Original Research

Small Bowel Hydro-MR Imaging for Optimized Ileocecal Distension in Crohn's Disease: Should an Additional Rectal Enema Filling Be Performed?

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Purpose: To assess the impact of an additional rectal enema filling in small bowel hydro-MRI in patients with Crohn's disease.

Materials and Methods: A total of 40 patients with known Crohn's disease were analyzed retrospectively: 20 patients only ingested an oral contrast agent (group A), the other 20 subjects obtained an additional rectal water enema (group B). For small bowel distension, a solution containing 0.2% locust bean gum (LBG) and 2.5% mannitol was used. In all patients, a breathhold contrast-enhanced T1w three-dimensional volumetric interpolated breathhold examination (VIBE) sequence was acquired. Comparative analysis was based on image quality and bowel distension as well as signal-to-noise ratio (SNR) measurements. MR findings were compared with those of conventional colonoscopy, as available ($N = 25$).

Results: The terminal ileum and rectum showed a significantly higher distension following the rectal administration of water. Furthermore, fewer artifacts were seen within group B. This resulted in a higher reader confidence for the diagnosis of bowel disease, not only in the colon, but also in the ileocecal region. Diagnostic accuracy in diagnosing inflammation of the terminal ileum was 100% in group B; in the nonenema group there were three false-negative diagnoses of terminal ileitis.

Conclusion: Our data show that the additional administration of a rectal enema is useful in small bowel MRI for the visualization of the terminal ileum. The additional time needed for the enema administration was minimal, and small and large bowel pathologies could be diagnosed with high accuracy. Thus, we suggest that a rectal enema in small bowel MR imaging be considered.

Key Words: small bowel hydro-MRI; Crohn's disease; bowel distension; terminal ileum; ileocecal valve
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THE CLINICAL DIAGNOSIS of small bowel disease is complicated by nonspecific symptoms and a low index of suspicion. Therefore, a diagnostic test for identification of disease should be as noninvasive as possible, to reduce harm to the large subgroup of nondiseased patients (1,2).

Conventional enteroclysis, the infusion of contrast medium via a nasoduodenal tube directly into the small bowel, is a precise, rapid method for thorough small bowel examination. The principal advantage of conventional enteroclysis is that the jejunum and ileum can be optimally distended (3–5). However, conventional enteroclysis is invasive and painful, and it makes use of a relatively high dose of ionizing radiation; furthermore, it provides only indirect information on the state of the bowel wall (3–7). A technique that could combine enteroclysis with cross-sectional imaging methods would be expected to take the diagnosis of small bowel disease a step further.

Today, there is great consensus about replacing the conventional Sellinck test by computed tomography (CT) or MRI of the small bowel (8–12). The advantage of MRI is that it is not only not burdened by ionizing radiation, but it can also be performed without the insertion of a nasoduodenal tube, thus increasing patient acceptance. For this purpose, a high osmotic oral contrast agent is given, which leads to sufficient distension of the jejunum and ileum (10,12).

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It is known that Crohn's disease mostly affects the terminal ileum and/or the ilioceal region. Therefore, a good distension of the terminal ileum and ileocecal region is also necessary to detect inflammations in these regions (13–17). Theoretically, this could be facilitated by applying an additional rectal enema.

The purpose of this study was to assess the impact of rectal enema filling combined with oral small bowel distension (hydro-MRI) in patients with Crohn's disease for better visualization of the terminal ileum and the ileocecal region. Furthermore, pathologies of the large bowel were documented and compared to colonoscopy.

MATERIALS AND METHODS

The study was performed according to good clinical practice (GCP)-rules and was approved by the local ethics committee. Written informed consent was obtained from all patients. Exclusion criteria included contraindications to MRI, such as presence of a pacemaker, metallic implants in the central nervous system, or claustrophobia.

Subjects

Over an eight-month period, 40 patients with known Crohn's disease underwent a hydro-MRI examination (23 women, 17 men, age range 19–47 years, mean age 33 years). A total of 20 patients ingested only the oral contrast agent (group A); the other 20 (group B) ingested the oral contrast agent and obtained an additional rectal water enema. Patients had been referred to hydro-MRI for various clinical indications including abdominal pain (N = 9), suspected active inflammatory process (N = 21), suspected bowel obstruction (N = 6), and suspected abdominal fistulae (N = 4).

Small Bowel Distending Agent and Patient Preparation Protocol

A 0.2% nonosmotic locust bean gum solution (LBG; Roeper, Hamburg, Germany) was used as a baseline substance for oral ingestion. LBG is extracted from the seeds of *Ceratonia siliqua*, the European carob tree. It is known for its thickening properties and is used in ice creams, dairy gels, and canned products (18). The baseline LBG solution was mixed with the additive mannitol in 2.5% concentration (Merck, Darmstadt, Germany). The choice of LBG and mannitol concentrations was based on previous studies (12).

A 1.5-liter LBG/mannitol solution was given orally over 45 minutes prior to the MR examination. To assure homogenization of bowel activity across subjects and examinations, all MR examinations were performed following a six-hour fasting period. Prior to each examination, 1500 mL of the respective contrast solution was orally ingested continuously over 45 minutes at an evenly distributed rate. To ensure a consistent ingestion, volunteers were asked to drink 150 mL every four minutes. To enhance gastric emptying, 100 mg erythromycin (Abbott Pharmaceutics, Wiesbaden, Germany) was administered intravenously directly following the ingestion of the first 150 mL of the contrast solution. Erythromycin in low doses can be used for faster emptying of the stomach (19,20); earlier attempts without erythromycin had shown a delayed gastric emptying with associated nausea and vomiting (personal observation).

Rectal Enema Filling and MRI

Without any prior bowel preparation, following the placement of a rectal enema tube (E-Z-Em; Westbury, NY, USA), the colon was filled with approximately 500–1000 mL of warm tap water using hydrostatic pressure (1–1.5-m water column). No fluoroscopic guidance was used, as our experience shows that only the subjective beginning pain marks the maximum amount of administerable rectal water.

To minimize bowel peristalsis, 40 mg of hyoscine butylbromide (Buscopan®; Boehringer Ingelheim, Germany) were injected intravenously either immediately before the MR examination (in the case of non-hydro-MRI) or prior to the colonic filling. All patients did not present any contraindications to the administration of scopolamine, such as the presence of glaucoma or severe cardiac arrhythmia. MR examinations were performed on a 1.5-T system (Magnetom Sonata; Siemens Medical Systems, Erlangen, Germany) equipped with high-performance gradient systems characterized by a maximum gradient amplitude of 40 mT/m and a slew rate of 200 mT/m/msec. For signal reception a set of two large flex surface array coils was used together with the built-in spine array coils. Patients were examined in the prone position, as this reduces bowel and respiratory movement, leading to higher image quality. A T1w three-dimensional gradient echo data set with integrated fat suppression (volumetric interpolated breathhold examination [VIBE] sequence) was collected in the coronal plane. Sequence parameters included: TR/TE = 3.1/1.1 msec, flip angle = 12°, field of view (FOV) = 450 × 450 mm, matrix size = 168 × 256, number of slices = 96, and use of zero filling interpolation with a slice thickness of 3 mm and an effective slice thickness of 1.54 mm. Subsequently, paramagnetic contrast (Gadolinium (Gd)-BOPTA, Multihance®, Bracco, Italy) was administered intravenously at a dosage of 0.2 mmol/kg and a flow rate of 3.5 mL/second. Following a delay of 75 and 120 seconds, the three-dimensional acquisition was repeated twice with identical imaging parameters. The three-dimensional data were collected with breathholding in 22 seconds.

Data Analysis

For each subject, the precontrast and both contrast-enhanced VIBE three-dimensional MRI data sets were transferred to a postprocessing workstation (Virtuoso; Siemens Medical Solutions, Erlangen, Germany). Regarding the presence of pathologies, all data sets were then assessed by two radiologists in a consensus mode. A multiplanar reformation mode was used, which permitted scrolling through the three-dimensional data sets in all three orthogonal as well as oblique planes.

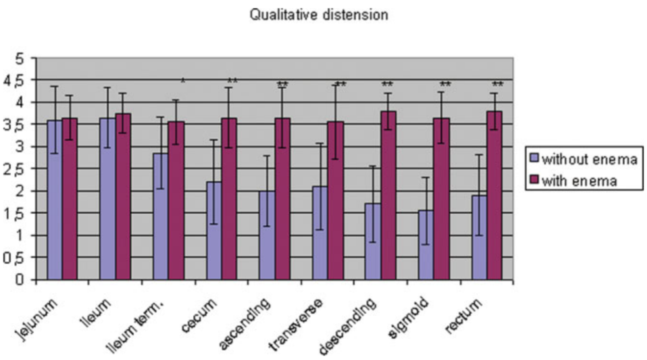

Figure 1. Qualitative distension of the terminal ileum and the whole colon was significantly higher after rectal enema with water, when compared to nonenema MR ($*P < 0.02$; $**P < 0.005$).

Small and Large Bowel Distension

All qualitative and quantitative analyses were performed by the same abdominal radiologists. The image quality was assessed both qualitatively and quantitatively. The distension of each colonic segment was classified as: 1 = excellently distended, 2 = well distended, 3 = moderately distended, and 4 = poorly distended. For purposes of analysis the small bowel was divided into jejunum, ileum, and terminal ileum, the colon was divided into six segments: rectum (s1), sigmoid colon (s2), descending colon (s3), transverse colon (s4), ascending colon (s5), and cecum (s6).

The quality of visualization and distension of the terminal ileum and the ileocecal region was assessed and classified as: 1 = excellently distended, 2 = well distended, 3 = moderately distended, and 4 = poorly distended. Furthermore, each region was evaluated for the presence of artifacts (susceptibility artifacts and motion artifacts): 1 = no artifacts, 2 = little artifacts, 3 = moderate artifacts, diagnostic image quality, and 4 = extensive artifacts, nondiagnostic image quality. For this purpose, the reader was asked to scroll coronally through the various bowel parts. All MR data sets were assessed for the presence of inflammatory bowel disease (IBD). Employed criteria included bowel wall thickening, increased contrast uptake of segmental parts of the bowel, and loss of haustral folds (1 = definitively affected, 2 = probably affected, 3 = indefinite, 4 = probably not affected, and 5 = definitively not affected).

Wall Thickness and Signal-to-Noise Ratio (SNR)

For all bowel parts the wall thickness was measured. To determine this parameter the coronal MR images were magnified by a factor of three.

For quantitative analysis, regions of interest (ROIs) were placed in the wall of all segments (SI). Image noise, defined as the SD of signal intensities measured in a ROI placed outside the body, was determined. Based on these measurements SNRs for representative parts of all bowel segments were calculated (SNR = SI (bowel wall)/(SD of image noise)). SNR was measured for native and both contrast-enhanced data sets.

Conventional Colonoscopy

After completion of the MR examination, conventional colonoscopy was performed using standard equipment (model CFQ 140; Olympus). Time delay between MR and colonoscopy varied between three hours and one week. The attending gastroenterologist was unaware of the MR findings. When necessary, sedatives (Midazolam, Dormicum®, Roche, Germany) or analgesics (Pethidin, Dolantin®; Hoechst, Germany) were administered. Location of inflammatory lesions and colorectal masses were recorded and biopsied. All biopsy materials were analyzed by histopathology.

Statistical Analysis

Ratings of both groups were compared by a Wilcoxon rank test, considering a *P*-value of <0.05 to indicate a statistical significance.

RESULTS

All 40 patients tolerated the MR examination well and no complications occurred in conventional colonoscopy.

Distension

Regarding the qualitative and quantitative assessment of the distension within the jejunum and ileum, no statistically significant differences were found for both groups. However, the distension grade was higher in the enema group for the terminal ileum and all colonic parts, which was statistically significant (Figs. 1 and 2). The qualitative and quantitative distension of the terminal ileum were valuable predictors of disease: the area under the receiver operating curve (ROC) was 0.68 and 0.74, respectively, which is statistically significantly more "accurate" than guessing.

Artifacts

Concerning the presence of artifacts and the diagnostic accuracy, statistically significant differences were found for the rating for the terminal ileum and the whole colon in favor of the enema group ($P < 0.04$), but not for the jejunum and ileum in both groups (Fig. 3).

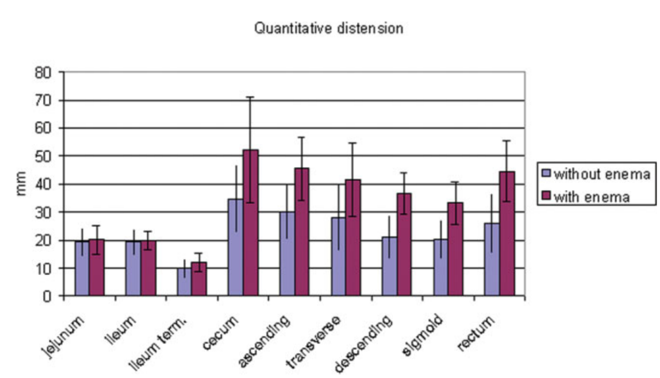

Figure 2. Quantitative distension of the bowel segments. A significantly higher distension is reached by additional rectal enema ($P < 0.005$ for the colon).

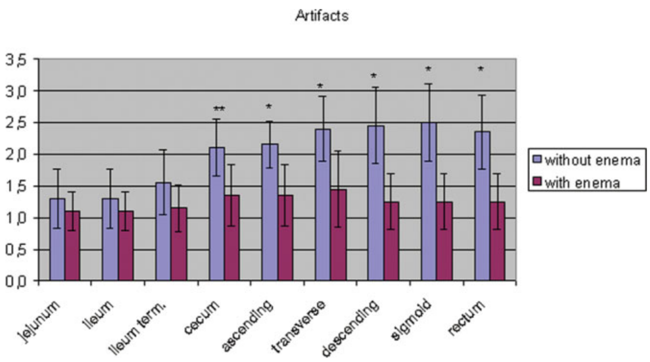

Figure 3. Artifacts are rated higher for nonenema MR (**$P <$ 0.01; *$P < 0.005$).

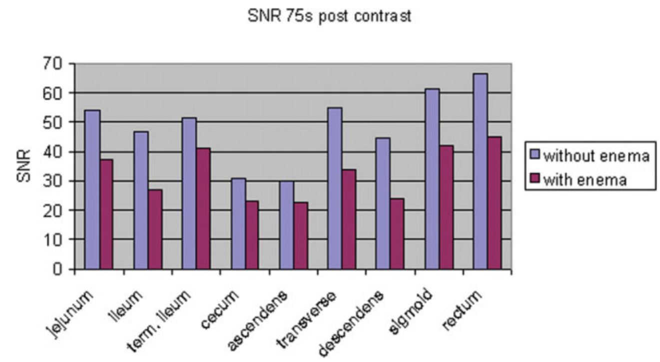

Figure 5. SNR of the bowel wall was lower for the enema MR group than for the nonenema MR group, if postcontrast signals are assessed. Differences are statistically significant for terminal ileum and all colonic parts.

Thickness of Bowel Wall

The wall thickness was significantly lower in all colonic parts in the enema group than in the nonenema group; jejunum, proximal ileum, and the terminal ileum did not show significantly different wall thickness (Fig. 4). Correlations between wall thickness and bowel involvement, according to the reader's judgment, were significant for the terminal ileum and all colonic parts ($P <$ 0.01).

Signal-to-Noise-Ratio (SNR) of Bowel Wall

Only in the first postcontrast phase, differences in SNR between the enema MR-group and nonenema MR-group were statistically significant for the terminal ileum and the whole colon (Fig. 5).

Bowel Findings

A total of 27 patients underwent conventional colonoscopy within a time frame of one week after the MR examination. The sigma was not passable in one of these 27 patients, and the right colonic flexure was not passable in another patient. Thus, 25 subjects had a complete conventional colonoscopy (11 in the enema group and 14 in the nonenema group).

In the nonenema group, the reader rated the presence and absence of disease in the terminal ileum as uncertain in one case, whereas no uncertainty occurred in the enema group.

Regarding the analysis of patients with a complete endoscopic reference standard, seven patients of the enema group showed an inflammation of the terminal ileum (ileitis terminalis) (Fig. 6). Furthermore, in three patients the large bowel was affected (one case with segmented colitis, and two with pancolitis), and in three patients small and large bowel were unsuspicious. In addition, in two patients with pancolitis multiple hyperplastic small polyps (Fig. 7) and in two patients interenteric fistulae were correctly diagnosed (Table 1). Thus, all of the MR diagnoses in these patients were correct for the terminal ileum as well as for the colon, resulting in a sensitivity, specificity, and accuracy of 100%.

In the nonenema group, 14 patients were included in the analysis with presence of a complete reference standard. The entire small and large bowel was classified as normal in six of these 14 patients both by MRI and endoscopy. By means of MRI, six patients were rated to have an inflammation of the terminal ileum (ileitis terminalis; Fig. 8), which was confirmed in only three patients by endoscopy. Due to the lack of colonic distension, no inflammatory disease of the large bowel could be visualized on the MR images (Fig. 9). However, endoscopic results revealed inflammatory changes of the colon in five patients (segmented colitis, $N = 3$; pancolitis, $N = 2$). This led to a sensitivity value of 100%, a specificity value of 72%, and an accuracy of 79% for the assessment of the terminal ileum, while the evaluation of the colon resulted in a sensitivity of 0%, a specificity of 100%, and an accuracy of 64%. (Table 2).

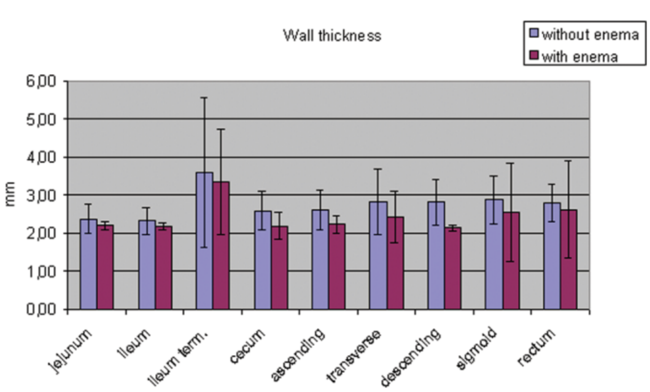

Figure 4. Wall thickness was statistically significantly higher in the nonenema group for all bowel segments.

DISCUSSION

The data presented indicate that an additional rectal enema leads to a significantly better distension of all colonic parts and additionally also of the terminal ileum. In addition, the terminal ileum and all colonic segments showed less artifacts in the enema MR than in the nonenema group. This resulted in a higher diagnostic accuracy of the large bowel in the enema group than in the nonenema group; but the most important

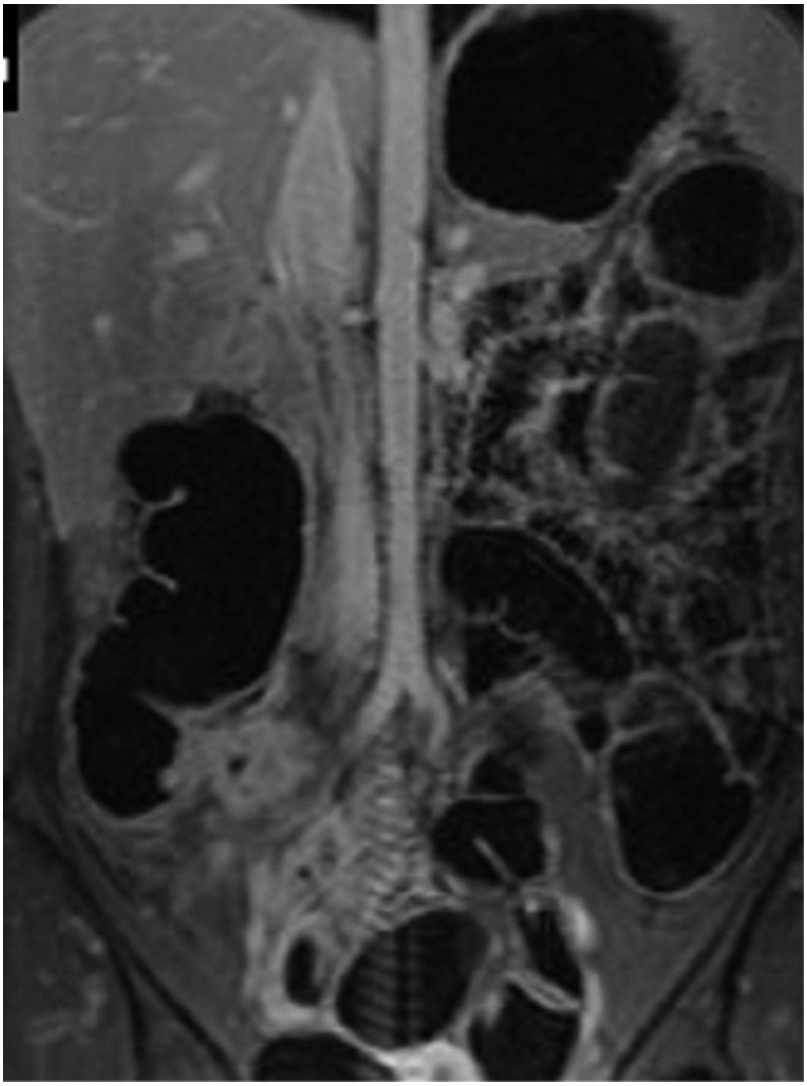

Figure 6. Additional rectal enema in hydro-MRI-exam of a 31-year-old female patient with known Crohn's disease. The colonic segments show a sufficient distension after rectal enema. The thickened wall of the terminal ileum shows an increased contrast uptake (arrow). Subsequent endoscopy and biopsy confirmed the presence of an acute inflammation of the terminal ileum.

finding of this study is that the diagnostic accuracy with relation to the terminal ileum is also increased in the enema group (100% vs. 78.6%).

MRI has emerged as alternative for imaging and diagnosis of pathologies of the small and large bowel (10,12,21–24). Based on the principles of ultrafast, contrast-enhanced three-dimensional gradient echo (GRE) acquisitions, breathhold three-dimensional abdominal imaging has become possible. With ultrafast MRI using a T1-weighted sequence (VIBE sequence), small and large bowel imaging is possible within 22 seconds (24). Many studies proved the accuracy and advantages of hydro-MR for the small bowel distension and detection of inflammatory changes of small bowel loops (3,21,25).

A new noninvasive method for the distension of the small bowel in abdominal MRI has recently been developed. A hyperosmolar solution is usually given orally before the MR examination (10,12). Due to a reduced resorption, this contrast agent leads to a high bowel distension even if applied orally without a jejunal intubation.

Dark lumen MR colonography (MRC) has been become an attractive method for the detection of colorectal pathologies and is well described in many studies (22–24). The technique is based on the acquisition of a T1w sequence collected following the administration of a water-enema and the intravenous administration of paramagnetic contrast. The technique of intravenous application of paramagnetic contrast allows for the direct depiction of the colorectal wall. Beyond the identification of colorectal lesions, dark lumen MRC permits the detection and characterization of colonic wall inflammation. Based on the assessment of both bowel wall thickness and bowel wall contrast-enhancement diverticulitis, Crohn's disease and ulcerative colitis can be diagnosed with high accuracy (24). Thus, gadolinium-enhanced MRI of the bowel has been shown to be more accurate than CT imaging (26) and has also advantages over T2w MRI (27). The underlying diagnostic criteria have been established by others (22–24). Common to all three entities, the colonic wall is thickened and characterized by an increased contrast uptake; ulcerative colitis results in a classical loss of haustral folds extending orally from the rectum, whereas skip lesions are the hallmark of Crohn's disease.

In patients with IBD, assessment of the terminal ileum and colonic segments is important for monitoring

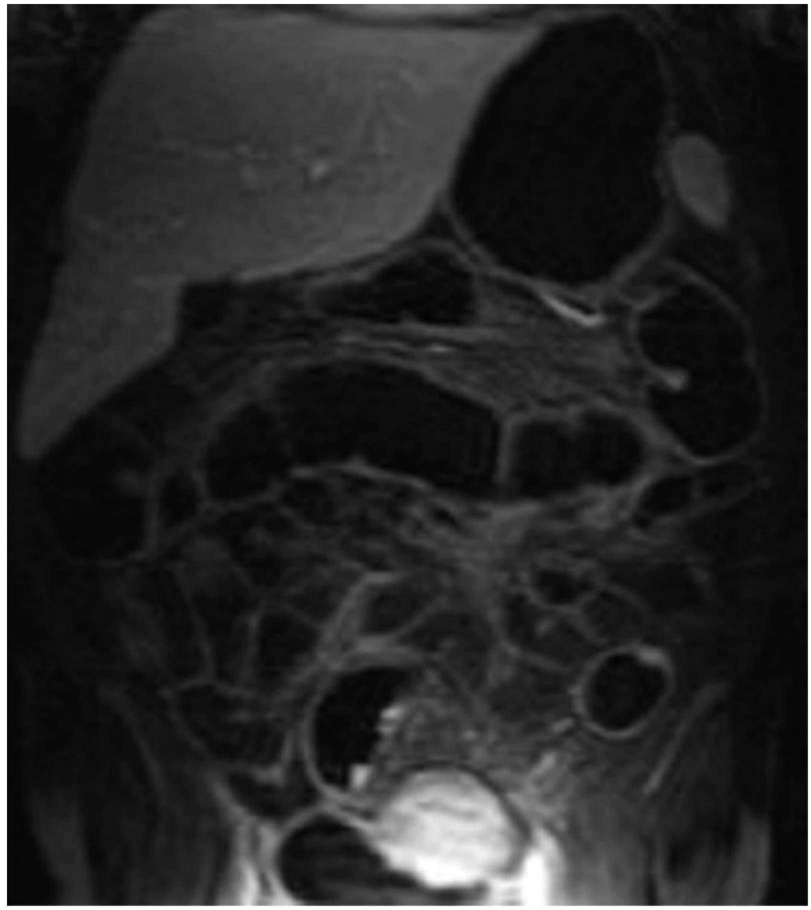

Figure 7. Additional rectal enema in hydro-MRI of a 39-year-old male patient with known Crohn's disease. Multiple hyperplastic small polyps can be detected in the descending and sigmoid colon (arrows).

and therapy. Crohn's disease predominantly involves the distal bowel (20%), the colon (30%), or the small and large bowel (50%). The diagnostic benefits of the administration of rectal enema for the diagnosis the assessment of colonic wall and colonic masses are well documented in the CT and MRI literature (23,24,28,29). Nevertheless, in Crohn's disease, MRI has in fact been shown to be more accurate than CT for demonstrating

Table 1
Diagnostic Accuracy of Hydro MR With Additional Water Enema

Enema group	MR	Coloscopy	Accuracy for terminal ileum[a]	Accuracy for colon[a]
1	Terminal ileitis	0	0	0
2	Terminal ileitis	0	0	0
3	Terminal ileitis	0	0	0
4	Terminal ileitis	0	0	0
5	Terminal ileitis	0	0	0
6	Terminal ileitis	Terminal ileitis	TP	TN
7	Terminal ileitis	Terminal ileitis	TP	TN
8	Terminal ileitis	Terminal ileitis	TP	TN
9	Terminal ileitis with segmented colitis	0	0	0
10	Terminal ileitis with segmented colitis	0	0	0
11	Terminal ileitis and pancolitis with polyps	Terminal ileitis and pancolitis with polyps	TP	TP
12	Terminal ileitis and pancolitis with polyps	Terminal ileitis with pancolitis and polyps	TP	TP
13	Terminal ileitis and fistula	Terminal ileitis and fistula	TP	TN
14	Terminal ileitis and fistula	Terminal ileitis and fistula	TP	TN
15	Normal small and large bowel	Normal small and large bowel	TN	TN
16	Normal small and large bowel	Normal small and large bowel	TN	TN
17	Normal small and large bowel	Normal small and large bowel	TN	TN
12	Normal small and large bowel	0	0	0
19	Segmented colitis	Segmented colitis	TN	TP
20	Segmented colitis	0	0	0

[a]TN, true negative; TP, true positive; FN, false negative; FP, false positive.

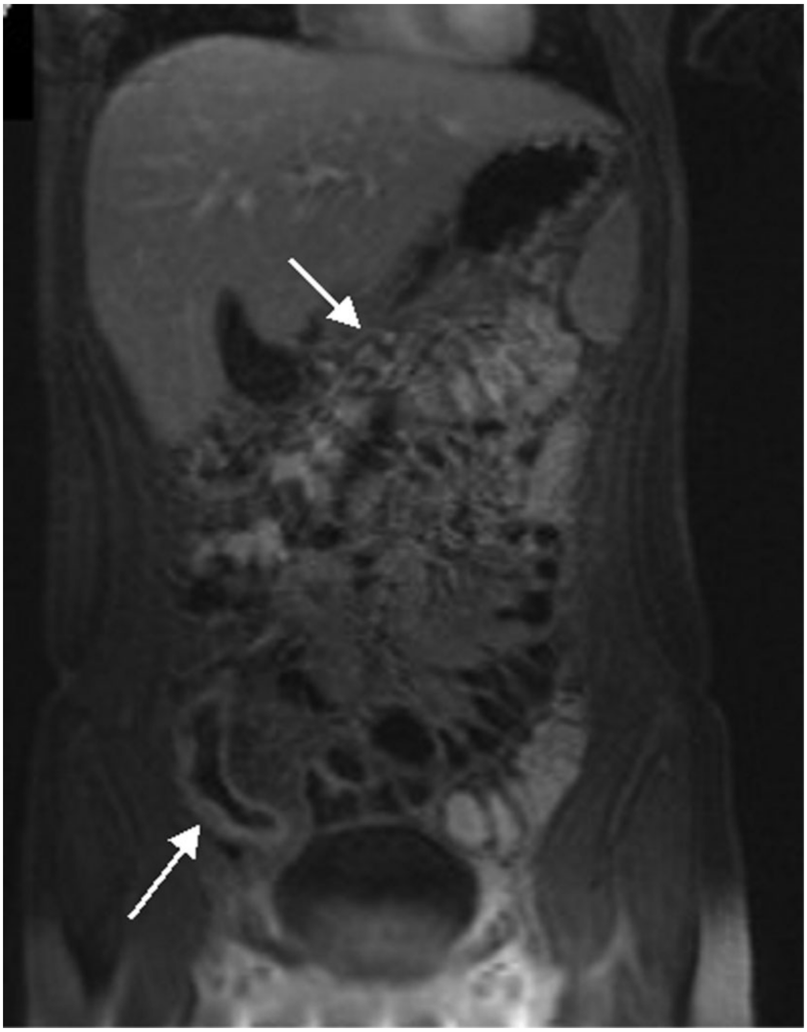

Figure 8. Hydro-MRI without a rectal enema of a 33-year-old female patient with known Crohn's disease. The colonic segments like the transversal colon (arrow) show an insufficient distension. The thickened wall of the terminal ileum shows an increased contrast uptake (arrow). Subsequent endoscopy and biopsy confirmed the presence of an acute inflammation in the terminal ileum.

well known disease characteristics, including bowel wall thickening along the mesenteric border with ulcerations, changes in the antimesenteric border, and localized fibrotic proliferations (22–24) In addition, MRI can easily detect lymphadenopathy commonly associated with Crohn's disease.

In our study, a statically significant difference between both groups were observed in favor of the enema group regarding the distension of all colonic segments and terminal ileum, the presence of artifacts, and the diagnostic confidence, not only in the colon, but also in the terminal ileum, which also lead to a higher diagnostic accuracy with respect to the diagnosis of a terminal ileitis in our study. No false result was encountered in the enema group, whereas in the nonenema group there were three false-negatives alone for the terminal ileum. This enhances the impact of a sufficient terminal ileum distension, which can be obtained by an additional rectal enema.

Wall thickness was significantly smaller in all colonic segments in the enema group than in the nonenema group due to the increased distension; only the terminal ileum did not show a significantly different wall thickness. This might reflect the high number of cases with inflammatory changes in this region; a thickened inflammatory bowel wall might not be distendable by oral or rectal distension in the same way as normal bowel wall.

The statistically significant difference in SNR of the terminal ileum and the colon between the enema and nonenema group in the first postcontrast phase might reflect a higher intraluminal pressure: an enema might lead to a reduced arterial wash-in of the contrast agent. But this did not weaken the otherwise positive results.

The lack of correlation between MRC and conventional colonoscopy findings in the nonenema group with respect to the presence of inflammation in the large bowel and the terminal ileum can be explained by insufficient distension of the colon and the impossibility of differentiating between the bowel wall and intraluminal stool, which enhances the importance of a rectal enema. The fact that some residual stool might be present did not alter the results; wall enhancement and thickening could be nevertheless observed with high confidence.

Clearly, the present study is not without its limitations. First and foremost, it must be considered that we compared two patient groups consisting of different individuals. However, this was logistically unavoidable, because otherwise our patients would have had to undergo MRI on two separate occasions. Furthermore, the

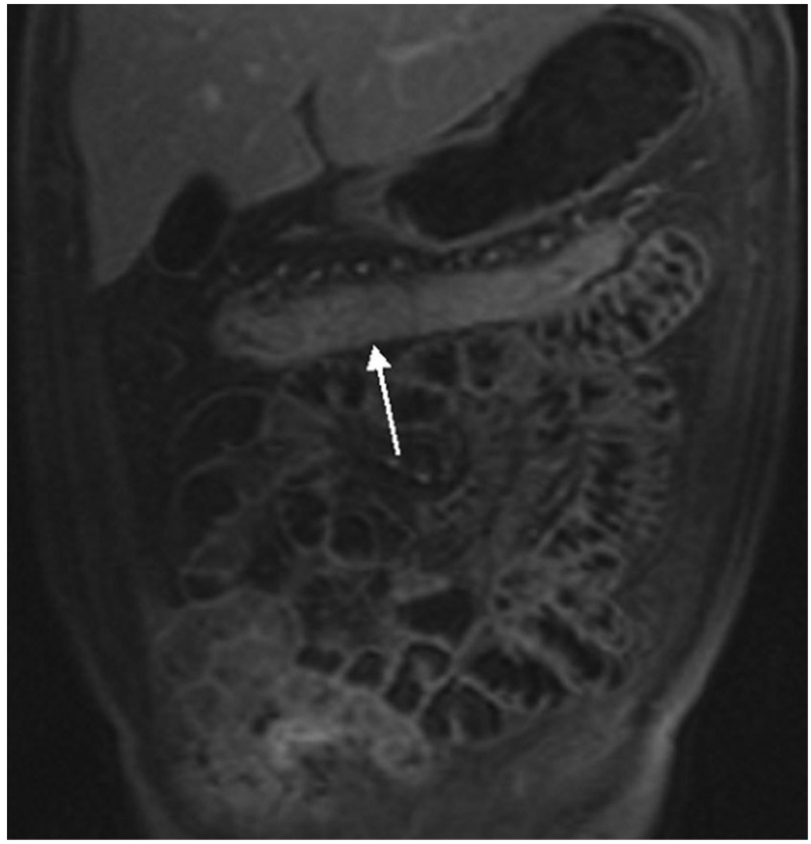

Figure 9. Hydro-MRI without a rectal enema of a 41-year-old male patient with known Crohn's disease. The colonic segments like the transverse colon (arrow) show an insufficient distension. Conventional colonoscopy diagnosed an acute inflammation in the transverse colon that was missed in MRI.

data analysis was hampered due to the lack of a full standard of reference in 15 patients. Thus, only a part of the MR examinations could be evaluated regarding the accuracy of this method for the detection of IBD.

In conclusion, we believe that the advantages of hydro-MR in combination with a rectal enema outweigh the minimally increased time effort. Furthermore, hydro-MR with additional rectal enema is technically fea-

Table 2
Diagnostic Accuracy of Hydro MR Without Additional Water Enema

Non-enema group	MR	Coloscopy	Accuracy for terminal ileum[a]	Accuracy for colon[a]
1	Terminal ileitis	0	0	0
2	Terminal ileitis	Normal terminal ileum and segmented colitis	FP	FN
3	Terminal ileitis	Normal terminal ileum and segmented colitis	FP	FN
4	Terminal ileitis	Normal terminal ileum and segmented colitis	FP	FN
5	Terminal ileitis	Terminal ileitis	TP	TN
6	Terminal ileitis and fistula	Terminal ileitis and fistula	TP	TN
7	Terminal ileitis and fistula	Terminal ileitis and fistula	TP	TN
8	Normal small and large bowel	Normal small and large bowel	TN	TN
9	Normal small and large bowel	Normal small and large bowel	TN	TN
10	Normal small and large bowel	Normal small and large bowel	TN	TN
11	Normal small and large bowel	Normal small and large bowel	TN	TN
12	Normal small and large bowel	Normal small and large bowel	TN	TN
13	Normal small and large bowel	Normal small and large bowel	TN	TN
14	Normal small and large bowel	Pancolitis	TN	FN
15	Normal small and large bowel	Pancolitis	TN	FN
16	Normal small and large bowel	0	0	0
17	Normal small and large bowel	0	0	0
12	Segmented colitis	0	0	0
19	Pancolitis	0	0	0
20	Pancolitis	0	0	0

[a]TN, true negative; TP, true positive; FN, false negative; FP, false positive.

sible and provides adequate image quality and sufficient distension of the small and large bowel, resulting in a higher diagnostic accuracy in the diagnosis of all affected bowel segments including the terminal ileum.

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