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Gabriele Masselli
Emanuele Casciani
Elisabetta Polettini
Gianfranco Gualdi

Comparison of MR enteroclysis with MR enterography and conventional enteroclysis in patients with Crohn's disease

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G. Masselli (✉) · E. Casciani · E. Polettini · G. Gualdi
Radiology DEA Department, Academic Hospital "Umberto I". La Sapienza University Rome, Viale del Policlinico 155, 00161 Rome, Italy
e-mail: gabrielemasselli@libero.it
Tel.: +39-3356066868
Fax: +39-06-6622279

Abstract To prospectively compare the diagnostic accuracy of MR enteroclysis with duodenal intubation with MRI after drinking oral contrast agent only (MR enterography) with conventional enteroclysis (conv-E) as reference standard in patients with Crohn's disease. Forty consecutive patients (22 males and 18 females; mean age 36; range 16–74 years) with proven Crohn's disease underwent conv-E and MR imaging. Twenty-two patients underwent MR enteroclysis with intubation (MRE) and 18 underwent MR-enterography (MR per OS). Two radiologists reached a consensus about the following imaging findings: luminal distension and visualization of superficial mucosal, mural and mesenteric abnormalities. Standard descriptive statistics and a Wilcoxon rank sum test were used. Statistical significance was inferred at $P<0.05$. There was no significant difference in the adequacy of luminal distention between the MRE and conv-E ($P=0.08$), and both were statistically superior in comparison to MR per OS in the distension of the jejunum ($P<0.01$) and less significant at the ileum and terminal ileum levels ($P<0.05$). MRE and conv-E were comparable for the accuracy of superficial mucosal abnormalities; meanwhile conv-E compared with MR per OS was statistically superior ($P<0.01$). MRE compared with MR per OS was statistically better when visualizing superficial abnormalities ($P<0.01$). No statistically significant differences were found in assessing the diagnostic efficacy between MR examinations for the depiction of mural stenosis ($P=0.105$) and fistulae ($P=0.67$). The number of detected mesenteric findings was significantly higher with both MRE and MR per OS compared to conv-E ($P<0.01$). MRE can serve as the diagnostic procedure for initially evaluating patients suspected of having Crohn's disease. MR per OS may have a role in patients that refuse or have failed intubation and also for follow-up.

Keywords MR enteroclysis · MR enterography · Crohn's disease

Introduction

Magnetic resonance imaging (MRI) has an increasing diagnostic impact on patients suffering from inflammatory bowel disease. Its attributes include: high soft tissue contrast, static and dynamic imaging capabilities, direct multiplanar imaging capabilities, and the use of non-ionizing radiation [1]. MR would be the preferable diagnostic procedure, due to the absence of ionizing radiation and its easy comparability, for the initial evaluation and the follow-up of these patients that need to repeat examinations during their life [2].

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 [3, 4].

The major advantage of this technique is the combined visualization of luminal, mural, and extramural abnormalities [4, 5].

Nevertheless, intubation of the patient and positioning of an intestinal tube are still necessary for the examination, which is often the most traumatic part of the examination from the patient's point of view. A more comfortable and highly sensitive examination of the small bowel would therefore increase patient's acceptance of repeated examinations, often necessary in patients with Crohn's disease. The dilemma between using the oral approach (MR enterography), which is more acceptable to the patient, and the intubation-infusion method (MR enteroclysis), which is less well tolerated in the absence of conscious sedation, has not been resolved by the radiologic community [6]. The study was designed to prospectively compare the diagnostic accuracy of MR enteroclysis with duodenal intubation (MRE) and of MR enterography after drinking an oral contrast agent only (MR per OS) with conventional enteroclysis (conv-E) as reference standard in patients with Crohn's disease.

Materials and methods

Patients

Forty consecutive patients (22 males and 18 females; mean age 36; range 16–74 years) with proven Crohn's disease visiting our Inflammatory Bowel Disease Clinic from November 2005 to December 2006 were enrolled for this prospective study.

The study was conducted in accordance with all guidelines set out by the approving institutional review board, and written informed consent was obtained prior to each examination from all patients. Inclusion criteria included histologically proven Crohn's disease and previously scheduled small bowel conventional enteroclysis examination. Exclusion criteria included contraindications to MRI, such as the presence of a pacemaker, metallic implants in the central nervous system, or claustrophobia. The Crohn's Disease Activity Index (CDAI) according to the criteria proposed by Best et al. [7] was used to evaluate all patients.

This index was used to assign a specific score to the different clinical signs and symptoms (e.g., duration of symptoms, diarrhea, body temperature, and abdominal pain). A CDAI score lower than 150 was considered inactive; meanwhile, a score higher than 150 was considered active.

The CDAI score was used to differentiate two groups of patients with active or nonactive disease who were treated separately for alternate assignment: patients in active and clinical remission based on CDAI were alternately assigned by our study coordinator to undergo either a nonivasive peroral MR enterography protocol or MR enteroclysis with a nasojejunal tube. If a patient refused the assigned MRE protocol, the patient was given the option of choosing the alternate MR per OS protocol.

This procedure was random to minimize the bias, and we originally decided to assign more patients to undergo MRE (n=24) rather than MR per OS (n=16), because it would be more probable that a patient could have refused the intubation protocol rather than an oral one.

A flow diagram that shows the progression of subjects as they passed through the study is presented in Fig. 1.

Group 1 (MRE) finally included 22 patients (13 males and 9 females with years of Crohn's disease diagnosis between 4 months and 14 years); 3/22 patients had ileal surgery.

Group 2 (MR per OS) included 18 patients (9 males and 9 females with years of Crohn's disease diagnosis between 3 months and 11 years), and 2/18 patients had ileal surgery.

All patients of both groups were undergoing pharmacologic treatment with oral corticosteroids or other drugs (i.e., azathioprine, infliximab, masalazine, or antibiotics).

All patients were required to complete a questionnaire after the MR examinations describing nausea, vomiting and abdominal pain.

MR imaging

The same intraluminal contrast agent in polyethylenglycol water solution was used for both MR procedures. It was prepared by dissolving a granular powder containing 34.8 g PEG 4000 (Isocolan;Bracco, Princeton, NJ), 1.42 g anhydrous sodium sulphate, 0.42 g sodium bicarbonate, 0.36 g sodium chloride, and 0.18 g of potassium chloride in 500 ml of tap water.

The PEG preparation used is already fully licensed as a bowel-cleaning agent and is routinely used before endoscopy, barium X-ray procedures, and intestinal surgery [8].

The PEG solution is an iso-osmotic biphasic contrast agent that provides low signal intensity on T1-weighted images and high on T2-weighted images, with an excellent performance in MR of the small bowel [9, 10].

All MR examinations were performed by using a 1.5-T whole-body MR imaging unit (Signa; GE Medical Systems, Milwaukee, WI), with eight–channel abdomen phased array coil.

Patients were placed feet first into the bore of the magnet in prone position; 2/40 (5%) patients were placed in the supine position, one of whom underwent an MRE and another underwent a MR per OS.

In the literature, the prone position of the patient is recommended because of associated abdominal autocompression, which means that fewer coronal images can be obtained [3, 4].

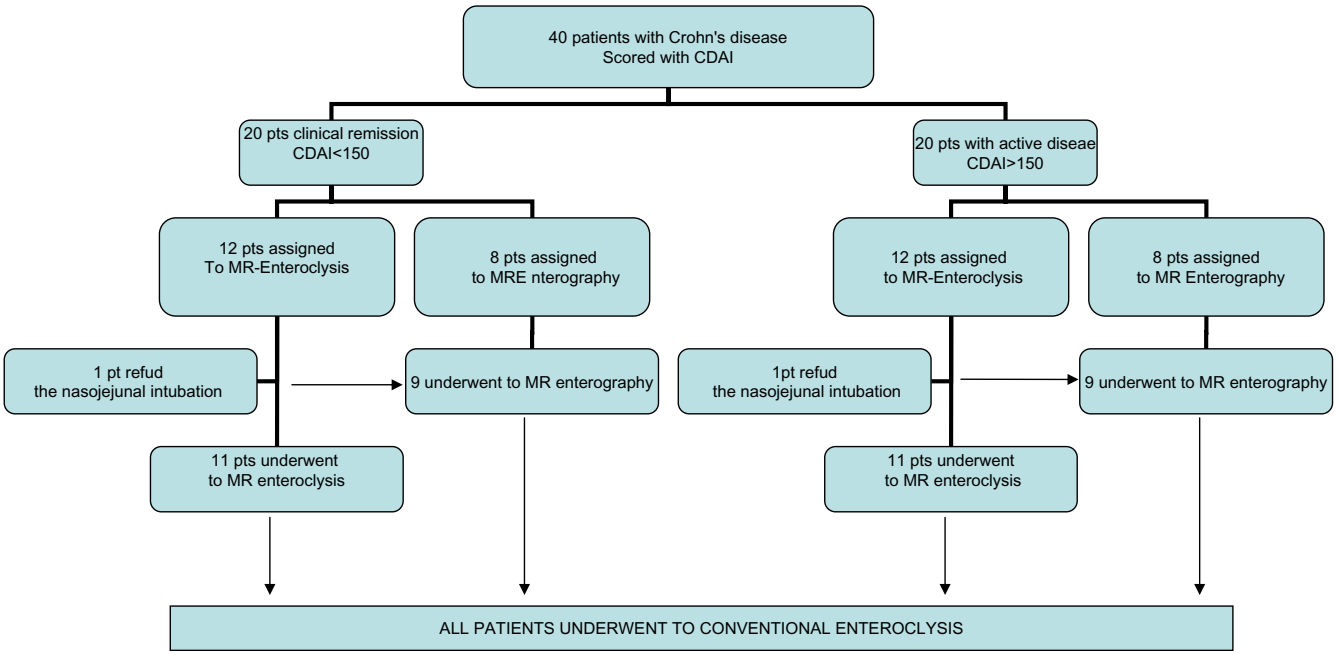

Fig. 1 A flow diagram that shows the progression of subjects as they passed through the study

MR enteroclysis (MRE)

Patients enrolled in the MRE protocol underwent nasojejunal intubation with a 13-F 155-cm nasojejunal tube (Maglinte enteroclysis catheter; Lafayette Pharmaceutical) with the patient on the fluoroscopy table. The Maglinte catheter was positioned with its tip at the level of duodenojejunal flexure; the balloon was inflated with 20 ml room air. Immediately afterwards the patients were transferred to the MR unit.

A total of 1,600-2,000 ml of PEG solution was administered at an infusion rate of 80 to 150 ml/min, employing a manual MR compatible pump, with the patient lying inside the magnet.

The PEG solution was administered in two phases. A low infusion rate of 80 to 100 ml/min was used during the first phase, which lasted until the terminal ileum began to distend. During the second phase the infusion rate was increased up to 150 ml/min to acheive reflex atony.

A coronal thick-slab ssFSE image MR fluoroscopy (TR/TE=8/950) (FOV 350 mm, matrix 256×256, flip angle 90°) was used to assess contrast passage speed, peristalsis, and luminal distension.

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 imaging.

MR enterography (MR per OS)

Patients enrolled in the MR per OS protocol drank four 450-ml aliquots of PEG in 50 min, for a total of 1,800 ml.

MR protocol

The same imaging sequences for MRE with duodenal intubation as MRI of the abdomen after oral administration were used, except for MR fluoroscopy sequence, which was only performed with MRE.

MR fluoroscopy was performed with a dynamic breath-hold two-dimensional T2-weighted fast spin echo sequence. The acquisition time was 1.8 s per image. The breath-hold projections were oriented in the coronal plane with a section thickness of 350 mm to include the entire small bowel. The inclusion of the stomach in these images is important to facilitate detection of retrograde filling of the stomach.

Before acquiring 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.

Trasverse and coronal single-shot fast SE MR images (min/60.0) (repetition time ms/echo time ms), 256×224 matrix, 4-mm thickness (axial) and 3-mm thickness (coronal) with no gap, echo train length of 94, receiver bandwidth of 62.50 kHz) were acquired during breath-hold.

Non-interleaved sets of 16 sections were obtained during each 20-s breath-hold.

Next, coronal and axial FIESTAs (Fast Imaging Employing Steady State Acquisition) (3.5/1.8; repetition time ms/echo time ms; 256×224 matrix; one signal acquired; 6-mm thickness with no gap; 50 flip angle; receiver bandwidth of 125 kHz) were acquired during breath-hold.

Finally, coronal T1-3D FAME (Fast Acquisition with Multiphase Efgre 3D) (4.2/2/15; repetition time ms/echo time ms/inversion time ms); 256×192 matrix; one signal acquired; 3-mm thickness with no intersection gap, 12 flip angle, receiver bandwidth of 62.50 kHz) were acquired before and during two phases of contrast material enhancement (25-75 s) with 0.1 mmol/kg gadopentetate dimeglumine (Magnevist; Schering, Berlin, Germany) as a bolus, at a rate of 2 ml/s, followed by bolus-injection of 20 ml isotonic saline. We acquired trasverse 2D fast-spoiled GR breath-hold with fat saturation 180 s after contrast material injection.

The images obtained from the T1-3D FAME sequences were successively reconstructed using a dedicated workstation (4.2 Advantage GE, Milwaukee, WI) in the axial, sagittal and oblique planes using the multiplanar reformatting algorithm.

Conventional enteroclysis (conv-E)

Conventional enteroclysis was performed as described in the literature [11]. A total of 250–500 ml of barium as 50% weight/volume barium sulfate suspension and 1,500–2,000 ml of methylcellulose (Entrocel; Lafayette Pharmaceuticals), which was composed of 500 ml of concentrated methylcellulose and 1,500 ml of water, was used. All small bowel examinations were double contrast examinations performed at our institution. All fluoroscopy was performed by a radiologist not involved in the MR procedures, and all images were digital.

MR enteroclysis and conv-E were performed the same day; the conv-E was perfomed after MRE in all patients. Following completion of MRE, conventional small bowel enteroclysis examination was performed with 3–5 h interval. In our experience we did not have any problems of imaging quality at conv-E related to the presence of fluid remaining within the small bowel after MRE examination.

MR per OS was performed 1–4 days from conv-E (mean range 2 days).

Image analysis

The amount of time that each examination required was evaluated.

Consensus reading was performed by two abdominal radiologists (GM and EC with 8 and 6 years of experience in abdominal MR, respectively), who evaluated the image quality, the degree of small bowel distension, and the presence of superficial, mural, and mesenteric abnormalities, without any prior knowledge of the patient's clinical history or the results of conventional enteroclysis.

MR image quality was graded as follows: (1) non-diagnostic images; (2) images with numerous artifacts; (3) diagnostic images with few artifacts; (4) diagnostic images with good quality, and (5) diagnostic images with excellent quality.

Three small bowel segments were evaluated seperately: (1) jejunum, (2) ileum proximal to the terminal ileum, and (3) terminal ileum defined as the most distal 50 cm of the small bowel. For this study, jejunal loops were distinguished from ileal loops both by their respective locations

Table 1 Crohn's disease-associated radiologic abnormalities detected by conventional enteroclysis (CE) and MR enteroclysis (MRE) and MR enterography (MR per OS)

Radiologic abnormality	No. of findings					
	CE versus	MRE	(*p*)	CE versus	MR per OS	(*p*)
Superficial erosions	6	5	*NS*	4	2	*<0.01*
Mural ulcers	12	11	*NS*	9	6	*<0.01*
Mural pseudopolyps	7	6	*NS*	6	4	*<0.01*
Stenosis	12	12	*NS*	9	8	*NS*
Prestenotic dilatation	5	5	*NS*	3	2	*NS*
Fistula	8	7	*NS*	9	7	*NS*
Abscess/fluid collection	0	4	*<0.01*	0	3	*<0.01*
Separation of Small bowel	11	13	*<0.01*	9	14	*<0.01*
Lymphadenopathy	0	15	*<0.01*	0	18	*<0.01*
Skip colonic lesion	0	4	*<0.01*	0	2	*<0.01*
Detection of involved segments	25	25	NS	20	15	<0.01

NS=not significant; $p>0.05$

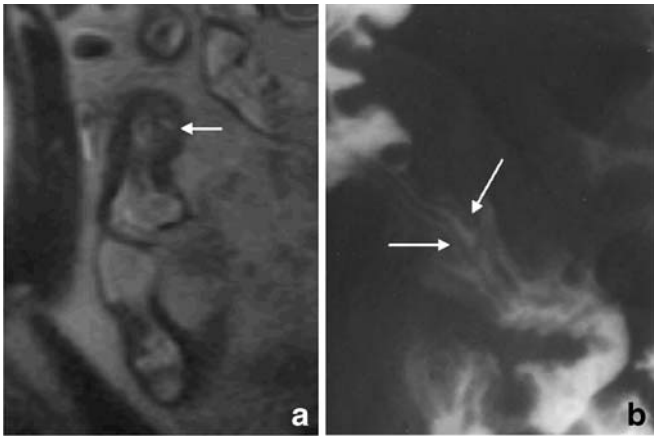

Fig. 2 A 19-year-old man with clinical remission (CDAI<150). **a** Coronal T2 weighted ssFSE (3 mm) MR enteroclysis show two dots of high signal intensity due to intraluminal fluid surrounded by a moderate signal intensity halo, the appearance of superficial erosions (arrows) in a segment with normal bowel wall thickness. **b** Conv-E shows two puntiforms collections of barium surrounded by radiolucent halos (arrows)

(left abdomen for jejunum, right abdomen for ileum) and by the appearance of their folds (more closely packed, jejunum; sparse, ileum).

The adequacy of luminal distension in the jejunum and in the proximal and terminal portions of the ileum was also graded by using a five-point scale: 0, <20% of the small bowel adequately distended; 1, 20%–40% adequately distended; 2, 40%–60% adequately distended; 3, 60%–80% adequately distended; 4, excellent distention, >80% distended.

Conventional enteroclysis and MR studies were specifically analyzed for the findings listed in Table 1. Both methods were compared for the assessment of disease extent and distribution. Conventional enteroclysis findings served as the gold standard for mucosal, mural abnormalities and fistulae.

Superficial erosions were identified as small dots of high signal intensity surrounded by a low signal intensity rim on T2-weighted sequence, less than 1 cm in diameter (Fig. 2).

Post-inflammatory regenerative pseudopolyps were defined as well-defined, round or oval filling defects (Fig. 3a).

Mural ulcer was defined as thin linear structures, exceeding the mucosa layer, and/or penetrating the thickened bowel wall (Fig. 4).

A bowel wall thickness of 3 mm or less was considered normal. Thickness was determined by means of visual inspection and with the use of calipers (Figs. 5, 6). Prestenotic dilatation was considered when the bowel lumen proximal to the stenosis measured more than 3 cm in diameter (Fig. 5). A fistula was defined as abnormal communication between two epithelial surfaces or from the bowel wall to the skin (Figs. 3c, 6). Abscesses were diagnosed as circumscribed, round, or oval fluid collections with a contrast enhancement wall (Fig. 6).

Skip colonic lesions were defined as an additional segmental inflammatory abnormalities in colonic segments.

Additional abnormalities included mesenteric lymphadenopathy and conglomeration of bowel loops, matted due to transmural inflammatory changes.

Statistical analysis

To summarize luminal distention scores, we reported the mean, standard deviation, and range of distension scores for the jejunum, ileum, and terminal ileum between MRE, MR per OS and conv-E by using the Wilcoxon rank sum test ($P \leq 0.05$ considered significant).

Receiver operating characteristic (ROC) curves were generated with 95% confidence intervals (CIs), and the area under the ROC curve (A*z*) was calculated for each imaging sign assessed in MR enteroclysis and MR per OS with images by using LABMRMC (Metz CE. LABMRMC 1.0B software, University of Chicago).

In addition, the sensitivity, specificity, positive predictive value, negative predictive value, and accuracy were assessed for each type of MR techniques in the visualization of mucosal erosions, of ulcer wall, of mural stenosis, and of fistulae.

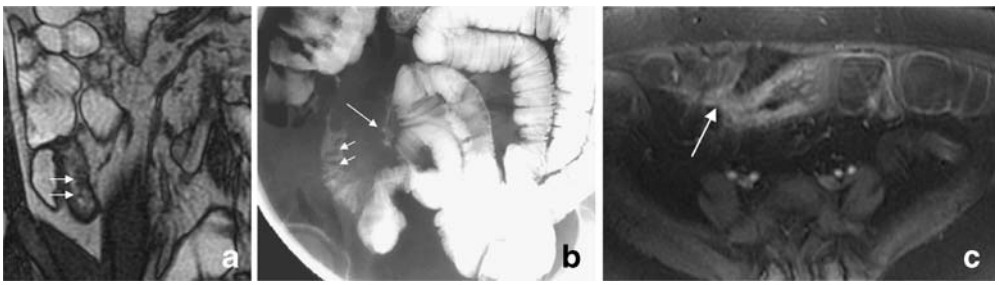

Fig. 3 A 43-year-old man with a 20-year history of Crohn's disease and clinical remission (CDAI <150). Coronal FIESTA MR enteroclysis (**a**) shows the presesence of pseudopolyps in the thickened bowel wall of the terminal ileum that appear as small nodular defects at conv-E (small arrows in **b**). **c** Axial enhanced T1 GRE shows an ileoilial fistula (arrow) as confirmed on conv-E (**b**) (long arrow)

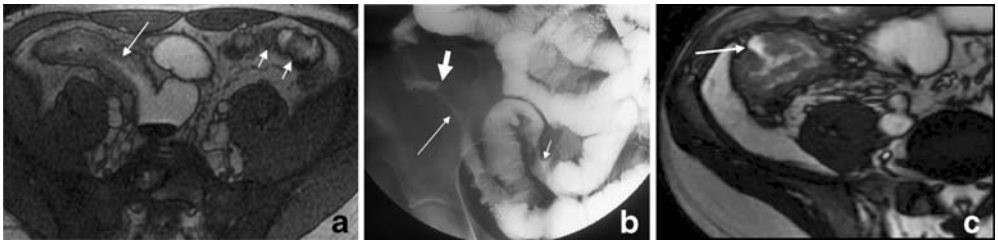

Fig. 4 A 27-year-old female with positive clinical indexes of activity (CDAI >150). **a** Axial FIESTA MR enterography images show wall thickening of terminal ileum with marked narrowing of the lumen (arrows). **b** Conventional enteroclysis confirms the marked narrowing of the lumen of the terminal ileum (arrow) and shows another marked narrowing of the proximal ileum loop (short arrow) not depicted at MR enterography due to the poor distension of some ileal loops (short arrows in A). **c** Axial FIESTA acquired at an above level compared to Fig. A shows the presence of ulcer walls that appear as thin lines of high signal intensity, longitudinally or transversely (arrows), oriented within the thickened bowel wall as shown at conv-E (thick arrow in **b**)

Statistical analysis other than ROC analyses was performed with commercially available software (SPSS 10.0 for Windows; SPSS, Chicago, IL).

Results

MRE and MRI per OS examinations were well tolerated by all patients. No clinically significant side effects occured in either the adults or the pediatric population.

Two patients had mild nausea during the exam, but no patients were excluded from the study because they were unable to finish the examination.

The duration of MRE was 30–35 min (range) and 31 min (mean), the time of the small bowel filling was 10–15 min (range) and 12 min (mean), while the duration of MR per OS was 16–22 min (range) and 19 min (mean).

The time needed for duodenal intubation was 8–21 min (range), 12 min (mean).

The time difference between the two MR tecniques was statistically significant ($p<0.01$).

The average scores of imaging quality were 4.5 for MRE and 4.4 for MR per OS.

Reasons for reduced image quality were motion artifacts caused by bowel movement (n=8), breathing or motion (n=5), and coprostasis (n=2). There were no statistically significant differences between the imaging quality of the two MR procedures ($p=0.13$).

Good or excellent small bowel filling and distension were obtained in 21/22 patients (95%) examined with MRE and in 12/18 (66%) with MR per OS.

There was no significant difference in the adequacy of luminal distention between MR enteroclysis and conv-E ($p=0.08$), and both were statistically superior in comparison to MR enterography in the distension of jejunum ($p<0.01$), and less significant at the ileum and terminal ileum levels($p<0.05$) (Table 2).

Twenty-four out of 40 (60%) patients had abnormal findings at conv-E. In the segment-by-segment analysis, 120 segments were evaluated. A total of 45/120 (38%) segments were affected by Crohn's disease at conv-E; 4/45 (9%) of the involved segments were located at the jejunum, 11/45 (24%) at the ileum and 30/45 (67%) at the terminal ileum.

Twenty-five of 45 (56%) segments were tested by MRE located 2/25 (8%) at the jejunum, 7/25 (28%) at the ileum and 16/25 (64%) at the terminal ileum, respectively, while

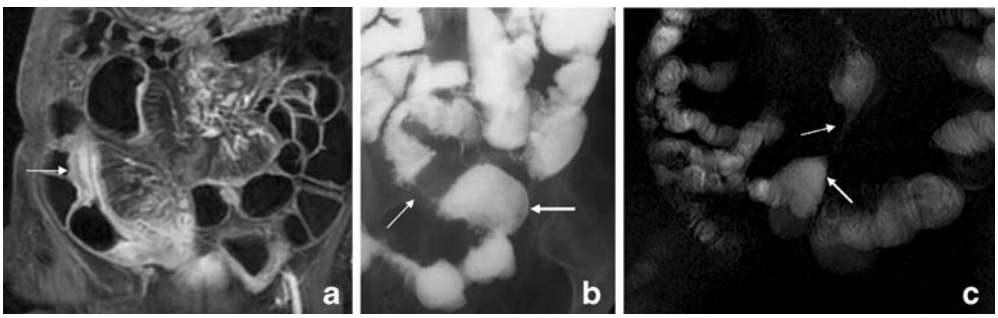

Fig. 5 A 46-year-old male patient with positive clinical activity indexes (CDAI >150). Patient history included recent mild worsening of symptoms. **a** Coronal-enhanced T1 GRE MR enteroclysis image shows segmental wall thickening with layered enhancement of the wall and marked narrowing of the lumen of the terminal ileum (arrow). **b** Conv-E confirms the presence of marked narrowing of the lumen of the terminal ileum (arrows). The high grade of the stenosis with dilatation of the bowel loop proximal is shown (thick arrows). **c** MR fluoroscopy sequence shows the high grade of the stenosis (arrow) with dilatation of the bowel loop proximally (thick arrow)

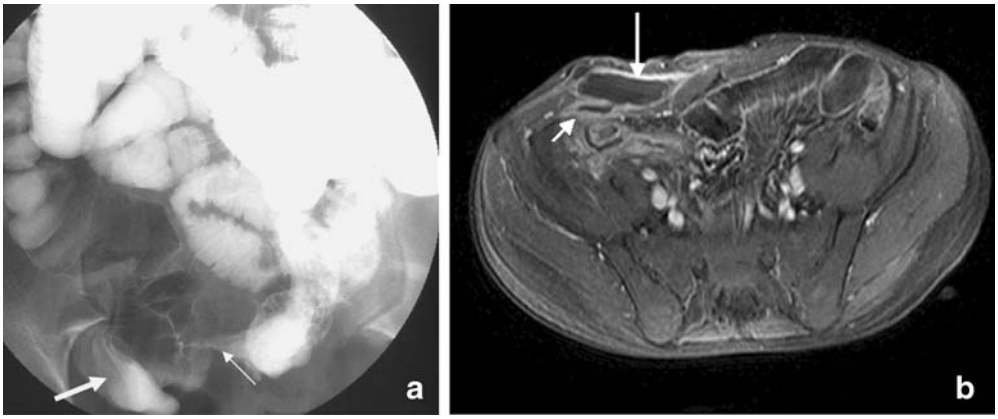

Fig. 6 A 25-year-old woman with positive clinical activity indexes (CDAI >150) and abdominal pain. **a** Conventional enteroclysis image shows a stenotic segment of distal ileum (thin arrow) from which contrast material has been extravasated (thick arrow). **b** Axial enhanced T1-weighted images show the contrast enhancement of the wall of the abscess (arrow). Sinus tract communicating between terminal ileum and an abscess in the abdominal wall is shown as the central low signal intensity cavity surrounded by a brightly enhancing rim (short arrow)

20/45 (44%) segments were tested by MR per OS located 2/20 (10%) at the jejunum, 4/25 (20%) at the ileum and 14/20 (70%) at the terminal ileum, respectively.

MRE localized and estimated the length of the affected segments in all cases (25/25), while MR per OS failed to detect 5/20 (25%) segments affected; two segments were located at the jejunum, one of the proximal ileum, and two of the terminal ileum. In 4/5 of these segments the superficial ulcers were the only sign of disease, while in 1/6 segments the ulcer was associated with bowel wall thickness.

There was a significant difference ($p<0.01$) between MRE and MR per OS in detecting affected segments (Table 1).

The sensitivity, specificity, positive predictive value, negative predictive value, accuracy, and area under the ROC curve (A*z*) are reported in Tables 3 and 4 for each type of MR technique in the visualization of mucosal erosions, ulcer wall, regenerative pseudopolyps, parietal stenosis, and fistulae.

Conv-E shows more mucosal and mural abnormalities than MRE, but it is not statistically superior ($P=0.07$); meanwhile conv-E was statistically superior compared to MR per Os ($P<0.01$) (Table 1).

Superficial erosions, deep ulcers in the wall, and pseudopolyps were statistically better delineated with MRE than MR per os ($p<0.01$).

No statistically significant differences were found in assessing the diagnostic efficacy between MR examinations for the depiction of mural stenosis ($P=0.105$) and fistulae ($P=0.67$).

Thin-section SSFSE sequence (3 mm) was statistically better in the depiction of superficial erosions compared to FIESTA and T1-FAME ($P<0.01$).

Regarding the contribution of the different chosen sequences, the accuracy of FIESTA and SSFSE sequences was statistically higher in depicting wall ulcers compared to T1-FAME (<0.01), whereas it wasn't of statistical significance for pseudopolyps and fistulae depictions ($p>0.05$). Contrast T1-FAME was superior for mural stenosis

Table 2 Overall distention of the three different examination procedures

Diagnostic procedure	Location		
	Jejunum	Ileum	Terminal ileum
MR enteroclysis (MRE)	3.1±0.6	3.6±0.4	3.5±0.6
MR enterography (MR OS)	2.0±0.3	2.9±0.2	3.0±0.6
Conventional ent (conv-E)	3.5±0.6	3.4±0.6	3.6±0.8
P Value			
MRE *vs* MR OS	p<0.01	p<0.05	p<0.05
MRE *vs* Con-E	p>0.05	p>0.05	p>0.05
MR OS *vs* Con-E	p<0.01	p<0.05	p<0.05

Numbers are presented as mean ± standard error of the mean on a scale from 1 (poor) to 5 (excellent).

Table 3 Comparison results of various MRE imaging findings by considering conv-E as a gold standard

Imaging sign	Sensitivity (%)	Specificity(%)	PPV (%)	NPV (%)	Accuracy (%)	Area under ROC (95% CI)
Mucosal erosion	67%	98%	80%	96%	95%	0.725 (0.654–0.823)
Mural ulcers	84%	98%	91%	97%	95%	0.854 (0.795–0.939)
Pseudopolyps	86%	100%	100%	85%	98%	0.880 (0.827–0.903)
Stenosis	100%	100%	100%	100%	100%	1.000 (0.933–1.000)
Fistulae	88%	100%	100%	98%	98%	0.932 (0.880–0.990)

visualization compared to SSFSE ($p<0.01$) and FIESTA ($p<0.01$).

Additional information about MR studies was obtained from 19/40 patients (47%).

The number of detected abscesses, fibrofatty proliferation, lymphadenopathy, and skip colonic lesions was significantly higher with MRE enteroclysis and with MR enterography compared to conv-E ($p<0.01$) (Table 1).

There was no difference in the diagnostic sensitivity of these additional findings between MRI after enteroclysis and MRI with oral contrast only ($p>0.05$).

MR imaging revealed seven abscesses (four with MRE and three with MR per OS); all abscesses were confirmed at surgery, but were undetected at conv-E. Twelve of 40 (30%) patients underwent surgery to treat an abscess (n=7), severe intestinal stenosis (n=3), and a complex enteroenteric and entero-colic fistula (n=2). In five patients, intestinal inflammation, defined by thickening of the bowel wall or contrast enhancement after IV Gd-DTPA of the surrounding fat tissue, was found in the colon. Other important findings seen exclusively on MR images were mesenteric lymphadenopathy in 15 patients, mesenteric fibrous and fatty proliferation in 13 patients, fluid collection in 4 patients, and diverticular disease of the sigmoid colon in 3 patients.

Discussion

Two major techniques are used to achive this bowel distension: MR enteroclysis (MRE) with infusion of the contrast through a nasojejunal tube and MR enterography with oral contrast administration (MR per os) [4, 5, 9, 10]. Conv-E has been documented in the literature as the most accurate radiologic method for the diagnosis of Crohn's disease and obstruction of the small bowel. Some authors have reported a sensitivity of 98.2% and a positive predictive value of 93.4% [11, 12]. The biphasic enteroclysis examination, with methylcellulose as the double-contrast agent, has been the most commonly performed enteroclysis method in many countries [13–15]. However, it has two major disadvantages: limited information regarding the extramural-mesenteric extension of the disease and the radiation exposure for the patients, who are mainly young patients.

As patients with Crohn's disease normally undergo several radiological investigations of the small bowel during the course of their disease, comparability of diagnostic efficacy of conv-E, MRE, and MR per OS is of clinical importance. One previous study has compared the diagnostic and technical value of MRE and MR per OS with conv-E [15]; in that study no difference in the image quality and filling of the proximal small bowel were found, while in the terminal ileum the image quality and filling was slightly better with MRE. In their study MRE was performed immediately after conv-E. It was reported that because of technical and organizational reasons, patients had to wait an average of 26 min between conv-E and MRE, so there was less bowel distension than MRE during intraluminal administration of the contrast, and the MR fluoroscopy was not performed. For these reasons they didn't correlate the state of the art of MRE during infusion of a contrast agent with MR per os as we have done in this study. Other authors [16] compared MRI per OS and MRE in patients with suspected Crohn's disease and found that the bowel distension in MRI per OS was inferior to that achieved with MRE, but the diagnostic accuracy in the terminal ileum was not statistically different. However

Table 4 Comparison results of various MR per OS imaging findings by considering conv-E as a gold standard

Imaging sign	Sensitivity (%)	Specificity(%)	PPV (%)	NPV (%)	Accuracy (%)	Area under ROC (95% CI)
Mucosal erosion	50%	78%	66%	73%	72%	0.540 (0.480–0.601)
Mural ulcers	56%	96%	83%	93%	93%	0.668 (0.510–0.750)
Pseudopolyps	67%	98%	80%	97%	88%	0.774 (0.624–0.883)
Stenosis	89%	100%	100%	98%	98%	0.855 (0.695–0.889)
Fistulae	78%	100%	100%	90%	90%	0.875 (0.722–0.927)

superficial abnormalities and fistulas were not evaluated in their study as well as lesions in the jejunum.

Some authors have stated that CT enterography is as good as CT enteroclysis [17], but the infusion of contrast material was not continuous in their study as it should be with enteroclysis.

According with another author [18] unless enteroclysis (enteric infusion) is performed, there is no oral contrast material that adequately distends the entire small intestine.

Good distension of small bowel loops during MR examinations is crucial to evaluate of bowel wall pathologies correctly, because collapsed bowel loops can hide lesions or mimic disease by suggesting pathologically thickened bowel wall in collapsed segments [3, 6].

In our study there was no statistical difference in luminal distention of the ileum between MRE and conv-E ($P > 0.05$), whereas both were statistically better in comparison to MR per OS in luminal distension of all small bowel segments (Table 3). Our results indicate that MRE and conv-E are comparable regarding the accuracy of intraluminal findings. In fact, based on the our data (Table 1) conv-E shows more mucosal and mural abnormalities than MRE, but it is not statistically superior, while conv-E and MRE were statistically superior compared to MR per OS in visualizing superficial changes.

The lowest agreement between MR per OS and conv-E was found in the detection of superficial abnormalities, because it is necessary to obtain an optimal distension of the small bowel wall to identify this subtle lesion. In particular there was a significant difference when comparing ulcers as the only sign of disease between MRE and MR per os ($p < 0.5$), and this aspect is important in detecting involved segments in patients who have only superficial abnormalities.

According to recent studies, the use of sequences with a thin section improves spatial resolution in the visualization of superficial abnormalities [19, 20] (Fig. 2).

The superficial erosions may heal or may enlarge and coalesce to form deeper, usually linear ulcerations, which frequently assume a longitudinal and trasverse orientation that appears at T2-weighted images as thin lines of high signal intensity within the thickened bowel wall (Fig. 4).

MRE has better soft tissue contrast, showing it to be far more sensitive in detecting mucosal lesions of the small bowel than CT enteroclysis [21], and for this reason MR seems superior in the the detection of segments with only superficial abnormalities.

Wireless capsule endoscopy (WCE) will probably become the best method for visualizing mucosal abnormalities; in a recent study MRE had a lower sensitivity compared to WCE for proximal small bowel lesions in 18 patients with known Crohn's disease [22]. However WCE is not able to assess mural and mesenteric abnormalities and is controndicated in patients suspected of bowel stricture, history of prior small bowel surgery, swallowing disorders, motility disorders, and intestinal pseudobstruction [23]. Other disadvantages of WCE are its inability to definitively localize the lesions, to have a biopsy of them and to visualize extraluminal manifestations. For these reasons according to other authors MR should be performed before WCE examination [23].

In the present study no significant difference was found between MR enteroclysis and MR enterography in the detection of mural stenosis ($P=0.105$) (Figs. 4 and 5). The use of thinner sequence, as used in our study and in recent studies, has increased the diagnostic accuracy of MR in depicting fistulae [19, 20]. In our series there was no significant difference ($P=0.67$) between MRE an MR per os in the detection of fistulae. Both the transmural component of Crohn's disease as well as extraintestinal complications associated with Crohn's disease cannot be assessed with endoscopy and conventional enteroclysis [11, 12]. In both MRI modalities, additional diagnostic information was obtained in 47% of patients, in agreement with other studies reporting 25%–58% additional pathological findings [20, 25–27] (Fig. 6). Our results point out that MRE and conv-E were comparable in the evaluation of patients with Crohn's disease, and both were superior to MR per OS when evaluating the superficial and intraluminal abnormalities, whereas there were no statistical differences in the assessment of parietal stenosis and fistulae among the three techniques. Both MR techniques were better than conv-E in evaluating mesenteric manifestations and colonic skip lesions; conv-E can only evaluate the cecal region and the ascending colon partially because of insufficient filling. Moreover, another important advantage of MRI over small bowel X-ray is based on its superb soft tissue contrast and its information about wall vascularity that enable differentiating active inflammation from fibrosis. Some studies have suggested that the layered pattern of enhancement on T1 with gadolinium (Fig. 5a) and the increased signal of water on T2 ssFSE sequences are specific for active disease [28, 29]. As radiation exposure is significant and diagnostic capability for extraluminal disease limited, conventional enteroclysis should be abandoned as a diagnostic tool for inflammatory bowel disease if the modern MRI tecnique is available [24]. There are some limitations to our study: firstly, MR findings were not correlated in all patients with a real gold standard for mesenteric abnormalities; the lack of a non-surgical "gold standard" for comparison is the most common problem inherent in diagnostic studies in small bowel Crohn's disease. Secondally, there is a small discrepancy between the two groups: the patients assigned to MRE had conv-E on the same day, while those assigned to MR per OS has the exam 1–4 days following conv-E. This delay of a few days between the tests could affect the presence or absence of some disease-related findings. MR enteroclysis and conventional enteroclysis are comparable for evaluating patients with Crohn's disease, and both are superior to MR enterography when evaluating the mucosa and intraluminal abnormalities. MR imaging should replace conventional

enteroclysis with suspected as well as known Crohn's disease. MRE delineates superficial changes better than MR per OS, and this aspect has to influence the revealing and localizing of the disease in patients with only superficial manifestations. For these reasons MRE should be preferred as the initial study in patients with suspected Crohn's disease, while MR per OS can play an important role in patients who refuse or fail to have intubation and also for follow-up in patient's with known Crohn's disease.

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