

MR imaging of the colon: “Technique, indications, results and limitations”

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Abstract

In the last few years virtual colonography using MR imaging has shown a proceeding development regarding detection and quantification of colorectal pathologies. Dark-lumen MR colonography (MRC) has been a leading tool for the diagnosis of the entire colon and their pathologies. This review article describes some of the underlying techniques of MRC concerning data acquisition, the need for intravenously applied paramagnetic contrast agent, as well as indications, results and limitations of MRC for the detection of colorectal pathologies. In addition, new techniques to improve patient acceptance are discussed.

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1. Introduction

Colorectal pathologies including colorectal masses and chronic inflammatory bowel diseases (IBD) are common in the western countries [1–3]. Conventional colonoscopy (CC) with endoscopic biopsy is considered the gold standard for the detection of colorectal masses and quantification of IBD [4,5]. However, there are several drawbacks due to its invasiveness, procedure-related discomfort and risk of perforation. Imaging techniques of the colon have the potential to overcome these limitations. The development of computed tomography (CT) and magnetic resonance imaging (MRI) including intravenously applied contrast agents and computer software has opened a new area to detection of colorectal pathologies.

The aim of this review article is to describe the underlying techniques of dark-lumen MR colonography (MRC) concerning data acquisition, the need for intravenously applied paramagnetic contrast agents, as well as indications, results and limitations of MRC for the detection of colorectal pathologies. In addition, new techniques to improve patient acceptance will be discussed.

2. Dark-lumen MR colonography

MRC is based on a combination of an aqueous enema with intravenous administration of Gadolinium-based contrast agents and is a rapidly evolving, almost non-invasive method for evaluation of the entire colon. MRC 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. The intravenous application of paramagnetic contrast agents allows the direct depiction of the colorectal wall. 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.

3. Bowel preparation

Since residual stool impedes an appropriate evaluation of the large bowel, patients need to undergo bowel preparation in a manner similar to that required for CC. In our department we use a standardized bowel cleansing procedure with 3000 ml

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of a polyethylene glycol solution (Golytely®: sodium chloride 1.46 g, sodium hydrogencarbonate 1.68 g, sodium sulfate 5.68 g, potassium chloride 0.75 g, polyäthylen glykol 59 g). 2000 ml of the solution should be ingested the night before and 1000 ml in the morning of the examination day.

4. MR scanner

MRC should be performed on a MR system scanner with high-performance gradient systems and a minimum of 1.5 T. Thus, data acquisition is to be confined to one single breath hold. Prior to the examination the patient has to be screened for contraindications to MRI such as presence of cardiac pacemakers, metallic implants in the central nervous system or claustrophobia.

5. MR imaging

To limit patient discomfort related to extended fasting, MRC should be performed in the early morning. Patients should be examined in the prone position. Thus, imaging in the prone position reduces breathing artifacts. A combination of two surface coils is 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 should be injected intravenously prior to the rectal filling. Following the placement of a rectal enema tube the colon is to fill with approximately 2000–2500 ml of warm tap water (Fig. 1a and b). This enema can be performed without fluoroscopic control, as the maximum amount of water that can be administered depends only on the patient's subjective feeling. Following bowel distension, a pre-contrast T1w 3D gradient echo data set like VIBE sequence (VIBE: Volumetric Interpolated Breathhold-examination with integrated fat suppression) is performed in the coronal plane in a single breath-hold. In our department we use following sequence parameters: TR/TE 3.1/1.1 ms, flip angle 12°, field of view (FOV) 450 mm × 450 mm, matrix 168 × 256 without using of interpolation, receiver bandwidth 490 Hz/Px, number of actual slices 96 and an effective slice thickness of 1.6 mm with a distance factor of 20%. Subsequently paramagnetic contrast is intravenously administered at a dosage of 0.2 mmol/kg body weight and a flow rate of 3.5 ml/s. Following a delay of 75 s, the 3D acquisition is to repeat with identical imaging parameters. Following completion of the MRC the colonic contents is to drain. Thus, the water is to drain while the enema bag is placed on the floor.

6. Image analysis

For data interpretation, several commercially available hardware systems are available. The 3D data sets should be transferred to a post processing work-station. MRC should initially be interpreted in the multiplanar reformation mode by scrolling through the contrast enhanced 3D-data sets in all three orthogonal planes. Whenever a mass protruding from the colonic wall is detected, the identical part of the colon should be analyzed

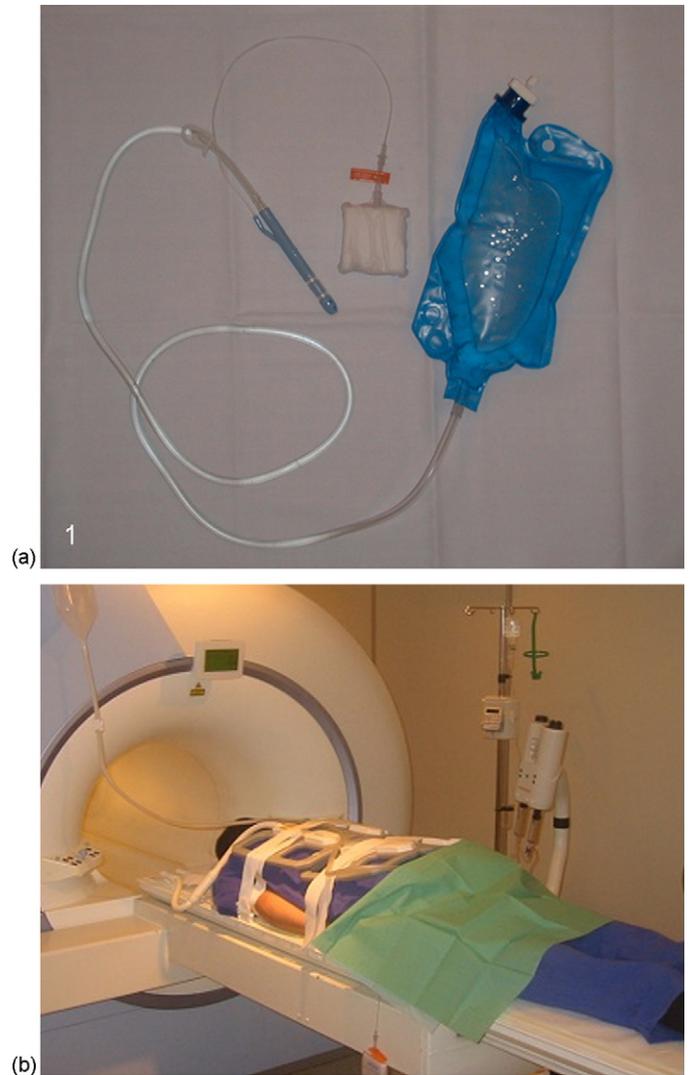


Fig. 1. A water-containing enema bag is connected by way of a catheter with a rectal tube (a). After placement the catheter in the rectum the tube may be blocked at its tip with a balloon (a). Preparation of MRC (b): the patient is placed in prone position on the MR scanner table. A combination of two phased-array surface coils ensures complete coverage of the entire colon and a homogenous signal reception (b). After i.v. injection of 40 mg of scopolamine the rectal enema filling can be started.

on the pre-contrast scan. By measuring signal intensities of the mass in both native and post-contrast scan a contrast enhancement value can be detected. Hence, small residual stool particles can be distinguished from colorectal lesions: while residual stool does not show any contrast enhancement (Fig. 2a and b), colorectal lesions always do (Fig. 3a and b). Moreover, the data should be evaluated based on virtual endoscopic renderings displaying the inside of the colonic lumen. A virtual endoscopic fly-through facilitates the depiction of small structures protruding into the colonic lumen. Furthermore, the three-dimensional depth perception allows the assessment of haustral fold morphology, thereby enhancing the observer's ability to distinguish polyps from haustra. To assure an entire visualization of both sides of haustral folds, the virtual fly-through should be performed in an antegrade as well as retrograde direction.



Fig. 2. Dark-lumen MRC. A pre-contrast T1 weighted 3D VIBE sequence (a). After the intravenous administration of gadolinium the bowel wall is bright due to a contrast enhancement (b). Residual stool (arrows) appears bright on the pre- and post-contrast scan and does not show any contrast uptake.

7. Diagnostic accuracy of dark-lumen MRC

7.1. Colorectal masses

Colonic polyps are common in 10% of adults [6,7] and become more frequent in older adults with a prevalence of 20% in the age group >60 years. Up to 90% of colorectal cancers

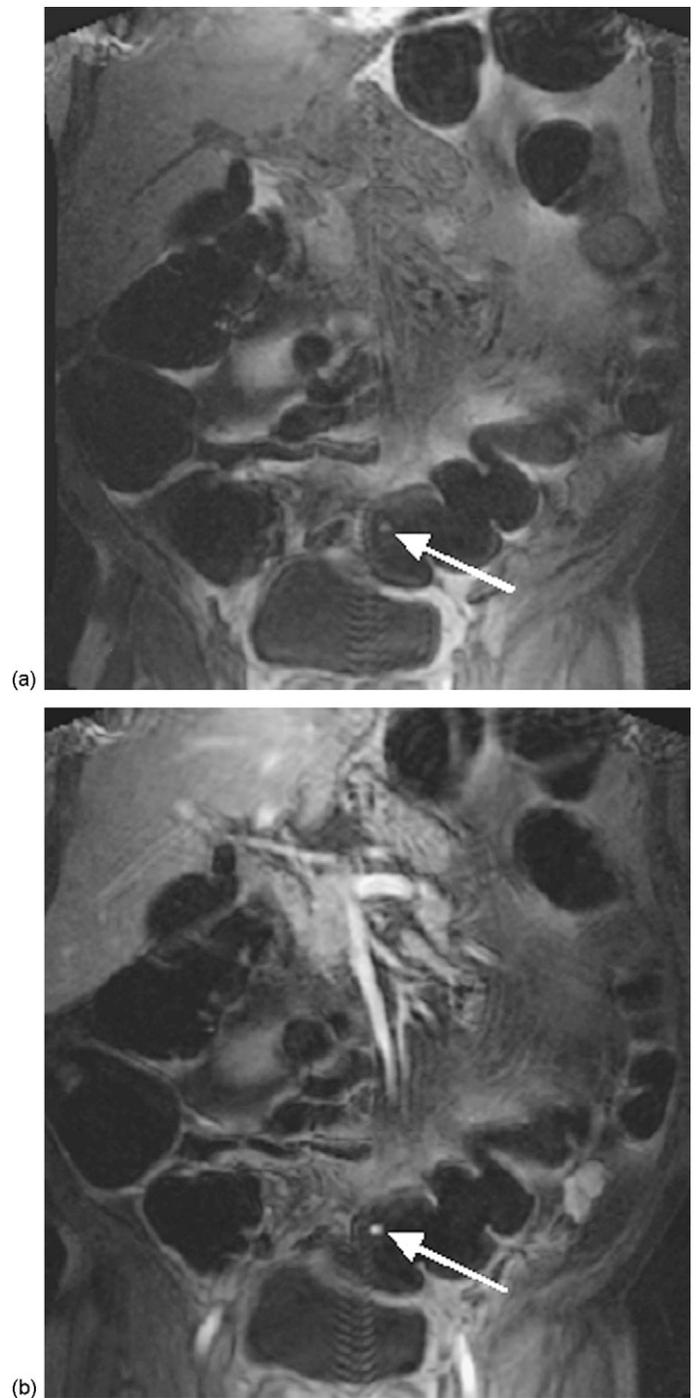


Fig. 3. Dark-lumen MRC: On the coronal T1-weighted pre-contrast phase a hypointense lesion (arrow in (a)) is shown in the sigmoid colon. After intravenous injection of paramagnetic contrast, the lesion (arrow in (b)) demonstrates a high-contrast enhancement, in distinction to residual stool. Conventional endoscopy confirmed the presence of a polyp in the sigmoid colon.

develop from benign adenomas by a series of genetic alteration: the adenoma–carcinoma sequence [8]. Colorectal cancer is an important cause of morbidity and mortality in the western world and is the second most common cancer after bronchial (male) and breast cancer (female) [5,8]. The current consideration is that colorectal cancer is preventable if all adenomas are removed before they have the chance to progress to cancer. In a large study

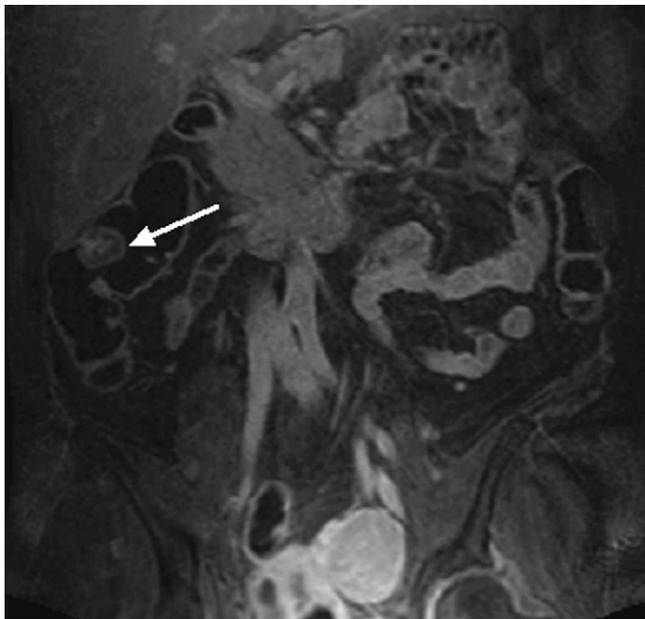


Fig. 4. Coronal reformatted image of a 3D T1-weighted data set acquired 75 s after intravenous contrast injection shows a 20 mm lesion in the ascending colon (arrow) and was rated as a large colorectal lesion. This was confirmed by conventional endoscopy and has been removed. The histopathologic result confirmed the presence of an adenomatous polyp.

to assess the accuracy of MRC compared to CC 122 patient with different colorectal diseases underwent MRC after colonic cleansing and prior to CC [9]. A high accuracy for MRC could be shown regarding the detection of colonic masses exceeding 5 mm in diameter with sensitivity and specificity values amounting to 93% and 100% compared to CC (Fig. 4). However, none of polyps measuring <5 mm identified by CC could be detected based on MRC images [9].

8. Inflammatory bowel diseases

Crohn's disease and ulcerative colitis are the most frequent specific inflammatory bowel diseases (IBD) with a prevalence of approximately one in 500 [1–3]. Features indicating colitis include mural thickening exceeding 3 mm, submucosal edema, mesenteric fat stranding, mesenteric hypervascularity and fibrofatty proliferation. When diagnostic guidelines are followed and adequate clinical information is available, IBD is correctly classified in 80–90% of cases upon the first examination [10,11]. In another trial containing 23 patients with IBD, MRC was assessed regarding the ability to detect and quantify IBD affecting the colon [12]. Endoscopically obtained histopathology specimens were used as the standard of reference [12]. Presence of inflammatory changes was documented based on bowel wall contrast enhancement, bowel wall thickness, presence of perifocal lymph nodes and loss of haustral folds [12]. All criteria were quantified and summarized in a single score subdividing the inflammation into mild, moderate and severe lesions [12]. MRC correctly identified 68 of 73 bowel segments with proven IBD changes by histopathology [12] (Fig. 5). All severely inflamed segments were correctly identified as such and there were no false pos-

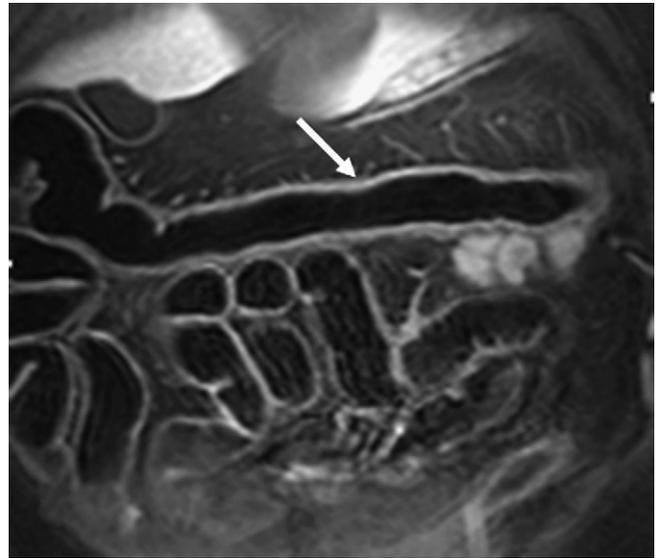


Fig. 5. T1w 3D GRE image of a 41 year-old female patient with known ulcerative colitis. A loss of haustral markings and an increased contrast uptake of the colonic wall as well as a bowel wall thickening (arrow) could be determined leading to the diagnosis of inflammation. Subsequent endoscopy and biopsy confirmed the presence of an acute moderate inflammation of the transverse colon.

itive findings [12]. MRC detected and characterized clinically relevant IBD of the large bowel with sensitivity and specificity values of 87/100% [12].

9. Incomplete conventional colonoscopy

The value of standard CC is predicated upon 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. There are many causes for failure of complete CC [13]. Most common is severe procedure-related abdominal discomfort, often in combination with technical challenges associated with elongation of the sigmoid colon, as well as operator difficulties to reach the right colonic flexure and the cecum. The presence of intraluminal stenosis represents another important cause. Thus, the failure rate of CC increases up to 50% in patients with known inflammatory bowel disease as well as in the presence of colorectal carcinoma [13]. In order to assess the utility of MRC in patients with an incomplete CC 37 patients underwent MRC for the completion of not endoscoped large bowel segments [14]. For analysis purposes, the colon of each patient was divided into six segments (cecum, ascending, transverse, descending, sigmoid colon and rectum) [14]. CC failed to assess 127 potentially visible colonic segments in the 37 patients whereas MRC permitted assessment in 119 of these 127 segments [14] (Fig. 6). Non-diagnostic image quality in eight segments was attributed to inadequate distension of pre-stenotic colonic segments due to high grade tumor stenosis [14]. All inflammation- and tumor-induced stenosis as well as all five polyps, identified by CC in post-stenotic segments were correctly detected on MRC [14]. Besides, MR-based assessment of pre-stenotic segments additionally revealed two carcinoma-

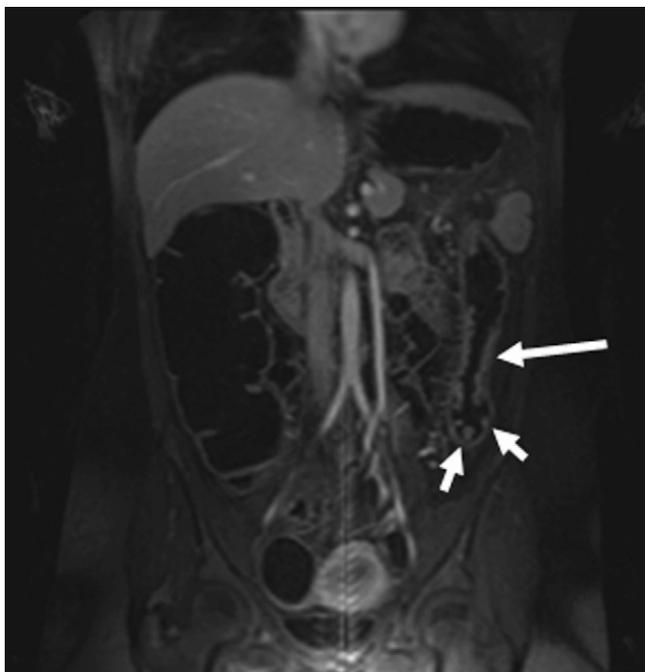


Fig. 6. Coronal T1-w 3D VIBE source image of a 37 year-old female patient with ulcerative colitis and inflammatory occlusion in the descending colon (large arrow). CC was incomplete due to a moderate-grade stenosis. MRC permitted assessment of the segments proximal to the site of stenosis. In addition, MRC revealed multiple small lesions in the descending colon (small arrows).

suspected lesions, five polyps, and four colitis-affected segments [14].

10. Sigmoid diverticulitis

The hypotheses on the etiology of colonic diverticulosis are variant including high age, high pressure within the large bowel, prolonged gastrointestinal transit time, fibre-deficient diet and hereditary diseases [15]. Diverticular disease (DD) involving the left colon is a common condition in Western countries affecting 30–50% of adults at age over 60 years [16]. The incidence of DD is increasing because of nutritional habits and population aging. DD predominantly involves the sigmoid colon. However, most patients with diverticulosis are asymptomatic without evidence of complications. Just 10–30% of the age group over 60 years develop an acute diverticulitis [16]. Complications of DD beside diverticulitis include stricture, peri-colic abscess, bleeding and perforation. In a recently study, 40 patients with suspected sigmoid diverticulitis underwent MRC within 72 h prior to CC. MRC classified 17 of the 40 patients as normal with regard to sigmoid diverticulitis [17]. However, CC confirmed the presence of light inflammatory signs in 4 patients which were missed in MRC [17]. MRC correctly identified wall thickness and contrast uptake of the sigmoid colon in the other 23 patients [17] (Fig. 7). In 3 cases of those patients false positive findings were observed and MRC classified the inflammation of the sigmoid colon as diverticulitis whereas CC and histopathology confirmed invasive carcinoma [17]. MRC detected additionally relevant pathologies of the entire colon and could be performed in 4 cases where CC was incomplete [17].

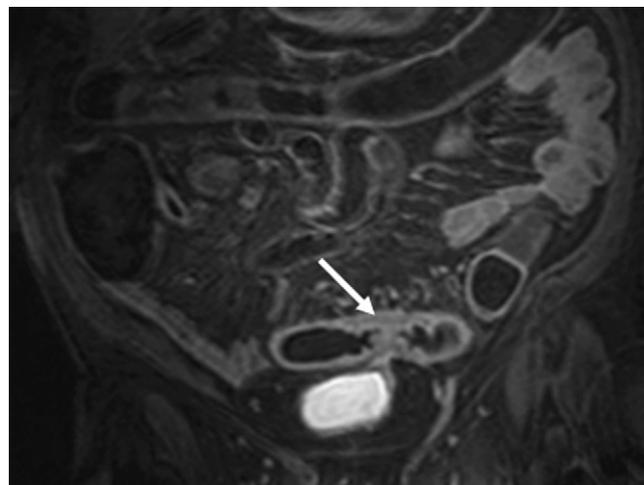


Fig. 7. Post-contrast coronal MR-source image of a 76 year-old female patient with known diverticulosis of the sigmoid colon. The patient was transferred to the department of gastroenterology because of acute abdominal pain. Increase of contrast uptake and thickening of the sigmoid bowel wall could be seen (arrow) and the patient was diagnosed with diverticulitis. This suspicion was subsequently confirmed by endoscopy.

11. MRC for the assessment of colonic anastomoses

Colonic resection with end-to-end-anastomosis is a common procedure in colorectal surgery for patients with colorectal malignancy or chronic inflammatory bowel diseases [18,19]. However, postoperative recurrences at the anastomosis with consecutive stricture are frequent. Even after second or third resection, the peri-anastomotic area remains the most frequent site of disease recurrence [18,19]. In a new study to assess the diagnostic accuracy of MRC for the evaluation of colonic anastomoses 39 patients with previous colonic resection and end-to-end-anastomosis underwent MRC [20]. In 23 patients the anastomosis was rated to be normal by means of MRC (CC: 20 patients), whereas in 3 patients CC revealed a slight inflammation of the anastomosis missed by MRC [20]. A moderate stenosis of the anastomosis without inflammation was detected by MRC in 5 patients, which was confirmed by CC. In the remaining 11 patients a relevant pathology of the anastomosis was diagnosed both by MRC and CC [20] (Fig. 8). In 2 patients with history of colorectal carcinoma a recurrent tumor was diagnosed [20]. In the other 9 patients inflammation of the anastomosis was seen in 7 with Crohn's disease and 2 with ulcerative colitis [20]. MRC did not show any false positive findings resulting in an overall sensitivity/specificity for the assessment of the anastomosis of 84%/100% [20].

12. Air-based distension of the colon in MRC

Better density properties and the assumption that air provides less discomfort compared to water has resulted in the predominant use of gaseous agents for CT-colonography. Although similar to water regarding MR signal properties on T1-weighted images, the fear of susceptibility artifacts rendered the use of air or other gases a lot less intuitive for MRC. The feasibility of

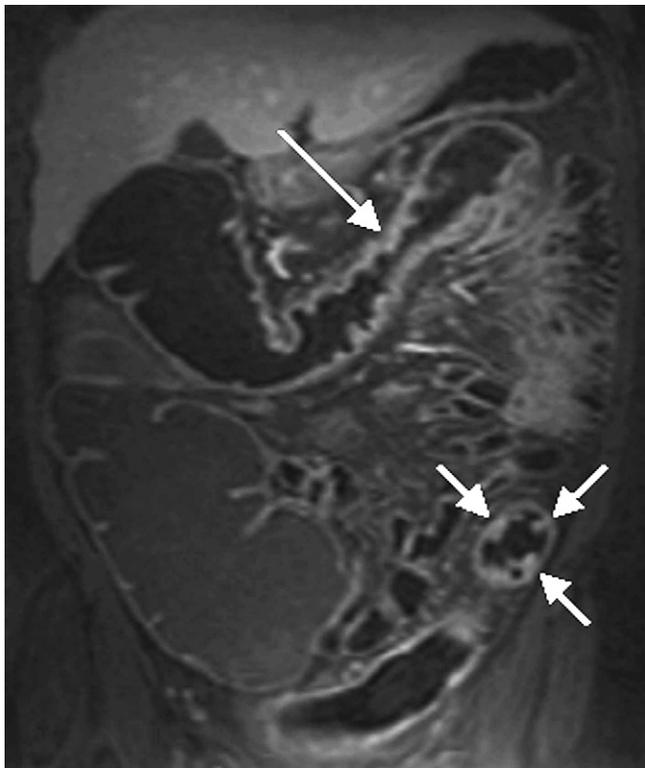


Fig. 8. Contrast-enhanced coronal 3D VIBE sequence of a patient with ulcerative colitis and previous history of descendo-transverso-stomy. Increased contrast uptake of the anastomosis region confirmed the recurrence of inflammatory disease (arrow). In addition multiple small lesions in the sigmoid colon are shown (small arrows).

air-distended MRC could be proved. In a recent study, 5 volunteers and 50 patients, who had been referred to colonoscopy for a suspected colorectal pathology were randomised into water-distension and air-distension groups [21]; MRC was performed in both groups. Comparative analysis was based on qualitative ratings of image quality and bowel distension as well as CNR measurements for the colonic wall with respect to the colonic lumen [21]. In addition, patient acceptance was evaluated. No significant differences were found between air-and water-distension regarding discomfort levels and image quality [21]. 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 distension were superior on air-distended 3D data sets. Both techniques permit assessment of the colonic wall and identification of colorectal masses (Fig. 9).

13. Combined hydro-MRI and MRC

It is known that Crohn's disease mostly affects the terminal ileum and/or the ileocecal region. Crohn's disease predominantly involves the distal bowel (20%), the colon (30%) or the small and large bowel (50%). Therefore, a good distension also of the terminal ileum and ileocecal region is necessary to detect inflammations in these regions. Moreover, in patients with IBD assessment of the terminal ileum and colonic segments is important for monitoring and therapy. In a recently study underwent



Fig. 9. Coronal source images of T1w 3D GRE scan of a 65-year old patient undergoing dark-lumen MRC in conjunction with rectal application of room air. A large lesion with irregular borders (arrow), which turned out to be a 22 mm carcinoma of the descending colon and was confirmed in conventional colonoscopy.

40 patients with known Crohn's disease hydro-MRI of the small bowel after ingestion of 1,5 l of a hydro-solution containing 0.2% locust bean gum (LBG) and 2.5% mannitol [22]. In addition to the hydro-MRI underwent 20 patients of them, without large bowel cleansing, MRC after rectal water enema [22]. The latter resulted in a statically significant difference between both groups in favor of the enema group regarding the distension of all colonic segments and terminal ileum, the presence of artifacts and the diagnostic confidence not only in the colon, but also in the terminal ileum, which lead to a higher diagnostic accuracy also regarding the diagnosis of a terminal ileitis [22]. No false result was encountered in the enema group, whereas in the non-enema group there were 3 false negatives alone for the terminal ileum (Fig. 10) [22]. This enhances the impact of a sufficient terminal ileum distension, which can be yielded by an additional rectal enema [22].

14. Assessment of the extra intestinal organs in MRC

MRC offers in contrast to CC an additional viewing of the extra intestinal organs and is not limited to view the entire colon. Analysis of the 3 data sets is especially very important in patients with suspect on colorectal tumor in order to assess the presence of metastases like in the liver or in the lymph nodes which very important for the choice of the therapy (Fig. 11). In addition, patients with IBD or diverticulitis could profit from MRC through the evidence or the exclude of complications of IBD like fistulae and abscesses which often are not suspected by CC and can not confirmed through conventional methods and are decided for the therapy. Furthermore, screening patient and patients with prone

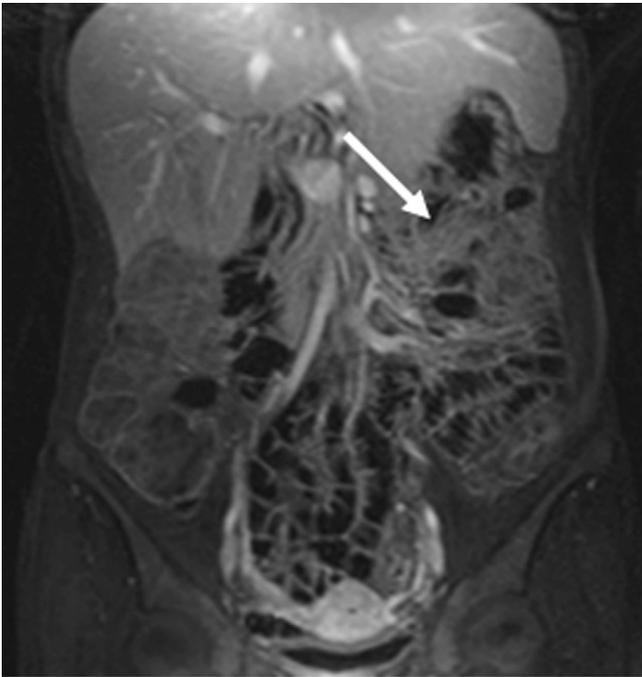


Fig. 10. Hydro-MRI without a rectal enema of a 41 year-old male patient with known Crohn's disease. The colonic segments like the transverse colon (arrow) show an insufficient distension. Conventional colonoscopy diagnosed an acute inflammation in the transverse colon which was missed in MRI.

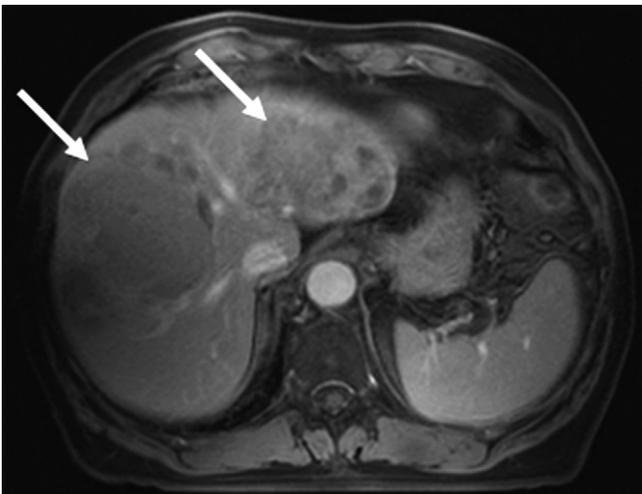


Fig. 11. Transverse image of a 60-year-old female patient who underwent MRC and conventional colonoscopy. A stenotic colonic carcinoma was detected in the sigmoid colon by means of MRC and CC. However, in MRC multiple hepatic metastases were visualized simultaneously (arrows).

discomfort could profit from MRC through the assessment of the entire colon and the extra intestinal organs. So many therapy relevant or non-relevant findings could be found which may be known or unknown. In these cases additional imaging of the prone could be avoided and saved.

15. MRC without bowel cleansing: future development

As stated above virtual colonography still mandates bowel purgation, which negatively impacts patient acceptance. If bowel

cleansing can be avoided, patient acceptance of MRC could be considerably increased. This can be accomplished by modulating the signal characteristics of the fecal material and increase of the signal intensity of the stool on the T1 weighted sequence. To date there are two concepts: fecal tagging and fecal cracking.

16. Fecal tagging

Fecal tagging is a concept based on altering the signal intensity of stool by adding contrast modifying substances to regular meals [23]. Thus, fecal tagging may render stool virtually indistinguishable from the distending rectal enema on MR images. The fecal tagging based MRC was applied successfully in a volunteer study [23] however has shown a poor diagnostic accuracy and poor acceptance in a patient study [24]. In a recently trial 42 patients underwent fecal tagging based MRC after ingestion of 150 ml of 100% barium at each of 6 main meals prior CC [24]. On a lesion-by-lesion basis, the sensitivity for polyp detection was 100% for polyps exceeding 20 mm, a sensitivity of 40% for polyps of 10–19 mm, of 16.7% for polyps of 6–9 mm, and of 9.1% for polyps smaller than 6 mm [24]. The main reason for these was the high stool signal in the colon (Fig. 12), which impeded a reliable in- or exclusion of polyps and barium preparation, which was rated worse than the bowel cleansing procedure for CC. Therefore, fecal tagging MRC must be further optimized and other strategies, such as rising the hydration of stool, must be developed.

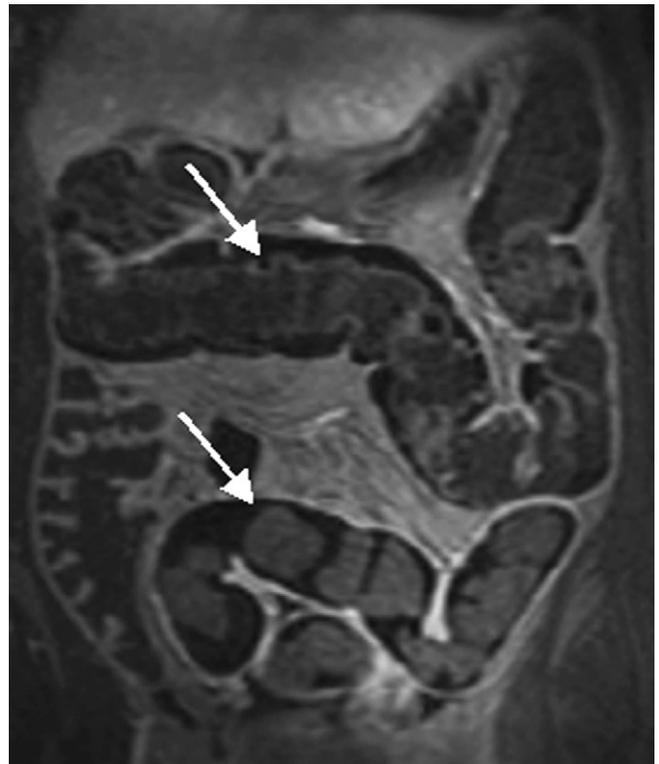


Fig. 12. Post-contrast coronal MR-source image of a 50 year-old female patient who underwent fecal tagging based MRC. Bright stool in the whole entire colon is displayed (arrows). Colorectal lesions are hardly to be diagnosed due to the bright stool signal in this patient.

17. Fecal cracking

The Fecal cracking concept is based on the administration of oral and rectal stool softener which lead to hydration of the stool and thereby to an increase of the signal intensity of the stool on the T1 weighted sequence [25]. The effect of oral and rectal softener on the signal intensity of stool was assessed in a study with volunteers [25]: 10 volunteers underwent fecal cracking based MRC repeated at four different times. A baseline examination was performed without oral or rectal administration of stool softeners [25]. In a second examination, volunteers ingested 60 ml

of lactulose 24 h prior to MRC and in the third examination, water as a rectal enema was replaced by a solution of 0.5% docusate sodium (DS) [25]. The fourth MR-examination was performed both in conjunction with oral administration of lactulose and rectal application of docusate sodium [25]. Without oral ingestion of lactulose or rectal enema with docusate sodium, stool intensity was high and did not decrease over time; lactulose and docusate sodium together caused a statistically significant decrease of stool intensity over time [25]. Thus, feces hardly could be distinguished from dark rectal enema allowing for the assessment of the colonic wall (Fig. 13a and b).

18. Conclusion

Dark-lumen MRC based on colonic cleansing shows a high sensitivity and specificity and can be considered as a promising alternative method to conventional colonoscopy for the detection of colorectal diseases as well as extra luminal organs. Future techniques to avoid colonic cleansing and to improve the patient acceptance should be more optimized and should be performed in large studies before they can be inserted in the clinical routine.

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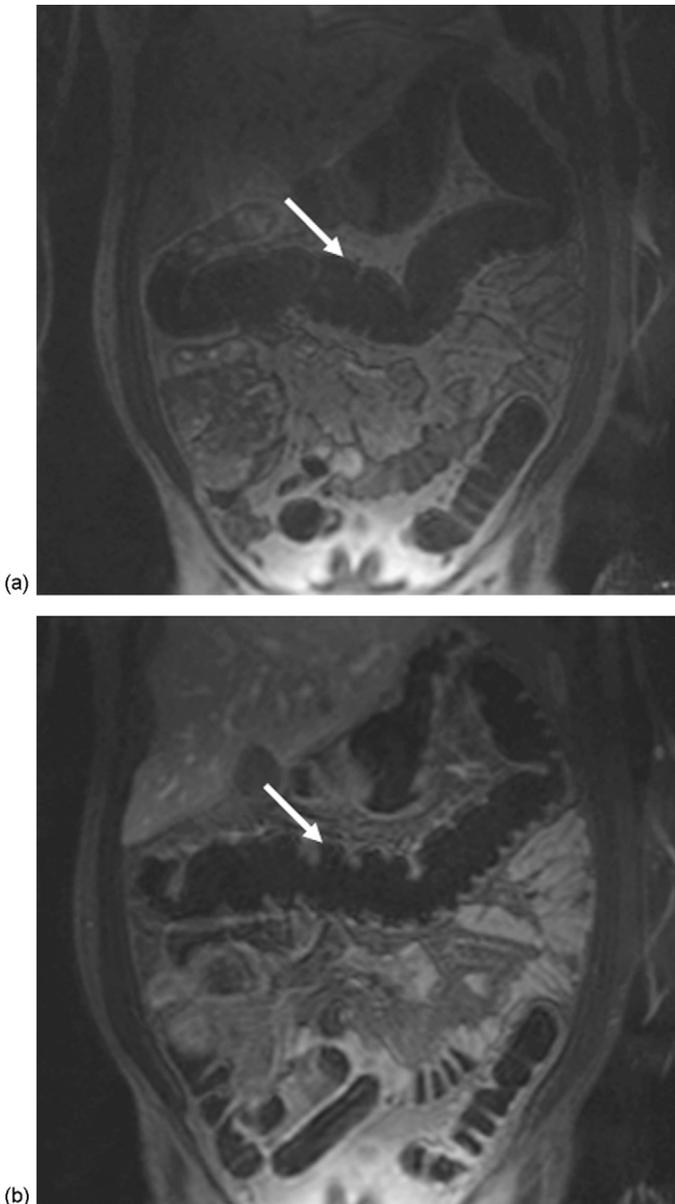


Fig. 13. Coronal MR-sources of a volunteer undergoing MRC after oral ingestion of 60 ml lactulose and rectal enema with docusate sodium. The stool is already dark (arrow in a) on the T1-weighted sequence at scan time 0 min after the rectal enema. 10 min after rectal enema the stool intensity decreases (arrows in b) by soaking and cracking the stool. In addition, after i.v. injection of contrast agents the colonic wall can be more easily delineated from the dark colonic lumen.

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