Technical Note

Digital Subtraction Dark-Lumen MR Colonography: Initial Experience

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Purpose: To evaluate image subtraction for the detection of colonic pathologies in a dark-lumen MR colonography exam.

Materials and Methods: A total of 20 patients (12 males; 8 females; mean 51.4 years of age) underwent MR colonography after standard cleansing and a rectal water enema on a 1.5-T whole-body MR system. After suppression of peristaltic motion, native and Gd-contrast-enhanced three-dimensional T1-w gradient echo images were acquired in the coronal plane. Two radiologists analyzed the MR data sets in consensus on two separate occasions, with and without the subtracted images for lesion detection, and assessed the value of the subtracted data set on a five-point Likert scale (1 = very helpful to 5 = very unhelpful). All imaging results were compared with endoscopy.

Results: Without subtracted images, MR-colonography detected a total of five polyps, two inflammatory lesions, and one carcinoma in eight patients, which were all verified by endoscopy. Using subtraction, an additional polyp was found, and readout time was significantly shorter (6:41 vs. 7:39 minutes; $P < 0.05$). In two patients, endoscopy detected a flat adenoma and a polyp (0.4 cm) that were missed in the MR exam. Sensitivity and specificity without subtraction were 0.67/1.0, and 0.76/1.0 with the subtracted images, respectively. Subtraction was assessed as helpful in all exams (mean value 1.8 ± 0.5; Likert scale).

Conclusion: : We consider subtraction of native from contrast-enhanced dark-lumen MR colonography data sets as a beneficial supplement to the exam.

Key Words: large bowel disease; MR colonography; digital subtraction; comparative study; colorectal polyps
J. Magn. Reson. Imaging 2005;21:841–844.

DARK-LUMEN MR colonography combining an aqueous enema with intravenous administration of Gd-based contrast agents is a rapidly evolving, almost noninvasive method for evaluation of the entire colon. Results of several preliminary studies indicate that this technique has a high sensitivity for detection of colorectal masses, diverticulitis, and inflammatory disease of the large bowel (1–3). Dark-lumen MR colonography is based on focal uptake of T1-shortening contrast material in colonic lesions, which are displayed as bright areas on T1-weighted sequences, whereas the lumen is rendered totally dark due to water or water-based solutions that serve as filling material. The latter leads to uniform luminal darkening as well as sufficient distention of the colon. Recently, the use of gaseous agents for colonic distension has been proposed (4,5). In either situation, intravenous administration of butylscopolamine or glucagon guarantees temporary depression of bowel movements in order to reduce motion artifacts throughout image acquisition. During spasmolysis, both nonenhanced and contrast-enhanced data sets are acquired. Thus, a digital subtraction technique comparable to MR angiographic studies (6–9) for elimination of unwanted background signal and residual stool might facilitate detection of colorectal regions with increased contrast uptake. The purpose of this study was to assess such a subtraction technique in dark-lumen MR colonography.

MATERIALS AND METHODS

Subjects

After receiving institutional review board approval, we performed dark lumen MR colonography on 20 consecutive subjects (male, 12; female, 8; age range, 36–64 years; mean, 51.4 years) in whom colonic pathologies were suspected; all of the subjects underwent conventional endoscopy prior to the MR experiment for the following indications: positive fecal occult blood test ($N = 10$), ulcerative colitis ($N = 3$), a positive family history of colorectal cancer ($N = 2$), chronic diarrhea ($N = 2$), a previous history of colorectal cancer ($N = 2$), and polyposis ($N = 1$). Patient preparation included abstinence from any food starting the night before the examination and bowel purgation with a standard preparation for bowel cleansing (oral ingestion of 3000 mL polyethylene glycol solution, GoLYTELY; Braintree Laboratories, Braintree, Massachusetts, USA). Prior to

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Received July 1, 2004; Accepted March 3, 2005.
DOI 10.1002/jmri.20332
Published online in Wiley InterScience (www.interscience.wiley.com).

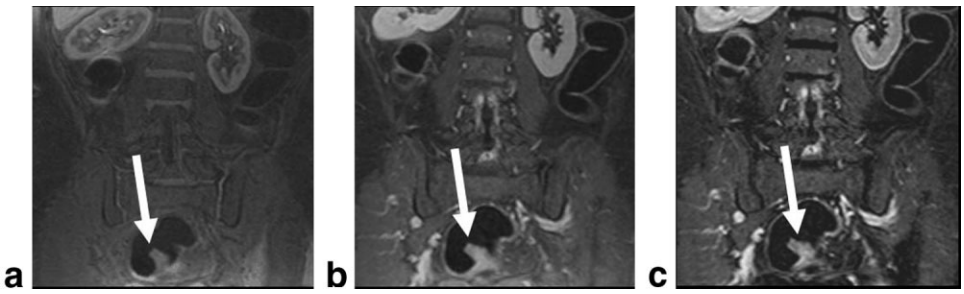

Figure 1. A 64-year-old male patient with a colon carcinoma in the rectosigmoid region. The tumor is readily detectable as a large mass on the non-enhanced sequence (**a**), and shows considerable enhancement after Gd-contrast material administration (**b**). The tumor appears even sharper delineated against the dark background on the subtracted image (**c**). The sequence used was a T1-w gradient recall echo sequence, volumetric interpolated breath-hold examination (VIBE); TR = 3.1 msec; TE = 1.1 msec; FA = 12°; TA = 22 seconds. All images are shown in an oblique coronal plane of view.

MR colonography, a rectal enema tube (E-Z-Em; Westbury, New York, USA) was placed, butylscopolamine (40 mg, Buscopan; Boehringer, Ingelheim, Germany; $N = 15$) or glucagon (1 mg, Glucagen; Bayer AG, Leverkusen, Germany; $N = 5$) was intravenously administered, and the colon was filled with 2000 mL of body temperature tap water. Instillation of the enema was carried out in stages over a one-minute period to minimize discomfort and bowel cramping. The total time from injection of the spasmolytic agent and completion of data acquisition was approximately four minutes.

MR Imaging

The filling process of the colon was monitored with a real-time fluoroscopic sequence (TrueFISP; repetition time [TR]/echo time [TE] = 2.4/1.2 msec, flip angle [FA] = 60°, slice thickness [SL] = 5 mm) permitting the acquisition of one image per second. After sufficient distention of the colon, a three-dimensional T1-weighted gradient recall echo sequence (volumetric interpolated breath-hold examination [VIBE]) in the coronal plane was acquired (10). VIBE is characterized by a TR and a TE of 3.1 and 1.1 msec, respectively, and a FA of 12°. The acquisition time (TA) was 22 seconds, and the field of view was 400 × 400 mm. The matrix size was 168 × 256 (zero interpolation to 512), the effective slice thickness was 4.0 mm. Interpolated voxel size was 2.1 × 1.6 × 1.8 mm. Roughly 75 seconds after intravenous contrast administration (gadobenate dimeglumine, MultiHance®; Bracco Sp.A., Milan, Italy; 0.2 mmol/kg) the sequence was repeated. Subjects were instructed to hold their breath in expiration during image acquisition. All imaging was performed on a 1.5-T whole-body magnet (Magnetom Sonata; Siemens Medical Solutions, Erlangen, Germany).

Data Analysis

All native and contrast-enhanced three-dimensional MR colonography data sets were transferred to a postprocessing workstation (Leonardo; Siemens Medical Solutions) for digital subtraction. All data were assessed in consensus on two separate occasions by two experienced radiologists (T.C.L. and C.U.H., each with four years of experience with MR colonography). Only one readout session included the subtracted datasets. The readouts were separated by four weeks and performed in random patient order. Readout times were measured for each case. The readers were unaware of the reason for MR colonography. Evaluation time and number of lesions detected in the readouts were compared for lesion delineation, signal, and conspicuity. In addition, helpfulness in terms of diagnostic confidence for normal and abnormal findings in the subtracted images was rated on a five-point Likert scale, with the following values: 1 = very helpful; 2 = helpful; 3 = equivocal; 4 = unhelpful; and 5 = very unhelpful.

Statistical Analysis

For comparative statistical analysis of the readout times of data sets with and without subtracted images, a paired Student's *t*-test was employed in which statistical significance was established at $P < 0.05$. The mean value for the assessment of helpfulness of subtracted images was determined. With conventional colonoscopy as the standard of reference, accuracy of dark-lumen MR colonography with and without subtraction was assessed by calculating point estimates for sensitivity and specificity.

RESULTS

Digital subtraction of dark-lumen MR colonography datasets resulted in images in which focal contrast uptake of the wall was easily detectable, since areas of contrast uptake were displayed as bright spots against a homogeneously dark background. Hence, both large and small lesions arising from the colon wall could readily be detected, such as malignant tumors and small polypous lesions (Figs. 1 and 2). As currently implemented, no extra imaging time was needed for the postprocessing, and subtraction was fully accomplished by standard software programs integrated to the workstation.

In comparing the assessment of the data with and without the subtracted images, we found a significant reduction of the readout time when using the subtracted data set (6:41 vs. 7:39 minutes; $P < 0.05$).

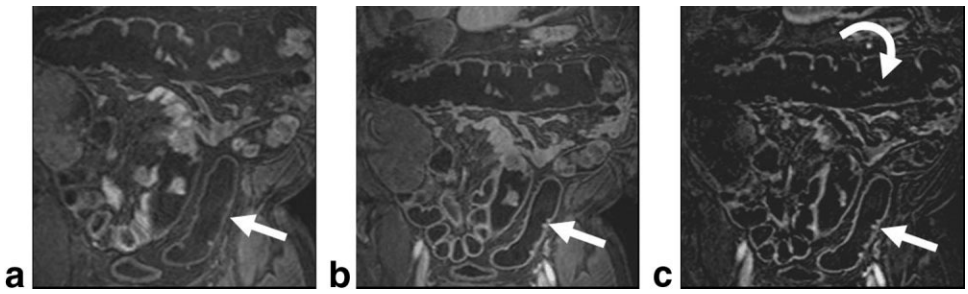

Figure 2. A 36-year-old female patient with polyposis coli. While the mural polyps (arrows) in the sigmoid colon were not seen on the native scan (**a**), they became clearly visible to the same advantage on the Gd-contrast-enhanced images (**b**) as on the subtracted data set (**c**). Note the subtracted stool in both the transversal and sigmoid colon (curved arrow in c). The sequence used was a T1-w gradient recall echo sequence, volumetric interpolated breath-hold examination (VIBE); TR = 3.1 msec; TE = 1.1 msec; FA = 12°; TA = 22 seconds. All images are shown in an oblique coronal plane of view.

Subtracted datasets were judged as helpful (mean 1.8 ± 0.5).

Dark-lumen MR colonography without subtracted data sets detected three polyps (size range, 0.8–1.4 cm; mean, 1.1 cm), two inflammatory lesions, and one carcinoma. In addition to these findings, one polyp (0.5 cm) was detected on the subtracted data, which was overlooked on the readout without the additional images (Fig. 3). All lesions in the same individuals were confirmed by endoscopy. Nevertheless, conventional endoscopy detected one additional polyp (0.4 cm) and one flat adenoma that were missed in the MR exam, independent of whether the subtracted MR colonography dataset was considered or neglected for the readout. The overall sensitivity and specificity of the MR-colonography protocol with digital subtraction was 0.78/1.0, respectively, and 0.67/1.0 without consideration of subtracted images.

DISCUSSION

Digital subtraction of dark-lumen MR colonography datasets translates into an excellent delineation of colorectal wall pathologies and offers the possibility of reducing readout time, together with a better sensitivity for detecting areas of increased contrast media uptake.

The idea of subtracting cross-sectional MR data in Gd-enhanced MR imaging similar to digital subtraction angiography for image quality improvement is not new (11). This technique is a quick and efficient means of obtaining fat suppression, avoiding the limitations of incomplete fat saturation due to field inhomogeneity and increased imaging times associated with conventional fat-suppression techniques. Zalis and Hahn (12) and Zalis et al (13) recently proposed a subtraction technique for virtual colonic cleansing in computed tomography (CT) colonography. To this end, patients ingest positive contrast material approximately two days before the exam; this material is afterward subtracted from the images by dedicated software. This allows for detection of colonic lesions that remain unaffected by the subtraction technique. This practice obviates the duress of colonic cleansing prior to the examination, which might improve compliance to colon cancer screening. Different fecal tagging methods have likewise been introduced for MR colonography dealing with both bright and dark lumen techniques. However, reflecting the complexity of the MR signal and the necessity to render stool homogeneously dark or bright prior to the examination, this approach still remains challenging and not yet clinically practical.

In our work, all patients underwent standard bowel purgation, which is generally known to negatively affect patient acceptance (14). However, recent fecal tagging concepts for dark-lumen MR colonography point to a substantial improvement of patient comfort when pre-

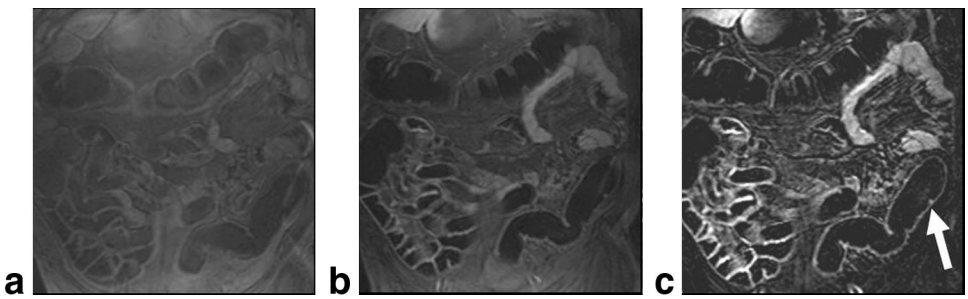

Figure 3. A 46-year-old male patient with a positive fecal occult blood test presenting with a small polyp (5 mm) in the descending colon. While on the nonenhanced scan (**a**) and after intravenous Gd-contrast administration (**b**) the tumor was overlooked, both readers correctly detected the polyp on the subtracted data set (arrow; **c**). The sequence used was a T1-w gradient recall echo sequence, volumetric interpolated breath-hold examination (VIBE); TR = 3.1 msec; TE = 1.1 msec; FA = 12°; TA = 22 seconds. All images are shown in an oblique coronal plane of view.

paring for colonic imaging (15–17). Fecal tagging is based on altering the signal intensity of stool by adding contrast-modifying substances to regular meals preceding the MR exam. Barium sulfate appears to be a safe and inexpensive agent that renders stool virtually indistinguishable from the distending aqueous enema on T1-weighted images. However, further studies will reveal the role of fecal tagging with respect to patient acceptance and diagnostic accuracy.

Bowel peristalsis in between the native and contrast-enhanced colon examinations may impair the quality of the subtracted dataset, as incongruent structures might imitate lesions or reduce structural sharpness of the colon wall. In conjunction with different levels of breathholds of the unenhanced and contrast-enhanced scan, this might lead to misregistration and false-positive results. However, this was not true in our study cohort due to the signal difference between the native and the Gd-enhanced dataset and sufficient pharmacological spasmolysis. We did not observe substantial differences between the effect of butylscopolamine and glucagon. However, experience with these muscle-relaxing agents for cross-sectional colonography varies between no influence on colonic distention after glucagon (18,19) and improved distension, especially of proximal colonic segments after butylscopolamine (20). Yet, most of these results were corroborated for CT colonography, in which spasmolysis is less likely to influence image quality due to faster image acquisition in comparison to MR imaging. We consider anticholinergic drugs as an essential prerequisite for MR colonography, particularly for later data subtraction. In case of contraindication to butylscopolamine (i.e., glaucoma, prostate hypertrophy, severe coronary heart disease), we administer glucagon for spasmolysis. Independent of major peristaltic movements, digital subtraction of colonographic MR datasets might be particularly useful in more fixed parts of the colon, e.g., the ascending or descending colon.

Relating to subtraction of consecutive datasets, patient movement during the first and second data acquisition as well as different levels of breathholds might also weaken image quality and cause falsely-positive colorectal findings. Since patients were examined only in the prone position and underwent MR imaging in breathhold expiration, this risk was minimized in our study, which is also reflected by the lack of false-positive findings on the subtracted datasets.

The present study has recognized limitations. First, this was only a small study cohort and indications for the MR examinations were rather inhomogeneous. Second, all patients underwent endoscopy before referral to the MR exam. This might have increased the alertness for lesion detection during the readout. Another concern relates to the inability of dark-lumen MR colonography to identify colorectal lesions smaller than 5 mm in size. This might get better through the implemented subtraction technique; however, overall spatial resolution remains unaffected. Still, polyps smaller than 1 cm in size appear not to be prone to malignant dysplasia. In addition, small lesions will probably become detectable on dark lumen MR colonography with or without subtraction as technical refinements including parallel acquisition techniques are implemented. Nevertheless, flat adenomas remain a challenge for cross-sectional colonography and are most likely to remain only detectable with endoscopy.

In summary, digital subtraction appears to be a cost-free supplemental tool in dark-lumen MR colonography that warrants clinical implementation and further investigation in a larger study cohort.

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