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UPDATE

Crohn disease of the small bowel: MR enteroclysis versus conventional enteroclysis

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Abstract

Enteroclysis has been suggested as the technique of choice for the evaluation of Crohn disease of the small intestine. Adequate distention of the entire small bowel with barium suspension allows the radiologic demonstration of mucosal abnormalities and provides functional information by defining distensibility or fixation of the small bowel loops. The principal disadvantage of conventional enteroclysis is the limited indirect information on the state of the bowel wall and extramural extension of Crohn disease, and its effectiveness may be hindered owing to overlapping bowel loops. Moreover, the radiation dose administered to patients, mostly at a young age, should be considered. Magnetic resonance (MR) enteroclysis is an emerging technique for small bowel imaging and was introduced to overcome the limitations of conventional enteroclysis and MR cross-sectional imaging by combining the advantages of both into one technique. MR enteroclysis has the potential to change how the small bowel is assessed because of the functional information, soft tissue contrast, direct multiplanar imaging capabilities, and lack of ionizing radiation.

Key words: Crohn disease—Magnetic resonance imaging—Conventional enteroclysis—Small bowel

Crohn disease is a chronic granulomatous inflammatory disease of the gastrointestinal tract with a tendency toward remission and relapse. Its etiology is unknown, although evidence is mounting that the condition represents an abnormal mucosal response to unknown luminal antigens [1]. Excluding malignant neoplasms, Crohn disease is the most devastating disease commonly involving the gastrointestinal tract.

Crohn disease involves the small bowel in 80% of cases, in particular the terminal ileum, which is characterized by luminal, transmural, and mesenteric abnormalities [2].

Radiologic evaluation remains of particular importance, especially when involvement is confined to the mesenteric small intestine between the ligament of Treitz and the ileocecal valve because this part of the gastrointestinal tract generally cannot be evaluated endoscopically [3].

Conventional enteroclysis has been shown to be highly accurate, with a sensitivity of 95% and a specificity of 96.5% in diagnosing small bowel diseases, and permits detection of partly or nonobstructive lesions that may not be demonstrated with cross-sectional imaging techniques [4, 5]. The principal disadvantage is the limited indirect information on the state of the bowel wall and extramural extension of Crohn disease, and its effectiveness may be hindered owing to overlapping bowel loops. Moreover, the radiation dose administered to patients, mostly at a young age, should be considered.

Evaluation of mural and extramural alterations of Crohn disease has been performed with sectional imaging modalities such as ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI), but these procedures are not able to assess superficial mucosal lesions [6–9].

Of recent interest has been the use of CT enteroclysis for the evaluation of patients with small bowel diseases [9, 10]. Its disadvantages are increased exposure of ionizing radiation, lack of functional information, lack of fluoroscopic control of filling of the small bowel, and poor soft tissue contrast.

Although evaluation of the anorectal complications of Crohn disease is a recognized strength of MRI [11, 12], evaluation of the remainder of the gastrointestinal tract has been limited by motion artifact. Because of its excellent soft tissue contrast and multiplanar imaging

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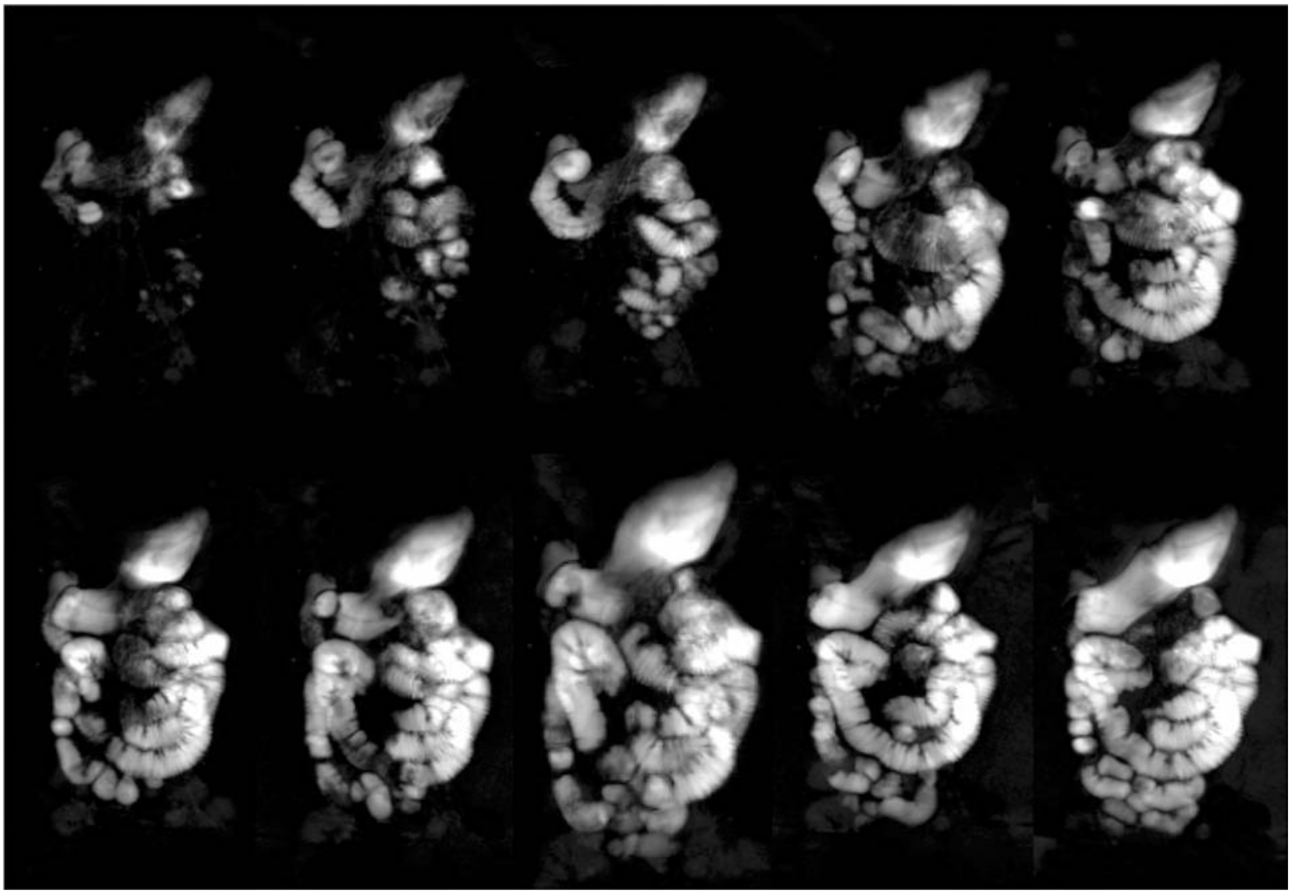

Fig. 1. Normal MR fluoroscopic appearance. Ten sequential, dynamic SSFSE images demonstrate progressive bowel filling with the PEG water solution.

capabilities, MRI could be the optimal imaging method for evaluation of the small bowel. However, peristalsis, respiratory motion artifact, and long acquisition time were severe limitations of MRI of the small bowel and MRI was rarely used for evaluation of small bowel diseases [13, 14].

Recent advances in MRI hardware and software allowed for rapid acquisition of high-resolution images of the small intestine, and there is an increasing interest in small bowel examination with MRI [15–17]. Problems related to small bowel distention and functional information remain as limitations. Adequate distention of the entire small bowel is a key requirement because collapsed bowel loops may hide or simulate small bowel lesions.

Magnetic resonance enteroclysis (MRE) is an emerging technique for small bowel imaging that combines the advantages of conventional enteroclysis with those of cross-sectional imaging [18–21].

Several new contrast agents for MRI of the gastrointestinal tract have been proposed and are classified as positive, negative, or biphasic [22, 23]. Positive agents exhibit increased signal intensity within the bowel lumen, whereas negative agents exhibit dark or absent intraluminal signal. Biphasic contrast agents behave as positive or negative, depending on the applied pulse sequence. To date, an ideal and universally available enteric contrast agent has yet to find widespread clinical use.

Because MR fluoroscopy is a heavily T2-weighted sequence, the contrast medium for MRE must have high signal intensity on T2-weighted images. Further, the contrast medium must have low signal intensity on T1-weighted images to facilitate perception of enhancement of the normal and diseased bowel wall. Moreover, the high signal intensity of intraluminal contrast on T2-weighted images is helpful to visualize mural ulcers and fistulous tracts. For these reasons, in our opinion and in accord with other studies [24, 25], an optimal contrast agent for MRE should be biphasic. We have used polyethylene glycol (PEG) water solution with electrolytes, which is an iso-osmotic, biphasic contrast agent with excellent performance in MRE [26, 27], appearing as low signal intensity on T1-weighted MR images and high signal intensity on T2-weighted images.

MRE: technique

Patients fast the night before examination. Immediately after positioning of the nasojejunal catheter with the

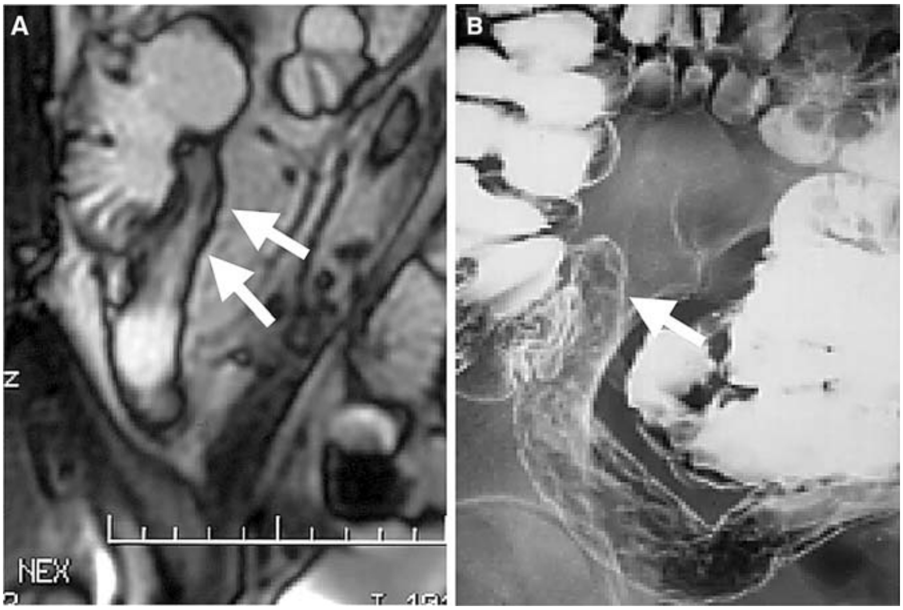

Fig. 2. Straightened and thickened folds are shown on Coronal FIESTA sequence (**A**) and conventional enteroclysis image (**B**).

patient on the fluoroscopy table, the patient is transferred to the MR unit. We use a balloon nasoenteric catheter.

Patients in the prone position are placed feet first into the bore of the magnet. Such a position exerts mild pressure to the anterior abdomen wall, thus facilitating separation of the small bowel loops and decreasing the volume of peritoneal cavity to be imaged and thus the number of coronal section to be acquired. The imager display, in combination with the real-time imaging, provides direct MR fluoroscopic guidance for small bowel filling in the examination room (Fig. 1).

The small bowel is distended with PEG water solution (KleanPrep, Norgine, UK), which is prepared by dissolving a powder of 38.4 g of PEG, 1.42 g of sodium sulphate, 0.42 g of sodium bicarbonate, 0.36 g of sodium chloride, and 0.18 g of potassium chloride in 500 mL of water. The solution is administered by manual infusion. A total of 1500 to 2300 mL of PEG solution is administered at an infusion rate of 80 to 200 mL/min and small bowel filling is controlled by MR fluoroscopy.

The PEG solution is administered in three phases. A low infusion rate of 80 to 100 mL/min is used during the first phase, which lasts until the terminal ileum begins to distend. During the second phase, the infusion rate is increased to 200 mL/min to achieve reflex atony.

If the infusion rate is increased too soon, retrograde filling of the stomach occurs more often and this may result in vomiting.

As soon as the solution reaches the ascending colon and the entire small bowel is adequately distended, MR fluoroscopy is stopped and the MR examination is completed with cross-sectional imaging. During the third phase, the infusion rate is decreased to 80 to 100 mL/min and this infusion rate is continued throughout the acquisition of cross-sectional images to guarantee adequate distention of the proximal jejunum. Before acquisition of the cross-sectional MR images, 20 mg of hyoscine butylbromide (Buscopan, Boehringer Ingelheim, Ingelheim, Germany) is administered intravenously to decrease small bowel peristalsis and prolong small bowel distention.

The duration of MRE is 30 to 40 min.

MRI protocol

MRI is performed with a 1.5-T imager with abdomen phased array coil.

MR fluoroscopy

MR fluoroscopy is performed with a dynamic breath-hold two-dimensional T2-weighted fast spin-echo sequence (repetition time infinity, echo time 950 ms, field of view 350 mm, matrix 256 × 256, flip angle 90°). The acquisition time is 1.8 s per image. These parameters result in heavily T2-weighted images, and only fluid-filled structures are depicted.

The breath-hold projections are oriented in the coronal plane with a section thickness of 100 to 180 mm to include the entire small bowel. Inclusion of the stomach in these images is important to facilitate detection of retrograde filling of the stomach.

Initially, one image is acquired before administration of the PEG solution, and subsequent images are obtained during the injection.

MR fluoroscopy provides real-time monitoring and documentation of the small bowel filling and allows adjustment of the infusion rate of the PEG solution.

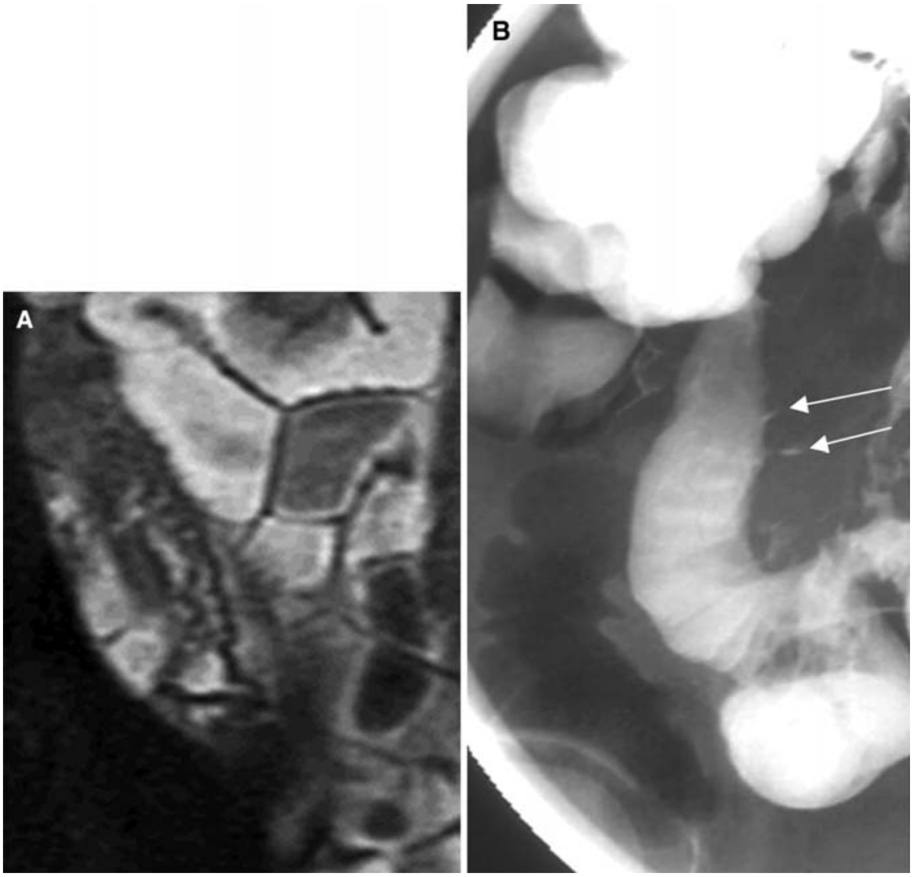

Fig. 3. A Mural ulcers are visualized on coronal FIESTA as thin lines of high signal intensity that are longitudinally or transversely (fissure ulcers) oriented within the thickened bowel wall. **B** Intersecting longitudinal and transverse ulcers with segmental wall thickening are visible on conventional enteroclysis.

When retrograde filling of the stomach occurs, the infusion rate should be decreased to avoid vomiting.

On MR fluoroscopic images, fluid-filled bowel loops are depicted and other structures, such as the biliary system and the urinary tract, are displayed. In addition, ascites can be visualized with MR fluoroscopy. A small amount of ascites does not impair image quality but large amounts may obscure small bowel loops.

Cross-sectional MRI

At the end of administration of the PEG solution, transverse and coronal single-shot fast spin-echo (SSFSE) MR images (minimum repetition time, echo time 60.0 ms, matrix 256 × 224, 5-mm thickness with 1-mm gap, echo train length 94, receiver bandwidth 62.50 kHz) are acquired during breath-hold. Noninterleaved sets of 16 sections are obtained during each 20-s breath-hold.

Transverse SSFSE images are acquired with and without fat saturation. Typically, three breath-holds are required to image the abdomen and pelvis in the transverse plane and two breath-holds in the coronal plane.

Next coronal and axial fast imaging employing steady-state acquisition (FIESTA; repetition time 3.5 ms, echo time 1.8 ms, matrix 256 × 224, one signal acquired, 5-mm thickness with no gap, flip angle 50°, receiver bandwidth 62 kHz) are acquired during breath-hold. Three breath-holds are required to image the abdomen and pelvis in the transverse plane and two breath-holds in the coronal plane.

Coronal three-dimensional (3D) fast-spoiled gradient echo breath-hold with fat saturation (FSPGR; repetition time 4.2 ms, echo time 2 ms, inversion time 15 ms, matrix 256 × 192, three-quarter field of view, one signal acquired, 5-mm thickness with no intersection gap, flip angle 12° flip angle, receiver bandwidth 62.50 kHz) are acquired before and during two phases (25 and 75 s) of contrast enhancement with 0.1 mmol/kg gadopentetate dimeglumine at a bolus at a rate of 2 mL/s, followed by bolus injection of 20 mL of isotonic saline. We acquire transverse two-dimensional FSPGR images 180 s after contrast material injection.

Images obtained from the 3D-FSPGR sequences in the axial, sagittal, and oblique planes are successively reconstructed by using a dedicated workstation employing the multiplanar reformatting algorithm.

MRE versus conventional enteroclysis

Crohn disease starts in the submucosal layer and progresses to the entire wall; it is characterized by aphthous

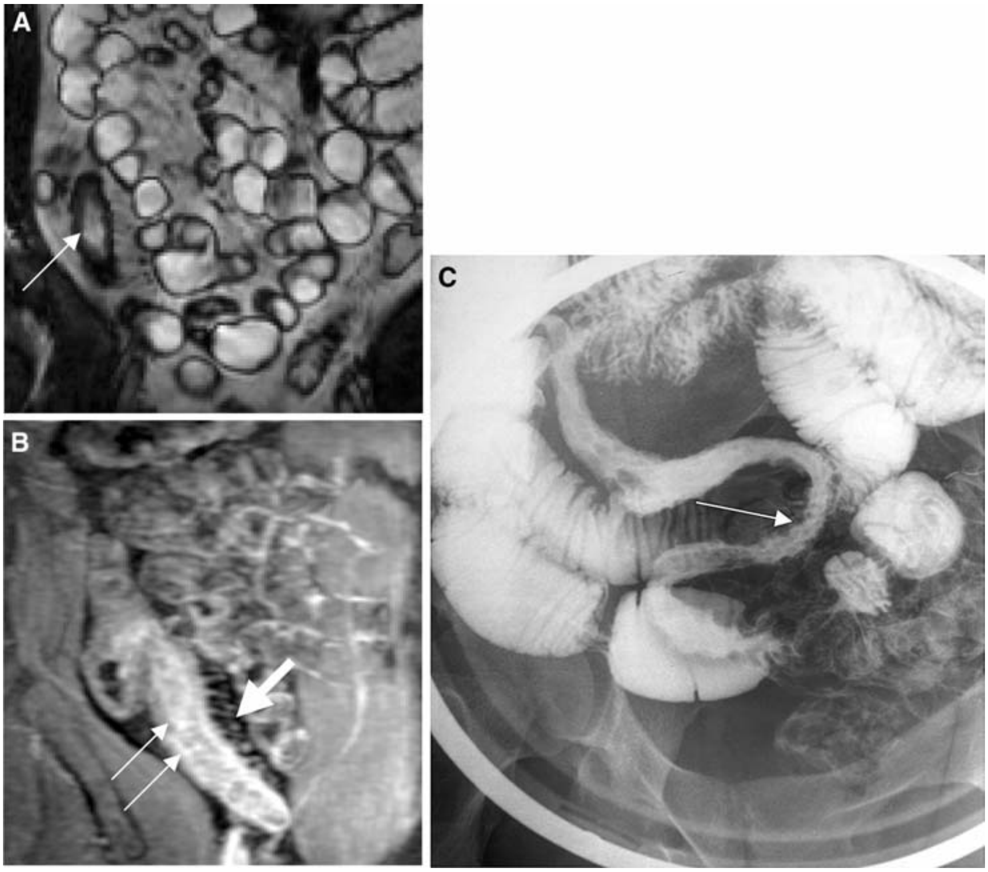

Fig. 4. Pseudopolyps are seen as small nodular defects and a marginal protrusion in the thickened bowel wall (*arrows*) on (**A**) coronal FIESTA and (**B**) contrast 3D-FSPGR images and (**C**) conventional enteroclysis, appearing as a "cobblestone mucosa." Note engorgement of the vasa recta close to mesenteric border of the bowel wall (**B,** *thick arrow*), i.e., the "comb sign," suggesting perienteric hyperemia and active inflammation.

ulceration and cobblestoning, leading to diffuse perivisceral inflammation, adhesions, strictures, fissures, fistulas, and abscesses.

The earliest change occurs in the submucosa and consists of lymphoid hyperplasia and lymphedema. Radiologic findings at this stage include subtle elevations and aphthoid ulcers that are visualized on double-contrast barium enteroclysis; however, in our experience and in accord with other studies [24], they are not consistently depicted with MRE due to its inferior spatial resolution.

Mucosal and submucosal edema secondary to lymphatic obstruction and the inflammatory process may cause thickening and distortion of valvulae conniventes. The thickened folds may appear straightened, fused, or nodular. These findings are not specific for the diagnosis of Crohn disease; similar changes can also be seen in nodular lymphoid hyperplasia, radiation ileitis, and ischemia.

MRE images provide sufficient resolution to detect some early lesions of Crohn disease, such as blunting, flattening, thickening, and distortion of small bowel folds (Fig. 2).

The inflammatory process in more established disease extends discontinuously through the lamina propria, is most intense in the submucosa, but tends to involve all layers of the bowel wall.

Aphthous ulcers may heal or may enlarge and coalesce to form deeper, usually linear ulcerations or fissures, which frequently assume a longitudinal and transverse orientation, that appear on FIESTA and SSFSE images as thin lines of high signal intensity within the thickened bowel wall (Fig. 3).

In accord with Gourtsoyannis et al. [18], in our experience the FIESTA sequence is the most accurate in the visualization of mural ulcers.

The rigidity of the mesenteric border is due to transmural inflammation that extends from the linear ulcer into the mesentery. Another highly characteristic feature is the usual noninvolvement of the relatively redundant antimesenteric border, which retains pliability and forms folds and sacculation.

Deformity of bowel loops such as pseudodiverticulum formation caused by asymmetric involvement by longitudinal ulcers and ulcer scars is well demonstrated on axial and coronal images. The combination of mesenteric border shortening and ulceration is virtually pathognomonic of small bowel Crohn disease.

The term *pseudopolyps* refers to islands of relatively normal mucosa surrounded by areas of mucosal denudation, giving the impression of being elevated above the mucosal level. They are more frequent in colonic rather than in the small bowel Crohn disease. When seen in the small bowel, they form well-defined,

Fig. 5. Segmental wall thickening with marked narrowing of the lumen (*arrows*) are shown on (**A**) FIESTA coronal, (**B**) contrast T1 3D-FSPGR, and (**D**) conventional enteroclysis images. The high grade of the stenosis with dilatation of the proximal bowel loop is demonstrated by (**C**) MR fluoroscopy and conventional enteroclysis (**C, D,** *thick arrow*).

round or oval filling defects, usually in an area without folds.

Multiple polypoid elevations can produce a radiographic "cobblestone" appearance that reflects severe edema between longitudinal and transverse ulceration. Cobblestoning is seen on MRE images as patchy areas of high signal intensity that are sharply demarcated along affected small bowel segments (Fig. 4).

The normal thickness of the wall of the small intestine is 1 to 3-mm when the lumen is distended. Any portion of the bowel wall that exceeds 4 to 5-mm is considered abnormal. Bowel wall thickening, usually from 1 to 2 cm, is the most consistent feature of Crohn disease on cross-sectional images. A thickened wall in the absence of extensive edema has low to moderate signal intensity on FIESTA and SSFSE images.

MRE shows optimal accuracy that is well correlated with small bowel enteroclysis in the identification, localization and evaluation of the length of involved intestinal segments and in the assessment of mural

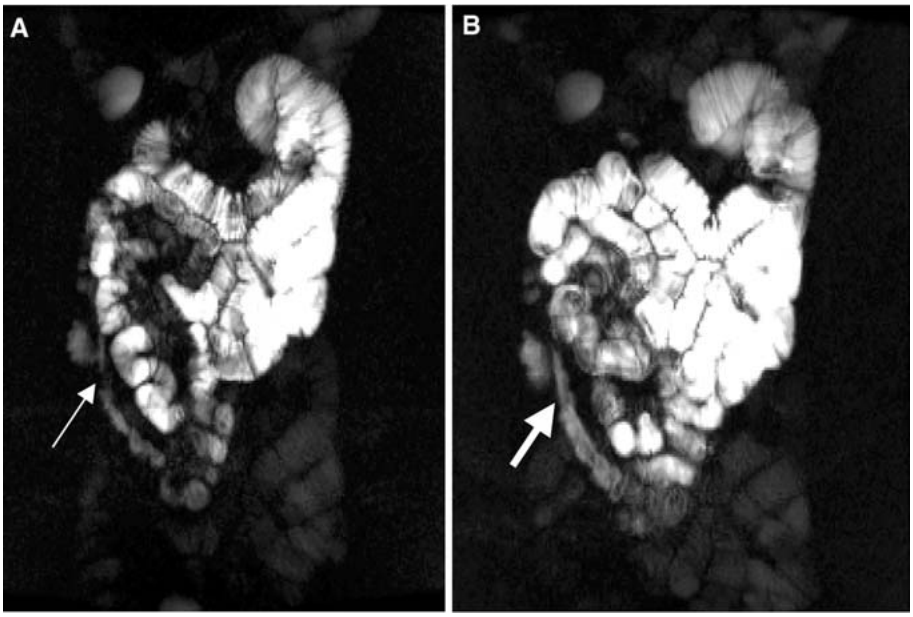

Fig. 6. A, B Functional information provided by MR fluoroscopy. Note the high-grade stenosis that is visible at an early stage of filling (*thin arrow*) in the terminal ileum. Further luminal distention overcame the spasm and the lumen is shown to be distensible (*thick arrow*), i.e., the "string sign." The differentiation between a high-grade and a low-grade partial small bowel obstruction frequently is missed by static cross-sectional sequences.

thickening (Fig. 5). Unlike other investigators [18], we have found that depiction of bowel wall thickness and determination of the extent of stenosis are more accurate with gadolinium-enhanced spoiled gradient recall echo MR images than with FIESTA sequences. The latter sequence is prone to susceptibility artifacts from intraluminal air and from "black boundary" artifact due to the chemical shift phenomenon, which may obscure subtle bowel wall thickening.

The degree of stenosis is variables. Differentiation between high-grade and low-grade partial small bowel obstruction frequently is missed by static cross-sectional sequences, but MR fluoroscopy is particular useful in this distinction. MR fluoroscopic images can be reviewed in a cine loop format to obtain functional information concerning bowel obstruction. The ability of MR fluoroscopy to demonstrate the enteric agent makes it ideal for assessment of the severity of small bowel obstruction and the presence of prestenotic dilatation, a question frequently posed by physicians who treat patients with mechanical small bowel obstruction (Fig. 6).

Stenosis of the small intestine lumen occurs frequently in Crohn disease and results from a combination of fibrosis, inflammatory thickening, and spasm. The differentiation between fibrotic and inflammatory stricture is crucial for selecting patients for medical (edematous) versus surgical (fibrotic) treatment and may be difficult to make on conventional enteroclysis findings [11]. Combining functional and vascular informations on MRE can be useful in this differentiation. The bowel wall of the involved segment may have a homogeneous or stratified appearance.

The demonstration on intravenous contrast-enhanced CT or MRI of "mural stratification" indicates edema from active inflammation. This mural stratification is composed of an inner ring of mucosal enhancement surrounded by an outer ring of muscular and serosal enhancement, with an intermediate low-density ring due to submucosal edema. This mural stratification is lost in longstanding disease if transmural fibrosis has supervened [11]. On MRI, the rich tissue contrast helps to facilitate the differentiation between fibrotic and edematous bowel wall thickening. Collagen, the main component of the fibrotic wall thickening, has long T1 and short T2 relaxation times, thus exhibiting low signal intensity with T1 and T2 relaxation times and rendering high signal intensity on T2-weighted images and low signal intensity on T1-weighted images.

Deep ulcers precede sinus and fistulae formation to adjacent bowel loops and other organs. Sinus tracts and fistulas are demonstrated by the high signal intensity of their fluid content on FIESTA and SSFSE and on enhanced fat-suppressed, T1-weighted, 3D, gradient echo images, the central cavity has low signal intensity and is surrounded by a brightly enhancing rim (Fig. 7).

Gourtsoyannis et al. [18] found that true fast imaging with steady precession sequence was superior to half-Fourier acquisition single-shot turbo spin-echo sequence in visualizing linear ulcers, cobblestoning, and intramural tracts, whereas 3D fast low-angle shot sequence was less satisfactory in depicting such lesions smaller than 3-mm in diameter.

The reported sensitivity of MRE for depicting sinus tract is 50% to 75% when a conventional enteroclysis study is used as a reference [12].

In our opinion, small oblique fistulas are more difficult to visualize because of partial volume averaging and inferior spatial resolution on MRE. According to Umschaden et al. [19], multiplanar imaging (perpendicular to

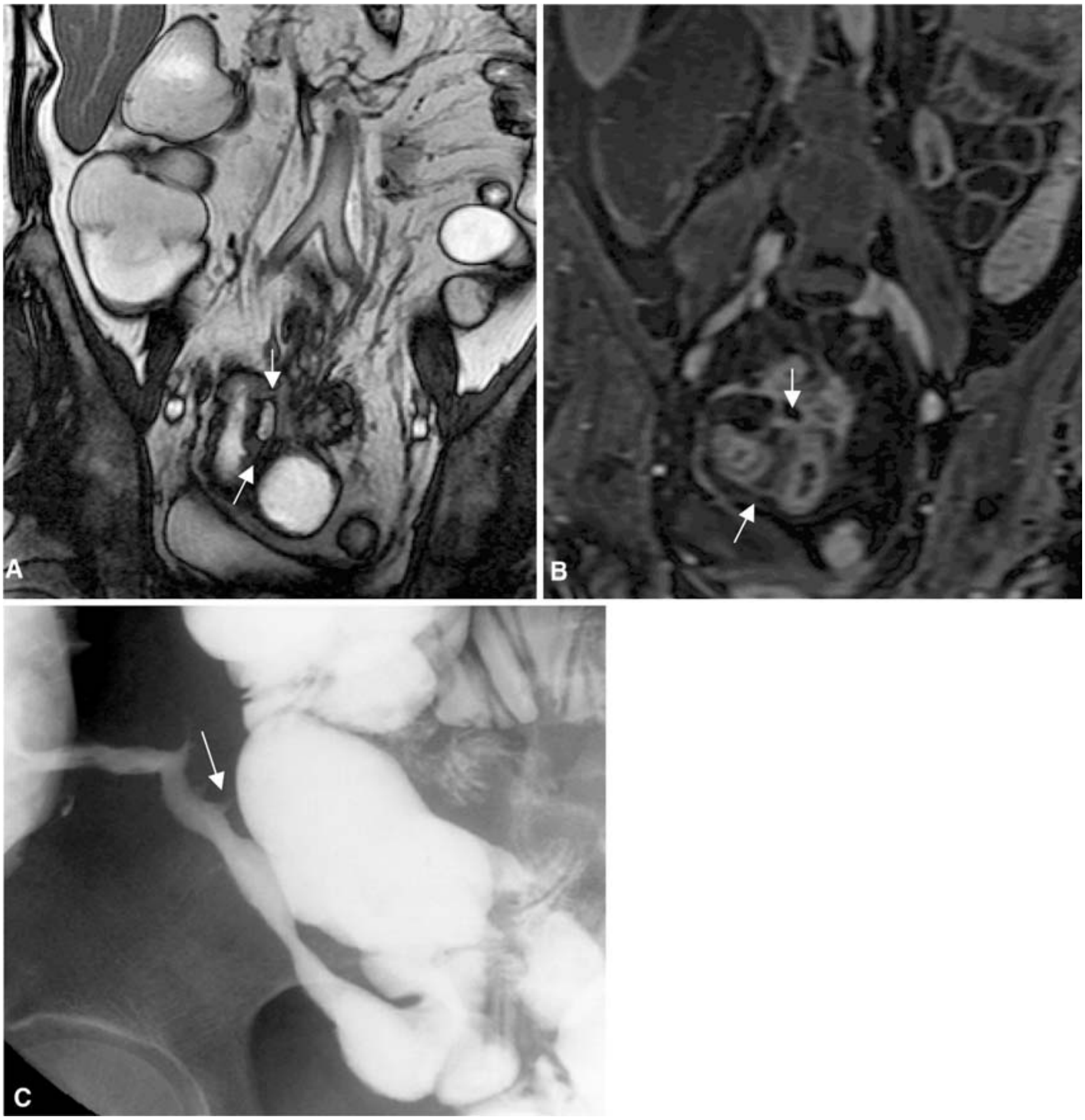

Fig. 7. Multiple ileoileal fistulas are demonstrated by high signal intensity of their fluid content on (**A**) coronal FIESTA sequence as confirmed by (**C**) conventional enteroclysis. **B** Multiplanar imaging (perpendicular to the diseased bowel loop) is important to avoid missing tiny sinus tracts because of partial volume artifact.

the diseased bowel loop) is necessary to avoid missing sinus tracts.

MRE has a clear advantage over conventional enteroclysis in the demonstration of extramural manifestations and complications of Crohn disease.

Umschaden et al. [20] reported that MRE in 24% of patients demonstrated abnormalities not seen at conventional enteroclysis.

Fibrofatty proliferation of the mesentery is the most common cause of bowel loop separation seen on small bowel studies in patients with Crohn disease. As proposed by Herlinger et al. [28], fibrofatty proliferation is the result of perivascular inflammation with fibrosis and muscularis propria contraction. Fibrofatty proliferation is due to transmural extension of advanced Crohn disease. Extent of fibrofatty proliferation and its mostly fatty or fibrotic composition can be assessed with MRE, especially with FIESTA images (Fig. 8), but can be suspected only at conventional enteroclysis by separating adjacent small bowel loops.

Abscess is the second most common cause of bowel loop separation. Abscesses can be recognized by their fluid content and contrast enhancement of the wall, and MRE can detect, localize, and demonstrate the cause of

Fig. 8. **A** Fibrofatty proliferation appears as linear low signal intensity structures (*arrows*) that separate bowel loops on coronal FIESTA sequence. **B** Small mesenteric nodes (*small arrow*) are demonstrated by their low signal intensity within the bright mesenteric fat on coronal FIESTA sequence.

fluid collections. Phlegmon show the signal intensity as a thickened bowel wall on T2-weighted images, which is only slightly increased compared with the signal intensity of the psoas muscle, and there is continuous extension of the inflammatory process from the bowel wall into the adjacent tissues (Fig. 9). Sinus tracts are often associated with phlegmon in adjacent tissue.

The "comb sign," initially described for CT [29] and corresponding to increased vascularity and extension of the inflammatory process along the mesenteric vessels, can be depicted clearly on contrast-enhanced T1-weighted images (Fig. 4B).

Prassopolous et al. [24] found the FIESTA sequence to be ideal in demonstrating the comb sign in the form of a short, parallel, low signal intensity, linear structure perpendicular to the long axis of the small bowel loop. In our experience, fibrofatty proliferation and the comb sign can have a similar appearance on FIESTA sequences, and the comb sign is better demonstrated on contrast-enhanced T1-weighted FSPGR sequences as a high signal linear structure due to vascular enhancement.

Small mesenteric lymph nodes are easily detected by their low signal intensity scattered within the bright mesenteric fat on FIESTA sequences (Fig. 8). The presence of lymph nodes is not as obvious with the use of other MRE sequences because of short T2 filtering effects on half-Fourier acquisition single-shot turbo spin-echo images and saturation effects of mesenteric fat signal on 3D images. Gadolinium uptake on 3D-FSPGR images allows identification of small inflammatory nodes.

Static and functional imaging information, rich soft tissue contrast, direct multiplanar capabilities, lack of radiation exposure, and demonstration of luminal, mural, and extramural abnormalities suggest that MRE can become a common diagnostic procedure.

Unlike conventional enteroclysis, MRE does not have problems with overlapping bowel loops and it is useful to assess activity of Crohn disease. However, conventional enteroclysis remains more widespread in the radiologic community and is more accurate in visualizing subtle mucosal lesions, but the new procedure of capsule endoscopy seems to be better in depicting luminal abnormalities [30].

In conclusion, we believe that radiologists who are interested in performing MRE should have a basic understanding of MR technology and knowledge of conventional enteroclysis findings to exploit the full potential of MRE. Only in this manner MRE can become a primary method for investigation of small bowel Crohn disease, and conventional enteroclysis may have an increasing role as a problem-solving examination after inconclusive imaging studies.

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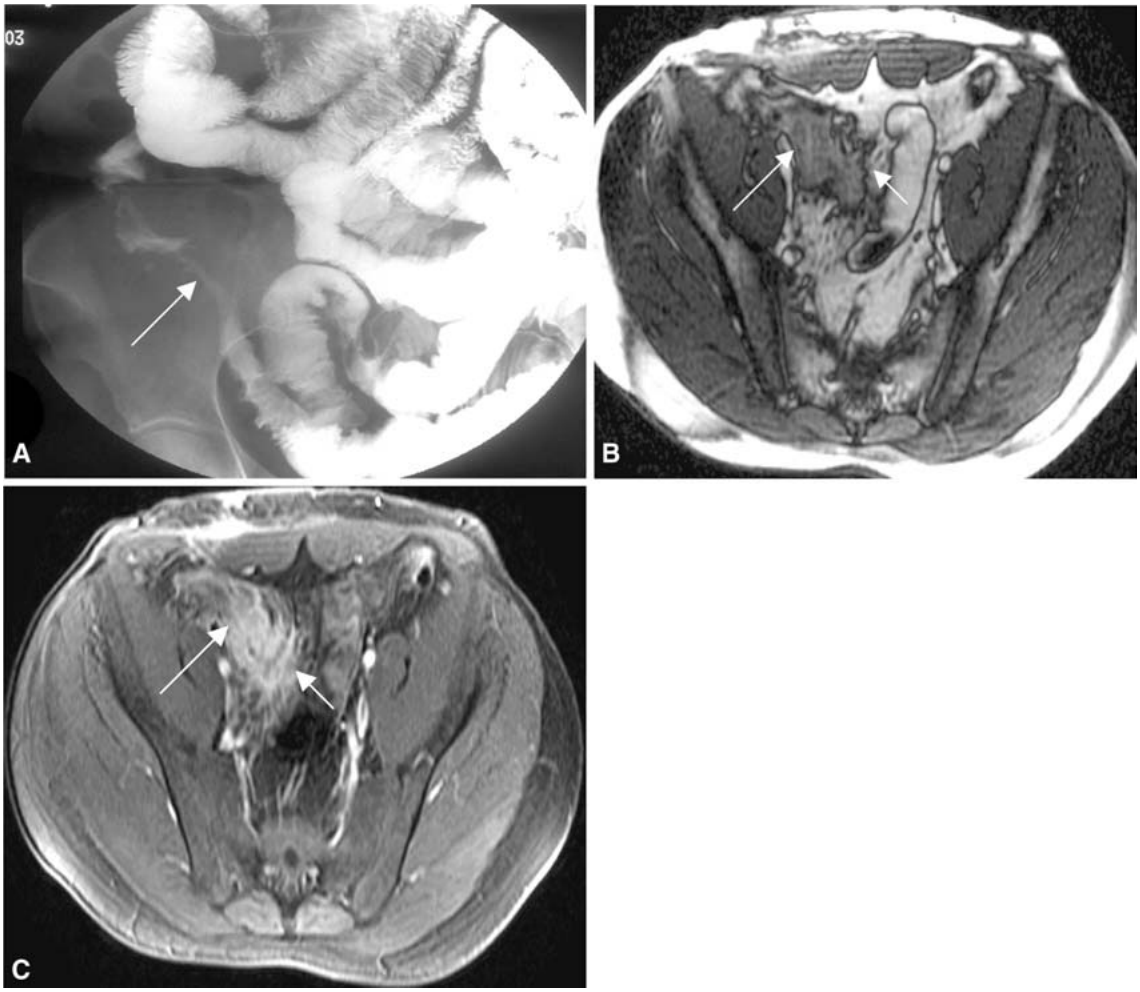

Fig. 9. A Conventional enteroclysis shows a high-grade stenosis of the terminal ileum (*arrow*) with abnormal separation between loops, an indirect sign of mesenteric involvement. A high-grade stenosis of terminal ileum (*arrow*) with adjacent phlegmon (*short arrow*) are shown on axial (**B**) FIESTA and (**C**) Contrast-enhanced T1 two-dimensional FSPGR images.

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