American College of Radiology
ACR Appropriateness Criteria®
Crohn Disease-Child

Variant: 1 Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging.

Procedure	Appropriateness Category	Peds Relative Radiation Level
MR enterography	Usually Appropriate	O
MRI abdomen and pelvis without and with IV contrast	Usually Appropriate	O
CT enterography	Usually Appropriate	☢☢☢☢
US abdomen	May Be Appropriate	O
Fluoroscopy upper GI series with small bowel follow-through	May Be Appropriate	☢☢☢☢
MRI abdomen and pelvis without IV contrast	May Be Appropriate	O
CT abdomen and pelvis with IV contrast	May Be Appropriate	☢☢☢☢
US abdomen with IV contrast	Usually Not Appropriate	O
Radiography abdomen	Usually Not Appropriate	☢☢
Fluoroscopy contrast enema	Usually Not Appropriate	☢☢☢☢
CT abdomen and pelvis without IV contrast	Usually Not Appropriate	☢☢☢☢
CT abdomen and pelvis without and with IV contrast	Usually Not Appropriate	☢☢☢☢☢
FDG-PET/CT skull base to mid-thigh	Usually Not Appropriate	☢☢☢☢
WBC scan whole body	Usually Not Appropriate	☢☢☢☢

Variant: 2 Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging.

Procedure	Appropriateness Category	Peds Relative Radiation Level
MR enterography	Usually Appropriate	O
MRI abdomen and pelvis without and with IV contrast	Usually Appropriate	O
CT abdomen and pelvis with IV contrast	Usually Appropriate	☢☢☢☢
CT enterography	Usually Appropriate	☢☢☢☢
US abdomen	May Be Appropriate	O
Radiography abdomen	May Be Appropriate	☢☢
Fluoroscopy upper GI series with small bowel follow-through	May Be Appropriate	☢☢☢☢
MRI abdomen and pelvis without IV contrast	May Be Appropriate	O
US abdomen with IV contrast	Usually Not Appropriate	O
Fluoroscopy contrast enema	Usually Not Appropriate	☢☢☢☢
CT abdomen and pelvis without IV contrast	Usually Not Appropriate	☢☢☢☢
CT abdomen and pelvis without and with IV contrast	Usually Not Appropriate	☢☢☢☢☢
FDG-PET/CT skull base to mid-thigh	Usually Not Appropriate	☢☢☢☢
WBC scan whole body	Usually Not Appropriate	☢☢☢☢

Variant: 3 Child. Known Crohn disease, disease surveillance or monitoring therapy.

Procedure	Appropriateness Category	Peds Relative Radiation Level
MR enterography	Usually Appropriate	O
MRI abdomen and pelvis without and with IV contrast	Usually Appropriate	O
CT enterography	Usually Appropriate	☢☢☢☢

US abdomen	May Be Appropriate	O
US abdomen with IV contrast	May Be Appropriate	O
Fluoroscopy upper GI series with small bowel follow-through	May Be Appropriate	☢☢☢☢
MRI abdomen and pelvis without IV contrast	May Be Appropriate	O
CT abdomen and pelvis with IV contrast	May Be Appropriate	☢☢☢☢
FDG-PET/CT skull base to mid-thigh	May Be Appropriate	☢☢☢☢
Radiography abdomen	Usually Not Appropriate	☢☢
Fluoroscopy contrast enema	Usually Not Appropriate	☢☢☢☢
CT abdomen and pelvis without IV contrast	Usually Not Appropriate	☢☢☢☢
CT abdomen and pelvis without and with IV contrast	Usually Not Appropriate	☢☢☢☢☢
WBC scan whole body	Usually Not Appropriate	☢☢☢☢

Variant: 4 Child. Known Crohn disease, perianal fistula. Initial imaging.

Procedure	Appropriateness Category	Peds Relative Radiation Level
MRI pelvis with IV contrast	Usually Appropriate	O
MRI pelvis without and with IV contrast	Usually Appropriate	O
US pelvis transperineal	May Be Appropriate	O
MRI pelvis without IV contrast	May Be Appropriate	O
CT pelvis with IV contrast	May Be Appropriate	☢☢☢☢
Fluoroscopy contrast enema	Usually Not Appropriate	☢☢☢☢
CT pelvis without IV contrast	Usually Not Appropriate	☢☢☢☢
CT pelvis without and with IV contrast	Usually Not Appropriate	☢☢☢☢

Panel Members

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Summary of Literature Review

Introduction/Background

Crohn disease is an inflammatory condition of the gastrointestinal tract with episodes of exacerbation and remission occurring in children, adolescents, and adults. In a genetically predisposed patient, the underlying mechanism is due to an inappropriate inflammatory reaction to intestinal flora [1-3]. Along with ulcerative colitis, Crohn disease is a common inflammatory bowel disease (IBD) with increasing frequency. The prevalence of IBD is 100 to 200 cases per 100,000 children with approximately 10 new cases per 100,000 children diagnosed each year in the United States [4]. Twenty-five percent of all IBD patients are diagnosed prior to 20 years of age [4]. Of these children with IBD, 18% were diagnosed before 10 years of age [4]. Unlike ulcerative colitis, Crohn disease is characterized by transmural granulomatous inflammation as well as discontinuous or skip lesions that can occur anywhere in the gastrointestinal tract. Any portion of the gastrointestinal tract may be involved, most frequently the small bowel and colon, yet perianal

Crohn disease is another common manifestation occurring in 15% to 25% of pediatric patients with Crohn disease [5,6].

Crohn disease diagnosis and treatment depend upon a combination of clinical, laboratory, endoscopic, histological, and imaging findings. Appropriate use of imaging provides critical information in the settings of diagnosis, assessment of acute symptoms, disease surveillance, and therapy monitoring. Although portions of the alimentary tract are accessible by either upper endoscopy or ileocolonoscopy, imaging is necessary for many reasons, including assessment of the bowel (particularly small bowel) not amenable to endoscopy, detection of transmural disease without overlying mucosal abnormality, assessment of extraluminal penetrating and extraintestinal disease, and when diagnostic information is sought without invasive endoscopy [1]. For patients with high clinical concern for Crohn disease and both conventional endoscopy and imaging are unrevealing, video capsule endoscopy may also be considered [4].

Special Imaging Considerations

Both MR enterography (MRE) and CT enterography (CTE) require oral contrast material ingestion by the patient. Sufficient bowel distention is necessary to decrease bowel collapse, which can imitate or obscure Crohn disease [7]. Commonly used oral contrast agents for both MRE and CTE include sugar alcohol-based beverages, polyethylene glycol, and low-concentration barium suspensions. Oral contrast administration ultimately depends upon institutional preference. The total volume of oral contrast ingested typically ranges from 900 to 1,500 mL administered over 45 to 60 minutes before the examination, with total volume based on patient weight [7]. Even in the absence of specific concern for perianal fistula, when imaging with MRE/CTE (or nonenterography MR/CT), coverage should include the perineum to facilitate detection of perianal Crohn disease. If discovered, more focused additional imaging of the perineum may be considered (as discussed in Variant 4). Another imaging consideration for perianal Crohn disease is MRI field strength. Although children may be imaged using either 1.5T or 3T MRI, the higher field strength (3T) provides greater signal-to-noise ratio that is advantageous for delineating penetrating Crohn disease anatomic location in relation to anal sphincter complex [6].

MR/CT enteroclysis requires placement of a postpyloric balloon-tipped tube, most often a nasoduodenal tube, to allow enteric contrast infusion directly into the small bowel. Enteroclysis is performed under fluoroscopy with subsequent patient transfer to MR or CT afterward, which can result in logistical challenges. A study directly comparing MR enteroclysis and MRE in adult patients with suspected or established Crohn disease showed both techniques to be equivalent for detecting terminal ileal inflammation, small bowel fistulae, and strictures [8]. In rare circumstances when enteroclysis may be considered (eg, attempt at uniform small bowel distention to assess for a partial stricture), enteroclysis has been shown to be effective in pediatric patients [9]. However, because enteroclysis is substantially more invasive than enterography, is less well tolerated than enterography, and is without clear added benefit, it is presently infrequently used in children.

Initial Imaging Definition

Initial imaging is defined as imaging at the beginning of the care episode for the medical condition defined by the variant. More than one procedure can be considered usually appropriate in the initial imaging evaluation when:

- There are procedures that are equivalent alternatives (i.e., only one procedure will be ordered to provide the clinical information to effectively manage the patient's care)

OR

- There are complementary procedures (i.e., more than one procedure is ordered as a set or simultaneously wherein each procedure provides unique clinical information to effectively manage the patient's care).

Discussion of Procedures by Variant

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging.

In this variant, the patient has signs and symptoms suggestive of Crohn disease such as weight loss, loose stools, vomiting, and intermittent abdominal pain. Following clinical and laboratory evaluation, endoscopy with biopsy is often performed initially as the standard for Crohn disease diagnosis. Imaging is generally sought following endoscopy, because imaging may not be as sensitive for colonic or more proximal small bowel disease [4]. Small bowel imaging is used to detect the severity and distribution of inflammatory changes of the bowel (including to help distinguish Crohn disease from ulcerative colitis) as well as identify complications such as fistulizing disease or abscess formation at the time of presentation. Extraintestinal Crohn disease manifestations include nephrolithiasis, cholelithiasis, primary sclerosing cholangitis, avascular necrosis, and sacroiliitis can also be detected [1]. Imaging may also assist in excluding other etiologies of a patient's abdominal symptoms.

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging.
A. CT Enterography

CTE is a specialized CT imaging protocol of the abdomen and pelvis tailored to evaluate the small bowel. It consists of ingestion of a large volume of neutral oral contrast material to distend the small bowel using the same set of oral contrast agents used for MRE as discussed above in the Special Imaging Considerations section above. The use of neutral oral contrast material is helpful to visualize mural hyperenhancement associated with active Crohn disease that can be obscured by positive oral contrast material [1]. CTE image acquisition occurs during the enteric phase (45–70 seconds post injection), similar to MRE, although a single image acquisition is performed unlike an MRE multiphase acquisition. A main advantage of CTE is short image acquisition time of <2 seconds, and as such can typically be performed with the patient awake, thereby decreasing potential patient risks associated with anesthesia [10]. The very short image duration of CTE often leads to more consistent spatial resolution and a lack of motion artifact in pediatric patients compared with MRE for initial diagnosis of Crohn disease [1]. The relatively higher image quality of CTE can also be helpful at the time of initial Crohn disease diagnosis to exclude other etiologies such as Meckel diverticulum, celiac disease, and abdominal malignancy [1].

CTE provides high diagnostic performance for evaluation of Crohn disease activity in pediatric patients, as in adults, with a sensitivity >80% and a specificity >85% compared with endoscopic and histologic reference [11-13]. These studies directly compared CTE and MRE and did not find any significant difference in performance between the two modalities. Furthermore, a meta-analysis based on 290 patients from 6 studies showed sensitivity and specificity in detecting active small bowel Crohn disease was 85.8% and 83.6%, respectively, with an area under the curve (AUC)

of 0.898 [14]. CTE imaging features of active Crohn disease inflammation are very similar to those reported for MRE and include mural (eg, wall thickening and hyperenhancement) and perienteric (eg, engorged vasa recta, fibrofatty proliferation, adenopathy) features of disease [15]. A study comparing the performance of different CTE and MRE imaging features compared with histologic reference showed that mural features of disease (wall thickening and hyperenhancement) performed better than perienteric features in evaluating activity and may be more reliable features in cases where some but not all features of activity are present [16].

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging.
B. CT Abdomen and Pelvis

CT of the abdomen and pelvis with intravenous (IV) contrast but without enterography technique may need to be performed in patients who cannot tolerate a large volume of neutral oral contrast material. Conventional, nonenterography CT can either be performed without any oral contrast material or with smaller volume of positive oral contrast material. A pediatric study comparing standard CT abdomen/pelvis with positive oral and IV contrast material with MRE in patients with Crohn disease showed high agreement between CT and MRE for detection of bowel wall thickening (k = 0.88), fluid collections (k = 0.86), and fistulae (k = 1.00) [17]. It is known that IBD in pediatric patients is diagnosed on abdominal CT examinations performed for evaluation of nonspecific abdominal pain, which are typically performed with IV contrast, but may or may not include oral contrast depending on institutional preference. In cases in which the patient is presenting acutely, poor oral contrast material ingestion can make underdistended or air-filled bowel loops difficult to evaluate; in this scenario, standard CT with IV contrast may be preferred to MRE for small bowel evaluation [1]. There is insufficient literature to support the use of CT without IV contrast in children.

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging.
C. FDG-PET/CT Skull Base to Mid-Thigh

At the present time, there is a paucity of larger clinical studies published for fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)-PET/CT in the setting of Crohn disease, particularly in children, and an absence of literature to support this as an initial imaging modality prior to diagnosis. Adding metabolic information from FDG-PET to anatomic CT imaging shows the potential to further diagnostic accuracy in children. A meta-analysis of 7 studies with a total of 219 patients (3 studies with 93 patients were pediatric focused) on a per segment basis showed sensitivity was 85%, specificity 87%, and area under the receiver operating characteristic curve was 0.93. PET/CT may be particularly helpful to assess the level of active inflammation from fibrosis [18]. One pediatric study with 23 patients showed a sensitivity and specificity for the terminal ileum of 89% and 75%, respectively [19]. A limitation that must be noted is physiological distribution of FDG, including normal uptake in the terminal ileum, which may compromise PET imaging of patients with IBD. Although potentially promising, additional development for PET/CT in children is necessary. If performing FDG-PET/CT for the evaluation of Crohn disease, the area of coverage from skull base to mid-thigh may be sufficient for bowel evaluation, although some institutions do perform full-body imaging (from vertex to toes); therefore area of coverage may be determined according to institutional practices.

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging.
D. Fluoroscopy Contrast Enema

Colonoscopy is the most useful modality for evaluation of the colon in patients with suspected or known Crohn disease involving the colon [2]. Fluoroscopy contrast enema is uncommonly used in

current practice. An institutional study confirmed this decline in which the average number of contrast enema per Crohn disease patients per year dropped from 0.05 in 2001 to 0.01 in 2010 [20]. Fluoroscopy contrast enema, however, may remain an option if selected problem solving is necessary, such as stricture assessment during contrast injection [21].

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging. E. Fluoroscopy Upper GI Series with Small Bowel Follow-Through

Using fluoroscopy small bowel follow-through (SBFT) with barium is a historically well-established modality for small bowel evaluation [2]. There is, however, a significant decrease in use of SBFT with current widespread use of cross-sectional imaging modalities including MRI and CT. Although fluoroscopy SBFT allows accurate intraluminal and mucosal assessment, bowel wall thickness among other signs cannot be directly visualized. Additionally, although internal fistulas may be visualized, extraluminal pathologies including abscess formation may only be indirectly inferred. In a study of 87 pediatric patients with IBD utilization histology as criterion standard, 31% of patients had pathology identified on MRI not visualized on SBFT. In this study, the SBFT sensitivity and specificity were 76% and 67%, respectively, whereas MRI demonstrated greater sensitivity and specificity of 83% and 95%, respectively [22]. Fluoroscopy SBFT, however, does remain an option if problem solving is necessary, such as cutaneous fistula evaluation [21]. Fluoroscopy SBFT may also serve as an alternative to MRI and CT to avoid sedation, particularly in younger children.

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging. F. MR Enterography

MRE represents a specialized MRI protocol of the abdomen and pelvis tailored to evaluate the small bowel. MRE includes ingestion of a large volume of biphasic (T1-weighted hypointense, T2-weighted hyperintense) contrast agent that distends the small bowel on T1-weighted fat-suppressed postcontrast images. Oral contrast agents are further discussed above in the special imaging considerations section. Traditionally, MRE also includes the use of IV contrast, with enteric phase (45–70 seconds after injection) being most commonly used to assess for mural hyperenhancement accompanying active bowel inflammation [7,16]. Other standard pediatric MRE pulse sequences include single-shot T2-weighted, balanced steady-state free precession, and diffusion-weighted imaging [23]. Administration of a hypoperistaltic medication (eg, glucagon or hyoscine butylbromide) during MRE may improve image quality through reduced peristaltic motion artifact but can be associated with nausea in some patients [7].

The role of MRE in this scenario includes diagnosis, delineation of disease extent including discrimination of Crohn disease from ulcerative colitis, depiction of extraintestinal manifestations of Crohn disease, and detection of penetrating disease complications that may influence treatment decisions. The latter may include fistulae that may be indicators for biologic therapy or abscess formation that may necessitate antibiotics and/or drainage. Evaluation of small bowel disease is an especially important role for MRE given the limitations of optical endoscopy in small bowel accessibility and visualization, particularly when Crohn disease terminal ileitis causes luminal narrowing [1].

MRE has high diagnostic performance for the detection of Crohn disease–related active bowel inflammation in pediatric patients compared with both endoscopy and histologic reference. Sensitivity values range from 66% to 95%, and specificity values range from 64% to 97% on a bowel segmental basis [17,23-27]. A number of MRE imaging features have been well-established imaging biomarkers of active Crohn disease inflammation. These include mural (eg, wall

thickening, hyperenhancement, and edema) and perienteric (eg, engorged vasa recta, fibrofatty proliferation, and lymphadenopathy) features of disease [15]. Penetrating disease complications may include sinus tracts, fistulae, abscesses, inflammatory masses, and bowel perforation [15]. Recent evidence indicates that IV contrast does improve MRE sensitivity for detecting these penetrating Crohn disease complications in children [28]. This study, however, also showed similar performance for detection of active inflammation in the terminal ileum and colon without IV contrast administration [28]. Another recent study indicated no additional benefit of IV gadolinium beyond non-IV contrast-enhanced MRE for detection of active IBD in pediatric patients [29]. Additionally, a study of IV contrast-enhanced MRE compared with diffusion-weighted MRE in children and young adults demonstrates that diffusion weighted imaging in lieu of IV contrast administration provides comparable identification of both inflammatory wall thickening and lesion detection [30].

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging. G. MRI Abdomen and Pelvis

MRI of the abdomen and pelvis without oral contrast enterography technique can be considered for Crohn disease patients who may be unable to tolerate ingesting sufficient oral contrast material, particularly for those with acute abdominal symptoms at the time of diagnosis. A study comparing noncontrast (no IV or oral contrast) MRI with MRE (with oral and IV contrast) in adult IBD patients showed MRE to be superior for detection of bowel inflammatory lesions, with sensitivity, specificity, and positive predictive value (PPV) of noncontrast MRI of 50%, 94%, and 28% for detection of small bowel wall thickening and 86%, 93%, and 86% for detection of terminal ileal wall thickening compared with the study's internal MRE reference standard (of 100%) [31]. Although such a study has not yet been performed in pediatric patients, noncontrast MRI abdomen and pelvis is likely to perform worse in the pediatric population given the relative paucity of mesenteric fat and the smaller caliber of bowel, which can make evaluation of the bowel wall and perienteric inflammation more difficult by MRI [16]. If MRI needs to be performed without oral contrast material, the use of cinematic steady-state free precession sequences can be helpful to distinguish normal underdistended small bowel from bowel wall thickening [7]. Overall, pediatric Crohn disease MRI studies have focused on enterography with less current supporting literature for the nonenterography MRI technique in children. However, when sufficient oral contrast intake is not feasible to perform MRE (eg, for acutely ill patients), MRI abdomen and pelvis either with IV or without IV contrast can serve as a reasonable alternative.

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging. H. Radiography Abdomen

Visualization of bowel pathology is limited on abdominal radiographs, which often restricts utilization for initial diagnoses.

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging. I. US Abdomen

Ultrasound (US) abdomen can be used for imaging Crohn disease during initial diagnosis. US may be a suitable alternative for evaluation of the terminal ileum in younger children who would otherwise require sedation for MRE or CTE examinations [21]. Sonographic technique requires a systematic assessment of the entire bowel including terminal ileum, colon, and more proximal small bowel. All four quadrants of the bowel should be evaluated in both the transverse and longitudinal planes [32]. Color Doppler US is also performed to facilitate hyperemia assessment. Sonographic features include abnormal bowel wall thickening (>3 mm in children), alteration of

bowel wall signature, adjacent fatty proliferation, hyperemia, and engorgement of the vasa recta [32]. Patient features may adversely affect US including elevated body mass index as well as bowel gas resulting in shadowing. In the setting of pediatric Crohn disease though, obesity is less likely given that many patients have diminished nutrition [32]. The detection of alternative diagnoses is also decreased compared with CT or MRI.

A meta-analysis of prospective US studies indicated a sensitivity of 88%, specificity of 97%, and accuracy of 94% [33]. Although this meta-analysis was adult focused, pediatric literature is also available. A comparative study between MRE and US was performed, including 31 pediatric patients with histology as a reference standard. For the terminal ileum, the sensitivity and specificity for US was 89% and 55%, respectively, compared with MRE of 78% and 46%, respectively. Overall, including all segments within the colon, sensitivity for both modalities was 46% (US and MRE) and specificity was 87% (US) and 85% (MRE) [34]. A study comparing bowel US and MRE in children with 33 patients prospectively showed that US readings are substantially reliable in the colon and terminal and distal ileum (intraclass correlation coefficients [ICC] of 0.79–0.88) but highly unreliable in the mid and proximal small bowel (ICC of 0.0) [35]. A prospective study of 41 pediatric patients demonstrated sensitivities of 67% and 78% and specificities of 78% and 83% for the two readers, respectively, versus clinicopathologic diagnosis (compared with MRE sensitivity and specificity of 75% and 100%) [36]. These authors concluded that "US has limited sensitivity for detecting terminal ileitis" [36].

In addition to routine abdominal US without contrast, further discussed below, oral contrast material may be administered by some institutions. Intraluminal oral contrast administration, most commonly with polyethylene glycol, is also termed small intestine contrast ultrasonography (SICUS). SICUS may heighten sensitivity and decrease radiologist interpretation variability [2]. A meta-analysis indicated a pooled sensitivity of 88% and sensitivity of 86% [37]. However, this analysis did not compare SICUS to US without oral contrast administration, and therefore the added benefit was not ascertained. In a prospective pediatric study of 25 patients, the SICUS sensitivity in the terminal ileum was 94%, proximal ileum 80%, and jejunum 92%, with authors concluding SICUS was an effective option for imaging the small bowel [38]. Additional pediatric-focused literature for SICUS is more limited, and direct comparison with and without oral contrast is currently lacking. At present, administration of oral contrast during abdominal US is uncommon in clinical practice.

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging.
J. US Abdomen With IV Contrast

IV contrast-enhanced US (CEUS) assesses the microbubble enhancement pattern predominately of the bowel wall. Multiple CEUS agents are available, all with strong safety profiles. Following IV administration of these microbubbles, high-frequency sonographic waves cause oscillation of the microbubble core gas resulting in pronounced conspicuity. Quantitative features, such as time to peak enhancement, maximum enhancement, and areas under the enhancement curve, may be determined to supplement analysis. Studies in adult populations found that quantitative analysis facilitated differentiation of inflammatory from fibrostenotic strictures [39] and that both increased maximum peak intensity and wash in slope coefficient was indicative of active disease [40].

A meta-analysis of CEUS based on 8 studies with 428 adult patients indicated a sensitivity of 93%, a specificity of 87%, and an AUC of 0.96 [41]. A different meta-analysis of CEUS of 8 articles with a total of 332 adult patients indicated a pooled sensitivity of 94% and specificity of 79% [42]. Also,

there is a paucity of literature that reveals added benefit beyond US without IV contrast. One adult study, however, did show that quantitative CEUS parameters integrated with grayscale US with color Doppler imaging reduced indeterminate results [43]. Currently, there is a lack of studies using CEUS in children. This fact, combined with a paucity of literature supporting added benefit of CEUS beyond routine US, limits CEUS appropriateness at the present time as the initial imaging study. However, future studies are anticipated given the CEUS safety profile and adult literature. CEUS will likely be an area of future development for children with Crohn disease. Another avenue of potential future development that may supplement CEUS is determining the role to US shear wave elastography in pediatric patients, because literature is starting to emerge in adults [44].

Variant 1: Child. Suspected Crohn disease, no prior Crohn diagnosis. Initial imaging.
K. WBC Scan Whole Body

Tc-99m-hexamethyl propylene amine oxime-labeled white blood cell (Tc-99m HMPAO WBC) scan studies show sensitivities from 75% to 94% and specificities from 92% to 99% for intestinal inflammation in children [45]. More recently, Chroustova et al [46] found a sensitivity of 89% and specificity of 91% in 85 children. Although the diagnostic parameters of a WBC scan whole body are useful for both diagnosis and disease activity assessment, significant practical limitations exist. One disadvantage is the decreased ability to detect and evaluate alternative diagnoses. Other significant disadvantages are the technical aspects, including the volume of blood required for labeling, longer acquisition times, and limited usage for initial diagnosis.

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging.

In this variant, the child already has an established diagnosis of Crohn disease, and the patient presents with acute worsening of symptoms. The primary concern is active inflammation resulting in a Crohn disease complication such as fistula development, abscess, or bowel perforation. Transmural inflammation and/or fibrosis may also result in stricture formation associated with luminal stenosis and bowel obstruction. Acute exacerbation of extraintestinal manifestations such as nephrolithiasis, cholelithiasis, and primary sclerosing cholangitis may also be detected [1]. In this variant, the clinical suspicion for other etiologies of abdominal pain is low.

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging.
A. CT Enterography

CTE is a specialized CT imaging protocol of the abdomen and pelvis tailored to evaluate the small bowel. It consists of ingestion of a large volume of neutral oral contrast material to distend the small bowel using the same set of oral contrast agents used for MRE as discussed above in the Special Imaging Considerations section. The use of neutral oral contrast material is helpful to visualize mural hyperenhancement associated with active Crohn disease that can be obscured by positive oral contrast material [1]. CTE image acquisition occurs during the enteric phase (45–70 seconds postinjection), similar to MRE, although a single image acquisition is performed unlike an MRE multiphase acquisition. A main advantage of CTE is short image acquisition time of <2 seconds and as such can typically be performed with the patient awake, thereby decreasing potential patient risks associated with anesthesia [10]. The very short image duration of CTE often leads to more consistent spatial resolution and lack of motion artifact in pediatric patients compared with MRE for initial diagnosis of Crohn disease [1]. The relatively higher image quality of CTE can also be helpful at time of initial Crohn disease diagnosis to exclude other etiologies such as Meckel diverticulum, celiac disease, and abdominal malignancy [1].

CTE provides high diagnostic performance for evaluation of Crohn disease activity in pediatric

patients, as in adults, with a sensitivity >80% and a specificity >85% compared with endoscopic and histologic reference [11-13]. These studies directly compared CTE and MRE and did not find any significant difference in performance between the two modalities. Furthermore, a meta-analysis based on 290 patients from 6 studies showed sensitivity and specificity in detecting active small bowel Crohn disease was 85.8% and 83.6%, respectively, with the AUC of 0.898 [14]. CTE imaging features of active Crohn disease inflammation are very similar to those reported for MRE and include mural (eg, wall thickening and hyperenhancement) and perienteric (eg, engorged vasa recta, fibrofatty proliferation, lymphadenopathy) features of disease [15]. A study comparing the performance of different CTE and MRE imaging features compared with histologic reference showed that mural features of disease (wall thickening and hyperenhancement) performed better than perienteric features in evaluating activity and may be more reliable features in cases in which some but not all features of activity are present [16].

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging. B. CT Abdomen and Pelvis

CT of the abdomen and pelvis with IV contrast but without the enterography technique may need to be performed in patients who cannot tolerate a large volume of neutral oral contrast material. Conventional, nonenterography CT can either be performed without any oral contrast material or with a smaller volume of positive oral contrast material. A pediatric study comparing standard CT abdomen/pelvis with positive oral and IV contrast material with MRE in patients with Crohn disease showed high agreement between CT and MRE for detection of bowel wall thickening (k = 0.88), fluid collections (k = 0.86), and fistulae (k = 1.00) [17]. It is known that IBD in pediatric patients is frequently diagnosed on abdominal CT examinations performed for evaluation of nonspecific abdominal pain, which are typically performed with IV contrast, but may or may not include oral contrast depending on institutional preference. In cases in which the patient is presenting acutely, poor oral contrast ingestion can make underdistended or air-filled bowel loops difficult to evaluate; in this scenario, standard CT with IV contrast may be preferred to MRE for small bowel evaluation [1]. There is insufficient literature to support the use of CT without IV contrast in children.

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging. C. FDG-PET/CT Skull Base to Mid-Thigh

It would be unusual for FDG-PET/CT for Crohn disease to be performed in an acute setting with absence of supporting literature for assessment of acute exacerbation in children.

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging. D. Fluoroscopy Contrast Enema

Colonoscopy is the most useful modality for evaluation of the colon in patients with suspected or known Crohn disease involving the colon [2]. Fluoroscopy contrast enema is uncommonly used in current practice, given its limited ability to evaluate the small bowel. An institutional study confirmed this decline in which the average number of contrast enema per Crohn disease patients per year dropped from 0.05 in 2001 to 0.01 in 2010 [20]. Fluoroscopy contrast enema, however, may remain an option if selected problem solving is necessary, such as stricture assessment during contrast injection [21].

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging. E. Fluoroscopy Upper GI Series with Small Bowel Follow-Through

Using fluoroscopy SBFT with barium is a historically well-established modality for small bowel

evaluation [2]. There is, however, a significant decrease in use of SBFT with current widespread use of cross-sectional imaging modalities including MRI and CT. Although fluoroscopy SBFT allows accurate intraluminal and mucosal assessment, bowel wall thickness among other signs cannot be directly visualized. Additionally, although internal fistulas may be visualized, extraluminal pathologies including abscess formation may only be indirectly inferred. In a study of 87 pediatric patients with IBD utilization histology as criterion standard, 31% of patients had pathology identified on MRI not visualized on SBFT. In this study, the SBFT sensitivity and specificity were 76% and 67%, respectively, whereas MRI demonstrated greater sensitivity and specificity of 83% and 95%, respectively [22]. Fluoroscopy SBFT, however, does remain an option if problem solving is necessary, such as cutaneous fistula evaluation [21]. Fluoroscopy SBFT may also serve as an alternative to MRI and CT to avoid sedation, particularly in younger children.

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging.
F. MR Enterography

MRE represents a specialized MRI protocol of the abdomen and pelvis tailored to evaluate the small bowel. MRE includes large volume ingestion of a biphasic (T1-weighted hypointense, T2-weighted hyperintense) contrast agent that distends the small bowel on T1-weighted fat-suppressed postcontrast images. Oral contrast agents are further discussed above in the special imaging considerations section. Traditionally, MRE also includes the use of IV contrast, with enteric phase (45–70 seconds after injection) being most commonly used to assess for mural hyperenhancement accompanying active bowel inflammation [7,16]. Other standard pediatric MRE pulse sequences include single-shot T2-weighted, balanced steady-state free precession, and diffusion-weighted imaging [23]. Administration of a hypoperistaltic medication (eg, glucagon or hyoscine butylbromide) during MRE may improve image quality through reduced peristaltic motion artifact but can be associated with nausea in some patients [7].

The role of MRE in this scenario include delineation of disease extent, depiction of extraintestinal manifestation of Crohn disease, and detection of penetrating disease complications that may influence treatment decisions (eg, fistulae that may be indicators of biologic therapy or abscess formation that may necessitate antibiotics and/or drainage). Evaluation of small bowel disease is an especially important role for MRE given the limitations of optical endoscopy in small bowel accessibility and visualization, particularly when Crohn disease terminal ileitis causes luminal narrowing [1].

MRE has high diagnostic performance for the detection of Crohn disease–related active bowel inflammation in pediatric patients compared with both endoscopy and histologic reference. Sensitivity values range from 66% to 95%, and specificity values range from 64% to 97% on a bowel segmental basis [17,23-27]. Several MRE imaging features have been well-established imaging biomarkers of active Crohn disease inflammation. These include mural (eg, wall thickening, hyperenhancement, and edema) and perienteric (eg, engorged vasa recta, fibrofatty proliferation, and lymphadenopathy) features of disease [15]. Penetrating disease complications may include sinus tracts, fistulae, abscesses, inflammatory masses, and bowel perforation [15]. Recent evidence indicates that IV contrast does improve MRE sensitivity for detecting these penetrating Crohn disease complications in children [28]. This study, however, also showed similar performance for detection of active inflammation in the terminal ileum and colon without IV contrast administration [28]. Another recent study indicates no additional benefit of IV gadolinium beyond non-IV contrast-enhanced MRE for detection of active IBD in pediatric patients [29]. Additionally, a study of IV contrast-enhanced MRE compared with diffusion-weighted MRE in

children and young adults demonstrates that diffusion-weighted imaging in lieu of IV contrast administration provides comparable identification of both inflammatory wall thickening and lesion detection [30].

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging. G. MRI Abdomen and Pelvis

MRI of the abdomen and pelvis without oral contrast enterography technique can be considered for Crohn disease patients who may be unable to tolerate sufficient oral contrast, particularly for those with acute abdominal symptoms at the time of initial diagnosis. A study comparing noncontrast (no IV or oral contrast) MRI with MRE (with oral and IV contrast) in adult IBD patients showed MRE to be superior for detection of bowel inflammatory lesions, with a sensitivity, specificity, and PPV of noncontrast MRI of 50%, 94%, and 28% for detection of small bowel wall thickening and 86%, 93%, and 86% for detection of terminal ileal wall thickening compared with the study's internal MRE reference standard (of 100%) [31]. Although such a study has not yet been performed in pediatric patients, noncontrast MRI abdomen and pelvis is likely to perform worse in the pediatric population given the relative paucity of mesenteric fat and the smaller caliber of the bowel, which can make evaluation of the bowel wall and perienteric inflammation more difficult by MRI [16]. If MRI needs to be performed without oral contrast, the use of cinematic steady-state free precession sequences can be helpful to distinguish normal underdistended small bowel from bowel wall thickening [7]. Overall, pediatric Crohn disease MRI studies have focused on enterography with less current supporting literature for the nonenterography MRI technique in children. However, when sufficient oral contrast is not feasible to perform MRE, MRI abdomen and pelvis either with IV or without IV contrast can serve as a reasonable alternative.

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging. H. Radiography Abdomen

Visualization of bowel pathology is limited on abdominal radiographs, which restricts utilization. Although cross-sectional techniques have largely supplanted the previous role, radiographs may continue to provide diagnostic information for severely ill children, including those with bowel perforation or bowel obstruction. A recent study of 643 abdominal radiographs (16% were >17 years of age) revealed four cases of pneumoperitoneum, two cases of obstruction, and no cases of toxic megacolon, indicating that these scenarios are uncommon [47]. If present, the information may help modify additional imaging or emergent clinical management, such as additional CT for emergent surgical planning in the setting of a bowel perforation. If radiography is performed for emergent clinical assessment, a left lateral decubitus or upright radiograph should be performed in addition to a supine radiograph for pneumoperitoneum assessment.

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging. I. US Abdomen

US abdomen can be used for imaging Crohn disease during acute exacerbation. US may be a suitable alternative for evaluation of the terminal ileum in younger children who would otherwise require sedation for MRE or CTE examinations [21]. Sonographic technique requires a systematic assessment of the entire bowel including terminal ileum, colon, and more proximal small bowel. All four quadrants of the abdomen should be evaluated in both the transverse and longitudinal planes [32]. Color Doppler US is also performed to facilitate mural hyperemia assessment. Sonographic features include abnormal bowel wall thickening (>3 mm in children), alteration of bowel wall signature, adjacent fatty proliferation, hyperemia, and engorgement of the vasa recta [32]. Patient features may adversely affect US including elevated body mass index as well as bowel gas resulting

in shadowing. In the setting of pediatric Crohn disease, though, obesity is less likely given that many patients have impaired nutrition [32]. The detection of alternative diagnoses is also decreased compared with CT or MRI.

A meta-analysis of prospective US studies indicated a sensitivity of 88%, a specificity of 97%, and an accuracy of 94% [33]. Although this meta-analysis was adult focused, pediatric literature is also available. A comparative study between MRE and US was performed including 31 pediatric patients with histology as a reference standard. For the terminal ileum, the sensitivity and specificity for US was 89% and 55%, respectively, compared with MRE of 78% and 46%, respectively. Overall, including all segments within the colon, sensitivity for both modalities was 46% (US and MRE) and specificity was 87% (US) and 85% (MRE) [34]. A study comparing bowel US and MRE in children with 33 patients prospectively showed that US readings are substantially reliable in the colon and terminal and distal ileum (ICC of 0.79–0.88) but highly unreliable in the mid and proximal small bowel (ICC of 0.0) [35]. A prospective study of 41 pediatric patients demonstrated sensitivities of 67% and 78% and specificities of 78% and 83% for the two readers, respectively, versus clinicopathologic diagnosis (compared with MRE sensitivity and specificity of 75% and 100%) [36]. These authors concluded that "US has limited sensitivity for detecting terminal ileitis" [36].

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging. J. US Abdomen With IV Contrast

Currently, there is a lack of studies to support using CEUS in children in the acute or emergent setting.

Variant 2: Child. Known Crohn disease, suspected acute exacerbation. Initial Imaging. K. WBC Scan Whole Body

Tc-99m HMPAO WBC scan has very significant practical limitations in the acute setting. One disadvantage is the decreased ability to detect and evaluate alternative diagnoses. Other significant disadvantages are the technical aspects including volume of blood required for labeling and longer acquisition times limiting usage in this variant.

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy.

In this variant, imaging helps determine the presence or absence of active inflammation in an otherwise well child. Imaging will assist in determining patient management. Many of these patients are on immunosuppressive medical therapies (eg, targeted antibodies such as anti-tumor necrosis factor [TNF]-α agents) that carry significant risk of complications with prolonged administration, necessitating optimal assessment of residual or recurrent disease activity on treatment. Additionally, when symptomatic Crohn disease strictures are present, imaging may help determine if luminal narrowing is primarily a result of active inflammation or underlying fibrosis, although definitive distinction is often challenging because both are frequently present. When feasible, differentiation between these is important, because active inflammation is treated medically, whereas fibrostenotic disease is often treated surgically.

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy. A. CT Enterography

CTE is a specialized CT imaging protocol of the abdomen and pelvis tailored to evaluate the small bowel. It consists of ingestion of a large volume of neutral oral contrast material to distend the small bowel using the same set of oral contrast agents used for MRE as discussed above in the Special Imaging Considerations section. The use of neutral oral contrast material is helpful to

visualize mural hyperenhancement associated with active Crohn disease that can be obscured by positive oral contrast material [1]. CTE image acquisition occurs during the enteric phase (45–70 seconds postinjection), similar to MRE, although a single image acquisition is performed unlike an MRE multiphase acquisition. A main advantage of CTE is the short image acquisition time of <2 seconds, and as such it can typically be performed with the patient awake, thereby decreasing potential patient risks associated with anesthesia [10]. The very short image duration of CTE often leads to more consistent spatial resolution and lack of motion artifact in pediatric patients compared with MRE for initial diagnosis of Crohn disease [1]. The relatively higher image quality of CTE can also be helpful at time of initial Crohn disease diagnosis to exclude other etiologies such as Meckel diverticulum, celiac disease, and abdominal malignancy [1].

CTE provides high diagnostic performance for evaluation of Crohn disease activity in pediatric patients, as in adults, with a sensitivity >80% and a specificity >85% compared with endoscopic and histologic reference [11-13]. These studies directly compared CTE and MRE and did not find any significant difference in performance between the two modalities. Furthermore, a meta-analysis based on 290 patients from 6 studies showed sensitivity and specificity in detecting active small bowel Crohn disease was 85.8% and 83.6%, respectively, with the AUC of 0.898 [14]. CTE imaging features of active Crohn disease inflammation are very similar to those reported for MRE and include mural (eg, wall thickening and hyperenhancement) and perienteric (eg, engorged vasa recta, fibrofatty proliferation, adenopathy) features of disease [15]. A study comparing the performance of different CTE and MRE imaging features compared with histologic reference showed that mural features of disease (wall thickening and hyperenhancement) performed better than perienteric features in evaluating activity and may be more reliable features in cases in which some but not all features of activity are present [16]. Although relative radiation levels are beyond the purview of this discussion, they are listed in the tables at the beginning of the document and may be considered by the requesting physician particularly in the setting of disease surveillance and therapy monitoring in children. For additional information, please see the Relative Radiation Level Information section at the end of this document.

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy.
B. CT Abdomen and Pelvis

CT of the abdomen and pelvis with IV contrast but without the enterography technique may need to be performed in patients who cannot tolerate a large volume of neutral oral contrast material. Conventional, nonenterography CT can either be performed without any oral contrast material or with smaller volume of positive oral contrast material. A pediatric study comparing standard CT abdomen/pelvis with positive oral and IV contrast material with MRE in patients with Crohn disease showed high agreement between CT and MRE for detection of bowel wall thickening ($k = 0.88$), fluid collections ($k = 0.86$), and fistulae ($k = 1.00$) [17]. It is known that IBD in pediatric patients is frequently diagnosed on abdominal CT examinations performed for evaluation of nonspecific abdominal pain, which are typically performed with IV contrast, but may or may not include oral contrast depending on institutional preference. In cases in which the patient is presenting acutely, poor oral contrast ingestion can make underdistended or air-filled bowel loops difficult to evaluate; in this scenario, standard CT with IV contrast may be preferred to MRE for small bowel evaluation [1]. There is insufficient literature to support the use of CT without IV contrast in children. Although relative radiation levels are beyond the purview of this discussion, they are listed in the table at the beginning of the document and may be considered by the requesting physician particularly in the setting of disease surveillance and therapy monitoring in children.

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy.
C. FDG-PET/CT Skull Base to Mid-Thigh

Combining metabolic information from FDG-PET with anatomic CT imaging shows potential to further diagnostic accuracy in children. A meta-analysis of 7 studies with a total of 219 patients (3 studies with 93 patients were pediatric focused) on a per segment basis showed sensitivity was 85%, specificity 87%, and area under the receiver operating characteristic curve was 0.93. PET/CT may be particularly helpful to assess the level of active inflammation from fibrosis [18]. One pediatric study with 23 patients showed a sensitivity and specificity for the terminal ileum of 89% and 75%, respectively [19]. At the present time, however, there is a paucity of larger clinical studies published, particularly in children. In selected monitoring or surveillance scenarios, however, FDG-PET/CT may supplement existing imaging to further help determine the presence of metabolic activity (eg, stricture assessment for surgical planning) [48,49].

A limitation that must be noted is physiological distribution of FDG, including normal uptake in terminal ileum, which may compromise PET imaging of patients with IBD. If performing FDG-PET/CT for the evaluation of Crohn disease, the area of coverage from skull base to mid-thigh may be sufficient for bowel evaluation; however, some institutions do perform full-body imaging (from vertex to toes); therefore the area of coverage may be determined according to institutional practices.

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy.
D. Fluoroscopy Contrast Enema

Colonoscopy is the useful study for evaluation of the colon in patients with suspected or known Crohn disease involving the colon [2]. Fluoroscopy contrast enema is uncommonly used in current practice because of its limited ability to evaluate the small bowel. Fluoroscopy contrast enema, however, may remain an option if selected problem solving is necessary, such as stricture assessment during contrast injection [21].

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy.
E. Fluoroscopy Upper GI Series with Small Bowel Follow-Through

Utilizing fluoroscopy SBFT with barium is a historically well-established modality for small bowel evaluation [2]. There is, however, a significant decrease in use of SBFT with current widespread use of cross-sectional imaging modalities including MRI and CT. Although fluoroscopy SBFT allows accurate intraluminal and mucosal assessment, bowel wall thickness among other signs cannot be directly visualized. Additionally, although internal fistulas may be visualized, extraluminal pathologies including abscess formation may only be indirectly inferred. In a study of 87 pediatric patients with IBD utilization histology as criterion standard, 31% of patients had pathology identified on MRI not visualized on SBFT. In this study, the SBFT sensitivity and specificity were 76% and 67%, respectively, whereas MRI demonstrated a greater sensitivity and specificity of 83% and 95%, respectively [22]. Fluoroscopy SBFT, however, does remain an option if problem solving is necessary, such as cutaneous fistula evaluation [21]. Fluoroscopy SBFT may also serve as an alternative to MRI and CT to avoid sedation, particularly in younger children.

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy.
F. MR Enterography

MRE represents a specialized MRI protocol of the abdomen and pelvis tailored to evaluate the small bowel. MRE includes large volume ingestion of a biphasic (T1-weighted hypointense, T2-weighted hyperintense) contrast agent that distends the small bowel on T1-weighted fat-

suppressed postcontrast images. Oral contrast agents are further discussed above in the special imaging considerations section. Traditionally, MRE also includes the use of IV contrast, with enteric phase (45–70 seconds after injection) being most commonly used to assess for mural hyperenhancement accompanying active bowel inflammation [7,16]. Other standard pediatric MRE pulse sequences include single-shot T2-weighted, balanced steady-state free precession, and diffusion-weighted imaging [23]. Administration of a hypoperistaltic medication (eg, glucagon or hyoscine butylbromide) during MRE may improve image quality through reduced peristaltic motion artifact but can be associated with nausea in some patients [7].

MRE has high diagnostic performance for the detection of Crohn disease–related active bowel inflammation in pediatric patients compared with both endoscopy and histologic reference. Sensitivity values range from 66% to 95%, and specificity values range from 64% to 97% on a bowel segmental basis [17,23-27]. Several MRE imaging features have been well-established imaging biomarkers of active Crohn disease inflammation. These include mural (eg, wall thickening, hyperenhancement, and edema) and perienteric (eg, engorged vasa recta, fibrofatty proliferation, and lymphadenopathy) features of disease [15]. Penetrating disease complications may include sinus tracts, fistulae, abscesses, inflammatory masses, and bowel perforation [15]. Recent evidence indicates that IV contrast does improve MRE sensitivity for detecting these penetrating Crohn disease complications in children [28]. This study, however, also showed similar performance for detection of active inflammation in the terminal ileum and colon without IV contrast administration [28]. Another recent study indicates no additional benefit of IV gadolinium beyond non-IV contrast-enhanced MRE for detection of active IBD in pediatric patients [29]. Additionally, a study of IV contrast enhanced MRE compared to diffusion-weighted MRE in children and young adults demonstrates that diffusion-weighted imaging in lieu of IV contrast administration provides comparable identification of both inflammatory wall thickening and lesion detection [30].

MRE has been shown to be effective for assessing mucosal healing in Crohn disease patients undergoing medical therapies compared with endoscopic reference in both pediatric and adult patients. A study of 48 adult Crohn disease patients undergoing optical endoscopy and MRE at baseline and 12 weeks after treatment (with corticosteroids or anti-TNF-α agents) showed that MRE quantitative assessment (Magnetic Resonance Index of Activity [MaRIA] that includes bowel wall thickness, T2-weighted signal intensity, mural enhancement, and ulceration) demonstrated 90% accuracy for detecting mucosal ulcer healing and 83% for detecting endoscopic disease remission compared with endoscopic reference [50]. A study of 30 pediatric Crohn disease patients undergoing serial ileocolonoscopy with closely timed MRE showed 74% accuracy, 84% sensitivity, and 62% specificity of MaRIA for detecting endoscopic mucosal healing, with resolution of either mural hyperenhancement or vasa recta engorgement having similar performance to the MaRIA score (72%, 98%, and 41%) [51]. These studies indicate that MRE has high performance for evaluation of treatment response in pediatric Crohn disease patients.

Another potential indication for MRE is surveillance of asymptomatic Crohn disease patients to assess subclinical disease activity. A study of 34 children and adolescents with asymptomatic Crohn disease patients undergoing MRE surveillance [52] found that several MRE imaging features (mural edema, hyperenhancement, engorged vasa recta, and restricted diffusion) were significant predictors of disease recurrence within 6 months, with sensitivity values of 71% to 86% and specificity values of 68% to 86%. Mural diffusion restriction was found to be the best predictor by

multivariate regression and predicted future disease recurrence with an AUC of 0.786.

MRE in this variant is also useful for stricture characterization. One study examined 31 bowel segments from pediatric Crohn disease patients who underwent surgical bowel resection and preoperative MRE [17]. Performance of MRE for fibrosis detection was relatively low accuracy (64.9%) because of mixed inflammation and fibrosis within strictures but was higher (83.3%) for fibrotic strictures without superimposed active inflammation. Another study of 20 pediatric Crohn disease patients with symptomatic small bowel strictures and preoperative MRE [53] showed a significant histological correlation between fibrosis and inflammation (*rho* = 0.55) within strictures, as well as a significant association between small bowel dilation >3 cm on MRE and stricture fibrosis (odds ratio = 43). A study of 25 pediatric Crohn disease patients who underwent bowel stricture resection with preoperative MRE showed that texture analysis of the bowel wall signal intensities for detecting stricture fibrosis had a goodness-of-fit AUC value of 0.995 [54].

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy. G. MRI Abdomen and Pelvis

MRI of the abdomen and pelvis without the oral contrast enterography technique can be considered for Crohn disease patients who may be unable to tolerate sufficient oral contrast, particularly for those with acute abdominal symptoms at the time of initial diagnosis. A study comparing noncontrast (no IV or oral contrast) MRI with MRE (with oral and IV contrast) in adult IBD patients showed MRE to be superior for detection of bowel inflammatory lesions, with a sensitivity, specificity, and PPV of noncontrast MRI of 50%, 94%, and 28% for detection of small bowel wall thickening and 86%, 93%, and 86% for detection of terminal ileal wall thickening compared with the study's internal MRE reference standard (of 100%) [31]. Although such a study has not yet been performed in pediatric patients, noncontrast MRI abdomen and pelvis is likely to perform worse in the pediatric population given the relative paucity of mesenteric fat and smaller caliber of bowel, which can make evaluation of bowel wall and perienteric inflammation more difficult by MRI [16]. If MRI needs to be performed without oral contrast, the use of cinematic steady-state free precession sequences can be helpful to distinguish normal underdistended small bowel from bowel wall thickening [7]. Overall, pediatric Crohn disease MRI studies have focused on enterography with less current supporting literature for the nonenterography MRI technique in children. However, when sufficient oral contrast intake is not feasible to perform MR enterography, MRI abdomen and pelvis either with IV or without IV contrast can serve as a reasonable alternative.

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy. H. Radiography Abdomen

Visualization of bowel pathology is limited on abdominal radiographs, which restricts use for disease surveillance or monitoring therapy.

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy. I. US Abdomen

US abdomen can be used for imaging Crohn disease during therapy monitoring. US may be a particularly suitable alternative for younger children who would otherwise require sedation for MRE or CTE examinations [21]. Sonographic technique requires a systematic assessment of the entire bowel including terminal ileum, colon, and more proximal small bowel. All four quadrants of the abdomen should be evaluated in both the transverse and longitudinal planes [32]. Color Doppler US is also performed to facilitate mural hyperemia assessment. Sonographic features include abnormal bowel wall thickening (>3 mm in children), alteration of bowel wall signature,

adjacent fatty proliferation, hyperemia, and engorgement of the vasa recta [32]. Patient features may adversely affect US including elevated body mass index as well as bowel gas resulting in shadowing. In the setting of pediatric Crohn disease though, obesity is less likely given that many patients have diminished nutrition [32]. The detection of alternative diagnoses is also decreased compared with CT or MRI.

A meta-analysis of prospective US studies indicated a sensitivity of 88%, a specificity of 97%, and an accuracy of 94% [33]. Although this meta-analysis was adult focused, pediatric literature is also available. A comparative study between MRE and US was performed including 31 pediatric patients with histology as a reference standard. For the terminal ileum, the sensitivity and specificity for US was 89% and 55%, respectively, compared with MRE of 78% and 46%, respectively. Overall, including all segments within the colon, sensitivity for both modalities was 46% (US and MRE) and specificity was 87% (US) and 85% (MRE) [34]. A study comparing bowel US and MRE in children with 33 patients prospectively showed that US readings are substantially reliable in the colon and terminal and distal ileum (ICC of 0.79–0.88) but highly unreliable in the mid and proximal small bowel (ICC of 0.0) [35]. A prospective study of 41 pediatric patients demonstrated sensitivities of 67% and 78% and specificities of 78% and 83% for the two readers, respectively, versus clinicopathologic diagnosis (compared with MRE sensitivity and specificity of 75% and 100%) [36]. These authors concluded that "US has limited sensitivity for detecting terminal ileitis" [36].

Literature supporting the use of US for grading disease activity is only partially developed. In a meta-analysis, based on only three studies with 86 patients, it demonstrated an accuracy of only 44% [55]. A prospective pediatric study with subjects undergoing US before and after initiation of medical therapy with 29 patients and 231 US examinations was performed. US agreement was only moderate for involved length, bowel wall Doppler signal, and stricture; however, it was more substantial for maximum bowel wall thickness, penetrating disease, and abscess [56]. These authors did question US accuracy and reproducibility for assessment of medical therapy.

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy.
J. US Abdomen With IV Contrast

CEUS assesses microbubble enhancement pattern predominately of the bowel wall. Multiple CEUS agents are available, all with strong safety profiles. Following IV administration of these microbubbles, high-frequency sonographic waves cause oscillation of the microbubble core gas resulting in pronounced conspicuity. Quantitative features, such as time to peak enhancement, maximum enhancement, and areas under the enhancement curve, may be determined to supplement analysis. Studies in adult populations found that quantitative analysis facilitated differentiation of inflammatory from fibrostenotic strictures [39] and that both increased maximum peak intensity and wash in slope coefficient was indicative of active disease [40].

A meta-analysis of CEUS based on 8 studies with 428 adult patients indicated a sensitivity of 93%, a specificity of 87%, and an AUC of 0.96 [41]. A different meta-analysis of CEUS of 8 articles with a total of 332 adult patients indicated a pooled sensitivity of 94% and a specificity of 79% [42]. Also, there is a paucity of literature that reveals added benefit beyond US without IV contrast. One adult study, however, did show that quantitative CEUS parameters integrated with grayscale US with color Doppler imaging reduced indeterminate results [43]. Currently, there is a paucity of studies using CEUS in children. CEUS will be an area of future development for children with Crohn disease and is currently being used clinically by several committee members to supplement US abdomen (without IV contrast) for monitoring and surveillance imaging. In this setting, CEUS is most useful in

Crohn disease patients with a single segment of bowel involvement that is sonographically visible. Another avenue of potential future development that may supplement CEUS is determining the role to US shear wave elastography in pediatric patients, as literature is starting to emerge in adults [44].

Variant 3: Child. Known Crohn disease, disease surveillance or monitoring therapy.
K. WBC Scan Whole Body

Tc-99m HMPAO WBC scan studies show sensitivities from 75% to 94% and specificities from 92% to 99% for intestinal inflammation in children [45]. More recently, Chroustova et al [46] found a sensitivity of 89% and a specificity of 91% in 85 children. Although the diagnostic parameters of a WBC scan whole body are useful for both diagnosis and disease activity assessment, significant practical limitations exist. One disadvantage is the decreased ability to detect and evaluate alternative diagnoses. Other significant disadvantages are the technical aspects including volume of blood required for labeling, longer acquisition times, and significantly limited usage for initial diagnosis.

Variant 4: Child. Known Crohn disease, perianal fistula. Initial imaging.

Perianal Crohn disease manifesting as either a fistula or an abscess is common, with 15% to 25% of patients exhibiting perianal Crohn disease in childhood and 38% during their lifetime [5,6]. Although examination under anesthesia by a pediatric surgeon has been a standard of care for assessment, advancements in imaging complement the clinical assessment. Imaging may also supplant examination under anesthesia in circumstances when noninvasive diagnostic information is sought, such as preprocedural planning or assessment of therapy response [2].

Variant 4: Child. Known Crohn disease, perianal fistula. Initial imaging.
A. CT Pelvis

If present, perianal disease may be identified within the field of view during acquisition if CTE is used for diagnosis, acute exacerbation, or therapy response. There is, however, insufficient literature to support primary imaging of perianal disease by pelvic CT.

Variant 4: Child. Known Crohn disease, perianal fistula. Initial imaging.
B. Fluoroscopy Contrast Enema

Fluoroscopy contrast enema is uncommonly used in current practice. There is insufficient pediatric literature to support routine use for perianal Crohn disease.

Variant 4: Child. Known Crohn disease, perianal fistula. Initial imaging.
C. MRI Pelvis

Because of the superior soft-tissue resolution allowing anatomic localization of penetrating disease in relation to the sphincteric musculature and perianal soft tissues, MRI pelvis with IV contrast is the study of choice for assessing perianal Crohn disease [5,6]. MRI of the pelvis in this setting is primarily acquired with higher-resolution T2-weighted fat-suppressed sequences and postgadolinium T1-weighted fat-suppressed images. Imaging in the axial and coronal planes may be obliqued to the anal canal depending upon institutional preference. Diagnostic performance of MRI pelvis with gadolinium may be as high as 81% sensitive and 100% specific in children [5]. Also, an adult meta-analysis of four studies showed MRI sensitivity and specificity for fistula detection were 87% and 69%, respectively, with greater specificity than US at 43% [57]. With standard pediatric MRE, which included this region, the sensitivity and specificity were 82% and 100% for perianal disease [58]. Unlike MRE, however, for MRI pelvis in this variant, oral contrast material is not necessary. There is little literature to specifically support pelvic MRI without IV contrast for

perianal Crohn disease. However, noncontrast MRI will likely still yield diagnostic information for monitoring therapy response, whereas optimal anatomic distribution has previous been ascertained [6].

Pelvic MRI with contrast can also assist in predicting and monitoring treatment response. A study of 36 children with perianal fistulizing Crohn disease study found that a maximum fistula length of <2.5 cm predicted treatment response, and a length >2.5 cm predicted disease progression [6]. Another pediatric study based on the Van Assche MRI scoring system demonstrated interval decrease in score following treatment compared with the baseline score at diagnosis (P = .0170) [59]. Because of the superb soft-tissue resolution allowing determination of fistulous tracts and abscesses in relation to the anal sphincter musculature, as well as high diagnostic performance, MRI pelvis with administration of IV contrast in an integral part of care for perianal Crohn disease.

Variant 4: Child. Known Crohn disease, perianal fistula. Initial imaging.
D. US Pelvis Transperineal

Transperineal US of the pelvis in children may serve as a useful alternative when perianal imaging is indicated, although anatomic delineation is more limited than MRI. US is an imaging option for perianal Crohn disease. Differing sonographic techniques have been described in adults and children including transcutaneous/transperineal approaches as well as endoanal US. Endoanal US is a technique used in adult patients with variable diagnostic accuracy and can be limited by luminal stenosis [2]. A meta-analysis of endoanal US based on four studies in adult patients showed a sensitivity of 87% and a specificity of 43%, with a specificity inferior to MRI [57]. There is insufficient literature to support endoanal US in children, and technical limitations such as smaller size and need for anesthesia preclude usefulness in pediatric patients.

Other US techniques, however, are potentially more feasible in children. Transcutaneous perianal US was studied in 38 pediatric patients using MRI as the reference standard. Transcutaneous perianal US demonstrated a sensitivity, specificity, PPV, and negative predictive value of 76%, 53%, 84%, and 41% for fistulae and 56%, 98%, 90%, and 88%, respectively, for abscess compared with MRI [60]. An adult-focused meta-analysis of transperineal US from 12 studies showed a sensitivity and PPV of 98% and 95% for detecting fistula and a sensitivity and PPV of 86% and 90% for abscess detection, respectively [61]. A prospective study of 23 patients including adults as well as adolescents (mean patient age of 29.9 years) showed sensitivity for MRI, transrectal US, and transperineal US for fistula diagnosis were 84.6%, 84.6%, and 100%, respectively [62]. US may be somewhat limited in its ability to identify and characterize complex perianal fistulous disease (multiple tracks and/or extending above the levator ani) and abscesses when compared with MRI, likely because of a combination of technical factors including operator dependence. Although there is a lack of current pediatric literature to substantially support this, in a 2013 study of 46 adult patients, Maconi et al reported an overall detection rate of 89% for fistulous disease by transperineal US compared with MRI/clinical reference but a sensitivity rate of 47% for abscesses and 56% for extrasphincteric fistulae [63].

Summary of Highlights

- **Variant 1**: CTE or MRE or MRI abdomen and pelvis without and with IV contrast is usually appropriate for the initial imaging of children with suspected Crohn disease with no prior Crohn diagnosis. These procedures are equivalent alternatives (ie, only one procedure will be

ordered to provide the clinical information to effectively manage the patient's care).

- **Variant 2**: CT abdomen and pelvis with IV contrast or CTE or MRE or MRI abdomen and pelvis without and with IV contrast is usually appropriate for the initial imaging of children with known Crohn disease with suspected acute exacerbation. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 3**: CTE or MRE or MRI abdomen and pelvis without and with IV contrast is usually appropriate for disease surveillance or monitoring therapy of children with known Crohn disease. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 4**: MR pelvis with IV contrast or MRI pelvis without and with IV contrast is usually appropriate for the initial imaging of children with known perianal fistulizing Crohn disease. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document.

Relative Radiation Level Designations

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as “Varies.”

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Disclaimer

The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.

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