CD has a bimodal peak—the first peak in the second or third decade of life and a smaller second peak in the sixth or seventh decade. There is equal evidence, however, of a unimodal peak in the second or third decade that explains the high incidence in the adolescent population [1, 2]. CD is more common than UC among adolescents, and adolescents with UC tend to have more severe and extensive disease at presentation than their adult counterparts do: Approximately 90% of adolescents present with total colonic involvement [3]. Because the bowel disease in UC is confined to the colon, total colonic surgical resection is curative for patients whose condition is refractory to medical therapy. In contrast, the potential involvement of the entire gastrointestinal tract in CD often leads to lifelong intermittent symptomatic recurrence, and medical rather than surgical management is the primary therapy.

Imaging of Pediatric Patients With Inflammatory Bowel Disease

Shauna Duigenan1
Michael S. Gee2

**OBJECTIVE.** The goal of this review is to examine the current imaging literature and develop basic imaging guidelines for evaluation of children with inflammatory bowel disease (IBD). The three following typical clinical scenarios in the imaging evaluation of IBD are considered: patient with an initial diagnosis of suspected IBD, the goals being to determine disease extent and severity and to differentiate Crohn disease from ulcerative colitis; patient with known IBD presenting with new acute symptoms (fever, peritonitis, leukocytosis) requiring urgent evaluation; and patient with known IBD presenting with nonacute symptoms (abdominal pain, diarrhea), the goals being to assess the efficacy of the current treatment and to evaluate the possible need for additional medical or surgical intervention.

**CONCLUSION.** Imaging of pediatric patients with IBD must balance considerations of diagnostic accuracy against concerns about patient exposure to ionizing radiation and tolerance of the imaging technique. The imaging modality chosen depends on the clinical presentation and expected pathologic finding.

**Key Imaging Questions**

Imaging of pediatric patients with inflammatory bowel disease (IBD) must balance considerations of diagnostic accuracy against concerns about patient exposure to ionizing radiation and tolerance of the imaging technique. With the many imaging modalities available, it is often difficult to determine which modality to use. The goal of this review is to examine the current imaging literature and develop basic imaging guidelines for evaluation of children with IBD. The imaging modality chosen depends on the clinical presentation and expected pathologic finding.

**Background and Importance**

IBD is one of the most common gastrointestinal diseases affecting pediatric patients in the developed world [1]. Crohn disease (CD) and ulcerative colitis (UC) are the two predominant subtypes of IBD, differing both in distribution of gastrointestinal tract involvement and depth of inflammation. Both disorders are most common in Europe and North America, where the ranges of incidence and prevalence are 3.1–14.6 cases per person-years and 26–199 cases per 100,000 persons for CD and 2.2–14.3 cases per 100,000 person-years and 37–246 cases per 100,000 persons for UC [1]. The classic teaching is that CD has a bimodal peak—the first peak in the second or third decade of life and a smaller second peak in the sixth or seventh decade. There is equal evidence, however, of a unimodal peak in the second or third decade that explains the high incidence in the adolescent population [1, 2]. CD is more common than UC among adolescents, and adolescents with UC tend to have more severe and extensive disease at presentation than their adult counterparts do: Approximately 90% of adolescents present with total colonic involvement [3]. Because the bowel disease in UC is confined to the colon, total colonic surgical resection is curative for patients whose condition is refractory to medical therapy. In contrast, the potential involvement of the entire gastrointestinal tract in CD often leads to lifelong intermittent symptomatic recurrence, and medical rather than surgical management is the primary therapy.

No consensus exists regarding the optimal technique and imaging modality for evaluating IBD. The choice of imaging is informed by the clinical presentation of the patient. The choice of specific modality is based on the need to assess the distribution or activity of the disease and to detect extraluminal complications, such as intraabdominal abscess, perforation of bowel, and enteric fistula. Pediatric patients...
need additional attention to minimization of radiation exposure during imaging examinations because the chronic remitting and relapsing nature of IBD, especially CD, frequently necessitates repeat imaging with a resultant greater cumulative lifetime radiation exposure.

**Radiation Risk**

Because of their small size and higher rate of cellular proliferation, pediatric patients have a higher cancer risk per unit radiation dose than do adults [4, 5]. Data suggest that the radiation from even a single CT examination can alter lifetime estimates of cancer mortality for a pediatric patient. Among children, the lifetime estimate of cancer mortality risk due to the radiation of a single abdominal CT examination is 4 times that among adults [6, 7]. Because of the relapsing remitting nature of the disease, this increased risk is of particular relevance to the pediatric IBD population, who may undergo numerous imaging tests over a lifetime. Organ and effective doses are 3–5 times higher for MDCT than for small-bowel followthrough (SBFT) [8, 9], which is also concerning because of the current trend in IBD imaging away from fluoroscopic techniques in favor of MDCT owing to widespread availability in emergency departments and the rapid scanning time associated with CT. This problem was illustrated in a 2007 study from the Mayo Clinic [8] that showed a 65% decrease in the use of SBFT and a concomitant 840% increase in CT enterographic studies between 2003 and 2007. Patients with CD tend to be exposed to more radiation than patients with UC owing to disease distribution in the upper gastrointestinal tract and lack of a curative surgical option. Because of early age at disease onset, pediatric IBD patients are at particular risk of high radiation exposure from imaging. In recent studies, such patients were found twice as likely as their counterparts in the 17- to 40-year age range to have a cumulative radiation exposure exceed 75 mSv [10, 11]. Advances in CT technology, such as tube current and voltage modulation, dynamic collimation, and iterative reconstruction techniques, have led to substantial reduction in CT radiation dose and should be used to scan pediatric patients whenever possible [12].

**Role of Imaging in Inflammatory Bowel Disease**

Imaging has remained a vital component of IBD evaluation, initially because of its unique ability to evaluate loops of small bowel not amenable to endoscopic visualization and more recently because of the development of cross-sectional imaging modalities that accurately depict both intraluminal and extraluminal disease manifestations [13]. Cross-sectional techniques are also relied on for the detection of extraintestinal IBD manifestations (e.g., nephrolithiasis, primary sclerosing cholangitis, sacroiliitis) that can be the source of symptoms. Imaging plays an important role in the initial diagnosis of CD, which can occur anywhere in the gastrointestinal tract and often is localized to the small bowel. There is currently no single diagnostic test for CD, and the

### TABLE 1: Summary of Imaging Techniques

<table>
<thead>
<tr>
<th>Imaging Technique</th>
<th>Major Advantages</th>
<th>Major Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasound</td>
<td>Accessible, Low cost, No radiation</td>
<td>Limited assessment of some parts of colon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operator dependent</td>
</tr>
<tr>
<td>CT enterography</td>
<td>Quick and accessible</td>
<td>Radiation</td>
</tr>
<tr>
<td></td>
<td>Good for extraintestinal evaluation</td>
<td>Oral preparation required</td>
</tr>
<tr>
<td></td>
<td>Can be performed on acutely ill patient</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multiplanar imaging capacity</td>
<td></td>
</tr>
<tr>
<td>CT enteroclysis</td>
<td>Good for extraintestinal evaluation</td>
<td>Radiation</td>
</tr>
<tr>
<td></td>
<td>Multiplanar imaging capacity</td>
<td>Nasojejunal intubation invasive</td>
</tr>
<tr>
<td>MR enterography</td>
<td>High contrast resolution</td>
<td>Limited accessibility</td>
</tr>
<tr>
<td></td>
<td>No radiation</td>
<td>Long examination time</td>
</tr>
<tr>
<td></td>
<td>Good for extraintestinal evaluation</td>
<td>Oral preparation required</td>
</tr>
<tr>
<td></td>
<td>Multiplanar imaging capacity</td>
<td></td>
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<tr>
<td>MR enteroclysis</td>
<td>High contrast resolution</td>
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<tr>
<td></td>
<td>No radiation</td>
<td>Long examination time</td>
</tr>
<tr>
<td></td>
<td>Good for extraintestinal evaluation</td>
<td>Nasojejunal intubation invasive</td>
</tr>
<tr>
<td></td>
<td>Can be used to assess for stricture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fluid challenge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multiplanar capacity</td>
<td></td>
</tr>
<tr>
<td>Barium enteroclysis</td>
<td>Best for aphthous ulcerations</td>
<td>Radiation</td>
</tr>
<tr>
<td></td>
<td>Can be used to assess for stricture</td>
<td>Extraintestinal manifestations not seen</td>
</tr>
<tr>
<td></td>
<td>Fluid challenge</td>
<td>Nasojejunal intubation invasive</td>
</tr>
<tr>
<td>Small-bowel followthrough</td>
<td>Accessible</td>
<td>Radiation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extraintestinal manifestations not seen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inferior mucosal detail</td>
</tr>
</tbody>
</table>
Pediatric Inflammatory Bowel Disease

Summary and Synthesis of Evidence

Synopsis of Imaging Modalities

A summary of the advantages and disadvantages of the various imaging modalities appears in Table 1.

Small-bowel barium fluoroscopic studies—
Barium fluoroscopic studies of the small bowel are traditional mainstays of imaging for CD. Conventional enteroclysis is considered the reference standard imaging test. The technique involves nasojejunal intubation with an entero-
clysis catheter after bowel preparation. Air and barium or barium and methylcellulose are then instilled by gravity, syringe, or pump to distend the small bowel with gas and to coat of the mucosal surface with contrast material [18–20]. The sensitivity of conventional enteroclysis is approximately 95% and the specificity 96.5% in the diagnosis of small-bowel disease [21, 22]. The advantages include excellent mucosal delineation due to the double-contrast technique and the ability to evaluate the distensibility of the bowel wall, which can be directly observed with infusion of contrast mate-
rial. Disadvantages of the technique include its relative invasiveness (nasojejunal tube), long examination duration, and lack of utility in as-
se ssment for transmural and extraluminal complica-
tions such as abscess [13]. Radiation dose varies according to technique but is generally less than that of MDCT. Overall, conventional enteroclysis yields the best imaging assessment of mucosal lesions. Imaging findings of IB are seen at conventional enteroclysis include aph-
thous ulcerations, fold thickening, granular vil-
li, spasm, increased intraluminal fluid, nodular pattern, ulcerations, mesenteric border rigidity, stricture, sinus track, and fistula formation [21].

Barium SBFT is a less invasive, easier to perform fluoroscopic technique whereby ingestion of a barium suspension is followed by acquisition of serial overhead radiographs until the contrast agent reaches the ileocecal valve, whereupon spot images of the terminal ileum are obtained. SBFT images show inferior mucosal detail compared with images obtained by conventional enteroclysis and suffers from the same lack of detection of evidence of extraluminal complications. In addition, SBFT is typically less sensitive than conventional en-
teroclysis for small-bowel evaluation of pa-
tients with symptomatic disease because bow-
el distention is limited by the patient’s ability to ingest barium. In the pediatric population, the average effective dose for SBFT is approx-
imately 1.8–2.2 mSv [9]. SBFT and conventional enteroclysis are the historical imaging tests of choice in the diagnosis of CD. These fluoroscopic techniques, however, are being superseded by cross-sectional modalities such as CT and MRI, which have advantages of excellent delineation of pathologic changes in the bowel wall and of extent of disease and superior capability in depiction of evidence of extraintestinal complications [9, 23–25].

Ultrasound—Ultrasound has the advantage of being a noninvasive test that imparts no ionizing radiation. High interoperator variability, however, is a practical consideration for determining its true diagnostic accuracy. Targeted assessment of the bowel wall is usu-
ally performed with a high-frequency linear-
array probe. As with fluoroscopy, with ultra-
sound, bowel loops can be observed over time for evaluation of peristalsis and function. The ultrasound criteria for assessment of CD include assessment of wall thickness, loop stiff-
ness, bowel dilatation, presence or absence of strictures, abnormal peristalsis, presence of fistula or abscess, and mesenteric inflammatory change [26–31]. A previous meta-analysis [32] revealed mean per patient sensitivity of 89.7% and specificity of 95.6% and per bow-
el segment sensitivity and specificity of 73.5% and 92.9%. Patient preparation is not usually required, although the studies are usually performed after the patient has fasted. Use of con-
trast material has been found to increase ac-
curacy, and Doppler evaluation of bowel wall vascularity may help to determine the pres-
ence of disease activity or quiescence [33, 34]. Poor visualization of the rectum and sigmoid colon, owing to the location of these structures in the pelvis, makes ultrasound less suitable for assessment of UC [34]. The spatial resolution of ultrasound also is lower than that of barium studies [34].

CT enterography and CT enteroclysis—
CT enteroclysis is the CT equivalent of conven-
tional enteroclysis and involves insertion of a nasojejunal catheter and infusion of con-
trast material through the catheter. Like conven-
tional enteroclysis, CT enteroclysis en-
tails reliable and controlled distention of the small bowel and allows assessment of bowel distensibility and stricture [34, 35]. Insertion of the nasojejunal tube makes CT enterco-
ysis quite invasive and suboptimal for pedi-
atriic patients [13]. As an alternative to CT enteroclysis, CT enterography has the advan-
tage of being noninvasive and rapid. Wold et al. [36], in a study comparing CT enterocly-
sis and CT enterography found similar diag-
nostic accuracy of the two techniques. Most CT enterography protocols require patients to fast and involve some degree of bowel prep-
araion [34, 37–40]. Administration of a large volume of negative or neutral oral contrast material (contrast material with lower attenuation than the bowel wall) is preferred to opt-
imally distend and visualize the bowel wall. Positive contrast material (contrast material with higher attenuation than the bowel wall) is not as desirable because it can obscure mural enhancement [13, 34, 41]. Antimotil-
ity medication can be administered to reduce peristalsis [9, 13, 37]. Indications for first-
time CT enterography include identifying and staging IBD, assessing potential compli-
cations of IBD such as obstruction, and evalu-
ating for fistula or abscess. CT is preferred.
for acute presentations that may have complications, such as perforation, abscess, severe stricture with prestenotic dilatation, and fistula, that require surgical management [13, 42].

The CT diagnostic criteria for disease include wall thickening, increased bowel wall enhancement, edema, fat deposition in the submucosa, and mesenteric inflammatory change, including lymphadenopathy (Fig. 1). Compared with ultrasound and barium studies, CT depicts more imaging features of disease. In UC, inflammatory pseudopolyps can be seen on CT images, as can pneumatosis in patients with toxic megacolon [43]. On a more chronic basis, fatty infiltration of the submucosa can be seen, as can rectal narrowing and widening of the presacral space by proliferation of peri-rectal fat [43]. Fistulas that are smaller and have edematous origins that are not well opacified on SBFT or conventional enteroclysis images may be detected with CT [43]. Previous studies comparing CT enteroclysis and endoscopy have shown better detection of fistulas, lymphadenopathy, skip lesions, and abscesses and more accurate observed length of diseased segments with CT than with endoscopy [35]. Sensitivity and specificity on a per patient basis are 84.3% and 95.1%, and sensitivity and specificity on a per segment basis are 67.4% and 90.2% [32]. CT is not as sensitive as SBFT or conventional enteroclysis for detection of ulcerating lesions [34]. It is better for detection of extraluminal manifestations and has the advantages of greater availability, shorter examination time, and higher spatial resolution [13, 43]. In a study of MDCT in which an anthropomorphic phantom of a 10-year-old child represented pediatric CD patients [9], the estimated average dose for the imaging examination was 3.48 mSv.

**MRI**—Pelvic MRI is the imaging modality of choice for assessing perianal and perirectal complications of CD [43, 44]. MR enterography or MR enteroclysis techniques analogous to their CT counterparts also have been developed for small-bowel evaluation. Luminal distention of the bowel is achieved with negative, biphasic, or positive contrast agents, negative or biphasic agents being preferred for the best visualization of the bowel wall [13, 45].

In MR enteroclysis, methylcellulose suspension is administered through a nasojejunal tube [34]. In MR enterography, large volumes of oral contrast material are ingested to distend the bowel [13, 34, 45]. MR enteroclysis allows fluoroscopic monitoring of the administered contrast material to assess for bowel distensibility. However, it is less well tolerated than MR enterography, which does not require nasojejunal intubation [34]. Indications to use MR enteroclysis rather than MR enterography include the patient’s inability to ingest the large amounts of oral contrast material required for optimal small-bowel distention and low-grade small-bowel obstruction in which achieving greater distention of the small bowel can increase sensitivity for stenosis or obstruction, as found on CT enteroclysis studies [45–47].
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Both MRI techniques compare favorably with conventional enteroclysis and CT in terms of diagnostic sensitivity and accuracy [48, 49]. As in CT, antiperistaltics can be administered to reduce motion artifacts [45]. Although there are many permutations of protocols for MR enterography, most are performed with some type of fast T2-weighted sequence in the coronal and axial planes and steady-state free precession sequences in the coronal plane. Some centers use a thick-slab cine steady-state sequence to assess bowel peristalsis. Unenhanced and contrast-enhanced T1-weighted fat-suppressed images are also usually obtained in various planes, typically with 3D volumetric gradient-echo techniques and parallel imaging to decrease acquisition time and allow serial dynamic contrast-enhanced bowel evaluation [34, 45].

The advantages of MRI include no radiation; acquisition of dynamic information about bowel distention and motility; and a good soft-tissue contrast profile. The disadvantages include high cost, limited accessibility, variable protocols, and lower spatial and temporal resolution [45]. Previous studies [34, 50] have shown comparable sensitivity of MR enteroclysis and conventional enteroclysis in the detection of transmural disease, but MRI, with its lower spatial resolution, is not as sensitive for detection of superficial mucosal disease such as aphthous ulcers. MRI also shows promise in that active inflammation and inactive disease and fibrosis can be differentiated. Fibrotic bowel wall appears hypointense on T2-weighted images and has minimal transmural enhancement without hyperenhancement of the mucosa [51]. The diagnostic MRI features of acute bowel inflammation include increased mural thickness; layered pattern of enhancement in the target, or double halo, sign (bowel wall stratification); and high mural signal intensity relative to muscle on fat-suppressed T2-weighted images [34, 52–54]. Fibrofatty proliferation of the mesentery and lymphadenopathy can also be seen [13]. A 2008 meta-analysis [32] showed that MRI had per patient sensitivity and specificity of 93.0% and 92.8% and per segment sensitivity and specificity of 70.4% and 94.0%.

Evidence Assessment

Study selection and inclusion—A systematic PubMed search was performed with search criteria designed to capture all literature published on the topic of IBD imaging with MRI, ultrasound, and CT from the period spanning 1993–2010. A keyword search was performed with the term “inflammatory bowel disease” and the various descriptors for imaging modality to ensure capture of all relevant articles. There were no limits on age or language.

Eligibility criteria for inclusion were prospective study and histologic, endoscopic, or conventional barium enteroclysis as the reference standard. Studies had to pertain to at least one of the following clinical scenarios: determination of disease extent and severity in initial diagnosis, evaluation of disease exacerbation in known IBD, and assessment of disease recurrence in patients with known IBD. Conventional barium enteroclysis was used as an acceptable imaging standard, but SBFT was not because conventional enteroclysis is superior to SBFT for assessment of mucosal disease [19]. If there was doubt about whether an article would fit the criteria after examination of the abstract alone, the article was assessed in its entirety. After literature review, a total of 34 articles met the inclusion criteria and were organized according to imaging modality. All articles were then assessed for the following parameters: number of patients, age of patient population, adherence to reference standard, imaging technique, sensitivity, specificity, positive predictive value, and negative predictive value. For each modality, two to five studies were selected as the most representative studies for each modality in the context of a pediatric patient. Because of the paucity of prospective studies of pediatric IBD patients, studies of adult IBD patients were included in the analysis if they met all of the inclusion criteria.

Studies were excluded if they were not prospective and if sensitivity, specificity, or data from which these values could be calculated were not reported. Acceptable reference standards were conventional enteroclysis, endoscopy, and histologic analysis. If a histologic or endoscopic reference was obtained for all patients but the final reference standard was a consensus diagnosis based on imaging, laboratory, endoscopic, surgical, and histologic findings, this standard was accepted as reflective of how IBD is diagnosed in clinical practice. For literature specific to North America, studies not performed with high-frequency transducers (at least 10 MHz) were excluded. Studies performed with a nonstandard technique, such as contrast-enhanced ultrasound, were also excluded. CT enteroclysis and MR enteroclysis articles were not included because these techniques are not feasible for routine evaluation of IBD in the pediatric population.

For the cross-sectional imaging modalities (CT and MRI), studies that included both wall thickening and enhancement characteristics as criteria for disease activity were chosen preferentially over studies in which only enhancement characteristics were used. The rationale was that use of both criteria would yield greater diagnostic accuracy [52, 53, 55–57].

A total of 11 articles addressed the three typical clinical scenarios (three ultrasound, two CT enterography, six MR enterography). A summary of the relevant articles is presented in Table 2.

Summary of evidence—CT and MRI have similarly high sensitivity and specificity. For CT, the range of sensitivity is 0.82–0.95, and the range of specificity is 0.4–1.0. For MR enteroclysis, the range of sensitivity is 0.81–0.91, and the range of specificity is 0.67–0.89 [36, 51, 55, 58–63]. Sensitivities and specificities for CT and MRI were similar for both adults and pediatric patients. The pediatric study of CT enteroclysis showed sensitivity similar to that in the adult studies despite use of thicker slices to achieve a reduced dose. If the results from the CT enteroclysis studies apply to CT enterography, this finding has potential implications for performance of low-dose pediatric CT enterography, which has sensitivity similar to that of higher-dose adult CT enterography [60]. The negative predictive value was quite low for some of the reference studies (e.g., 0.25 for CT enterography) in which there were false-negative examination findings because very minimal inflammation was diagnosed at endoscopy [36].

In all of the ultrasound studies, wall thickness was the principal imaging parameter. The sensitivities and specificities were consistently much lower than with the cross-sectional modalities; the range of sensitivity was 0.48–0.8 and that of specificity was 0.57–0.93 across the three papers [64–66]. Ultrasound yields useful information on bowel wall abnormalities and can be accurate in experienced hands; however, because of low sensitivity and specificity and high interoperator variability, ultrasound is not recommended for first-line imaging in the three clinical scenarios posed.

Evidence-Based Guidelines

Current Recommendations of the American College of Radiology

The current American College of Radiology (ACR) appropriateness criteria for imaging of a child or young adult with suspected
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CD at initial presentation gives equal weighting to CT enterography and MR enterography. For imaging of children and young adults with known CD and an acute presentation (abdominal pain, fever, or leukocytosis), the ACR gives equal weighting to CT of the abdomen and pelvis with contrast administration (routine or CT enterography) and MR enterography. The newer ACR recommendation for a child or young adult with known CD with stable nonacute mild symptoms on surveillance is to use MR enterography.

Summary of Recommendations Based on Evidence Assessment

On the basis of the available evidence, CT enterography and MR enterography appear to be the two imaging modalities with the highest confirmed accuracy for IBD evaluation. Each of these modalities has shortcomings, which are of varying importance depending on the clinical scenario. CT enterography is associated with ionizing radiation exposure of the patient, whereas MR enterography involves long acquisition times, lower spatial resolution, and poor sensitivity for detecting bowel perforation. Both enterographic techniques rely on bowel distention with a large volume of enteric contrast medium, which may not be possible in the care of severely ill patients. The best imaging modality to choose depends on the clinical scenario.

Imaging Recommendations for the Three Typical Clinical Scenarios

Pediatric patient: initial diagnosis of suspected IBD, differentiation of Crohn disease from ulcerative colitis—The sensitivity of MR enterography is similar to that of CT enterography for detection of active IBD, so either modality would be a reasonable evidence-based choice. Our opinion is that the superior spatial resolution of CT enterography may make it preferable to MR enterography in IBD patients because the overall evidence-based choice of CT enterography is often prohibitive in the pediatric population and there is not compelling evidence that CT enterography is superior to MR enterography for IBD evaluation.

### Table 2: Relevant Articles Evaluating Imaging Modalities in Inflammatory Bowel Disease

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Modality</th>
<th>No. of Patients</th>
<th>Age Range (y)</th>
<th>Reference Standard Technique</th>
<th>Diagnostic Criterion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pradel et al.</td>
<td>1997</td>
<td>Ultrasound</td>
<td>59</td>
<td>17–58</td>
<td>Barium enteroclysis</td>
<td>Wall thickness</td>
<td>0.7</td>
<td>0.93</td>
<td>0.91</td>
<td>0.75</td>
</tr>
<tr>
<td>Bremner et al.</td>
<td>2006</td>
<td>Ultrasound</td>
<td>44</td>
<td>3.5–16.5</td>
<td>Endoscopy</td>
<td>Wall thickness</td>
<td>0.48</td>
<td>0.93</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td>Paredes et al.</td>
<td>2010</td>
<td>Ultrasound</td>
<td>33</td>
<td>Mean, 41</td>
<td>Endoscopy</td>
<td>Wall thickness</td>
<td>0.85</td>
<td>0.4</td>
<td>0.7</td>
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</tr>
<tr>
<td>Jamieson et al.</td>
<td>2003</td>
<td>CT enterography</td>
<td>18</td>
<td>7–16</td>
<td>Endoscopy, histologic analysis</td>
<td>Wall thickness</td>
<td>0.86</td>
<td>1</td>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>Siddiki et al.</td>
<td>2009</td>
<td>CT enterography</td>
<td>41</td>
<td>20–60</td>
<td>Endoscopy</td>
<td>Wall thickness</td>
<td>0.95</td>
<td>0.82</td>
<td>0.91</td>
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</tr>
<tr>
<td>Siddiki et al.</td>
<td>2009</td>
<td>MR enterography</td>
<td>41</td>
<td>20–60</td>
<td>Endoscopy</td>
<td>Wall thickness</td>
<td>0.91</td>
<td>0.67</td>
<td>0.86</td>
<td>0.75</td>
</tr>
<tr>
<td>Laghi et al.</td>
<td>2003</td>
<td>MR enterography</td>
<td>75</td>
<td>8–17</td>
<td>Endoscopy</td>
<td>Wall thickness</td>
<td>0.84</td>
<td>1</td>
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<tr>
<td>Koh et al.</td>
<td>2001</td>
<td>MR enterography</td>
<td>30</td>
<td>18–58</td>
<td>Endoscopy</td>
<td>Wall thickness</td>
<td>0.88</td>
<td>0.71</td>
<td>0.92</td>
<td>0.63</td>
</tr>
<tr>
<td>Borthe et al.</td>
<td>2006</td>
<td>MR enterography</td>
<td>20</td>
<td>5–16</td>
<td>Endoscopy</td>
<td>Wall thickness</td>
<td>0.81</td>
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<tr>
<td>Negaard et al.</td>
<td>2007</td>
<td>MR enterography</td>
<td>40</td>
<td>18–73</td>
<td>Endoscopy</td>
<td>Wall thickness</td>
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<tr>
<td>Gee et al.</td>
<td>2011</td>
<td>MR enterography</td>
<td>21</td>
<td>12–22</td>
<td>Endoscopy, histologic analysis</td>
<td>Wall thickness</td>
<td>0.9</td>
<td>0.83</td>
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</tr>
</tbody>
</table>

Note:—PPV = positive predictive value, NPV = negative predictive value, PEG = polyethylene glycol.

*Oral contrast barium preparation, VoLumen (E-Z-EM).

*Ferumoxsil, Gastromark (Mallinckrodt).


Pediatric Inflammatory Bowel Disease

Pediatric patient: known inflammatory bowel disease with new acute presentation (fever, peritonitis, leukocytosis)—Extraluminal complications such as bowel perforation with or without associated abscess must be ruled out in acutely ill patients. Although MR enterography has high sensitivity and specificity for detecting acute inflammation and is as sensitive as CT for abscess, it is not as good as CT for detecting free intraperitoneal air, which is the best imaging feature of bowel perforation [51, 67]. For this reason, CT with positive oral contrast administration is recommended as the primary study for patients with known IBD presenting with fever, peritonitis, and leukocytosis. Another advantage of CT over MRI is the rapid acquisition time, which is better tolerated by acutely ill patients and minimizes bowel motion artifact from peristalsis. This second feature is helpful for assessing collapsed or underdistended bowel loops for active inflammation, given that most acutely ill patients cannot tolerate the large volume of oral contrast material (because of nausea or bowel obstruction) required for CT enterography. Positive rather than neutral or negative oral contrast material is recommended for imaging of acutely ill patients to better differentiate an abdominopelvic abscess, which appears as a low-attenuation rim-enhancing collection, from high-attenuation ingested intraluminal content, despite a decrease in sensitivity for detecting mucosal disease [68]. Many acutely ill patients may be unable to tolerate any oral contrast material, in which case CT with IV contrast administration alone is the preferred imaging modality.

Pediatric patient: known inflammatory bowel disease with symptomatic recurrence (abdominal pain, diarrhea), not acutely ill—MR enterography is the most appropriate imaging test when a patient has known IBD and a symptomatic recurrence because it can depict evidence of intraluminal and extraluminal disease with high sensitivity and specificity without ionizing radiation. In patients with known IBD, the risk of high cumulative radiation exposure from multiple imaging studies leads to avoidance of CT whenever possible. When MRI is used to image these patients, lifetime radiation exposure can be decreased. MR enterography is effective for detection of active inflammation, which would be an indication for initiation or modification of medical therapy. MR enterography also shows promise for differentiating active inflammation and the fibrosis of chronic inflammation [51]. This distinction has important implications in patient management because fibrotic strictures are typically refractory to medical therapy and require surgical resection to produce durable symptomatic relief. MR enteroclysis can be considered a provocative study if obstruction or stricture is suspected, particularly if MR enterography does not show a lesion [47]. MR enteroclysis is particularly useful for identifying short strictures causing intermittent obstruction because it bypasses the patient’s normal instinct to restrict oral intake to avoid symptoms and temporally associates visualization of luminal narrowing with elicitation of symptoms.

Recommendations for Future Research and Limitations

The numerous prospective studies in the current literature are limited by small sample size, and the pediatric studies have some of the smallest sample sizes. As a result, for this analysis, we included studies involving adult IBD patients in addition to pediatric patients. It is clear that multicenter prospective trials are needed to obtain a larger aggregate sample and to improve comparison of IBD imaging modalities. In terms of patient selection, most of the studies have been performed with pediatric patients who already have high clinical suspicion of having IBD, and this potentially reduces the relevance of results extrapolated to clinical practices with more variable disease prevalence. It is unclear whether CT performed with low-dose technique at pediatric-specific imaging centers would perform as well as CT enteroclysis or CT enterography in the detection of inflammation and extraintestinal complications. This area needs further study in the pediatric population. A comparison of conventional low-dose CT of the abdomen in children who have had no special oral preparation and CT enterography to determine whether the low-dose technique is as accurate for detecting IBD is another area of future investigation that could clarify which type of oral contrast material to administer to a pediatric patient with known IBD who has acute symptoms. Finally, prospective evaluation of high-frequency bowel ultrasound would be helpful for identifying a potential role in routine surveillance because the speed, ability to image bowel function, and lack of ionizing radiation associated with ultrasound are ideally suited for pediatric IBD assessment.

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