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Abbreviation:
3D = three-dimensional

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MR Colonography in Patients with Incomplete Conventional Colonoscopy[1]

PURPOSE: To assess dark-lumen magnetic resonance (MR) colonography for the evaluation of colonic segments in patients in whom conventional colonoscopy could not be completed.

MATERIALS AND METHODS: Institutional review board approval and written informed consent were obtained. Within 24 hours of incomplete conventional colonoscopy, 37 patients (22 women, 15 men; age range, 25–63 years) underwent MR colonography. Contrast material–enhanced T1-weighted three-dimensional images were collected after rectal administration of water for colonic distention. Data from MR colonography were evaluated by two radiologists. With a three-point scale, image quality was characterized in terms of colonic distention (1 = good; 2 = moderate, diagnostic; and 3 = poor, nondiagnostic) and presence of artifacts (1 = none; 2 = moderate, diagnostic; and 3 = extensive, nondiagnostic). Depiction of colorectal disease was assessed according to the following colonic segments: cecum, ascending colon, transverse colon, descending colon, sigmoid colon, and rectum.

RESULTS: Four patients had history of colorectal cancer, and each had undergone partial colonic resection of two segments. Hence, 214 segments were evaluated. Conventional colonoscopy failed in assessment of 127 of 214 potentially visible colonic segments in the 37 patients. MR image quality was rated diagnostic in 35 patients and permitted assessment of 206 of 214 potentially visible segments. Nondiagnostic image quality in two patients was attributed to inadequate distention of prestenotic colonic segments owing to high-grade tumor stenosis. All inflammation- and tumor-induced stenoses and all five polyps identified at conventional colonoscopy in poststenotic segments were correctly detected at MR colonography. However, MR-based assessment of prestenotic segments revealed two lesions suspected of being carcinoma, five polyps, and four segments affected by colitis.

CONCLUSION: MR colonography proved reliable in evaluating the majority of colonic segments inaccessible with conventional colonoscopy. The identification of additional disease at MR colonography underscores the need for a second diagnostic step in the setting of incomplete conventional colonoscopy.

Conventional colonoscopy represents the standard for the evaluation of the colon (1,2). Procedure-related discomfort and technical challenges can limit the success of colonoscopy in patients with colonic elongation, as well as in patients with inflammatory- or tumor-based stenosis (3,4). Colonic segments inaccessible with colonoscopy can be depicted with various imaging techniques. Thus, single- and double-contrast barium enema examinations have long been used for this purpose (5,6). Recently, computed tomography (CT) after colonic air insufflation, referred to as CT colonography, has been used in the setting of incomplete colonoscopy (7,8). Both techniques expose patients to ionizing radiation (9). In young patients with inflammatory bowel disease, the repetitive exposure to ionizing radiation must be considered undesirable. Magnetic resonance (MR) colonography based on the acquisition of three-dimensional (3D) data sets can overcome this

limitation. Because of its noninvasive character and lack of ionizing radiation, this technique is preferred over conventional colonoscopy by a majority of patients (10–14).

Recently, dark-lumen MR colonography has been introduced (12–15). The technique is based on the performance of a T1-weighted sequence after rectal administration of water or CO_2 for colonic distention and intravenous bolus injection of a paramagnetic contrast agent (16–18). The colonic wall enhances brightly and is thus easily delineated against the background of a dark water- or CO_2-filled colonic lumen. Authors of several studies have documented the high diagnostic accuracy of dark-lumen MR colonography with regard to its ability to depict colonic disease (12–15). Thus, the aim of our study was to assess dark-lumen MR colonography for the evaluation of colonic segments in patients in whom conventional colonoscopy could not be completed.

MATERIALS AND METHODS

Patients and Groups

Over a 9-month period, MR colonography was performed in 37 consecutive patients (22 women, 15 men; age range, 25–63 years; mean age, 45.6 years) with an incomplete conventional colonoscopy (4.8% of all colonoscopies at our center during this period). Exclusion criteria included contraindications to MR imaging, such as presence of a pacemaker, metallic implants in the central nervous system, or severe claustrophobia. Patients had been referred to undergo conventional colonoscopy for various indications, including abdominal pain (n = 11), suspected Crohn disease, ulcerative colitis or sigmoid diverticulitis (n = 9), positive result of fecal occult blood test (n = 13), and history of colorectal cancer (n = 4). The study was conducted in accordance with all guidelines set forth by the approving institutional review board. Written informed consent was obtained.

Colonoscopy revealed an impassable high-grade stenosis in 21 patients. Histopathologic examination of biopsy material obtained during colonoscopy revealed an inflammatory cause in nine patients, while a tumor was the cause of stenosis in the remaining 12 patients. Stenoses were located in the rectum (n = 5), the sigmoid colon (n = 7), the descending colon (n = 4), the transverse colon (n = 3), and the ascending colon (n = 2). Segments proximal to the site of stenosis (prestenotic) could not be assessed with conventional colonoscopy. In 10 patients, technical challenges associated with an elongated colon prohibited completion of conventional colonoscopy. In another six patients, conventional colonoscopy was terminated prior to reaching the cecum because of extreme abdominal discomfort during the procedure (n = 6).

Thus, the 37 patients making up the study were assigned into the following two groups: group A, composed of 21 patients with a high-grade stenosis, and group B, composed of 16 patients with incomplete conventional colonoscopy owing to colonic elongation and/or severe procedural discomfort.

Conventional Colonoscopy

After a standard preparation for bowel cleansing with oral ingestion of 3000 mL of macrogol (Golytely; Braintree Laboratories, Braintree, Mass), conventional colonoscopy was performed (G.H.) by using standard equipment (CFQ 140; Olympus, Tokyo, Japan). When necessary, sedatives (midazolam, Dormicum; Roche, Grenzach-Wyhlen, Germany) or analgesics (pethidin, Dolantin; Hoechst, Bad Soden, Germany) were administered. The number of fully assessable colonic segments was determined. Suspicious inflammatory lesions or colorectal masses were recorded and subjected to biopsy. All biopsy materials were analyzed at histopathologic examination. In addition, presence of colonic diverticula was assessed.

MR Colonography

All MR examinations were performed the same day following incomplete colonoscopy by using a 1.5-T MR system (Magnetom Sonata; Siemens Medical Solutions, Erlangen, Germany) equipped with high-performance gradients. Patients were examined in the prone position as this, in our experience, proved most comfortable for the patients. To permit coverage of the entire colon, signal reception was based on a combination of two surface coils in conjunction with the built-in spine-array coil. To minimize bowel peristalsis, 40 mg of scopolamine (Buscopan; Boehringer-Ingelheim, Ingelheim, Germany) was injected intravenously just prior to the examination. After the placement of a rectal enema tube (E-Z-Em, Westbury, NY) and inflation of the retention balloon, the colon was filled with up to 2000 mL of warm tap water by using hydrostatic pressure (1.0–1.5-m water column). Filling was monitored with a real-time sequence (repetition time msec/echo time msec of 2.4/1.2, 60° flip angle), which permitted the acquisition of one image per second.

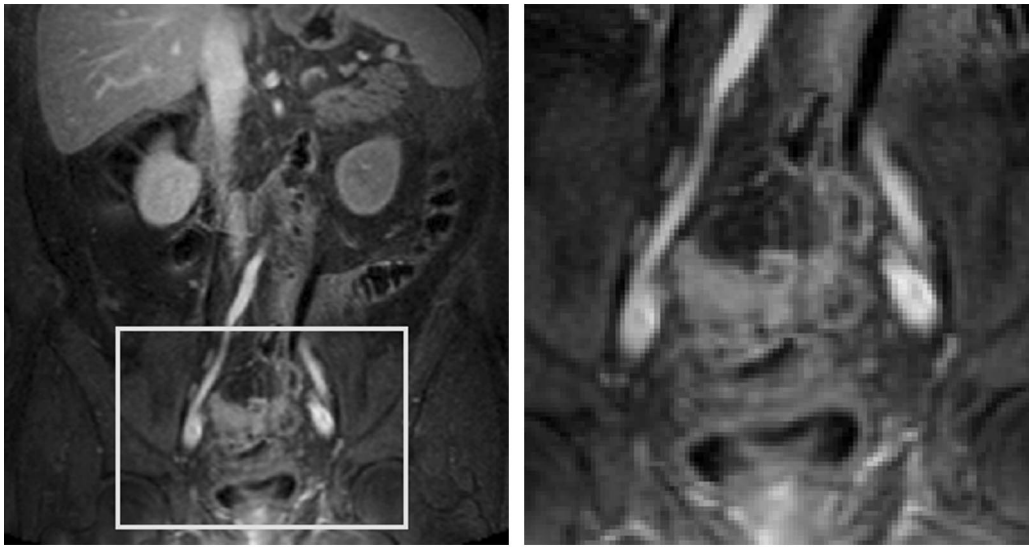
After bowel distention, a T1-weighted 3D gradient-echo data set with integrated fat suppression (volumetric interpolated breath-hold examination) was acquired in the coronal plane. Sequence parameters were 3.1/1.1, 12° flip angle, 450 × 450 mm field of view, and 168 × 256 matrix. With zero filling interpolation, a 1.6–2.0-mm section thickness, depending on the size of the patient, was achieved; the total number of the calculated sections was 96. Subsequently, 0.2 mmol of a paramagnetic contrast agent (gadobenate dimeglumine, Multihance; Bracco, Milan, Italy) per kilogram of body weight was administered intravenously at a flow rate of 3.5 mL/sec. After a delay of 75 seconds, the 3D acquisition was repeated with identical imaging parameters. The 3D data were collected in 22 seconds during a breath hold.

Data Analysis

Both nonenhanced and contrast material–enhanced 3D MR data sets were transferred to a postprocessing workstation (Virtuoso; Siemens Medical Solutions). The data sets were assessed by two experienced radiologists (T.C.L. and S.G.R., with 4 and 6 years, respectively, of MR colonography experience) in consensus. Both radiologists were informed about the incomplete colonoscopy but were unaware of the reason for the failure.

MR data were analyzed in the multiplanar reformation mode, which permitted scrolling through the 3D data sets in all three orthogonal planes. For analysis, the colon was divided into the following six segments: rectum (segment 1), sigmoid colon (segment 2), descending colon (segment 3), transverse colon (segment 4), ascending colon (segment 5), and cecum (segment 6).

The quality of MR colonography was assessed. Each colonic segment was classified as well distended (score 1); moderately distended, diagnostic (score 2); and poorly distended, nondiagnostic (score 3). Furthermore, each segment was evaluated for the presence of wrap-around, breathing, bowel motion, or susceptibility artifacts. Score 1 indicated no artifacts; score 2 indicated moderate artifacts, diagnostic; and score 3 indicated extensive artifacts, nondiagnostic.



a. **b.**

Figure 1. Dark-lumen MR colonographic images in a 51-year-old man with history of colorectal carcinoma and end-to-end anastomosis. **(a)** Coronal T1-weighted 3D source image obtained with volumetric interpolated breath-hold examination (3.1/1.1, 12° flip angle) shows high-grade stenosis (white box), which was histologically verified as being caused by an infiltrative recurrent carcinoma, that could not be passed with the endoscope. **(b)** MR colonography also failed, because there was not sufficient water passing through the stenosis to permit adequate distention of prestenotic segments.

Subsequently, MR data sets were assessed for the number of fully assessable segments and the presence of colonic disease by using colonoscopy as the standard of reference for all segments subjected to endoscopy. Residual stool particles potentially imitating colonic polyps were identified owing to the lack of contrast enhancement. Segments not subjected to endoscopy were also evaluated for the presence of diseases at MR colonography. Extracolonic diseases were also noted.

RESULTS

Conventional Colonoscopy

Incomplete colonoscopy permitted assessment of merely 53 of 118 possible segments in the 21 patients in group A. Prior surgery in four patients (hemicolectomy and end-to-end-anastomosis) had reduced the number of potentially visible segments from 126 to 118. Histopathologic examination confirmed the presence of colorectal carcinoma in 12 patients, inflammatory bowel disease in seven patients, and sigmoid diverticulitis in two patients. In the 16 patients in group B, endoscopy was successfully performed in 34 of 96 possible segments.

Conventional colonoscopy depicted five polyps (size range, 7–12 mm) in poststenotic segments in three patients in group A and two patients in group B. In addition, changes associated with Crohn disease or ulcerative colitis were diagnosed in 14 poststenotic segments in group A patients. Six patients in group B had sigmoid diverticulosis, and five patients demonstrated signs of unspecific colitis involving the rectum and sigmoid colon.

MR Image Quality

MR image quality was rated diagnostic in 35 of the 37 patients. Nondiagnostic image quality was attributed to inadequate distention of poststenotic colonic segments in two patients in group A. In both patients, large tumor masses, which were located in the sigmoid colon in one patient and in the descending colon in the other patient, prevented retrograde passage of the rectally administered water (Fig 1). Hence, MR colonography permitted assessment of only 110 of 118 potentially visible segments in group A. MR colonography permitted diagnostic assessment of all 96 segments in the 16 patients in group B (Fig 2).

For all patients, the best image quality in terms of the presence of artifacts was found in segment 1 (mean value, 1.30), and poorest results were seen in segments 3 and 5 (mean value, 1.50). Artifacts were mainly related to moderate respiratory motion or wrap around. The mean distention value among group A patients was 1.41, with best results in segment 1 (mean value, 1.35) and poorest results in segment 2 (mean value, 1.50). The mean distention value in group B patients was 1.26, with best results in segment 1 (mean value, 1.20) and poorest results in segment 2 (mean value, 1.37). Detailed data for all segments are listed in the Table.

MR Colonographic Findings

All inflammation- and tumor-induced stenoses were confirmed on MR colonographic data sets (Fig 3). Furthermore, all five polyps identified in poststenotic segments at conventional colonoscopy were detected at MR colonography. Similarly, MR colonography correctly demonstrated diverticulosis in the sigmoid colon in six patients and inflammatory alterations in 14 poststenotic segments in group A patients who were affected by either Crohn disease or ulcerative colitis. The latter were characterized by loss of colonic folds, thickened colonic wall, and increased contrast agent uptake.

MR-based assessment of prestenotic segments in group A patients revealed two lesions suspected of being carcinoma in two patients (Fig 4), two polyps (9 and 11 mm in size, Fig 5) in two patients, and

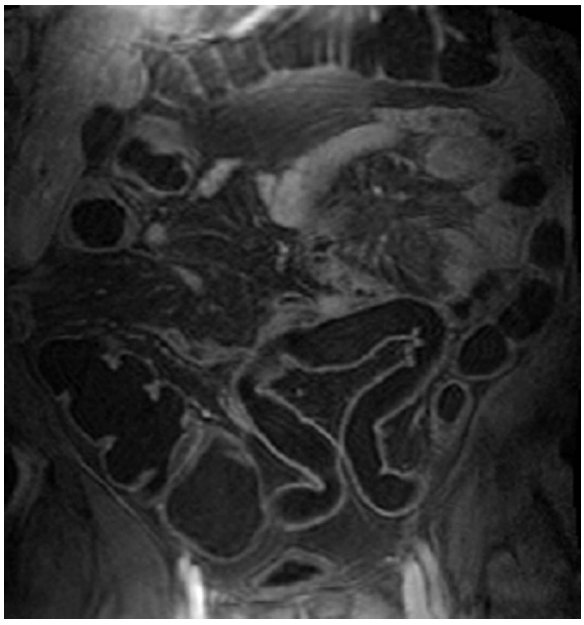


Figure 2. Coronal T1-weighted 3D source image obtained with volumetric interpolated breath-hold examination (3.1/1.1, 12° flip angle) in a 44-year-old woman undergoing dark-lumen MR colonography, with abdominal pain and incomplete colonoscopy because of elongation of sigmoid colon. Colonic elongation did not prove to be a hindrance for MR colonography. All segments inaccessible with conventional colonoscopy in group B patients were accurately assessed with MR colonography.

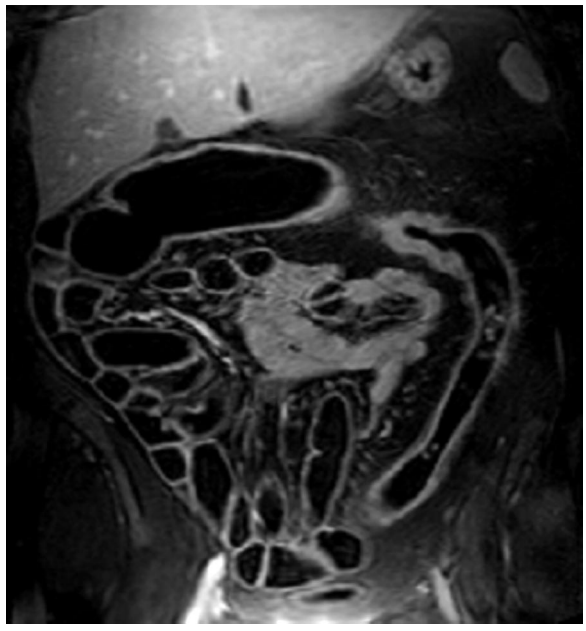


Figure 3. Coronal T1-weighted 3D source image obtained with volumetric interpolated breath-hold examination (3.1/1.1, 12° flip angle) in a 37-year-old woman with ulcerative colitis and inflammatory occlusion in the descending colon. Conventional colonoscopy was incomplete because of high-grade stenosis. MR colonography permitted assessment of segments proximal to the site of stenosis and revealed inflammatory changes affecting the transverse colon, as evidenced by loss of colonic folds and increased contrast agent uptake in the colonic wall.

four segments affected by colitis in three patients. Among group B patients, three polyps (size range, 8–12 mm; Fig 6) in three patients were diagnosed in colonic segments not reached at conventional colonoscopy. Residual stool particles did not turn out to be a problem for the assessment of the colon and could be distinguished from colonic masses in all cases.

MR colonography permitted the assessment of extracolonic parenchymal organs. A variety of relevant and nonrelevant diseases were identified. Hepatic metastases were detected in three patients, and a hepatic hemangioma was identified in one patient (Fig 7). Hepatic and renal cysts were seen in nine patients.

Image Quality of MR Colonography for Artifact Evaluation and Bowel Distention

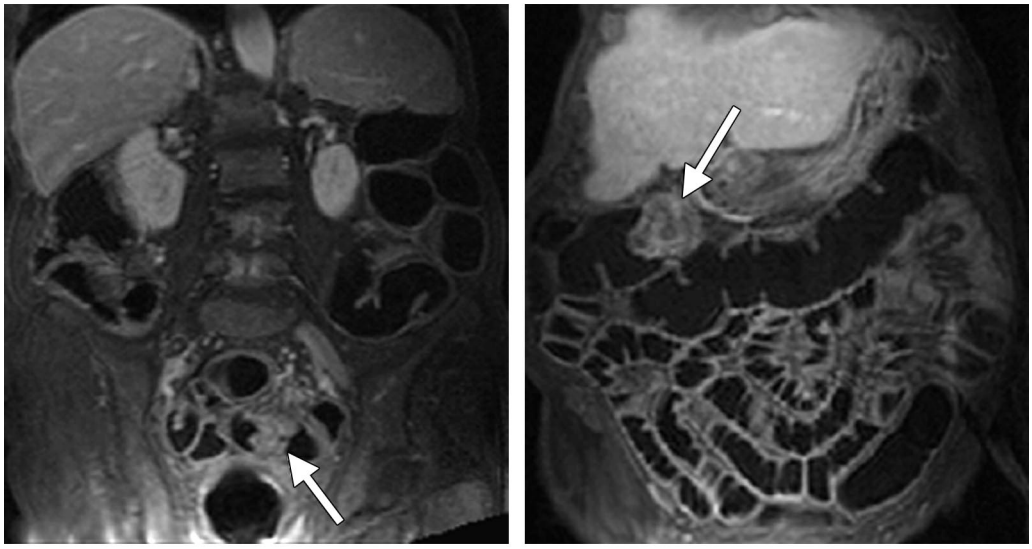
Segment	Artifacts	Distention	
		Group A	Group B
1 (rectum)	1.30 ± 0.2	1.35 ± 0.4	1.20 ± 0.2
2 (sigmoid colon)	1.33 ± 0.4	1.50 ± 0.4	1.37 ± 0.4
3 (descending colon)	1.50 ± 0.5	1.42 ± .04	1.27 ± 0.5
4 (transverse colon)	1.33 ± 0.3	1.41 ± 0.3	1.25 ± 0.3
5 (ascending colon)	1.50 ± 0.5	1.42 ± 0.4	1.27 ± 0.5
6 (cecum)	1.40 ± 0.5	1.40 ± 0.4	1.25 ± 0.5
Average	1.32	1.41	1.26

Note.—Unless otherwise indicated, data are the mean values ± standard deviations.

DISCUSSION

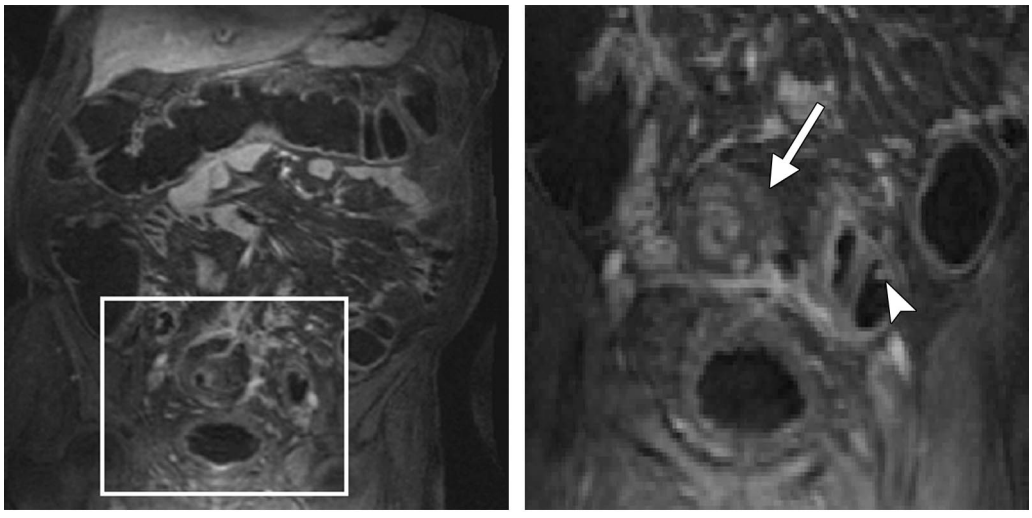
The presented data underscore the usefulness of dark-lumen MR colonography with regard to detection of colorectal disease. Dark-lumen MR colonography can aid in the examination of colonic segments that are inaccessible with colonoscopy. The fact that all relevant findings that could be viewed during conventional colonoscopies were also detected at MR colonography suggests that MR colonography depicts colon disease in unviewed segments. MR colonography provided diagnostic assessment of all but eight of the 127 colonic segments not accessible during conventional colonoscopy. MR colonography increased the number of potentially visible colonic segments from 87 to 206. Image quality was sufficient to detect a considerable number of diseases in the colonic segments not reached with conventional colonoscopy.

The value of standard conventional colonoscopy is predicated on the ability to reach the cecum. Unfortunately, failure to complete conventional colonoscopy is not a rare event. Rather, it is observed in 5%–26% of colonoscopic examinations performed by experienced endoscopists (4,19–21). There are many causes for failing to complete conventional colonoscopy (22). The most common cause is severe procedure-related abdominal discomfort, often in combination with technical challenges associated with the elongation of the sigmoid colon and operator difficulties in reaching the right colonic flexure and the ce-



a. b.

Figure 4. **(a)** Coronal T1-weighted 3D source image obtained with volumetric interpolated breath-hold examination (3.1/1.1, 12° flip angle) in a 60-year-old woman undergoing dark-lumen MR colonography, with stenotic carcinoma in the sigmoid colon (arrow) and incomplete colonoscopy. **(b)** MR colonographic image reveals metachronous carcinoma (arrow) in a prestenotic segment at the right colonic flexure.



a. b.

Figure 5. **(a)** Coronal T1-weighted 3D source image obtained with volumetric interpolated breath-hold examination (3.1/1.1, 12° flip angle) in a 62-year-old woman with stenotic sigmoid diverticulitis (white box, arrow in **b**) and incomplete colonoscopy. **(b)** MR colonography-based assessment of the prestenotic segments revealed a small polyp (arrowhead).

cum (3,4). The presence of intraluminal stenosis represents another important cause. Thus, the failure rate of conventional colonoscopy increases up to 50% in patients with known inflammatory bowel disease and in the presence of colorectal carcinoma (23,24).

Compared with colonoscopy, all imaging techniques available for assessing the colon are associated with considerably higher completion rates. There are many reasons for the higher success rates; from an operator's viewpoint, the methods are technically less challenging. Considerably less abdominal discomfort enhances patient compliance, as is evidenced by the vastly reduced use of analgesics and sedatives for colonic imaging as compared with conventional colonoscopy (25–28). Finally, only the tightest stenosis will prohibit passage of air or water required for distending prestenotic segments, whereas conventional colonoscopy does require absence of high-grade strictures or elongated bowel segments to safely pass the endoscope. This is well reflected in the data of this study: Inspection of prestenotic segments with MR colonography failed in only two of 21 patients (group A) in whom conventional colonoscopy had remained incomplete because of high-grade stenosis.

Similar to conventional colonoscopy,

all imaging techniques of the colon require a cleansed colon and colonic distention. The latter is achieved with rectal administration of either air or fluid. For fluoroscopy-based single- or double-contrast examinations, barium with or without air is used for colonic distention and for contrast enhancement to provide an assessment of the colonic lumen. About 90%–94% of colonic segments inaccessible with conventional colonoscopy can be inspected with double-contrast barium enema examination (5,6,27). In the setting of incomplete conventional colonoscopy owing to the presence of stenotic lesions, barium enema examinations have been reported to depict neoplastic masses exceeding 1 cm in size at a rate of 3.2%–18.0% in prestenotic colonic segments. Because barium enema examinations require the patient to comply well with complex moving instructions, they are generally not performed on the day of incomplete colonoscopy if sedatives were used during conventional colonoscopy (27–31). Unfortunately this is the case in most incomplete conventional colonoscopies. Other limitations inherent to fluoroscopy-based colonic examinations relate to the two-dimensionality of the underlying imaging technique, which limits its diagnostic accuracy (32–34).

Lack of diagnostic accuracy because of inherent two-dimensionality can be overcome with the use of cross-sectional imaging techniques. By using air to distend the colon, CT colonography provides a most accurate 3D depiction of the distended colon (35,36). For a thorough inspection of the surrounding parenchymal organs, the intravenous administration of potentially nephrotoxic contrast agents is required. Hence, CT colonography has been advocated as a rapid, well-tolerated, and noninvasive alternative in the setting of an incomplete colonoscopy (37,38). The presence of residual fluid does however require the acquisition of data sets in both prone and supine positions (39,40). Associated doses of ionizing radiation as high as 4.7–7.2 mSv should trigger the search for an alternative, particularly in young patients with inflammatory bowel disease (39–44).

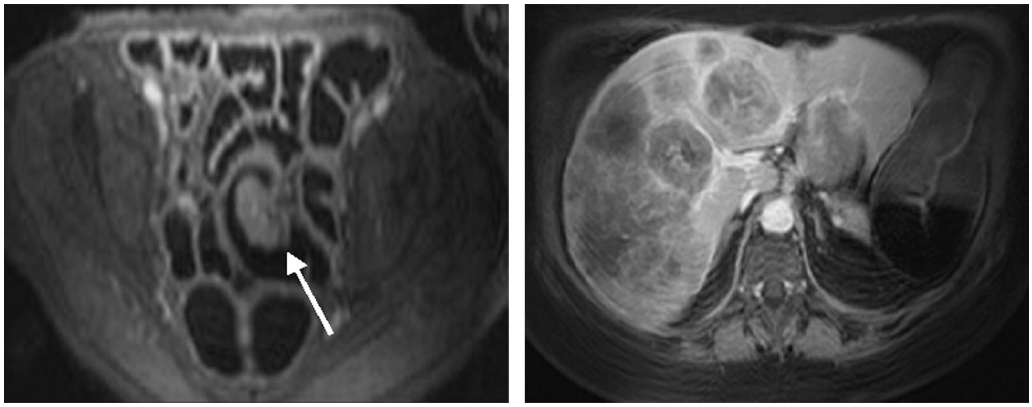
MR colonography is based on bowel distention by means of rectal administration of water or air (10–18). To enhance the wall and the masses arising from it, a paramagnetic contrast agent is administered intravenously. Unlike iodinated agents, a paramagnetic contrast agent is not nephrotoxic (10,12,15). Filling of the colon is eased by the administration of scopolamine. Hydrostatic pressure is used to fill the colon, a process closely monitored with real-time fluoroscopic MR imaging. The pronely positioned patient does not need to be repositioned during the MR examination. MR colonography merely requires two 3D acquisitions, each lasting 22 seconds. A break of more than 1 minute between the two acquisitions ensures excellent patient compliance with breath-holding instructions. Thus, the patent spends less than 5 minutes in the bore of the imager.

Figure 6. Coronal T1-weighted 3D source image obtained with volumetric interpolated breath-hold examination (3.1/1.1, 12° flip angle) in a 56-year-old man with incomplete colonoscopy owing to elongation of sigmoid colon depicts a small polyp (arrow) with contrast agent uptake in the transverse colon at the right colonic flexure.

Diagnostic MR colonography is predicated on the fulfillment of two requirements: good bowel distention and sufficient contrast between the bowel lumen and the colonic wall, as well as diseases originating from the colonic wall. The contrast between the lumen and the surrounding wall is largely determined by the contrast characteristics of the MR sequence used. In this study, the quality of MR colonography was sufficient to ensure accurate assessment of colonic segments not visualized with conventional colonoscopy in 35 of 37 patients. The rectally administered water enema adequately distended 110 of 118 inaccessible segments (93%) in group A patients and all inaccessible segments in group B patients. Thus, MR colonography permitted proper evaluation of 96% of all colonic segments, whereas conventional colonoscopy had been capable of inspecting merely 40%. Beyond its inherent noninvasiveness, lack of exposure to ionizing radiation, and excellent diagnostic performance in assessing the colon, MR colonography delivers additional relevant data pertaining to parenchymal abdominal organs (12,15). These data are of particular value in the preoperative assessment of patients suspected of having tumor-induced stenosis. Within one examination, the colon can be assessed for the presence of metachronous lesions and the liver can be assessed for the presence of metastases.

Certainly, the present study had some limitations. First, a real standard for the segments not accessed with conventional colonoscopy was lacking. Surgical findings could have been such a standard, but data were not available for all patients. Therefore, the real potential of MR colonography was not assessed. At least one might wonder if there also had been false-positive or false-negative findings for the evaluation of prestenotic segments. In addition, the number of patients and consequently the number of colorectal diseases was limited. Further studies will be needed to underline the effect of MR colonography regarding patients with incomplete colonoscopy.

In conclusion, findings of this study



a. b.

Figure 7. **(a)** MR colonographic image in a 63-year-old woman with incomplete colonoscopy because of high-grade stenotic carcinoma (arrow) in the sigmoid colon. **(b)** Transverse reformation of T1-weighted 3D volumetric interpolated breath-hold examination sequence (3.1/1.1, 12° flip angle). MR colonography helped exclude relevant disease in prestenotic colonic segments but did demonstrate multiple hepatic metastases.

show that in patients with an incomplete colonoscopy, MR colonography could confirm the disease found at conventional colonoscopy and provide additional information. The identification of additional disease at MR colonography in segments not reached at conventional colonoscopy underscores the need for a second diagnostic step in the setting of incomplete conventional colonoscopy.

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