Magnetic Resonance Colonography: Comparison of Contrast-Enhanced Three-Dimensional Vibe With Two-Dimensional FISP Sequences

Preliminary Experience

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Purpose: The purpose of this study was to compare a dark-lumen magnetic resonance colonography (MRC) approach with a True FISP-based bright-lumen technique concerning presence of artifacts and the detection rate of colorectal pathologies.

Materials and Methods: Thirty-seven patients with suspected colorectal lesions were included in this trial. The colon was filled with 2500 mL of tap water. Two-dimensional True FISP datasets as well as T1-weighted GRE sequences (pre- and post intravenous contrast) were acquired. The detection rate of colorectal masses and inflammatory lesions was determined for both techniques separately. Besides, image quality was assessed. All patients underwent conventional colonoscopy as the standard of reference.

Results: By means of dark-lumen MRC datasets, all polyps >5 mm were correctly diagnosed, whereas 4 polyps <5 mm were missed. Sensitivity of dark-lumen MRC amounted to 78.9%. There were no false-positive results: residual stool could correctly be differentiated from colorectal masses. The True FISP-based bright-lumen MRC, however, failed to detect 2 additional polyps resulting in a sensitivity of 68.4%. Furthermore, bright-lumen MRC led to false-positive results in 5 patients. Both techniques visualized inflammatory bowel disease in 5 patients. However, image quality of True FISP was rated superior to that of dark-lumen MRC.

Conclusion: Dark-lumen MRC proved to be superior over bright-lumen MRC regarding the detection of colorectal masses. However, True FISP imaging can turn out to be helpful as a result of high image quality and motion insensitivity.

Received June 28, 2004 and accepted for publication, after revision, October 3, 2004.

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ISSN: 0020-9996/05/4002-0089

Key Words: magnetic resonance imaging (MRI), virtual colonoscopy, FAST imaging with steady-state precession (True FISP), volumetric interpolated breathhold imaging (VIBE)

(*Invest Radiol* 2005;40: 89–96)

Magnetic resonance colonography (MRC) is considered an accurate diagnostic tool for detecting colorectal pathologies, including colorectal polyps, carcinomas, and inflammatory processes.[1–5] For a reliable assessment of the large bowel, 2 main criteria need to be fulfilled: a high contrast between bowel lumen and bowel wall as well as an adequate colonic distension.[6] The latter condition can be accomplished by the rectal administration of liquid[1–3,7,8] or gaseous distending agents.[4,9,10] Regarding the contrast mechanisms, 2 main techniques have been described. A "dark-lumen" MRC is based on the administration of a rectal water enema and the intravenous injection of paramagnetic contrast.[11] On T1-weighted datasets, the colonic wall as well as masses arising from it brightly enhance. Thus, bowel wall and colorectal masses can easily be delineated against the background of the dark colonic lumen. In the "bright-lumen" MRC, however, colorectal lesions appear as dark filling defects within the bright colonic lumen. This can be achieved by administering a rectal enema containing paramagnetic contrast.[1–3] On T1-weighted datasets, only the contrast-containing colonic lumen is bright, whereas the surrounding tissues, including colonic wall and polyps, remain low in signal intensity.

A new approach for "bright-lumen" MRC is based on the acquisition of fast imaging with steady-state precession sequences.[12] Different vendor-specific names for these sequences have been used: True FISP (Siemens Medical Solution), FIESTA (General Electric Medical Systems), and Balanced Fast Field Echo (Philips Medical Systems). Image features are characterized by a mixture of both T1- and

T2-contrast leading to a homogenous bright signal intensity in vessels and fluid-containing organs.[13] Using water as a rectal enema, the contrast mechanism of a True FISP-based MRC is comparable to that of the approach in conjunction with a paramagnetic contrast enema and the acquisition of T1-weighted GRE sequences. Because the True FISP technique does not require the administration of intravenous or of rectal paramagnetic contrast, it is economically attractive.

The purpose of this study was to compare dark-lumen MRC with a True FISP-based bright-lumen technique concerning sensitivity and specificity for the detection of colorectal masses and inflammatory pathologies. Besides, image quality of both methods was assessed.

MATERIALS AND METHODS

Subjects

Thirty-eight patients with suspected colorectal pathologies were initially included in this study (14 men and 24 women, age range 18–89 years, mean age 49.6 years). One subject was rated as a dropout as a result of symptoms of claustrophobia and consecutive abortion of the MR examination. The remaining 37 patients had been referred for conventional colonoscopy to the Department of Gastroenterology because of symptoms, including rectal bleeding (n = 8), positive fecal occult blood tests (n = 8), or chronic diarrhea (n = 6). In addition, 11 patients were examined because of a positive family history of colorectal cancer and in 4 patients a history of chronic inflammatory bowel disease was known. The study was conducted in accordance with all guidelines set forth by the approving Institutional Review Board. Written informed consent was obtained before each examination.

Magnetic Resonance Colonography

All subjects underwent a standardized protocol for bowel purgation on the day before the MR examination. For this, 3000 mL of an electrolyte solution (Golytely; Braintree Laboratories, Braintree, MA) was ingested. MR colonography was performed on a 1.5-T system (Magnetom Sonata; Siemens Medical Systems, Erlangen, Germany) equipped with gradient systems characterized by a maximum gradient amplitude of 40 mT/m and a slew rate of 200 mT/m/ms. A combination of 2 large "flex surface coils" was used for signal reception to assure the coverage of the entire colon. To alleviate bowel spasms and reduce artifacts as a result of bowel motion, 20 mg of scopolamine (Buscopan; Boehringer, Ingelheim, Germany) was administered intravenously. After the placement of a rectal tube (E-Z-Em, Westbury, NY), the colon was filled in the prone position with approximately 2500 mL of tap water using hydrostatic pressure (1-m water column). The filling procedure was stopped either after the application of the entire 2500 mL of water or whenever patients complained about inconveniences such as increasing abdominal pressure.

In a first step, the bright-lumen MR examination was performed starting with the acquisition of a True FISP scan in the prone position under breathhold conditions. Image parameters are listed in Table 1. No intravenous contrast was applied. To compensate for the presence of residual air pockets in the colon, an identical second True FISP dataset was acquired in the supine position. After the completion of the bright-lumen MRC, the patient stayed in the supine position in the scanner. Because of the short half-life of Buscopan, a second dose (20 mg scopolamine) was administered intravenously. For the dark-lumen MRC, a first "precontrast" T1-weighted 3-dimensional gradient echo dataset was collected with the patient in the supine position only. Imaging parameters of the T1-weighted sequence are shown in Table 1. Subsequently, paramagnetic contrast (gadobenate dimeglumine, Gd-BOPTA; Multihance, Bracco, Italy) was administered intravenously at a dosage of 0.2 mmol/kg and a flow rate of 3.0 mL/s using an automatic injector (Spectris, Medrad, Germany). The paramagnetic contrast application was followed by rapid injection of 20 mL normal saline at the same flow rate. After a delay of 75 seconds, the "precontrast" 3-dimensional acquisition was repeated with identical imaging parameters. The 3-dimensional dataset was collected breathheld in 22 seconds. Eventually, the enema bag was

TABLE 1. Acquisition Parameters of the T1-Weighted Volumetric Interpolated Breathhold Imaging (VIBE) Sequence for Dark-Lumen Magnetic Resonance Colonography and the True FISP Sequence for Bright-Lumen Magnetic Resonance Colonography

	TR (ms)	TE (ms)	Flip (°)	Slice Thickness (mm)	No. of Slices	Slice Gap (%)	Field-of-View Read (mm)	Field-of-View Phase (mm)	Matrix	Acquisition Time (s)	Plane
T1w 3D VIBE	3.1	1.1	12	1.8*	96	20	400	350	180 × 256	22	Coronal
2D TrueFISP	4.5	2.2	70	3.0	60(2)	10	400	350	402 × 512	3 × 21	Coronal

*Using zero-filling interpolation.

†To assure breathhold conditions, data acquisition was divided into 3 blocks of each 20 slices. An overlap of 10 mm between the blocks was performed to deal with a possible misalignment resulting from different depth of breathhold.

placed on the floor for draining the water and the patient was removed from the scanner.

Image Analysis

Image interpretation was done in a consensus mode by 2 experienced MR radiologists (SCG, SGR) who did not have access to information about the patient's history or the reason for the patient's referral. The analysis was performed in 2 steps: an initial reading was based on the data of either the dark- or the bright-lumen MRC, which were presented in a randomized order. To avoid any recognition bias, the second reading session of the remaining MR data was separated by a 4-week interval.

For each patient, both True FISP as well as 3-dimensional volumetric interpolated breathhold imaging (VIBE) datasets were postprocessed using commercially available software and hardware (Virtuoso; Siemens Medical Systems). Dark-lumen MR colonography was interpreted in the multiplanar reformation mode scrolling through the 3-dimensional dataset in all 3 orthogonal planes as well as based on virtual endoscopic renderings. The True FISP data, however, was evaluated in the coronal plane only.

For both examination types, the location and size of all detected endoluminal lesions were determined. Based on lesion size and morphology, the detected masses were characterized as either polyp ($<$1.5 cm/homogeneous morphology) or carcinoma ($>$1.5 cm/inhomogeneous morphology). The presence of inflammatory bowel disease was assessed based on increased bowel wall thickening, straining of the periintestinal fat, or loss of haustral markings. Furthermore, both bright- and dark-lumen MRC datasets were assessed concerning concomitant hepatic disease.

Regarding dark-lumen MRC data, region of interest (ROI) measurements were performed in all suspected colonic lesions (ellipse, mean diameter 2.0 mm). Image noise is defined as the standard deviation of signal intensities measured in an ROI placed in the recorded field of view outside the abdomen. Based on these measurements, signal-to-noise ratios (SNR) were calculated for the pre- and postgadolinium scan: SNR = SI (colonic lesion)/noise. These enhancement characteristics help to distinguish colorectal lesions from residual fecal material. Although stool does not show any contrast enhancement, colorectal polyps and carcinomas brightly enhance.[8]

Furthermore, both dark- and bright-lumen MRC sequences were assessed concerning image quality. Thus, data were evaluated for the presence of motion and breathing artifacts and were graded on a 3-point scale: 1 = no artifacts, 2 = moderate artifacts, but diagnostic image quality, 3 = avid artifacts, not diagnostic.

Conventional Colonoscopy

After completing MRC, patients were transferred to the Department of Gastroenterology. Conventional colonoscopy was performed using standard equipment (model CFQ 140; Olympus). The attending gastroenterologist was unaware of the MR findings. Analgesics (Dolantin; Hoechst, Germany) or sedatives (Dormicum; Roche, Germany) were administered when necessary. Location and size of colorectal masses were recorded. All polyps were removed. Suspicious cancers and inflammatory lesions were biopsied. All polyps and bioptic materials were analyzed by histopathology.

Data Analysis

Conventional colonoscopic findings were considered the standard of reference. The accuracy of dark and bright-lumen MR colonography concerning the detection of colorectal masses was assessed by calculating point estimates for sensitivity and specificity. Ratings of MR image quality were compared by a Wilcoxon's rank test using a P value of <0.05 to indicate statistical significance.

RESULTS

Image Quality

All MR examinations were rated as diagnostic with no or only moderate artifacts. Moderate artifacts were found in 14 dark-lumen-based examinations (mean image quality in-

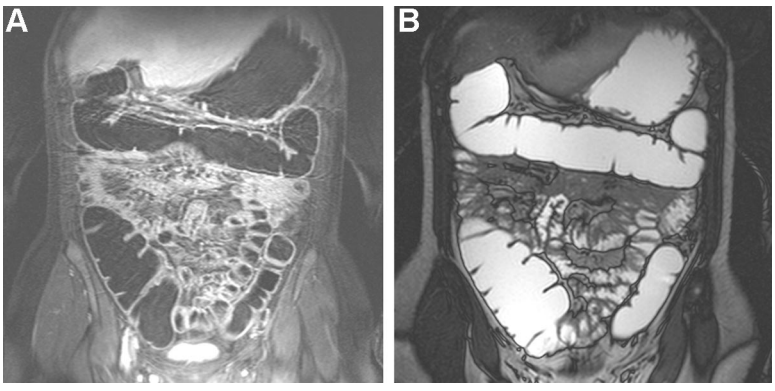

FIGURE 1. A 54-year-old female patient undergoing magnetic resonance colonography (MRC). Image quality of the contrast-enhanced T1-weighted VIBE dataset (dark lumen MRC, **A**) is slightly inferior to the True FISP-based bright-lumen MRC (**B**) as a result of motion artifacts in the transverse colon.

dex 1.4). Only 4 of 37 True FISP-based examinations showed minor artifacts (mean index 1.1). Comparing both MR techniques (Fig. 1), image quality of the bright-lumen True FISP-based examination turned out to be statistically significant higher ($P = 0.002$).

Colorectal Masses and Concomitant Hepatic Disease

By means of conventional endoscopy, a total number of 19 colorectal lesions (15 polyps/4 carcinomas) were detected in 12 patients. The size of colorectal polyps ranged between 3 and 13 mm. Regarding dark-lumen MRC, 11 patients showed colorectal lesions. All polyps >5 mm and all carcinomas were correctly visualized (Figs. 2 and 3), whereas 4 little polyps <5 mm were missed. There were no false-positive results. Thus, lesion-based sensitivity and specificity of dark-lumen MRC for the detection of colorectal masses amounted to 78.9% and 100%, respectively. All colorectal masses revealed an enhancement with signal intensities increasing by a mean factor of 2.8 (SNR = 13.1 ± 2.0 for the precontrast scan and SNR = 36.7 ± 5.1 for the postcontrast dataset). Residual stool particles did not show any contrast uptake though (Fig. 4).

By means of True FISP-based bright-lumen MRC, colorectal masses were seen in 10 patients. The same 4 polyps <5 mm as well as 2 additional polyps (7 and 8 mm in diameter) failed to be detected. The remaining colorectal polyps as well as all carcinomas were visualized (Figs. 2 and 3). However, bright-lumen MRC led to false-positive findings in 5 patients (Fig. 4). This resulted in a lesion-based sensitivity of 68.4% and a patient-based specificity of 83.3% for the True FISP MR examination. All results are listed in Tables 2 and 3.

As for concomitant hepatic disease, both MR imaging techniques revealed liver metastases in 2 of the 4 patients with a colorectal carcinoma (Fig. 5). Findings were confirmed by clinical follow-up examinations.

Inflammatory Bowel Disease

Ulcerative colitis was revealed in bowel segments of the same 4 patients both by dark- and bright-lumen MRC (Fig. 6). Besides, 1 patient presented inflammatory changes of the ileocecal valve and the terminal ileum rated as Crohn's disease, which was documented by means of both MRI techniques (Fig. 7). The presence of all inflammatory lesions was endoscopically confirmed. There were no inflammatory lesions additionally detected by conventional colonoscopy.

DISCUSSION

The present study indicates that dark-lumen MR colonography based on the acquisition of contrast-enhanced T1-weighted data is superior to True FISP bright-lumen MRC regarding the depiction of colorectal masses. Especially lesions between 5 and 8 mm in size were more precisely detected by dark-lumen MRC. Furthermore, this technique allowed a secure differentiation between residual stool particles and colorectal polyps resulting in a specificity of this method amounting to 100%. Inflammatory bowel lesions were found with high accuracy by means of both MRI techniques. However, True FISP-based imaging provided a higher image quality with less artifacts compared with the T1-weighted GRE imaging.

True FISP has been increasingly integrated into MR imaging protocols of the abdomen. Beyond short acquisition times and excellent image quality, it provides a similarly high sensitivity and specificity concerning the detection of hepatic lesions compared with T2-weighted imaging such as HASTE (half-Fourier acquisition single-shot turbo spin-echo[14]). Furthermore, great impact of True FISP imaging has been documented regarding the ability to assess inflammatory changes

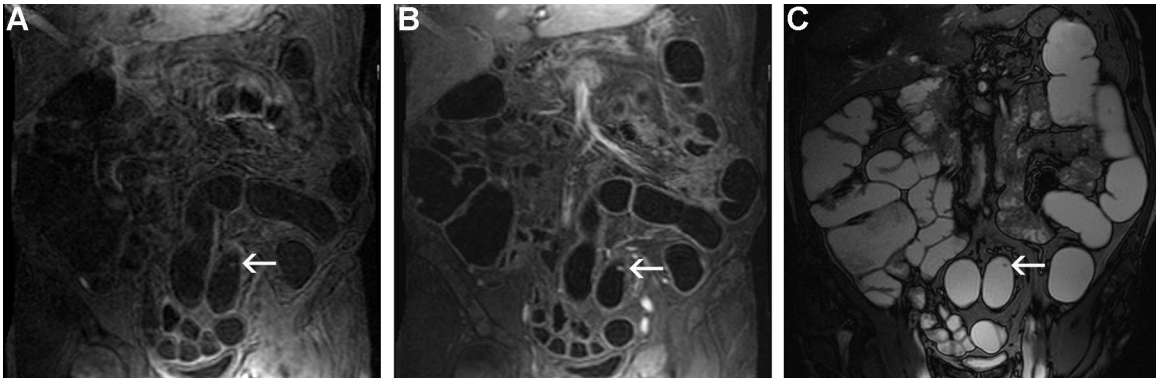

FIGURE 2. A 42-year-old male patient presenting a 7-mm-sized polyp in the sigmoid colon (arrow). The lesion is captured by the dark-lumen magnetic resonance colonography (MRC) as a bright contrast-enhancing lesion comparing the precontrast scan (**A**) and the postcontrast scan (**B**). The same polyp has also been detected by means of bright lumen MRC (**C**).

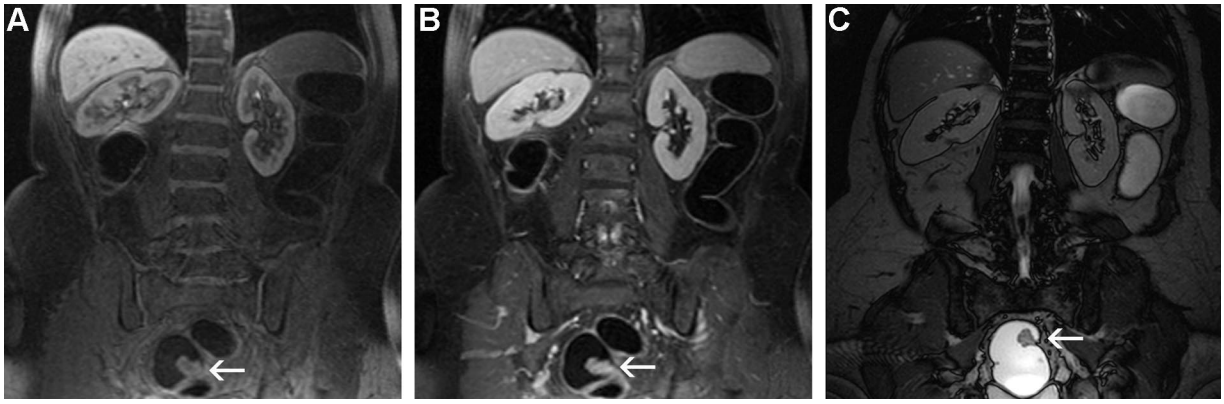

FIGURE 3. A 68-year-old female patient with a large colorectal mass in the sigmoid colon (arrow), which was rated as a colonic carcinoma. By means of dark-lumen magnetic resonance colonography (MRC), this lesion was displayed both by the native scan (**A**) as well as the postcontrast scan (**B**) and a contrast-uptake could be verified. The carcinoma has also been detected by means of bright-lumen MRC (**C**).

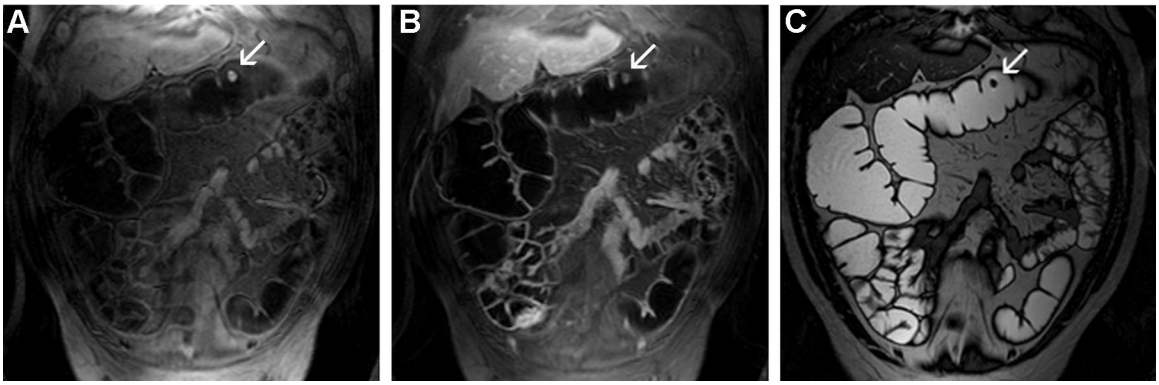

FIGURE 4. Residual fecal material (arrow) in the transverse colon of a 51-year-old female patient. Stool was correctly identified by means of dark-lumen magnetic resonance colonography (MRC), because it already had a high signal intensity in the precontrast scan (**A**) and did not show any contrast uptake (**B**). However, this stool particle impressed as a dark filling defect on bright-lumen MRC (**C**) and was incorrectly interpreted as a polyp.

TABLE 2. Number of Colorectal Masses and Respective Sensitivity Values for Dark-Lumen and Bright-Lumen Magnetic Resonance Colonography as Well as Conventional Colonoscopy

	No. of All Colorectal Masses (Sensitivity)	No. of All Polyps (Sensitivity)	No. of Polyps >5 mm (Sensitivity)	Carcinomas (Sensitivity)
T1w 3D VIBE	15 (78.9%)	11 (73.3%)	11 (100%)	4 (100%)
2D TrueFISP	13 (68.4%)	9 (60.0%)	9 (81.8%)	4 (100%)
Conventional cColonoscopy (standard of reference)	19	15	11	4

VIBE, volumetric interpolated breathhold imaging.

of the small bowel.[15,16] Thus, thickening of the small bowel wall, increased vascularity of the mesenteries, and the presence of ulcers, abscesses, or mesenteric lymph nodes can be depicted with high accuracy. MR colonography based on the acquisition of fast imaging with steady-state precession sequences was first described by Martin et al.[12] They assessed True FISP MRC ex vivo using a bovine colon. In a second step, 3 healthy volunteers underwent MR colonography in

TABLE 3. Patient-Based Sensitivity and Specificity Values of Dark-Lumen and Bright-Lumen Magnetic Resonance Colonography for the Detection of Colorectal Masses

	No. of Patients Examined	No. of Patients With Colorectal Lesions (Sensitivity)	No. of Patients With False-Positive Findings (Specificity)
T1w 3D VIBE	37	11 (91.7%)	0 (100%)
2D TrueFISP	37	10 (83.3%)	5 (83.3%)
Conventional colonoscopy (standard of reference)	37	12	—

VIBE, volumetric interpolated breathhold imaging.

conjunction with the acquisition of True FISP and VIBE datasets. Similar to our findings, image quality of the True FISP datasets was rated to be superior as a result of the high contrast and because of relative motion insensitivity. To compensate for the presence of residual air obscuring the outline of the colonic wall, data acquisition in 2 different patient positions was postulated. However, no evaluation of True FISP imaging had been made so far regarding the ability to detect colorectal pathologies.

Dark-lumen MRC was evaluated for the first time in a highly selected small group of 12 patients.[11] Like in the present trial, the contrast mechanism of dark-lumen MRC was based on the rectal application of water and the intravenous administration of gadolinium. Three of the 12 subjects underwent an additional bright-lumen MRC on a separate day. To that, T1-weighted datasets were acquired after the administration of an enema containing paramagnetic contrast. By means of dark-lumen MRC, 5 colorectal polyps larger than 7 mm were correctly identified and no false-positive findings were described. However, bright-lumen MRC led to false-positive results in 2 of 3 patients. These initial findings are confirmed by the results of the present study: True FISP-based bright-lumen MRC incorrectly rated 5 patients to have colorectal masses. The main reason for the reduced specificity is related to the way colorectal lesions are visualized by bright-lumen MRC: polyps or carcinomas impress as dark filling defects within the bright colonic lumen and can often not be adequately distinguished from residual fecal material or air bubbles. Although 2 different datasets in prone and supine positions are acquired and residual stool or air might change their position in between (although colorectal masses do not), severe interpretation difficulties are possible. Adherent stool to the bowel wall may not move, which can produce false-positive results, or a long, stalked polyp may sufficiently move leading to false-negative findings.

Dark-lumen MRC copes with the underlying issue in a very simple way: residual stool or air bubbles do not show any contrast enhancement. In opposition, colorectal polyps or carcinomas as well as inflammatory bowel lesions significantly enhance after the intravenous injection of paramagnetic contrast.[17–19] Hence, whenever a suspicious lesion is detected on the postcontrast dataset, comparison with the signal characteristics on the precontrast images is required to assure the correct diagnosis. Some centers also claim in this context the use of intravenous contrast for computed tomography colonography,[18] which has been shown to improve the depiction of colorectal lesions in suboptimal prepared large bowels.

Further advantages and improvements of the dark-lumen technique have been demonstrated: water as a rectal enema can be replaced by CO_2 as a result of the signalless character on T1-weighted datasets,[4] leading to higher patient comfort. In a recently published trial, room air as a distending agent was compared with water for dark-lumen MRC.[20] Both distending media permitted a reliable assessment of the colonic wall and identification of colorectal masses. Although discomfort levels were similar for air and water, MRC with room air provided a slightly better colonic distension and higher contrast-to-noise ratio values. Another advantage of dark-lumen MRC is related to the possible application of fecal tagging. This method obviates bowel purgation by orally administering contrast compounds before the MR examination. Thus, signal intensity of feces is diminished and the low-signal stool cannot be discriminated from the dark rectal enema.[8]

The diagnostic impact of dark-lumen MRC has already been evaluated in larger patient cohorts.[17] In a recently published study, 122 patients were evaluated by means of dark-lumen MRC regarding the presence of pathologies, including polyps, carcinomas, or inflammatory lesions. With conventional endoscopy serving as the standard of reference, sensitivity for the detection of colorectal masses >5 mm as well as inflammatory lesions amounted to nearly 90%. However, small polyps (<5 mm) were not detected at all. The present study confirms these results: the visualization of small colorectal lesions was impossible by means of dark- or by bright-lumen MRC. The importance of this limitation, however, is controversially discussed. Observational data on growth rates indicate that small polyps remain stable over several years and are not prone to malignant degeneration.[21,22] Anyway, flat adenomas right now seem not to be detectable by MR colonography, which certainly casts a shadow over the impact of this modality.

Clearly, there are limitations inherent to the study design. Because 2 datasets in different patient positions had to be acquired for the bright-lumen protocol, the patient had to be moved. This implies a certain time loss, because new localizer sequences were required to assure full coverage of the abdomen. Meanwhile, water may have escaped into the small bowel thereby leading to reduced bowel distension.

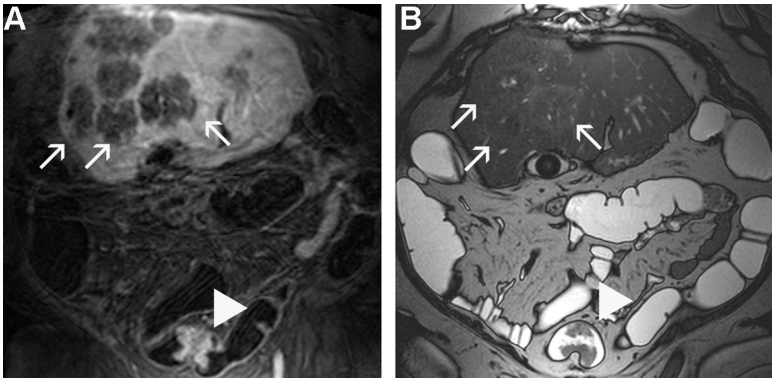

FIGURE 5. A 66-year-old female patient with a carcinoma in the sigmoid colon (arrowhead) detected by means of dark-lumen magnetic resonance colonography (MRC) (**A**) and bright-lumen MRC (**B**). Both MRC modalities displayed concomitant hepatic metastases (arrows).

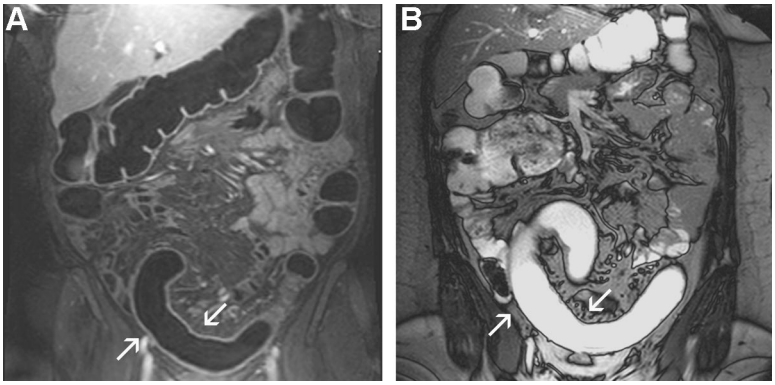

FIGURE 6. A 34-year-old male patient. By means of contrast-enhanced dark-lumen magnetic resonance colonography (MRC) (**A**) and True FISP-based bright-lumen MRC (**B**), a loss of haustral markings was noted in the sigmoid colon (arrow), which was rated as changes resulting from ulcerative colitis.

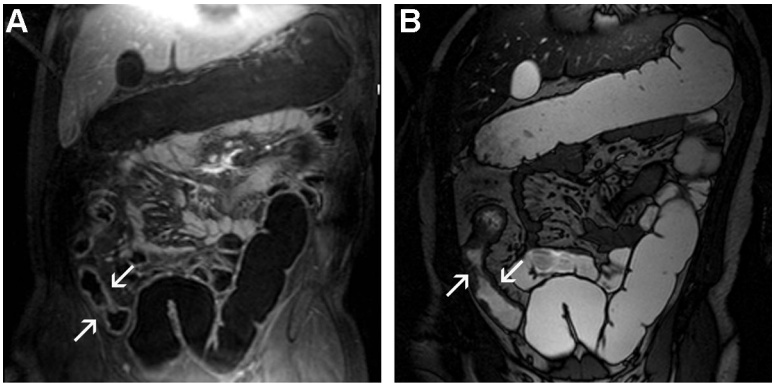

FIGURE 7. A 25-year-old female patient with Crohn's disease. By means of dark-lumen magnetic resonance colonography (MRC), an increased contrast enhancement of the bowel wall in the terminal ileum is visualized (**A**, arrow), whereas True FISP-based bright-lumen MRC displays the according bowel wall thickening (**B**, arrow).

This might have had a negative impact, especially on the accuracy of the dark-lumen MRC, which was performed after the bright-lumen technique. Therefore, a randomized order of the 2 MR methods would have been favorable. Furthermore, a 2-dimensional True FISP sequence has been compared with a 3-dimensional–T1-weighted GRE sequence. This could be one of the explanations why a certain number of lesions <10 mm was missed by True FISP imaging. However, the implementation of 3-dimensional True FISP sequences as well as technical refinements such as parallel acquisition techniques[23] may improve the diagnostic accuracy of this imaging modality.

Although dark-lumen MRC provides apparent advantages, including higher sensitivity and specificity rates for the detection of colorectal pathologies, we are convinced that True FISP imaging can be a valuable part of any imaging protocol for MRC. Especially in elderly patients who are not able to hold their breath during the entire acquisition time, bright-lumen MRC based on True FISP imaging can be a helpful tool because of high image quality and motion insensitivity.

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