Original Research

MR Colonography: How Does Air Compare to Water for Colonic Distention?

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Purpose: To prove the feasibility of air-distended magnetic resonance colonography (MRC) and compare it with water-based distention.

Materials and Methods: In five volunteers, the colon was imaged twice: once after distending the colon with air and a second time after distending the colon with water. A total of 50 patients, who had been referred to colonoscopy for a suspected colorectal pathology were randomized into water-distention ($N = 25$) and air-distention ($N = 25$) groups. A contrast-enhanced T1-weighted three-dimensional volume interpolated breath-hold (VIBE) sequence was collected. Comparative analysis was based on qualitative ratings of image quality and bowel distention, as well as contrast-to-noise ratio (CNR) measurements for the colonic wall with respect to the colonic lumen. In addition, patient acceptance was evaluated.

Results: Inflammatory changes and colorectal masses were correctly identified on MRC in eight patients each. One 4-mm polyp identified at colonoscopy was missed on water-distended MRC. There were no false positive findings. No significant differences were found between air- and water-distention regarding discomfort levels and image quality. The presence of air in the colonic lumen was not associated with susceptibility artifacts. CNR of the contrast-enhanced colonic wall, as well as bowel distention, were superior on air-distended three-dimensional data sets.

Conclusion: MRC can be performed using either water or air for colonic distention. Both techniques permit assessment of the colonic wall and identification of colorectal masses. While discomfort levels are similar for both agents, MRC with air provides higher CNR and better colonic distention.

Key words: MR colonography; air; water; contrast agent; enema
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MAGNETIC RESONANCE (MR) colonography (MRC) has been shown to be an appropriate diagnostic tool for the detection of pathologies, including colorectal masses, diverticula, and inflammatory disease (1–4). Reliable assessment of the colon by means of MR imaging is predicated upon the fulfillment of two requirements: sufficient distention of the colonic lumen and sufficient contrast between the colonic lumen and pathologies arising from the colonic wall. Hence, the cleansed colon is filled either with liquid, such as tap water, with or without the addition of paramagnetic contrast (2,5,6), or gaseous agents, such as room air, CO_2, and hyperpolarized helium (7–9). While initial experience was based on techniques rendering the colonic lumen bright, dark lumen MRC has recently been found to be advantageous (1,3).

The fear of compromised image quality due to susceptibility effects at air/tissue interfaces has long favored the use of water or water-based solutions for colonic distention in MRC (6,10). With the availability of high performance gradients permitting data acquisition with very short echo times, the potential of relevant susceptibility effects is reduced. Accordingly, interest in the use of gaseous agents has grown. They avoid the risk of spillage and have been suggested to be associated with less discomfort compared to fluid (7,8).

The purpose of this study was to prove the feasibility of air-distended MRC. Resultant image quality, distention, and CNR of the colonic wall were compared to that achieved with water-distended MRC. Furthermore, patient acceptance of both techniques was assessed.

MATERIALS AND METHODS

Subjects

MRC was performed on five healthy volunteers and 50 patients. Written informed consent was obtained from all 55 subjects in accordance with the local institutional review board, which had approved the study. The volunteers (three women, two men, age range 35–50 years, mean age 43 years) underwent MRC on two separate occasions: once using water enema and a second time using room air for bowel distention. Patients (28 men, 22 women, age range 44–77 years, mean age 60.6 years) had been referred for conventional colonoscopy for a variety of indications, including a positive family history of colorectal cancer ($N = 22$), a positive fecal

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occult blood test ($N = 17$), or chronic diarrhea ($N = 11$). Patients were randomized into two groups: 25 patients underwent water-distended MRC while the other 25 patients underwent air-distended MRC. All patients underwent conventional colonoscopy on the same day immediately after MRC.

MR Imaging

After a standard preparation for bowel cleansing (oral ingestion of 3 L Golytely, Braintree Laboratories, Braintree, MA), MR examinations were performed on a 1.5-T MR system (Magnetom Sonata, Siemens Medical Solutions, Erlangen, Germany) in prone position only. A combination of two surface coils was used in conjunction with the built-in spine array coil for signal reception to permit coverage of the entire colon. To minimize bowel peristalsis, 40 mg of scopolamine (Buscopan; Boehringer Ingelheim, Germany) was injected intravenously before the rectal filling. After placement of a rectal enema tube (E-Z-Em, Westbury, NY), the colon was filled with approximately 2000 mL of warm tap water in the water-distended patient group or with 2000 mL of room air via a bladder catheter (Curity®, Foley Catheter, 22 FR, Kendal) in the air-distended group. After bowel distention, a T1-weighted (T1w) three-dimensional gradient-echo data set 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 168 × 256 without using interpolation, receiver bandwidth 490 Hz/pixel, number of actual slices 96, and an effective slice thickness of 1.54 mm with a distance factor of 20% without interpolation. Subsequently, paramagnetic contrast (Gd-BOPTA, Multihance, Bracco, Italy) was administered intravenously at a dose of 0.2 mmol/kg and a flow rate of 3.5 mL/second. After a delay of 75 seconds, the three-dimensional acquisition was repeated with identical imaging parameters. The three-dimensional data were collected breath-held in 22 seconds.

After completion of the MRC exam, the colonic contents were drained. The water was drained into the enema bag that was placed on the ground, while the air was evacuated freely through the enema tip.

Data Analysis

For each subject, both non-contrast and contrast-enhanced three-dimensional data sets were made available on a post-processing workstation (Virtuoso, Siemens Medical Solutions, Erlangen, Germany). The three-dimensional MRC data sets were assessed interactively in the multiplanar reformation mode in consensus by two experienced radiologists who were blinded to the colonoscopic results.

For purposes of analysis, 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 contrast-to-noise ratio (CNR) between the colonic wall and the colonic lumen was calculated for all bowel segments on the contrast-enhanced data sets. Furthermore, the distention of each colonic segment was classified in three grades: 1 = well distended, 2 = moderately distended, and 3 = poorly distended. Furthermore, each segment was evaluated for the presence of artifacts and graded on a three-point scale: 1 = no artifacts; 2 = moderate artifacts, diagnostic; and 3 = extensive artifacts, not diagnostic. Ratings were compared by an unpaired Student's *t*-test using a *P*-value of <0.05 to indicate statistical significance. For the adaptation to multiple samples, a Bonferroni correction was employed.

All MRC data sets were assessed for the presence of colorectal pathologies including colorectal masses and/or changes indicating inflammatory bowel disease or diverticulitis. Masses detected on contrast-enhanced three-dimensional data sets were evaluated quantitatively by determining signal intensities both on the contrast-enhanced and the non-contrast three-dimensional data sets. Regions-of interest (ROIs) were placed both in the lesions and the colonic wall adjacent to them. Evidence of contrast enhancement confirmed the presence of a colorectal mass and permitted easy differentiation from residual stool, which did not reveal any signal change.

Patient Acceptance

Patient acceptance was evaluated using a standardized questionnaire. In telephone interviews conducted between 24 and 48 hours after the MR examination, all patients were asked to rate the discomfort associated with the bowel distention on a five-point scale ranging from 1 = no discomfort to 5 = extensive discomfort. Ratings of both groups were compared by an unpaired Student's *t*-test, again considering a *P*-value of <0.05 to indicate statistical significance. In addition, all subjects were asked about side-effects in conjunction with the examination.

The five healthy volunteers who had undergone both air- and water-distended MRC were asked which of the two procedures they would prefer if MRC needed to be repeated.

RESULTS

Colorectal Pathologies

Water-distended MRC revealed four colorectal masses (25, 20, 10, and 8 mm in diameter) in four patients and changes compatible with inflammatory bowel diseases in another four patients (Fig. 1). All inflammatory pathologies impressed as a loss of haustral markings and were associated with increased contrast uptake of the bowel wall. All findings were confirmed by subsequent colonoscopy. The two largest masses were malignant. In addition, colonoscopy revealed a 4-mm polyp in the sigmoid colon that was missed on MRC.

Air-distended MRC also revealed four colonic masses (28, 9, 7, and 7 mm, Fig. 2) in four patients. Changes indicative of ulcerative colitis were identified in three patients (Fig. 3). One patient exhibited changes suggestive of diverticulitis on MRC, impressing as a narrowing of the colonic lumen and straining of the pericolic fat. In this group of 25 patients, endoscopy confirmed all findings and did not reveal any additional pathologies. The 28-mm lesion was found to be malignant.

All detected colorectal masses enhanced after the intravenous administration of paramagnetic contrast.

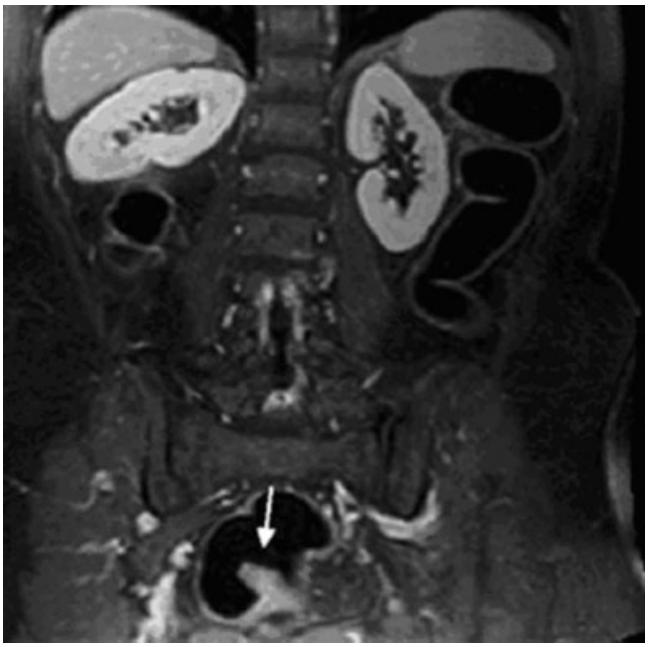

Figure 1. MRC with rectal application of tap water in a 66-year-old patient. Coronal source images of T1w three-dimensional gradient-echo scan show a bowel wall thickening with irregular borders (arrow), which turned out to be a 22-mm carcinoma of the sigmoid colon.

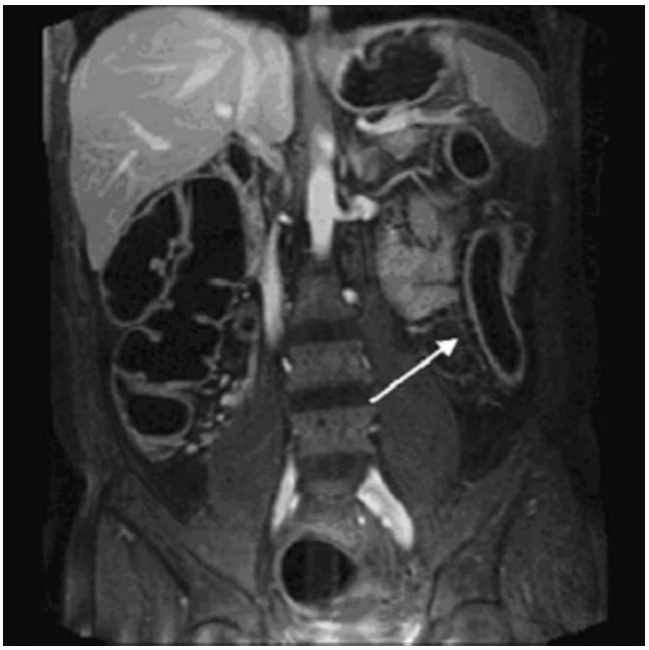

Figure 3. MRC with rectal application of room air in a 33-year-old patient. An ulcerative colitis was diagnosed due to a loss of haustral markings and increased contrast uptake of the colonic wall (arrow).

Four lesions (three carcinomas and one polyp) revealed contrast enhancement in excess of that seen in the normal colonic wall. Of these two, each were detected in water- and air-distended MRC data sets. The other four lesions, including one carcinoma and three polyps, revealed an enhancement identical to the colonic wall.

Figure 2. A 59-year-old patient undergoing MRC in conjunction with rectal application of room air. An 11-mm stalked polyp was depicted in the sigmoid colon (arrow) on the T1w three-dimensional gradient-echo data.

Again, two of these lesions were detected in water- and air-distended MRC data sets.

Image Quality

Colonic distention proved robust in all subjects (Fig. 4 a–c). Despite a trend favoring air, intraindividual differences between air- and water-distention in the five volunteers were not statistically significant regarding colonic distention (1.2 vs. 1.3, respectively). In patients, mean values for water-distention amounted to 1.31 with poorest results in s2 (mean 1.52) and best distention in s6 (mean 1.2). The use of air resulted in significantly better colonic distention ($P < 0.05$) with a mean rating of 1.07 ranging between 1.0 (s5 and s6) and 1.24 (s2).

The assessment for artifacts did not show a statistically significant difference between the patient groups or the intraindividual volunteer exams. Both bowel distending media provided high image quality with few artifacts related mainly to motion or wrapping. Susceptibility effects did not impair assessment of the colon. Mean image quality was rated as 1.25 for water and 1.13 for air. There were no statistically significant differences between bowel segments. There was no "non-diagnostic" rating.

Statistically significant differences were detected when comparing CNR values. Both the intraindividual volunteer comparison and the comparison between patient groups showed air-distended MRC to be associated with higher CNR values than water-distended MRC. Overall, air-distention was associated with a mean CNR of 43.5, while water-distention resulted in a mean CNR of merely 36.3 ($P < 0.05$). The parameters of all colonic segments are listed in Table 1.

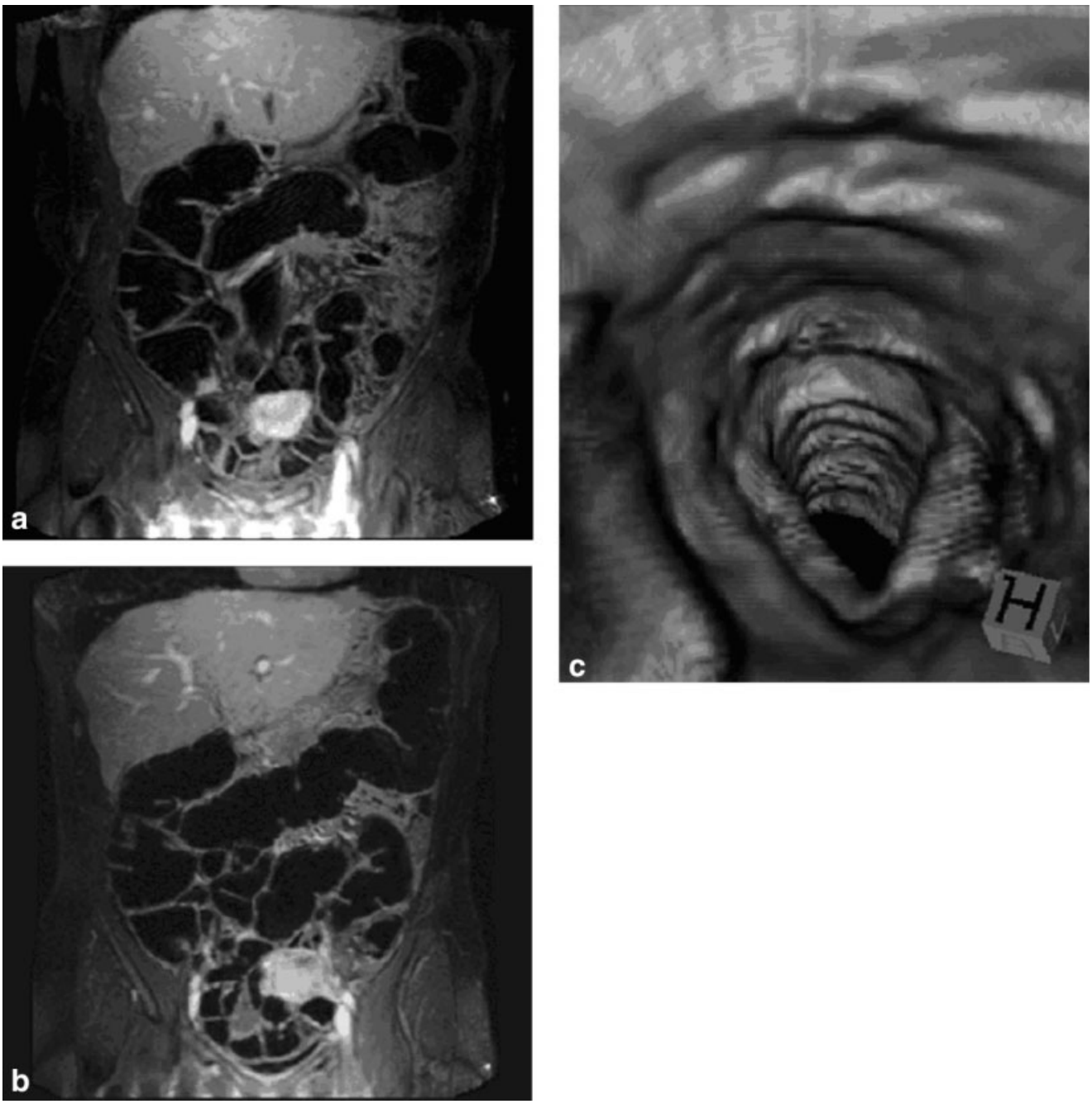

Figure 4. a: A 40-year old volunteer undergoing MRC on two separate days. Coronal source images of T1w three-dimensional gradient-echo scan acquired 75 seconds after intravenous. gadolinium application provide high image quality both in the examination with water. **b:** Colonic distention with air by the same volunteers. **c:** Due to the high contrast between the bright colonic wall and the dark colonic lumen, a virtual endoscopic rendering of the three-dimensional data is possible even for the examination with air.

Patient Acceptance

Both MRC techniques were well tolerated by volunteers and patients alike. Water- and air-distention was each preferred by two of the five volunteers. One volunteer did not have a preference for either water or air. For patients, the mean discomfort level associated with colonic air filling amounted to 1.56 (SD ± 0.58). Water-filled MRC was rated only slightly better, with a mean discomfort level of 1.48 (SD ± 0.51). The difference did not prove statistically significant ($P > 0.05$).

Two subjects who had undergone air-filled MRC reported slight bowel spasms. Symptoms subsided after the oral ingestion of 100 mg Simethicon (Lefax®, Bayer AG, Germany). No unpleasant side-effects were reported in the patient group undergoing water-distended MRC. In two cases, however, part of the water enema was spilled on the scanner table. The spills were absorbed by towels and remained without further consequence. After completing water-distended MRC, one patient suffered from rectal incontinence on the way to the restroom.

Table 1
Image Quality of MRC with Water and Air*

	Water							Air						
	S1	S2	S3	S4	S5	S6	Av	S1	S2	S3	S4	S5	S6	Av
Distension	1.40	1.52	1.28	1.24	1.24	1.20	1.31	1.08	1.24	1.04	1.08	1.00	1.00	1.07
$N = 1$	15	13	19	20	20	21		23	19	24	23	25	25	
$N = 2$	10	11	5	4	4	3		2	6	1	2	0	0	
$N = 3$	0	1	1	1	1	1		0	0	0	0	0	0	
Artifacts	1.24	1.28	1.24	1.24	1.24	1.24	1.25	1.08	1.16	1.16	1.12	1.12	1.16	1.13
$N = 1$	19	18	19	19	19	19		23	21	21	22	22	21	
$N = 2$	6	7	6	6	6	6		2	4	4	3	3	4	
$N = 3$	0	0	0	0	0	0		0	0	0	0	0	0	
CNR	44.0	51.0	23.5	47.9	23.3	28.0	36.3	49.5	58.0	30.6	54.2	30.6	38.3	43.5

*Indices for distension artifacts and CNR are listed. Furthermore, total numbers of patients in each category (N = 1–3) are shown. S1 = rectum, S2 = sigmoid colon, S3 = descending colon, S4 = transverse colon, S5 = ascending colon, S6 = cecum, CNR = contrast to noise ratio, Av = average valuves of all segments S1–S6.

DISCUSSION

This paper carries three messages we believe to be important: 1) It is feasible to perform MRC using room air for bowel distention; 2) the assessment of the colonic wall in an air-distended colon on T1w three-dimensional gradient-echo data sets is not corrupted by susceptibility artifacts; and 3) while both air and water are similarly well tolerated as colonic distending agents, the use of air provides slightly better bowel distention and higher CNR of the colonic wall.

The technical basis for MRC has been considerably altered since its first description in 1997 (11). Initially, MRC was based on the rectal application of water spiked with paramagnetic contrast. While the liquid was administered to distend the colon, the paramagnetic contrast rendered the colonic lumen bright, thereby permitting the detection of colorectal masses protruding into the lumen as "negative" filling defects (3). The technique was handicapped by difficulties differentiating polypoid masses from residual stool or even small air bubbles (12,13). The introduction of the dark lumen technique was aimed at overcoming these limitations. Instead of searching for "negative" filling defects in a bright colonic lumen, colorectal masses are identified based on their characterization as perfused, and thus contrast-enhancing, tissue. After the intravenous administration of paramagnetic contrast, the colonic wall and masses arising from it enhance brightly. They are easily delineated on T1w images against a darkened lumen distended with plain water (5,10,13,14).

Better density properties and the assumption that air provides less discomfort compared to water (15) has resulted in the predominant use of gaseous agents for CT-colonography (16–22). Although similar to water regarding MR signal properties on T1w images, the fear of susceptibility artifacts rendered the use of air or other gases less applicable for MRC. The practicability of administering room air for bowel distention in MRC was first evaluated by Morrin et al (8). Seven patients underwent MRC after the insufflation of air per rectum. T2-weighted half-Fourier acquisition single-shot turbo spin-echo (HASTE) images were acquired. Although the presence of susceptibility artifacts rendered image quality suboptimal in five of seven examinations, a 15-mm polyp was correctly detected but a 6-mm polyp was missed. Even more promising results were reported by Lomas et al (7) who used a half-Fourier single-shot fast spin-echo sequence for MRC. Using CO_2 to distend the colon, seven patients with known colorectal tumors were examined. Image quality was considered diagnostic in all exams and all colorectal tumors were correctly identified.

Detailed analysis of these two feasibility studies reveals several downsides to the pursued imaging approach. Thus, the technique was limited by the two-dimensional nature of the T2-weighted sequences providing only thick 5-mm sections (7,8). Furthermore, the acquisition of the relatively thick two-dimensional sections has to be grouped into several blocks collected over several breath-holds. Hence, misregistration of adjacent blocks may occur, rendering image interpretation rather complex. Because data acquisition is prolonged, peristaltic motion and altered colonic distention due to the rapid resorption of CO_2 can further impair diagnostic accuracy (23).

The MRC technique presented in this study overcomes many of the outlined limitations. The three-dimensional nature of the utilized T1w sequence provides excellent spatial resolution in all three planes, thereby permitting the detection of colorectal masses as small as 5 mm (15). In line with other studies reporting on the diagnostic accuracy of water-distended MRC (24), eight of nine colorectal masses identified by colonoscopy were correctly detected with MRC. Among the air-filled MRC exams, not a single lesion was missed. Furthermore, the underlying T1 contrast mechanism between a brightly enhancing bowel wall and a dark colonic lumen provides a far more comprehensive assessment of the colon compared to the hitherto pursued T2 contrast mechanism. Residual stool can be readily distinguished from colorectal lesions and even inflammatory changes are accurately depicted (24). Thus, changes induced both by inflammatory bowel disease and diverticulitis were accurately identified.

Finally, the use of ultrashort sub-millisecond echo times virtually eliminated the presence of susceptibility artifacts in the presence of air-distention. With an echo time lasting merely 0.6 msec, there simply is not sufficient time for dephasing to occur. Thus it was not surprising that image quality of air- and water-distended data sets did not reveal a statistically significant differ-

ence. Similar observations with ultrashort echo times have been made in the lungs (25,26). In this context, it is important to point out, however, that the use of ultrashort sub-millisecond echo times is predicated upon the availability of a scanner with high performance gradient systems.

The replacement of water by air for colonic distention led to two unexpected improvements of the dark lumen MRC technique: both the CNR and bowel distention were mildly improved. Differences proved statistically significant. The improvement in CNR relates to the fact that air within the colonic lumen is associated with less signal than water. At the same time, signal enhancement of the colonic wall was not affected, resulting in an increase in CNR. Improvements in colonic distention, particularly in the sigmoid colon and rectum are more difficult to explain. Although not measured, the distending process with air could have been faster than that with water, providing less time for the air to escape through the ileocecal valve into the small bowel. Both aspects may contribute toward enhancing the diagnostic performance of dark lumen MRC even further.

Interpretation of patient acceptance data revealed no significant difference between the two patient groups. Within the groups, the data were fairly heterogenous. Most patients tolerated bowel distention well regardless of the distending agent. Small water spills and one instance of rectal incontinence after the procedure were offset by two patients complaining about bowel spasms after air insufflation. The data may have been more favorable for air-distention if carbon dioxide (CO_2) would have been used. Albeit somewhat more expensive than room air, the accelerated absorption from the gastrointestinal tract has favored CO_2 as the optimal gaseous agent for colonic imaging as it results in less discomfort (27,28). From an imaging point of view, air and CO_2 seem to be interchangeable (7).

We conclude that MRC based on fast three-dimensional T1w data sets depicting a dark colonic lumen in conjunction with a brightly enhancing colonic wall can be performed using either water or air as the distending agent. Both techniques permit assessment of the bowel wall and identification of colorectal masses. Discomfort levels are similar for both agents. Slightly better CNR and improved distention of the rectum and sigmoid colon seem to favor air insufflation.

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