MR Enterography of Inflammatory Bowel Disease with Endoscopic Correlation[1]

Pankaj Kaushal, MD
Alexander S. Somwaru, MD
Aline Charabaty, MD
Angela D. Levy, MD

Abbreviations: CD = Crohn disease, FISP = fast imaging with steady-state precession, IBD = inflammatory bowel disease, RARE = half-Fourier rapid acquisition with relaxation enhancement, UC = ulcerative colitis, VIBE = volumetric interpolated breath-hold examination

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[1]From the Departments of Radiology (P.K., A.S.S., A.D.L.) and Gastroenterology (A.C.), MedStar Georgetown University Hospital, 3800 Reservoir Rd NW, Room CG201, Washington, DC 20007. Presented as an education exhibit at the 2015 RSNA Annual Meeting. Received March 14, 2016; revision requested June 7 and received July 5; accepted August 9. For this journal-based SA-CME activity, the authors, editor, and reviewers have disclosed no relevant relationships. **Address correspondence to** P.K. (e-mail: *p.kaushal@yahoo.com*).

See discussion on this article by Fidler (pp 132–135).

SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- List the strengths and limitations of MR enterography and endoscopy in the characterization of IBD.
- Describe endoscopic correlates of the MR enterographic findings of IBD.
- Discuss the MR enterographic and endoscopic findings that are based on CD and UC stage.

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Crohn disease (CD) and ulcerative colitis (UC) are the two main forms of idiopathic inflammatory bowel disease (IBD). CD is a transmural chronic inflammatory disorder that can affect any part of the gastrointestinal tract in a discontinuous distribution. UC is a mucosal and submucosal chronic inflammatory disease that typically originates in the rectum and may extend proximally in a continuous manner. In treating patients with CD and UC, clinicians rely heavily on accurate diagnoses and disease staging. Magnetic resonance (MR) enterography used in conjunction with endoscopy and histopathologic analysis can help accurately diagnose and manage disease in the majority of patients. Endoscopy is more sensitive for detection of the early-manifesting mucosal abnormalities seen with IBD and enables histopathologic sampling. MR enterography yields more insightful information about the pathologic changes seen deep to the mucosal layer of the gastrointestinal tract wall and to those portions of the small bowel that are not accessible endoscopically. CD can be classified into active inflammatory, fistulizing and perforating, fibrostenotic, and reparative and regenerative phases of disease. Although CD has a progressive course, there is no stepwise progression between these disease phases, and various phases may exist at the same time. The endoscopic and MR enterographic features of UC can be broadly divided into two categories: acute phase and subacute-chronic phase. Understanding the endoscopic features of IBD and the pathologic processes that cause the MR enterographic findings of IBD can help improve the accuracy of disease characterization and thus optimize the medication and surgical therapies for these patients.

Introduction

Inflammatory bowel disease (IBD) comprises two broad subtypes of chronic gastrointestinal disorders: Crohn disease (CD) and ulcerative colitis (UC). The exact causes of these disorders are unknown. However, growing evidence suggests that an inappropriate inflammatory response to the intestinal environment is a contributing factor in patients with genetic susceptibilities (1). Genetic susceptibilities that are important in the pathogenesis of IBD include genetic defects that result in gastrointestinal tract epithelial barrier function abnormalities and an abnormal immune response to a normal luminal microenvironment (2). The worldwide incidence of IBD is increasing. UC tends to precede CD when IBD is recognized in a new population (3,4). A westernized environment and lifestyle have been associated with IBD, and there is a higher incidence of IBD in the developed world (4). In North America, the incidence of UC is estimated to be 249 cases per 100 000 persons; and the incidence of CD, 319 cases per 100 000 persons (5).

TEACHING POINTS

- Given the transmural inflammatory nature of CD and the resultant transmural extension, cross-sectional imaging is important for evaluating the extent and stage of CD. Imaging is important in the setting of UC when complications are encountered and/or endoscopy is limited.
- CD can be classified as active inflammatory, fistulizing and perforating, fibrostenotic, or reparative and regenerative disease. There is no stepwise progression between these disease phases, and various phases may exist at the same time.
- With active inflammatory CD, wall thickening is due to edema and inflammatory infiltrates, which cause slightly increased signal intensity within thickened bowel segments on T2-weighted RARE images.
- Although patients with superimposed active inflammation may experience some relief with therapy, patients with symptomatic, purely fibrostenotic disease are best treated with surgical resection or strictureplasty. Patients often have recurrent disease despite having undergone surgical resection.
- The inflammatory changes seen with UC tend to be confluent, with a sharp demarcation between the affected and unaffected segments; however, this pattern may be disrupted with treatment, which can result in disease remission in certain bowel segments.

Endoscopy and magnetic resonance (MR) enterography are complementary diagnostic methods in the assessment of IBD. Radiologic evaluation has evolved from barium enema studies to advanced cross-sectional imaging procedures such as MR enterography. MR enterography has been shown to correlate well with endoscopy in the prediction of disease activity, especially CD (6,7). Histopathologic analysis is commonly performed in conjunction with endoscopy for diagnostic confirmation. In this article, we describe the endoscopic correlates of the MR enterographic findings seen in CD and UC. Key pathologic processes that underlie the endoscopic and imaging appearances are outlined. Relevant therapeutic and disease management implications also are described.

Imaging and Endoscopic Evaluation of IBD

Endoscopy and imaging have essential roles in the diagnosis and management of IBD. In addition to enabling assessment of disease type and distribution, endoscopic evaluation enables the histopathologic analysis that is necessary for establishing the diagnosis and differentiating the subtypes of IBD (8). Endoscopy also facilitates therapeutic interventions such as stricture dilation. Another option for direct mucosal visualization is capsule endoscopy, which may be useful for visualizing early-manifesting mucosal ulcerations and aphthous lesions that may not be seen at MR enterography. The primary advantage of using capsule endoscopy is the ability to visualize a small-bowel mucosa that is inaccessible with conventional endoscopy. In addition, it is less invasive than push endoscopy (9,10). The major limitation is the risk for capsule retention from small-bowel strictures in patients with CD. Normal findings at endoscopic evaluation of the small bowel and colon include a glistening salmon-colored mucosa with a normal vascular pattern—but without areas of edema, erythema, ulceration, or plaque formation (Fig 1).

Although endoscopy has distinct advantages, it cannot be used to assess extraintestinal abnormalities and can be limited when strictures impede the passage of the endoscope and thus prevent completion of the examination (11). Given the transmural inflammatory nature of CD and the resultant transmural extension, cross-sectional imaging is important for evaluating the extent and stage of CD. Imaging is important in the setting of UC when complications are encountered and/or endoscopy is limited (11). MR enterography is a sensitive imaging option with the advantage that it does not involve use of ionizing radiation; this can be an important consideration in young patients with IBD. MR enterography is also useful for helping to classify newly diagnosed IBD in patients who have isolated colon disease or an indeterminate form of colitis. MR enterographic identification of clinically unsuspected small-bowel inflammation may become a key step in diagnosis of CD and subsequently guide therapy.

MR enterography involves imaging of the gastrointestinal tract after the patient ingests a large volume of oral contrast material to achieve adequate distention of the small bowel (12). At our institution, patients ingest 1450 mL of a barium sulfate suspension (VoLumen; Bracco, Westbury, NY) and then 500 mL of water in divided doses 1 hour before the examination. A 0.5-mg dose of glucagon is administered intramuscularly before the image acquisition to reduce small-bowel peristalsis. A second 0.5-mg dose of glucagon is administered intramuscularly before the intravenous administration of gadolinium-based contrast material (Gadavist; Bayer Healthcare Pharmaceuticals, Wayne, NJ). The following abdominal and pelvic multiplanar MR enterographic examinations are performed by using a dedicated phased-array torso coil: axial and coronal T2-weighted half-Fourier rapid acquisition with relaxation enhancement (RARE); T1-weighted volumetric interpolated breath-hold examination (VIBE); coronal and axial nonenhanced T2-weighted fat-saturated true fast imaging with steady-state precession (FISP); coronal and axial T1-weighted fat-saturated imaging; coronal T1-weighted dynamic fat-saturated VIBE, with images obtained

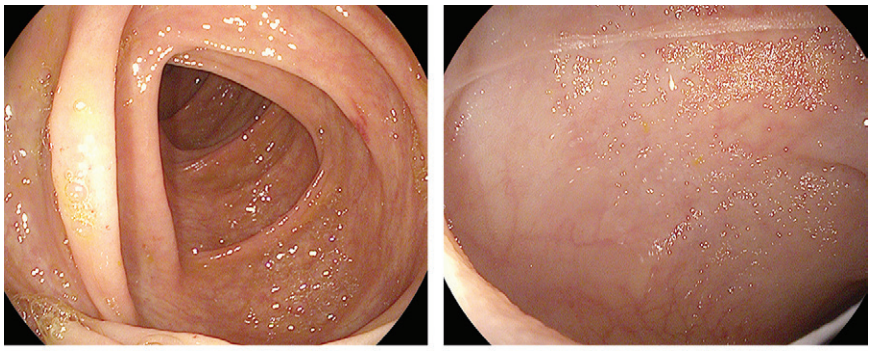


Figure 1. Normal colonoscopic findings in a 54-year-old man. Colonoscopic images of the colon **(a)** and terminal ileum **(b)** demonstrate a smooth glistening mucosa without hyperemia, edema, ulceration, or hemorrhagic foci. A normal vascularity pattern is visible.

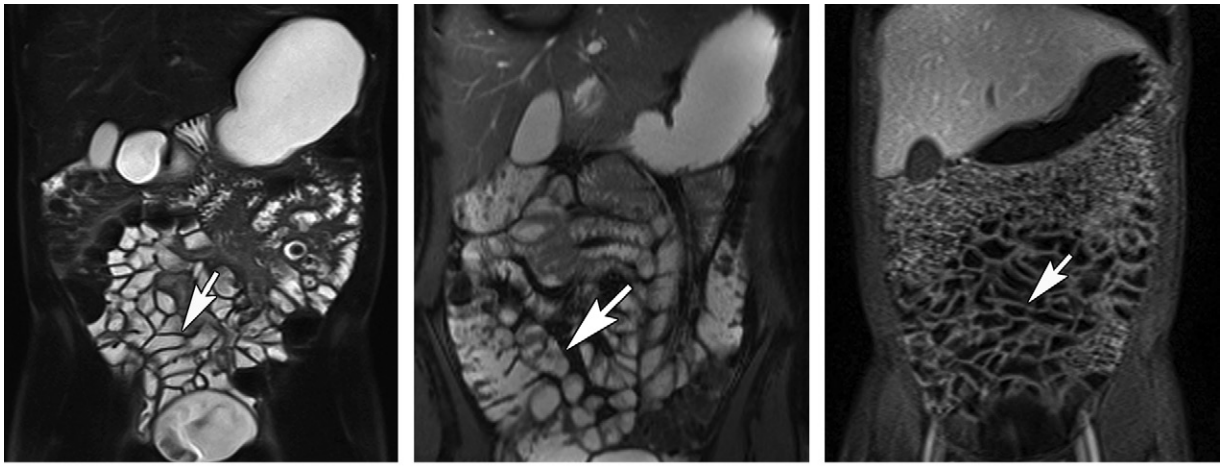


Figure 2. Normal MR enterographic findings. **(a)** Coronal T2-weighted RARE image in a 14-year-old boy shows the wall of the small bowel (arrow) as a thin hypointense line. **(b)** Coronal T2-weighted true FISP image in a 33-year-old woman shows the small-bowel wall (arrow) as either imperceptible or a thin intermediate-signal-intensity line. **(c)** Coronal T1-weighted VIBE image obtained during the portal venous phase in the same patient as in **a** shows normal enhancement and thickness of the small-bowel wall (arrow). The entire small bowel enhances uniformly throughout all phases of contrast enhancement.

approximately 25, 60, and 90 seconds after contrast material injection; diffusion-weighted (b = 50 sec/mm^2 and b = 800 sec/mm^2) MR imaging with apparent diffusion coefficient mapping; and axial T1-weighted fat-saturated delayed VIBE.

RARE images are T2 weighted and thus helpful for assessing the presence of mural edema and/or fat deposition. In addition, on RARE images, the mucosal features are accentuated against a bright background that is created by ingested enteric contrast material. However, RARE images are prone to flow-related artifacts that can mimic intraluminal lesions. Normal findings of an MR enterographic examination include the appearance of the bowel wall as a thin hypointense line on RARE images (Fig 2a). FISP images are based on steady-state precession and thus are less prone to the flow artifacts that can be seen on RARE images. However, FISP images are more prone to susceptibility artifacts (13). Diffusion-weighted imaging findings can corroborate the presence or absence of active inflammation. For instance, with CD, restricted diffusion in a diseased segment of bowel is suggestive of active inflammation. T1-weighted VIBE images are useful for assessing the degree of contrast enhancement and vascular features such as vasa recta engorgement. Normal enhancement is defined as uniform enhancement of the gastrointestinal tract wall through all phases of contrast enhancement (Fig 2c).

Crohn Disease

CD is a relapsing-remitting chronic inflammatory disorder that manifests pathologically as discontinuous transmural inflammation of the gastrointestinal tract. It commonly manifests during adolescence; the median patient age at diagnosis is 20–30 years, with a reported second disease peak in individuals aged 60–70 years (14,15). The first widely accepted description of CD published in the medical literature was that by Crohn, Ginzburg, and Oppenheimer (16) in 1932. As characterized in the earliest description, where it was referred to as *regional ileitis,* CD typically involves the distal ileum and proximal colon. This pattern is seen in up to one-half of all patients with CD

MR Enterographic Features of CD Subtypes

CD Subtype	MR Enterographic Features			Pertinent Extraintestinal Features
	T2-weighted Images	Diffusion-weighted Images	Contrast-enhanced T1-weighted Images	
Active inflammatory	High mural signal intensity	Restricted diffusion	Arterial phase hyperenhancement that progressively increases throughout all enhancement phases Mucosal, homogeneous, or layered enhancement pattern	Vasa recta engorgement and reactive lymphadenopathy
Fistulizing and perforating	Linear tracks of hyperintense signal arising from serosal surface of bowel and connecting another structure or bowel segment	Restricted diffusion may be present within the sinus or fistulous tract	Sinus or fistulous tracts may exhibit contrast enhancement	Sinus tracts may lead to an intra-abdominal abscess
Fibrostenotic	Hypointense signal on RARE images and intermediate signal intensity on FISP images Increased bowel wall signal intensity indicates superimposed active inflammation	Unrestricted diffusion Restricted diffusion is suggestive of superimposed active inflammation or due to fibrosis	Enhancement is restricted to mucosa and less prominent compared with that associated with active inflammatory disease Mucosal, homogeneous, or layered enhancement pattern can be seen	No vasa recta engorgement or reactive lymphadenopathy; presence of these features suggests superimposed active inflammation
Reparative and regenerative	Pseudopolyps with low signal intensity Intermediate signal intensity within bowel wall can be seen in the setting of fat deposition	Unrestricted diffusion	No hyperenhancement	No vasa recta engorgement or reactive lymphadenopathy

(17). Involvement exclusive to the small intestine, with a predilection for the ileum, is seen in up to one-third of these patients (17). However, CD may affect any part of the gastrointestinal tract, and it can be limited to the colon.

The clinical manifestations of CD are based on the site of involvement and level of disease activity. Patients most commonly present with diarrhea (17). Abdominal pain, low-grade fever, and weight loss are additional common symptoms (15,17). Perianal disease in the form of skin tags, fissures, and abscesses are seen in close to one-third of patients (17,18). Although gastrointestinal bleeding can occur with CD, it occurs more frequently with UC. The gastrointestinal blood loss associated with CD is usually occult and often leads to anemia (15,17). Extraintestinal manifestations of CD may occur. Commonly affected organs include the skin, bile ducts and liver, bones and joints, eyes, and kidneys (19).

Imaging Features and Endoscopic Correlation

CD can be classified as active inflammatory, fistulizing and perforating, fibrostenotic, or reparative and regenerative disease (Table) (20). There is no stepwise progression between these disease phases, and various phases may exist at the same time. For instance, a patient may have active inflammation superimposed on a fibrostenotic stricture, or there may be different subtypes of the disease in different bowel segments in the same patient. CD can also be inactive—because of the natural history of the disease, which involves intermittent inflammatory flares interspaced with periods of quiescent disease, or because the disease has remained in remission owing to effective treatment. Although the disease location tends to change less frequently, changes in disease behavior are seen much more commonly (21). For example, the majority of patients do not have penetrating-fistulizing or

fibrostentotic disease at diagnosis; however, they are found to have developed manifestations of these two disease subtypes when they are followed up over time (22).

MR enterographic interpretative reports should include a number of pertinent points regarding diagnostic utility that guide disease management and therapy for patients with IBD. These data include the phase of disease activity (ie, active inflammation, reparative and regenerative, fibrostenotic, fistulizing and perforating); number and length of involved bowel segments; presence (or absence) and number of strictures; and presence (or absence) of obstruction, abscess, and fistula. Moreover, certain fistulas are particularly important owing to their effect on treatment management. Surgical intervention is required when enterocolonic fistulas are found, whereas enteroenteric fistulas are managed conservatively.

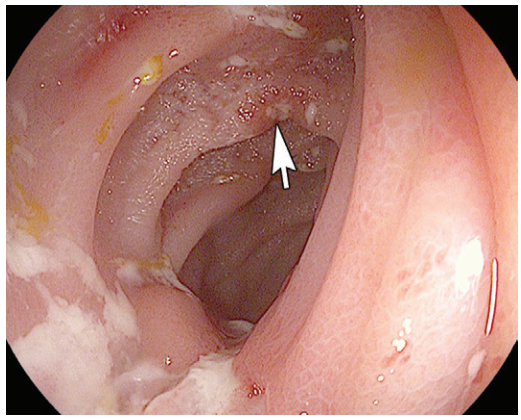


Figure 3. Colonic aphthous ulcers in a 22-year-old woman with CD. Colonoscopic image shows a shallow mucosal defect (arrow) with a central white component and mild peripheral erythema. These findings are typical of aphthous ulcers. Additional larger confluent ulcers also are present.

Active Inflammatory Disease

The histopathologic features of active inflammatory CD include bowel segments with chronic focal inflammatory changes interspersed between disease-free intestinal segments (referred to as *skip lesions*). The inflammation can be transmural, but it does not extend beyond the serosa. Transmural inflammation tends to be more severe within the mucosa and submucosa (2).

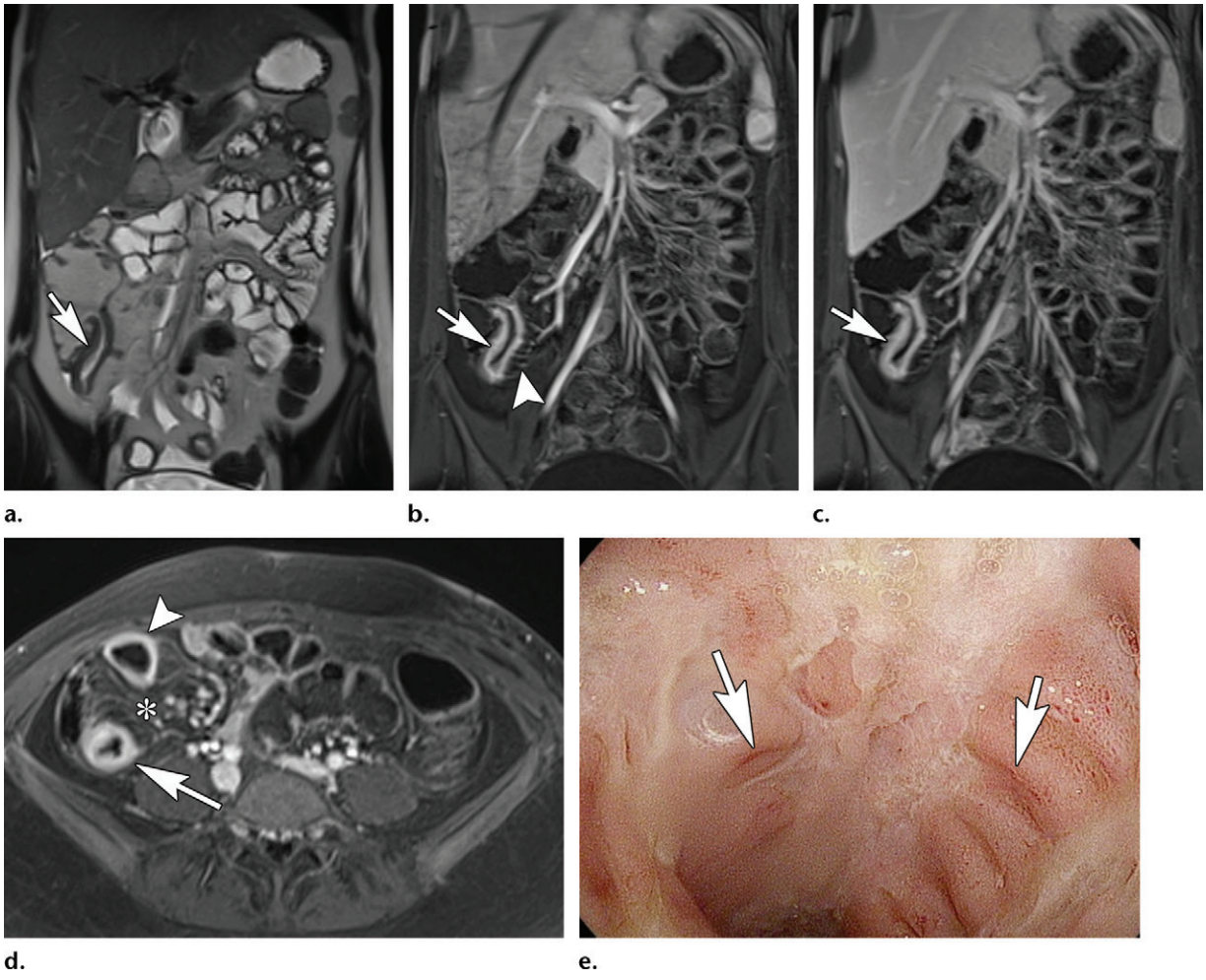
The gross pathologic lesion seen earliest with CD is an aphthous ulcer (Fig 3), which appears as a shallow mucosal defect with peripheral erythema at endoscopy (23). Aphthous ulcers are preceded by microscopic evidence of epithelial necrosis (2). They tend to develop above areas of lymphoid follicle hyperplasia in the intestinal tract and represent areas of immune activation (2,17). Noncaseating granuloma formation is an additional nonspecific but key microscopic pathologic feature of CD; it is seen in up to two-thirds of patients, but there is wide variation in estimates of its prevalence (14,17).

Although early-manifesting abnormalities such as aphthous ulcers and mucosal fold abnormalities may be difficult to appreciate on MR enterographic images, they are readily detected at endoscopy and may be seen at thin-section MR enteroclysis (24). However, other features of active inflammation are easily depicted on MR enterographic images. The upper limit of normal thickness for an adequately distended small bowel is 2 mm, and this limit is 3 mm for the colon (12). Wall thickness greater than these limits is pathologic. With active inflammatory CD, wall thickening is due to edema and inflammatory infiltrates, which cause slightly increased signal intensity within thickened bowel segments on T2-weighted RARE images. During the arterial phase, intravenous contrast-enhanced T1-weighted VIBE images of these thickened bowel segments with active inflammation show hyperenhancement that progressively increases throughout all phases of contrast enhancement. Bowel wall hyperenhancement has been associated with active CD (25). However, the relationship between degree of mural hyperenhancement and severity of inflammation is less well established. Instead, bowel wall enhancement pattern has been shown to correlate with inflammation degree (26). At qualitative assessment, contrast enhancement can be divided into three main patterns: mucosal (ie, confined to mucosa-submucosa region), homogeneous, and layered. The layered enhancement pattern results in mucosa-submucosa and serosal enhancement (27) and correlates with the greatest degree of inflammation at histopathologic analysis (26). The smallest degree of inflammation has been associated with the homogeneous pattern of mural enhancement (26).

Diffusion-weighted images show restricted diffusion in areas of active inflammation. The luminal narrowing that results from bowel wall thickening in active inflammatory disease can result in proximal bowel dilatation and obstructive symptoms (Fig 4). When reporting bowel obstruction in active inflammatory CD, it is important to determine and note whether the obstruction is due to active inflammation or fibrostenotic disease because the treatments for these two disease phases differ. Luminal narrowing due to edema from active inflammation is managed with medication, whereas surgical resection is considered for bowel obstruction due to fibrostenotic disease.

Progressive inflammation results in the formation of transmural ulcers (28). The aphthous ulcers seen with early-manifesting CD may enlarge and

Figure 4. Active inflammatory CD in a 15-year-old girl with intermittent right lower quadrant pain of increasing severity and elevated inflammatory biomarker levels. **(a)** Coronal T2-weighted RARE image shows marked mural thickening of the terminal ileum (arrow), with slightly high signal intensity in the submucosa. The terminal ileum is separated from the adjacent small bowel by fat proliferation of the small bowel mesentery. **(b, c)** Coronal T1-weighted fat-saturated VIBE images obtained during the arterial **(b)** and late portal venous **(c)** phases show progressive transmural hyperenhancement of the terminal ileum (arrow), with associated engorgement of the vasa recta (arrowhead in **b**). **(d)**. Axial delayed contrast-enhanced T1-weighted fat-saturated VIBE image shows marked transmural enhancement of the terminal ileum (arrow), edema of the vasa recta (*), and numerous small enhancing mesenteric lymph nodes. An adjacent segment of the distal ileum (arrowhead) also shows hyperenhancement of the thickened wall. **(e)** Colonoscopic image of the terminal ileum shows active inflammatory changes, including multiple linear ulcerations (arrows) and a paucity of unaffected normal mucosae.



coalesce to form the characteristic linear transmural ulcers seen with CD (Fig 4e) (23,28). Linear ulcers tend to develop on the mesenteric border during the early phase of disease; however, over time the inflammation will spread to involve the antimesenteric border (28). Although mural fibrosis is a feature of fibrostenotic disease, it is interesting that the mesenteric border also tends to have a higher degree of fibrosis and resultant retraction, with relative sparing of the antimesenteric border (18,28). Consequently, the antimesenteric border tends to be more stretchable and can expand to form sacculations, which have been classically described with CD (18). As the linear ulceration tracks intersect, different ulceration patterns—such as the stellate ulcers and deep serpiginous ulcers seen at endoscopy—emerge (14,23). The intervening nonulcerated mucosa can become edematous and result in the "cobblestone" appearance observed at endoscopy and MR enterography (18) (Fig 5). Cobblestoning appears as nodular mucosal protrusions between areas of mucosal ulceration. These are best appreciated on T2-weighted RARE images, which accentuate the mucosal features against bright intestinal luminal contrast. The nodularity of the mucosa on the luminal side of the bowel also can be seen well on intravenous contrast-enhanced images owing to the nonenhancing crevasses between the cobblestones. The MR enterographic findings correlate well with the cobblestone morphology seen at endoscopy.

A distinct advantage of MR enterography, as compared with endoscopic assessment, is that it enables evaluation of the mesentery. Inflammatory

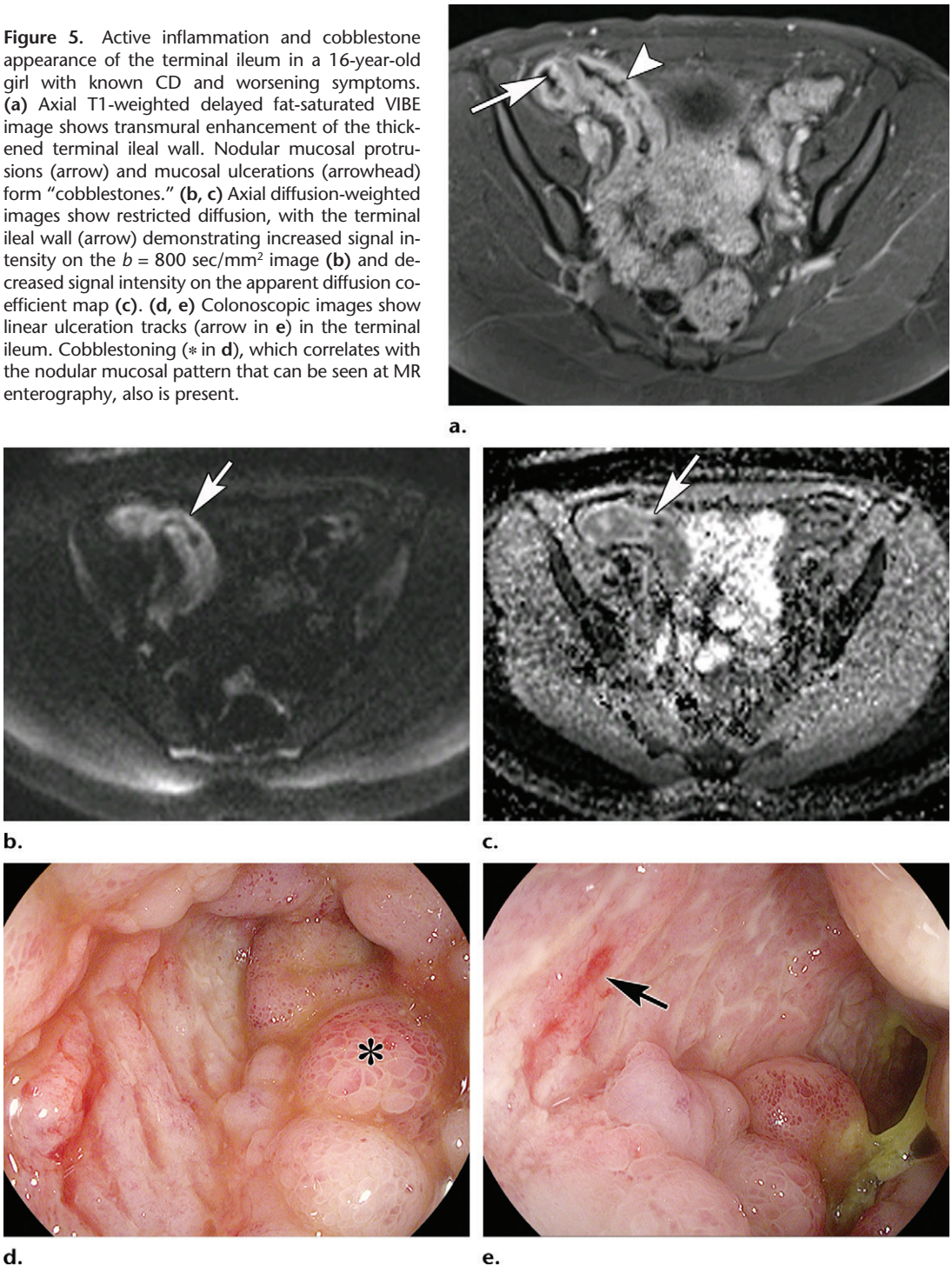


Figure 5. Active inflammation and cobblestone appearance of the terminal ileum in a 16-year-old girl with known CD and worsening symptoms. **(a)** Axial T1-weighted delayed fat-saturated VIBE image shows transmural enhancement of the thickened terminal ileal wall. Nodular mucosal protrusions (arrow) and mucosal ulcerations (arrowhead) form "cobblestones." **(b, c)** Axial diffusion-weighted images show restricted diffusion, with the terminal ileal wall (arrow) demonstrating increased signal intensity on the b = 800 sec/mm^2 image **(b)** and decreased signal intensity on the apparent diffusion coefficient map **(c)**. **(d, e)** Colonoscopic images show linear ulceration tracks (arrow in **e**) in the terminal ileum. Cobblestoning (* in **d**), which correlates with the nodular mucosal pattern that can be seen at MR enterography, also is present.

changes in the mesentery adjacent to diseased segments can help corroborate the presence of active inflammation. The mesenteric changes that can be seen with active inflammation include engorgement of the vasa recta (ie, the "comb sign"), increased T2 signal intensity in the mesentery resulting from edema, and reactive lymphadenopathy. The separation of bowel loops due to fibrofatty proliferation, while not exclusive to the active inflammatory subtype of CD, is included herein because of its relation to vasa recta engorgement. It is likely that vasa recta engorgement and tortuosity are due in part to hyperemia related to active inflammation. The pathogenesis of fibrofatty proliferation, which is sometimes also described as fat wrapping, is not completely understood. A possible explanation is the contribution of chronic perivascular inflammation and the subsequent perivascular fibrosis adjacent to the mesenteric border, which result in the contraction of these vessels that brings the hypertro-

phied mesentery closer to the bowel wall and causes fat wrapping (29). Perivascular fibrosis and vessel contraction could also be contributors to the dilatation and tortuosity of the vasa recta seen with CD. Longitudinal contraction of the muscularis propria also might contribute to the accentuation of mesenteric fat on the serosal surface (29). Reactive lymph nodes, which are typically up to 8 mm in diameter, can be seen with CD and may further corroborate the evidence of active inflammation (18).

Grading of Disease Severity.—Categorization of the degree of inflammation—as mild, moderate, or severe—can help guide therapy and is frequently used in CD research. Although certain imaging features—for instance, the contrast enhancement pattern—have been individually linked to the degree of inflammation, categorizing the severity of inflammation on the basis of a conglomerate of imaging findings is a more robust way to grade severity. Radiologic-pathologic correlation data indicate associations between high T2 mural signal intensity, wall thickening, mucosal ulcerations, layered contrast enhancement, and severity of inflammation (26,27). Multiple grading schemes based on varying combinations of MR enterographic features have been proposed for categorizing the degree of inflammation. For instance, the CD MR imaging index and MR imaging index of activity, both of which are based on a combination of multiple imaging characteristics used to assess inflammation severity, have been found to have a moderate correlation with the CD endoscopic index of severity, which is a grading scale used to measure disease activity at endoscopy (30). Scoring indexes are used to grade inflammation severity on the basis of individual imaging characteristics; then, a composite score to determine the final severity category is assigned. Such an approach, while precise, may be less desirable in day-to-day clinical practice. A simpler approach might involve grading inflammation severity on the basis of the presence or absence of imaging features that have been associated with the degree of inflammation seen in histopathologic specimens, whereby more features indicate greater inflammation severity. For example, a bowel segment with mucosal ulcerations, layered contrast enhancement, and a thickened wall with increased T2 signal intensity would be deemed to have more severe active inflammation than a bowel segment that had only homogeneous contrast enhancement and increased mural T2 signal intensity. It should be noted, however, that a concordance between the inflammation severity results derived with this method and those derived by using the CD endoscopic index of severity has not been formally established, and scoring indexes such as the CD MR imaging index are still considered more formal tools for determining the severity of inflammation.

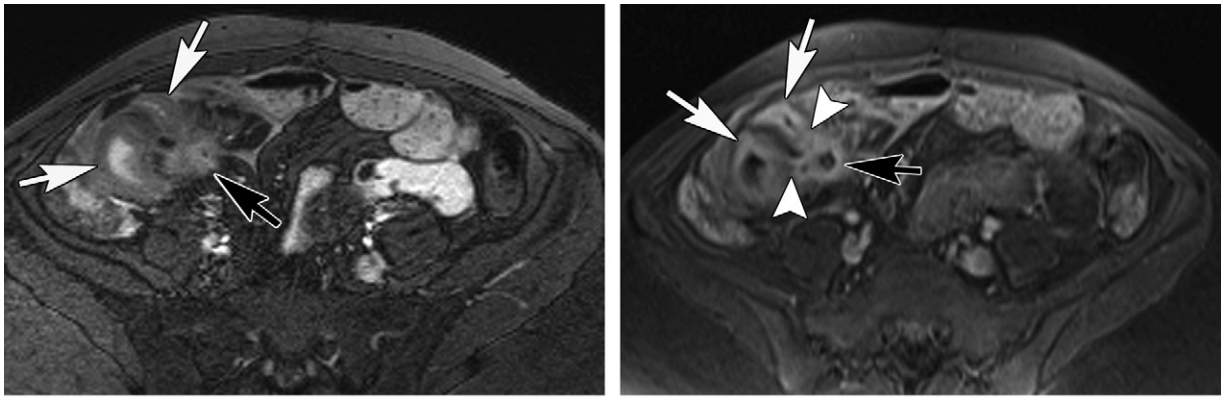
Fistulizing and Perforating Disease

The transmural inflammation and deep penetrating ulcers involved with CD may result in extension of inflammation through the serosa (23). In nearly one-third of patients, transmural inflammation results in the formation of fissuring ulcers, which are vertically oriented slitlike ulcers extending as far as the muscularis externa (2). Continued inflammation results in sinus tract and fistula formation through the serosa (17). The pathogenesis of these disease processes is tissue destruction caused by inflammation, with contributions from mechanical factors such as increased endoluminal pressure within certain segments of the gastrointestinal tract where sinus tracts and fistulas form (17,18). A fistula is an abnormal communication between two epithelialized surfaces—for instance, between the gastrointestinal tract lumen and cavity of another organ, another bowel segment, or the skin surface, whereas a sinus tract is a blind-ending abnormal connection with only one opening to an epithelialized surface. Perianal fistulas are an example of fistulas commonly seen with CD; however, fistulas and sinus tracts can develop at any anatomic location (17). Sinus tracts leading to an intra-abdominal abscess are a common complication observed in patients with CD.

On endoscopic images, sinus tracts and fistulas may appear as abnormal openings arising from the gastrointestinal tract. The sensitivity of endoscopy in appreciating the origin of the fistula or sinus tract may be based on the structure's size, and the ability to distinguish a sinus tract from a fistula is limited because the distal aspect of the tract cannot be visualized. These limitations can be overcome by using MR enterography. On MR enterographic images, fistulous tracts appear as linear regions of T2 hyperintense signal arising from the serosal surface of the bowel and connecting to another organ cavity, another bowel segment, or the skin surface. Sinus tracts and fistulas may arise from bowel segments that have mural thickening and signs of active inflammation (Fig 6). Abscesses appear as rim-enhancing fluid collections in proximity to a fistula or sinus tract.

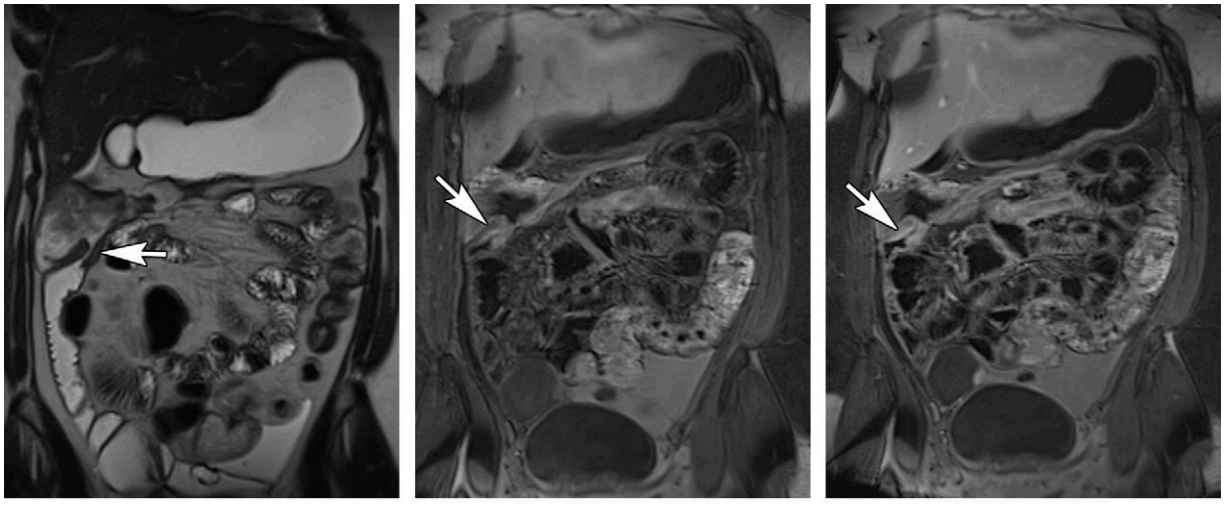
Fibrostenotic Disease

The results of long-term follow-up studies indicate that approximately 18%–27% of patients with CD develop fibrostenotic disease within 10–20 years after diagnosis (21,31). The fibrostenotic subtype of CD is pathologically characterized by transmural fibrosis due to a dysregulated normal healing response to tissue

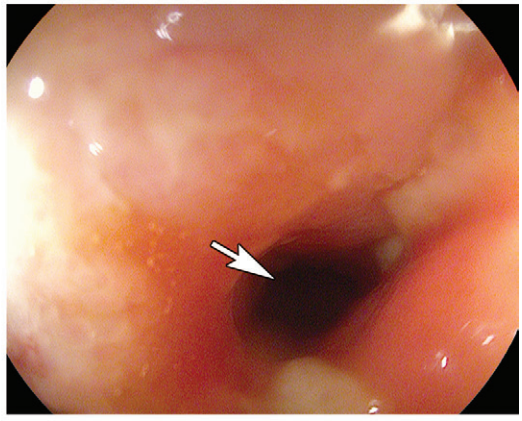


a. b.

Figure 6. Small-bowel interloop fistula with an abscess in a 23-year-old woman who underwent ileocolectomy for CD. She reported having severe right lower quadrant pain and a fever. **(a)** Axial T2-weighted fat-saturated true FISP image shows marked wall thickening of two segments of the adjacent distal ileum (white arrows), which are interconnected by adjacent linear strands and a small fluid collection (black arrow). **(b)** Axial delayed gadolinium-enhanced T1-weighted VIBE image shows transmural wall enhancement (white arrows), interloop fistulous tracts (arrowheads), and a small rim-enhancing abscess (black arrow).



a. b. c.



d.

Figure 7. Recurrent fibrostenotic CD in a 41-year-old woman who underwent ileocolectomy for CD. **(a)** Coronal T2-weighted RARE image shows short-segment wall thickening and luminal narrowing of the neoterminal ileum (arrow). **(b, c)** Coronal gadolinium-enhanced T1-weighted fat-saturated VIBE images obtained during the arterial **(b)** and late portal venous **(c)** phases show mild mucosal enhancement of the strictured neoterminal ileum (arrow). There is no transmural enhancement or vasa recta engorgement. **(d)** Colonoscopic image shows smooth luminal narrowing (arrow), which represents a fibrotic stricture at the ileocolonic anastomosis. There is no evidence of active inflammation such as ulceration, edema, or erythema. The endoscope could not be passed beyond this point.

injury and inflammation (32). Thickening of all layers of the intestinal wall is observed and is predominantly due to excess extracellular matrix deposition by mesenchymal cells (22,32). With CD, type III collagen is overexpressed in the extracellular matrix deposit and predisposes the intestinal wall to scar contraction (22). Progressive fibrosis results in luminal narrowing and stricture formation, which are standard characteristics of fibrostenotic CD. As a result, patients present with bowel obstruction symptoms.

On endoscopic images, strictures appear as regions of luminal narrowing without active inflammatory mucosal changes (Fig 7d). Strictures can sometimes limit the passage of the endoscope and thereby prevent assessment beyond the stricture. Depending on their length, they can sometimes

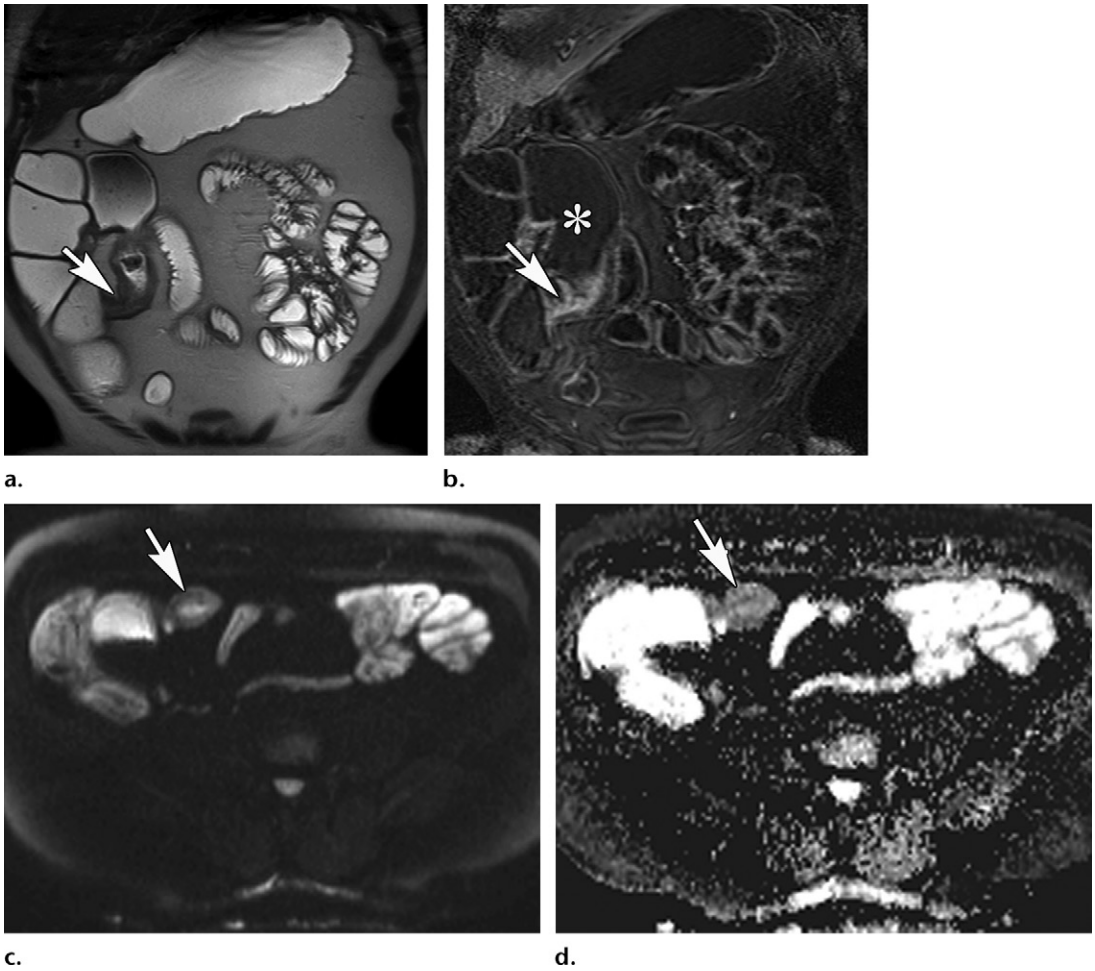
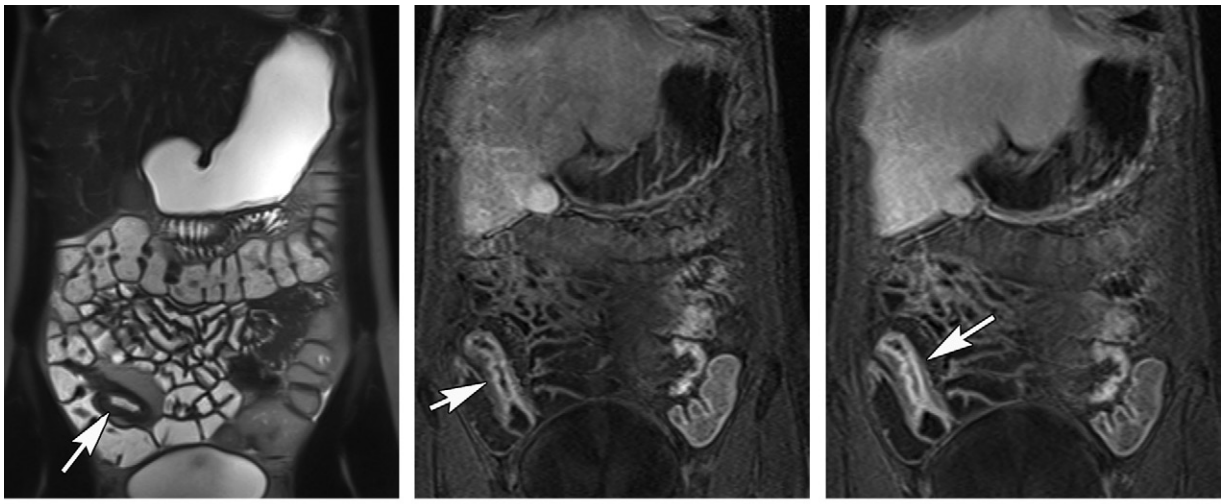


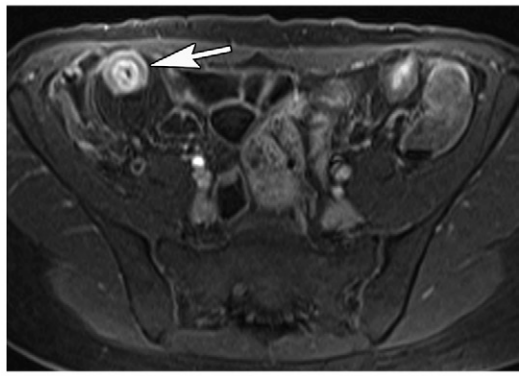
Figure 8. Obstructive stricture in a 36-year-old man with CD who reported having recurrent episodes of abdominal distention, nausea, and vomiting. **(a)** Coronal T2-weighted RARE image shows short-segment wall thickening and luminal narrowing of the terminal ileum (arrow). **(b)** Coronal gadolinium-enhanced T1-weighted fat-saturated VIBE image obtained during the portal venous phase shows mucosal hyperenhancement (arrow) and bowel dilatation proximal to the stricture (*). **(c, d)** Axial diffusion-weighted images show unrestricted diffusion. The terminal ileum (arrow) has decreased signal intensity on both the $b = 800$ sec/mm^2 image **(c)** and the apparent diffusion coefficient map **(d)**.

also limit the evaluation of regions of superimposed inflammation within the stricture.

On MR enterographic images, fibrostenotic disease appears as focal short- or long-segment wall thickening that is hypointense on T2-weighted RARE images and of intermediate signal intensity on T2-weighted FISP images. Depending on the degree of luminal narrowing caused by the stricture, proximal bowel dilatation may be present (Fig 8). In patients with CD, postoperative adhesions can cause luminal narrowing and small bowel obstruction. However, narrowing related to adhesions tends to be angulated and does not have circumferential mural thickening from fibrosis. Contrast-enhanced images of the affected segment demonstrate less prominent enhancement compared with that seen on contrast-enhanced images depicting active inflammation. The enhancement seen with fibrostenotic disease is usually restricted to the mucosa (Fig 9). However, other patterns of enhancement such as layered and homogeneous patterns can be seen (26). There is no vasa recta engorgement or reactive lymphadenopathy. Unrestricted diffusion is typically seen on diffusion-weighted images (Fig 8c, 8d); however, lower apparent diffusion coefficient values have been associated with the degree of fibrosis, with median apparent diffusion coefficient values for fibrotic strictures being lower than those for nonfibrotic strictures (30). The use of other, newer MR enterography techniques—for instance, those involving homogeneous 7-minute delayed enhancement and the progression of enhancement over time—has been linked to the identification of higher degrees of fibrosis (27). Interpreting these findings may be difficult, and it may be necessary to closely correlate them with the symptoms, inflammatory markers, and endoscopic findings in many cases. Multidisciplinary discussions of these findings help to maximize accuracy in determining the best course of treatment for many of these patients.



a. b. c.



d.

Figure 9. Fibrostenotic CD in a 24-year-old woman whose symptoms were not improving with anti–tumor necrosis factor therapy. **(a)** Coronal T2-weighted RARE image shows luminal narrowing and low-signal-intensity mural thickening of the terminal ileum (arrow), with adjacent fibrofatty proliferation. **(b, c)** Coronal gadolinium-enhanced T1-weighted fat-saturated VIBE images obtained during the arterial **(b)** and late portal venous **(c)** phases show mucosal hyperenhancement of the thick terminal ileal wall (arrow), without progressive or transmural enhancement. There is no vasa recta engorgement. **(d)** Axial delayed gadolinium-enhanced T1-weighted VIBE image shows persistent mucosal enhancement but a lower degree of enhancement in the muscularis mucosa (arrow). There is no submucosal enhancement. There also is no lymph node enlargement or inflammatory changes in the adjacent mesenteric fat.

When assessing fibrostenotic disease, it is important to evaluate the findings and symptoms for possible superimposed active inflammation. Although patients with superimposed active inflammation may experience some relief with therapy, patients with symptomatic, purely fibrostenotic disease are best treated with surgical resection or strictureplasty. Patients often have recurrent disease despite having undergone surgical resection. When active inflammation is present in conjunction with fibrostenotic disease, endoscopy will reveal mucosal ulceration within regions of stricture formation (Fig 10). MR enterographic images may show increased T2 signal intensity within regions of wall thickening and increased contrast enhancement. Diffusion-weighted images may demonstrate restricted diffusion and can aid in the assessment of active inflammation, which may not be appreciable on RARE or contrast-enhanced VIBE images (Fig 10).

Reparative and Regenerative Disease

The reparative and regenerative subtype of CD is characterized by a lack of active inflammation and findings of mucosal atrophy and regenerative polyp formation (20). There is no progressive mural fibrosis; instead, submucosal fat deposition may be seen with prolonged inactive disease (14). In addition to regenerative polyp formation, intermediate signal intensity within the bowel wall, which could be related to fat deposition, may be seen on MR enterographic images. MR enterographic and endoscopic images will show no evidence of active inflammation (Fig 11).

Cancer with CD

Patients with CD are at risk for colorectal carcinoma and hematologic malignancies such as lymphoma. An increased risk for lymphoma has been associated with immunomodulator and anti–tumor necrosis factor therapies (33). An increase in soft-tissue thickening or mass size in the bowel wall is indicative of lymphoma. As stated earlier, with CD, reactive lymph nodes are typically up to 8 mm in diameter, and lymph nodes larger than 1 cm in diameter should raise concern regarding possible lymphoma or carcinoma (18). Compared with the circumferential mural thickening seen with active inflammatory or fibrostenotic CD, the wall thickening seen with carcinoma tends to be more asymmetric. Pericolonic inflammatory changes, including sinuses and fistulas, can be seen with both CD and carcinoma and thus may pose a diagnostic dilemma. When no response to treatment is seen at follow-up examination, there should be concern regarding possible malignancy.

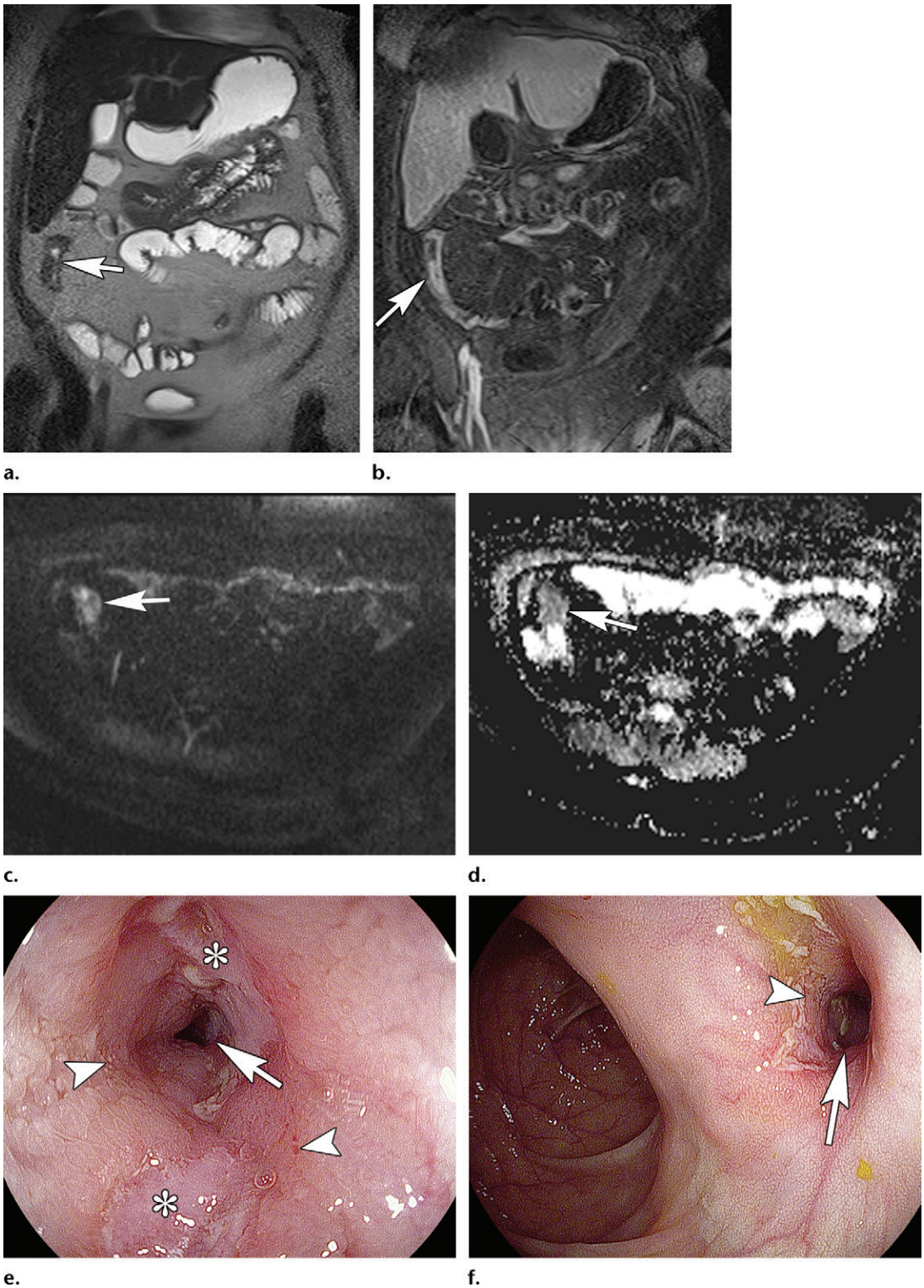
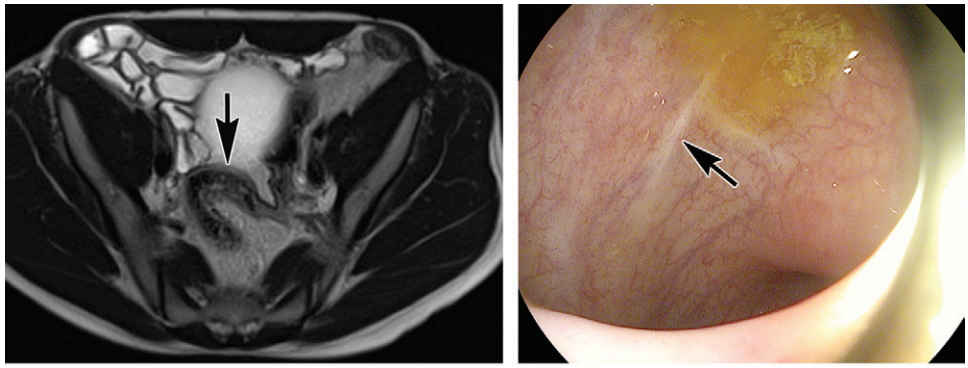


Figure 10. Active inflammation superimposed on fibrostenotic disease in a 66-year-old woman who underwent ileocolectomy for CD. She reported having increasing postprandial right lower quadrant pain. **(a)** Coronal T2-weighted RARE image shows long-segment mild wall thickening with luminal narrowing of the distal ileum proximal to the ileocolic anastomosis (arrow). **(b)** Coronal gadolinium-enhanced T1-weighted fat-saturated VIBE image obtained during the portal venous phase shows focal mucosal hyperenhancement (arrow) within the long segment of the narrowed distal ileum. **(c, d)** Axial diffusion-weighted images show restricted diffusion. The ileum (arrow) has increased signal intensity on the $b = 800$ sec/mm^2 image **(c)** and decreased signal intensity on the apparent diffusion coefficient map **(d)**. **(e, f)** Colonoscopic images of the neo-terminal ileum demonstrate luminal narrowing (arrow) consistent with a fibrotic stricture. Mucosal ulcerations (arrowheads) and edema (* in **e**), reflective of superimposed active inflammatory changes, also are present.



a. b.

Figure 11. Reparative phase of CD in a 31-year-old man who underwent surveillance colonoscopy and MR enterography for assessment of mucosal healing while undergoing anti–tumor necrosis factor therapy. **(a)** Axial T2-weighted RARE image shows long-segment intermediate-signal-intensity wall thickening of the sigmoid colon (arrow). Contrast-enhanced MR images (not shown) showed no abnormal mucosal or wall enhancement. **(b)** Colonoscopic image shows an atrophic-appearing mucosa with linear whitish fibrotic scars (arrow).

Ulcerative Colitis

UC is a chronic inflammatory disorder of the gastrointestinal tract that is limited to the mucosa and submucosa; it usually begins in the rectum and may extend to involve the proximal portions of the colon (4,18). Symptoms of UC typically begin when individuals are between the ages of 20 and 30 years (2). Similar to CD, UC has a bimodal distribution for initial diagnosis, with a second peak in incidence in individuals aged 70–80 years (2). The earliest description of UC in the medical literature dates back to 1859, when it was described in a published letter by Dr. Samuel Wilks to the editor of *The Medical Times and Gazette* (18,34). Mucosal inflammation extending from the rectum to the cecum, consistent with pancolitis, was described in this report (34). At initial presentation, only a small percentage of patients are found to have the pancolonic inflammation pattern; rather, the most common manifestation of UC is disease confined to the rectosigmoid colon, which is seen in approximately 45% of patients (35).

UC tends to have a gradual course, with relapsing and remitting symptoms; however, an abrupt onset of symptoms also can be seen (4,36). Characteristic symptoms of UC include bloody diarrhea and tenesmus (4,11). Patients may also have a fever and weight loss; these symptoms are used with biochemical markers to assess the severity of disease (11). Similar to patients with CD, patients with UC frequently have extraintestinal manifestations, which most commonly involve the musculoskeletal system (11,36).

Endoscopic evaluation with mucosal biopsy is often sufficient for the diagnosis and management of UC; imaging usually is unnecessary. When complications are suspected clinically or when endoscopy is not available or is limited by strictures, imaging becomes an important diagnostic modality (11). For example, imaging is particularly important when a patient with UC develops a colonic stricture, because this finding is associated with a high suspicion for the development of UC-related colorectal cancer. Endoscopic and MR enterographic features of UC can be broadly divided into acute phase and subacute-chronic phase findings (37).

Acute Phase

The inflammatory changes seen with UC tend to be confluent, with a sharp demarcation between the affected and unaffected segments; however, this pattern may be disrupted with treatment, which can result in disease remission in certain bowel segments (35). Focal appendiceal or cecal inflammation that resembles skip lesions may be seen in UC with left-sided colonic involvement (35). Although the inflammation with UC characteristically remains confined to the mucosa, transmural extension may occur in severe cases (18).

Early manifestations of UC include mucosal edema, granularity, and hyperemia (35,37). Mucosal edema can result in blunting of the colonic haustra (23). The mucosal edema is associated with an inflammatory infiltrate, which remains above the luminal end of the muscularis mucosa in the early disease stages (35). This inflammatory infiltrate collects at the base of the crypts and then within the crypt lumen, giving rise to crypt abscesses (2). There is resultant glandular destruction and changes in the production and quality of mucus (2,18). Progressive inflammation may result in some extension of the inflammatory infiltrate into the submucosa (35). Ongoing inflammation also results in mucosal hemorrhages and formation of variably sized ulcers that are superficial initially but then may extend to as far as the muscularis mucosa and submucosa (18,23,35). The ulcers

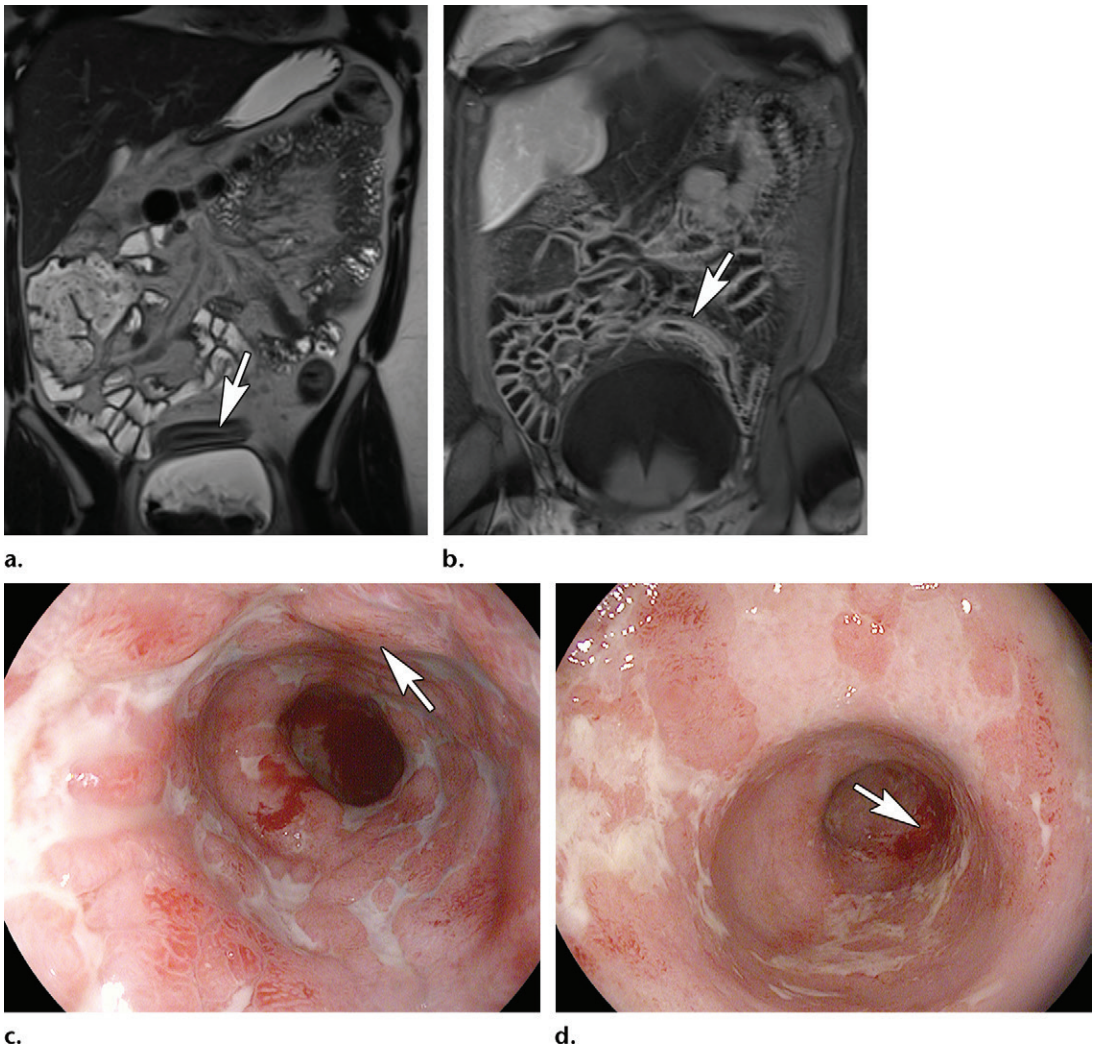


Figure 12. UC in a 40-year-old man who underwent diagnostic colonoscopy and MR enterography for evaluation of disease extent and assessment of the small bowel for unsuspected disease. MR enterography revealed no evidence of small-bowel disease. **(a)** Coronal T2-weighted RARE image shows thickening of the sigmoid colon wall, as characterized by high-signal-intensity thickening of the mucosal layer (arrow). **(b)** Coronal gadolinium-enhanced T1-weighted fat-saturated VIBE image obtained during the portal venous phase shows mucosal hyperenhancement of the thickened sigmoid colon (arrow). **(c, d)** Colonoscopic images show mucosal ulceration, with a heaped-up mucosa (arrow in **c**) between the ulcers, as well as ulceration with hemorrhagic foci (arrow in **d**).

may then also enlarge and coalesce to form larger confluent regions of ulceration with only small islands of spared mucosa, which are often described as inflammatory pseudopolyps (18,23). Severe UC inflammation can sometimes spread to the terminal ileum and result in superficial inflammatory changes within the ileum; these are termed *backwash ileitis* (2).

The mucosal granularity and edema seen during the early stages of UC are not seen on MR enterographic images, which show hyperenhancement of the mucosa. Progressive mucosal edema results in wall thickening and increased T2 signal intensity in the submucosa (Fig 12). Mucosal ulceration and inflammatory pseudopolyps are better appreciated on T2-weighted RARE and contrast-enhanced MR images, which accentuate the contrast between the bowel wall and bowel content.

Subacute and Chronic Phases

Long-standing UC, with bouts of remission and relapse, results in changes in the caliber and morphology of the bowel wall. The affected colon often becomes featureless, thickened, and shortened (23). The mural thickening seen during the subacute and chronic phases of UC is largely the result of neuronal hypertrophy and fibromuscular hyperplasia of the muscularis mucosa (35,37). Contraction of the thickened muscularis mucosa can result in bowel shortening and luminal narrowing (37). Submucosal fat deposition and fibrosis are additional entities that contribute to the wall thickening seen with UC (23,37). Perirectal fat deposition is a characteristic finding of chronic UC (37). At MR enterography, it is seen as a widening of the presacral space, with increased perirectal fat volume (Fig 13). Perirectal

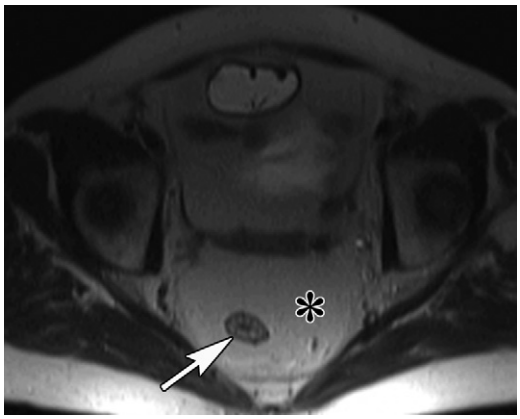


Figure 13. Long-standing UC in a 64-year-old woman. Axial T2-weighted RARE image shows high signal intensity in the submucosa (arrow) from fat deposition. The caliber of the rectum is narrowed, and there is proliferation of the perirectal fat (*).

fat deposition is often accompanied by a narrowed rectum due to circumferential mural thickening caused by muscularis hypertrophy and submucosal fat deposition, which result in slightly increased T2 signal intensity within the rectal wall. During disease remission, the ulcerated mucosa regenerates, and in some cases, it even overgrows, giving rise to postinflammatory pseudopolyps (18) (Fig 14). Because these polyps represent normal hypertrophic mucosa, they show enhancement. Varying degrees of mucosal inflammation can be present during the subacute and chronic phases (35).

Conclusion

The incidence of IBD is increasing. Endoscopy and MR enterography are complementary examinations used in the diagnosis and management of IBD. These procedures enable accurate characterization and classification of IBD in the majority of patients and thus accurate selection of the appropriate therapy and treatment management for these complex diseases. Familiarity with endoscopic correlates of the imaging findings and with the pathologic processes underlying IBD is helpful for accurate interpretation of MR enterographic findings.

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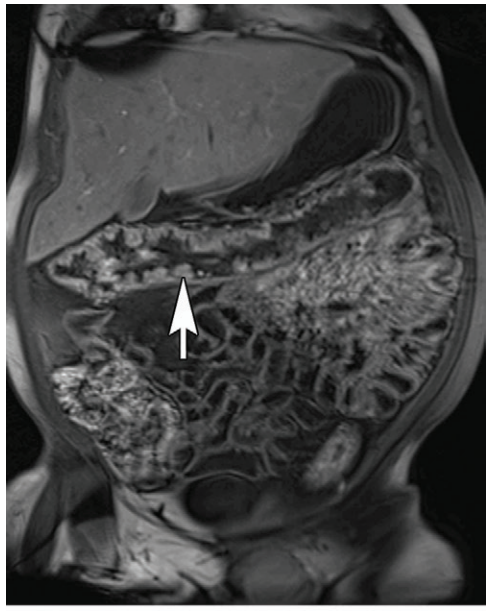
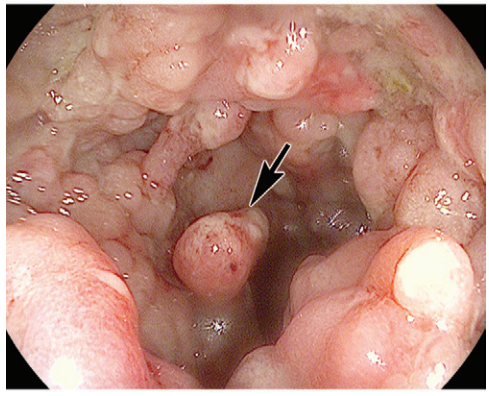


a.



b.

Figure 14. Postinflammatory polyps in a 48-year-old man with a long history of UC and recurrent *Clostridium difficile*–related colitis. MR enterography was performed to evaluate the small bowel for unsuspected small-bowel disease. **(a)** Coronal gadolinium-enhanced T1-weighted fat-saturated VIBE image obtained during the portal venous phase shows innumerable enhancing polyps (arrow) throughout the transverse colon. There were also findings of small-bowel inflammation. **(b)** Colonoscopic image of the transverse colon shows numerous polypoid lesions representing postinflammatory pseudopolyps (arrow), some of which are lined with an erythematous mucosa or a whitish exudate.

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