

Effectiveness of MR Enterography for the Assessment of Small-Bowel Diseases beyond Crohn Disease¹

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CME FEATURE

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LEARNING OBJECTIVES FOR TEST 2

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

- Describe the advantages and limitations of MR imaging, CT, and endoscopy for evaluating small-bowel diseases other than Crohn disease.
- Identify the MR enterographic features of small-bowel diseases other than Crohn disease.
- Explain the advantages of MR enterography over MR enteroclysis for the evaluation of diseases of the small bowel.

TEACHING POINTS

See last page

The use of cross-sectional imaging techniques for the noninvasive evaluation of small-bowel disorders is increasing. The effectiveness of magnetic resonance (MR) enterography for the evaluation of Crohn disease, in particular, is well described in the literature. In addition, MR enterography has an evolving though less well documented role to play in the evaluation of other small-bowel diseases, including various benign and malignant neoplasms arising in isolation or in polyposis syndromes such as Peutz-Jeghers, inflammatory conditions such as vasculitis and treatment-induced enteritis, infectious processes, celiac disease, diverticular disease, systemic sclerosis, and bowel duplication. MR enterography may be useful also for the evaluation of intermittent and low-grade small-bowel obstructions. Advantages of MR imaging over computed tomography (CT) for enterographic evaluations include superb contrast resolution, lack of associated exposure to ionizing radiation, ability to acquire multiplanar primary image datasets, ability to acquire sequential image series over a long acquisition time, multiphasic imaging capability, and use of intravenous contrast media with better safety profiles. MR enterography also allows dynamic evaluations of small-bowel peristalsis and distensibility of areas of luminal narrowing and intraluminal masses by repeating sequences at different intervals after administering an additional amount of the oral contrast medium. Limitations of MR enterography in comparison with CT include higher cost, less availability, more variable image quality, and lower spatial resolution. The advantages and disadvantages of MR enterography performed with ingestion of the oral contrast medium relative to MR enteroclysis performed with infusion of the oral contrast medium through a nasoenteric tube are less certain.

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Abbreviations: FISP = fast imaging with steady-state precession, GI = gastrointestinal, GIST = gastrointestinal stromal tumor, PEG = polyethylene glycol, RARE = rapid acquisition with relaxation enhancement, 3D = three-dimensional, VIBE = volumetric interpolated breath-hold examination

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Introduction

Traditionally, either a small-bowel follow-through examination or barium enteroclysis was used for the evaluation of suspected small-bowel diseases. These methods are currently being replaced by cross-sectional imaging techniques, which allow concurrent evaluations of luminal integrity, mural deformity, and extraluminal extension of disease. Endoscopic methods for evaluating the small bowel, including ileocolonoscopy, capsule endoscopy, and double-balloon enteroscopy, offer distinct advantages for assessing superficial mucosal abnormalities and obtaining biopsies for histologic assessment. However, endoscopic evaluation is invasive and may be limited by bowel strictures, and techniques such as double-balloon enteroscopy and wireless capsule endoscopy require special equipment and expertise that are available only at large tertiary-care centers. Moreover, no endoscopic technique allows assessment of extraenteric abnormalities. The main advantages of capsule endoscopy include a relatively low risk of complications, absence of ionizing radiation, and minimal patient discomfort. However, lesion localization and evaluation can be difficult at capsule endoscopy, and the technique does not allow the measurement of endoluminal masses.

Cross-sectional imaging modalities that are used for the evaluation of the small bowel include computed tomography (CT), magnetic resonance (MR) enterography, and MR enteroclysis. Small-bowel examinations performed with MR techniques are more time consuming and costly than CT enterography, and the image quality is more variable. Patients who have difficulty holding their breath are often better examined with CT. CT offers a short imaging time and spatial resolution that is superior to that of MR enterography, with isotropic voxels allowing high-quality multiplanar reformatting. However, CT enterography also has limitations, which include health risks posed by exposure of the patient to ionizing radiation, contraindications to the use of iodinated contrast media, and limited ability to perform a multiphasic examination. The use of MR imaging for diagnostic evaluation of the small bowel recently has been advocated because of its excellent soft-tissue contrast resolution, which allows the differentiation of various pathologic changes in the bowel wall; its multiplanar imaging capability; the lack of associated exposure to ionizing radiation; the possibility of repeated serial acquisitions; and the obviation of an iodinated contrast medium.

MR imaging of the small bowel may be performed with enterography or enteroclysis. In enterography, a large volume of fluid is ingested orally; in enteroclysis, enteric contrast material is administered through a nasoenteric tube. There is a general preference among radiologists for performing enterography over enteroclysis; however, this preference is controversial, and in our view the capabilities of the two techniques for the assessment of small-bowel diseases other than Crohn disease are not well documented. MR enteroclysis is known to provide better depiction of mucosal lesions in the small intestine than that achieved at MR enterography performed with an oral contrast agent (1). It is also generally acknowledged that MR enteroclysis provides optimal small-bowel distention and allows more accurate detection of strictures (2–4). However, nasoenteric intubation for MR enteroclysis may cause patient discomfort, and it involves various technical and logistical difficulties, as well as exposure to radiation. MR enteroclysis performed with the continuous administration of an enteric contrast agent is not possible at all facilities. At institutions such as ours, MR enterography is preferred to MR enteroclysis because it is easier, takes less time, is better tolerated by patients, and does not involve exposure to radiation (1,5–12). Although Crohn disease is the primary indication for MR imaging of the small bowel because many patients require multiple follow-up imaging examinations, MR enterography is performed with increasing frequency for the evaluation of other small-bowel diseases (8,9,13–15).

In this article, we describe our experience in performing MR enterography to evaluate small-bowel diseases other than Crohn disease. First, a detailed description of the technique is provided. Second, indications for the use of MR enterography as opposed to another diagnostic technique are discussed. Finally, abnormal MR enterographic findings are described and guidelines for their interpretation are offered to facilitate the differential diagnosis of bowel obstruction, benign and malignant neoplasms, immune and inflammatory diseases, and other conditions of the small bowel.

MR Enterographic Technique

A combination of good bowel distention and fast imaging sequences is required to obtain small-bowel MR images of diagnostic quality. The effectiveness of various enteric contrast agents has been described, including plain water, methylcellulose, and solutions containing locust bean gum, mannitol, barium sulfate, and polyethylene glycol (PEG).

Table 1
MR Enterography Protocol for Small-Bowel Assessment

Imaging Plane and Sequence*	Repetition Time (msec)	Echo Time (msec)	Matrix	Section Thickness (mm)	Intersection Gap (mm)	Field of View (mm)
Coronal T2-weighted FISP	3.65	1.83	307 × 320	4	0	400
Axial T2-weighted FISP	3.59	1.8	307 × 320	4	0	420
Axial T2-weighted half-Fourier RARE	1000	96	202 × 320	5	0	450
Coronal T2-weighted half-Fourier RARE	1000	96	216 × 320	4	0	450
Axial diffusion-weighted	5300	83	150 × 192	5	0.15	400
3D VIBE	4.68	2.38	240 × 320	3	0.2	400

*FISP = fast imaging with steady-state precession, RARE = rapid acquisition with relaxation enhancement, 3D = three-dimensional, VIBE = volumetric interpolated breath-hold examination.

These agents work by retarding the resorption of water in the intestine. Several studies have demonstrated that barium sulfate and PEG solution are better than plain water and methylcellulose solution for obtaining optimal small-bowel distention (16–19). Moreover, PEG solution is inexpensive. However, it causes mild diarrhea, and patients have to be informed of this disadvantage.

The ideal protocol for small-bowel filling before MR enterography is still the subject of investigation; however, there is a trend toward a standardized protocol for enteric contrast agent administration (5,9,10,20). Our specific protocol requires that the patient fast for at least 6 hours before the procedure. The patient then drinks a large volume (1–1.5 L) of an isosmotic solution of PEG and electrolytes mixed with water during a 45-minute period before the examination. The solution is prepared by dissolving a granular powder (Colopeg; Bayer, Paris, France) containing 59 g macrogol 3350, 1.461 g anhydrous sodium sulfate, 1.680 g sodium bicarbonate, and 0.746 g sodium chloride in 1.5 L of tap water. Although we aim for a total ingested volume of 1.5 L, some patients, particularly in the pediatric and elderly populations, cannot tolerate this volume, and adequate bowel distention may be achieved with as little as 500 mL, depending on the clinical indication for the study. All patients are given an information sheet that describes the procedure in detail and mentions the potential risk of diarrhea due to the ingestion of PEG before their imaging appointment. Patients with dyspnea or inability

to hold their breath are excluded because respiratory motion artifacts may compromise image quality. Generally, few patients experience major side effects such as nausea and diarrhea (8,10). Patients in whom the presence of a high-grade obstruction is suspected may not require any oral contrast medium, because intraluminal fluid within the distended small bowel immediately adjacent to the obstructed segment generally provides adequate contrast for confident diagnosis.

Most patients are placed in the prone position for MR imaging. This position reduces the area to be imaged and may help elevate small-bowel loops and separate them from the pelvis (1,10).

All MR imaging examinations of the small bowel are performed at our institutions by using a 1.5-T MR imaging system (Avanto; Siemens Healthcare, Erlangen, Germany) and two six-channel phased-array abdominal coils. We apply various pulse sequences in combination, to compensate for the limitations of individual sequences (Table 1). MR pulse sequences that are based on steady-state precession (eg, FISP; balanced fast field echo, or FFE; balanced steady-state free precession, or SSFP; and free induction echo stimulated acquisition, or FIESTA) are used because they are relatively insensitive to motion artifacts. We apply FISP sequences (TrueFISP; Siemens) during a single breath hold. Chemical shift artifact is sometimes seen on images obtained with steady-state precession sequences

and may complicate the assessment of bowel wall thickness; however, mesenteric vessels and lymph nodes are well depicted. Coronal and axial FISP images are obtained first to allow a rapid overview of the entire abdomen for the assessment of bowel distention. If distention is deemed adequate, T2-weighted MR images are obtained in the coronal and axial planes with a single-shot half-Fourier RARE sequence (ie, HASTE [half-Fourier acquisition single-shot turbo spin echo]; Siemens). **Fast or turbo spin-echo sequences that are based on the half-Fourier reconstruction technique help limit or overcome artifacts related to small-bowel peristalsis. They produce high contrast between the lumen and the bowel wall, providing excellent depiction of wall thickening and changes in the fold pattern. However, single-shot half-Fourier RARE sequences are susceptible to intraluminal motion, and the resultant images may be degraded by intraluminal low-signal-intensity artifacts due to flow void. Familiarity with these artifacts, and correlation of the half-Fourier RARE images with the corresponding FISP images, are important to avoid misinterpreting findings at MR enterography.**

A dose of 0.5 mg glucagon (Glucagen 1 mg/mL; Novo Nordisk, Paris, France) is intravenously administered to reduce small-bowel peristalsis 1 minute before the application of two-dimensional or 3D T1-weighted spoiled gradient-echo sequences. A baseline coronal T1-weighted fat-saturated ultrafast gradient-echo sequence (VIBE; Siemens) is applied first. We then administer 0.2 mg gadoterate dimeglumine (Dotarem; Guerbet, Roissy, France) per kilogram of body weight at an injection rate of 3 mL/sec. Next, VIBE sequences are applied in the coronal plane during both the arterial and the portal phase after administration of the intravenous contrast medium, followed by axial VIBE acquisitions covering the entire abdomen. Although the role of diffusion-weighted imaging in the diagnosis of small-bowel diseases other than Crohn disease has not yet been fully investigated, diffusion-weighted sequences also might be applied (with $b = 0$ and 800 sec/mm^2 , repetition time msec/echo time msec = $5300/83$, field of view = 400 mm, matrix = 150×192 , echo train length = 150, section thickness = 5 mm, and intersection gap = 0.15 mm) (21).

MR imaging of the small bowel can be performed with a 3-T system, but the higher field strength requires modifications in the pulse sequences that are used at 1.5 T. Higher specific absorption rates because of the long acquisition time needed to obtain axial sections of the entire abdo-

men with a half-Fourier RARE sequence at 3 T are often a limiting factor. The use of parallel imaging techniques may help reduce the acquisition time and decrease the specific absorption rate, but such reductions are achieved at the expense of the signal-to-noise ratio. The use of FISP sequences is not always feasible at 3 T because of distortion artifacts. However, it is possible to obtain dynamic T1-weighted images at 3 T that have spatial resolution commensurate with that of T1-weighted images obtained at 1.5 T (22).

Indications for MR Enterography

Many imaging modalities, with various advantages and limitations, are available for assessing the small bowel (Table 2). MR enterography seems to be a feasible alternative to CT enterography for small-bowel assessment (23–30). Although spatial resolution at MR imaging is lower than that at CT, a major advantage of MR imaging is its excellent contrast resolution.

Unenhanced T2-weighted MR imaging and gadolinium-enhanced fat-suppressed T1-weighted MR imaging are critical for characterizing wall thickening and identifying its cause: In a thickened bowel segment, a stratified enhancement pattern corresponding to the classic target sign is useful for excluding malignant conditions. This pattern is produced by enhancing mucosa with adjacent edematous submucosa, which demonstrates low signal intensity on T1-weighted images and high signal intensity on T2-weighted MR images. A wall thickness of more than 3 mm in a distended small-bowel loop may be considered abnormal. With few exceptions (lymphoma being one), thickening of a long segment of the small bowel is indicative of a benign condition (31). When perienteric fat stranding is seen adjacent to the thickened bowel segment, an inflammatory process should be suspected; when the perienteric fat adjacent to the thickened bowel segment has a normal appearance, an acute inflammatory condition is less likely.

With regard to the detection of small-bowel tumors, an advantage of MR enterography is its ability to generate images with differing signal intensity characteristics when different sequences are applied. At T2-weighted imaging with the use of a biphasic oral contrast agent, small-bowel masses display signal intensity lower than that of intraluminal fluid, a characteristic that may help identify masses that do not show substantial enhancement due to the intravenous contrast medium. Suboptimal small-bowel distention can be corrected when there is a specific concern by administering an additional amount of the oral contrast medium and repeating the imaging study at

Table 2
Comparison of Imaging Modalities for Evaluating Small-Bowel Diseases

Imaging Modalities	Advantages	Limitations	Indications
Conventional techniques	...	No extraluminal information is obtainable, interpretation of mucosal or mural change is difficult	Evaluation of small-bowel diseases when no other imaging modality is available
Barium enterography	Greater simplicity, greater availability, and lower cost in comparison with barium enteroclysis and endoscopic techniques
Barium enteroclysis	...	Increased patient discomfort in comparison with barium enterography, additional radiation exposure during nasojejunal tube insertion	...
Endoscopic techniques	Allow accurate mucosal assessment	Do not allow assessment of submucosal and extraenteric abnormalities	First-line examinations in patients with occult bleeding in the GI tract
Wireless capsule endoscopy	Low risk, minimal patient discomfort	Capsule may become lodged in tight bowel strictures, assessment of submucosal and extraenteric abnormalities is not possible, determining lesion size and location is difficult	First-line examination for suspected polyposis syndromes
Double-balloon enteroscopy	...	Prolonged, invasive; entire small bowel may not be seen; requires special equipment and expertise	...
Cross-sectional techniques	Improve visualization of extraluminal conditions, small-bowel wall, and abdomen; allow multiplanar visualization	More costly than conventional techniques	First-line examinations for nonspecific abdominal pain or suspected low-grade small-bowel obstruction
CT	Offers shorter imaging time, higher spatial resolution, and less variability in image quality than MR imaging	Involves exposure of patient to ionizing radiation, requires use of iodinated contrast medium; image data are acquired at relatively few time points	Most often used as first-line cross-sectional modality
CT enterography	Involves no additional radiation exposure and no tube insertion, is well tolerated by patients	Provides suboptimal small-bowel distention	...
CT enteroclysis	Provides optimal small-bowel distention	Requires nasojejunal tube placement, with additional radiation exposure during placement and with increased patient discomfort	Best for detection of small tumors; alternative to capsule endoscopy for occult GI tract bleeding
MR imaging	Capable of real-time and multiphasic imaging, does not involve exposure to ionizing radiation, provides excellent soft-tissue contrast for better tumor characterization	More costly, more time consuming, and less widely available than CT; provides lower spatial resolution and more variable image quality than CT; requires patient breath holding	Alternative to CT for evaluation of suspected small-bowel obstruction and tumor detection
MR enterography	Obviates use of an iodinated contrast medium	Provides suboptimal small-bowel distention	Alternative to capsule endoscopy for evaluation of suspected polyposis syndromes
MR enteroclysis	Provides optimal small-bowel distention, better depiction of mucosal lesions than MR enterography	Technical and logistical difficulty of nasojejunal tube placement, additional radiation exposure during tube placement, patient discomfort	Low-grade small-bowel obstruction

multiple time points after ingestion. Ultimately, enteroclysis may be necessary in some cases.

There is a paucity of data regarding the accuracy of MR imaging with distention of the small bowel for the detection of small-bowel masses, and diagnostic performance with MR enterography has yet to be prospectively evaluated in a large series of patients (9,23,24). However, the results of two recent studies suggest that MR enteroclysis enables accurate and reproducible detection of small-bowel neoplasms in symptomatic patients. In a retrospective study in which 91 patients with 30 histopathologically proved tumors were evaluated, sensitivity of 91%–94% and specificity of 97% were achieved in the detection of small-bowel neoplasms with MR enteroclysis, although no intravenous contrast medium was administered (23). Masselli et al (24) prospectively evaluated MR enteroclysis for the detection of small-bowel neoplasms in symptomatic patients and found the results to be both accurate (accuracy, 97%) and reproducible.

Only one recent study (9) investigated diagnostic performance at MR enterography relative to that at capsule endoscopy for the detection of small-bowel tumors in a population of 19 adult patients with Peutz-Jeghers syndrome. In that study, MR enterography depicted three large polyps in three patients, findings that were not seen at capsule endoscopy; however, a larger number of 6- to 10-mm polyps were detected at capsule endoscopy, evidence of the superior mucosal visualization achieved with that modality.

The first-line imaging examination for patients in whom the presence of a small-bowel tumor is suspected depends on the clinical manifestations and the biologic behavior of the neoplasm. Diagnostic performance data for the detection of small-bowel neoplasms with capsule endoscopy are difficult to obtain; because of the lack of a reference standard for negative findings, most studies of this method do not include calculations of sensitivity and specificity (32,33). So far, studies in which capsule endoscopy is directly compared with CT or MR imaging are scarce and not specifically focused on tumors (34,35). Capsule endoscopy often does not depict the totality of the small-bowel mucosa, thereby limiting its usefulness as a screening tool. Limitations of capsule

endoscopy also include the relatively subjective nature of the interpretation together with the difficulty of tumor localization within a specific bowel segment (36). In addition, capsule endoscopy does not depict submucosal tumors that produce little mass effect or displacement. Last, the presence of a small-bowel tumor is a risk factor for capsule retention due to small-bowel obstruction (37). Currently, CT enteroclysis is considered the best cross-sectional imaging modality for detecting small tumor masses. However, to the best of our knowledge, no comparison of the effectiveness of CT and MR enterographic techniques for the detection of small-bowel tumors has yet been reported in the literature (27).

Visualization of small-bowel tumors in the context of Peutz-Jeghers syndrome merits separate consideration. Various modalities can be used for surveillance of small-bowel polyps in this clinical setting. Capsule endoscopy is a feasible, safe, and diagnostically sensitive method for small-bowel surveillance in patients with Peutz-Jeghers syndrome, including children, and it causes substantially less patient discomfort than barium enterography (38). There are no data to support the use of double-balloon enteroscopy for small-bowel surveillance in patients with Peutz-Jeghers syndrome (39). Double-balloon enteroscopy is a prolonged and invasive procedure, and it does not ensure visualization of the entire small bowel, especially in those who previously have undergone abdominal surgery (2). MR enterography is reported to be a feasible alternative to capsule endoscopy for small-bowel surveillance in adults with Peutz-Jeghers syndrome (9,11,39), a conclusion supported by the results of another study of MR enterography in a small patient series (35). Although capsule endoscopy seems to allow better detection of small polyps (6–10 mm), the detection of large polyps is more relevant clinically, and the latter tend to be visible at MR enterography even when bowel segments are incompletely distended. Some large polyps may be missed at capsule endoscopy, although the difference in the rate of their detection with the two modalities does not approach statistical significance (9). **MR enterography, which allows improved localization of small-bowel polyps in patients with Peutz-Jeghers syndrome, is performed to identify larger lesions that should be resected at double-balloon enteroscopy or surgery. It may also be helpful for excluding the presence of lesions in bowel segments not examined at endoscopy or surgery.**



Figure 1. Adhesive ileal obstruction in a 30-year-old woman with a history of appendectomy and recurrent low-grade bowel obstruction. MR enterography was performed after the administration of 1 L of an oral contrast agent. Coronal FISP image from MR enterography demonstrates ileal loop dilatation (curved arrow), a transition point (straight arrow), and normal distal caliber (arrowhead). No mass, bowel wall thickening, stricture, or other specific cause of obstruction was identified. These findings were suggestive of an obstruction due to bowel adhesion, which was later confirmed at laparotomy.

If the patient presents with gastrointestinal (GI) tract bleeding, capsule endoscopy is likely to be performed because it has proven superiority over other imaging techniques for the detection of vascular abnormalities (40). If the indication is nonspecific abdominal pain or the suspected presence of a low-grade small-bowel obstruction, CT enterography or CT enteroclysis is usually the first-line imaging examination (2). However, at some institutions, MR enteroclysis or MR enterography is performed instead (25,26,41).

Interpretation of Findings at MR Enterography

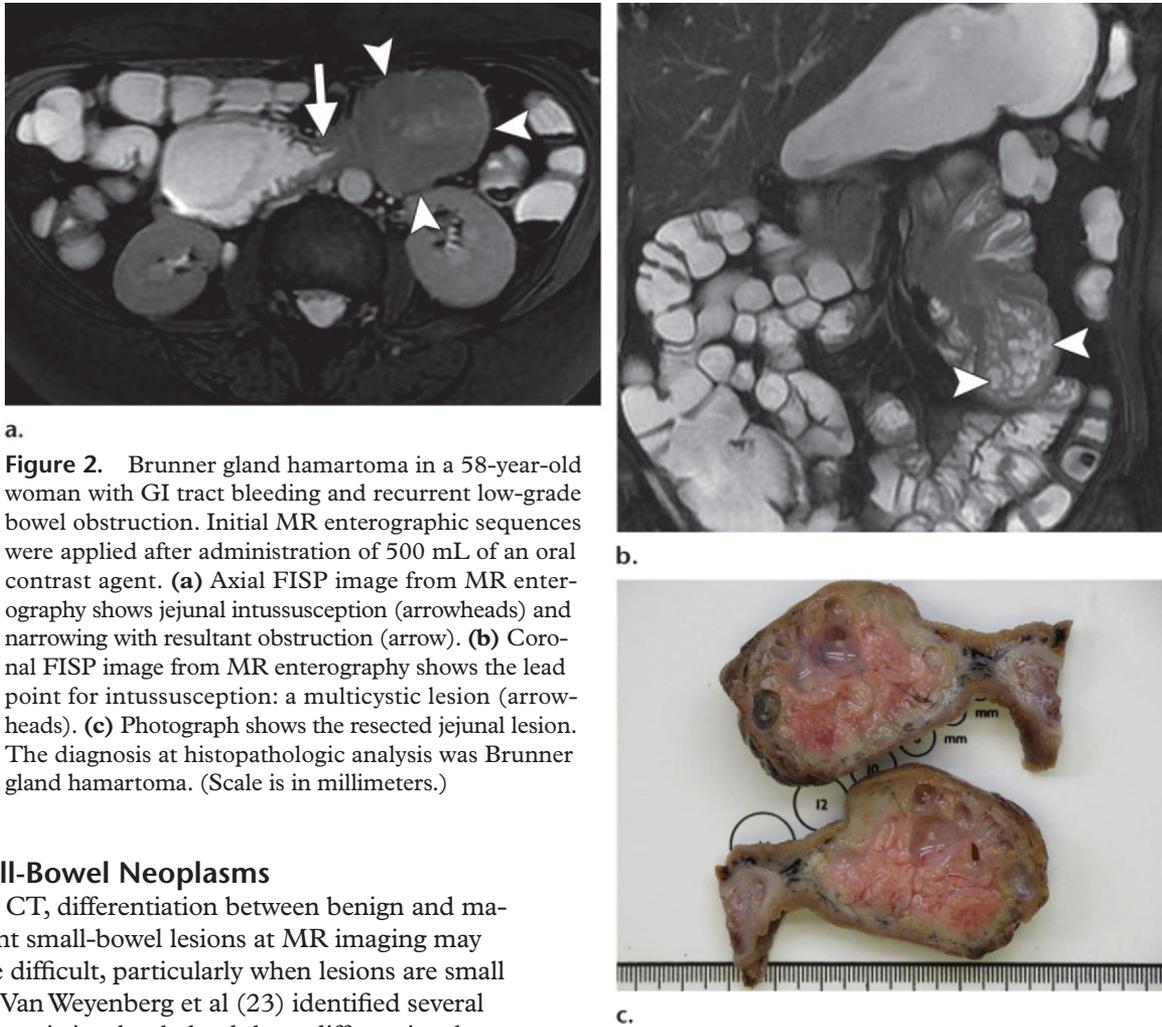
Small-Bowel Obstruction

The diagnosis of small-bowel obstruction at MR enterography is based on the identification of dilated loops of bowel proximal to the level of obstruction, a distinct transition point, and a normal-caliber or collapsed distal bowel segment. Ingestion of an inadequate amount of the oral contrast medium does not preclude MR enterography if the presence of a small-bowel obstruction is suspected. MR imaging allows diagnostic accuracy commensurate with that achieved at CT for the detection of high-grade small-bowel obstructions. Conversely, the detection of intermittent and low-

grade obstructions represents an imaging challenge and requires optimal small-bowel distention with intraluminal contrast material to increase the conspicuity of regions of stenosis (12,41,42).

The most common cause of small-bowel obstructions is postoperative adhesions. **Diagnosis of adhesions as the cause of a mechanical small-bowel obstruction should be based on the presence of an abrupt change in bowel caliber without evidence of another cause of obstruction in the vicinity of the transition point from the dilated segment to the collapsed segment of bowel. Adhesive strictures are not associated with thickening of the small-bowel wall (15) (Fig 1).** In some cases of small-bowel obstruction, low-signal-intensity soft-tissue bands may be seen coursing through high-signal-intensity mesenteric fat on T2-weighted images. Clustering or deformation of bowel loops also may be seen (12). Other possible causes of small-bowel obstruction, in addition to inflammatory diseases, include benign and malignant tumors, intussusception, strangulated hernia, volvulus, and radiation-induced enteritis (Fig 2).

Teaching Point



a.

Figure 2. Brunner gland hamartoma in a 58-year-old woman with GI tract bleeding and recurrent low-grade bowel obstruction. Initial MR enterographic sequences were applied after administration of 500 mL of an oral contrast agent. **(a)** Axial FISP image from MR enterography shows jejunal intussusception (arrowheads) and narrowing with resultant obstruction (arrow). **(b)** Coronal FISP image from MR enterography shows the lead point for intussusception: a multicystic lesion (arrowheads). **(c)** Photograph shows the resected jejunal lesion. The diagnosis at histopathologic analysis was Brunner gland hamartoma. (Scale is in millimeters.)

b.



c.

Small-Bowel Neoplasms

As at CT, differentiation between benign and malignant small-bowel lesions at MR imaging may prove difficult, particularly when lesions are small (27). Van Weyenberg et al (23) identified several characteristics that helped them differentiate between benign and malignant neoplasms at MR enteroclysis. Factors they found to be associated with malignancy were the presence of a long, solitary, nonpedunculated lesion; mesenteric fat infiltration; and mesenteric lymph node enlargement. However, the malignant lesions in their patient series included many small-bowel lymphomas and adenocarcinomas, malignancies for which the MR imaging features are generally diagnostic.

Benign Tumors.—Adenomas are the most common asymptomatic benign tumors of the small bowel and are most often seen in the duodenum. Small-bowel adenomas, like their counterparts in the large bowel, may have malignant poten-

tial. The tumors appear as well-defined sessile or pedunculated soft-tissue masses that are surrounded by clear fat planes. They show homogeneous moderate enhancement after the administration of an intravenous contrast medium. Adenomas may protrude into the small-bowel lumen without obstructing it (26).

Most lipomas are seen in the distal small bowel. They commonly arise in the submucosa and manifest with intussusception or bleeding. They display high signal intensity on T1- and T2-weighted MR images, with loss of signal intensity when fat suppression is used (Fig 3).

Small-bowel hemangiomas, which may consist of either capillaries or cavernous vessels, most commonly manifest with acute or chronic GI tract

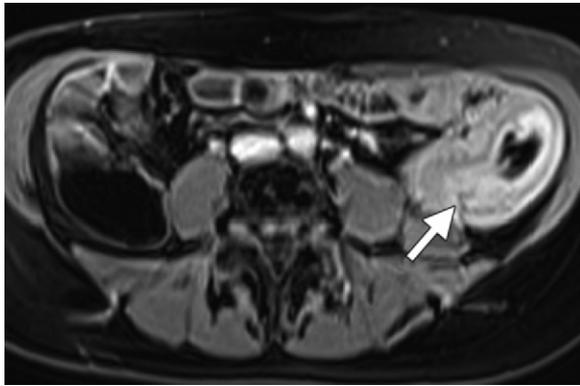


Figure 3. Jejunal intussusception due to a lipoma in a 63-year-old woman. Axial gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography shows intussusception of a proximal small-bowel segment. The lead point (arrow) is an ovoid lesion with low internal signal intensity, a finding suggestive of a lipoma. The diagnosis was confirmed at pathologic analysis.

bleeding. At MR imaging, small-bowel hemangiomas appear as submucosal polypoid tumors. It may be difficult to differentiate them from other vascular tumors or malformations on the basis of imaging criteria alone. Angiodysplasia usually appears as an avidly enhancing plaque or nodule with fading during the delayed phase (43).

Polyposis Syndromes.—Polyposis syndromes that may affect the small bowel include Peutz-Jeghers syndrome, juvenile polyposis, Cowden disease, and Gardner syndrome. Peutz-Jeghers syndrome, a genetic disorder with an autosomal dominant pattern of inheritance, is distinguished by multiple hamartomatous polyps throughout the GI tract, mostly in the small bowel, along with pigmented mucocutaneous lesions. The two main problems in the management of the GI tract lesions in patients with Peutz-Jeghers syndrome are the long-term cancer risk and polyp-related complications. Most patients who satisfy the clinical criteria for diagnosis have a causative mutation in the *STK11* gene, which is located at 19p13.3. The polyps in Peutz-Jeghers syndrome have characteristic histologic features, with an elongated frondlike epithelial component and cystic gland dilatation extending into the submucosa or muscularis propria and arborizing smooth muscle extending into the polyp fronds. Polyps in Peutz-Jeghers syndrome are usually referred to as hamartomas, but controversy surrounds their origin. How cancer arises in Peutz-Jeghers syndrome and the role of Peutz-Jeghers polyps in cancer development likewise remain controversial. However, it is now widely accepted that patients with the syndrome have increased risks for many cancers, including

small-bowel cancers, with a lifetime incidence of malignancy approaching 60% (39).

Large Peutz-Jeghers polyps (>15 mm) in the small bowel commonly manifest at an early age with GI tract bleeding, anemia, and intussusception or obstruction.

Current surveillance protocols are controversial and, because the condition is relatively rare, are not evidence based. Initially, endoscopy is performed to allow the detection of polyps that represent a predisposition to future intussusception or obstruction. Surveillance for the various cancers to which patients with Peutz-Jeghers syndrome are susceptible is an important part of later disease management. Expert consensus suggests that regular surveillance of the small bowel to enable identification and prophylactic removal of large luminal polyps may help reduce both the frequency of emergency laparotomy and the numbers of immediate and long-term complications associated with repeated abdominal surgeries in patients with Peutz-Jeghers syndrome.

Benign hamartomatous polyps are found throughout the small intestine, especially the jejunum, in patients with Peutz-Jeghers syndrome. FISP and gadolinium-enhanced fat-suppressed VIBE are the most useful MR imaging sequences for detecting small-bowel polyps. Polyps appear as hypointense filling defects on FISP images and typically show marked enhancement similar to that of the bowel wall mucosa after the intravenous administration of a gadolinium chelate (9,26,38) (Fig 4).

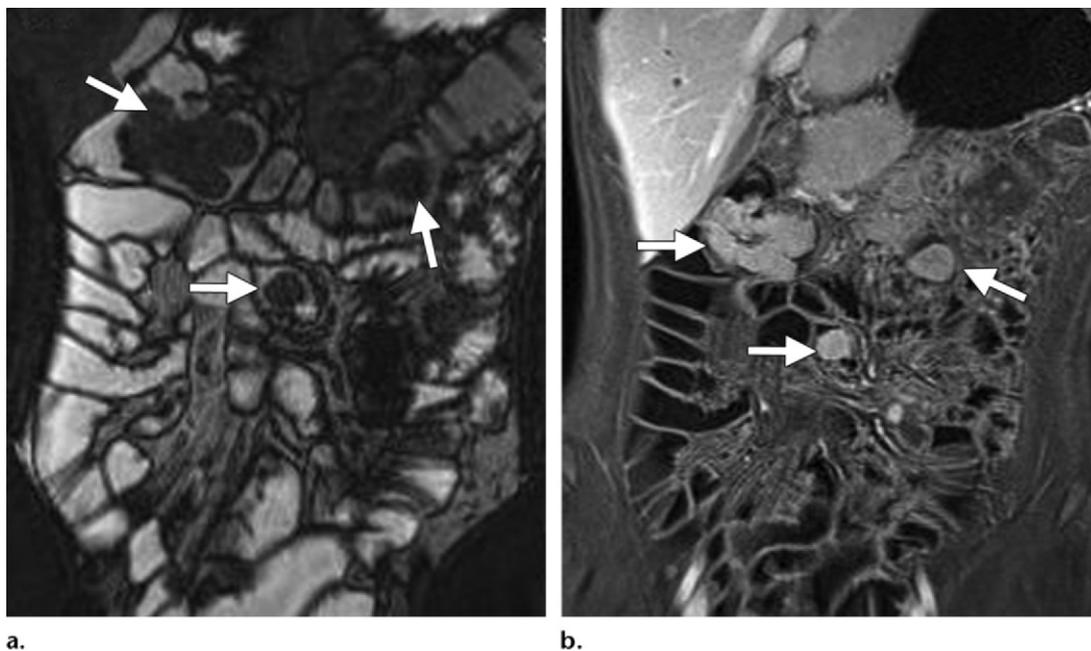


Figure 4. Surveillance of polyps in a 27-year-old man with Peutz-Jeghers syndrome. **(a)** Coronal FISP image from MR enterography shows at least three low-signal-intensity polyps (arrows) in the small bowel. **(b)** Coronal gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography shows moderate to marked enhancement of the polyps (arrows).

Gastrointestinal Stromal Tumors.—Gastrointestinal stromal tumor (GIST), the most commonly occurring mesenchymal neoplasm of the GI tract, is relatively rare. GISTs express the c-Kit (CD117, tyrosine kinase receptor) protein. The most frequent sites of GISTs are the stomach (60%) and the small bowel (30%) (Fig 5). The tumors are usually solitary but have been reported to occur in multiples, particularly in the setting of type 1 neurofibromatosis (44). GISTs in the small bowel most often originate from the muscularis propria and frequently involve the outer muscular layer of the bowel wall, exhibiting an exophytic growth pattern; less frequently, they arise intraluminally. Most (70%–80%) of the tumors are benign, but 20%–30% are malignant. Histopathologic predictors of malignancy are a size of more than 5 cm and a mitotic count of more than 5 mitoses per 50 high-powered fields

(45). Small-bowel GISTs may produce various clinical manifestations, including melena from acute GI tract bleeding secondary to mucosal ulceration, hematochezia, and hypovolemic shock. Chronic GI tract bleeding may lead to anemia. Small-bowel obstruction occurs rarely.

A GIST often manifests as an exoenteric, rounded mass that expands the small-bowel wall with a smooth, broadly pushing border; however, endoluminal development of the tumor is also possible. The tumor may show evidence of internal hemorrhage or necrosis, but satellite adenopathy is lacking. Small tumors usually enhance markedly. In lesions with extensive regions of hemorrhage or necrosis, cavities may form that communicate with the digestive lumen and contain air.

Leiomyomas are mesenchymal tumors that also may manifest with bleeding in the small bowel but, unlike GISTs, do not express the c-Kit protein. They are sharply defined spheroid or

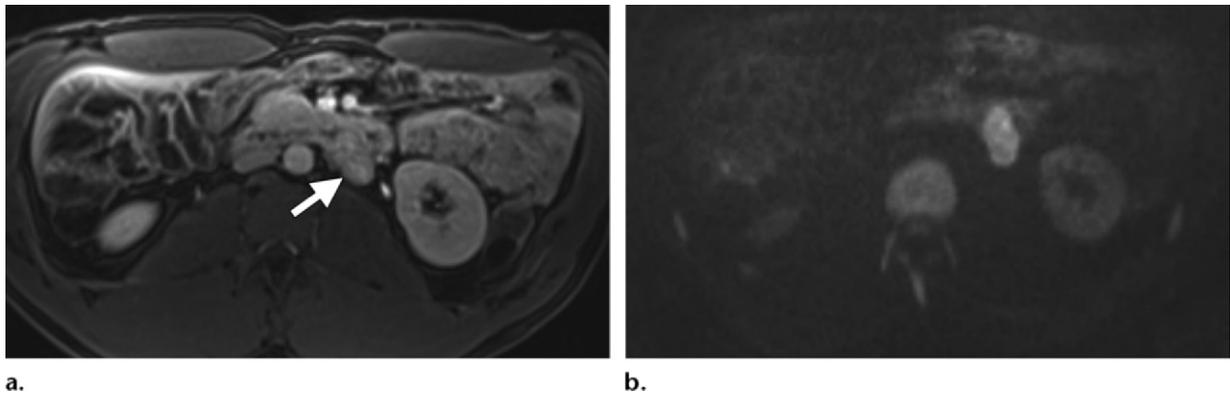


Figure 5. Duodenal GIST in a 21-year-old man with type 1 neurofibromatosis. MR enterography was performed for small-bowel assessment after a small GIST was seen at gastroduodenal endoscopy. **(a)** Axial gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography shows a large (2-cm), well-delimited exophytic duodenal lesion (arrow). **(b)** Diffusion-weighted MR image obtained with b of 800 sec/mm² optimally displays the high-signal-intensity lesion against a suppressed background.

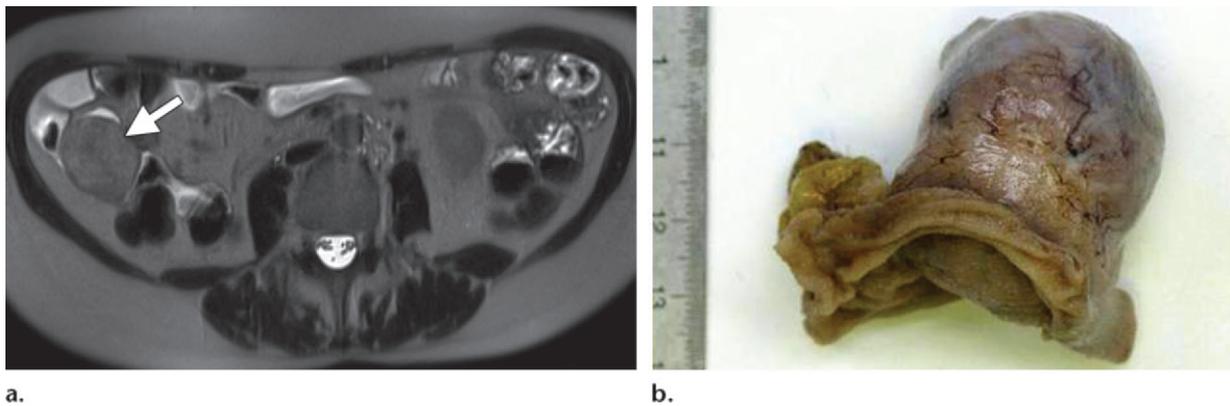


Figure 6. Leiomyoma in a 60-year-old woman referred for evaluation of unexplained GI tract bleeding and anemia. **(a)** Axial T2-weighted half-Fourier RARE image from MR enterography shows a round, homogeneous, exophytic ileal mass (arrow). **(b)** Photograph of the resected bowel segment shows a well-delimited extraluminal mass arising from the bowel wall. (Scale is in centimeters.)

ovoid masses with a maximal diameter of 1–10 cm that usually enhance after the administration of an intravenous contrast medium (Fig 6).

Malignant Tumors.—Malignant tumors of the small bowel account for 1%–2% of all GI tract neoplasms and are usually misdiagnosed at initial presentation or diagnosed late in the disease process. An estimated 60%–70% of symptomatic small-bowel tumors prove to be malignant (26,46).

Adenocarcinomas are the most common primary malignancies of the small bowel, accounting for 40% of malignancies in this part of the GI tract. They most often arise in the duodenum (50%), followed by the jejunum (30%) and ileum (20%). Adenocarcinomas typically involve a short segment of bowel, and they may lead to partial or complete bowel obstruction (Fig 7).

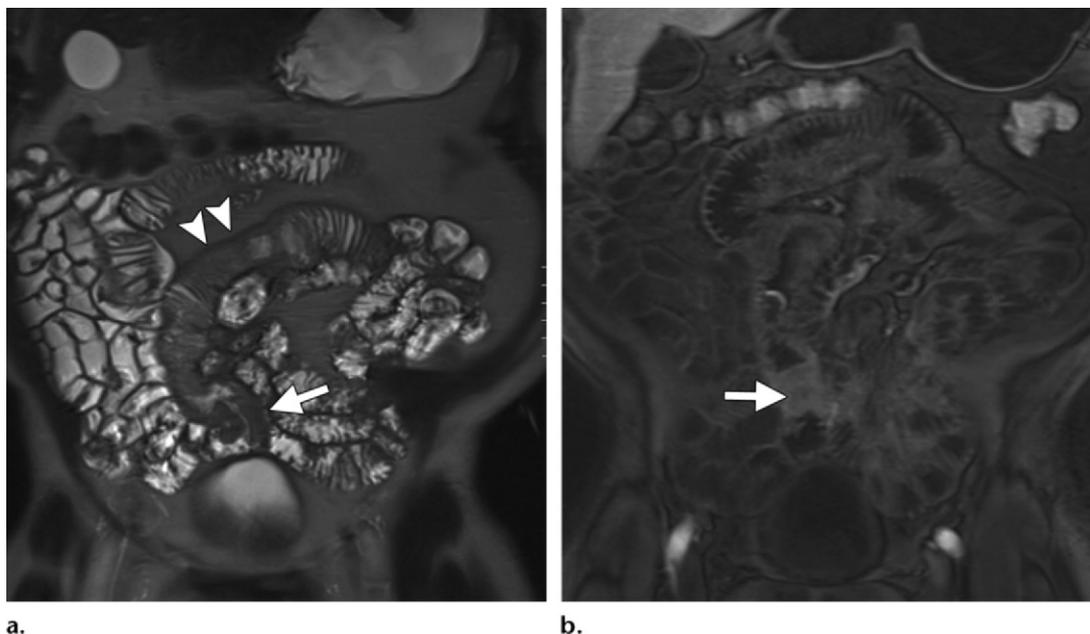


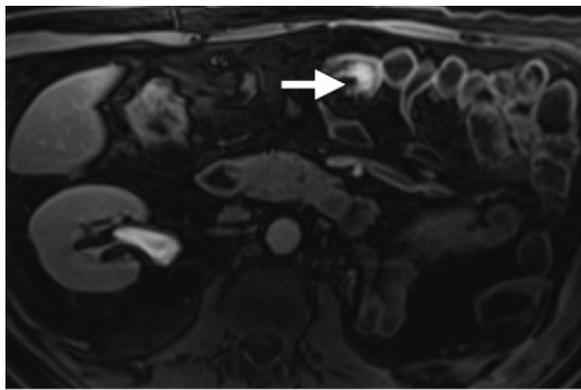
Figure 7. Pathologically proved jejunal adenocarcinoma in a 57-year-old man with abdominal pain and vomiting for 15 days. **(a)** Coronal T2-weighted half-Fourier RARE image from MR enterography shows a low-signal-intensity jejunal loop with irregular short-segment circumferential thickening and stenosis (arrow) and a dilated jejunal loop with some degree of ischemia proximal to the stenosed segment (arrowheads). **(b)** Coronal gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography shows moderate enhancement of the lesion (arrow).

MR enterographic features of adenocarcinomas include annular and constricting lesions; eccentric or circumferential wall thickening with irregular borders; and moderate, sometimes late enhancement after the administration of intravenous contrast material. Lymph node enlargement is not as marked in the presence of adenocarcinomas as it is in the setting of lymphomas. Metastases from bowel adenocarcinomas to local lymph nodes, liver, peritoneal surfaces, and ovaries may be depicted at MR enterography (31,46–48).

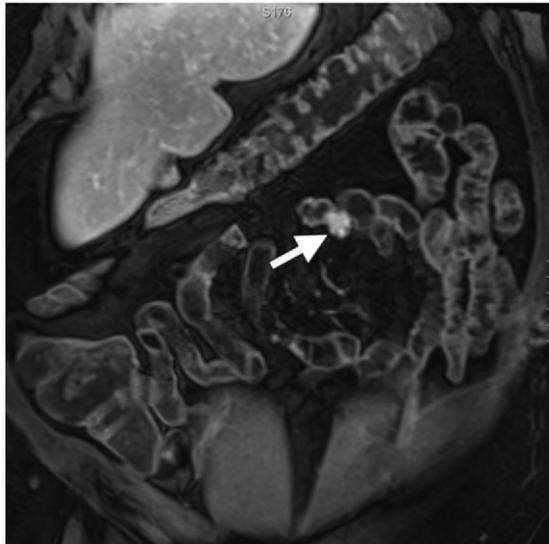
Carcinoid tumors are the second most common primary malignancies of the small bowel (33% of malignancies), after adenocarcinomas. They most often arise in the appendix (50%) and the distal ileum. Symptoms are often vague because carcinoid tumors are characteristically slow growing and may go unrecognized for many years. Only 10% of patients develop carcinoid syndrome (49). Carcinoid tumors of the small bowel may occur in multiples. Those occurring in the distal small bowel often involve the adjacent mesentery, stimulating considerable desmoplasia and fibrosis; the resultant angulation and kinking of the bowel often lead to obstruction and ischemia. Mesenteric carcinoid tumors have a maximal diameter of 2–4 cm, typically show signal isointense to that in muscle on T1- and T2-weighted images, and sometimes exhibit radiating spicule-like strands of tissue. Small-bowel car-

cinoid tumors are likely to be small and difficult to detect. MR enterographic appearances of carcinoid tumors of the small bowel vary and may include an avidly enhancing, well-delimited submucosal mass, often in the distal ileum; multifocal enhancing polypoid lesions in a segmental distribution; and numerous tiny enhancing lesions in a carpetlike configuration (31) (Fig 8). Hypervascular metastases may be seen in the liver (31).

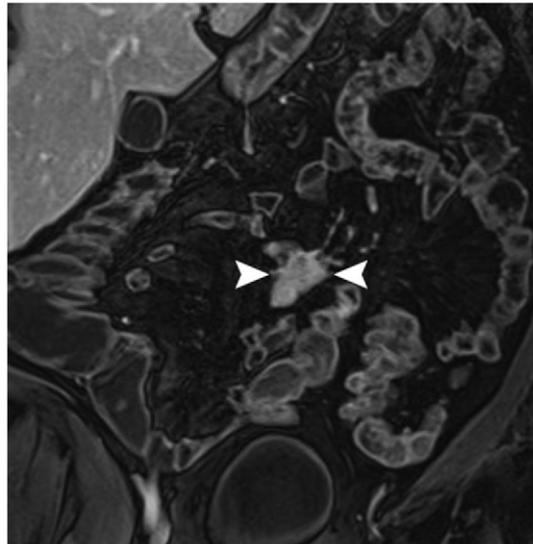
Lymphomas may arise as primary tumors of the small bowel or may represent secondary intestinal involvement in the setting of diffuse lymphomatous disease. Non-Hodgkin B-cell lymphoma, the most common histologic subtype found in the small bowel, is believed to arise from mucosa-associated lymphoid tissue. T-cell lymphomas of the small bowel are considerably less common and are associated with concomitant celiac disease (50). The use of MR enterography to investigate small-bowel lymphomas was described previously (25). Small-bowel lymphomas have varied appearances at imaging, depending on their gross morphologic features; they may differ considerably in regard to their location, their size, the extent of their involvement of bowel, and their effect on luminal integrity. A finding of an exoenteric mass or long segment of circumferential bowel wall thickening with adjacent lymphadenopathy or aneurysmal ulceration but without obstruction is suggestive of lymphoma as the primary diagnostic consideration (Figs 9, 10). The distal ileum is the most



a.



b.

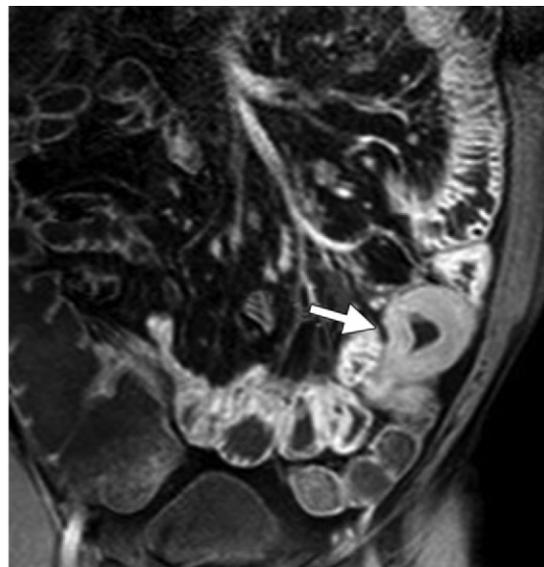


c.

Figure 8. Histologically proved isolated ileal carcinoid tumor in a 71-year-old man with a history of synchronous renal and rectal cancers. **(a)** Axial gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography shows a single 1.5-cm markedly enhancing submucosal ileal nodule (arrow). **(b, c)** Coronal gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE images from MR enterography show the submucosal ileal nodule (arrow in **b**) and a distant, spiculated, irregular mesenteric mass (arrowheads).



a.



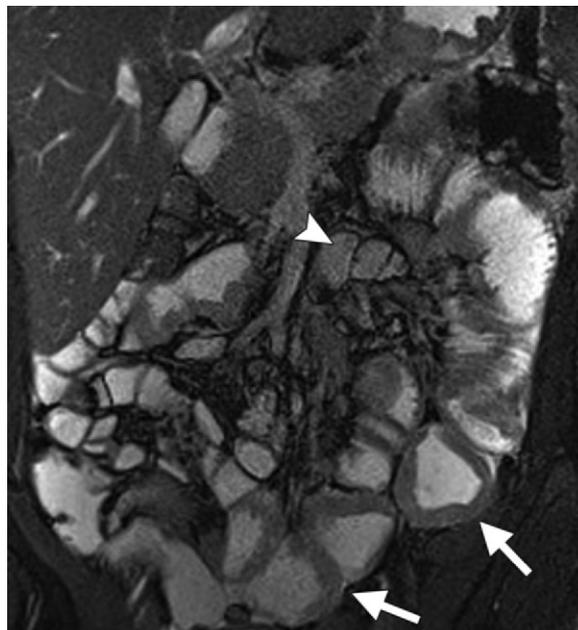
b.

Figure 9. Lymphoma in a 50-year-old man with abdominal pain. Coronal FISP **(a)** and gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE **(b)** images from MR enterography demonstrate segmental homogeneous and circumferential bowel wall thickening with a pseudoaneurysmal pattern (arrow).

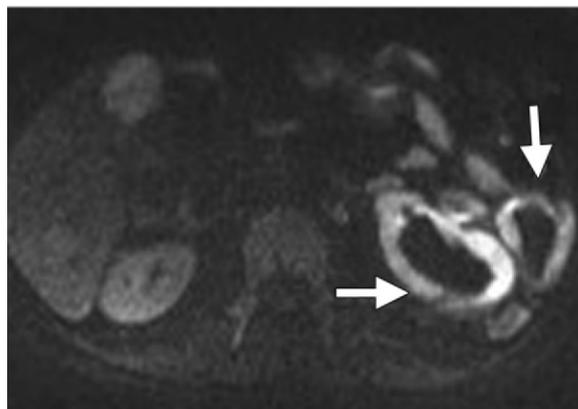
Figure 10. Burkitt-type lymphoma in a 19-year-old man with abdominal pain. **(a)** Coronal FISP image from MR enterography demonstrates segmental bowel wall thickening (arrows) with mesenteric adenopathy (arrowhead). **(b)** Axial diffusion-weighted image obtained with b of 800 sec/mm² optimally depicts high-signal-intensity abnormalities in the small-bowel wall (arrows) against a suppressed background.

common site of small-bowel B-cell lymphomas. Lymphomatous involvement may be localized to a single bowel segment, or multiple discrete sites may be involved. Small-bowel lymphomas may be diffusely infiltrating, with resultant thickening of the entire small-bowel wall; polypoid, with protrusion into the lumen; or masslike and exophytic, with mural ulceration and fistulation. Mesenteric involvement in the form of diffuse fat infiltration, discrete nodal involvement, or masslike deposition is relatively common in the presence of systemic lymphomatous disease. Mesenteric fat infiltration in the absence of discrete lymphadenopathy seems to be associated with high-grade non-Hodgkin lymphoma (25). Intussusception may occur in small-bowel lymphomas. After the intravenous administration of a gadolinium chelate, small-bowel lymphomas show mild enhancement. Some MR enterographic features have been identified that may be suggestive of the histologic subtype or underlying celiac disease (25). Among these features, the involvement of a single small-bowel segment, particularly a segment with a length of more than 10 cm, appears to be highly predictive of underlying celiac disease. Other suggestive features include a smooth contour of the bowel wall, diffuse aneurysmal dilatation of the involved small-bowel segment, and the absence of a specific mesenteric or antimesenteric predominance.

Secondary neoplasms that arise by means of intraperitoneal seeding may appear as small or large enhancing nodules along the serosal surface of the small bowel, mesentery, or omentum (Fig 11). Bowel metastases also may occur by direct extension from adjacent structures or by lymphatic spread. Hematogenous metastases to the intestine from extraenteric primary tumors are unusual, but melanoma, breast cancer, and lung cancer are the most common primary sources of such metastases. Metastases characteristically appear as mural nodules and may cause transient intussusception (26,46,51–53).



a.



b.

Inflammatory Conditions

Bowel Ischemia and Vasculitis.—Bowel ischemia is a common but complex disorder with various primary causes and diverse clinical and imaging manifestations. Primary causes of insufficient blood flow to the intestine are numerous and include thromboembolism, nonocclusive conditions (hypovolemia; hypotension; low cardiac output status; and therapy with digoxin, α -adrenergic agonists, or β -receptor-blocking agents), bowel obstructions, neoplasms, abdominal inflammatory conditions, chemotherapy- and radiation-induced enteropathies, and vasculitides. Regardless of the primary cause, the imaging findings of bowel ischemia are similar. MR imaging can depict the ischemic bowel segment and may also be helpful in determining the primary cause.

MR enterographic features of ischemia include thickening of the bowel wall with or without the

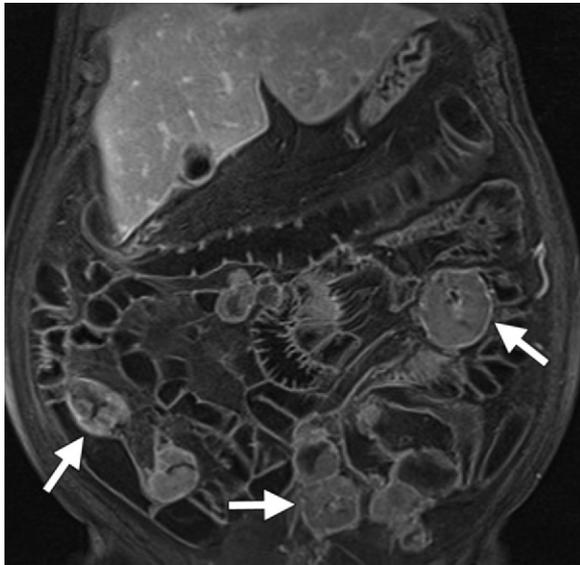


Figure 11. Metastases from stage IV melanoma in a 57-year-old man with abdominal pain. Coronal gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography demonstrates numerous rounded subserosal intestinal lesions (arrows) that represent metastases.

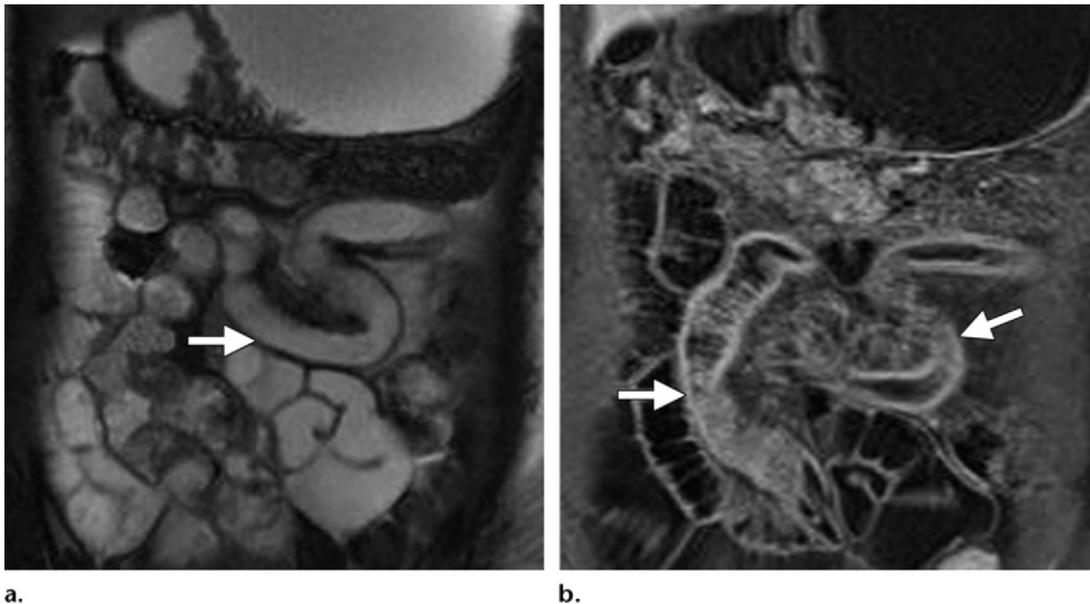
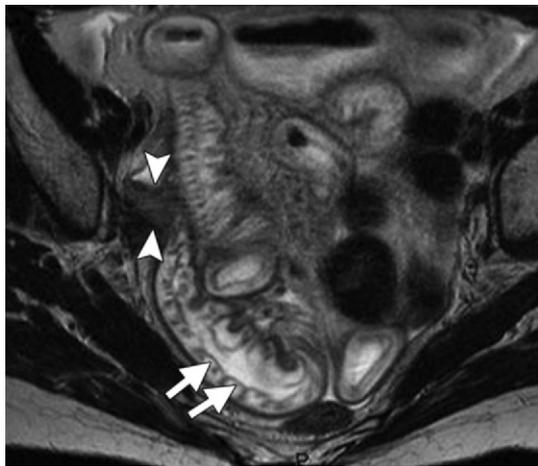


Figure 12. Small-bowel ischemia in a 67-year-old woman with hypovolemic shock. Coronal FISP (**a**) and gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE (**b**) images from MR enterography show a long segment of the proximal small bowel with a mildly thickened wall (arrows) that enhances in **b**. These findings are indicative of ischemia.

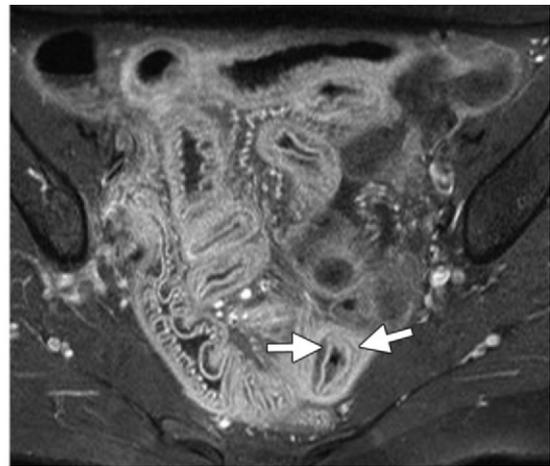
target sign, poor contrast enhancement of the bowel wall, and low-grade obstruction. Absence of enhancement or poor enhancement of the bowel wall appears to be the most specific finding. However, in some cases the ischemic segment shows prolonged enhancement (Fig 12) due to abnormal perfusion (eg, delayed return of venous blood with resultant slowing of the arterial supply or arteriospasm). Ischemia appears as marked enhancement of the bowel wall on gadolinium-enhanced T1-weighted fat-suppressed MR images, with persistent enhancement in the same

region on late venous phase images obtained after gadolinium chelate injection.

Differentiation of bowel ischemia from infiltrative or neoplastic disease may be difficult on the basis of imaging appearances alone. In such cases, the clinical manifestations and clinical history (eg, a history of radiation therapy or other intervention) often enable an accurate diagnosis of ischemia. Bowel ischemia also may arise in the presence of a malignancy, particularly colonic carcinoma (54).

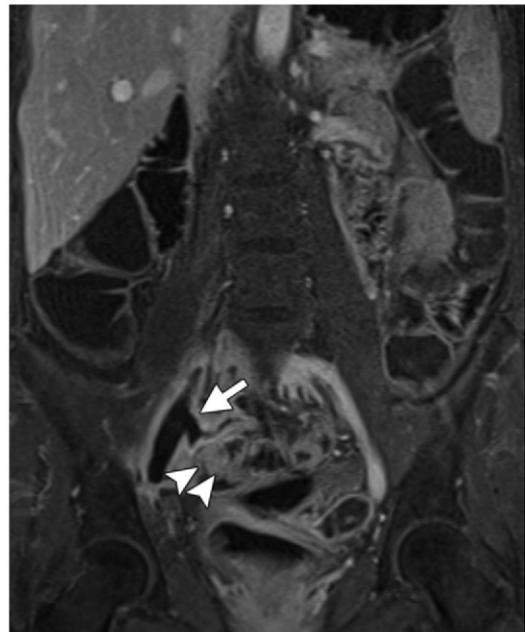


13a.



13b.

Figures 13, 14. (13) Radiation therapy–induced enteropathy in a 42-year-old woman with low-grade bowel obstruction and weight loss 4 years after undergoing surgery and external-beam radiation therapy for uterine cervical cancer. (a) Axial T2-weighted half-Fourier RARE image from MR enterography depicts thickened pelvic small-bowel loops (arrows) and a recurrent nodule (arrowheads) in the bowel wall. (b) Axial gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography demonstrates thick-walled pelvic small-bowel loops with a stratified enhancement pattern (arrows) produced by the low-signal-intensity edematous submucosa between the enhancing mucosa and serosa. (14) Enteropathy in a 46-year-old woman who underwent radiation therapy for mucinous cervical adenocarcinoma 2 years earlier. Coronal gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography demonstrates thick-walled inflamed ileal loops (arrowheads) and a fluid collection (arrow) due to ileal fistulation.



14.

Systemic vasculitides, such as systemic lupus erythematosus, polyarteritis nodosa, and Henoch-Schönlein purpura, rarely cause bowel ischemia. Mesenteric vasculitis usually involves a relatively long length of bowel and is nonsegmental in distribution. The finding of ischemic changes involving the duodenum is relatively specific for the presence of vasculitis; other causes of small-bowel ischemia typically involve the jejunum and ileum as well as the colon (28).

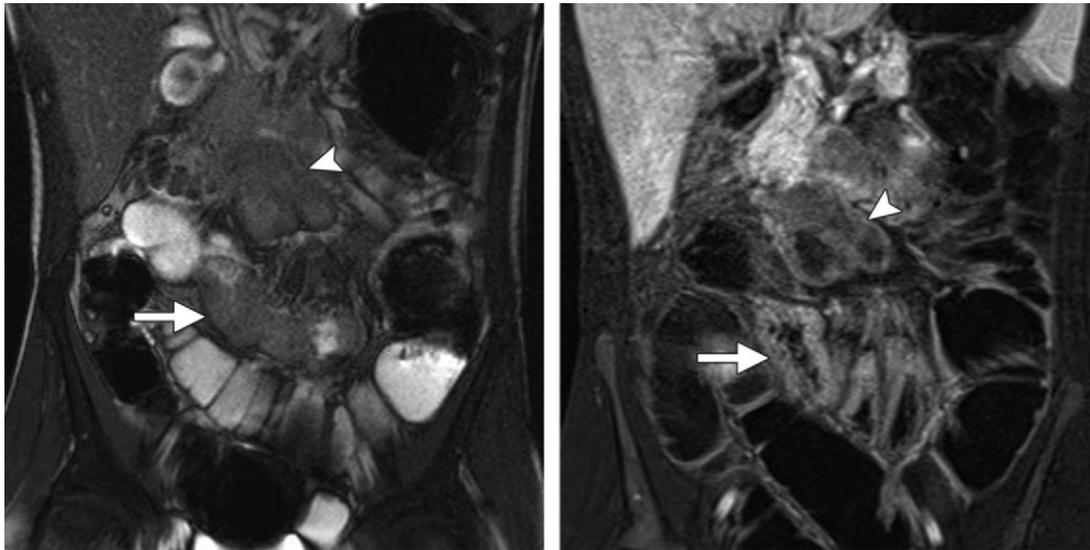
Treatment-induced Inflammation.—The frequency and severity of radiation therapy–induced enteritis depend on the radiation dose, treatment volume, and fractionation scale. Risk factors that predispose patients to chronic radiation therapy–related enteritis include hypertension, atherosclerosis, diabetes, adhesions due to previous abdominal surgery, and a history

of peritonitis. Radiation-induced enteropathy occurs in patients who receive a dose of more than 45 Gy to the pelvis. During the subacute phase (5–12 months after the completion of radiation therapy), severe endarteritis obliterans may develop, with resultant inflammatory thickening of loops of ileum within the pelvic radiation port. During the chronic phase (1–2 years after the completion of radiation therapy), these bowel loops may become fixed and angulated, with resultant stricture and obstruction. MR enterography may show narrowing of the bowel lumen secondary to mural thickening and bowel angulation due to adhesions and retraction of the mesentery; fistulas may also be observed (Figs 13, 14).

Chemotherapeutic agents also can induce enteropathy. Chemotherapy-induced enteritis appears as nonspecific focal or diffuse bowel



Figure 15. Enteropathy in a 50-year-old man with diarrhea and abdominal pain while undergoing chemotherapy for esophageal adenocarcinoma. Coronal gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography demonstrates wall thickening and stratified enhancement of a distal ileal loop (arrow), findings suggestive of inflammatory active ileitis. Symptoms resolved after a change in the chemotherapeutic agent.



a.

b.

Figure 16. Bacterial infection in a 35-year-old man with AIDS, bowel obstruction, and a mesenteric mass seen at CT. **(a)** Coronal FISP image from MR enterography shows thickened small-bowel loops (arrow) and a mesenteric mass (arrowhead). **(b)** Coronal gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE image from MR enterography depicts enhancing thickened small-bowel loops (arrow) and the partly necrotic mesenteric mass (arrowhead). Biopsy of the mass revealed *Mycobacterium* infection.

wall thickening with or without the target sign. Regional mesenteric vessel engorgement and haziness also may be seen (Fig 15).

Infectious Processes.—Infectious processes are rarely detected initially at MR enterography. However, MR imaging may be useful for visualizing small-bowel abnormalities that occur in the setting of chronic infectious diseases such as tuberculosis, as well as for monitoring such abnormalities during treatment. The diagnosis of infectious enterocolitis, a common cause of acute diarrhea, abdominal pain, and fever, rarely requires MR enterography; however, ileitis may

manifest on MR images as segmental circumferential wall thickening of the terminal ileum and cecum with moderate or marked enlargement of the mesenteric lymph nodes. Perforation and fistulation may be complicating factors in infectious terminal ileitis (31).

Less common small-bowel infections include giardiasis, tuberculosis, nontuberculous mycobacterial infection, and histoplasmosis. Such infections are more commonly seen in the setting of acquired immunodeficiency syndrome (AIDS) (Fig 16) (47). The associated MR

imaging findings tend to be nonspecific; these include bowel wall thickening, a stratified pattern of bowel enhancement, and enlargement of adjacent lymph nodes. GI tract tuberculosis tends to involve the ileocecal region; the cecum and ascending colon are usually involved to a greater degree than the terminal ileum (55). Characteristic MR features of tuberculous enteritis include asymmetric thickening of the ileocecal valve and medial wall of the cecum with deformation and contraction of the cecum and extension to the terminal ileum. Massive adjacent lymph nodes with central areas of necrosis are often seen. It may be difficult to differentiate small-bowel tuberculosis from Crohn disease in the absence of a clinical history of tuberculosis or a positive tuberculin skin test result (31,55).

Celiac Disease.—Celiac disease is a gluten-sensitive enteropathy that affects the small intestine in genetically susceptible individuals. The symptoms of celiac disease are frequently nonspecific, and the differential diagnosis, which is based on clinical and radiologic manifestations, includes viral enteritis, giardiasis, Crohn disease, AIDS, and Whipple disease. Although celiac disease previously was considered a pediatric condition, two later peak incidences have been observed, in the 4th and 6th–7th decades of life. Symptoms may relate directly to the abnormal small-bowel mucosa (eg, diarrhea, steatorrhea, pain, vomiting, abdominal distention) or to secondary effects of malabsorption (eg, osteoporosis). Although a diagnosis of celiac disease is verified with biopsy of the small intestine, imaging findings are often suggestive of the diagnosis in adult patients with nonspecific intestinal disorders and a presumably low risk for celiac disease, and they may be helpful for detecting complications such as intestinal intussusception, lymphoma, and carcinoma. The use of MR enterography and MR enteroclysis (29) has been proposed for the evaluation of celiac disease in both children and adults (8,13,29).

Celiac disease predominantly involves the duodenum and proximal jejunum, with the extent of involvement ranging from one or two segments to the entire small bowel (Fig 17) (13,14). The radiologist should examine the



Figure 17. Celiac disease in a 23-year-old woman. Coronal FISP image from MR enterography shows an increased number of folds in ileal loops (arrow).

folds attentively for signs of villous atrophy in the jejunum (seen as reversal of the normal jejunioileal fold pattern, with an increased number of ileal folds and a decreased number of jejunal folds) or dilatation of jejunal loops with absence of the valvulae conniventes. Findings such as inflammatory thickening of the bowel wall, lymphadenopathy, and mesenteric vascular engorgement also may be seen in patients with celiac disease. Complications of the disease may include nonobstructive intussusception and ulcerative jejunoileitis with circumferential thickening of the bowel wall seen at MR enterography. Cavitory mesenteric lymph node syndrome, which is characterized by fat-fluid levels, and the development of lymphoma or carcinoma, are rare associated conditions. The latter should be suspected when previously asymptomatic patients with celiac disease develop recurrent diarrhea, abdominal pain, or both after initiating a gluten-free dietary regimen.

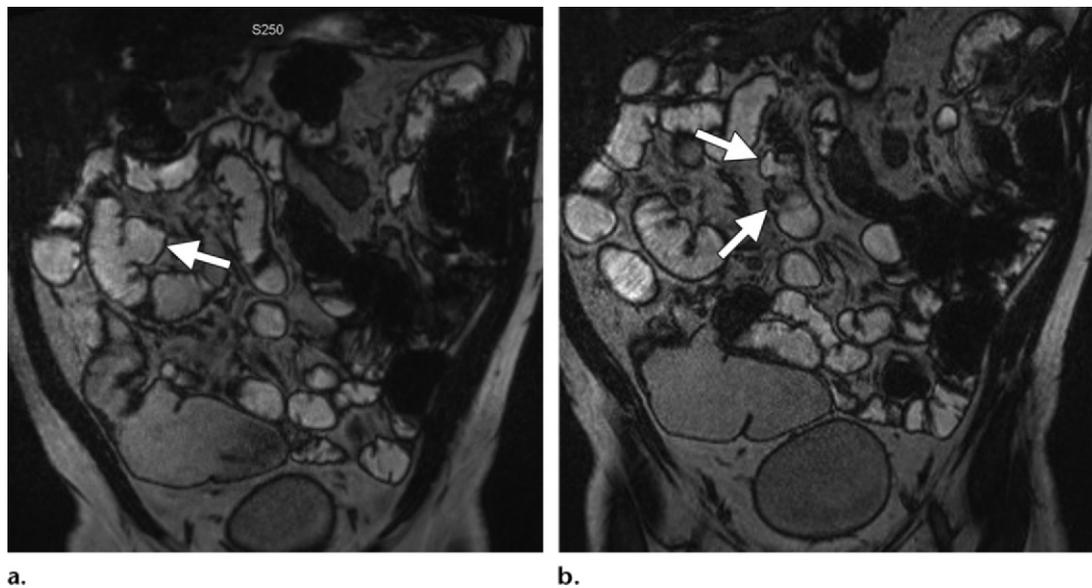


Figure 18. Small-bowel diverticula in a 40-year-old man with chronic abdominal pain, nausea, and diarrhea. Coronal FISP images from MR enterography (**a** obtained in a section anterior to **b**) show at least three small-bowel diverticula (arrows).

Diverticular Disease

Jejunioleal diverticulosis results from herniation of the mucosa at sites of small-bowel weakening. The condition develops predominantly on the mesenteric border of the jejunum and less frequently on that of the ileum (55). Most cases of jejunal diverticulosis are asymptomatic, and the condition is often overlooked at cross-sectional imaging. Multiple smooth, rounded outpouchings of variable size may be seen, with a discrete “neck” or constriction at the base (Fig 18). Although panjejunoileal diverticulosis is recognized, the more typical manifestation is a solitary diverticulum or several diverticula (56). Small-bowel diverticula are rarely symptomatic, often found incidentally, and usually of little clinical significance. Chronic symptoms of small-bowel diverticular disease include nonspecific abdominal discomfort and malabsorption in the presence of bacterial overgrowth. The condition is conservatively managed (Fig 18).

Diverticulitis results from acute inflammation or perforation of a diverticulum. At radiologic imaging, it manifests as inflammatory infiltration of the mesenteric fat around one or more

diverticula of the small bowel. Although CT is the more commonly used imaging modality, diverticulitis of the small bowel may be diagnosed at MR imaging.

Systemic Sclerosis

Systemic sclerosis is a connective-tissue disorder involving the lungs, kidneys, heart, and GI tract. The small bowel is the second most common site of GI tract involvement, after the esophagus. Systemic sclerosis is characterized by smooth-muscle atrophy and fibrosis with deposition of collagen and other pathologic changes that result in decreased small-bowel motility with stasis, bacterial overgrowth, diarrhea, and malabsorption. Diffuse dilatation of the small bowel may be seen and is most prominent in the jejunum (30,55). MR enterography may reveal the classic “hidebound sign,” an increased number of jejunal folds crowded together despite luminal distention, an appearance produced by small-bowel fibrosis and contraction. In some patients, small-bowel sacculation may be seen as

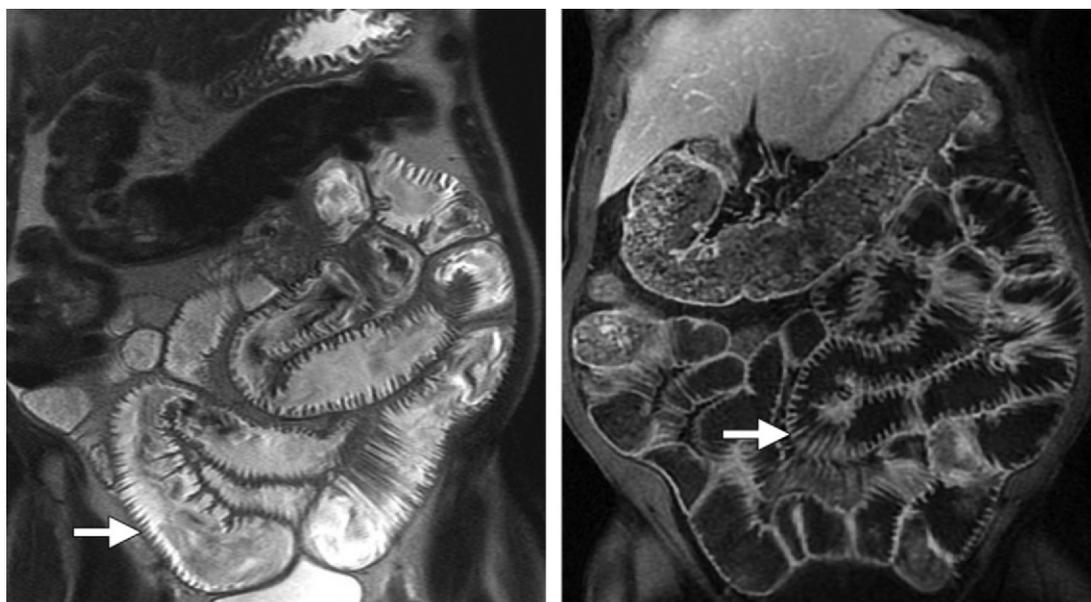


Figure 19. Systemic sclerosis in a 54-year-old woman with mild diarrhea. Coronal T2-weighted half-Fourier RARE (**a**) and gadolinium-enhanced T1-weighted fat-suppressed 3D VIBE (**b**) images from MR enterography show diffuse dilatation of the small bowel to the level of the cecum, without obstruction. Note the increased frequency of jejunal folds (arrow).

Figure 20. Duodenal duplication cyst in a 32-year-old man with nonspecific abdominal pain. Coronal FISP image from MR enterography shows a round, fluid-filled lesion in communication with the duodenum (arrow).



multiple wide-mouthed outpouchings containing all layers of the bowel; these features are due to asymmetric bowel wall fibrosis, especially in the jejunum. Other possible findings include intestinal pseudo obstruction, transient intussusception, and a benign form of pneumatosis cystoides intestinalis (Fig 19).

Bowel Duplication

Bowel duplications are uncommon congenital anomalies that appear on MR images as smoothly rounded, fluid-filled cystic or tubular structures with thin, slightly enhancing walls containing smooth muscle. These structures are either continuous with or located adjacent to the GI tract (Fig 20) (57).

Conclusion

MR enterography performed with the administration of an oral contrast medium for small intestine distention is a versatile, noninvasive, and accurate imaging method and a feasible alternative to CT enterography and MR enteroclysis for the evaluation of small-bowel disease.

Disclosures of Potential Conflicts of Interest.—G.C.:

Related financial activities: none. *Other financial activities:* board member for Ipsen; consultant for Novartis and Mayoly-Spindler; speakers' bureaus for Ipsen, Novartis, AstraZeneca, Abbott, Schering-Plough, Mayoly, Pfizer, and Nycomed.

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Effectiveness of MR Enterography for the Assessment of Small-Bowel Diseases beyond Crohn Disease

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Fast or turbo spin-echo sequences that are based on the half-Fourier reconstruction technique help limit or overcome artifacts related to small-bowel peristalsis. They produce high contrast between the lumen and the bowel wall, providing excellent depiction of wall thickening and changes in the fold pattern. However, single-shot half-Fourier RARE sequences are susceptible to intraluminal motion, and the resultant images may be degraded by intraluminal low-signal-intensity artifacts due to flow void. Familiarity with these artifacts, and correlation of the half-Fourier RARE images with the corresponding FISP images, are important to avoid misinterpreting findings at MR enterography.

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Unenhanced T2-weighted MR imaging and gadolinium-enhanced fat-suppressed T1-weighted MR imaging are critical for characterizing wall thickening and identifying its cause: In a thickened bowel segment, a stratified enhancement pattern corresponding to the classic target sign is useful for excluding malignant conditions. This pattern is produced by enhancing mucosa with adjacent edematous submucosa, which demonstrates low signal intensity on T1-weighted images and high signal intensity on T2-weighted MR images.

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MR enterography, which allows improved localization of small-bowel polyps in patients with Peutz-Jeghers syndrome, is performed to identify larger lesions that should be resected at double-balloon enteroscopy or surgery. It may also be helpful for excluding the presence of lesions in bowel segments not examined at endoscopy or surgery.

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Diagnosis of adhesions as the cause of a mechanical small-bowel obstruction should be based on the presence of an abrupt change in bowel caliber without evidence of another cause of obstruction in the vicinity of the transition point from the dilated segment to the collapsed segment of bowel. Adhesive strictures are not associated with thickening of the small-bowel wall (15) (Fig 1).

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Celiac disease predominantly involves the duodenum and proximal jejunum, with the extent of involvement ranging from one or two segments to the entire small bowel (Fig 17) (13,14).