MR Enterography of Pediatric Inflammatory Bowel Disease: Review of Imaging Techniques and Findings

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Introduction
Inflammatory bowel disease (IBD) consists of ulcerative colitis (UC), Crohn disease (CD), and indeterminate colitis. While sharing many clinical features, ulcerative colitis and Crohn disease are considered separate entities with unique characteristics. Due to the chronic nature of these diseases, frequent and repeated imaging is often necessary for diagnosis and therapeutic planning. Magnetic resonance enterography (MRE) has emerged as a robust imaging modality for the evaluation of IBD, offering many advantages over conventional imaging techniques while sparing the patient exposure to ionizing radiation. This review will briefly discuss the pathology and epidemiology of IBD, provide a practical guide to the performance of MRE, and highlight various classic imaging findings frequently encountered in these patients.

Background
Inflammatory bowel disease is, by nature, a chronic relapsing inflammatory condition. Crohn disease is a granulomatous process which leads to transmural inflammation with lymphoid aggregates extending to the serosal surface. In distinction, ulcerative colitis is nongranulomatous with inflammatory change typically limited to the mucosa. UC involves the colon in a contiguous fashion extending from the anorectum proximal to a variable extent. In cases of pancolonic ulcerative colitis, a mild inflammatory process may also involve the terminal ileum, the so-called “backwash ileitis". Crohn disease may involve any portion of the intestinal tract from the mouth to the anus in a decidedly non-contiguous pattern. While terminal ileal involvement is frequently seen and favors the diagnosis of CD, it is not requisite. The histologic hallmark of CD is a nonnecrotizing sarcoïd-like granuloma found within the deep submucosa or lymph nodes.1 The aphthous ulceration which leads to fissures and forms the cobblestone mucosal appearance visualized endoscopically may also extend through the bowel wall and lead to sinus tracts or fistula formation. This transmural process may incite a regional inflammatory response and lead to fibrofatty proliferation and hyperemia in addition to abscess formation.

The etiology of IBD appears to be complex with both genetic and environmental components. Multiple genes have been implicated in the pathogenesis of both UC and CD.2,3 The genetic subtleties involved in IBD are beyond the scope of this review, however in addition to defects in innate immunity, genetic abnormalities have been implicated which lead to alterations in cytokine-mediated immune response.4 Patients harboring specific gene mutations are likely predisposed to developing IBD in response to a multitude of environmental triggers.

While more frequently encountered in the adult population, approximately 25% of IBD cases are diagnosed in pediatric patients.5 The incidence of ulcerative colitis in patients less than age 20 is estimated at 28:100,000 and Crohn disease at 43:100,000.6 Recent studies have shown that the incidences of both CD and UC are rising.7 The chronic and debilitating nature of these diseases is substantial and lead to frequent and prolonged hospital stays. The estimated annual inpatient cost to care for pediatric patients with IBD is $152.4 million and requires nearly 65,000 hospital days, stunning figures for diseases with relatively low incidences.8

There has been a significant increase in awareness both within the medical community and the public at large regarding the potential increase in cancer risk associated with diagnostic medical radiation. A majority of the collective dose from radiologic exams results from high-dose procedures...
such as CT and fluoroscopic studies. The ensuing organ doses are sufficiently large as to result in small, but statistically significant, increase in cancer risk. Children with IBD have traditionally been evaluated with CT or fluoroscopy for both initial diagnosis and for the evaluation of disease recurrences and complications such as fistula or abscess formation. While all children with IBD are typically exposed to a higher level of radiation than their unaffected peers, a smaller subset of IBD patients are exposed to particularly high levels of medical radiation. This group includes patients with Crohn disease, those requiring IBD-related surgery, those with an increased number of hospital admissions, and those with elevated platelet counts at the time of diagnosis.

Diagnostic modalities which do not involve ionizing radiation should be favored in children with IBD, particularly in light of their unique pre-existing elevated lifetime cancer risk and the increased sensitivity to radiation noted in pediatric population, in general. MR enterography has been shown to be an excellent substitute for CT in the evaluation of IBD. In fact, the information gained with MRE regarding activity of disease and the extent of extraluminal processes such as fistula and sinus tracts is unmatched by other conventional modalities.

**Technique**

Patient preparation, coil selection, and sequences utilized at our institution will be reviewed. While many variations on MRE technique have been described, we have found the following protocol produces consistent results for patients with UC, CD, or indeterminate colitis.

Patients are instructed to arrive two hours prior to their examination time to begin their oral contrast preparation. Oral contrast consists of 1 teaspoon of Metamucil (Proctor & Gamble, Cincinnati, Ohio) dissolved in 8 ounces of water. The patient drinks one dose of oral contrast every 30 minutes for a total of four glasses (32 ounces of contrast) prior to scanning. Diluted barium products such as those used for CT enterography may also be used. We have found that Metamucil is well tolerated by patients and produces reliable small bowel distention. This product is also cost effective and is conveniently stored and administered by technologists (Metamucil is available prepackaged in 1 tsp doses).

High quality MRE studies can be easily obtained using conventional 1.5 Tesla magnets. With minor modifications, our protocol can also be translated to 3.0 Tesla systems. The majority of MRE exams at our institution are performed on a 1.5T Siemens Avanto (Siemens Medical, Erlangen, Germany) with a standard 8 channel body coil. Patients are scanned in the supine position without sedation.

The following sequences are specific to Siemens magnets; however, equivalent GE sequences have been provided (Table 1). After the initial 3-plane localizer sequences, axial T2 images with fat suppression (T2 HASTE) are performed with patient breath holding extending from above the diaphragms through the perineum. In larger patients, this sequence may be divided into two acquisitions to avoid impractically long breath holds. This heavily T2-weighted sequence is exceptionally fluid sensitive and allows for detection of bowel wall thickening (Fig. 1).

<table>
<thead>
<tr>
<th>Siemens</th>
<th>GE</th>
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<tbody>
<tr>
<td>T1 Post</td>
<td>VIBE (Volume Interpolated B reath)</td>
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<tr>
<td>T1 Post</td>
<td>FLASH (Fast Low Angle Shot)</td>
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<tr>
<td>T2 Post</td>
<td>FIESTA (Fast Imaging Employing Steady state Acquisition)</td>
</tr>
<tr>
<td>DWI</td>
<td>Diffusion weighted images</td>
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<tr>
<td>T2 (3D) SPACE</td>
<td>Diffusion weighted images</td>
</tr>
<tr>
<td>T2 HASTE (Half Fourier Acquisition Single shot Turbo spine Echo)</td>
<td>SSFSE (Single Shot Fast Spin Echo)</td>
</tr>
<tr>
<td>TrueFISP (True Fast Imaging with Steady state free Precession)</td>
<td>FIESTA</td>
</tr>
<tr>
<td>SPACE</td>
<td>FSE-Cube</td>
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<td>Sampling Perfection with Application oriented Contrasts using</td>
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<td></td>
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<tr>
<td>VIBE (Volume Interpolated B reath) with Examination</td>
<td>FAME (Fast Acquisition with Multiphase EFGRE3D)</td>
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Table 1. MRE Sequences.
Coronal steady state free precession images (TrueFISP) are then performed to cover the entire abdomen and pelvis. This sequence gives valuable information regarding bowel distention, bowel wall thickening, and extent of disease (Fig. 2). Image contrast is largely determined by the TR in this T2*-weighted sequence. The speed of TrueFISP imaging produces clear images despite bowel peristalsis, helping to obviate the need for glucagon administration. The coronal TrueFISP is then repeated as a non-gated, non-breath hold cine sequence similar to a cardiac bright blood sequence. The cine TrueFISP runs for 7-8 seconds per coronal slab and results in approximately 40 images per slice position. This sequence allows for evaluation of normal peristalsis and highlights aperistaltic loops as seen in Crohn disease.

If the study is performed on a 3T system, the static and cine SSFP sequences will suffer from dielectric effect and should be replaced with corresponding gradient echo sequences. While dielectric artifact is not fully resolved in this situation, artifact is generally confined to the periphery of the image and does not hinder the diagnostic quality of the exam (Fig. 3).

After cine imaging, axial diffusion-weighted images (DWI) are performed with the same coverage as the axial fat-suppressed T2 images. DWI is obtained with β values of 0, 500, and 1000 (Fig. 4). Unlike neuroimaging where the β 1000 value is relied upon, the β 500 images are often the most revealing in body imaging.

The final precontrast sequence is a 3 dimensional isotropic T2-weighted sequence with fat suppression (T2 SPACE) obtained in a sagittal plane through the midline pelvis (Fig. 5). This sequence is obtained with 0.9 mm contiguous slices which allows for reformatting in the curved plane coronal and oblique axial planes (Fig. 6).
sagittal orientation allows for the most efficient coverage of the anorectum and distal sigmoid colon. A 3D fat suppressed T2-weighted sequence is vital for the evaluation of rectal fistulas encountered in Crohn disease.

Figure 6. Orientation of oblique axial T2 SPACE reformats (A). Oblique axial T2 SPACE reformat (B). Orientation of T2 SPACE curved plane coronal reformat (C). Curved plane T2 SPACE reformat (D).

After the administration of a standard dose of gadolinium, post contrast axial and coronal T1-weighted images are obtained. For coronal imaging, we perform a contiguous thin section fat suppressed T1-weighted sequence (VIBE) with the same coverage as the precontrast coronal SSFP sequences (Fig. 7). Axial T1-weighted images with fat suppression (FLASH) are then performed with breath holding. Typically, two to three axial acquisitions are required to cover the abdomen and pelvis with tolerable breath hold durations.

The entirety of the MRE protocol can be performed in under an hour, including time for patient positioning, starting an IV for contrast, and contrast injection. Imaging parameters for the above sequences have been provided (Table 2).

Figure 7. Coronal T1 VIBE post contrast showing hyperenhancement of bowel wall (arrows).

Table 2. MRE imaging parameters.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Plane</th>
<th>TR (milliseconds)</th>
<th>TI (milliseconds)</th>
<th>Slice Thickness (mm)</th>
<th>Slice Gap (mm)</th>
<th>Fat Sat</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2 SPACE</td>
<td>Sagittal</td>
<td>1500</td>
<td>120</td>
<td>0.9</td>
<td>0</td>
<td>Strong SPAIR</td>
<td>isotropic acquisition is reformatted into oblique axial and coronal planes</td>
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<tr>
<td>TRUEFISP (Fat Sat)</td>
<td>Coronal</td>
<td>3500</td>
<td>120</td>
<td>7</td>
<td>2.1</td>
<td>None</td>
<td>No pare time for T1 edit</td>
</tr>
<tr>
<td>TRUEFISP (T1)</td>
<td>Coronal</td>
<td>3500</td>
<td>120</td>
<td>7</td>
<td>2.1</td>
<td>None</td>
<td>No pare time for T1 edit</td>
</tr>
<tr>
<td>DISA</td>
<td>Axial</td>
<td>3500</td>
<td>120</td>
<td>7</td>
<td>2.1</td>
<td>None</td>
<td>No pare time for T1 edit</td>
</tr>
<tr>
<td>FLASH (post contrast)</td>
<td>Axial</td>
<td>3500</td>
<td>120</td>
<td>7</td>
<td>2.1</td>
<td>None</td>
<td>No pare time for T1 edit</td>
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Imaging findings

Many of the imaging findings of IBD depicted with MRE will be familiar to those already versed in the CT evaluation of UC and CD. The colonic wall thickening noted in ulcerative colitis is well depicted with MRE. Contiguous involvement of the colon beginning at the anorectum and extending a variable distance proximal is the sine qua non of UC. Wall thickening is concentric and even, typically measuring less than 10 mm in width (Fig. 8). Loss of haustral markings may also be observed resulting in the so called “lead-pipe“ colon (Fig. 9). Another frequently visualized feature of ulcerative colitis is the “target sign”. Hyperemia of the mucosa and serosa with interposed mural edema results in a target appearance of concentric hyper- and hypoenhancement on postcontrast T1-weighted images (Fig. 10).
Figure 8. Axial T1 FLASH postcontrast (A) showing concentric wall thickening (arrow) in a patient with ulcerative colitis. Axial T1 FLASH superior to first image (B) showing contiguous involvement of the sigmoid (arrow).

Figure 9. Coronal TrueFISP in a patient with UC demonstrating a “lead-pipe” colon (arrows).

Figure 10: Axial T1 FLASH postcontrast in a patient with UC showing enhancement of the mucosa and serosa of the descending colon with intervening mural edema resulting in a “target sign” (arrow).

Patients with UC are often treated with complete colectomy with a small bowel pull-through. The resulting neorectal pouch may become inflamed, a condition termed pouchitis. The isotropic fat suppressed T2-weighted sequence which depicts anorectal fistula in patients with Crohn disease excels equally for the evaluation of pouchitis (Fig. 11).

Figure 11. Axial T1 FLASH (A) in a patient with UC and pouchitis. Pouch (*) is surrounded by inflammatory change with breakdown and abscess formation (arrow). Coronal T2 SPACE (B) in the same patient shows the abscess (arrow) through the left side of the pouch (*).

The MRE evaluation of Crohn disease surpasses CT, fluoroscopy, and endoscopy in its scope and effectiveness. Unlike the concentric wall thickening seen in UC, Crohn disease typically manifests as eccentric wall thickening often measuring greater than 10 mm in width (Fig. 12). Bowel which is actively inflamed will demonstrate restricted diffusion, a feature which is vital for the discrimination of disease from unaffected collapsed loops of bowel or chronic quiescent strictures (Fig. 13). It is our institutional experience that the presence of diffusion abnormalities is more reliable than wall thickening or enhancement as a sign of active disease, particularly when dealing with the proximal small bowel (Fig. 14).

Figure 12: Axial T2 HASTE in a patient with CD shows multiple loops of bowel with eccentric wall thickening (*).

Alternating regions of affected bowel and normal bowel are also seen, unlike the proximally contiguous disease pattern of UC (Fig. 15). Affected loops of bowel often demonstrate decreased motion due to inflammation or chronic scarring and stricture formation. Dysmotility is well visualized on the coronal cine SSFP sequence.
Figure 13. Axial DWI (A) in patient with CD shows restricted diffusion (arrow) in the bowel wall indicating acute disease. Corresponding ADC map (B) confirms diffusion abnormality.

Figure 14. Axial T2 HASTE (A) in a patient with CD reveals apparent diffuse bowel wall thickening throughout the jejunum. DWI in the same patient (B) shows active disease within a short segment of the jejunum (arrow).

Figure 15. Coronal TrueFISP in a patient with CD showing an dilated “skip lesion” (*) with wall thickening proximal (black arrow) and distal (white arrow) to the segment.

Transmural pathology is the hallmark of Crohn disease and may result in sinus tract or fistula formation. Fat suppressed T2-weighted and postcontrast T1-weighted images are excellent for the depiction of transmural disease (Fig. 16). Transmural disease may also result in abscess formation. A fluid collection noted on T2-weighted imaging which demonstrates an enhancing rim and restricted diffusion is indicative of abscess formation (Fig. 17).

Figure 16. Axial T1 FLASH postcontrast (A) reveals sinus tract (arrow) extending through the abdominal wall musculature in a patient with CD. Coronal T1 VIBE in the same patient (B) reveals sinus tract connection to the bowel (arrow).

Figure 17. Axial T2 HASTE (A) in a patient with CD with fever and abdominal pain. Axial DWI (B) in the same patient shows focal fluid collection with restricted diffusion (arrow). Corresponding ADC map (C) confirms diffusion abnormality. Abscess was found at surgery.

Classic extraluminal imaging findings such as fibrofatty proliferation and prominence of the vasa
recta ("comb sign") are as well illustrated with MRE as with traditional imaging modalities such as CT (Fig. 18). Patients suffering from Crohn disease often are affected by perianal fistula. Acquisition of a three dimensional isotropic fat suppressed T2-weighted sequence centered in the midline pelvis allows for exquisite evaluation of fistula. Fistula should be described as intersphincteric or transphincteric depending on their course (Fig. 19). Location of a fistula is best described with reference to a clock face as the patient lies in a dorsal lithotomy position (i.e. 12 o'clock is the anterior aspect of the anorectum and 3 o'clock is the patient’s left side).

**Figure 18.** Axial T1 VIBE (A) showing fibrofatty proliferation (arrow) in the ileocecal region in a patient with CD. Axial T1 VIBE (B) in a different patient showing prominence of the vasa recta (arrow).

**Figure 19.** Curved plane coronal reformat of T2 SPACE (A) in a patient with CD reveals a left intersphincteric fistula (arrow). Coronal T2 SPACE (B) in a different patient shows a rightsided transphincteric fistula (arrow).

**Summary**

MR enterography is an elegant and efficient means to image inflammatory bowel disease. The inherent tissue contrast of MRI makes MR enterography the modality of choice for the depiction of extraluminal processes such as fistula or abscess formation. The lack of ionizing radiation and superior image quality more than offset the increased time and cost associated with MRE compared to CT or fluoroscopic studies. The ability to evaluate the entirety of the small and large bowel in addition to the noninvasive nature of the exam makes MRE a desirable alternative to endoscopy. MR enterography can be performed with conventional scanners and will be quickly adopted by radiologists familiar with conventional imaging techniques for IBD. In pediatric patients with suspected or known inflammatory bowel disease, MRE should be considered the imaging modality of choice.

**References**

10. Fuchs Y, Markowitz J, Weinstein T, Kohn N, Choi-Rosen J, Levine J. Pediatric inflammatory bowel disease and imaging-related radiation: are we increasing the likelihood of