Colonography by magnetic resonance imaging

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Dark-lumen magnetic resonance colonography has been shown to be an appropriate diagnostic tool for the detection of colorectal pathologies. This review describes the underlying techniques of dark-lumen magnetic resonance colonography concerning data acquisition, image interpretation and diagnostic accuracy for the detection of colorectal pathologies. In addition, techniques to improve patients' acceptance are discussed. *Eur J Gastroenterol Hepatol* 17:815–820 © 2005 Lippincott Williams & Wilkins.

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Detection of colorectal pathologies

The incidence of colorectal cancer is the second highest of all malignant tumours in the Western world [1]. The majority of colorectal cancers originate from benign adenomatous polyps through a series of genetic alteration: the adenoma–carcinoma sequence. The incidence of colorectal cancer can be dramatically reduced if polyps are detected and removed before their malignant transformation [2]. Crohn's disease and ulcerative colitis are the most frequent specific inflammatory bowel diseases (IBDs) with a prevalence of approximately one in 500 [3]. Diagnostic procedures in IBD serve to validate the diagnosis and to optimize therapeutic options.

Conventional colonoscopy is considered the 'gold standard' for the detection of colorectal masses and IBDs [4,5]. Invasiveness, procedure related discomfort, and poor patient acceptance for conventional colonoscopy have driven the exploration of alternatives to endoscopy for diagnosing colorectal pathologies. Efforts have mainly focused on virtual endoscopy based on the acquisition of cross-sectional images. This can be accomplished by using either computed tomography or magnetic resonance imaging (MRI). Recent studies have shown computed tomography and magnetic resonance colonography to be effective regarding the detection of clinically relevant diseases. However, computed tomography colonography exposes patients to considerable doses of ionizing radiation [6]. This issue is of major concern, since patients with IBD usually are young. Furthermore, screening examinations for colorectal cancer need to be repeated every 3–5 years. Therefore, it is reasonable to focus on MRI for colorectal screening.

Magnetic resonance colonography

The first techniques of magnetic resonance colonography (MRC) were based on the rectal application of water spiked with a paramagnetic contrast [7]. On T1-weighted 3-D gradient echo (GRE) sequences, the colonic lumen is rendered bright, whereas the colonic wall as well as pathologies arising from it remain dark. Since the presence of air bubbles can hamper the evaluation of several bowel loops, the technique requires data acquisition in the prone and supine patient positions. In addition, differentiation between colorectal masses and residual faecal material can be difficult and in some cases even impossible.

A further development of MRC is based on a different contrast mechanism and is referred to as 'dark-lumen MRC' [8]. This modality is more accurate and less time-consuming compared to 'bright lumen' techniques. For dark-lumen MRC the colon is filled with tap water. Data are acquired before and after the intravenous administration of paramagnetic contrast. Based on the principles of ultra-fast, T1-weighted 3-D GRE acquisitions, the colonic lumen is rendered dark with this technique. Focal uptake of T1-shortening contrast material in the colonic wall results in a high signal intensity of the bowel wall on the post-contrast data sets. Thus, the bright colonic wall can be easily discriminated from the dark, water-filled, colonic lumen. This form of direct visualization of the bowel wall and of all colorectal pathologies originating from it reduces the incidence of false positive findings: residual stool or air bubbles, which might mimic small polyps in the bright lumen technique, remain dark as there is no uptake of the paramagnetic contrast.

Technical considerations

Prior to the examination the patient has to be screened for contraindications to MRI such as the presence of cardiac pacemakers, metallic implants in the central nervous system or claustrophobia. 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 conventional colonoscopy. To

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limit patient discomfort related to extended fasting, MRC should be performed in the early morning.

Magnetic resonance examination

After placing the patient in prone position on the scanner table, the colon is filled with 2000–2500 ml of warm tap water using hydrostatic pressure (1–1.5 m water column). Instillation of the enema should be carried out in stages over 1 min to reduce discomfort and bowel cramping. To minimize bowel peristalsis, spasmolytic agents such as scopolamine or glucagon have to be injected intravenously immediately prior to the colonic filling. Alternatively, air or CO_2 can be used for colonic distension. It could be proven that there are no relevant differences between air distension and water distension regarding discomfort levels and image quality [9]. A combination of two surface coils should be used for signal reception to permit coverage of the entire colon (Fig. 1). A T1-weighted 3-D gradient echo data set with fat suppression is collected in the coronal plane. At present, at our institution we use a 3-D volumetric interpolated breathhold examination sequence with the following scan parameters: TR/TE 3.1/1.1 ms, flip angle 12°, field of view 450 × 450 mm, matrix 168 × 256, slice thickness of 1.6 mm. Subsequently, paramagnetic contrast is administered intravenously at a dose of 0.2 mmol/kg and a flow rate of 3.5 ml/s. A second 3-D acquisition is acquired in a portal–venous contrast phase after 75 s delay. Eventually, 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 less than 20 min.

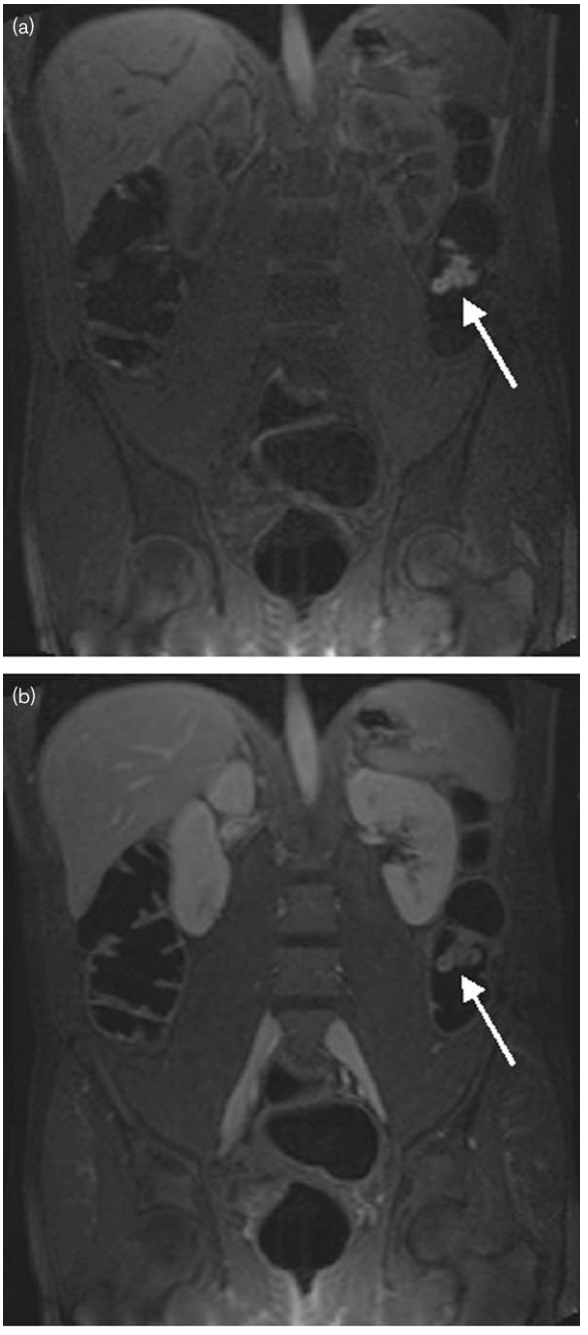
Fig. 1

Preparation of magnetic resonance colonography (MRC). The patient is placed in prone position on the magnetic resonance scanner table. A combination of two phased-array surface coils ensures complete coverage of the entire colon and a homogeneous signal reception.

Image analysis

The 3-D data sets should be transferred to a post-processing workstation. MRC initially should be interpreted in the multiplanar reformation mode scrolling through the contrast enhanced 3-D data set in all three orthogonal planes. Whenever a mass protruding from the colonic wall is detected, the identical part of the colon

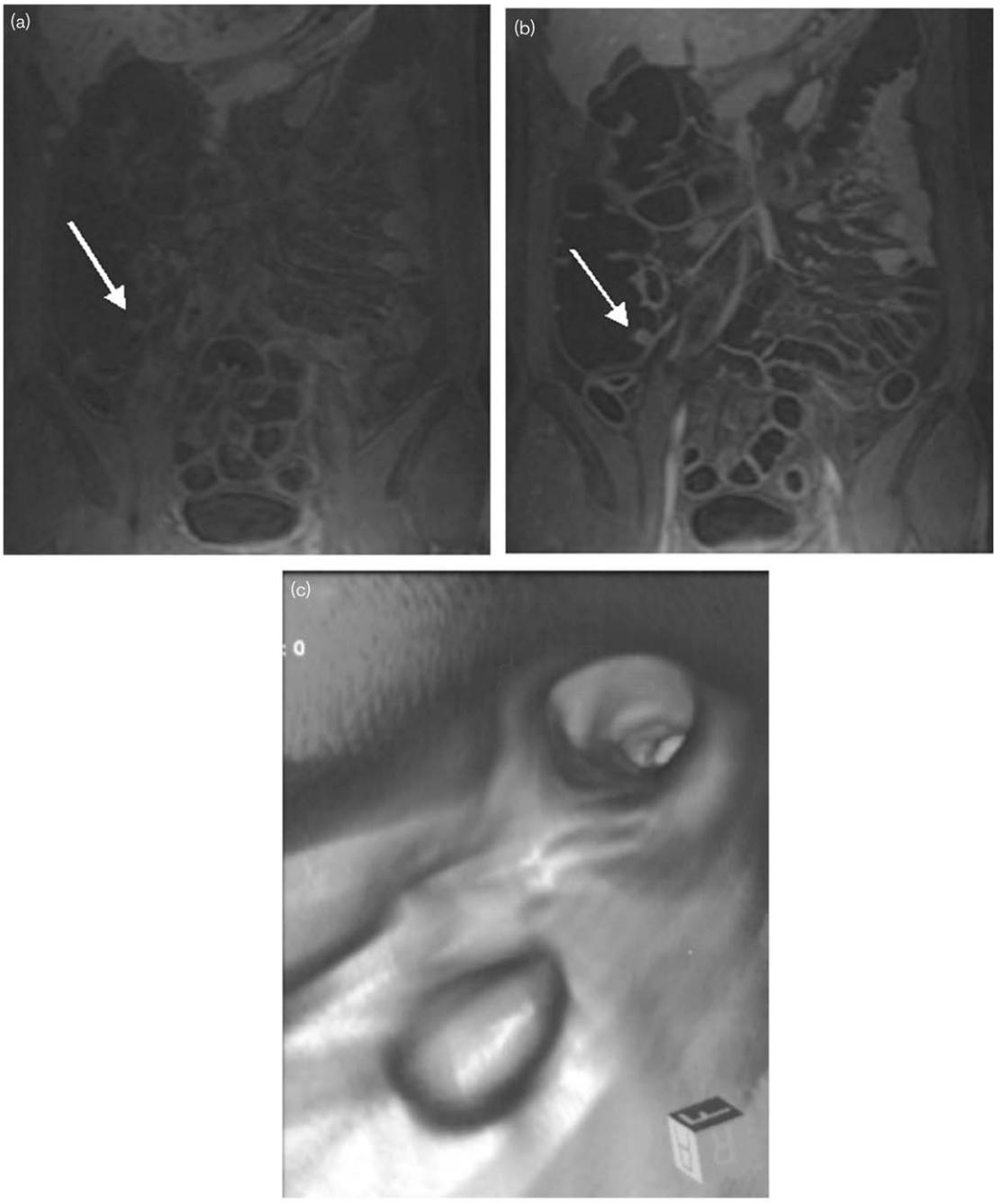
Fig. 2



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

should be analysed on the pre-contrast scan. Measuring signal intensities of the mass in both native and post-contrast scan, a contrast enhancement value can be determined. Hence, small residual stool particles can be distinguished from colorectal lesions: while residual stool does not show any contrast enhancement (Fig. 2(a,b)), colorectal lesions always do (Fig. 3(a–c)). 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 3-D depth perception allows

Fig. 3



Dark-lumen MRC. (a) A small lesion arising from the bowel wall in the ascending colon shows a contrast uptake comparing the pre-contrast scan and (b) the post-contrast scan. (c) Virtual endoscopic reformation of the lesion is shown on image. Conventional endoscopy confirmed the presence of a polyp in the ascending colon.

the assessment of haustral fold morphology, thereby enhancing the observer's ability to distinguish polyps from haustra. To ensure an entire visualization of both sides of haustral folds, the virtual fly-through should be performed in an antegrade as well as retrograde direction.

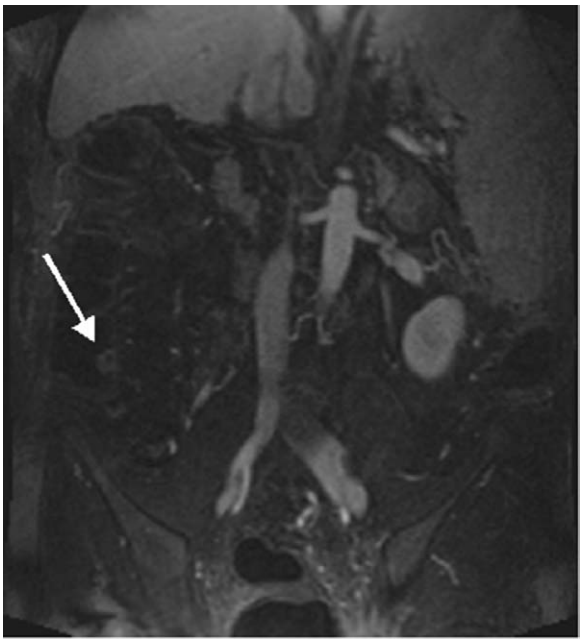
Diagnostic accuracy

Recently, a study encompassing 122 patients with different colorectal diseases was performed [10]. All patients underwent dark-lumen MRC according to the previously described protocol. Subsequent conventional endoscopy served as the standard of reference. 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 conventional colonoscopy (Figs 4 and 5). However, polyps < 5 mm were not detected at all on MRC images. Conventional colonoscopy documented inflammatory wall alterations consistent with Crohn's disease in 15 and ulcerative colitis in 13 patients. Of those, MRC correctly diagnosed inflammatory changes in 13 and 12 patients with Crohn's disease and ulcerative colitis, respectively (Fig. 6). Acute diverticulitis was diagnosed on both conventional colonoscopy and MRC in the same five patients. MRC also permitted the assessment of extra-intestinal organs. A variety of relevant and non-relevant pathologies were identified. Hepatic metastases were observed in four patients (Fig. 7) and bone metastases were seen in seven patients.

In another study MRC was performed in 37 patients with an incomplete conventional colonoscopy [11]. Incompletion of endoscopy was related to presence of stenoses or elongated bowel segments. For analysis purposes, the colon of each patient was divided into six segments (caecum, ascending, transverse, descending, sigmoid colon and rectum). Conventional colonoscopy failed to assess 127 potentially visible colonic segments in the 37 patients. MRC permitted assessment in 119 of these 127 segments (Fig. 8). Non-diagnostic image quality in eight segments was attributed to inadequate distension of pre-stenotic colonic segments due to high grade tumour stenosis. All inflammation- and tumour-induced stenosis as well as all five polyps, identified by conventional colonoscopy in post-stenotic segments, were correctly detected on MRC. Besides, magnetic resonance-based assessment of pre-stenotic segments additionally revealed two lesions suspected of being carcinomas, five polyps and four colitis-affected segments.

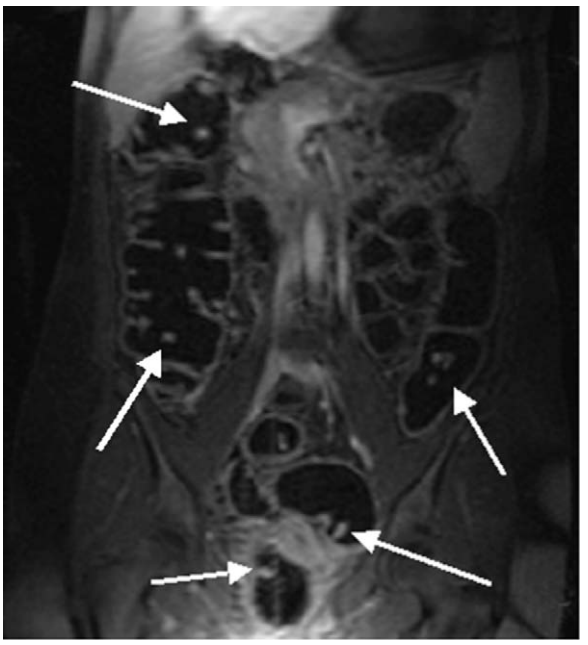
In another trial, MRC was assessed regarding the ability to detect and quantify IBD affecting the colon [12]. Endoscopically obtained histopathology specimens were used as the standard of reference. The presence of inflammatory changes in 23 patients was documented

Fig. 4



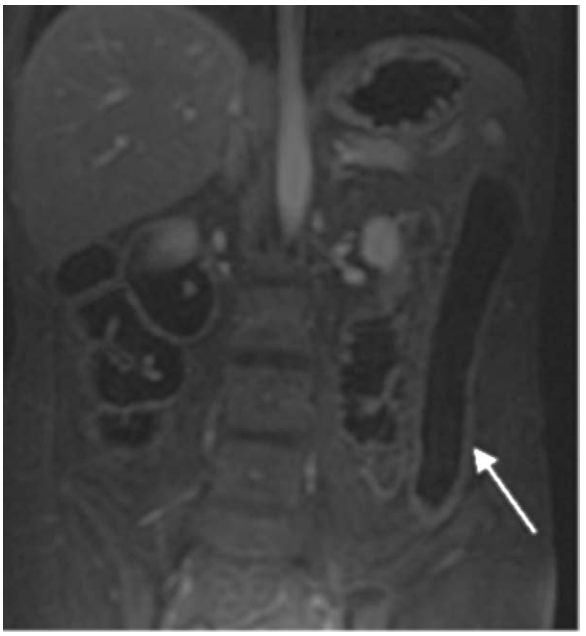
Source image of a 3-D T1-weighted data set acquired 75 s after intravenous gadolinium injection. A 12 mm lesion in the ascending colon with contrast enhancement (arrow) was rated as a carcinoma, which was confirmed by conventional endoscopy.

Fig. 5



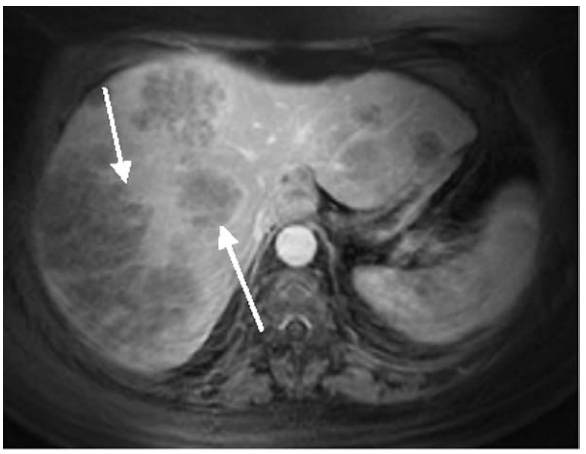
Dark-lumen MRC of a 23-year-old male patient with polyposis coli. Multiple small polyps can be detected in different colonic segments (arrows).

Fig. 6



Dark-lumen MRC of a 47-year-old male patient. A loss of haustral markings and increased contrast uptake of the colonic wall could be determined (arrow). Conventional colonoscopy confirmed the diagnosis of ulcerative colitis.

Fig. 7



Axial reformatted dark-lumen MRI of a 65-year-old female patient with a colonic carcinoma of the sigmoid colon. Multiple hepatic metastases were visualized simultaneously (arrows).

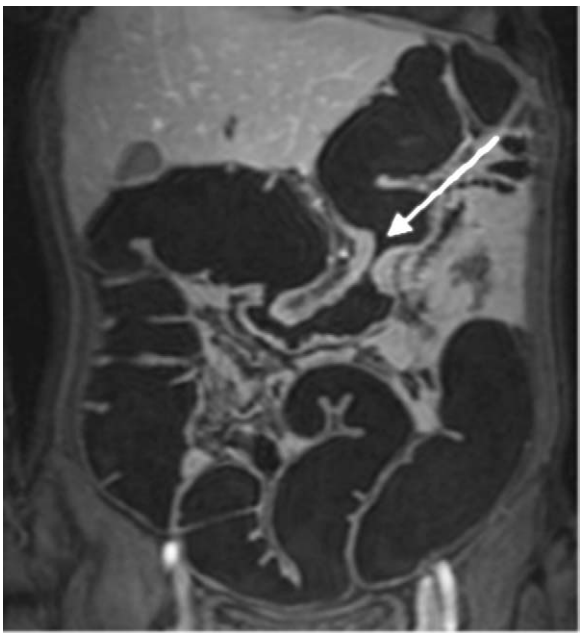
based on bowel wall contrast enhancement, bowel wall thickness, presence of perifocal lymph nodes and loss of haustral folds. All criteria were quantified and summarized in a single score subdividing the inflammation into mild, moderate and severe lesions. MRC correctly identified 68 of 73 bowel segments with proven IBD changes by histopathology (Fig. 9). All severely inflamed segments were correctly identified as such and there were no false positive findings. MRC detected and characterized clinically relevant IBD of the large bowel with sensitivity and specificity values of 87/100%.

Future improvements

As stated before, virtual colonography still requires bowel cleansing, which negatively impacts patient compliance. If bowel cleansing was avoided, patient acceptance of MRC could be considerably increased. By adding contrast modifying substances to regular meals the signal intensity of stool can be modified and adapted to the signal properties of the rectal enema.

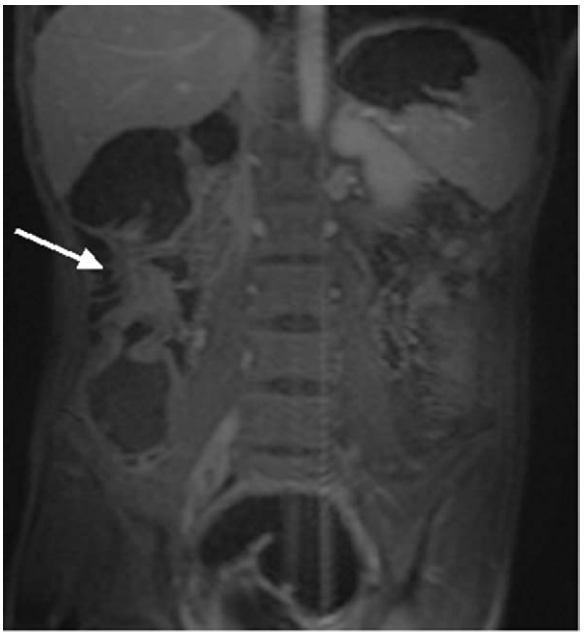
For dark-lumen MRC without bowel cleansing, a highly concentrated, barium sulphate containing contrast agent can be administered in a volume of 200 ml with each of four principal meals beginning 36 h prior to MRC. Barium is not absorbed and mixes well with stool. The barium-based approach to faecal tagging has been successfully assessed [13]. The signal reducing effects upon stool has been documented in volunteer studies. By ingesting barium prior to the magnetic resonance examination, stool is rendered virtually indistinguishable from the administered water enema on heavily T1-weighted 3-D GRE images. In spite of diagnostic image quality for barium-based faecal tagging, a recent study revealed that

Fig. 8



Dark-lumen MRC of a 46-year-old female patient with a stenotic carcinoma in the transversal colon (arrow) and incomplete colonoscopy. MRC permitted assessment of the colonic segments proximal to the site of stenosis.

Fig. 9



Dark-lumen MRC of a 35-year-old female patient with known Crohn's disease. The thickened bowel wall of the ascending colon shows an increased contrast uptake (arrow). Subsequent endoscopy and biopsy confirmed the presence of an acute inflammatory bowel disease.

patient acceptance was not increased [14]: ingestion of the highly concentrated barium formula was considered nearly as unpleasant as bowel cleansing protocols. A new approach is based on the administration of oral and/or rectal stool softener. Their effect on signal intensity of faecal material was assessed in a volunteer study [15]. It could be shown that the oral administration of lactulose 24 h prior to the MRC in combination with a rectal enema containing ducosate sodium led to high image quality with low signal intensity values of faeces. Furthermore, neither the ingestion of lactulose nor the rectal enema containing ducosate sodium negatively affected patients' acceptance. Thus, this combination of oral and rectal stool-softener may evolve as a promising technique of dark-lumen MRC.

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