderate to severe endoscopic inflammation (25,37,78–80). (Moderate) 6. Unenhanced MR enterography with diffusion-weighted imaging has a moderate sensitivity and specificity for detection of ileal Crohn's disease (25,49,81,82). (Moderate)
Asymmetric	Asymmetric in cross-sectional or longitudinal direction compared to the lumen Mesenteric border is often more affected than antimesenteric border	Specific finding for Crohn's disease (41) Can refer to morphologic pattern of hyperenhancement, wall thickening or stratification	
Stratified (bi- or tri- laminar)	Inner-wall hyperenhancement or halo sign	In Crohn's disease, can be due to submucosal edema, intramural fat deposition or inflammatory infiltration Can also be due to other causes of segmental mural hyperenhancement above "Mucosal hyperenhancement" is erroneous descriptor as mucosa is often absent at endoscopy in inflamed loops with stratified segmental hyperenhancement Intramural fat indicates chronicity and is unrelated to whether inflammation is present or not Intramural edema indicates active inflammation if due to Crohn's disease At this time, no clinical significance is attributed to either the bi- or tri-laminar pattern; the tri-laminar pattern is more often identified on contrast enhanced MR, likely owing to its superior contrast resolution vis-à-vis CT	
Homogeneous, symmetric	Transmural hyperenhancement	Can be due to many other causes including edema, collagen deposition, infiltration, ischemia, shock bowel	
Wall thickening		Only measured or estimated in bowel loops distended by enteric contrast Measure the thickest portion of most distended segment or site of most severe inflammation	
Mild	3–5 mm (23,24,26,41)		
Moderate	5–9 mm		
Severe	≥10 mm (22)	Look for signs of tumor for focal stenoses >1.5 cm in diameter—mass, extension into adjacent mesentery (3,59,83,84)	

(Table 1 continues)

Table 1 (continued)

Imaging Findings Associated With Small Bowel Crohn's Disease Inflammation

Imaging findings	Description/definition	DDX considerations/comments	Conclusions (level of evidence)
Intramural edema	Hyperintense signal on fat-saturated T2-weighted images; only on MR (cannot comment on intramural edema with CT) (24)	In comparison to normal small bowel Increased hyperintensity on T2-weighted images is associated with more severe inflammation (24) In regions of Crohn's disease-related inflammation on gadolinium-enhanced images, increased diffusion-weighted signal abnormality is associated with more severe inflammation (25)	
Stricture	Luminal narrowing in area of Crohn's disease with unequivocal upstream dilation	Location and length should be described for potential subsequent surgical or endoscopic intervention Remember that strictures also arise from NSAID and radiation enteropathy, and adhesions can mimic Crohn's disease strictures (85)	7. Most Crohn's disease strictures have both inflammation and fibrosis (22,53,54,56). (High) 8. A stricture is present when the lumen is narrowed, and there is proximal small bowel dilation (31,53,54,76,86). (High) 9. Proximal small bowel dilation may correlate with a higher burden of fibrotic disease (22,31,53,54,87). (Low) 10. CTE and MRE can detect unsuspected small bowel strictures in Crohn's disease patients (11,88). (Low)
Without upstream dilation	Upstream lumen <3 cm When multiple pulse sequences, fluoroscopic observation, or serial imaging exams demonstrated fixed narrowing without upstream dilation, it is appropriate to describe that a **probable stricture** is present	Degree of upstream dilation can be highly variable based on many factors including chronicity, ingested material Focal reduction in luminal diameter despite adequate enteric contrast in a bowel loop with imaging findings of Crohn's disease	
With mild upstream dilation	Upstream lumen 3–4 cm		
With moderate to severe upstream dilation	Upstream lumen >4 cm	When present, careful assessment of the transition point should be performed in order to determine the cause of the bowel obstruction. Differential diagnosis includes a Crohn's stricture (with or without imaging findings of inflammation), adhesive disease and tumor; when moderate to severe may be appropriate to state in Impression "small bowel obstruction"	
Ulcerations	Appear as small focal breaks in the intraluminal surface of the bowel wall with focal extension of air or enteric contrast into the inflamed bowel wall Do not extend beyond the bowel wall	When seen at cross-sectional imaging, correlates with severe endoscopic inflammation (4,23) Avoid the term *penetrating ulcer* so that it is not confused with penetrating disease, such as fistula or abscess If transmural, useful in Lemann score	11. Visualization of ulcers at cross-sectional enterography is a marker of severe inflammation (4,20,23,89). (High)
Sacculations	Broad-based outpouchings that occur along the anti-mesenteric border due to acute or chronic mesenteric border inflammation	Sequela of asymmetric mural inflammation with shortening of the gut along the mesenteric border	
Diminished motility	Alerts radiologist to locations of potential disease	Rely on conventional imaging features of intestinal inflammation for diagnosis and severity assessment Cine balanced steady state free precession imaging can display peristalsis and may be helpful in improving confidence in diagnosis of inflammation or stricture	12. Altered motility can be helpful in identifying Crohn's inflammation (90–93). (Moderate)

Note.—Items in boldface are required descriptive terms that should be used when present. Conclusions are based on criteria identified in the methods, with the level of evidence summarized accordingly as very low, low, moderate, or high. DDX, differential diagnosis; NSAID, nonsteroidal anti-inflammatory drug.

Figure 1

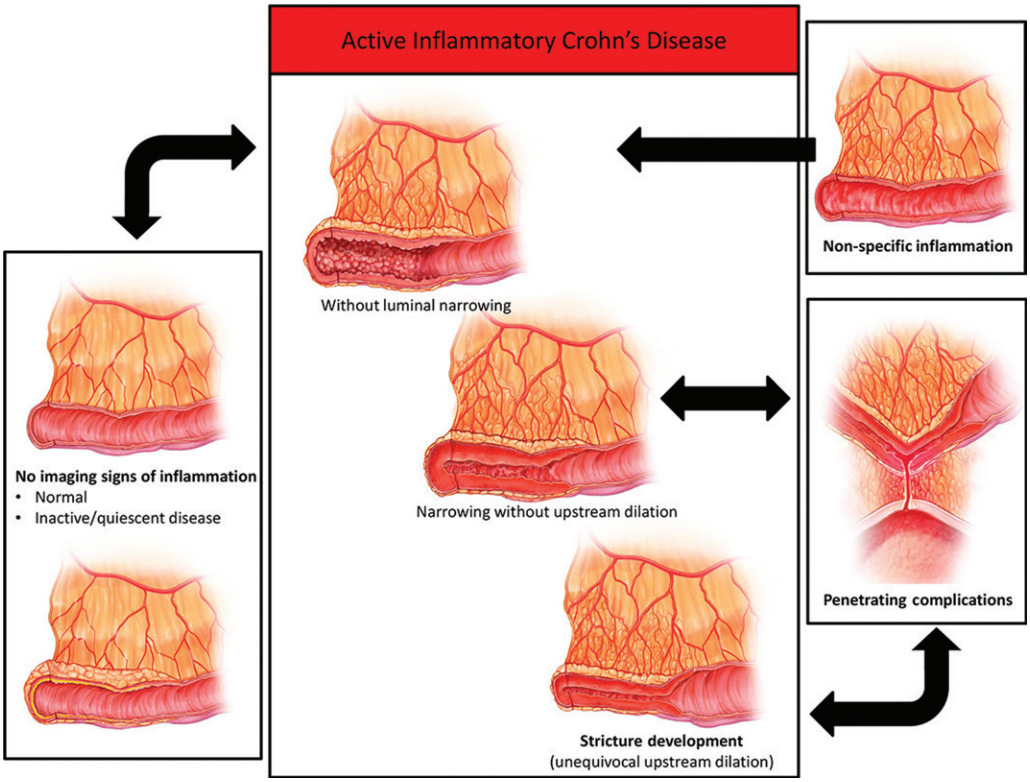

Figure 1: Imaging-based morphologic construct that demonstrates the role of mural inflammation in driving small bowel Crohn's disease and its stricturing and penetrating complications. Mild nonspecific mural inflammation can progress into asymmetric disease with greater and more characteristic mucosal and mural inflammation. Similarly, small bowel loops affected by active inflammatory small bowel Crohn's disease can progress to stricturing and penetrating complications, revert to normal in appearance, or have residual sequela of prior inflammation, such as asymmetric mural fat and pseudosacculation, but without imaging signs of inflammation.

reproducibly describe the anatomic burden of inflammation and Crohn's disease complications.

These recommendations define imaging findings that should be evaluated, how disease burden should be described, and pathophysiologic conclusions that will improve the ability of gastroenterologists and intestinal surgeons to best make management decisions. For example, radiologists should examine for Crohn's disease strictures, which are defined in this guideline as small bowel segments with luminal narrowing and unequivocal proximal (upstream) dilation. Moreover, these recommendations emphasize that when strictures are found, the length of the stricture and radiologic findings of concurrent inflammation and obstruction should be described. These elements provide much of the critical information a gastroenterologist will need to consider in determining options for medical, surgical, or endoscopic therapy. The benefits of a shared understanding and improved communication of cross-sectional enterography examinations will facilitate:

1. Improved use of imaging to guide treatment options, and assess for therapeutic response.
2. Improved understanding for how to compare and assess Crohn's inflammatory burden.
3. Improved systematic assessment of important complications.
4. Improved ability to track and understand the natural history of Crohn's disease.

Methods

The SAR Crohn's Disease-Focused Panel was established in March 2014 to disseminate knowledge and improve the quality and availability of small bowel and Crohn's disease imaging techniques, with an overall aim to improve the care of patients with Crohn's disease. After approval from the SAR Board of Directors and the American Gastroenterological Association's (AGA) Institute Council, this panel met with representatives from the AGA's Imaging and Advanced Technology section in person, via e-mail, and through conference calls, to develop a shared understanding of imaging findings across enterography techniques and their physiologic

Figure 2

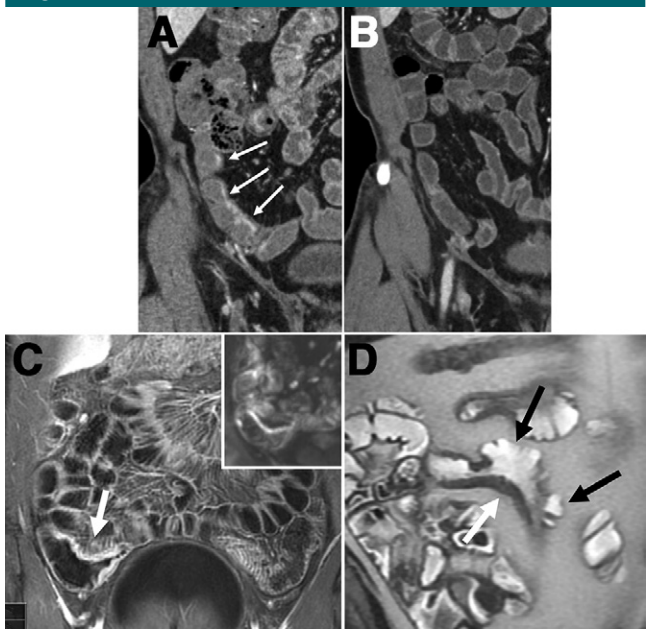

Figure 2: Asymmetric imaging findings of inflammation are characteristic of active inflammatory small bowel Crohn's disease and occur most prominently along the mesenteric border. *A,* CTE images show patchy hyperenhancement along the mesenteric border indicative of inflammation in the terminal ileum *(top left, arrows),* which nearly completely resolves after patient received combination therapy over 1 year *(B, top right). C,* Another patient demonstrates marked asymmetric wall thickening and hyperenhancement along the mesenteric border *(bottom left, white arrow)* accompanied by corresponding increased signal within the bowel wall on diffusion-weighted imaging, indicating restricted diffusion and moderate to severe inflammation *(bottom left, inset). D,* A third patient shows findings of asymmetric involvement with mesenteric border wall thickening *(bottom right, white arrow)* and antimesenteric pseudosacculation *(bottom right, black arrows).*

substrates. Representatives with expertise in Crohn's disease were also sought and included from the Society of Pediatric Radiology, the European Society of Gastrointestinal and Abdominal Radiology, the Society for Surgery of the Alimentary Tract, the American Society of Colon and Rectal Surgeons, and the North American Society for Pediatric Gastroenterology, Hepatology and Nutrition. Through electronic communications and conference calls, consensus recommendations were reached and submitted to the SAR Board and AGA Council for approval.

A primary aim of this work was to define and describe key imaging findings that relate to the diagnosis, severity, and type of Crohn's disease involvement in the small bowel. To this end, the evidence of Crohn's disease inflammation for specific imaging findings at CTE and MRE was evaluated according to the GRADE (Grading of Recommendations Assessment, Development and Evaluation) system for evaluation of diagnostic tests (32–34). For this purpose, CTE and MRE were not considered as standalone tests, but as part of an imaging strategy combined with clinical assessment and ileocolonoscopy (32). In developing these recommendations, authors from the SAR Crohn's Disease-Focused Panel and the AGA's Imaging and Advanced Technology section reviewed original investigations and meta-analyses from the medical literature relating to each imaging finding. Practical conclusions were reached relating to each imaging finding reviewed, with the quality of the evidence for each conclusion graded along a 4-point scale (ie, very low, low, moderate, high) based on formalized, agreed-upon evaluation criteria: high-quality studies were those that enrolled consecutive patients in a clinically relevant cohort, with universal application of an endoscopic or histologic reference standard, clear blinding of readers, and site-specific correlation between reference and reader findings. Quality was downgraded if these criteria were not met, if there was substantial variation between studies without a clear explanation, or if there was major uncertainty about the effect of false positives and negatives. Conclusions for the level of evidence relating to each imaging finding were proposed by each pair of reviewers along with their assessment of the formalized criteria for evaluating the scientific evidence, with final agreement by consensus of panel and section members, respectively. Based on these conclusions, recommendations for use of CTE or MRE or incorporation of each imaging finding into a clinical report were created by the entire author group, with strong recommendations indicating confidence that incorporation will have desirable effects on patient outcomes and outweigh undesirable effects or alternatives (35). The strength of the recommendation also takes into account alternative management strategies. All authors then approved the final document by consensus. Subsequently, this document was submitted to the AGA Institute Council, the Board of Directors for SAR, and the Society of Pediatric Radiology, all of which approved the document.

Imaging Findings

Table 1 defines and describes imaging findings of mural inflammation at CTE and MRE, along with important diagnostic considerations and practical conclusions. Figure 1 pictorially illustrates

Figure 3

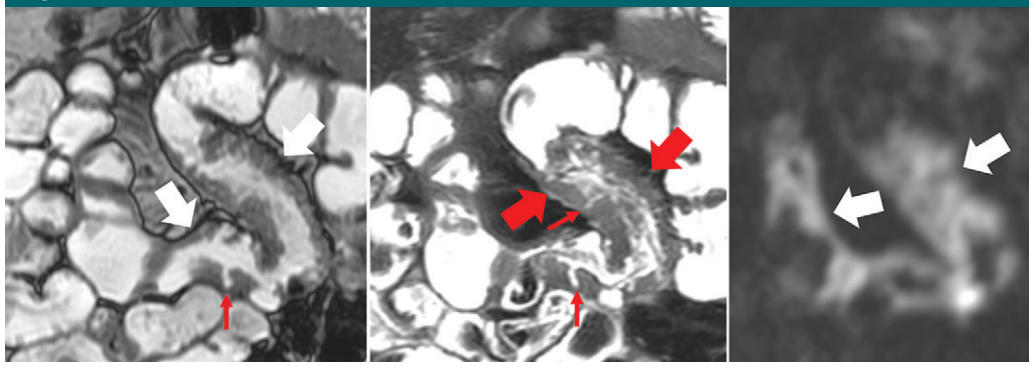

Figure 3: Imaging findings of jejunal stricture with severe inflammation at MRE with marked asymmetric wall thickening *(left, white arrows)*, bowel wall edema on T2-weighted imaging with fat saturation *(middle, large red arrows)*, small ulcers *(left and middle images, small red arrows)*, and increased intramural signal on high b-value diffusion-weighted image *(right, white arrows)*.

Figure 4

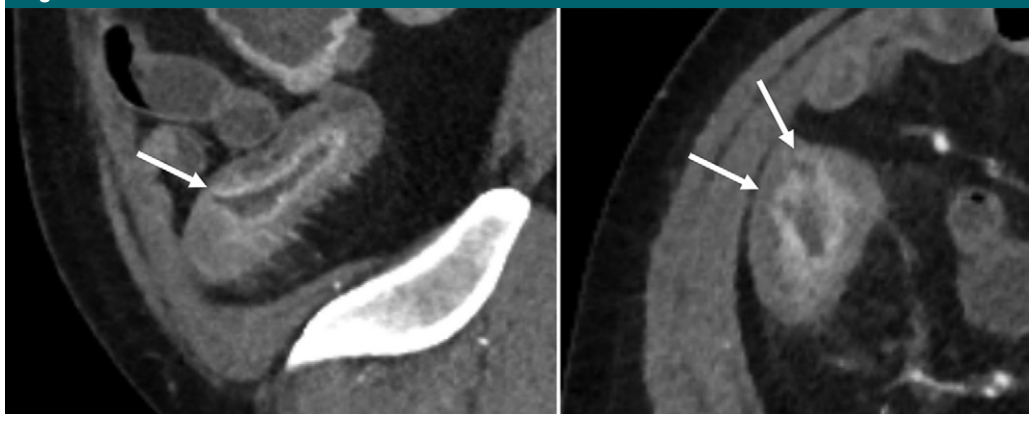

Figure 4: Imaging findings of severe inflammation at CTE with marked wall thickening and small ulcerations on sagittal *(left image, arrow)* and axial images *(right image, arrows)*.

an imaging-based morphologic construct that demonstrates the role of mural inflammation in driving Crohn's disease exacerbations and response as seen at cross-sectional enterography, and which will be explained in greater depth after individual imaging findings have been reviewed. The pictorial representation of a single bowel loop is used to facilitate a unified understanding of how mural inflammation can change independent of signal properties of cross-sectional imaging modalities. Multiple studies have shown that in patients with Crohn's disease, imaging findings of inflammation are strongly associated with the presence of histologic inflammation (36–40). Evidence describing and supporting the use of these imaging findings for small bowel inflammation is provided in references within Table 1. By extension and inference, similar findings can reflect enteric inflammation in the stomach and colon.

While the co-existence of segmental hyperenhancement and wall thickening are used in combination as imaging findings reflecting Crohn's disease inflammation (40,41), a number of other conditions can result in these imaging findings even when segmental involvement is multifocal (42,43). Additionally, other imaging findings often seen in small bowel Crohn's disease inflammation, such as mural stratification and intramural edema, can also be seen in a number of other conditions. Asymmetric inflammation in the bowel wall in Crohn's disease is commonly more severe along the mesenteric border and is probably a specific feature in Crohn's disease (Figure 2) (44). The co-existence of mural inflammation and penetrating complications should also suggest Crohn's disease, in the absence of other known causes of penetrating complications, such as appendicitis, diverticulitis, tumor, and tuberculosis. Given these considerations, radiologists should diagnose inflammatory small bowel Crohn's disease either in known Crohn's disease patients when the nonspecific imaging findings of

Figure 5

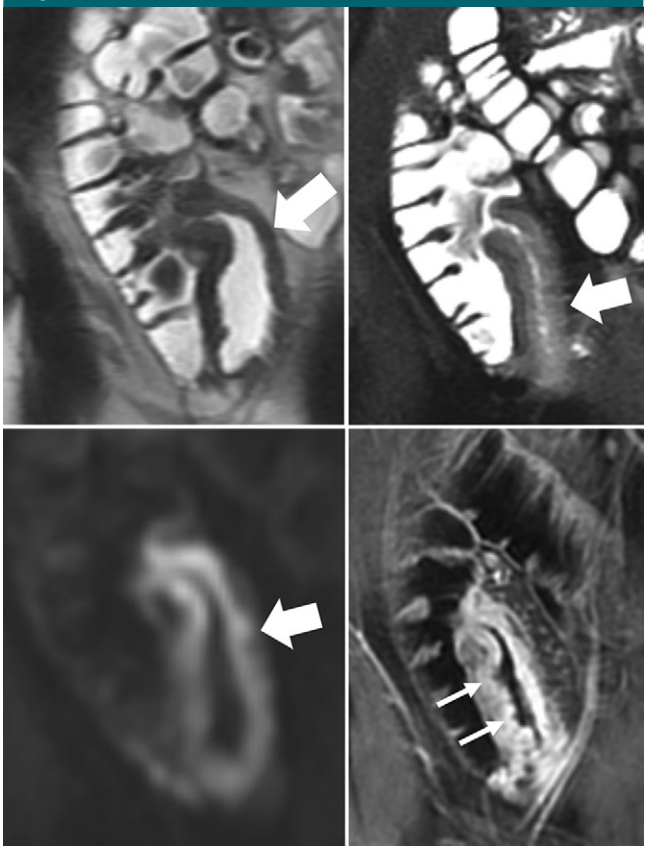

Figure 5: Imaging findings of severe inflammation of the terminal ileum at MRE, as indicated by marked wall thickening *(top left, arrow)*, intramural edema or hyperintensity on a T2-weighted image with fat saturation *(top right, arrow)*, increased intramural signal on high b-value diffusion-weighted images *(bottom left, arrow)*, and small ulcerations on gadolinium-enhanced images *(bottom right, small white arrows)*.

inflammation are present, or when enteric inflammation is asymmetric or co-exists with the typical penetrating complications of Crohn's disease. In the absence of a clinical diagnosis of Crohn's disease, asymmetric inflammation, or typical penetrating complications, radiologists should describe the location and length of nonspecific small bowel inflammation. Gastroenterologists can then correlate these nonspecific radiologic findings with endoscopic and other clinical data to guide further management.

In addition to describing the length of intestinal inflammatory involvement, radiologists should describe imaging findings of severe inflammation based on wall thickness, presence of luminal ulcerations, and increased intramural T2 signal (4,23,45,46) (Figure 2). Luminal ulcerations appear as small focal breaks in the intraluminal surface of the bowel wall with focal extension of air or enteric contrast into the inflamed bowel wall (Figures 3 and 4). Because Crohn's disease itself, as well as physiologic factors and technical factors affecting acquisition, can affect the degree of bowel wall contrast-enhancement, hyperenhancement is a sign of active inflammation, but is not used to describe severity unless quantitative measures are utilized (47). Mild inflammation is described when segmental hyperenhancement is present with minimal wall thickening of 3–5 mm and rarely causes luminal narrowing. Severe inflammation is present if ulcerations or high T2 intramural signal are identified (Figures 3 and 5). Restricted diffusion is a nonspecific sign of Crohn's disease mural inflammation, but when other typical findings of mural inflammation are present on contrast-enhanced and/or T2-weighted images, restricted diffusion is a complementary and supportive finding that has been shown to correlate with severe inflammation at endoscopy (25). Restricted diffusion is present when intramural hyperintensity is present on high b-value images (often similar to reactive lymph nodes), and should prompt a careful assessment for other signs of severe inflammation. However, radiologists should be aware that false positives on diffusion-weighted imaging can be due to many factors, including suboptimal fluid distention. For example, the normal jejunum demonstrates increased relative nonfocal restricted diffusion in comparison to the normal ileum. The diagnosis of active Crohn's disease should not be made on the basis of restricted diffusion alone (46,48).

Multiple MR-based scoring systems that describe inflammatory severity have been developed based on measures of histologic or endoscopic inflammation and rely on the described visual observations (eg, ulcers, intramural hyperintense T2 signal) and/or quantitative measurements (eg, wall thickness, relative contrast enhancement). Scoring systems, such as MaRIA, Clermont score, and MEGS, differ in the imaging findings evaluated and the potential weighting given to each finding or measurement, and are used in clinical studies to quantitate improvement or worsening of active inflammatory Crohn's disease (4,24,49–51). The advantage of the severity scoring systems is that they integrate imaging findings in a systematic and reproducible manner. When transmural healing occurs or penetrating complications develop at CTE/MRE after therapy, however, cross-sectional images clearly demonstrate information that can be quickly assessed and conveyed without performing systematic scoring. Moreover, scoring systems do

Figure 6

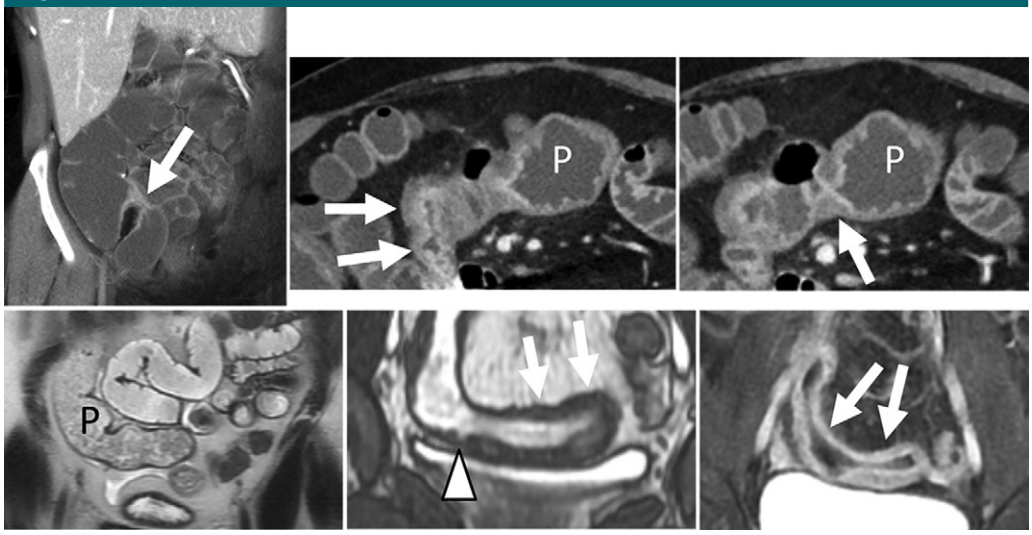

Figure 6: Imaging findings of small bowel strictures in Crohn's disease patients. Coronal CTE image in patient with prior ileocecectomy demonstrates short segment stenosis *(top left, white arrow)* without imaging findings of inflammation, with subsequent endoscopy not identifying any evidence of mucosal inflammation either. Two jejunal strictures seen at CTE examination in another patient *(top middle and right, white arrows)* with proximal small bowel dilation *(top middle and right, P)* demonstrate imaging findings of inflammation with mural hyperenhancement and stratification with wall thickening. Subsequent surgical resection demonstrated stricture formation with transmural inflammation in all layers of the bowel wall. Bottom row shows images from MRE in a third patient with small bowel dilation *(bottom left, P)* proximal to a long segment stricture. Fast imaging employing steady-state acquisition through the stricture shows wall thickening *(bottom middle, white arrows)* and ulceration *(bottom middle, white arrowhead)*, and 7-minute delayed gadolinium image shows mural stratification *(bottom right, white arrows)*.

not reflect how inflammatory severity can vary over an inflamed bowel segment or convey adequate information regarding length and location of disease, which is needed for clinical decision-making. Further refinement of specific imaging criteria that can be readily incorporated into clinical practice for mild, moderate, and severe inflammation will be a subject for future interdisciplinary investigation.

Crohn's disease strictures result from complex interactions between inflammatory cells, cytokines, mesenchymal cells, and enteric flora, and result in variable degrees of luminal narrowing (52). The majority of Crohn's disease strictures have both an inflammatory and a fibrotic component due to repeated inflammation and reparative damage (53,54). Estimating the relative contribution of inflammation, fibrosis, and smooth muscle hypertrophy in dominant strictures has been an area of active imaging investigation (55,56). However, there is no universally accepted clinical or histologic scoring system for stricture-related fibrosis (52). Gastroenterologists and radiologists generally refer to different physical findings when identifying a stricture. Endoscopists generally think of luminal narrowing as a stricture. Radiologists generally rely on the presence of proximal dilation (often defined as >3 cm), as many bowel segments with Crohn's-related inflammation demonstrate luminal narrowing, and cross-sectional imaging cannot assess luminal compliance or readily differentiate between spasm or fixed narrowing at a single time point. Moreover, both predominantly fibrotic and predominantly inflammatory strictures can fail to respond to medical therapy and ultimately require surgical intervention. Several imaging techniques and findings, such as magnetization transfer, ultrasound elastography, diffusion-weighted imaging, and relative contrast enhancement on delayed MR imaging with gadolinium, are actively being investigated for their ability to estimate fibrosis in Crohn's disease strictures, but none of them have been fully validated. However, multiphase cinematic thick slab imaging with balanced steady-state free precession (eg, true-FISP, FIESTA, or balanced FFE) can be helpful in detecting and increasing confidence in stricture presence at MRE (57,58). Until prospective studies validating the relationship of imaging findings to histologic fibrosis are completed and a consensus emerges, Crohn's disease strictures can be reliably identified by both luminal narrowing and unequivocal upstream dilation in order to minimize false-positive findings (Table 1) (54). Fixed luminal narrowing without upstream dilation cannot reliably be diagnosed as a stricture on a single image, but when multiple pulse sequences, fluoroscopic observation, or serial imaging examinations demonstrate fixed narrowing without upstream dilation, it is appropriate for radiologists to describe that a probable stricture is present. Enteroclysis

Table 2

Imaging Findings of Penetrating Disease and Mesenteric Inflammation in Crohn's Disease

Imaging findings	Description/definition	Comments	Finding
Fistulas			
Simple fistula	Appears as an extra-enteric tract, with or without internal air or fluid (94); affected loops are often angulated or tethered[95]	Fistulas should be described by bowel loop origin and structure to which they connect Usually arise from within or just proximal to a stricture (29,30) Usually arise from a stricture with active inflammation Consider postoperative leak in addition to fistulizing Crohn's disease when examining extra-enteric tracks originating in the region of enteric anastomoses	13. CTE and MRE have similar and moderately high accuracy for penetrating Crohn's disease (fistulas, inflammatory mass, abscess) (53,76,94–97). (Moderate) 14. Penetrating complications detected at CTE and MRE may occur in unsuspected patients (94,98,99). (Low)
Complex fistulas	Multiple tracts often forming an asterisk-shaped or "clover-leaf" appearance, or "star sign"; affected loops often angulated or tethered; an interloop abscess or inflammatory mass may be present		
Sinus tract	Wall defect that extends outside bowel wall but not to adjacent organs or skin (usually accompanied by angulation and tethering of adjacent bowel)		
Perianal fistulas	Arise from rectum or anus and extend to skin in perineal region or vagina	Describe according to Parks' or St James' Classification (100,101), and recommend dedicated pelvic MR for assessment before surgical intervention or for activity assessment Imaging of the anus mandatory part of any CTE or MRE exam About one-quarter present at or before time of Crohn's disease diagnosis Incidence varies by age and location of disease (102,103)	15. Pelvic MRI is the most accurate test for the detection and characterization of perianal Crohn's disease, but every CTE and MRE should image the anal sphincter complex and perineum (63,104,105). (High)
Inflammatory mass	Ill-defined mass-like process of mixed fat and/or soft tissue attenuation/signal intensity (not water attenuation/signal intensity) usually associated with penetrating disease, such as complex fistulas	Associated with inflammatory stranding in mesenteric tissues. Use of the term *phlegmon* is discouraged	
Abscess	Mesenteric/peritoneal/perianal fluid collection with rim enhancement and/or internal air	May be difficult to distinguish from confined leak in postoperative setting	
Perienteric edema/inflammation	Increased attenuation (CT) or high T2 signal or restricted diffusion (MR) in mesenteric fat adjacent to abnormal bowel loops; if perirectal, then circumferential	Often associated with mesenteric border inflammation. Associated with elevated C-reactive protein (106)	
Engorged vasa recta	Engorged vasa recta that supply an inflamed bowel loop ("comb sign" [44])	May be a marker of inflammation but may also reflect past inflammation	

(Table 2 continues)

Table 2 (continued)

Imaging Findings of Penetrating Disease and Mesenteric Inflammation in Crohn's Disease

Imaging findings	Description/definition	Comments	Finding
Fibrofatty proliferation	Increased fat adjacent to abnormal bowel, displacing bowel loops; usually along mesenteric border, but can be circumferential	Also called "creeping fat"	
Mesenteric venous thrombosis/ occlusion	If acute, an intraluminal thrombus is seen If chronic, narrowed central mesenteric veins are seen, with dilated peripheral collaterals forming via mesenteric branches and potentially small bowel varices Use the term *chronic mesenteric venous occlusion* if an acute thrombosis is not seen	Central, acute mesenteric thromboses in PV/SMV often resolve, but peripheral mesenteric thromboses often become chronic (67) Associated with stricture formation and surgery (68)	16.Acute mesenteric vein thromboses and chronic mesenteric vein occlusions can be detected at CT and MR in Crohn's disease patients, and may be central or peripheral (68,95,107). (Low)
Adenopathy	Lymph node >1.5 cm in short axis	Reactive lymphadenopathy 1–1.5 cm in short axis diameter is considered normal in Crohn's disease	

Note.—PV, portal vein; SMV, superior mesenteric vein.

assessment can be helpful in equivocal cases, as it is more sensitive for stricture presence. Radiologists and clinicians should be aware that when strictures are in close proximity to each other, the ability to radiographically detect downstream small bowel strictures is compromised, as an upstream stricture is already causing an obstruction.

Following stricture identification, radiologists should state whether findings of inflammation are present or absent within the stricture (Figure 6). Findings of inflammation within a stricture are critical, as current medical treatments can alleviate inflammation and avoid or delay surgery, while true fibrotic strictures are likely to require strictureplasty, excision, or endoscopic bowel dilation. Additionally, strictures should be evaluated for symmetry, nodularity, or extension of soft tissue into the adjacent mesentery that may signal development of a neoplasm (59). Radiologists should report the number, location and length of Crohn's disease strictures in patients so that gastroenterologists and surgeons can decide on the best therapeutic option and approach. While it is understood that the degree of bowel dilation proximal to a stricture is a result of many factors, including chronicity and ingested material, the degree of upstream dilation is often useful to endoscopists and surgeons in deciding if treatment is warranted, or which strictures to treat if multiple strictures are present. The combination of presence/absence and severity of inflammation, stricture length, and degree of upstream dilation and fistulas can provide clinicians with necessary information for treatment decisions (60).

Table 2 summarizes imaging findings in penetrating complications and mesenteric findings in Crohn's disease. Penetrating complications result from transmural inflammation and include sinus tracts, fistulas, inflammatory masses, abscesses, and, rarely, free intraperitoneal perforation. Sinus tracts can be blind-ending in the mesentery, terminate at fascial planes, or extend longitudinally within the bowel wall. Fistulas should be described by the 2 epithelial structures they connect (eg, enteroenteric, enterocolic, enterocutaneous, rectovaginal, or enterovesical). Enteric fistulas within the abdominal cavity should be described as simple or complex similar to perianal fistulas (61). Complex, asterisk-shaped fistula complexes are often seen that tether multiple loops of small bowel and/or colon (Figure 7). Inflammatory mass describes dense mesenteric inflammation adjacent to severe mural inflammation or penetrating complications that is not an abscess and does not have a well-defined fluid component. The term *phlegmon* is discouraged due to its ambiguous definition, as it does not describe if there is a drainable component as in an abscess, or nondrainable, as in localized inflammation or inflammatory mass. It should be noted that clinical experience and the pathologic literature supports the strong association between stricture formation and penetrating disease (29,30). Thus, when penetrating disease is present, visual inspection should be directed at the site of fistula origin for an inflamed and stenotic bowel segment with upstream dilation, as these are nearly always present. Conversely, the proximal end of an inflamed and stenotic bowel segment should be scrutinized for detection of penetrating complications, as most arise from that part of the involved segment. We acknowledge that a weakness of the current proposal is

Figure 7

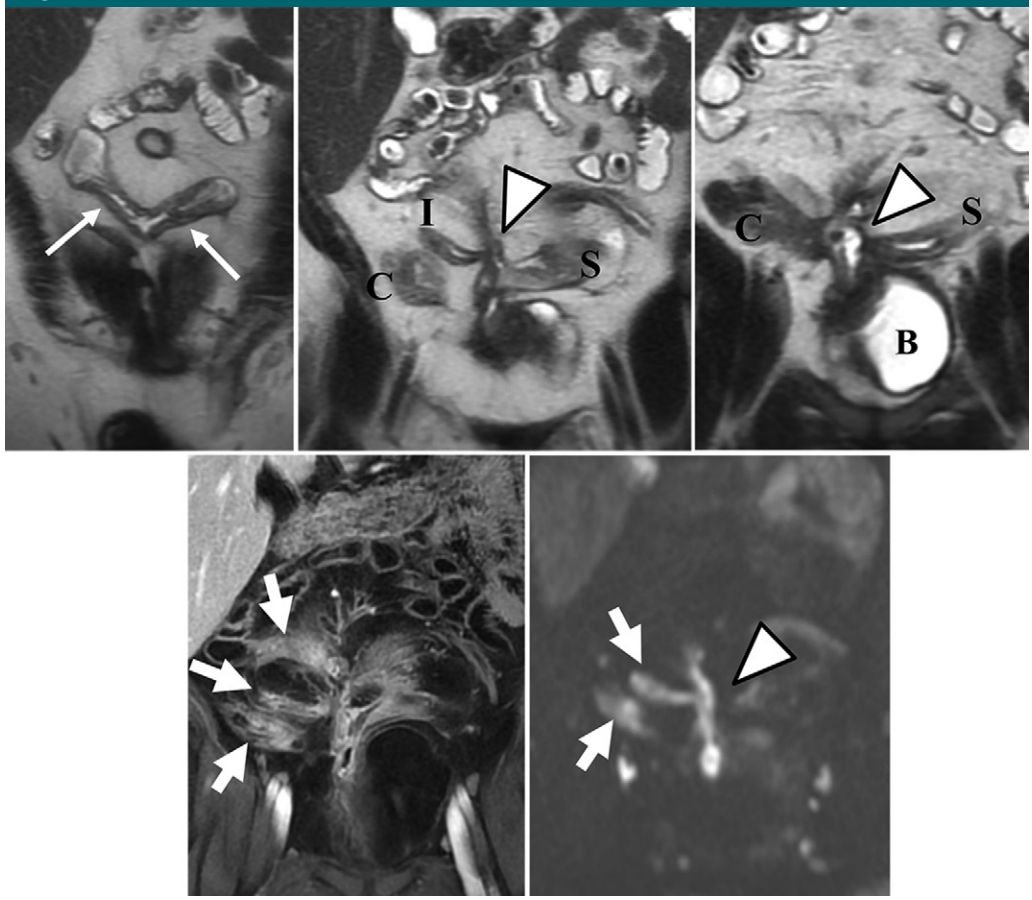

Figure 7: Top row shows coronal MRE single-shot fast spin-echo images from anterior to posterior that demonstrate a thickened ileal loop that is tethered and angulated *(top left, arrows)*, which points to an asterisk-shaped fistula complex *(top middle, arrowhead)* involving multiple loops of ileum *(top middle, I)*, sigmoid colon *(top middle and top right, S)*, cecal pole *(top middle and top right, C)*, and bladder *(top right, B)*. An enterocutaneous fistula also connects to this fistula complex, but is not shown. Note inflammation, as evidenced by hyperenhancement of involved bowel loops *(bottom left, white arrows)* and increased signal on diffusion-weighted imaging in fistula complex *(bottom right, arrowhead)* and inflamed ileum and cecum *(bottom right, white arrows)*.

that some inflamed small bowel segments giving rise to fistulas will not cause proximal small bowel dilation, as the upstream pressure gradient causes decompression through the fistula rather than dilation of the proximal bowel; these segments would not be identified or termed *strictures* based on a strict interpretation of our proposed scheme. However, because the evidence is overwhelming when a complex fistula is seen to arise from a small bowel segment with active inflammation and no upstream dilation is present, one might consider an impression in the clinical report, such as "complex penetrating disease with active inflammatory small bowel Crohn's disease with luminal narrowing; stricture with imaging findings of active inflammation highly likely."

Because approximately one-quarter of Crohn's disease patients present with an anorectal fistula, complete imaging of the anal sphincters and perineum is imperative for every CTE and MRE examination (Figure 8). Artifacts often occur over the anus due to the placement of exterior phased-array coils at MRE, but adequate anal imaging can be performed in such cases using the body coil that is intrinsic to the magnet itself. Anatomic classification, multimodality treatment, and imaging endpoints and limitations relating to perianal fistulas are outside of the focus of this work focusing on CTE and MRE in small bowel Crohn's disease and can be found elsewhere (62); however, it should be the expectation that every CTE and MRE examination image the entire anus, and that the presence or absence of perianal disease be evaluated by the radiologist along with other imaging findings. In clinical care, gastroenterologists are often most interested in the presence or absence of a perianal fistula or abscess; detailed fistula anatomy is often not required. In

Figure 8

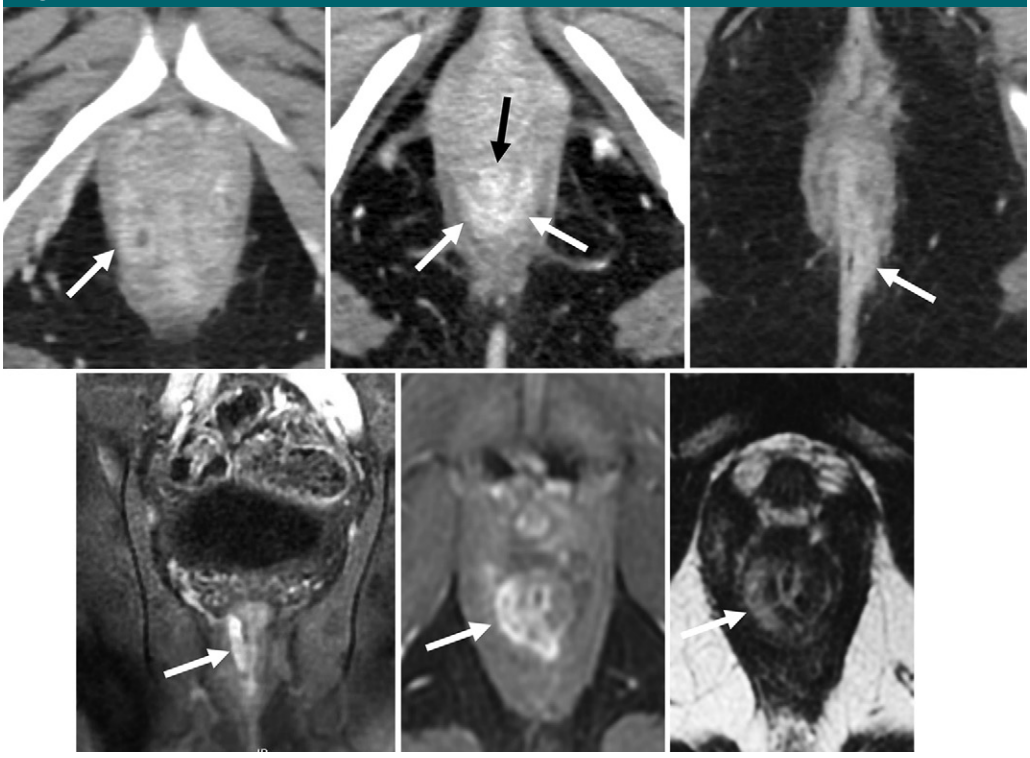

Figure 8: Importance of imaging the anal sphincters at every CTE and MRE exam. Top row shows CTE images demonstrating a small perianal abscess adjacent to right puborectalis *(top left, arrow)* with intersphincteric horseshoe ramifications posteriorly *(top middle, white arrows)*, with inferior ramification to left gluteal crease *(top right, white arrow)*. The enhancement of the normal internal anal sphincter *(top middle, black arrow)* permits differentiation from the surrounding external anal sphincter. Patient subsequently underwent examination under anesthesia with drainage of abscess and seton placement. Bottom row shows coronal image from routine MRE demonstrating a small enhancing fistula tract *(bottom left, white arrow)*, with subsequent dedicated pelvic MR better showing an intersphincteric fistula with horseshoeing in the interspincteric space at dynamic gadolinium enhancement *(bottom middle, white arrow)* and T2-weighted imaging *(bottom left, white arrow)*.

the absence of an abscess, therapy with immunosuppressive or biologic medications can proceed, whereas an abscess will require antibiotic treatment and/or drainage before the initiation or continuation of therapy, depending on its size. The question of the presence or absence of an anorectal abscess can typically be answered with CTE or MRE. Because dedicated imaging of the anus for multimodality treatment of perianal Crohn's disease requires additional pulse sequences centered about the anus (and not included in the MRE examination), dedicated perianal MR imaging should be performed when clinically indicated as noted in a recent global consensus statement (63). Some institutions offer combined MRE and dedicated perianal examinations in patients with known small bowel and perianal disease. It should be noted that perianal disease is not considered penetrating disease in either this guideline or the Paris classification (27). The mechanism of perianal disease is distinctly different than that of classic penetrating disease (64). In addition to the anus and colorectum, radiologists should carefully inspect the appendix, as it is frequently involved with ileocolonic Crohn's disease (65,66), and appendicitis is rarely the first presentation of Crohn's disease. Imaging findings of appendiceal Crohn's disease involvement are similar to those in the small bowel, and ileal-appendiceal fistulas are consequently not uncommon.

The spectrum of mesenteric vein thrombosis or occlusion has recently been described in Crohn's disease patients (67,68). Radiologists should evaluate for and distinguish between acute mesenteric thrombosis and sequela from prior thrombosis, sometimes referred to as chronic mesenteric vein thrombosis, but more accurately termed *chronic mesenteric venous occlusion*. Acute portal and superior mesenteric vein thrombus can be seen in Crohn's disease patients as a hypoattenuating thrombus, expanding the vein. These thrombi have been observed to generally resolve without anticoagulation. However, peripheral mesenteric venous thrombi frequently evolve into chronic peripheral

Figure 9

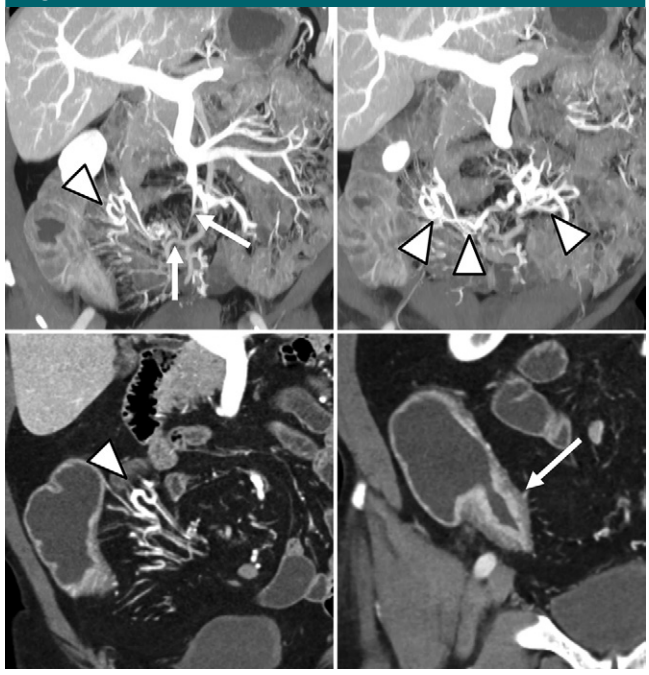

Figure 9: Thick coronal maximum intensity projection images from CTE show typical findings of chronic mesenteric venous occlusion with narrowed peripheral mesenteric vein *(top left, white arrows)* and dilated peripheral marginal veins *(top right and bottom left, white arrowheads)* that return blood back to the portal system through collateral pathways. Note distal active small bowel inflammation *(arrow, bottom right)*.

mesenteric venous occlusion on follow-up imaging, with segmental pruning of the mesenteric arcade with development of collateral pathways or small bowel varices. Chronic peripheral mesenteric venous occlusions typically correspond anatomically to small bowel segments with active or prior Crohn's disease inflammation (Figure 9). Coronal imaging with maximum intensity projections are especially helpful in visualizing the mesenteric venous arcade. Acute and chronic mesenteric venous thrombosis/occlusion have been correlated to increased risk for stricture or surgery in a retrospective series (68), but their impact on the natural history of disease is poorly understood.

Table 3 lists extra-intestinal findings related to Crohn's disease (or Crohn's disease therapies) that should be searched for in every CTE and MRE examination. The most clinically important findings are sacroiliitis, primary sclerosing cholangitis, and avascular necrosis, most often involving the femoral heads. Many patients with Crohn's disease complain of low back pain. Identifying the changes of sacroiliitis identifies the cause and facilitates therapy. Early primary sclerosing cholangitis is often first identified on enterography, and is manifest by the presence of discontinuous, intrahepatic bile ducts that do not connect to nondilated central ducts. Once identified, the patient can be followed more closely for complications of primary sclerosing cholangitis, typically with MR imaging/magnetic resonance cholangiopancreatography and endoscopic retrograde cholangiopancreatography. Lastly, identifying avascular necrosis will again assist in the care of a patient with hip pain and prompt avoidance of steroids when possible.

Characterization of Disease Activity

Table 4 lists recommendations for clinical practice based upon the evidence for specific imaging findings. Each recommendation is accompanied by a description of the strength of the recommendation (ie, strong vs weak), with strong recommendations having anticipated desirable effects on patient outcomes (35). These recommendations set forth imaging criteria for the imaging diagnosis of Crohn's, as well as describing its severity and complications at CTE and MRE. Furthermore, they recommend cross-sectional enterography be performed at diagnosis to detect small bowel involvement that may not be identified by other methods (Figure 10), and recommend it be considered in disease monitoring when small bowel disease or penetrating complications are present (Figure 8). The selection of CTE or MRE will vary according to a variety of factors, including patient preference, age and clinical presentation and concerns, imaging availability, and local expertise, and have been addressed, in part, in practice parameters published jointly between radiology societies (9,69). Potential factors to consider in selecting CTE or MRE as the most appropriate examination for an individual patient are listed in Table 5. MRE is generally preferred in the pediatric population, although CTE is an acceptable alternative, and some practices perform CTE at time of diagnosis. The imaging findings of Crohn's disease at CTE and MRE are identical between pediatric and adult patients (70,71).

Table 6 lists recommended impressions in radiology reports for summarizing imaging findings and grouping them into recognized patterns of disease in a manner that is useful to referring physicians, and accounts for exacerbations and response to therapy as seen at cross-sectional enterography (Figure 1). This imaging-based morphologic construct comes from an observation of the dynamic nature of Crohn's inflammation. As observed by Cosnes and Lemann (26,72), active inflammation is thought to eventually progress to stricturing and

Table 3

Extra-Intestinal Findings Relevant to Crohn's Disease and Seen at Computed Tomography and Magnetic Resonance Enterography

Imaging findings	Description/definition	Comments
Sacroiliitis	Subtle erosions to frank fusion of sacroiliac joint, including increased T2 signal, subchondral marrow edema or enhancement; contrary to dogma, this is often asymmetric with only one side affected or one side more affected than the other	
Primary sclerosing cholangitis	Discontinuous, intrahepatic biliary ductal visualization and/or extrahepatic ductal wall thickening/enhancement without significant upstream dilation	
Avascular necrosis	Focal sclerosis along the anterior aspect of the femoral head, best seen on coronal views with bone windows	Describe if articular collapse is present or not
Pancreatitis	Can be medication-induced, due to cholelithiasis or idiopathic duct centric pancreatitis (steroid-responsive pancreatitis; formerly type II autoimmune pancreatitis)	
Nephrolithiasis and cholelithiasis (108)	—	Describe presence and burden
Cutaneous findings	Including pyoderma gangrenosum, erythema nodosum or cutaneous vasculitis	Can be seen in multiple locations (eg, thighs, abdominal wall, vulva)

penetrating disease complications in a high proportion of patients, with some patients presenting with penetrating or stricturing disease complications, which may portend a more aggressive course. With mild inflammation, wall thickening and hyperenhancement is often seen without luminal narrowing. As inflammation progresses and becomes more severe, enterographic images may display increased intramural T2 signal, restricted diffusion, and ulcer formation in conjunction with luminal narrowing. Adoption of a consistent and well-defined reporting mechanism that links imaging findings of inflammation, stricturing disease and penetrating complications with estimates of disease severity will facilitate selection of optimal therapies and communicate disease progression and reversibility (73), and directly parallel similar linkages provided in the Lemann index without the onerous per-segment analysis required by the research tool (Appendix 2) (73).

Several terms should be used in describing the pathophysiological significance of imaging findings associated with current or prior small bowel inflammation. Active Crohn's disease inflammation should be identified based on the predefined criteria, as should nonspecific inflammation. Active inflammation may respond to medical therapy. When no imaging findings of active inflammation are identified in patients with suspected Crohn's disease, this should be explicitly stated in the radiologic report. Complete resolution of small bowel or colonic inflammatory findings can occur in Crohn's disease patients, with the bowel returning to a normal appearance. In these cases, it is also correct to report that no small bowel inflammation is seen. Partial response to medical therapy may be indicated by a decrease in the severity of imaging findings within an inflamed segment, or evolution to much shorter and patchy areas of involvement over the length of the involved segment (Figure 1) (13). Alternatively, inflammation may resolve with residual findings, such as asymmetric fat deposits within the small bowel wall, residual pseudosacculation and scarring, or mild wall thickening without luminal narrowing, or other morphologic or signal changes reflecting active inflammation (ie, absent T2 signal hyperintensity, hyperenhancement, restricted diffusion). When sequelae of prior inflammation are present without active inflammation, "Crohn's disease with no imaging signs of active inflammation is present" should be stated in the conclusion of the report. Terms such as *quiescent* or *chronic* are discouraged because their meaning may be erroneously interpreted, especially by patients who now, in many institutions, have access to their imaging reports. Gastroenterologists and patients making clinical decisions based on imaging findings should be aware that active vs inactive disease based on imaging criteria does not always equate to histologically, endoscopically, or clinically active or inactive disease. There is a relationship between these assessment modalities, but the properties assessed with different modalities vary.

Stricture formation occurs when there is focal or segmental luminal narrowing with unequivocal upstream dilation. Imaging findings of concomitant active inflammation are most often present (53), and we have termed this pattern *stricture with findings of active inflammation* (Figures 1 and 4). Strictures without imaging findings of inflammation may also exist. In this situation, the bowel wall is thickened without other imaging findings of inflammation. Adler et al (31) found that strictures without imaging findings of inflammation had less inflammation and less fibrosis, but lack of imaging findings of inflammation did not imply that histologic inflammation was absent. While there is a paucity of published data on the subject, in the experience of the radiologist coauthors,

Table 4

Recommendations for Use of Computed Tomography or Magnetic Resonance Enterography, and Incorporation of Imaging Findings Into the Clinical Report

Recommendations
1. Radiologists should indicate that inflammatory small bowel Crohn's disease is likely when either (i) in known Crohn's patients when mural hyperenhancement and wall thickening are present, or (ii) when enteric inflammation is asymmetric or co-exists with the typical penetrating complications of Crohn's disease. (Strong)
2. Radiologists should report the number of involved bowel segments, approximate location (proximity to ileocecal valve or ligament of Treitz), length and degree of upstream dilation of Crohn's strictures so that gastroenterologists and surgeons can decide on the best therapeutic option and approach. (Strong)
3. When describing bowel loops having a Crohn's stricture or penetrating disease (sinus tract, abscess or enteric fistula), radiologists should state if imaging findings of mural inflammation are present (Strong).
4. Cross-sectional enterography should be performed at diagnosis of Crohn's disease to detect small bowel inflammation and penetrating complications beyond the reach of standard ileocolonoscopy. (Strong)
5. Cross-sectional enterography should be considered in disease monitoring paradigms when small bowel disease or penetrating disease complications are present. (Strong)
6. Dedicated pelvic MR (perianal fistula MR imaging protocol) is required for the adequate preoperative assessment of perianal Crohn's disease and its complications (number of fistula tracts, location and relationship to anal sphincter muscle complex, and presence of abscess), but every CTE or MRE should image the anus, and radiologists should comment if findings suspicious for perianal disease (fistula or abscess) are present. (Strong)
7. Because intramural T2 hyperintensity, restricted diffusion, peri-enteric stranding, wall thickness and mural ulcerations seen at cross-sectional enterography generally correlate with severity of endoscopic and histologic inflammation, radiologists should comment on these findings and describe them when present. (Strong)
8. MRE should be used rather than CTE, when possible, for estimating response to medical treatment in asymptomatic Crohn's disease, as its multiparametric nature permits evaluation of multiple imaging parameters that reflect inflammation and avoids radiation. (Weak)
9. If cross-sectional enterography is indicated and intravenous contrast cannot be administered, noncontrast MRE with T2-weighted and diffusion-weighted imaging should be used an acceptable alternative. (Weak)
10. CTE and MRE exams should be carefully evaluated for evidence of mesenteric venous thromboses or occlusions and small bowel varices. (Strong)

Note.—Strong recommendation indicates confidence that the desirable effects of the test or interpretation will result in a positive impact on patient care. Weak recommendation indicates that uncertainty exists relating to the positive and negative impacts on patient care.

penetrating disease has not been seen to arise in the setting of a stricture without inflammation. Imaging criteria for fibrosis are currently being developed and evaluated (54,56).

Internal penetrating disease (not perianal disease) may occur at any time point during the course of the disease, but occurs overwhelmingly in patients with strictures associated with active inflammation. Sinus tract and fistula formation, abscess, and free perforation are all findings of penetrating disease. Fistulas may be simple or complex. Simple fistulas are comprised of a single tract connecting a bowel loop to adjacent bowel or other structures, such as the urinary bladder. Complex fistulas connect multiple adjacent bowel loops or structures. With both simple and complex fistulas, the bowel loops affected are often angulated and appear tethered by the fistula tract (Figure 7). Furthermore, it is common to see small, interloop abscesses along the course of these complex fistulas. If no active inflammation is associated with a fistula, this should also be stated. Postoperative fistulas are often not associated with inflammation, but obviously arise at or near the site of anastomoses.

Colonoscopy is considered the reference standard for colorectal inflammation. This guideline only addresses small bowel Crohn's disease and complications frequently seen on CTE and MRE in these patients. A comprehensive guide for describing colorectal inflammation at cross-sectional imaging is beyond the scope of this work, as we considered CTE and MRE as part of an imaging strategy combined with clinical assessment and ileocolonoscopy. Transabdominal ultrasound (with or without intravenous contrast) and video capsule endoscopy are used at many institutions in the diagnosis and surveillance of Crohn's disease, and their role in clinical management continues to evolve; however, integration of their imaging findings is also beyond the scope of this work, which focuses exclusively on CTE and MRE for small bowel Crohn's disease.

Structured Reporting

Structured reporting templates are used by many radiologic practices for specific clinical scenarios to insure important clinical information is always captured in a systematic fashion. They have been shown to improve the quality of information conveyed to referring clinicians (74). Several groups have advocated for structured reporting for CTE and MRE. Table 7 demonstrates a structured cross-sectional enterography report and is adapted from Baker et al (7).

Conclusions

CTE and MRE can provide key information to guide treatment relating to the presence, severity, and extent of Crohn's disease and its complications that is not available from clinical and endoscopic evaluation, for both adult and pediatric patients. This guideline establishes a common expectation for the use of CTE and MRE in patients with small bowel Crohn's disease, as well as elucidating anatomic structures to be systematically evaluated, the significance of specific imaging findings, and agreed-upon terms for describing imaging findings of small bowel Crohn's disease inflammation and its complications. A

Figure 10

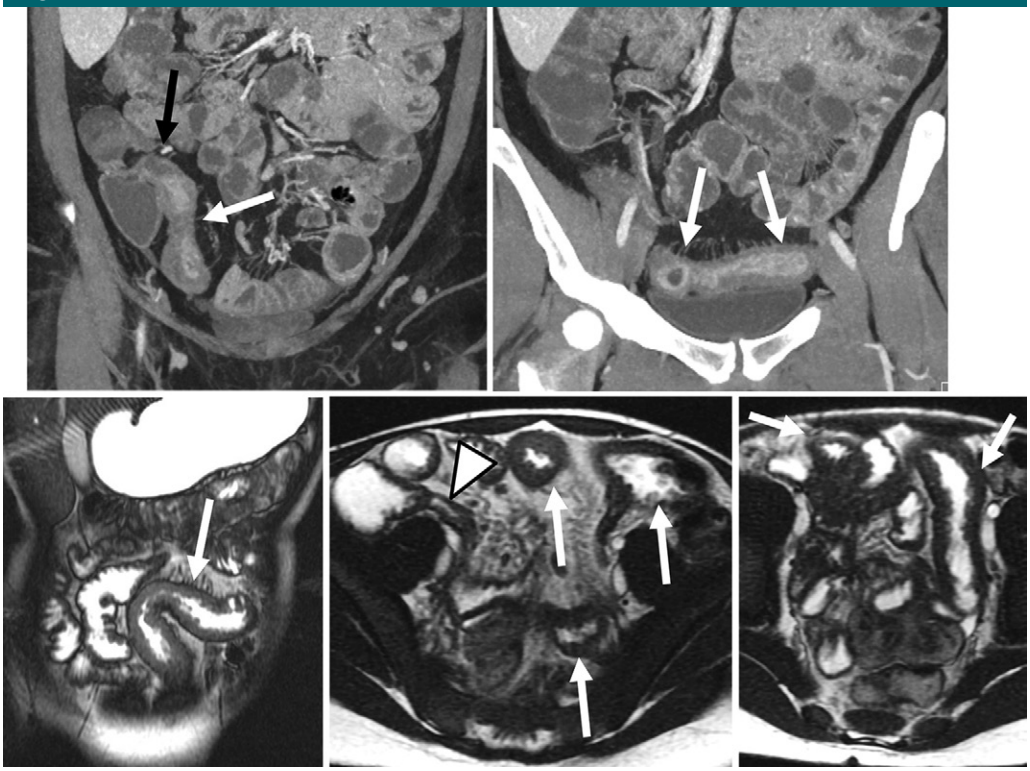

Figure 10: CTE performed 2 weeks after normal ileocolonoscopy shows that the very distal terminal ileum *(top left, black arrow)* appears normal, but marked asymmetric wall thickening, comb sign, and mural stratification indicating active inflammatory Crohn's disease is present in the more proximal terminal ileum for approximately 20 cm *(top row, white arrows)*. On bottom row in a different patient, MRE images demonstrate extensive active small bowel inflammation as evidenced by marked wall thickening *(arrows)* involving long segments of jejunum and ileum, but normal-appearing terminal ileum *(arrowhead)*. Subsequent ileoscopy and biopsy were normal.

Table 5

Potential Considerations for Selecting Computed Tomography or Magnetic Resonance Enterography in a Crohn's Patient

Consider CTE	Consider MRE
Concern for sepsis, or suspect complex intra-abdominal penetrating disease with need for potential subsequent intervention	Prior CTE
Older patient (over 35 years old)	Young patient (under 35 years old)
First cross-sectional enterography exam or acutely symptomatic patient	Exam performed to evaluate Crohn's patient that is not acutely ill or assess response to therapy
Test to rule out other diseases, which may cause diarrhea, or to evaluate for other small bowel diseases	Known perianal fistula or perianal sepsis
When low-dose CT techniques utilized	Pregnancy (performed without intravenous contrast)
Contraindications to MR imaging, allergy to gadolinium-based contrast media, or claustrophobia with prior MR exams	Iodinated contrast media allergy
Local imaging access and expertise	Local imaging access and expertise

shared approach for linking specific imaging findings to clinically useful impressions can be used to better guide therapeutic decision making in the short-term, and improve our understanding of the natural history of long-term complications of Crohn's disease. As imaging techniques, new therapies, and a better understanding of the Crohn's disease pathophysiology are developed, this shared approach can also evolve to reflect these new advances.

Acknowledgments

Members of the Society of Abdominal Radiology Crohn's Disease-focused Panel include Mahmoud Al-Hawary (Department of Radiology, University of Michigan, Ann Arbor, Michigan), Sudha Anupindi (Department of Radiology, The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania), Mark E. Baker (Imaging Institute, Cleveland Clinic, Cleveland, Ohio),

Table 6

Recommended Impressions Summarizing Imaging Findings of Small Bowel Crohn's Disease at Computed Tomography and Magnetic Resonance Enterography

Impression	Imaging findings	Comments
Inflammation		
Nonspecific small bowel inflammation	Segmental hyperenhancement and/or wall thickening in a patient without known Crohn's disease	Please see segmental hyperenhancement in Table 1 for differential diagnosis
Active inflammatory small bowel Crohn's disease Without luminal narrowing With luminal narrowing	Asymmetric wall thickening, hyperenhancement and mural edema (ie, intramural T2-weighted signal) are specific for Crohn's disease involvement Ulcers, wall thickening, restricted diffusion, and perienteric stranding indicate more severe disease Asymmetry is not required at sites of known prior disease or in a known Crohn's disease patient	Describe sites, lengths, and add descriptors representing severity Compare lengths and severity of disease if assessing for disease response or progression Severe inflammation is manifested by ulcerations, marked T2-weighted signal hyperintensity and restricted diffusion, and severe wall thickening Mild disease is manifested by hyperenhancement, mild wall thickening, and absence of severe signs of inflammation
Crohn's disease with no imaging signs of active inflammation (known prior active inflammatory Crohn's disease with residual radiologic findings)	Imaging findings of inflammation are absent Patchy intramural fat or residual pseudosacculation/scarring without inflammation may be seen	Mural healing can only be described when the present study demonstrates a normal bowel segment that was inflamed on a prior exam
No imaging signs of active inflammation	Imaging findings of inflammation are absent	
Stricture		
With imaging findings of active inflammation	Persistent luminal narrowing in area of Crohn's disease with upstream dilation Accompanying imaging findings of active inflammation Consider adding "with small bowel obstruction" if upstream dilation is moderate to severe	
Without imaging findings of active inflammation	Persistent segmental luminal narrowing with upstream dilation Wall thickening is present, but with absence of inflammatory findings on imaging	Describe location, length, degree of obstruction
Penetrating Crohn's disease (added *in addition* to determination of inflammatory Crohn's disease and stricture)	Fistula and/or sinus tract; inflammatory mass; abscess; free perforation	Describe location and type, as well as association with Crohn's disease stricture or inflamed bowel segment State if fistulas are simple or complex Carefully examine for asterisk-shaped fistula complexes
Perianal Crohn's disease	State if perianal fistula or abscess is present or absent. If present, state if fistulas are simple or complex	Describe perianal disease classification, including associated abscess, with size, according to accepted criteria, if possible (63,109) Recommend consideration of pelvic MR imaging
Other complications	Mesenteric venous thrombosis or occlusion, AVN, PSC, sacroiliitis, pancreatitis, neoplasm, cholelithiasis, or kidney stone	

Note.—Colonoscopy is considered the reference standard for colorectal inflammation. Recommendations for CTE and MRE descriptions of colorectal inflammation are not provided, but can parallel descriptions of small bowel inflammation, stricture, and penetration.

AVN, avascular necrosis; MRI, magnetic resonance imaging; PSC, primary sclerosing cholangitis.

David Bruining (Division of Gastroenterology and Hepatology, Mayo Clinic, Rochester, Minnesota), Kassa Darge (Department of Radiology, The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania), Jonathan Dillman (Department of Radiology, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio), David Einstein (Imaging Institute, Cleveland Clinic, Cleveland, Ohio), Jeff L. Fidler (Department of Radiology, Mayo Clinic, Rochester, Minnesota), Joel G. Fletcher (Department of Radiology, Mayo Clinic, Rochester, Minnesota), Michael S. Gee (Department of Radiology, Massachusetts General Hospital, Boston, Massachusetts), David Grand (Department of Radiology, Brown University, Providence, Rhode Island), Falvius Guglielmo (Department of Radiology, Thomas Jefferson University, Philadelphia, Pennsylvania); Amy K. Hara (Department of Radiology, Mayo Clinic, Scottsdale, Arizona); Tracy A. Jaffe (Department of Radiology, Duke University, Durham, North Carolina), Dean Maglinte (Department of Radiology, Indiana University, Indianapolis, Indiana), Alec Megibow (Department of Radiology, NYU-Langone Health, New York, New York), Seong Ho Park (Department of Radiology, University of Ulsan College of Medicine, Asan Medical Center, Seoul, Korea); Joel Platt (Department of Radiology, University of Michigan, Ann Arbor, Michigan), Daniel Podberesky (Department of Radiology, Nemours Children's Health System, Nemours Children's Hospital, Orlando, Florida), Jordi Rimola (Department of Radiology, Hospital Clinic Barcelona, University of Barcelona, Barcelona, Spain), Dushyant V. Sahani (Department of Radiology, Massachu-

Table 7

Suggested Reporting Template Adapted From Baker et al

MRE or CTE with intravenous contrast
Appropriate entries for patient history, CT technique, oral and intravenous contrast media, other medications, and radiation dose as per institutional guidelines.
Comparison:
Findings:
Disease location (stomach, duodenum, jejunum, mid or distal ileum, terminal ileum, colon, rectum, anus)
Number of diseased segments
Type(s) of disease (if all segments have similar findings then report once; if one or more segments are different then report each separately)
Inflammation
Describe imaging findings of inflammation (hyperenhancement, enhancement pattern, bowel wall thickening, intramural edema, ulcerations, restricted diffusion)
Describe location, length and severity (see Table 1), and describe stability or increase or decrease compared to prior studies
Other mesenteric findings (eg, mesenteric vein thrombosis, perienteric edema, comb sign, fibrofatty proliferation)
Stricture
State if imaging findings of inflammation is/are present
Describe location and length
Describe degree of upstream dilation (mild <4 cm, moderate to severe ≥4 cm)
Penetrating complications: describe sinus tract, fistula, inflammatory mass, abscess, or perforation
Site
Complexity
Relationship to inflamed bowel or stricture
Perianal disease
Site
Complexity/classification
Associated abscess: presence or absence
Response to therapy
Compare to earlier exams to describe resolution or exacerbation of inflammatory findings
Extra-intestinal findings: sacroiliitis, AVN, PSC, cholelithiasis, nephrolithiasis,
Other complications or unrelated findings, eg, chronic mesenteric vein occlusion
Impressions (add modifiers as shown in Table 4):
Inflammation statement: If inflammation is present, specify location and length, estimate severity or change
Nonspecific small bowel inflammation
Active inflammatory small bowel Crohn's disease (± luminal narrowing)
Crohn's disease with no imaging signs of active inflammation
No imaging signs of small bowel inflammation
Stricture statement
Stricture with signs of active inflammation, specify length of stricture and degree of proximal obstruction
Stricture without signs of active inflammation, specify length and degree of proximal obstruction
Penetrating statement: describe type of fistula, simple or complex, and other penetration, and association with strictures and enteric inflammation
Perianal fistula (if present)
± Other complications

Note.—Adapted From Baker et al (7). AVN, avascular necrosis; PSC, primary sclerosing cholangitis.

setts General Hospital, Boston, Massachusetts), Jorge Soto (Boston Medical Center, Boston, Massachusetts); Stuart A. Taylor (Centre for Medical Imaging, University College London, London, England).

The authors gratefully acknowledge the assistance of Dr Prakkal Deepak in literature searches to identify original research publications and meta-analyses relating to each imaging finding evaluated.

Reviewed and approved by the Society of Abdominal Radiology Board, American Gastroenterological Association Institute Council, and Society for Pediatric Radiology Board.

Conflicts of interest: All authors were required to complete disclosure statements. These statements were maintained by the Society of Abdominal Radiology Crohn's Disease-Focused Panel. The authors disclose the following: William Sandborn reports grants and personal fees from Prometheus Laboratories, grants and personal fees from AbbVie, grants and personal fees from Boehringer Ingelheim, grants and personal fees from Takeda, grants and personal fees from Atlantic Pharmaceuticals, grants and personal fees from Janssen, grants and personal fees from Bristol-Myers Squibb, grants and personal fees from Genentech, grants and personal fees from Nutrition Science Partners, personal fees from Kyowa Hakko Kirin, personal fees from Millennium Pharmaceuticals, personal fees from Celgene Cellular Therapeutics, personal fees from Santarus, personal fees from Salix Pharmaceuticals, personal fees from Catabasis Pharmaceuticals, personal fees from Vertex Pharmaceuticals, personal fees from Warner Chilcott, personal fees from Gilead Sciences, personal fees from Cosmo Pharmaceuticals, personal fees from Ferring Pharmaceuticals, personal fees from Sigmoid Biotechnologies, personal fees from Tillotts Pharma, personal fees from Am Pharma BV, personal fees from Dr. August Wolff, personal fees from Avaxia Biologics, personal fees from Zyngenia, personal fees from Ironwood Pharmaceuticals, personal fees from Index Pharmaceuticals, personal fees from Nestle, personal fees from Lexicon Pharmaceuticals, personal fees from UCB Pharma, personal fees from Orexigen, personal fees from Luitpold Pharmaceuticals, personal fees from Baxter Healthcare, personal fees from Ferring Research Institute, personal fees from Amgen, personal fees from Novo Nordisk, personal fees from Mesoblast Inc., personal fees from Shire, personal fees from Ardelyx Inc., personal fees from Actavis, personal fees from Seattle Genetics, personal fees from MedImmune (AstraZeneca), personal fees from Actogenix NV, personal fees from Lipid Therapeutics Gmbh, personal fees from Eisai, personal fees from Qu Biologics, personal fees from Toray Industries Inc., personal fees from Teva Pharmaceuticals, personal fees from Eli Lilly, personal fees from Chiasma, personal fees from TiGenix, personal fees from Adherion Therapeutics, personal fees from Immune Pharmaceuticals, personal fees from Celgene, personal fees from Arena Pharmaceuticals, personal fees from Ambrx Inc., personal fees from Akros Pharma, personal fees from Vascular Biogenics, personal fees from Theradiag, personal fees from Forward Pharma, personal fees from Regeneron, personal fees from Galapagos, personal fees from Seres Health, personal fees from Ritter Pharmaceuticals, personal fees from Theravance, personal fees from Palatin, personal fees from Biogen, personal fees from Western University (owner of Robarts Clinical Trials), outside the submitted work; In addition, Dr. Sandborn has a patent Topical azathioprine to treat inflammatory

bowel disorders (US 5,691,343) issued, a patent Topical formulations of azathioprine to treat inflammatory bowel disorders (US 5,905,081) issued, a patent Colonic delivery of nicotine to treat inflammatory bowel disease (South African patent 97/1020; US 5,846,983, 5,889,028, and 6,166,044; Mexico patent 209636; Europe patents 0954337 and 893998; Hong Kong patent HK1019043; China patent ZL97192177; Czech patent 293616; Canada patent 2,246,235) issued, a patent The use of azathioprine to treat Crohn's disease (US 5,733,915) issued, a patent Azathioprine compositions for colonic administration (New Zealand patent 306062; Singapore patent 45647; Australia patent 707168; Czech patent 290428) issued, a patent Intestinal absorption of nicotine to treat nicotine responsive conditions (Australia patent 718052; US 6,238,689) issued, a patent The use of topical azathioprine and thioguanine to treat colorectal adenomas (US 6,166,024) issued, a patent Enema and enterically coated oral dosage forms of azathioprine (US 6,432,967) issued, a patent A pharmaceutical composition for the treatment of inflammatory bowel disease (US 7,341,741) issued, a patent Intestinal absorption of nicotine to treat nicotine responsive conditions (Canada patent 2,260,909) issued, and a patent Obesity treatment and device (US 7,803,195 B2) licensed to Enteromedics. Cary Sauer reports consultancy with personal fees from Abbvie. Mark E. Baker reports a grant to institution from Siemens Healthineers. Jonathan Dillman reports grants to institution from Bracco Diagnostics and Siemens Medical Solutions. Joel G. Fletcher reports grant to institution from Siemens Healthineers, and consultancy with fees to institution from Medtronic. Daniel Podberesky reports travel reimbursement from Philips, Siemens and GE Healthcare, and is on the Professional Speakers Bureau for Toshiba Medical Systems. Jordi Rimola reports grants/consultancy and personal fees from Robarts Clinical Trials, Abbvie, Takeda, TiGenix, Bioclinica, and Genentech. Stuart A. Taylor reports grants and personal fees from Robarts Clinical Trials. All other authors report no potential financial conflicts related this work.

Appendix Table 1

Grade	Stricturing lesion	Penetrating lesion
0	Normal	Normal
1	Wall thickening <3 mm or segmental enhancement; no prestenotic dilation	—
2	Wall thickening ≥3 mm or mural stratification; no prestenotic dilation	Deep transmural ulceration
3	Stricture with prestenotic dilation	Abscess or fistula

Appendix Table 2

Consensus disease state	Lemann stricture grade	Lemann penetrating grade
No imaging signs of active inflammation	0	0
Active inflammatory without luminal narrowing	1 or 2	Unlikely to occur (2 if deep transmural ulcers present; otherwise score of 0)
Active inflammatory with luminal narrowing	1 or 2	2 if deep transmural ulcers present; otherwise score of 0
Stricture with active inflammation	3	2 if deep transmural ulcers present; otherwise score of 0
Penetrating disease	Dependent upon coexisting enteric inflammation	3

Appendix 1. Key Technical Specifications for CT and MR Enterography

The Society of Abdominal Radiology Crohn's Disease-Focused Panel has published key technical parameters for the performance of CTE and MRE (7,8). Both techniques utilize per oral administration of >900 mL neutral or biphasic enteric contrast agents in divided doses over 45–60 minutes before CT or MR image acquisition, followed by contrast-enhanced imaging in multiple planes to permit visualization of the small bowel wall, lumen, and perienteric mesentery and vasculature. Imaging of the abdomen, pelvis, and perineum (including the anal sphincter complex) is performed. Contrast-enhanced imaging is initiated during the time period between enteric and portal phases of enhancement, which is 50–70 seconds after beginning the injection of intravenous contrast. For CTE, acquisition technique is adapted to patient size with consideration for low-dose techniques, such as tube potential selection, automatic exposure control, and iterative reconstruction, with slice thickness being 2–3 mm. For MRE, T2-weighted pulse sequences, such as single-shot fast spin echo, are acquired in multiple planes, with at least 1 plane having fat saturation so that bowel wall edema can be evaluated, with additional diffusion-weighted and balanced steady-state free precession imaging being helpful. Owing to the need to ingest larger amounts of oral contrast, CTE and MRE examinations are generally outpatient imaging examinations, with individual institutions adapting these examinations for emergent settings, depending upon the patient presentation and history, and institutional personnel, scanner access, and expertise.

Appendix 2. Linkage Between Lemann Index of Digestive Disease Damage and Society for Abdominal Radiology Terms for Disease State (Impressions)

The Lemann Index or Score was developed to describe the digestive disease location, severity, extent, and progression of Crohn's disease as measured by imaging findings and reflected in surgical resections. It is a measure of the cumulative burden of digestive disease damage. The scale is based on the following 3 aspects: stricturing lesions, penetrating lesions, and the history of surgery or any other interventional procedure. For each aspect, a grade is assigned from 0 to 3, and is summarized in Appendix Table 1[26,73].

The endorsed Consensus Terms for Disease State are analogous to the Lemann index, facilitating the transfer of imaging reporting into disease damage (Appendix Table 2), the primary difference

being that the Lemann index does not necessarily state that imaging findings of inflammation are present for grade 1 or 2 strictures. For example, findings of prior inflammation, such as intramural fat, could cause wall thickening, which would be classified as grade 2 strictures using Lemann, and which would not be classified as active inflammation or strictures under the current proposal. Additionally, the current proposal creates a stronger linkage to stricturing disease when penetrating complications are present.

References

1. Fletcher JG, Fidler JL, Bruining DH, Huprich JE. New concepts in intestinal imaging for inflammatory bowel diseases. Gastroenterology 2011;140:1795–1806.
2. Panes J, Bouhnik Y, Reinisch W, et al. Imaging techniques for assessment of inflammatory bowel disease: joint ECCO and ESGAR evidence-based consensus guidelines. J Crohns Colitis 2013;7:556–585.
3. Faubion WA Jr, Fletcher JG, O'Byrne S, et al. EMerging BiomARKers in Inflammatory Bowel Disease (EMBARK) study identifies fecal calprotectin, serum MMP9, and serum IL-22 as a novel combination of biomarkers for Crohn's disease activity: role of cross-sectional imaging. Am J Gastroenterol 2013;108:1891–1900.
4. Rimola J, Rodriguez S, Garcia-Bosch O, et al. Magnetic resonance for assessment of disease activity and severity in ileocolonic Crohn's disease. Gut 2009;58:1113–1120.
5. Samuel S, Bruining DH, Loftus EV Jr, et al. Endoscopic skipping of the distal terminal ileum in Crohn's disease can lead to negative results from ileocolonoscopy. Clin Gastroenterol Hepatol 2012;10:1253–1259.
6. Deepak P, Fletcher JG, Fidler JL, et al. Radiological response is associated with better long-term outcomes and is a potential treatment target in patients with small bowel Crohn's disease. Am J Gastroenterol 2016;111:997–1006.
7. Baker ME, Hara AK, Platt JF, et al. CT enterography for Crohn's disease: optimal technique and imaging issues. Abdom Imaging 2015;40:938–952.
8. Grand DJ, Guglielmo FF, Al-Hawary MM. MR enterography in Crohn's disease: current consensus on optimal imaging technique and future advances from the SAR Crohn's disease-focused panel. Abdom Imaging 2015;40:953–964.
9. American College of Radiology. ACR-SAR-SPR Practice parameter for the performance of CT enterography. https://www.acr.org/~/media/99D260410DF44A3BA01F1AB716DE8F2F.pdf. Published 2015. Accessed March 2, 2017.
10. Bruining DH, Siddiki HA, Fletcher JG, et al. Benefit of computed tomography enterography in Crohn's disease: effects on patient management and physician level of confidence. Inflamm Bowel Dis 2012;18:219–225.
11. Higgins PD, Caoili E, Zimmermann M, et al. Computed tomographic enterography adds information to clinical management in small bowel Crohn's disease. Inflamm Bowel Dis 2007;13:262–268.
12. Al-Hawary MM, Francis IR, Chari ST, et al. Pancreatic ductal adenocarcinoma radiology reporting template: consensus statement of the society of abdominal radiology and the American Pancreatic Association. Gastroenterology 2014;146:291–304. e291.
13. Bruining DH, Loftus EV Jr, Ehman EC, et al. Computed tomography enterography detects intestinal wall changes and effects of treatment in patients with Crohn's disease. Clin Gastroenterol Hepatol 2011;9:679–683. e671.
14. Bruining DH, Bhatnagar G, Rimola J, et al. CT and MR enterography in Crohn's disease: current and future applications. Abdom Imaging 2015;40:965–974.
15. Baert F, Moortgat L, Van Assche G, et al. Mucosal healing predicts sustained clinical remission in patients with early-stage Crohn's disease. Gastroenterology 2010;138:463–468. quiz e410–e461.
16. Beppu T, Ono Y, Matsui T, et al. Mucosal healing of ileal lesions is associated with long-term clinical remission after infliimab maintenance treatment in patients with Crohn's disease. Dig Endosc 2015;27:73–81.
17. Sakuraba A, Annunziata ML, Cohen RD, et al. Mucosal healing is associated with improved long-term outcome of maintenance therapy with natalizumab in Crohn's disease. Inflamm Bowel Dis 2013;19:2577–2583.
18. Schnitzler F, Fidder H, Ferrante M, et al. Mucosal healing predicts long-term outcome of maintenance therapy with infliximab in Crohn's disease. Inflamm Bowel Dis 2009;15:1295–1301.
19. Hashimoto S, Shimizu K, Shibata H, et al. Utility of computed tomographic enteroclysis/enterography for the assessment of mucosal healing in Crohn's disease. Gastroenterol Res Pract 2013;2013:984916.
20. Ordas I, Rimola J, Rodriguez S, et al. Accuracy of magnetic resonance enterography in assessing response to therapy and mucosal healing in patients with Crohn's disease. Gastroenterology 2014;146:374–382. e371.
21. Sauer CG, Middleton JP, McCracken C, et al. Magnetic resonance enterography healing and magnetic resonance enterography remission predicts improved outcome in pediatric Crohn disease. J Pediatr Gastroenterol Nutr 2016;62:378–383.
22. Zappa M, Stefanescu C, Cazals-Hatem D, et al. Which magnetic resonance imaging findings accurately evaluate inflammation in small bowel Crohn's disease? A retrospective comparison with surgical pathologic analysis. Inflamm Bowel Dis 2011;17:984–993.
23. Rimola J, Ordas I, Rodriguez S, et al. Magnetic resonance imaging for evaluation of Crohn's disease: validation of parameters of severity and quantitative index of activity. Inflamm Bowel Dis 2011;17:1759–1768.
24. Steward MJ, Punwani S, Proctor I, et al. Non-perforating small bowel Crohn's disease assessed by MRI enterography: derivation and histopathological validation of an MR-based activity index. Eur J Radiol 2012;81:2080–2088.
25. Kim KJ, Lee Y, Park SH, et al. Diffusion-weighted MR enterography for evaluating Crohn's disease: how does it add diagnostically to conventional MR enterography? Inflamm Bowel Dis 2015;21:101–109.
26. Pariente B, Cosnes J, Danese S, et al. Development of the Crohn's disease digestive damage score, the Lemann score. Inflamm Bowel Dis 2011;17:1415–1422.
27. Levine A, Griffiths A, Markowitz J, et al. Pediatric modification of the Montreal classification for inflammatory bowel disease: the Paris classification. Inflamm Bowel Dis 2011;17:1314–1321.
28. Silverberg MS, Satsangi J, Ahmad T, et al. Toward an integrated clinical, molecular and serological classification of inflammatory bowel disease: report of a Working Party of the 2005 Montreal World Congress of Gastroenterology. Can J Gastroenterol 2005;19(Suppl A):5A–36A.
29. Oberhuber G, Stangl PC, Vogelsang H, et al. Significant association of strictures and internal fistula formation in Crohn's disease. Virchows Arch 2000;437:293–297.
30. Kelly JK, Preshaw RM. Origin of fistulas in Crohn's disease. J Clin Gastroenterol 1989;11:193–196.
31. Adler J, Punglia DR, Dillman JR, et al. Computed tomography enterography findings

correlate with tissue inflammation, not fibrosis in resected small bowel Crohn's disease. Inflamm Bowel Dis 2012;18:849–856.

32. Schunemann HJ, Oxman AD, Brozek J, et al. Grading quality of evidence and strength of recommendations for diagnostic tests and strategies. BMJ 2008;336:1106–1110.

33. Guyatt GH, Oxman AD, Kunz R, et al. What is "quality of evidence" and why is it important to clinicians? BMJ 2008;336:995–998.

34. Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 2008;336:924–926.

35. Guyatt GH, Oxman AD, Kunz R, et al. Going from evidence to recommendations. BMJ 2008;336:1049–1051.

36. Bodily KD, Fletcher JG, Solem CA, et al. Crohn Disease: mural attenuation and thickness at contrast-enhanced CT enterography—correlation with endoscopic and histologic findings of inflammation. Radiology 2006;238:505–516.

37. Church PC, Turner D, Feldman BM, et al. Systematic review with meta-analysis: magnetic resonance enterography signs for the detection of inflammation and intestinal damage in Crohn's disease. Aliment Pharmacol Ther 2015;41:153–166.

38. Horsthuis K, Bipat S, Bennink RJ, et al. Inflammatory bowel disease diagnosed with US, MR, scintigraphy, and CT: meta-analysis of prospective studies. Radiology 2008;247:64–79.

39. Qiu Y, Mao R, Chen BL, et al. Systematic review with meta-analysis: magnetic resonance enterography vs. computed tomography enterography for evaluating disease activity in small bowel Crohn's disease. Aliment Pharmacol Ther 2014;40:134–146.

40. Siddiki H, Fletcher JG, Hara AK, et al. Validation of a lower radiation computed tomography enterography imaging protocol to detect Crohn's disease in the small bowel. Inflamm Bowel Dis 2011;17:778–786.

41. Baker ME, Walter J, Obuchowski NA, et al. Mural attenuation in normal small bowel and active inflammatory Crohn's disease on CT enterography: location, absolute attenuation, relative attenuation, and the effect of wall thickness. AJR Am J Roentgenol 2009;192:417–423.

42. Macari M, Balthazar EJ. CT of bowel wall thickening: significance and pitfalls of interpretation. AJR Am J Roentgenol 2001;176:1105–1116.

43. Plumb AA, Pendse DA, McCartney S, et al. Lymphoid nodular hyperplasia of the terminal ileum can mimic active crohn disease on MR enterography. AJR Am J Roentgenol 2014;203:W400–W407.

44. Meyers MA, McGuire PV. Spiral CT demonstration of hypervascularity in Crohn disease: "vascular jejunization of the ileum" or the "comb sign". Abdom Imaging 1995;20:327–332.

45. Tielbeek JA, Makanyanga JC, Bipat S, et al. Grading Crohn disease activity with MRI: interobserver variability of MRI features, MRI scoring of severity, and correlation with Crohn disease endoscopic index of severity. AJR Am J Roentgenol 2013;201:1220–1228.

46. Park SH. DWI at MR enterography for evaluating bowel inflammation in Crohn disease. AJR Am J Roentgenol 2016:1–9.

47. Makanyanga J, Punwani S, Taylor SA. Assessment of wall inflammation and fibrosis in Crohn's disease: value of T1-weighted gadolinium-enhanced MR imaging. Abdom Imaging 2012;37:933–943.

48. Morani AC, Smith EA, Ganeshan D, et al. Diffusion-weighted MRI in pediatric inflammatory bowel disease. AJR Am J Roentgenol 2015;204:1269–1277.

49 Hordonneau C, Buisson A, Scanzi J, et al. Diffusion-weighted magnetic resonance imaging in ileocolonic Crohn's disease: validation of quantitative index of activity. Am J Gastroenterol 2014;109:89–98.

50. Makanyanga JC, Pendse D, Dikaios N, et al. Evaluation of Crohn's disease activity: initial validation of a magnetic resonance enterography global score (MEGS) against faecal calprotectin. Eur Radiol 2014;24:277–287.

51. Deepak P, Fletcher JG, Fidler JL, Bruining DH. Computed tomography and magnetic resonance enterography in Crohn's disease: assessment of radiologic criteria and endpoints for clinical practice and trials. Inflamm Bowel Dis 2016;22:2280–2288.

52. Rieder F, Zimmermann EM, Remzi FH, et al. Crohn's disease complicated by strictures: a systematic review. Gut 2013;62:1072–1084.

53. Chiorean MV, Sandrasegaran K, Saxena R, et al. Correlation of CT enteroclysis with surgical pathology in Crohn's disease. Am J Gastroenterol 2007;102:2541–2550.

54. Barkmeier DT, Dillman JR, Al-Hawary M, et al. MR enterography-histology comparison in resected pediatric small bowel Crohn disease strictures: can imaging predict fibrosis? Pediatr Radiol 2016;46:498–507.

55. Higgins PD, Fletcher JG. Characterization of inflammation and fibrosis in Crohn's disease lesions by magnetic resonance imaging. Am J Gastroenterol 2015;110:441–443.

56. Rimola J, Planell N, Rodriguez S, et al. Characterization of inflammation and fibrosis in Crohn's disease lesions by magnetic resonance imaging. Am J Gastroenterol 2015;110:432–440.

57. Tielbeek JA, Ziech ML, Li Z, et al. Evaluation of conventional, dynamic contrast enhanced and diffusion weighted MRI for quantitative Crohn's disease assessment with histopathology of surgical specimens. Eur Radiol 2014;24:619–629.

58. Wnorowski AM, Guglielmo FF, Mitchell DG. How to perform and interpret cine MR enterography. J Magn Reson Imaging 2015;42:1180–1189.

59. Weber NK, Fletcher JG, Fidler JL, et al. Clinical characteristics and imaging features of small bowel adenocarcinomas in Crohn's disease. Abdom Imaging 2015;40:1060–1067.

60. Martin DR, Kalb B, Sauer CG, et al. Magnetic resonance enterography in Crohn's disease: techniques, interpretation, and utilization for clinical management. Diagn Interv Radiol 2012;18:374–386.

61. Morris J, Spencer JA, Ambrose NS. MR imaging classification of perianal fistulas and its implications for patient management. Radiographics 2000;20:623–635; discussion 635–627.

62. Sheedy SP, Bruining DH, Dozois EJ, et al. MR Imaging of perianal Crohn disease. Radiology 2017;282:628–645.

63. Gecse KB, Bemelman W, Kamm MA, et al. A global consensus on the classification, diagnosis and multidisciplinary treatment of perianal fistulising Crohn's disease. Gut 2014;63:1381–1392.

64. Tozer PJ, Whelan K, Phillips RK, et al. Etiology of perianal Crohn's disease: role of genetic, microbiological, and immunological factors. Inflamm Bowel Dis 2009;15:1591–1598.

65. Bass JA, Goldman J, Jackson MA, et al. Pediatric Crohn disease presenting as appendicitis: differentiating features from typical appendicitis. Eur J Pediatr Surg 2012;22:274–278.

66. Soyer P, Boudiaf M, Dray X, et al. Crohn's disease: multi-detector row CT-enteroclysis appearance of the appendix. Abdom Imaging 2010;35:654–660.

67. Vietti Violi N, Fournier N, Duran R, et al. Acute mesenteric vein thrombosis: factors

associated with evolution to chronic mesenteric vein thrombosis. AJR Am J Roentgenol 2014;203:54–61.

68. Violi NV, Schoepfer AM, Fournier N, et al. Prevalence and clinical importance of mesenteric venous thrombosis in the Swiss Inflammatory Bowel Disease Cohort. AJR Am J Roentgenol 2014;203:62–69.

69. American College of Radiology. ACR–SAR–SPR practice parameter for the performance of magnetic resonance (mr) enterography. https://www.acr.org/~/media/99F8D0F593E64860AA3B1EC6CA1C758D.pdf. Published 3015. Accessed March 2, 2017.

70. Dillman JR, Adler J, Zimmermann EM, et al. CT enterography of pediatric Crohn disease. Pediatr Radiol 2010;40:97–105.

71. Mollard BJ, Smith EA, Dillman JR. Pediatric MR enterography: technique and approach to interpretation-how we do it. Radiology 2015;274:29–43.

72. Cosnes J, Cattan S, Blain A, et al. Long-term evolution of disease behavior of Crohn's disease. Inflamm Bowel Dis 2002;8:244–250.

73. Pariente B, Mary JY, Danese S, et al. Development of the Lemann index to assess digestive tract damage in patients with Crohn's disease. Gastroenterology 2015;148:52–63. e53.

74. Schwartz LH, Panicek DM, Berk AR, Li Y, Hricak H. Improving communication of diagnostic radiology findings through structured reporting. Radiology 2011;260:174–181.

75. Coimbra AJ, Rimola J, O'Byrne S, et al. Magnetic resonance enterography is feasible and reliable in multicenter clinical trials in patients with Crohn's disease, and may help select subjects with active inflammation. Aliment Pharmacol Ther 2016;43:61–72.

76. Fiorino G, Bonifacio C, Peyrin-Biroulet L, et al. Prospective comparison of computed tomography enterography and magnetic resonance enterography for assessment of disease activity and complications in ileocolonic Crohn's disease. Inflamm Bowel Dis 2011;17:1073–1080.

77. Johnson KT, Hara AK, Johnson CD. Evaluation of colitis: usefulness of CT enterography technique. Emerg Radiol 2009;16:277–282.

78. Punwani S, Rodriguez-Justo M, Bainbridge A, et al. Mural inflammation in Crohn disease: location-matched histologic validation of MR imaging features. Radiology 2009;252:712–720.

79. Maccioni F, Staltari I, Pino AR, Tiberti A. Value of T2-weighted magnetic resonance imaging in the assessment of wall inflammation and fibrosis in Crohn's disease. Abdom Imaging 2012;37:944–957.

80. Choi SH, Kim KW, Lee JY, et al. Diffusion-weighted magnetic resonance enterography for evaluating bowel inflammation in Crohn's disease: a systematic review and meta-analysis. Inflamm Bowel Dis 2016;22:669–679.

81. Buisson A, Joubert A, Montoriol PF, et al. Diffusion-weighted magnetic resonance imaging for detecting and assessing ileal inflammation in Crohn's disease. . [Erratum appears in Aliment Pharmacol Ther 2013;37:1031 Note: Ines, D D [corrected to Da Ines, D]] Aliment Pharmacol Ther 2013;37:537–545.

82. Seo N, Park SH, Kim KJ, et al. MR enterography for the evaluation of small-bowel inflammation in Crohn disease by using diffusion-weighted imaging without intravenous contrast material: a prospective noninferiority study. Radiology 2016;278:762–772.

83. James S, Balfe DM, Lee JK, Picus D. Small-bowel disease: categorization by CT examination. AJR Am J Roentgenol 1987;148:863–868.

84. Palascak-Juif V, Bouvier AM, Cosnes J, et al. Small bowel adenocarcinoma in patients with crohn's disease compared with small bowel adenocarcinom de novo. Inflamm Bowel Dis 2005;11:828–832.

85. Frye JM, Hansel SL, Dolan SG, et al. NSAID enteropathy: appearance at CT and MR enterography in the age of multimodality imaging and treatment. Abdom Imaging 2015;40:1011–1025.

86. Soyer P, Boudiaf M, Sirol M, et al. Suspected anastomotic recurrence of Crohn disease after ileocolic resection: evaluation with CT enteroclysis. Radiology 2010;254:755–764.

87. Fornasa F, Benassuti C, Benazzato L. Role of magnetic resonance enterography in differentiating between fibrotic and active inflammatory small bowel stenosis in patients with Crohn's disease. J Clin Imaging Sci 2011;1:35.

88. Solem CA, Loftus EV Jr, Fletcher JG, et al. Small-bowel imaging in Crohn's disease: a prospective, blinded, 4-way comparison trial. Gastrointest Endosc 2008;68:255–266.

89. Sinha R, Murphy P, Sanders S, et al. Diagnostic accuracy of high-resolution MR enterography in Crohn's disease: comparison with surgical and pathological specimen. Clin Radiol 2013;68:917–927.

90. Cullmann JL, Bickelhaupt S, Froehlich JM, et al. MR imaging in Crohn's disease: correlation of MR motility measurement with histopathology in the terminal ileum. Neurogastroenterol Motil 2013;25:749–e577.

91. Froehlich JM, Waldherr C, Stoupis C, et al. MR motility imaging in Crohn's disease improves lesion detection compared with standard MR imaging. Eur Radiol 2010;20:1945–1951.

92. Menys A, Helbren E, Makanyanga J, et al. Small bowel strictures in Crohn's disease: a quantitative investigation of intestinal motility using MR enterography. Neurogastroenterol Motil 2013;25:967–e775.

93. Menys A, Atkinson D, Odille F, et al. Quantified terminal ileal motility during MR enterography as a potential biomarker of Crohn's disease activity: a preliminary study. Eur Radiol 2012;22:2494–2501.

94. Booya F, Akram S, Fletcher JG, et al. CT enterography and fistulizing Crohn's disease: clinical benefit and radiographic findings. Abdom Imaging 2009;34:467–475.

95. Vogel J, da Luz Moreira A, Baker M, et al. CT enterography for Crohn's disease: accurate preoperative diagnostic imaging. Dis Colon Rectum 2007;50:1761–1769.

96. Spinelli A, Fiorino G, Bazzi P, et al. Preoperative magnetic resonance enterography in predicting findings and optimizing surgical approach in Crohn's disease. J Gastrointest Surg 2014;18:83–90; discussion 90–81.

97. Lee SS, Kim AY, Yang SK, et al. Crohn disease of the small bowel: comparison of CT enterography, MR enterography, and small-bowel follow-through as diagnostic techniques. Radiology 2009;251:751–761.

98. Bruining DH, Siddiki HA, Fletcher JG, et al. Prevalence of penetrating disease and extraintestinal manifestations of Crohn's disease detected with CT enterography. Inflamm Bowel Dis 2008;14:1701–1706.

99. Garcia-Bosch O, Ordas I, Aceituno M, et al. Comparison of diagnostic accuracy and impact of magnetic resonance imaging and colonoscopy for the management of Crohn's disease. J Crohn Colitis 2016;10:663–669.

100. Spencer JA, Chapple K, Wilson D, et al. Outcome after surgery for perianal fistula: predictive value of MR imaging. AJR Am J Roentgenol 1998;171:403–406.

101. Parks AG, Gordon PH, Hardcastle JD. A classification of fistula-in-ano. Br J Surg 1976;63:1–12.

102. Hammer MR, Dillman JR, Smith EA, et al. Magnetic resonance imaging of perianal

and perineal crohn disease in children and adolescents. Magn Reson Imaging Clin N Am 2013;21:813–828.

103. de Miguel Criado J, del Salto LG, Rivas PF, et al. MR imaging evaluation of perianal fistulas: spectrum of imaging features. Radiographics 2012;32:175–194.

104. Beets-Tan RG, Beets GL, van der Hoop AG, et al. Preoperative MR imaging of anal fistulas: does it really help the surgeon? Radiology 2001;218:75–84.

105. Schwartz DA, Wiersema MJ, Dudiak KM, et al. A comparison of endoscopic ultrasound, magnetic resonance imaging, and exam under anesthesia for evaluation of Crohn's perianal fistulas. Gastroenterology 2001;121:1064–1072.

106. Colombel JF, Solem CA, Sandborn WJ, et al. Quantitative measurement and visual assessment of ileal Crohn's disease activity by computed tomography enterography: correlation with endoscopic severity and C reactive protein. Gut 2006;55:1561–1567.

107. Fichera A, Cicchiello LA, Mendelson DS, et al. Superior mesenteric vein thrombosis after colectomy for inflammatory bowel disease: a not uncommon cause of postoperative acute abdominal pain. Dis Colon Rectum 2003;46:643–648.

108. Paparo F, Bacigalupo L, Garello I, et al. Crohn's disease: prevalence of intestinal and extraintestinal manifestations detected by computed tomography enterography with water enema. Abdom Imaging 2012;37:326–337.

109. Shenoy-Bhangle A, Gee MS. Magnetic resonance imaging of perianal Crohn's disease in children. Pediatric Radiol 2016;46:838–846.