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Abbreviations:

RARE = rapid acquisition with
relaxation enhancement
SBO = small-bowel obstruction

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Small-Bowel Disease: Comparison of MR Enteroclysis Images with Conventional Enteroclysis and Surgical Findings¹

PURPOSE: To investigate if magnetic resonance (MR) enteroclysis can be performed routinely and to compare MR enteroclysis findings with those of conventional enteroclysis or surgery.

MATERIALS AND METHODS: MR enteroclysis was prospectively performed in 30 patients with symptoms of inflammatory bowel disease or small-bowel obstruction (SBO). A methylcellulose-water solution was used to distend the small bowel. To monitor dynamic changes in the small bowel, a single-shot fast spin-echo T2-weighted sequence was applied. For morphologic assessment, breath-hold T2-weighted fast spin-echo and coronal T1-weighted gradient-recalled-echo MR images were obtained without and with gadolinium enhancement. Image quality and degree of small-bowel distention were graded. MR imaging findings and degree of SBO were compared with findings at conventional enteroclysis ($n = 25$) or surgery ($n = 5$).

RESULTS: MR enteroclysis was well tolerated and provided adequate image quality and sufficient small-bowel distention. SBO grade based on MR enteroclysis images ($n = 10$) was identical to that based on conventional enteroclysis images ($n = 6$) or surgical findings ($n = 4$). There was exact agreement between MR enteroclysis and retrospective findings in all five patients who underwent surgery, and MR findings were identical to those at enteroclysis in 18 patients, superior in six patients, and inferior in one patient.

CONCLUSION: MR enteroclysis can be performed routinely with adequate image quality and sufficient small-bowel distention. The functional information provided by MR enteroclysis is identical to that provided at conventional enteroclysis.

The prevalence of small-bowel disease is low, and the clinical diagnosis is complicated by nonspecific symptoms and a low index of suspicion. This frequently leads to delays in diagnosis and treatment. An accurate radiologic examination is, therefore, important not only for recognition of small-bowel disease but also to help reliably document normal morphology (1). Conventional enteroclysis has been effective in the exclusion of small-bowel disease and in the work-up of patients suspected of having intestinal disease (2,3).

The principal advantage of conventional enteroclysis is that the jejunum and ileum can be optimally distended. Conventional enteroclysis also provides functional information by defining distensibility or fixation of the small-bowel loops. Conventional enteroclysis may permit detection of partially or nonobstructive small-bowel lesions that may not be demonstrated with cross-sectional imaging techniques (4). On the other hand, conventional enteroclysis gives only indirect information on the state of the bowel wall and its surrounding structures, and its effectiveness may be hindered owing to overlapping bowel loops. A technique that could combine enteroclysis with cross-sectional imaging methods—either computed tomography (CT) or magnetic resonance (MR) imaging—would be expected to take the diagnosis of small-bowel disease a step further.

Of recent interest has been the use of CT for the evaluation of patients with small-bowel disease (4–10). CT excels in demonstration of the bowel wall and extraluminal structures but lacks the ability to provide sufficient functional information. Helical CT enteroclysis has become a successful alternative imaging method for a more detailed small-bowel evaluation (11).

Owing to its excellent soft-tissue contrast and multiplanar imaging capabilities, MR imaging could be the optimal imaging method for evaluation of the small bowel. Although only infrequently used in the past, MR imaging has benefited from the availability of breath-hold gradient-recalled-echo and breath-hold half-Fourier rapid acquisition with relaxation enhancement (RARE) sequences (12–19). However, problems related to small-bowel distention and to functional information remain limitations of MR imaging of the small bowel. A combination of enteroclysis with MR imaging may overcome some of these limitations (20). In many regions of the body, MR imaging has changed from a purely morphologic imaging technique to one that combines functional and morphologic imaging. MR enteroclysis, a combined functional and morphologic imaging method for the small bowel, has now become possible.

The aim of our study was to investigate whether MR enteroclysis could be performed routinely to provide adequate image quality, with sufficient distention of the entire small bowel and without important side effects. To test these capabilities of MR enteroclysis and to define their possible clinical role, we compared diagnostic results with those of conventional enteroclysis or surgery in patients clinically considered to have inflammatory bowel disease or small-bowel obstruction (SBO).

MATERIALS AND METHODS

Study Population

The study protocol was approved in accordance with the recommendations of the human research committee. All patients gave written informed consent.

Between September 1997 and March 1998, MR enteroclysis was performed in 30 consecutive patients who had been referred for conventional enteroclysis because of symptoms suggestive of chronic inflammatory bowel disease or who had clinical indications for partial SBO. Exclusion criteria were general contraindications

for MR imaging and an inability to tolerate a 20-second breath hold. No patient had to be excluded. The study group comprised 16 women and 14 men aged 24–72 years (mean, 46 years).

Conventional enteroclysis was performed as described in the literature (21,22). We used an 8-F catheter without a balloon (model 815 disposable small-intestine catheter; Laboratoire Guerbet, Roissy, France), and transnasal intubation was performed. Twenty-three patients underwent conventional enteroclysis within 1 hour before MR enteroclysis. One of these patients vomited during conventional enteroclysis, the results of which were considered to be nondiagnostic; because the obstructed small bowel was still adequately distended, the patient was immediately transferred, and MR enteroclysis was performed without real-time MR fluoroscopy (described subsequently). In two other patients who vomited during conventional enteroclysis, MR enteroclysis was performed 2 days and 6 days later. Five patients refused to undergo conventional enteroclysis and, with the agreement of the referring gastroenterologists, underwent MR enteroclysis; their results were compared with surgical findings (four patients) or laparoscopic findings (one patient).

Seven patients had known Crohn disease, which was confirmed with surgical results (four patients) or clinical follow-up findings (three patients). Proof of disease in the remaining 23 patients was based on biopsy results in three patients (celiac disease in one, ileocecal tuberculosis in two), surgical findings in two (carcinoid tumor of the terminal portion of the ileum plus a tubulovillous adenoma in one, radiation-induced enteropathy in one), laparoscopic findings in two, and clinical follow-up results in 16.

MR Enteroclysis

Immediately after conventional enteroclysis, patients were transferred to the MR unit with the small-bowel tube still in place. A rectal tube was connected to an empty barium enema bag to evacuate the colon, if necessary, during imaging. Patients were placed feet first into the bore of the magnet so that the physician could be near the patient's head and the imager display. The imager display, in combination with real-time imaging, provided direct MR fluoroscopic guidance for small-bowel filling in the examination room.

The small bowel was distended with 0.5% methylcellulose in a 1:1 solution with water. The solution was adminis-

tered with an electric infusion pump (Röntgenkontrasmittelpumpe; Nicholas, Sulzbach, Germany). The infusion pump was placed at least 2.5 m from the bore of the magnet to avoid possible damage. A total of 1,500–3,000 mL of methylcellulose solution was administered at an infusion rate of 100–250 mL/min (mean, 150 mL/min).

Transit of the methylcellulose solution in the small bowel was documented with MR fluoroscopy. As soon as the solution reached the ascending colon and the entire small bowel was adequately distended, MR fluoroscopy was stopped and the MR examination was completed with cross-sectional MR imaging. After small-bowel enema administration was stopped and before acquisition of the cross-sectional MR images, 20 mg of hyoscine butylbromide (Buscopan; Boehringer Ingelheim, Germany) was administered intravenously to reduce small-bowel peristalsis and prolong small-bowel distention.

A major concern with MR enteroclysis was the possibility of a patient vomiting inside the bore of the magnet. To avert this, a physician in the examination room closely watched the patient during the entire study. MR fluoroscopy could demonstrate early retrograde flow into the stomach and allow for immediate adjustment of the infusion rate. Any patient with a fluid-filled stomach who complained of nausea was immediately removed from the bore of the magnet to avoid vomiting there.

MR Imaging Protocol

All MR studies were performed with a clinical 1.0-T imager (Gyroscan ACS NT; Philips Medical Systems, Best, the Netherlands) equipped with a quadrature body coil.

MR fluoroscopy.—MR fluoroscopy was performed with a dynamic breath-hold single-shot two-dimensional T2-weighted fast spin-echo sequence (1,783/920 [repetition time msec/effective echo time msec], echo train length of 256). To eliminate the effect of short T2 in tissue on the final image, the first 24 echoes were discarded for the purpose of image construction. The field-of-view was 370 mm with a 128 × 256 matrix, which resulted in a spatial resolution of 1.4 × 2.9 mm. Two signals were acquired, with fold-over suppression to avoid aliasing artifacts. Oversampling reduced the phase matrix to 128, despite an echo train length of 256. The acquisition time was 1.8 seconds per image. These parameters resulted in

heavily T2-weighted images, and only fluid-filled structures were depicted. The breath-hold projections were oriented in the coronal plane with a section thickness of 100–180 mm to include the entire small bowel. Initially, one image was acquired before administration of the methylcellulose solution, and subsequent images were obtained during the injection.

Cross-sectional MR imaging.—At the end of the administration of the small-bowel enema, coronal breath-hold T2-weighted fast spin-echo MR images (2,797/140 [effective], echo train length of 42, matrix of 179×256 , section thickness of 8 mm with 0.7-mm intersection gap, field of view of 370 mm, two signals acquired) were obtained. Two data acquisitions, each obtained with a breath hold of 20 seconds, were necessary to cover the abdomen with 20 sections. Next, transverse T2-weighted breath-hold fast spin-echo images (3,895/130 [effective], echo train length of 34, matrix of 193×256 , section thickness of 8 mm with 0.7-mm intersection gap, field of view of 350 mm, two signals acquired) were obtained. Again, two data acquisitions, each with a breath hold of 19 seconds, were necessary. Finally, coronal breath-hold (18 seconds) T1-weighted gradient-recalled-echo images (121/2.8, flip angle of 90° , matrix of 153×256 , section thickness of 6 mm with 1-mm intersection gap, field of view of 400 mm, one signal acquired) were obtained before and during two phases of contrast material enhancement with 0.1 mmol/kg gadopentetate dimeglumine (Magnevist; Schering, Berlin, Germany). The duration of MR enteroclysis was 30–40 minutes.

Image Analysis

Interpretation of image quality, degree of small-bowel distention, and degree of SBO was performed independently by two radiologists (H.W.U., J.G.). Each MR study was reviewed twice, once with MR fluoroscopic images alone and, at another time, with cross-sectional MR images alone. MR fluoroscopic images were reviewed at the workstation (Easy Vision; Philips Medical Systems) at one sitting, followed at least 1 week later by review of cross-sectional MR images.

The quality of MR fluoroscopic and cross-sectional images was graded by using a four-point scale: score of 0 for nondiagnostic images, score of 1 for diagnostic images with numerous artifacts, score of 2 for diagnostic images with few artifacts, and score of 3 for diagnostic images without artifacts. The adequacy of

luminal distention in the jejunum and in the middle and terminal portions of the ileum also was graded by using a four-point scale: score of 0 for no distention; score of 1 for fair distention; score of 2 for good distention, and score of 3 for excellent distention.

To evaluate the functional information obtained at MR enteroclysis, the results of MR enteroclysis were compared with those of conventional enteroclysis or surgery. A transition zone between dilated bowel above and narrowed bowel below marked the site of any obstruction. In one published series (23), low-grade partial SBO was diagnosed when contrast material reached the site of obstruction without delay and flowed into the loop beyond the obstruction, where the fold patterns were readily defined. Conversely, high-grade partial SBO was diagnosed when there was delay in the arrival of contrast material at the site of obstruction, and only minimal flow appeared in the collapsed loop beyond the obstruction, which made definition of fold patterns difficult.

A diagnosis of mechanical SBO was excluded at MR enteroclysis when unimpeded flow of the methylcellulose solution from the duodenojejunal junction to the ascending colon was observed. The conventional MR imaging diagnosis of SBO on both transverse and coronal images was based on changes in caliber between a distended segment, the point of obstruction, and collapsed bowel beyond the obstruction. Low-grade partial SBO was diagnosed when there was moderate distention (<3 cm) proximal to the point of obstruction without collapsed bowel seen distally. High-grade partial SBO was diagnosed when more pronounced distention was seen proximal to the point of obstruction (≥ 3 cm) with collapsed loops observed distal to the obstruction. These criteria are similar to those described by Maglinte et al (4,7) for CT diagnosis of SBO.

Analysis of MR enteroclysis images with regard to the presence and extent of small-bowel disease was performed at a consensus reading by three radiologists (H.W.U., J.G., M.U.) without knowledge of conventional enteroclysis or surgical findings. Diagnoses on the basis of MR enteroclysis and conventional enteroclysis findings were compared with the diagnoses established at the time of final discharge. The number of abnormalities detected at MR enteroclysis was compared with the number detected at conventional enteroclysis. To avoid positive bias, conventional enteroclysis was per-

formed by different radiologists, and the initial written report was compared with the MR enteroclysis findings.

RESULTS

Results in 30 patients suspected of having inflammatory and/or obstructive small-bowel disease were reviewed to form a preliminary database for the investigation of MR enteroclysis (Table). At conventional enteroclysis, five patients were found to have low-grade SBO and one was found to have high-grade partial SBO. At surgery, another three patients were found to have low-grade SBO and one was found to have high-grade SBO.

MR Fluoroscopy

MR fluoroscopy was performed in 29 patients (one patient with low-grade partial SBO vomited the small-bowel tube during conventional enteroclysis and proceeded directly to MR imaging). Image quality was graded as excellent or good in all 29 patients, with an average image quality score (\pm SD) of 2.8 ± 0.4 . MR fluoroscopic findings were considered to be normal in 19 patients (Fig 1a), but the final discharge diagnosis was normal in only 16 of these patients. The three prospectively overlooked diagnoses included small-bowel diverticula (Fig 2) in one patient, which were clearly visible retrospectively, and diseased small-bowel loops hidden behind normal bowel in two patients. MR fluoroscopy correctly demonstrated high-grade partial SBO in two patients (confirmed at surgery in one and at conventional enteroclysis in the other) and low-grade partial SBO in seven (confirmed at surgery in three and at conventional enteroclysis in four) (Fig 1b, 1c). In one patient, an MR fluoroscopic diagnosis of low-grade partial SBO was false-negative due to the obstruction being hidden by overlapping small-bowel loops. One short stenosis in a patient with Crohn disease, however, was seen only at MR fluoroscopy. A reduction in the number of folds in the jejunum and an increase in the number of folds in the ileum were well demonstrated at MR fluoroscopy in a patient with celiac disease (Fig 3a).

Cross-sectional Imaging

The imaging quality was rated as excellent or good in 29 patients and fair in 1 patient (mean score, 2.8 ± 0.5). The degree of small-bowel luminal distention was rated as consistently complete in the

Patient Characteristics, Findings, and Diagnoses					
Patient No./Sex/Age (y)	Reason for Referral	Conventional Enteroclysis Findings	MR Enteroclysis Findings		
			MR Fluoroscopy	Cross-sectional MR Imaging	Final Diagnosis
1/M/24	Crohn disease	Crohn disease, high-grade SBO	Crohn disease, high-grade SBO	Crohn disease, abscess, high-grade SBO	Crohn disease, abscess, high-grade SBO
2/M/57	Recurrent abdominal pain	Nondiagnostic, low-grade SBO	Not performed	Mass in terminal ileum, mass in ascending colon, low-grade SBO	Carcinoid tumor of terminal ileum, tubulovillous adenoma of ascending colon, low-grade SBO
3/M/64	Small-bowel mass	Normal	Normal	Normal	Normal
4/F/55	SBO	Segmental fold thickening	Segmental fold thickening	Superior mesenteric venous thrombosis, diffuse fold thickening	Superior mesenteric venous thrombosis
5/F/70	SBO	Extraluminal mass	Normal	Normal	Normal
6/F/61	Recurrent tumor, SBO	Not performed	Nondiagnostic, low-grade SBO	Radiation-induced enteropathy, low-grade SBO	Radiation-induced enteropathy, low-grade SBO
7/F/31	Diarrhea, Crohn disease	Crohn disease	Normal	Crohn disease	Crohn disease
8/M/51	Recurrent abdominal pain	Normal	Normal	Normal	Normal
9/M/43	SBO	Normal	Normal	Normal	Normal
10/M/28	Weight loss, diarrhea	Normal	Normal	Normal	Normal
11/M/54	Recurrent abdominal pain	Normal	Normal	Normal	Normal
12/M/26	Fever, diarrhea, abdominal pain	Normal	Normal	Normal	Normal
13/M/72	Recurrent abdominal pain	Normal	Normal	Normal	Normal
14/M/38	Recurrent abdominal pain	Normal	Normal	Normal	Normal
15/F/55	SBO	Small-bowel diverticula	Normal	Normal	Small-bowel diverticula
16/F/61	SBO	Normal	Normal	Normal	Normal
17/M/33	SBO	Not performed	Crohn disease, high-grade SBO	Crohn disease, high-grade SBO	Crohn disease, high-grade SBO
18/M/52	SBO	Normal	Normal	Normal	Normal
19/M/45	Crohn disease	Not performed	Crohn disease, low-grade SBO	Crohn disease, low-grade SBO	Crohn disease, low-grade SBO
20/M/42	Recurrent abdominal pain	Normal	Normal	Normal	Normal
21/F/35	SBO	Normal	Normal	Normal	Normal
22/F/32	SBO	Nondiagnostic, low-grade SBO	Nondiagnostic, low-grade SBO	Small-bowel tuberculosis, low-grade SBO	Small-bowel tuberculosis, low-grade SBO
23/M/42	SBO	Normal	Normal	Normal	Normal
24/M/50	Acute abdominal pain, small-bowel tuberculosis	Small-bowel tuberculosis, low-grade SBO	Low-grade SBO	Small-bowel tuberculosis, low-grade SBO	Small-bowel tuberculosis, low-grade SBO
25/F/44	Crohn disease	Crohn disease, low-grade SBO	Crohn disease, low-grade SBO	Crohn disease, low-grade SBO	Crohn disease, low-grade SBO
26/F/45	SBO	Normal	Normal	Normal	Normal
27/F/34	Celiac disease	Celiac disease	Celiac disease	Celiac disease	Celiac disease
28/M/47	Crohn disease	Not performed	Crohn disease, low-grade SBO	Crohn disease, low-grade SBO	Crohn disease, low-grade SBO
29/F/39	Crohn disease	Cecal tumor, low-grade SBO at ileocecal valve	Normal	Crohn disease, low-grade SBO at ileocecal valve	Crohn disease, low-grade SBO
30/F/54	SBO	Not performed	Normal	Normal	Normal

ileum (mean score, 2.8 ± 0.2). In the jejunum and terminal portion of the ileum, luminal distention varied between good and excellent (mean scores, 2.6 ± 0.6 for the jejunum and 2.3 ± 0.9 for the terminal ileum). The terminal portion of the ileum was the most common site of poor distention. MR enteroclysis correctly demonstrated low-grade partial SBO in eight patients (confirmed at conventional enteroclysis in five and at surgery in three) and high-grade partial SBO in two patients (confirmed at conventional

enteroclysis in one and at surgery in one). The inherent advantage of MR enteroclysis over conventional enteroclysis was related to the assessment of extraluminal disease.

In six (24%) of 25 patients, MR enteroclysis demonstrated abnormalities not seen at conventional enteroclysis. In one patient with longstanding Crohn disease, a jejunocolic fistula was demonstrated with both techniques; however, an ileoileal fistula, a chronic phlegmon, and an abscess formation were demonstrated

only with MR enteroclysis (Fig 4). In another patient in whom conventional enteroclysis results were nondiagnostic because of vomiting, subsequent MR imaging revealed an intensely enhancing mass of the terminal portion of the ileum and a second mass with higher signal intensity on T2-weighted images and lower gadolinium enhancement in the ascending colon; a small-bowel carcinoid tumor and a tubulovillous adenoma of the ascending colon were found at surgery. In a third patient (Fig 5), who com-

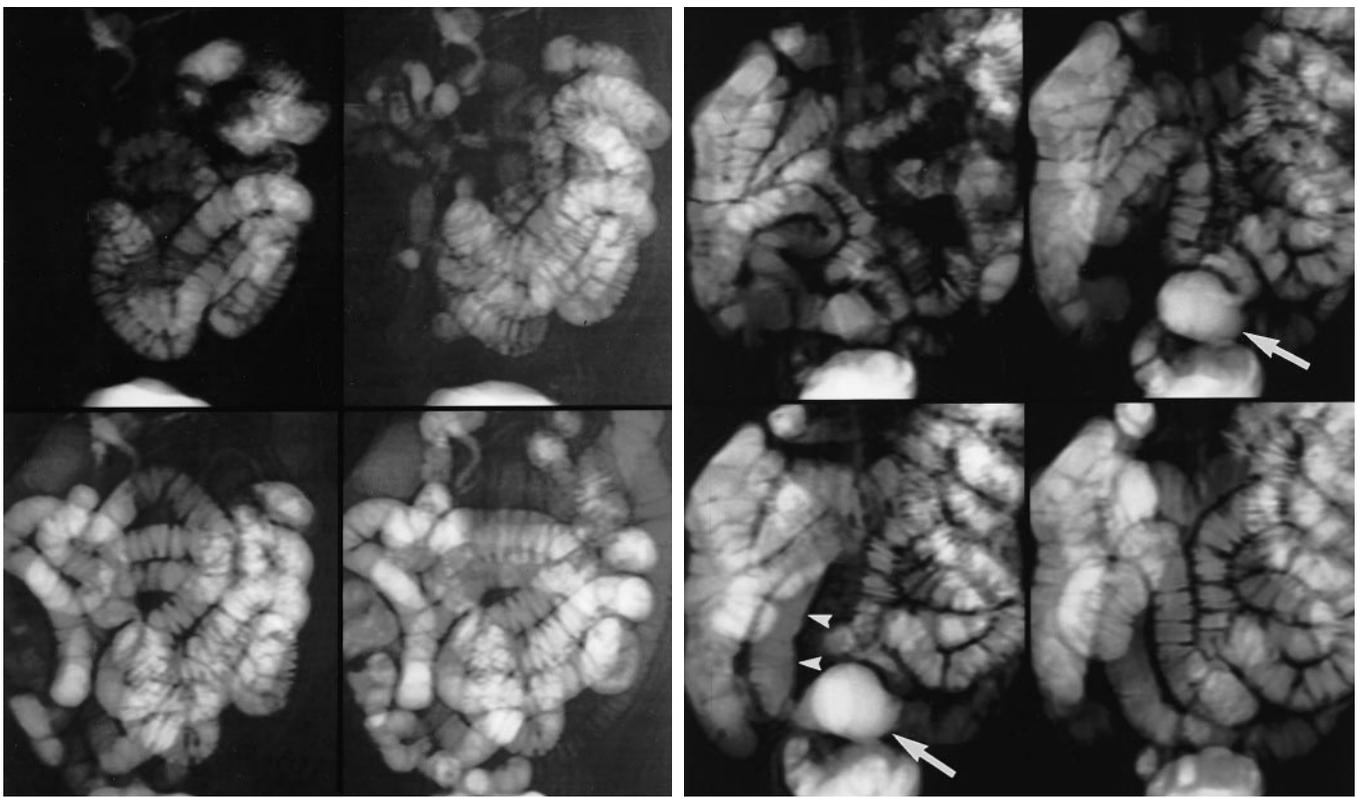
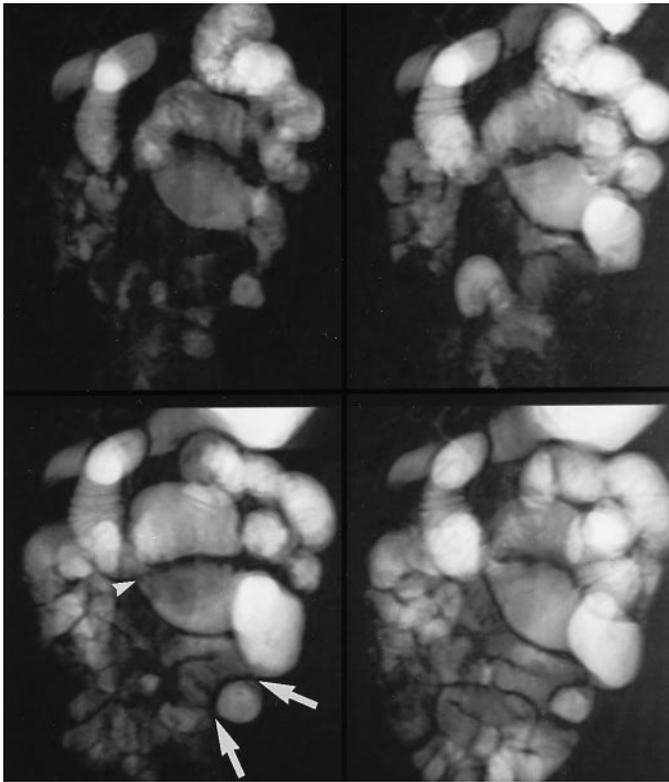


Figure 1. Functional information provided at coronal MR fluoroscopy (1,783/920 [effective]). (a) Progressive filling of a normal small bowel in a 54-year-old woman. (b) Low-grade partial SBO in a 45-year-old man with Crohn disease. Increasing saccular dilatation of an ileal loop (arrows) is demonstrated, as well as increasing moderate distention (arrowheads) proximal to the point of obstruction. (c) High-grade partial SBO in a 33-year-old man with Crohn disease. Increasing dilatation of the proximal jejunum caused by strictures (arrows) due to Crohn disease and collapse of the distal small-bowel loops are shown. A short stricture (arrowhead) in the proximal jejunum is visible; this stricture was not seen on cross-sectional images but was confirmed at surgery. Note also retrograde filling of the stomach.



plained of abdominal pain 1 week after resection of an ileal carcinoid tumor, images obtained at conventional enteroclysis revealed segmental thickening of jejunum folds. MR enteroclysis images revealed thrombosis of the superior mesenteric vein as the cause of bowel wall thickening. In addition, thrombosis of the right branch of the portal vein was demonstrated on contrast-enhanced gradient-recalled-echo MR images. In a fourth patient with a history of gastrectomy for carcinoma performed a year earlier, conventional enteroclysis images showed displacement of the terminal portion of the ileum, which was possibly due to an extraluminal mass. MR enteroclysis images revealed a rotated cecum as the cause of displacement of the terminal portion of the ileum. In a fifth patient, in whom small-bowel tuberculosis was later confirmed, images obtained at conventional enteroclysis depicted four lesions. MR enteroclysis images revealed a fifth lesion

in the ileum. In the sixth patient, conventional enteroclysis images showed an inadequately distended cecum, which was considered to be associated with a tumor. MR enteroclysis images revealed concentric cecal wall thickening and marked enhancement of the mucosa with a thickened and minimally enhancing outer layer, which was consistent with Crohn disease. On the other hand, in a single false-negative diagnosis, MR enteroclysis prospectively failed to demonstrate jejunal diverticula; in retrospect, these diverticula were clearly visible on MR fluoroscopic images (Fig 2b).

Other important findings seen exclusively on MR enteroclysis images were mesenteric lymphadenopathy in four patients (three with Crohn disease, one with celiac disease), mesenteric fibrous and fatty proliferation in four of seven patients with Crohn disease, cholecystolithiasis in three patients, ascites in three, dysontogenetic liver or renal cysts in four, avascular necrosis of the femoral head in one, diverticular disease of the sigmoid colon in two, and occlusion of the right common iliac artery in one.

Four patients vomited during MR enteroclysis. Two of these patients already had a fluid-distended stomach after conventional enteroclysis; the third patient had a high-grade partial SBO in the proximal jejunum due to Crohn disease. All four patients were removed from the bore of the magnet in time and vomited outside the bore. After a few minutes, cross-sectional MR imaging was continued. Despite vomiting, each study was considered to be diagnostic. Three patients complained of colicky pain during small-bowel distention, which was relieved by reduction of the methylcellulose infusion rate. No other side effects occurred during this study.

DISCUSSION

Performance of abdominal MR imaging has increased in recent years, aided by the availability of respiratory triggering and breath-hold sequences to prevent motion artifacts. The value of MR imaging in patients with inflammatory bowel disease or small-bowel tumors is well documented (12,13,15). The introduction of T2-weighted breath-hold sequences further allows MR imaging in patients with acute SBO (18,19).

Luminal distention is a requirement for all small-bowel imaging methods because collapsed bowel loops can hide even large lesions and may falsely appear as wall

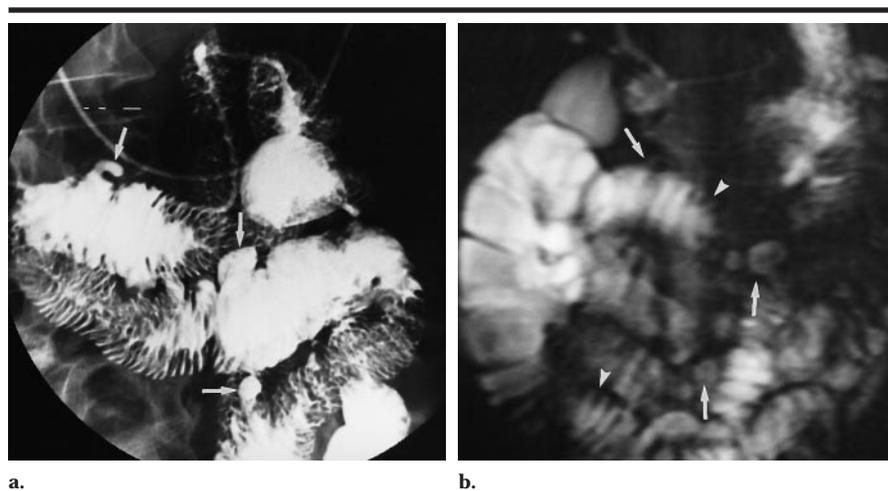


Figure 2. Images in a 45-year-old woman with a history of cervical cancer and ileal resection due to radiation-induced SBO. (a) Anteroposterior image obtained at conventional enteroclysis shows multiple diverticula of the small bowel (arrows) and moderate fold thickening, which probably is the result of radiation therapy. (b) Prospectively, the coronal MR fluoroscopic image (1,783/920) was considered to be normal, although several small-bowel diverticula (arrows) were clearly identified retrospectively, as was a moderate degree of fold thickening (arrowheads). Note a small liver cyst and depiction of a normal pancreatic duct.

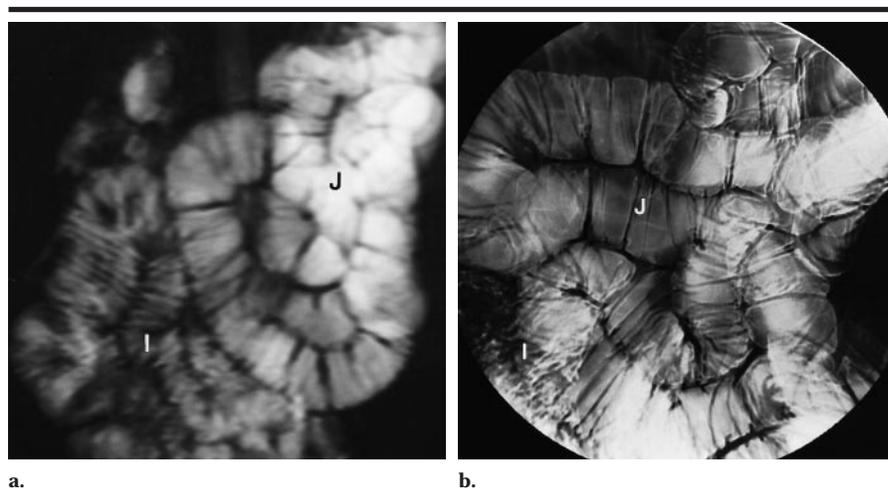


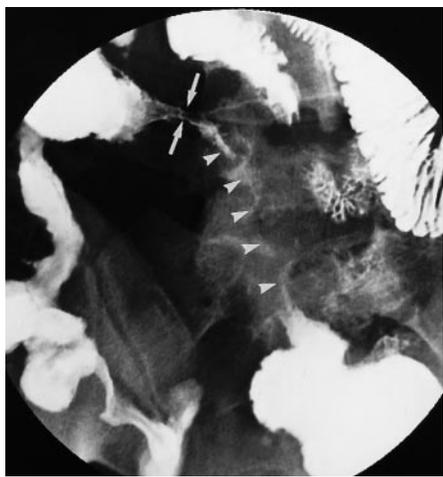
Figure 3. Celiac disease in a 34-year-old woman. Images obtained at (a) coronal MR fluoroscopy (1,783/920) and (b) conventional enteroclysis (posteroanterior projection) show reversal of the normal fold characteristics between ileum (I) and jejunum (J). Note the fewer folds in the jejunum and the increased number of folds in the ileum, typical of celiac disease.

thickening. In high-grade SBO, the small bowel is distended with fluid and can readily be examined with cross-sectional imaging methods such as CT or MR imaging. In patients with low-grade partial SBO or a nonobstructive lesion, the small bowel often is collapsed, and CT or MR imaging can be difficult (4). We believe that enteroclysis is the only method to achieve the required degree of luminal distention in such patients. MR enteroclysis was developed to combine the advantages of conventional enteroclysis with

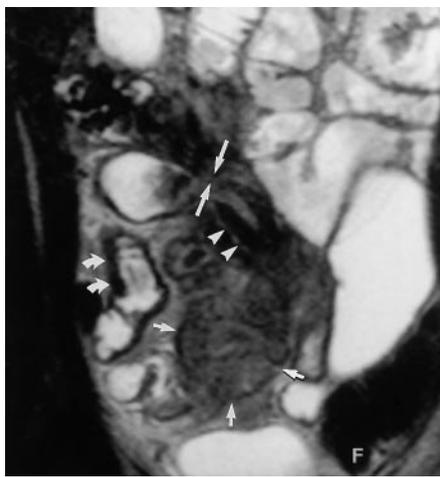
the morphologic imaging capabilities of MR.

The results of this study show that MR enteroclysis can be performed routinely by using a commercially available MR system. However, dyspneic patients or those in a very poor general condition should be excluded from MR enteroclysis to avoid vomiting and aspiration in the bore of the magnet and because respiratory motion artifacts may compromise image detail.

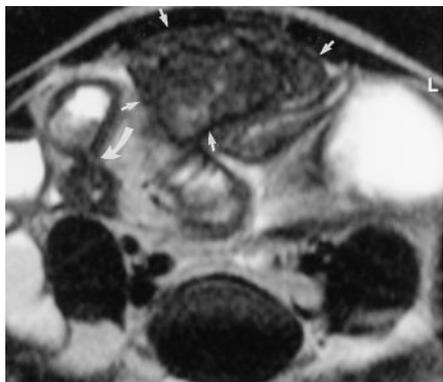
MR enteroclysis provided adequate im-



a.



b.



c.

Figure 4. Severe Crohn disease in a 24-year-old man. (a) Conventional posteroanterior enteroclysis image shows a long high-grade stricture of a jejunal loop (arrowheads) and a jejunocolic fistula (arrows) (b) Corresponding coronal T2-weighted fast spin-echo MR image (2,797/140 [effective]) demonstrates the jejunocolic fistula (long straight arrows) and the thickened bowel wall (arrowheads), which exactly correlates with the stricture in a. In addition, an inflammatory mass is shown in the adjacent mesentery (short straight arrows), which was confirmed to be a chronic abscess at surgery. Note an additional diseased ileal loop (curved arrows). *F* = toward the feet. (c) Transverse T2-weighted fast spin-echo MR image (3,895/130 [effective]) shows an ileoileal fistula (curved arrow), which was not seen at conventional enteroclysis, and the inflammatory mass (straight arrows). *L* = left.

age quality and achieved sufficient distention of the entire small bowel. The increased rate of infusion of the methylcellulose solution (mean, 150 mL/min) reduced small-bowel peristalsis, and the administration of antispasmodics allowed distention of the entire small bowel to be maintained throughout the cross-sectional imaging procedures.

Both observers were in agreement regarding the degree of SBO depicted on both MR enteroclysis and conventional enteroclysis images. MR enteroclysis was found to provide functional information comparable to that of conventional enteroclysis, even for low-grade partial SBO (Fig 1b). The inherent advantage of MR enteroclysis was related to the assessment of extraluminal pathologic conditions (Figs 4, 5). In six (24%) of 25 patients, MR enteroclysis revealed abnormalities not seen at conventional enteroclysis. Although we failed to prospectively recognize the presence of jejunal diverticula at MR enteroclysis in one (4%) patient, these

diverticula were clearly seen retrospectively (Fig 2b). In adequately prepared patients, the entire large bowel can frequently be included in the MR enteroclysis study, which is an important advantage in patients with inflammatory bowel disease.

There are, however, limitations to MR enteroclysis. The spatial and temporal resolutions of MR enteroclysis are inferior to those of conventional enteroclysis. Subtle small-bowel lesions may, therefore, not be detected. The use of a phased-array coil and faster gradient systems will help increase the spatial and temporal resolution. Further, MR enteroclysis is more expensive than conventional enteroclysis or CT.

Despite all precautions, vomiting inside the imager may occur and would disable the MR unit until it had been completely cleaned. A physician positioned near the opening of the bore could intervene quickly should there be an indication of impending vomiting.

Unfortunately, conventional fluoroscopy and, therefore, ionizing radiation are still necessary for guidance during tube placement. Technical improvements in interventional MR systems may, in the future, allow tube placement in the small bowel while the patient is positioned in the MR unit, without exposure to radiation. A further limitation of our MR system was that breath-hold fat-suppressed gradient-recalled-echo sequences could not be performed. Fat suppression has the attractive features of diminished breathing artifacts, expanded dynamic range of intraabdominal signal intensities, and increased conspicuity of gadolinium enhancement due to decreased competition from the high signal intensity of fat (12). The addition of transverse fat-suppressed gadolinium-enhanced gradient-recalled-echo images might have permitted recognition of further small-bowel lesions.

We believe that the advantages of MR enteroclysis over conventional enteroclysis outweigh its limitations. At our institution (General Hospital Klagenfurt, Austria), conventional enteroclysis has been replaced by MR enteroclysis in patients who are clinically considered to have inflammatory bowel disease or SBO. We are unaware of any previous reports on MR enteroclysis in the literature.

Although CT is highly accurate for the diagnosis of high-grade partial SBO, it has a reported (4) sensitivity of only 48% for low-grade partial SBO. As with any imaging method that does not test the distensibility and fixation of a bowel loop, these findings are not unexpected. CT, therefore, does not appear to have a role in the vexing clinical problem of establishing or excluding the diagnosis of low-grade partial SBO. Nonobstructive small-bowel lesions would be even more difficult to detect.

High accuracy in the diagnosis of SBO has also been reported with the half-Fourier RARE sequence (18,19). However, it seems unlikely that MR imaging, even with this sequence, can produce better results than CT in patients with low-grade partial SBO, given that the diagnosis must rely on the same criteria—that is, dilated bowel loops proximal to the site of obstruction. Although the half-Fourier RARE sequence is fast and can be performed in a breathing-independent fashion (approximately 2 seconds duration), image quality is decreased by blurring, and the soft-tissue contrast is less than that possible with breath-hold fast spin-echo sequences (24), which is the technique we prefer.

More recently, helical CT enteroclysis

has been introduced (11) as an alternative imaging method for evaluation in patients with small-bowel disease. With this technique, the administration of a water-soluble iodinated contrast agent during fluoroscopy is continued into the CT phase. Not unexpectedly, the reported sensitivity for low-grade partial SBO was 82%, higher than that with standard CT. The disadvantages of helical CT enteroclysis in comparison with MR enteroclysis are increased exposure to ionizing radiation, lack of fluoroscopic control during small-bowel filling in the CT room, inferior soft-tissue contrast, and uniplanar (transverse) imaging capability. The coronal plane is better suited to demonstrate small-bowel anatomy than the transverse plane, and coronal images are especially helpful to surgeons, who are accustomed to using radiographs obtained in the coronal plane; moreover, the coronal plane more closely resembles the surgeon's view during the operation. Although multiplanar reformations are possible with helical CT data, the quality of the reconstructed images is reduced, which is a disadvantage compared with the direct coronal images provided by MR imaging.

Recently, Faber et al (20) reported on MR imaging after enteroclysis. For conventional enteroclysis, they distend the small bowel in the fluoroscopic suite by using an optimized suspension of oral magnetic particles and then transport the patient to the MR suite. Unlike Faber et al, we distended the small bowel with the patient positioned in the bore of the magnet and infused an aqueous solution of methylcellulose, because water provides optimal contrast between the bowel wall and the lumen on T1- and T2-weighted MR images. In our experience, it has been impossible, in the absence of SBO, for small-bowel distention to persist long enough to complete MR imaging; the proximal jejunum frequently collapses before the MR examination can be started.

In conclusion, MR enteroclysis is technically feasible, provides adequate image quality and sufficient distention of the entire small bowel, and can be performed with a commercially available MR system. The functional information provided by MR enteroclysis equals that provided by conventional enteroclysis radiographs, which implies the ability to depict even low-grade partial SBO. The inherent advantages of this MR imaging approach over conventional enteroclysis are the potential to detect extraluminal pathologic conditions and the ability to provide detailed information about the

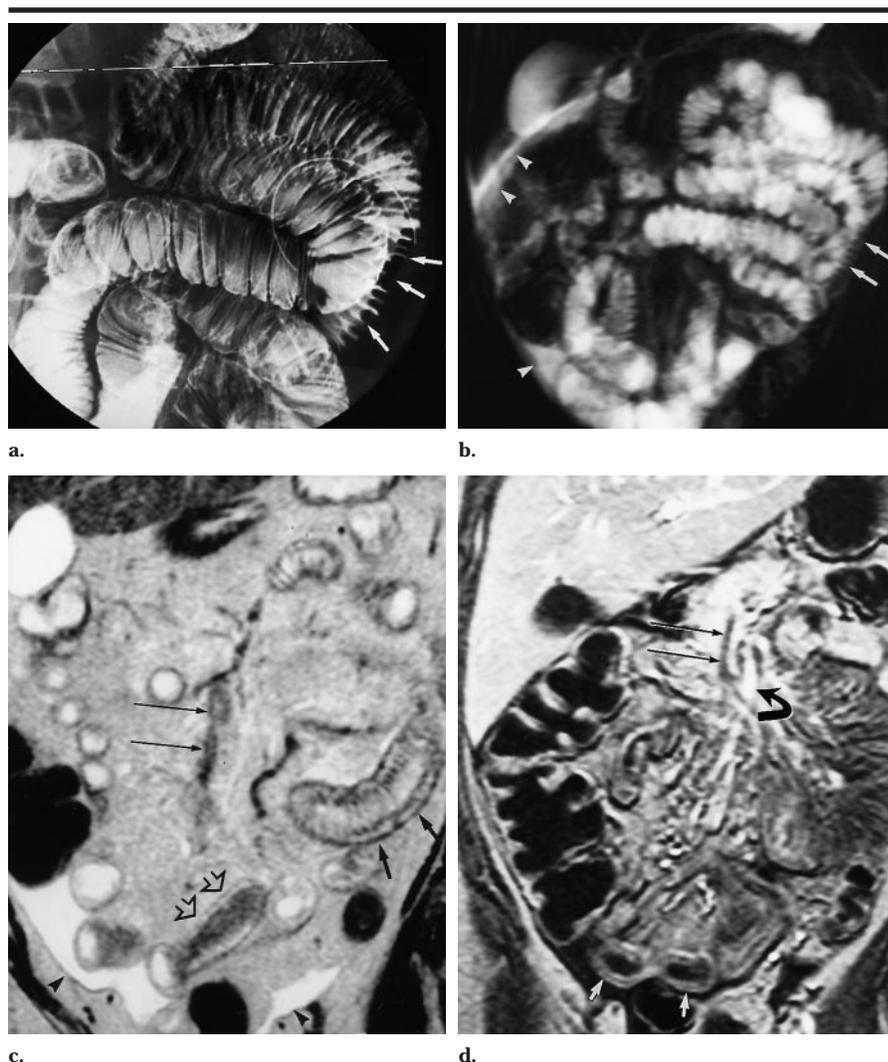


Figure 5. Images in a 55-year-old woman who complained of abdominal pain 1 week after partial ileal resection due to a carcinoid tumor. **(a)** Conventional posteroanterior enteroclysis image shows marked thickening of the valvulae conniventes (plica circulares) (arrows) in a loop of the proximal jejunum and moderate thickening of the adjacent jejunal loops. **(b)** Coronal MR fluoroscopic image (1,783/920 [effective]) shows marked bowel wall thickening (arrows) of a jejunal loop, comparable to that in **a**, and moderate fold thickening of the adjacent jejunal loops. Ascites (arrowheads) is also visible. **(c)** Coronal T2-weighted fast spin-echo MR image (2,797/140 [effective]) demonstrates diffuse wall thickening of the small bowel (short solid arrows) with high signal intensity secondary to thrombosis of the superior mesenteric vein (long solid arrows). Moderate bowel wall edema (open arrows), which was not seen at conventional enteroclysis, also is visible in the ileum. Ascites (arrowheads) can be seen in the right paracolic gutter. **(d)** Coronal gadolinium-enhanced T1-weighted gradient-recalled-echo MR image (121/2.8, 90° flip angle) shows thrombosis of the superior mesenteric vein (straight black arrows) and normal enhancement of the superior mesenteric artery (curved arrow). Hyperperfusion of parts of the right side of the liver is due to partial thrombosis of the right portal vein. Moderate bowel wall thickening (white arrows) of the ileum is present.

wall of the small bowel and the entire abdomen. Unlike conventional enteroclysis, MR enteroclysis does not have problems due to overlapping bowel loops. MR enteroclysis has the potential to be an excellent diagnostic method for examination of small-bowel disease because of the functional information, soft-tissue con-

trast, and multiplanar imaging capabilities.

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References

1. Maglinte DDT, O'Connor K, Bessette J, Gernish SM, Kelvin FM. The role of physician in the late diagnosis of primary malignant tumors of the small intestine. *Am J Gastroenterol* 1991; 86:304-308.
2. Maglinte DDT, Chernish SM, Kelvin FM, O'Connor KW, Hage JP. Crohn disease of the small intestine: accuracy and relevance of enteroclysis. *Radiology* 1992; 184:541-545.
3. Herlinger H. Barium examinations. In: Gore RM, Levine MS, Laufer I, eds. *Textbook of gastrointestinal radiology*. Philadelphia, Pa: Saunders, 1994; 766-788.
4. Maglinte DDT, Gage S, Harmon B, et al. Obstruction of the small intestine: accuracy and role of CT in diagnosis. *Radiology* 1993; 186:61-64.
5. Megibow AJ, Balthazar EJ, Cho KC, et al. Bowel obstruction: evaluation with CT. *Radiology* 1991; 180:313-318.
6. Fukuya T, Hawes DR, Lu CC, Chang PJ, Barloon TJ. CT diagnosis of small-bowel obstruction: efficacy in 60 patients. *AJR Am J Roentgenol* 1992; 158:765-772.
7. Maglinte DDT, Reyes BL, Harmon BH, et al. Reliability and role of plain film radiography and CT in the diagnosis of small-bowel obstruction. *AJR Am J Roentgenol* 1996; 167:1451-1455.
8. Frager D, Medwid SW, Baer JW, Mollinelli B, Friedmann M. CT of small-bowel obstruction: value in establishing the diagnosis and determining the degree and cause. *AJR Am J Roentgenol* 1994; 162:37-41.
9. Gazelle GS, Goldberg MA, Wittenberg J, Halpern EF, Pinkney L, Mueller PR. Efficacy of CT in distinguishing small-bowel obstruction from other causes of small-bowel dilatation. *AJR Am J Roentgenol* 1994; 162:43-47.
10. Raptopoulos V, Schwartz RK, McNicolaos MMJ, Movson J, Pearlman J, Joffe N. Multiplanar helical CT enterography in patients with Crohn's disease. *AJR Am J Roentgenol* 1997; 169:1545-1550.
11. Bender GN, Timmons JH, Williard WC, Carter J. Computed tomographic enteroclysis: one methodology. *Invest Radiol* 1996; 31:43-49.
12. Shoenut JP, Semelka RC, Silverman R, Yaffe CS, Micflikier AB. Magnetic resonance imaging in inflammatory bowel disease. *J Clin Gastroenterol* 1993; 17: 73-78.
13. Shoenut JP, Semelka RC, Magro CM, Silverman R, Yaffe CS, Micflikier AB. Comparison of magnetic resonance imaging and endoscopy in distinguishing the type and severity of inflammatory bowel disease. *J Clin Gastroenterol* 1994; 19:31-35.
14. Mirowitz SA. Contrast enhancement of the gastrointestinal tract on MR images using intravenous gadolinium-DTPA. *Abdom Imaging* 1993; 18:215-219.
15. Semelka RC, John G, Kelekis NL, Burdendy DA, Ascher SM. Small-bowel neoplastic disease: demonstration by MRI. *J Magn Reson Imaging* 1996; 6:855-860.
16. Ernst O, Asselah T, Cablan X, Sergent G. Breath-hold fast spin-echo MR imaging of Crohn's disease. *AJR Am J Roentgenol* 1998; 170:127-128.
17. Lee JKT, Marcos HB, Semelka RCF. MR imaging of the small-bowel using the HASTE sequence. *AJR Am J Roentgenol* 1998; 170:1457-1463.
18. Beall DP, Regan F. MRI of bowel obstruction using the HASTE sequence. *J Comput Assist Tomogr* 1996; 20:823-825.
19. Regan F, Beall DP, Bohlman ME, Khazan R, Sufi A, Schaefer DC. Fast MR imaging and the detection of small-bowel obstruction. *AJR Am J Roentgenol* 1998; 170: 1465-1469.
20. Faber SC, Stehling MK, Holzknicht H, Gauger J, Helmberger H, Reiser M. Pathologic conditions in the small-bowel: findings at fat-suppressed gadolinium-enhanced MR imaging with an optimized suspension of oral magnetic particles. *Radiology* 1997; 205:278-282.
21. Herlinger H. A modified technique for the double-contrast small-bowel enema. *Gastrointest Radiol* 1978; 3:201-207.
22. Antes G, Lissner J. Die doppelkontrastdarstellung des dünndarms mit barium und methylzellulose. *Rofo Fortschr Geb Rontgenstr Neuen Bildgeb Verfahr* 1981; 134:10-15.
23. Shrake PD, Rex DK, Lappas JC, Maglinte DDT. Radiographic evaluation of suspected small-bowel obstruction. *Am J Gastroenterol* 1991; 86:175-178.
24. Coates GG, Borrello JA, McFarland EG, Mirowitz SA, Brown J. Hepatic T2-weighted MRI: a prospective comparison of sequences, including breath-hold, half-Fourier turbo spin echo (HASTE). *J Magn Reson Imaging* 1998; 8:642-649.