
MR in the small bowel: Applications, techniques, and imaging findings

Kira Melamud, MD; Charles Colip, MD; and Jorge A. Soto, MD

With recent advances in magnetic resonance imaging (MRI) software and hardware, and increasing expertise among technologists and radiologists, MR techniques have come to the forefront of imaging patients with known or suspected bowel pathology in both emergent and outpatient settings. MRI provides a number of advantages over more conventional techniques for imaging the small bowel. Superior tissue contrast and lack of ionizing radiation are its major advantages over computed tomography (CT) and contrast-enhanced fluoroscopy. Furthermore, with its dynamic sequences, MRI permits assessment of functional information and improved visualization of the entire bowel.^{1,2} Lastly, MR imaging may also be used for patients with contraindications

to contrast-enhanced CT imaging, including those who are pregnant and those with allergies or contraindications to iodinated contrast.

MRI techniques available to evaluate the small bowel include MR enterography (MRE) and MR enteroclysis. In MR enteroclysis, enteric contrast is administered directly via a nasoenteric tube, providing superior distention of small-bowel loops compared to oral ingestion in MR enterography. However, MR enteroclysis remains of limited availability, perhaps due in part to patient discomfort, and at least partially because such distention may not be necessary to evaluate for a number of pathologic processes that may affect the small bowel. As a result, this review will focus primarily on MR enterography.

MRI applications in small-bowel imaging

The general limitations of MR imaging include limited availability, variable image quality, and higher cost, lower spatial resolution, and longer acquisition times than CT. In recent

years, however, a variety of advanced MR techniques have garnered great support and recognition from the radiology community in evaluating small bowel pathology. For example, current recommendations from the American College of Radiology (ACR), rate MRE with a high-priority score of 8-9 for initial evaluation of Crohn's disease in patients with nonacute presentations, as well as for surveillance and acute exacerbation of known Crohn's disease, in both adults and children/young adults.^{2,3} Of note, MR techniques also score well in situations of acute abdominal pain in pregnant females (appropriateness score of 7).⁴ Lastly, it's worth noting that MR enteroclysis has a high priority score of 8 in evaluating suspected intermittent or low-grade small bowel obstruction, on par with CT of the abdomen and pelvis with contrast, which also scores 8.⁵

Crohn's disease

Evaluating Crohn's disease is one of the most common indications for MRI of the small bowel. MR techniques are

Dr. Melamud is a fellow in abdominal imaging PGY6 at the Hospital of the University of Pennsylvania, Dr. Colip is a radiology resident PGY3, and Dr. Soto is a Professor at Boston University Medical Center, Boston, MA.

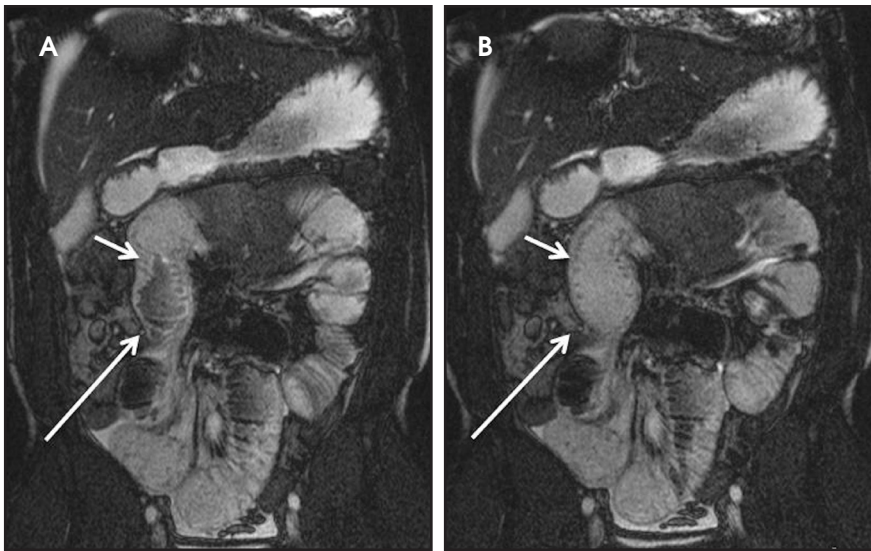


FIGURE 1. Stricture vs peristalsis in Crohn's disease. A 42-year-old man with history of Crohn's disease presents with abdominal pain and vomiting. Three sequential dynamic, MRE-balanced Turbo Field-Echo (bTFE) images, demonstrate distended loops of small bowel. Note focal narrowing of a segment of small bowel on the right (long arrows, A-C), which persists with time, representing a stricture. Comparatively, note focal narrowing in a loop of small bowel proximal to the stricture (short arrow, A), which expands on more delayed image (short arrow, B), compatible with peristalsis.

uniquely suited for imaging this disease, as its early age of onset and its waxing and waning nature require repeat imaging to detect complications or assess response to treatment, sparing patients potential exposure to high lifetime doses of radiation.^{6,7} Although many advocate for use of CT enterography as the initial study of choice to establish baseline, especially in the setting of acute abdominal pain, and this is a common practice in our own experience, MR enterography plays a major role in serial follow up and in assessing treatment response. As mentioned previously, one of the major advantages of MR enterography over CT is its ability to provide functional information about the small bowel via multiphasic dynamic sequences, which can confirm the presence of bowel stricturing, thus avoiding misinterpretation with underdistention, a common pitfall at CT imaging (Figure 1). MR techniques also allow superb evaluation of the perianal region, a frequent site of complications and fistula formation in patients with Crohn's disease. Lastly, MRE may more accurately depict submucosal pathology given its superior soft tissue

contrast, thus improving ability to distinguish between active inflammation and chronic fibrotic disease, as compared to CT enterography.⁸

Small bowel masses

Another application of MRE is detection and surveillance of small-bowel polyps, especially in patients with polyposis syndromes, who may require chronic surveillance. Although MR enteroclysis has been found to perform better in detecting small enteric lesions given greater luminal distention than MRE, in at least one study of 20 patients with polyposis syndromes, MRE performed similarly to capsule endoscopy in detection of larger polyps (>15mm in size), which are more clinically relevant.⁹ Furthermore, MR was found to be more accurate for determination of the exact size and localization of enteric polyps than capsule endoscopy.⁹ In addition, capsule endoscopy has limited ability to evaluate submucosal lesions, or to fully characterize the invasive nature of a small bowel tumor, while MRI can delineate lesion extent as well as localize potential regional (lymph node or mesenteric) or even

distal metastases (such as to the liver). A recent study aimed at prospectively evaluating the ability of MRE to detect small bowel tumors demonstrated sensitivity and specificity of 96% on a per-patient basis, but lower sensitivity of 70% on a per-lesion basis.¹⁰

Emerging applications of MR enterography

New applications for MRE have come to the forefront. For example, a number of authors in the radiology literature have described MRI in characterizing Celiac disease.¹ Imaging findings such as reversal of the jejunoileal fold pattern, which have classically been described on conventional barium fluoroscopic studies, can be well visualized at MRE. Associated findings, such as small bowel intussusception, mesenteric lymphadenopathy, and possible associated Celiac disease-related lymphoma, are also readily identifiable. MR enterography may also aid in evaluation of small bowel obstruction, especially in patients in whom it is desirable to avoid radiation exposure (children/young adults or pregnant patients).

MRE techniques

Oral contrast agents

MR enterography typically requires administration of a high volume of oral contrast material, usually on the order of 1500 to 2000 mL, to be ingested during the 2 hours preceding the examination. A number of enteric contrast agents may be used for MR imaging. These can be broadly classified into 3 major types: negative, positive, and "biphasic" contrast.¹¹ The majority of commercially available enteric contrasts are biphasic. Biphasic contrasts demonstrate different signal intensities on T1- and T2-weighted imaging. Specifically, on T1-weighted imaging these agents demonstrate low signal intensity, thus allowing for improved contrast between bowel lumen and bowel wall, and improving detection of pathologic wall hyper-enhancement. On T2-weighted imaging, these contrast agents are high in signal intensity, allowing for delineation

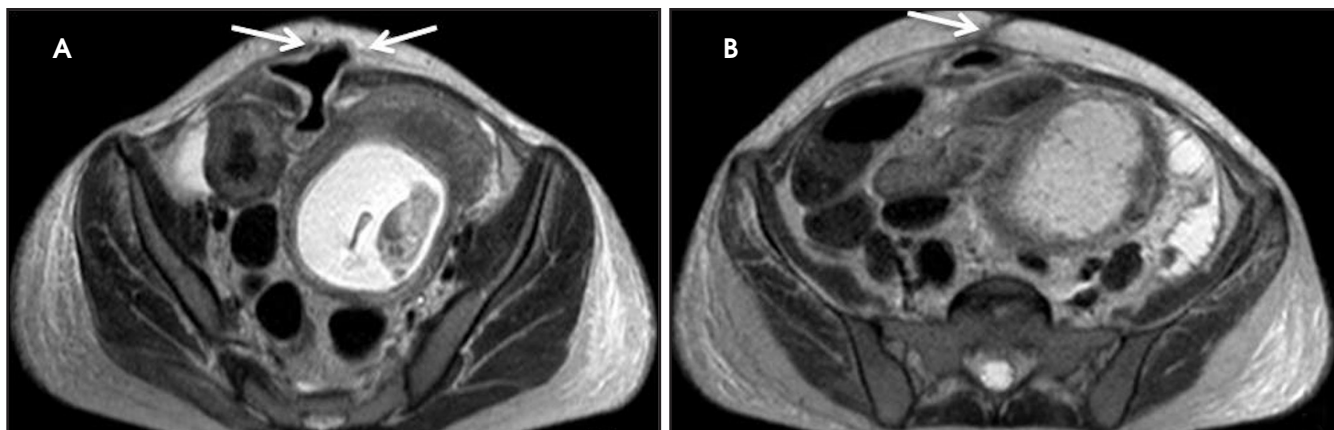


FIGURE 2. MRE in pregnant patients. Single-shot turbo spin echo (SSTSE) axial (A and B) images from a non-contrast MRE study performed in a 14-week pregnant patient with Crohn's disease, demonstrating a colonic sinus tract extending into the anterior abdominal wall with penetration through the subcutaneous tissue to the skin (arrows in A and B)

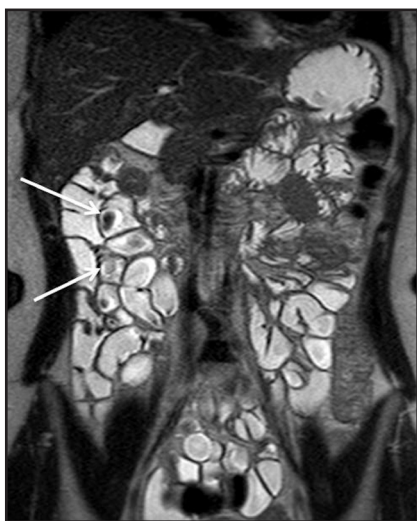


FIGURE 3. Artifact on T2-weighted imaging. Coronal T2-weighted SSTSE image demonstrates multiple apparent filling defects within small bowel loops in the right hemiabdomen (arrows), which represent flow related signal voids, a common artifact encountered on this sequence.

between the lumen and the dark bowel wall. There are a variety of commercially available enteric agents, with the preferred agent in our institution being barium sulfate (VoLumen; E-Z-Em/Bracco, Lake Success, NY). The intrinsic advantage of VoLumen is that it contains sorbitol, and thus acts as an osmotic agent, promoting luminal water retention¹.

Negative contrast agents have low signal intensity on T1- and T2-weighted imaging, and include superparamagnetic particles. On T2-weighted images this provides the benefit of improved



FIGURE 4. Acute chronic Crohn's inflammation. A 49-year-old woman, with Crohn's disease presents with abdominal pain. Coronal post-contrast fat-saturated T1-weighted image, demonstrating mucosal hyperenhancement in a strictured, and kinked loop of small bowel (arrow), indicative of acute chronic inflammation.

visualization of mural inflammatory high signal. This also allows for increased recognition and detection of interloop abscesses.² An example of a negative contrast agent is ferumoxsil oral suspension.

Unlike negative oral suspensions, positive enteric contrast agents are paramagnetic substances, which produce high signal intensity on both T1- and T2-weighted sequences. Although this may have the advantage of demonstrating bowel wall thickening on T1-weighted images, the drawback

is potential masking of mural enhancement abnormalities.

Spasmolytics

Spasmolytics may be useful in MRE to reduce motion artifact related to bowel peristalsis, and therefore improve lesion detection. Motion-related artifacts are most problematic for fast gradient echo sequencing obtained after intravenous contrast administration, where they can reduce lesion detection. Decreased peristalsis is also helpful for optimization of images obtained by half-Fourier acquisition single-shot turbo spin-echo technique, which may otherwise be fraught with intraluminal flow artifacts. Glucagon is a commonly used spasmolytic agent.¹²

Intravenous contrast

With administration of IV contrast, pathologic findings such as hyperenhancement of the bowel wall or enhancing mural/endoluminal mass lesions can be made more conspicuous.¹³ Intravenous contrast is not absolutely crucial to localizing small bowel pathology, as the excellent soft-tissue contrast resolution of MRI may be sufficient to delineate the small bowel abnormality. This may be especially useful in patients with contraindications to gadolinium-based contrast agents, such as patients with severe renal failure or those who are pregnant (Figure 2). However, in patients with Crohn's disease, although regions of bowel wall thickening, stricturing,

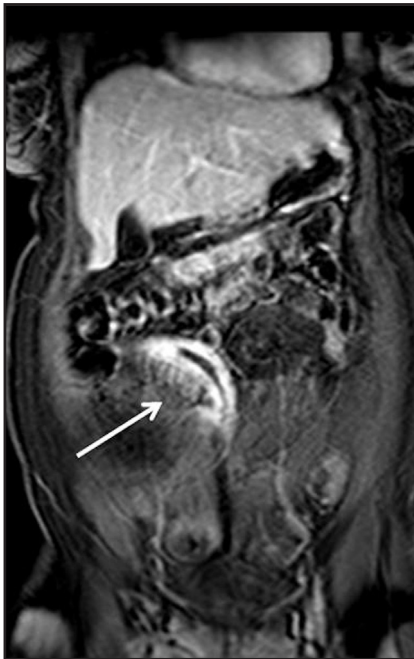


FIGURE 5. Active Crohn's inflammation. A 50-year-old woman with Crohn's disease presents with abdominal pain and diarrhea. Coronal post-contrast fat-saturated T1 weighted image, demonstrates thickening and avid mural hyperenhancement. Note the prominence of the vasa recta abutting this loop of bowel (arrow). This constellation of findings is compatible with active disease.

and mural edema may be detected without gadolinium chelates, some of the earliest signs of active disease such as mucosal hyperenhancement may be missed. Complications in Crohn's disease, including abscess or fistula formation, are also made more conspicuous on post-gadolinium imaging.

Sequences

Although there is no single universal protocol for optimal imaging of small bowel, it is generally accepted that T2-weighted and multi-phasic contrast-enhanced gradient-echo sequences are particularly useful. Specifically, we find single-shot half-Fourier T2-weighted turbo spin-echo sequences (SSFSE, SSTSE, or HASTE, depending on vendor) to be helpful, especially with biphasic oral contrast, as they provide superb spatial resolution, good T2-weighting, and fast scan times.¹⁴ These sequences can be used to obtain an overview of the entire

bowel and to localize pathology.¹⁵ One drawback of these sequences, however, as mentioned previously can be dark signal voids in fluid-filled bowel due to peristalsis, especially if spasmolytics are not used (Figure 3). To counteract the problem of bowel signal voids, balanced steady-state free precession sequences (FIESTA, balanced FFE, depending on the vendor) can be useful adjuncts as they have very rapid acquisition times, and also can be used to create cine loops which can depict bowel motility.¹⁵ Lastly, we obtain coronal T1-weighted dynamic, 3D fat-suppressed gradient echo sequences with and without gadolinium, to evaluate for regions of inflammation, peri-enteric complications, and possible regions of bowel stricture. Image subtraction sets may be created for each of the post-contrast phases (eg, arterial, venous or equilibrium), with areas of enhancement better delineated by the high signal remaining after the digital subtraction of the pre-contrast sequence from a post-contrast sequence. Subtraction images are useful for identifying equivocal enhancement, or for further characterizing known regions of abnormal enhancement.

Imaging findings Crohn's disease

Crohn's disease is a chronic granulomatous inflammatory disease of the gastrointestinal tract that can involve any portion of the tract but is most frequently encountered in the distal small bowel. It is characterized by ulcerations, which may be superficial (aphthous ulcers which are confined to the mucosa) or deep (break through the mucosa), involving all layers of the bowel wall, resulting in penetrating and fistulizing manifestation of the entity. Segmental distribution with classic "skip lesions" is typical.^{15, 16}

Identifying active inflammation is imperative for guiding clinical management algorithms for Crohn's disease. While active disease may be treated medically with systemic steroids or immunomodulators, chronic disease may

require surgery.¹⁷ Therefore, discerning active flare from chronic fibrostenotic disease is essential. Subtle mucosal hyperenhancement can be one of the earliest signs of active Crohn's flare (Figure 4). In more severe active inflammation, small bowel may demonstrate classic "stratified" appearance, as a result of submucosal edema. Serosal hyperenhancement may also be seen.

Once uniform enhancement of all layers of small bowel is achieved, discerning active inflammatory bowel disease from chronic fibrostenotic disease may become more challenging. Searching for secondary signs of regional inflammation, such as increased mesenteric vascularity ("comb sign") or perienteric fluid or enhancement can prove particularly fruitful in identifying regions of active inflammation (Figure 5).⁸ Wall thickening (>3mm) is also a nonspecific finding, and care must be taken not to confuse underdistention for thickening. Evaluation for wall enhancement or edema high signal on fat-suppressed T2-weighted images would indicate the presence of active disease. When reporting, it is critical to describe the number, length, and locations of the segments involved, as this can guide surgical planning. In at least one study, MR measurements of the length of abnormal segments of small bowel were found to be accurate compared with anatomic measurements.¹⁸

As on CT, evaluating for complications of Crohn's disease, which may include fistulizing/penetrating disease and obstruction (Figure 6), is critical. A detailed search of multiplanar images available at MR is essential when assessing for fistulizing disease. Sensitivities for detecting complex internal fistulas on MR is reported to be around 80%,^{1,19-20} with T1-weighted post-gadolinium fat-suppressed imaging being the most helpful. Tethering of small bowel loops, forming a stellate appearance can be seen in the setting of complex internal bowel fistulas or inflammatory adhesions, and may result in small bowel obstruction. True fistulas and sinus tracts typically demonstrate

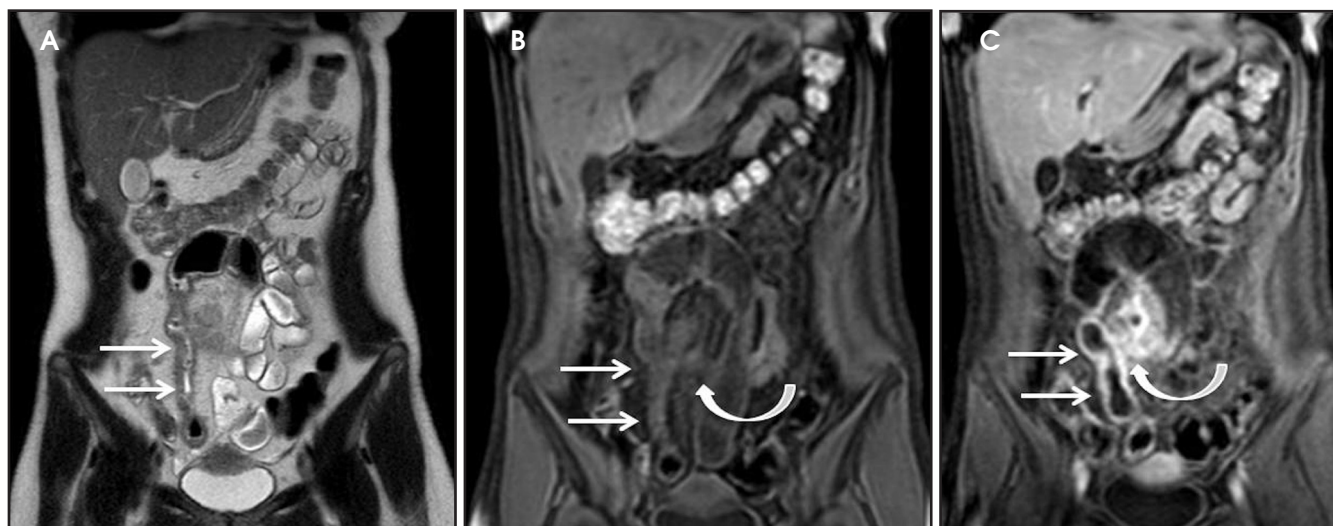


FIGURE 6. *Fistulizing disease. Coronal (A) SSTSE and pre- (B) and post-contrast (C) T1-weighted fat-saturated images in a 21-year-old woman with Crohn's disease, demonstrating a segment of strictured small bowel in the right hemi-abdomen (arrows, A-C) with entero-enteric fistula formation (curved arrows, A-C) to an adjacent ileal loop.*

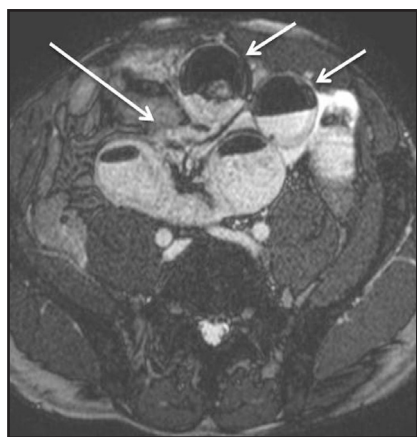


FIGURE 7. *Adhesive small bowel obstruction in a patient with a small bowel stricture. Same patient as in Figure 1. Axial bTFE image demonstrates dilated loops of proximal small bowel with air-fluid levels (short arrows) and a transition point related to adhesions within the mid-lower abdomen (arrow), away from the site of stricture seen in Figure 1.*

internal fluid signal with peripheral enhancement, and thus can be differentiated from tracts of inflammation, which would show uniform enhancement. Adhesions also tend to be thinner and enhance later than fistulas (Figure 7).¹⁵

Perienteric and interloop abscesses may form, but may be difficult to detect on MR, and thorough investigation of bowel loops and the mesentery in all available planes should be undertaken. Negative enteric contrast may be especially beneficial in recognition of inter-



FIGURE 8. *Pseudosacculations. Coronal (A) bTFE and (B) post-contrast fat-saturated T1 in equilibrium phase in a 36-year-old female patient with long history of Crohn's disease demonstrating multiple relative focal narrowings due to fibrosis, presenting as regions of wall thickening and wall hyperenhancement (arrows, A and B), interspersed with segmentally dilated bowel, due to relative sparing of the antimesenteric wall (curved arrows).*

loop abscesses, which may otherwise be masked by retracted, matted loops.

As discussed above, chronic fibrostenotic disease may present as mural thickening without associated active inflammation, such as mucosal hyperenhancement or wall edema.¹ Evaluating dynamic sequences for persistent regions of narrowing, with proximal dilatation can identify associated stenosis. The presence of submucosal fat can also

represent sequelae of chronic inflammation, although this finding is nonspecific and can be seen in normal cohorts. Other stigmata of chronic Crohn's inflammation may present in the forms of hypertrophy of the mesenteric fat and/or pseudosacculations, which is relative dilatation of the uninvolved antimesenteric wall, in the setting of a fore-shortened and fibrosed diseased mesenteric wall (Figure 8).¹⁶

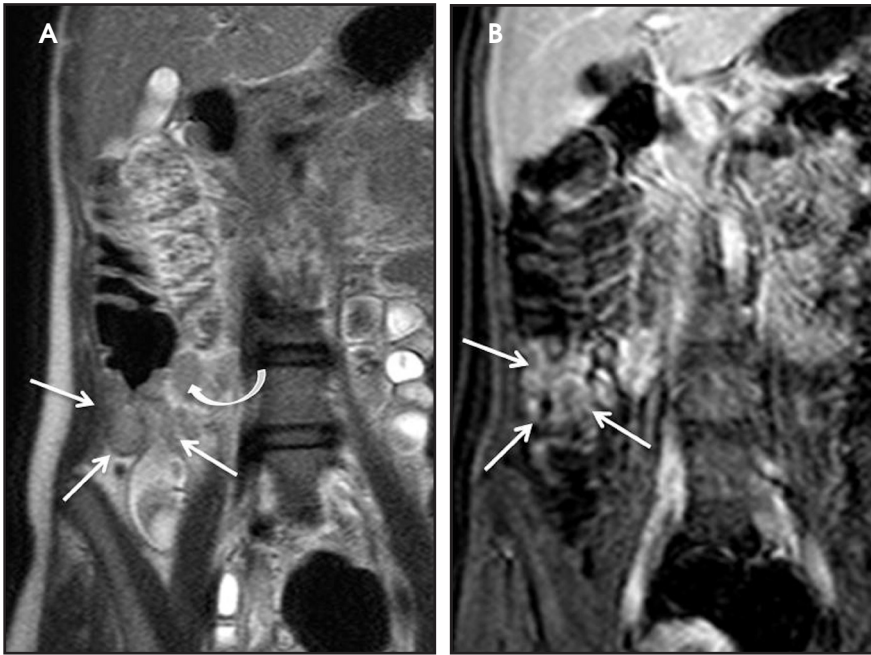


FIGURE 9. Tuberculous enterocolitis. MRE in a 17-year-old girl who recently arrived from Kenya with complaints of diarrhea, vomiting, and abdominal pain. (A) Coronal SSTSE demonstrates wall thickening of a short segment of terminal ileum, extending to involve the ileocecal valve and the cecum (arrows). Note an enlarged adjacent right lower quadrant lymph node (curved arrow). (B) Post-contrast coronal fat-saturated T1-weighted image demonstrates hyperenhancement of the same region (arrows). Although similar imaging findings may be seen in Crohn's disease, considering patient's history of recent PPD positivity, tuberculous enteritis was suspected, and later confirmed.

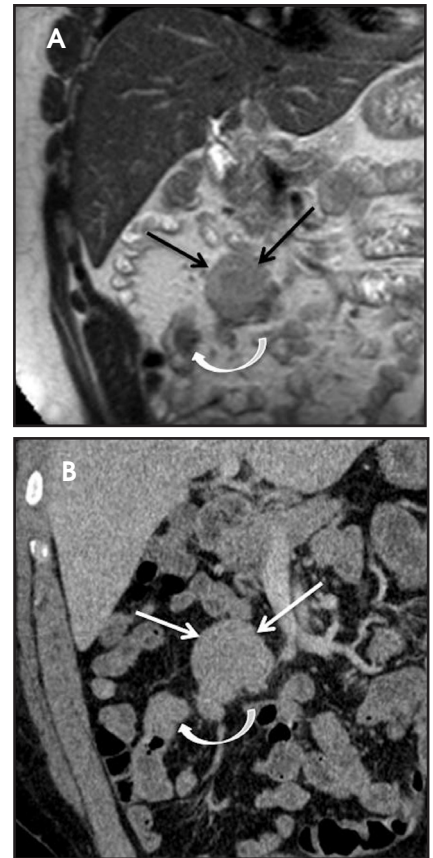


FIGURE 10. Superior soft-tissue contrast of MR imaging in small bowel lesion detection. (A) Coronal T2-weighted SSTSE image demonstrates a low signal intensity eccentric mural-based, partially exophytic mass arising from a loop of small bowel (curved arrow). Note a large, round associated mesenteric mass (black arrows). (B) Coronal contrast-enhanced image from a CT enterography (CTE) performed just two weeks prior, retrospectively demonstrates similar findings, however while the mesenteric mass (white arrows) which had calcifications and was suspected to be carcinoid, was noted at CTE, the primary small bowel lesion, which is isodense to the small bowel, was missed (curved arrow), and first noticed on MR. At surgery this was proven to be carcinoid.

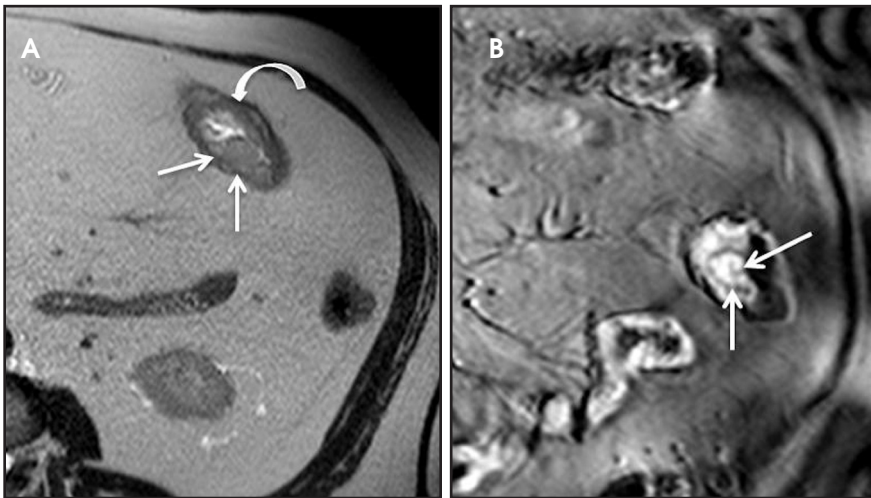


FIGURE 11. Small bowel tubular adenoma. MRE in a 60-year-old man performed for surveillance of chronic Crohn's ileitis. (A) Axial T2 SSTSE image demonstrates an incidentally noted mucosal mass that is hypointense on T2-weighted images within a loop of proximal ileum (arrows). Note that the apparent wall thickening of this loop is due to underdistension (curved arrow), a common pitfall and does not persist on the second image (B). (B) Coronal post-contrast fat-saturated T1-weighted images in venous phase demonstrates avid enhancement of the lesion (arrows). This was found to be a tubular adenoma at surgery.

Imaging mimics of IBD-related enteritis

A number of infectious, inflammatory, and treatment-related causes of

small bowel inflammation can mimic Crohn's disease on imaging. It is especially important to be mindful of these differential considerations at MR, as not

all small-bowel thickening or inflammation on MRE is necessarily Crohn's disease. Inflammation and potentially ischemia due to vasculitides, such as systemic lupus erythematosus, polyarteritis nodosa, and Henoch-Schönlein purpura, may present as variable segments of wall thickening, potentially with submucosal edema, and when ischemia is present may exhibit decreased wall enhancement.²¹

Radiation-induced enteritis also has nonspecific imaging findings on MR depending on the time elapsed from treatment, but involvement of noncontiguous, geographically adjacent loops of small bowel at the targeted location of the radiation field should be sufficient to suggest the diagnosis. Finally, several typical and atypical infectious entities may affect the small bowel. Tuberculous involvement of small bowel has a predilection for involving the terminal ileum, with contiguous involvement of the ileocecal valve and the cecum/ascending colon, and can thus mimic Crohn's disease given that distribution (Figure 9). Adjacent necrotic lymphadenopathy may be seen and may support tuberculosis as the diagnosis.²¹

Tumors of the small bowel

Superior soft-tissue contrast of MRI in conjunction with presence of enteric contrast for bowel distention has proven to be useful in evaluation for small bowel lesions (Figure 10). This is especially pertinent for patients with polyposis syndromes. Biphasic enteric contrast helps increase the conspicuity of mass lesions. Small bowel lesions demonstrate variable enhancement on post-gadolinium imaging. They are frequently also relatively lower in T2 signal intensity as compared to surrounding luminal fluid, but caution must be taken not to rely solely on these sequences, as luminal flow voids related to peristalsis may mask these lesions.

A variety of neoplastic and benign lesions can be found in the small bowel, each exhibiting variable imaging characteristics. Benign lesions such as lipomas can readily be characterized with MR given the hyperintense signal on T1-weighted imaging and loss of this high signal with fat-suppression techniques. Small bowel hemangiomas classically demonstrate high signal intensity on T2-weighted imaging. Adenomas, which are the most common asymptomatic benign tumor of the small bowel, can present as a pedunculated or sessile soft tissue mass, with moderate homogeneous enhancement

(Figure 11).²¹ Malignant tumors such as primary adenocarcinomas and carcinoid tumors, may also be encountered at MRI.

Lymphomatous involvement of the small bowel is associated with nonspecific findings and can be confused for inflammatory or infectious enteric disease. At least one study attempted to use MRE as a means to suggest histologic subtypes of lymphoma based on morphologic imaging findings.²² For instance, luminal stricture was found to be associated with low-grade lymphoma, while propensity for aneurysmal dilatation of involved segment of small bowel had a higher association with celiac related non-Hodgkin's lymphoma. Mesenteric involvement and infiltration were more characteristic of high-grade lymphoma.²²

Conclusions

Over the last decade the use of MR techniques in evaluating small bowel pathology has expanded greatly, and this continues to evolve as more versatile uses are being recognized. At this time MRE plays a critical role in surveillance of patients with established Crohn's disease and in follow up after medical treatment, sparing patients repeat radiation exposure, which is inherent in CT imaging. Additional applications of MRE include evaluation of small bowel benign and neoplastic lesions, and evaluation of non-inflammatory small bowel entities such as Celiac disease. Additional applications are sure to come as MR techniques continue to advance.

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