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INVITED UPDATE

Dark-lumen MR colonography

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Abstract

Magnetic resonance colonography (MRC) has been shown to be an appropriate diagnostic tool for the detection of colorectal pathologies. Recently, dark-lumen MRC has been introduced. This technique is based on the acquisition of a T1-weighted sequence after the administration of water enema and the intravenous administration of paramagnetic contrast. This report describes the underlying techniques of dark-lumen MRC concerning data acquisition and image interpretation. Furthermore, it points out the advantages of this approach as compared with conventional endoscopy or other MR methods. Possible improvements in the future such as the implementation of fecal tagging strategies to avoid bowel cleansing are discussed.

Key words: Colorectal cancer—Dark lumen magnetic resonance colonography—Fecal tagging

Colorectal cancer and screening

The incidence of colorectal cancer (CRC) in the United States amounts to 130,000 per year with 50,000 cases of death [1]. Thus, CRC has matured into the second most common cancer in both sexes in the Western world. Up to 90% of CRC cases originate from benign adenomas [2]. Hence, the incidence of CRC could be considerably reduced by more than 80% if polyps were detected and eliminated before their malignant transformation.

Despite the availability of several screening options, CRC remains a considerable cause of morbidity and mortality. The main reason is related to poor patient acceptance in current screening programs. Therefore, a real successful strategy has to overcome poor patient acceptance in the future by making the examinations comfortable and noninvasive. Magnetic resonance colonography (MRC) has the potential to be implemented as such a screening tool. Due to its noninvasive character, it is well accepted by patients. Moreover, it is highly accurate for the detection of colorectal polyps.

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MR colonography

Similar to contrast-enhanced three-dimensional (3D) MR angiography, MRC is based on the principles of ultra-fast, T1-weighted 3D gradient-echo acquisitions collected within the confines of a single breath-hold [3]. This requires the use of an MR system equipped with high-performance gradients. Initial approaches of MRC were based on the rectal application of water spiked with paramagnetic contrast. On T1-weighted data sets, the paramagnetic contrast renders the colonic lumen bright. Hence, polypoid colonic masses appear as dark filling defects within the bright colonic lumen. This appearance may make the differentiation of polyps from residual fecal material and/or small pockets of air difficult. Furthermore, the technique requires data acquisition in prone and supine patient positions to compensate for the presence of residual air. A recently introduced method of MRC is based on a different contrast mechanism and is referred as "dark-lumen MRC" [4]. It has turned out to be more accurate and less time consuming than "bright-lumen" techniques.

Dark lumen MRC—technical considerations

Before the examination, the patient has to be screened for contraindications to MR imaging (MRI) such as severe claustrophobia or the presence of metallic implants or cardiac pacemakers. The presence of hip prostheses, which normally is not regarded a contraindication to MRI, impedes complete analysis of the rectum and sigmoid colon. Therefore, these patients should not be examined. Because residual stool impedes appropriate evaluation of the large bowel, patients need to undergo bowel preparation in a manner similar to that required for conventional colonoscopy. To limit patient discomfort related to extended fasting, MRC should be performed in the early morning.

Patients should be examined on a 1.5-T MR system scanner equipped with strong gradient systems. Thus, data acquisition is to be confined to one breath-hold. The examination itself is performed in patients in the prone or supine position. A combination of two surface coils should be used for signal reception to permit coverage of the entire colon

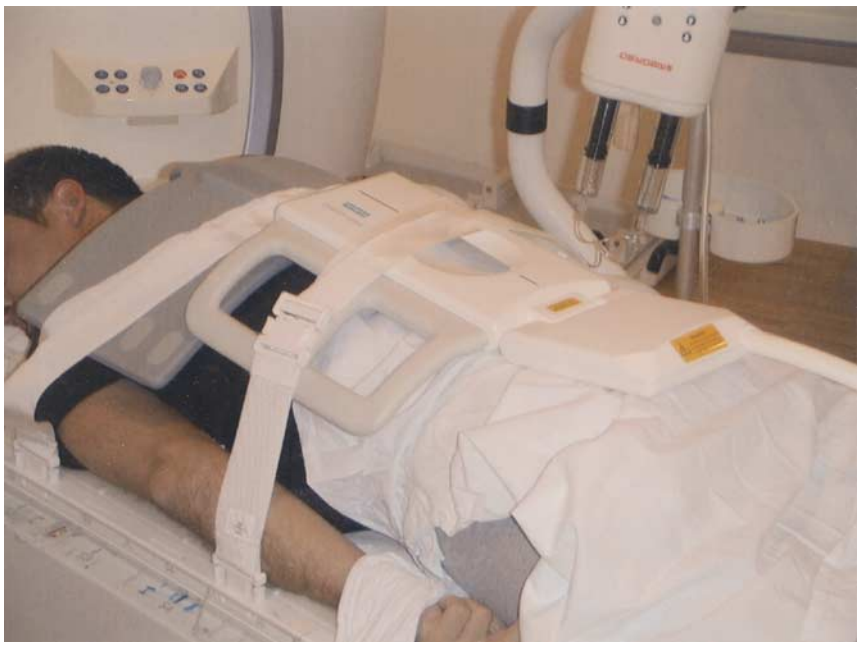

Fig. 1. Combination of phased-array surface coils to permit complete coverage of the entire colon and homogeneous signal reception.

(Fig. 1). To minimize motion artifacts due to bowel peristasis, a spasmolytic agent is administered intravenously (e.g., scopolamine or glucagon). A contrast enema consisting of 2 to 2.5 L of warm tap water is rectally administered using hydrostatic pressure (1- to 1.5-m water column). The filling process of the colon can be monitored by using a T2-weighted non-slice select acquisition that collects one image every 3 s (e.g., TrueFISP; repetition time/echo time, 2.4/1.2 ms; flip angle 60 degrees). Beyond assuring adequate filling, this two-dimensional overview allows recognition of high-grade stenoses and colonic spasm. Once the water enema has reached the cecum and a sufficient distention is assured, a 3D gradient-echo data set is collected (repetition time/echo time, 3.1/1.1 ms; flip angle, 12 degrees; field of view, 450 $\times$ 450 mm; matrix, 168 $\times$ 256; and effective slice thickness, 4 mm). Subsequently, paramagnetic contrast is administered intravenously at a dosage of 0.2 mmol/kg and a flow rate of 3.5 mL/s. A second 3D acquisition is acquired in a portal-venous contrast phase. After data acquisition, the enema bag is placed on the floor for facilitated emptying of the colon. This protocol allows completing the examination with an in-room time of 20 min.

Image analysis

For data interpretation, there are several commercially available hardware systems. The 3D data sets should be postprocessed and read in multiplanar reformation mode (MPR). This permits scrolling through the 3D data sets in all three orthogonal planes. The diagnostic workup should start interpreting the contrast-enhanced data. Whenever a mass protruding from the colonic wall is detected, the identical part of the colon should be analyzed on the precontrast scan. By measuring signal intensities of the mass in the native and postcontrast scans, a contrast enhancement value can be determined. Hence, the differentiation between small residual stool particles and colorectal lesions is simple: residual stool does not show contrast enhancement (Fig. 2A,B), whereas colorectal lesions always do (Fig. 3A,B).

In a second step, the data should be assessed based on virtual endoscopic renderings displaying the inside of the colonic lumen (Fig. 4A,B). A virtual endoscopic fly-through enables the radiologist to concentrate on the colon by facilitating the depiction of small structures protruding into the colonic lumen. Furthermore, the 3D depth perception allows discrimination between polyps and haustra. To assure complete visualization of both sides of the haustral folds, the virtual fly-through should be performed in antegrade and retrograde directions with regard to the detection of polyps, virtual endoscopic viewing renders improved sensitivity and specificity values as compared with inspection of the individual cross-sectional images alone [5].

Diagnostic accuracy

Dark-lumen MRC was first introduced and evaluated in 2001 [4]. Twelve patients with suspected colorectal lesions were examined. In addition to dark-lumen MRC, all patients underwent conventional colonoscopy performed within 5 to 14 days. Five polyps ranging in diameter from 7 to 12 mm were detected. All lesions were confirmed by conventional colonoscopy and subsequent polypectomy was performed. There were no false negative findings. The intravenous administration of paramagnetic contrast resulted in an average signal-to-noise ratio increase within the colonic wall of 170% from 9.2 to 24.8 $\pm$ 2.6. This difference was statistically significant ($p < 0.001$). Polyps showed even more enhancement with signal intensities increasing by 306%

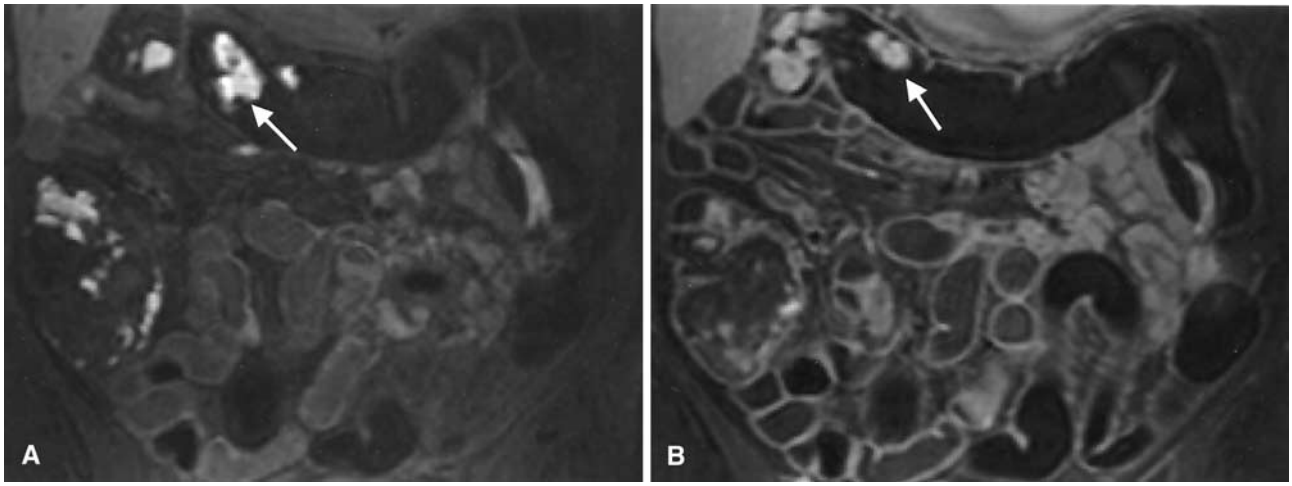

Fig. 2. Dark-lumen MRC. Tap water is used for bowel distention. **A** A native coronal T1-weighted 3D VIBE sequence. **B** The bowel wall is bright due to intravenous application of paramagnetic contrast. Residual stool (*arrow*) appears bright on pre- and postcontrast phases and shows no contrast enhancement.

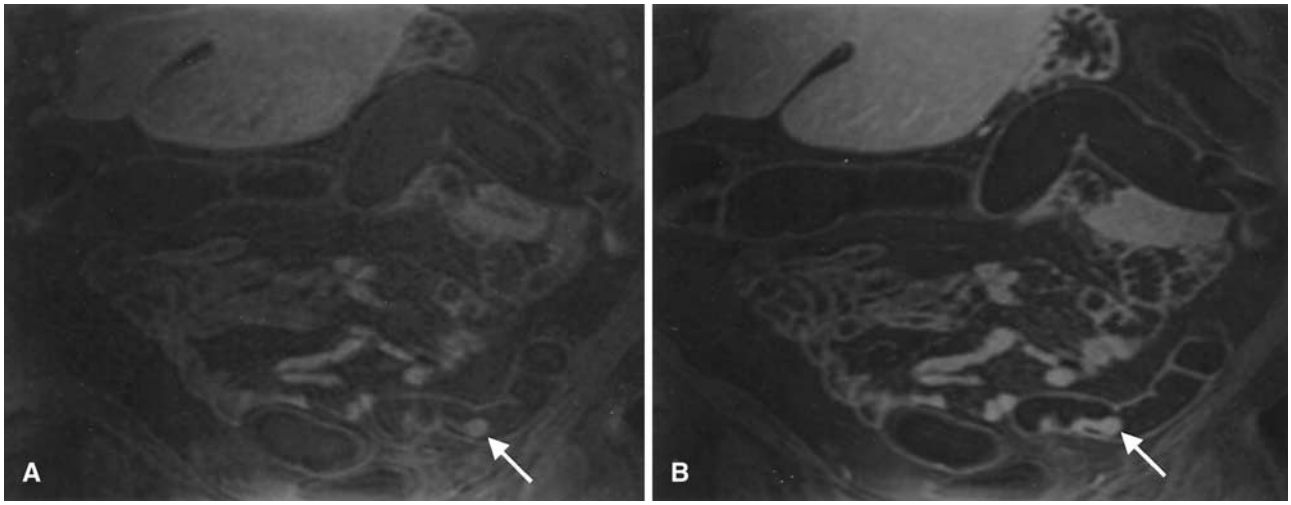

Fig. 3. Dark-lumen MRC. **A** On the coronal T1-weighted precontrast phase, a hypointense lesion (*arrow*) is shown in the sigmoid colon. **B** After intravenous injection of paramagnetic contrast the postcontrast phase demonstrates a high-contrast enhancement, in distinction to residual stool.

from 8.9 ± 1.6 to 36.1 ± 3.9. Lack of contrast enhancement correctly identified three bright "lesions" as residual stool. In addition, dark-lumen contrast-enhanced MRC depicted four extraintestinal lesions: two renal cysts in two patients, one hepatic hemangioma in one patient, and one aortic abdominal aneurysm measuring 4 cm in diameter in another patient.

A recent study used a larger patient cohort [6] of 122 patients undergoing dark lumen MRC and subsequent conventional colonoscopy. MRC did not detect lesions smaller than 5 mm. For lesions between 5 and 10 mm, MRC correctly detected 16 of 18 lesions. Nine of nine CRCs with lesions larger than 10 mm were seen on MRC images (Fig. 5A). In addition, conventional endoscopy documented inflammatory wall alterations (Crohn disease and ulcerative colitis) in 28 patients. MRC correctly diagnosed inflammatory changes in 25 patients. In three patients with Crohn disease, interintestinal fistulae were detected with MRC and conventional colonography. There were no false positive readings based on the MRC data sets. In addition, dark-lumen MRC permitted the reliable assessment of extraintestinal organs. Thus, a variety of therapy-relevant and irrelevant pathologies were identified. Hepatic metastases were observed in four patients, and bone metastases were seen in seven patients (Fig. 5B).

Both studies emphasize that dark-lumen MRC may overcome several limitations inherent to bright-lumen MRI techniques. The intravenous application of paramagnetic contrast technique allows the direct depiction of the colorectal wall.

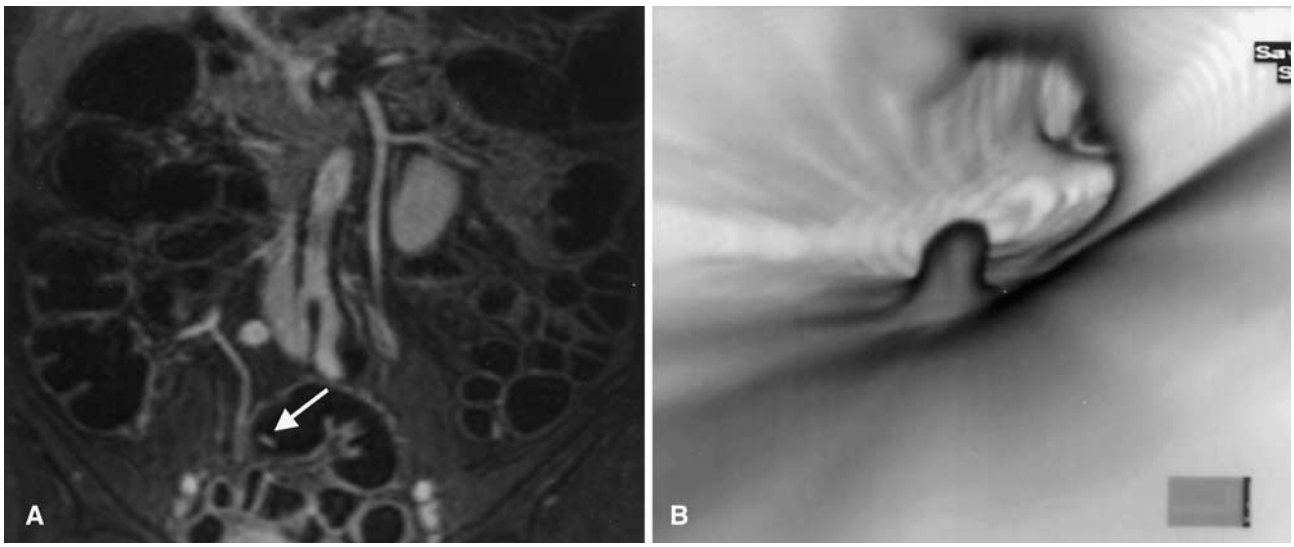

Fig. 4. **A** Coronal reformatted image of a 3D T1-weighted data set acquired 75 s after intravenous contrast injection shows a 10-mm lesion in the sigmoid colon with high contrast enhancement (*arrow*) and was rated as a colorectal polyp. This was confirmed by conventional endoscopy. **B** Virtual endoscopic reformation of the lesion. Subsequent polypectomy was performed.

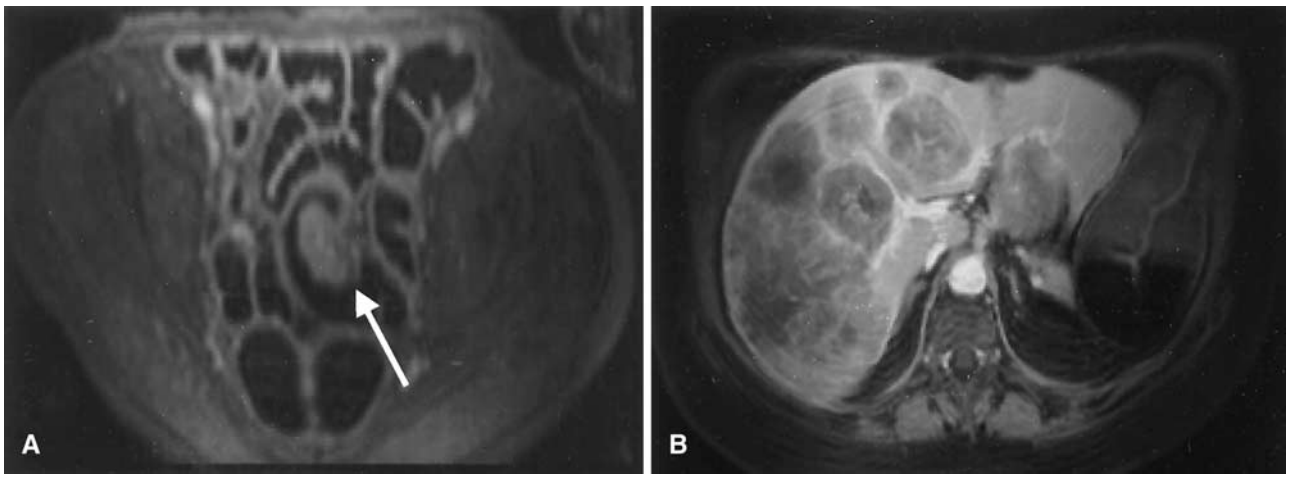

Fig. 5. A 60-year-old female patient. **A** A stenotic colonic carcinoma (*arrow*) was detected in the sigmoid colon by means of MRC. **B** In addition, multiple hepatic metastases were visualized simultaneously.

Thus, the bright colonic wall can be easily discriminated from the dark, water-filled colonic lumen. This form of direct visualization of all colorectal pathologies reduces the incidence of false positive findings: residual stool or air bubbles, which might mimic small polyps in the bright-lumen technique, remain dark. Hence, lack of contrast enhancement between the pre- and postcontrast scans rule out the presence of a colorectal mass. Beyond the identification of colorectal lesions, dark-lumen MRC permits the detection and characterization of colonic wall inflammation. Based on the assessment of bowel wall thickness and bowel wall contrast enhancement, diverticulitis, Crohn disease, and ulcerative colitis can be diagnosed with great accuracy. Common to all three entities, the colonic wall is thickened and characterized by increased contrast uptake.

Future improvements

Virtual colonography still mandates bowel purgation. Because more than 50% of patients undergoing bowel preparation complain about negative side effects, patient compliance is negatively affected. If bowel cleansing were avoided, patient acceptance of MRC could be considerably increased. This can be accomplished by fecal tagging, a concept based on altering the signal intensity of stool by adding contrast-modifying substances to regular meals.

Thus, fecal tagging may render stool virtually indistinguishable from the distending rectal enema on MR images. In an initial study barium sulfate was evaluated as a tagging agent in conjunction with dark-lumen MRC [7]. Two hundred milliliters of a barium sulfate containing contrast agent was ingested with each of four principal low-fiber meals. Barium proved to be a safe and inexpensive tagging agent rendering the stool homogeneously dark and permitting the selective depiction of the contrast-enhancing colonic wall. Due to the low signal intensity of barium-tagged stool, signal differences between the colonic lumen and the colonic wall were high throughout the entire large bowel. However, further studies need to be performed to evaluate to value of barium-based fecal tagging with respect to patient acceptance and diagnostic accuracy.

To date distention of the colonic lumen for MRC has been accomplished predominantly with water or water-based contrast media. Better density properties and the assumption that air provides less discomfort than water has resulted in the predominant use of gaseous agents for CT colonography. Although similar to water with regard to MR signal properties on T1-weighted images, the fear of susceptibility artifacts rendered the use of air or other gases much less intuitive for MRC. Recently, the feasibility of air-distended dark-lumen MRC has been proved [8]. Fifty patients who had been referred to colonoscopy for suspected colorectal pathology were randomized into water-distention and air-distention groups. Dark-lumen MRC was performed in both groups. Comparative analysis was based on qualitative ratings of image quality and bowel distention and on CNR measurements for the colonic wall with respect to the colonic lumen. In addition, patient acceptance was evaluated. No significant differences were found between air and water distention with respect to 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 and bowel distention were superior on air-distended 3D data sets. Hence, dark-lumen MRC can be performed with water or air for colonic distention. Both techniques permit assessment of the colonic wall and identification of colorectal masses.

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