MR Colonography

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Introduction

The technique of Magnetic Resonance Colonography (MRC) was first described in the late 1990s and is a form of virtual colonoscopy, enabling evaluation of the colon in a noninvasive manner. It is now studied predominantly in specialist centers, many of which are in Europe. Its major advantages include avoidance of exposure to ionizing radiation, and excellent soft tissue contrast, as well as the relative safety of gadolinium chelate intravenous contrast agents, should they be used. When MRC is performed routinely in an institution, the documented time to perform the examination is 20–23 min (Achiam et al. 2007).

MRC provides a less invasive alternative colonic examination to conventional colonoscopy (CC), with no post-procedural observation required. To date, there have been no reports of bowel perforation in patients undergoing MRC making this a very safe examination. This is in contradistinction to CC and CT colonography where, despite very low rates of perforation, this potentially serious complication is a real risk at 0.3% and 0.009%, respectively (Korman et al. 2003; Pickhardt 2006). This may be due to the lower pressure applied by fluid distension under hydrostatic pressure, used in many MRC examinations, compared to the pressure applied by air in CC and CTC, or may be due to the overall lower numbers of MRC examinations which have been performed in comparison to CC, and CTC. There is a lower rate of colonic perforation documented when an automatic carbon dioxide insufflator is utilized for colonic distension at CT colonography compared to air insufflation with a handheld balloon.

The current main disadvantages of MRC include the fact that MRC is available in only a few specialist centers, predominantly in Europe, as well as its high cost in comparison to CT. In addition, as with CTC, MRC does not offer a therapeutic option, unlike CC. It has been debated whether MRC is cost-efficient, when the fact that a subsequent therapeutic CC is required for positive studies is taken into account: however, this has not seen studied to date.

A meta-analysis of multiple MRC studies was published in 2010. Due to many small groups with heterogeneous data, a formal subgroup analysis could not be performed assessing an optimal MRC technique. There is currently no consensus as to whether full or limited bowel preparation is required, which intraluminal agent is optimal, whether dual or single positioning should be routinely performed, and whether stool tagging should be employed. In the following sections we shall outline the available data, and emphasize the techniques most commonly being employed in MRC.

Indications

Colon Cancer Screening

Colorectal cancer is the second most common cause of cancer-related death in men and women in the USA (Centers for Disease Control and Prevention 2010). Since most colorectal cancers develop from adenomatous polyps, surveillance for polyps has been shown to

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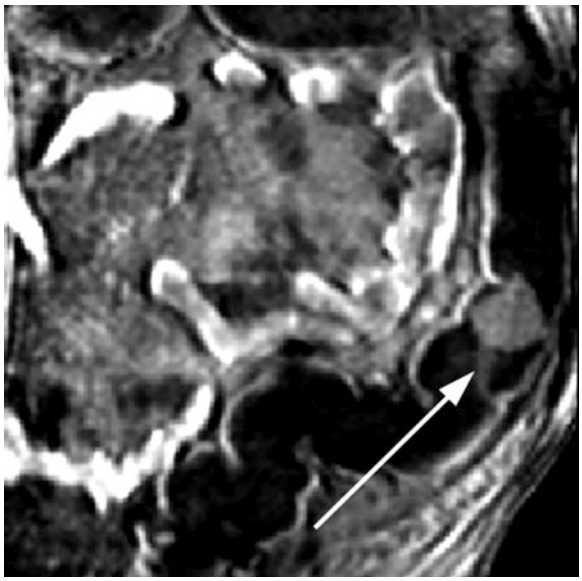

Fig. 50.1 Dark lumen MRC: Coronal T1-weighted SPGR post IV image shows a 2.2 cm pedunculated polyp on a 5 mm stalk within the sigmoid colon (Courtesy of Michael Patrick Achiam, MD, Copenhagen University Hospital Herlev, Herlev, Denmark)

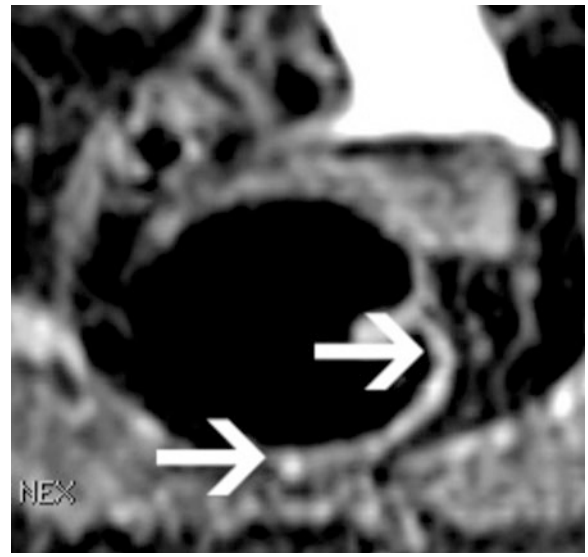

Fig. 50.2 Dark lumen MRC: Coronal subtracted T1-weighted SPGR with subtraction of the precontrast acquisition from 90 s MRC post IV contrast acquisition. Coronal reformated images shows less than 1 mm elevation of a flat cancer

decrease the prevalence of colorectal cancer by 76–90% (Winawer et al. 1990, 1993). Only 40% of eligible Americans undergo screening for colorectal cancer, which may be due to poor patient acceptance of bowel cleansing, and procedural discomfort, which can be associated with colonoscopy, the gold standard for colonic evaluation (Winawer et al. 1990, 1993). And so, there has been a search for a safe, sensitive, and specific alternative examination of the colon. There have been relatively few studies evaluating MRC as a screening tool for colonic polyps. On MRC, polyps may be described as sessile (broad based without a stalk) or pedunculated (with a stalk) (Figs. 50.1 and 50.2). Flat polyps and cancers are sessile lesions with only minimal elevation above the colonic wall, and can be difficult to identify on MRC (Fig. 50.3). Colon carcinomas may be polypoidal or mural based.

Recently, a meta-analysis of 13 MRC studies, which included 1,285 patients demonstrated a per-patient sensitivity and specificity between 88% and 99% for polyps measuring 10 mm or more, and a per-polyp sensitivity of 84% (Zijta et al. 2010). Sensitivity for the detection of colorectal cancer was 100%. The main advantage of MRC over CT colonography is the lack of ionizing radiation, which is preferable particularly in a screening population. Unfortunately, the data in these studies was too heterogeneous to accurately assess the sensitivity and specificity of this technique for smaller polyps measuring less than 10 mm. Ultimately, a large multicenter trial with screening patients is required, with only experienced radiologists with expertise in this area interpreting the studies, similar to the American College of Radiology Imaging Network (ACRIN) trial, which evaluated the sensitivity of polyp detection in CTC (Johnson et al. 2008).

Incomplete Colonoscopy

Incomplete colonoscopies occur in up to 13% of patients undergoing colonic evaluation (Shah et al. 2007). The cause of the incomplete colonoscopy is variable, ranging from redundant colon, to patient discomfort, to stenosis secondary to tumor, or inflammation, to significant diverticular thickening (Fig. 50.4).

MRC is ideal in these patients, particularly in those with obstructing lesions. Only air or fluid has to pass through the narrowed segment to distend the proximal colon to enable evaluation of the entire colon. In patients with a colonic malignancy, the colon can be evaluated for synchronous tumors, extracolonic

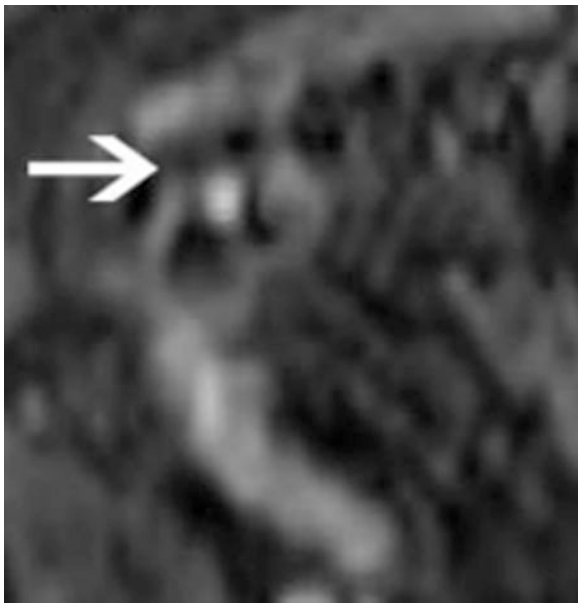

Fig. 50.3 Dark lumen MRC: Axial reformatted of coronally acquired T1-weighted SPGR with twofold acceleration using ASSET showing an intensely enhancing cecal adenoma (*arrow*)

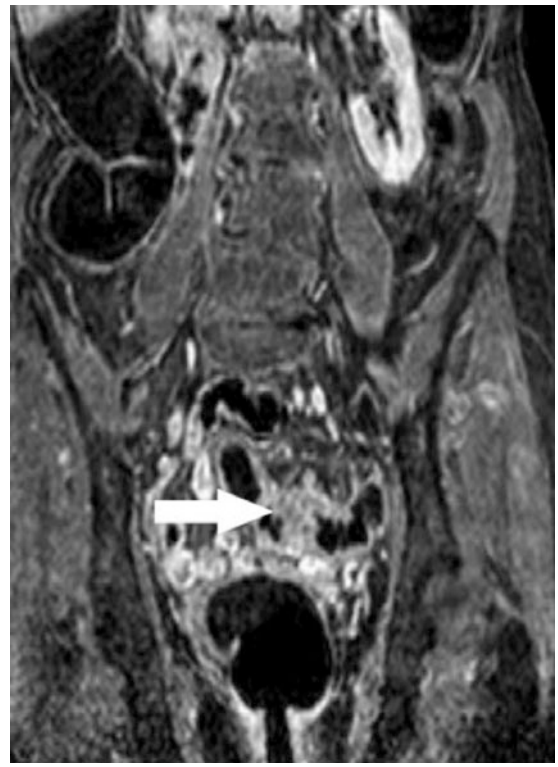

Fig. 50.4 Coronal T1-weighted SPGR post IV image in a patient who had a failed colonoscopy due to inability to pass the colonoscope beyond an occluding sigmoid lesion, which proved to be benign related to diverticular disease (Courtesy of Michael Patrick Achiam, MD, Copenhagen University Hospital Herlev, Herlev, Denmark)

disease, including adenopathy and liver metastases. It is essential to identify a synchronous tumor if present, as the planned colonic resection will be extended as a result. Consideration may also be given to performing a liver resection for a localized liver disease at the time of resection of the primary tumor.

Achiam et al. performed MRC on 47 patients with sigmoid or rectal cancer, to evaluate the proximal colon for synchronous cancers. Twelve synchronous lesions were detected in four patients. All polyps greater than 10 mm were detected; however, one flat polyp, three polyps measuring between 6 and 9 mm, and two polyps measuring 5 mm or less were missed on MRC (Achiam et al. 2009a).

More recently, Achiam et al. demonstrated that benign and malignant strictures of the colon might be accurately differentiated with the use of fast dynamic gadolinium-enhanced MRC. The theory behind this study was that malignant tumors have a higher blood flow compared to fibrotic scar tissue due to neovascularity. The wash-in and wash-out rates of intravenous contrast were significantly different between benign and malignant strictures. While benign strictures are rare (7% of all cases of diverticular disease), they can pose a diagnostic problem, as endoscopic visualization may be difficult due to a stiff, fibrotic segment of colon, caused by recurrent episodes of acute diverticulitis (McConnell et al. 2003). Furthermore, biopsies of malignant tumors may be falsely negative due to the presence of necrotic tissue, or nonrepresentative biopsies.

Evaluation of Colonic Anastomosis

The colonic anastomosis is the site at which disease recurrence can frequently occur, whether it is tumor recurrence, or recurrence of inflammation in patients with IBD. Strictures can also develop at these locations, which may cause symptoms. Ajaj et al. demonstrated a sensitivity of 84% and specificity of 100% for evaluating colonic anastomoses with MRC (Ajaj et al. 2006). MRC accurately demonstrated moderate stenosis without inflammation, IBD recurrence, and tumor recurrence at the anastomoses. False negative

examinations included patients with Crohn's disease with mild inflammation, and mild diverticulitis.

While 2-[fluorine 18] fluoro-2-deoxy-D-glucose (FDG) positron emission tomography with computed tomography (PET-CT) has been shown to be more accurate at detecting and staging local recurrence of colon cancer than CT and MRI, there have been no studies comparing PET-CT to MRC to date (Watson et al. 2007).

Inflammatory Bowel Disease

Inflammatory bowel disease includes both ulcerative colitis, which affects the colon diffusely, and Crohn's disease, which can affect the entire gastrointestinal tract with characteristic skip lesions. Conventional colonoscopy represents the gold standard for diagnosis and assessing disease activity for both disorders. The absence of ionizing radiation with MRC is particularly appealing in chronic diseases such as this; patients typically undergo several morphological explorations throughout the course of their disease. MRC is particularly useful in patients with more severe disease who require more frequent evaluations. Young patients, who are particularly affected by this disease, are more sensitive to ionizing radiation than older patients, making MRC a potentially safer alternative to CT.

There are few studies evaluating patients with IBD with MRC. Many of the available studies are limited due to low patient numbers; however, the preliminary research is promising, with MRC detecting active, and thus clinically relevant disease. It is not proposed that MRC replaces CC for the diagnosis of IBD, as tissue diagnosis is vital; however, MRC may be useful in assessing adequate response to medical treatment particularly relevant in acute inflammatory bowel disease.

Another advantage of MRC over CC is the ability to evaluate transmural and extraluminal disease, such as fistulae and abscess formation particularly in Crohn's disease. MR findings for CD includes bowel wall thickening, hyperenhancement of the mucosa or bowel wall after intravenous contrast administration (Fig. 50.5), bowel wall edema, stricture and fistula formation, abscesses, vascular engorgement, enhancing mesenteric lymph nodes, and fibrofatty proliferation (Rottgen et al. 2006; Gourtsoyianni et al. 2009; Paolantonio et al. 2009; Rimola et al. 2009). MRC allows differentiation between inflammatory and fibrostenotic disease in CD, which is clinically important, as there are different therapeutic approaches depending on the type of disease encountered. Fibrotic narrowing favors early surgery while the presence of inflammation favors a medical approach. Active inflammation is present when there is contrast enhancement of the mucosa, or bowel wall stratification (layers of enhancement in the colonic wall with the mucosa and serosa markedly enhancing unlike the interposed layer, resulting in a "target" or "double halo" appearance of the bowel wall). Submucosal edema, enlarged regional lymph nodes, and Comb's sign are other signs of acute inflammatory disease. Fibrosis is present when there is nonenhancing bowel wall thickening or prestenotic dilatation of the bowel. However, at times there can be both inflammatory and fibrotic characteristics present, which can pose a clinical dilemma for treatment (Martin et al. 2007). In ulcerative colitis, there is diffuse continuous thickening of the wall of the colon extending proximally from the rectum with or without pericolonic inflammatory changes (Fig. 50.6)

Ajaj et al. evaluated 23 patients with major clinical symptoms, and raised inflammatory markers with IBD (Ajaj et al. 2005c). CC with biopsy was used as the gold standard. The sensitivity and specificity for detection of inflammation was 87% and 100%, respectively (Ajaj et al. 2005c). However, these promising results may be biased due to the fact that asymptomatic patients, and patients with normal inflammatory markers, were not included. Another study which did not solely include symptomatic patients had less favorable results; a sensitivity for detection of inflammation in CD of 31.6% and UC of 58.8% (Schreyer et al. 2005). MRC was less sensitive for detecting mild inflammation than severe inflammation in both CD and UC (Schreyer et al. 2005). The degree of gadolinium enhancement at the level of inflamed bowel correlates well with the severity of inflammation (Ajaj et al. 2005c). However, in UC, even severe inflammation was not detected in 10% of segments of the evaluated colon (Schreyer et al. 2005). This was probably due to the fact that the mucosa alone becomes inflamed in UC in comparison with transmural inflammation in CD.

Recently, diffusion-weighted imaging (DWI) has been demonstrated to be effective in detecting

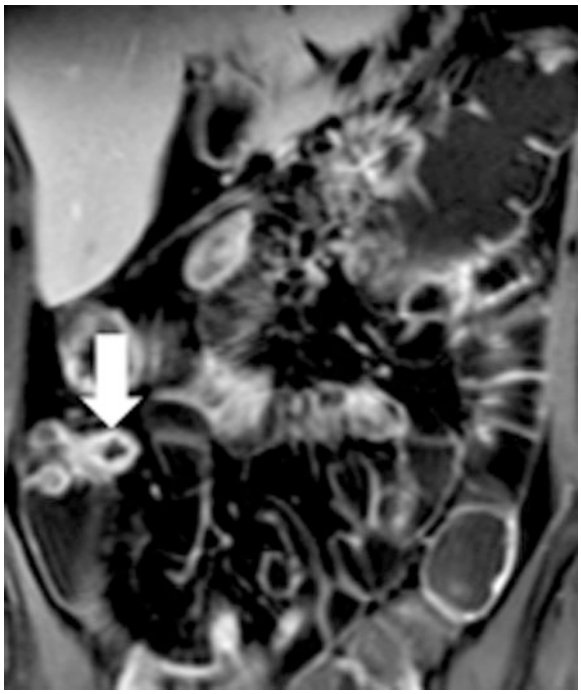

Fig. 50.5 Dark lumen MRC: Coronal T1-weighted SPGR post IV shows acutely inflamed distal ileum (*arrows*), in a patient with active Crohn's disease (Courtesy of Andrea Laghi, MD, University of Rome, Latina, Italy)

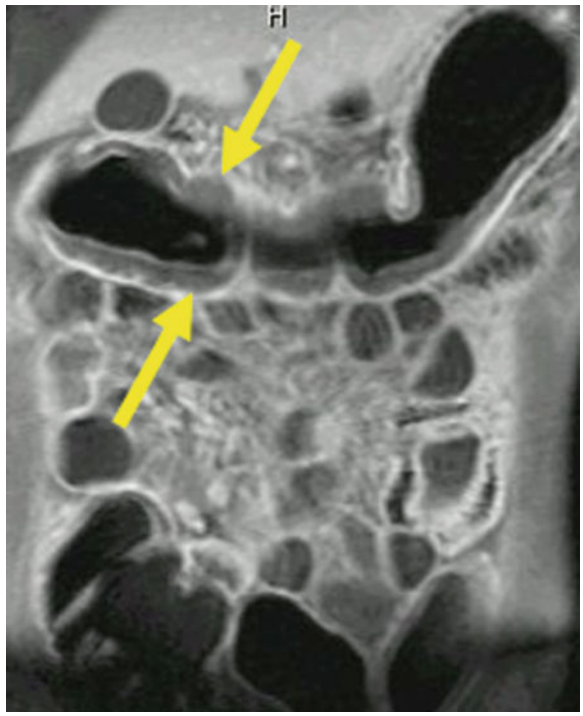

Fig. 50.6 Dark-Lumen MRC: Coronal T1-weighted SPGR post IV contrast shows moderate thickening and enhancement of the wall of the transverse colon in patient with ulcerative colitis (Courtesy of Andrea Laghi, MD, University of Rome, Latina, Italy)

inflammation in IBD, in a cohort of 96 patients who had not undergone bowel cleansing, and did not have an enema administered. Diffusion-weighted imaging derives its image contrast from differences in the random motion of water molecules between tissues; tissues with restricted diffusion are hyperintense on these sequences. This study demonstrated that restricted diffusion on DWI exhibited the same accuracy as increased enhancement with gadolinium for the detection of endoscopic inflammation in both UC and CD.

Diverticulitis

Diverticulitis is a clinical diagnosis based on clinical examination and elevated inflammatory markers, such as elevated white blood cell count and C-reactive protein. It occurs in 10–25% of patients with diverticulosis (Young-Fadok et al. 2000). Cross-sectional imaging, such as MRC, is useful to assess for complications of acute diverticulitis such as local perforation, and fistula and abscess formation. Other features on MR of diverticulitis include bowel wall thickening, increased enhancement of the wall of the colon, and pericolonic inflammatory changes in the presence of diverticular disease.

When MRC was compared to CT (not colonography), it was found to be as accurate as CT in detecting diverticulosis and acute diverticulitis (Schreyer et al. 2004). However, free intraperitoneal air can be difficult to detect on MRC, unlike with CT. Ajaj et al. found an overall sensitivity of 86% and specificity of 92% for dark lumen MRC when compared to CC (Ajaj et al. 2005b). MRC incorrectly identified 4 out of 40 cases of mild diverticulitis as being normal (Ajaj et al. 2005b). In addition, MRC was unable to differentiate between acute diverticulitis and colon cancer in three cases (Ajaj et al. 2005b). Given these drawbacks, and the widespread availability and speed of CT, CT will most likely remain the most commonly used imaging technique in patients with suspected diverticulitis.

Endometriosis

Endometriosis is defined as the presence of endometrial tissue outside of the uterine cavity. It affects the intestine in 4–37% of cases (Remorgida et al. 2007). The rectosigmoid junction is the most common site of bowel involvement seen in 85%, followed by the ileum, cecum, and appendix (Redwine 1999). Treatment of intestinal endometriosis involves surgical resection, which is associated with a low incidence of recurrence or further surgery and an improvement in fertility in younger women (Stepniewska et al. 2010). Preoperative evaluation, assessing the locations of disease is extremely helpful in treatment planning.

The gold standard for diagnosis of endometriosis is laparoscopic visualization. High-resolution MR of the pelvis has been shown to be successful in evaluating endometriosis within the pelvis; however, it does not evaluate the entire colon effectively. When MRC is compared to high-resolution MRI pelvis, the sensitivity and specificity for detection of colorectal endometriosis increases from 76% and 96%, to 95% and 97%, respectively for an experienced MR reader (Scardapane et al. 2011). Bowel involvement has varying appearances from hypointense nodular or plaque-like bowel wall thickening, with contrast enhancement after gadolinium injection, loss of the fat plane between a loop of bowel and the uterus, or other adjacent organ, to abnormal angulation of bowel (Scardapane et al. 2011).

MRC Techniques

Bright lumen MRC was the approach initially utilized when this imaging technique was first described. Bright lumen MRC typically takes approximately 20 min to perform. This involves the instillation of a gadolinium-spiked enema into the colon, which is allowed to fill under gravity. The enema typically is hung approximately 2–3 ft above the level of the patient. Between 1.5 and 2 l of the enema is instilled into the colon, according to patient tolerance and distension of the colon. A concentration of 5–10 mmol/l is obtained by mixing gadolinium with water.

Dual positioning is usually required in bright lumen MRC so as to displace air and stool, which will move with a change in patient position. Polyps and masses are seen as T1-hypointense filling defects against the bright, contrast-filled lumen. Occasionally, filling defects such as air or residual stool, fail to displace despite dual positioning and can be incorrectly identified as intraluminal polyps, resulting in false-positive examinations. Another disadvantage to this technique is the fact that administration of intravenous contrast is not useful in the presence of bright intraluminal contrast. The contrast enhancement of polyps is not easily appreciated with bright intraluminal contrast, and it is mainly for this reason that this technique is no longer popular, despite relatively good detection rates for polyps (Debatin and Lauenstein 2003).

Colon cancer screening with bright lumen MRC has a modest per-patient sensitivity of 75% with a better per-patient specificity of 95%, with double reading in patients with increased risk of CRC and limited bowel preparation (Florie et al. 2007b).

Dark lumen MRC makes use of a negative intraluminal contrast agent such as room air, carbon dioxide, or water (Fig. 50.7). The use of room air or carbon dioxide is usually preferable as there is no risk of spillage and therefore magnet soiling with gaseous agents. In addition, air has been shown to distend the colon greater than with water enema, and is not associated with increased susceptibility artifacts (Ajaj et al. 2004). Susceptibility artifacts can occur at the air/tissue interface, thus decreasing image quality and the sensitivity of the examination. However, with recent developments in MR technology, short echo times may be used to limit this artifact. Carbon dioxide is frequently used in CT colonography as it is absorbed quicker through the colon wall than room air and thus results in less post-procedural discomfort. However, data acquisition times in MRC are longer than in CTC, and so rapid absorption of carbon dioxide by the bowel may lead to variable colonic distension as well as bowel motion artifact. The use of automated continuous carbon dioxide insufflation as well as the administration of spasmolytics can help to avoid these issues (Zijta et al. 2011). However, there is currently no MR compatible automated insufflators, thus making carbon dioxide administration a logistical challenge for MRC.

Water is a biphasic luminal contrast agent, which is hyperintense on T2-weighted imaging and hypointense on T1-weighted imaging. In addition to the potential for spillage during the examination, another disadvantage of using water is that intraabdominal abscesses can be difficult to identify,

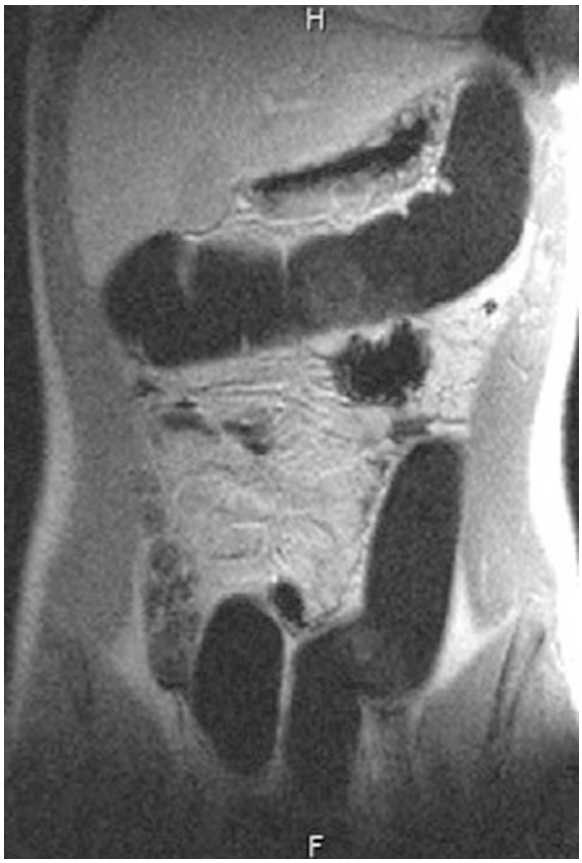

Fig. 50.7 Dark-Lumen MRC: Coronal T1-weighted SPGT images without intravenous contrast shows a well-distended colon with a featureless left colon in a patient with longstanding ulcerative colitis (Courtesy of Andrea Laghi, MD, University of Rome, Latina, Italy)

as the fluid within an abscess has similar MR characteristics as water, thus reducing the conspicuity of the abscess. This issue is particularly relevant in the setting of Crohn's disease and diverticulitis.

Recently, a study, including a small number of symptomatic patients, evaluated the use of orally administered fluid (polyethylene glycol (PEG) electrolyte solution to distend the colon with the hypotheses that this was less invasive than a rectal administered enema (Bakir et al. 2009). PEG has T1- and T2- weighted imaging signal intensity properties similar to those of water, and can be used in conjunction with the dark lumen technique. This technique required abdominal ultrasound to assess for colonic distension prior to commencement of the MR examination, which took on average 105 min from the time of ingestion (Bakir et al. 2009). Forty-four percent of patients described a strong urge to defecate during the examination, with the remainder of patients describing the need, or slight urge to defecate (Bakir et al. 2009). Despite this, the examination was completed in all cases, but the occurrence of spillage within the scanner was not mentioned in the results of this study. Adequate distension was obtained in 91–96% of patients in the supine position and 93–96% of patients in the prone position (Bakir et al. 2009).

Intravenous gadolinium is always administered for dark lumen MRC. Pre- and post-contrast imaging is compared, with the radiologist searching for enhancing filling defects representing colonic polyps. There are disadvantages of the routine use of intravenous gadolinium in dark lumen MRC. There is the risk of development of nephrogenic systemic fibrosis (NSF) in patients with a reduced glomerular filtration rate (Abujudeh et al. 2009). Renal impairment is more prevalent in older patients, which is the target population for colorectal cancer screening. Other disadvantages include the additional cost of the intravenous injection itself, the intravenous cannula, and syringe as well as the extra time required to place the cannula.

The largest single center trial evaluating dark lumen MRC for colon cancer screening delivered disappointing results at first glance, with a per-polyp/lesion sensitivity of 10.5% for lesions measuring less than 5 mm, 57.6% for polyps measuring between 5 and 10 mm, and 73.9% for lesions greater than 10 mm. However, many of the polyps that were missed were hyperplastic polyps, which are not the target of colorectal cancer screening. In addition, it has been proposed in the CTC literature that hyperplastic polyps are "more pliable" and therefore more likely to be missed with colonic distension. When adenomatous polyps only were included, the sensitivity increased to 80% for lesions greater than 5 mm. In fact, the specificity rates and negative predictive values were found to be more than 90% for lesions greater than 5 mm, which is important for a screening tool.

MRC Step-by-Step

Patients undergoing MRC require bowel cleansing similar to that required for CT colonography. Agents such as polyethylene glycol (PEG), and sodium phosphate are frequently used with between 1 and 4 l of oral

fluids prescribed the day before the examination. Bowel cleansing is required to eliminate residual stool, which can potentially be misinterpreted as an intraluminal filling defect, such as a polyp or a carcinoma. Residual stool can also obscure underlying disease resulting in false negative examinations. Generally, the bowel preparation is less intense than the bowel preparation for conventional colonoscopy, and so may be preferred by some patients.

The addition of stool tagging to the technique of MRC has the potential to reduce or even eliminate cathartic bowel cleansing (Rodriguez Gomez et al. 2008). Stool tagging deliberately alters the signal of stool to render it invisible. This is achieved by ingestion of agents to render the stool the same signal intensity as the enema being used, that is, dark stool for dark-lumen MRC, and bright stool for bright lumen MRC. If there is adequate tagging of stool the number of false positives and false negatives may be reduced. There have been varying acceptance rates by patients with this technique; favorable results have been described in some studies, while other studies have found that conventional colonoscopy with full cathartic bowel preparation is preferred by patients over MRC with stool tagging (Florie et al. 2007a) (Langhorst et al. 2007).

Many different agents have been used for stool tagging. Ideally a tagging agent should be well tolerated, inexpensive, and alter the signal of the stool in a uniform manner, without associated artifacts, which could degrade image quality. The agent is usually ingested with meals several times a day over the immediate few days prior to the MRC, so as to be incorporated into the stool. With bright lumen MRC, gadolinium chelates are typically used as a tagging agent. This can result in increased costs, as gadolinium chelates are more expensive tagging agents, particularly when administered with a gadolinium chelate–spiked enema at the time of the MR examination. In dark lumen MRC, barium has been used effectively as a tagging agent, and is relatively cheap; however, it may result in constipation (Lauenstein et al. 2001; Rodriguez Gomez et al. 2008). Ferumoxsil (Lumirem, Guerbet Group, Paris, France), which is composed of small iron particles, may alternatively be used, resulting in low-signal stool on dark lumen MRC (Achiam et al. 2008). When dark lumen MRC is being planned, the patient should also avoid manganese-rich foods, such as fruits and chocolates, as these can result in bright-signal stool artifacts, which would degrade the quality of the examination.

The quality of stool tagging has been shown to depend on individual patient characteristics, such as a patients' age; stool tagging in patients over the age of 55 years is significantly poorer than in younger patients. Therefore, prolonged tagging with ingestion of tagging agents for more than 72 h before MRC has been recommended in this cohort of patients.

The most recent literature showed that while stool tagging is associated with acceptable per-patient sensitivities, the per-polyp sensitivities are compromised. (Achiam et al. 2009b). Therefore, while stool tagging is still a promising tool, it may not be ready for widespread clinical use yet.

Fecal cracking has more recently been put forward as an alternative method of changing the signal of stool for MRC. This technique involves increasing the water content of stool, thus decreasing its signal intensity on dark lumen MRC. A combination of lactulose, with a docusate sodium rectal enema (0.5%) was found to be most effective; however, this single study only involved ten volunteers, and did not study symptomatic or screening patients (Ajaj et al. 2005a).

The usual contraindications to general MR imaging apply to MRC including claustrophobia, the presence of metallic implants such as intracranial aneurysm clips in the patient, as well as cardiac pacemakers. A specific consideration is the presence of hip prostheses and internal spinal fixation; while these are safe in the MR scanner, they result in significant artifacts, which can limit the evaluation of the colon. Hip prostheses with their associated artifacts in particular can limit evaluation of the rectum and sigmoid colon. Patients should be screened for impaired renal function if considering administering intravenous gadolinium chelates, to identify patients at risk of nephrogenic systemic fibrosis.

In concert with adequate colonic preparation, adequate colonic distension is vital to accurately assess the colon with MRC. Agents are generally administered using a soft-tipped rectal catheter, such as a Foley catheter, which is placed in the lower rectum, while the patient is in the left lateral decubitus position. To maximize distension of all segments of the colon, at most centers both prone and supine imaging is recommended as imaging the patient in one position alone may not allow the colon to adequately distend in all segments. However, in some institutions, only single positioning is used.

Lack of adequate colonic distension can result in pathology being missed, or may mimic bowel wall thickening or mucosal inflammatory changes in inflammatory bowel disease falsely suggesting abnormality in these segments. Conversely, collapsed segments may hide subtle mural thickening or mucosal inflammatory changes.

As with CTC, the entire colon must be imaged during the MRC examination. One or two surface coils can be used with the built-in phased array coil for signal reception. If a phased array coil is being utilized, it is ideally placed over the upper abdomen while the patient is placed in the supine position to cover the transverse colon, and over the lower abdomen and pelvis when the patient is in the prone position to maximize visualization of the sigmoid colon, and rectum.

Filling of the colon is monitored closely during colonic filling/insufflation to ensure maximal safe distension of the colon. Images are obtained every 3–5 s until the colon is deemed to be well distended. With bright lumen MRC, a non-slice selection gradient echo sequence is used for this purpose, while in dark lumen MRC a half-Fourier acquisition single-shot turbo spin-echo (HASTE; Siemens Medical Solutions, Malvern, Pa) or true fast imaging with steady-state precession sequences may be used.

In bright lumen MRC, a three-dimensional (3D) T1-weighted spoiled GRE sequence is typically utilized. The MR scanner must be equipped with high-performance gradients and a phased-array coil with a large field of view to perform these sequences with adequate signal-to-noise ratio throughout the entire colon. Slice thickness should be at the most 4 mm, and preferably closer to 1.5 mm in the coronal plane to ensure adequate resolution for polyp detection. Both repetition times and echo times are kept short to enable single breath-hold imaging (1.6–4 ms and 0.6–1.6 ms, respectively)

In dark-lumen MRC the sequences most frequently used include 3D pre- and post-contrast T1-weighted spoiled GRE sequences with fat suppression. In the setting of inflammatory conditions of the colon, T2-weighted fat-saturated single-shot images can demonstrate edema within the wall if present and can help differentiate active from chronic inflammation. Post-contrast imaging is obtained 75 s after injection. Additional arterial and equilibrium phase imaging of the liver in particular can be considered depending on the clinical question; however, this results in longer scan times.

It is recommended that an antispasmodic agent be administered to minimize peristalsis during the examination and as a result, minimize movement-related artifacts. Either butyl scopolamine (Buscopan; Boehringer Ingelheim am Rhein, Germany) (20 mg) or glucagon (1 mg) can be used. Glucagon may be associated with the unwanted side effect of reflux through the ileocecal valve, which may result in poor distension of the colon, and so butyl scopolamine is preferred. However, butyl scopolamine is not available in the USA.

Special MRC software enables the reader to perform multiplanar reformations at a workstation as well as a full endoluminal fly-through. Even for an experienced MR radiologist, interpretation can take 20 min or more. The endoluminal fly-through allows accurate assessment of haustral morphology, thus enabling the radiologist to differentiate between normal haustral folds and true lesions. Both ante grade and retrograde fly-throughs are recommended, so that all sides of the haustra are visualized. The ability to perform a fly-through in both directions is an advantage of MRC over conventional colonoscopy, which can only assess the colon in a single direction. The endoluminal fly-through is most helpful for the detection of polyps, and is less helpful in patients with inflammatory bowel disease, where mucosal and mural inflammation is poorly appreciated. When an apparent mass or polyp is detected on post-contrast T1-weighted imaging, direct comparison to pre-contrast T1-weighted imaging in the same location is necessary to evaluate for contrast enhancement of the apparent lesion. Both polyps and colon carcinomas enhance, while stool usually does not. T2-weighted imaging is useful for evaluation of inflammation, with pericolic inflammatory changes seen in conditions such as diverticulitis and colitis.

Extracolonic Findings on MRC

Since MRC provides a dataset covering the entire abdomen and pelvis, incidental extracolonic abnormalities may be detected (Figs. 50.8 and 50.9). Occasionally, potentially serious lesions are detected at an early stage, allowing for complete cure; however, further work-up of findings that subsequently turn out to be benign result

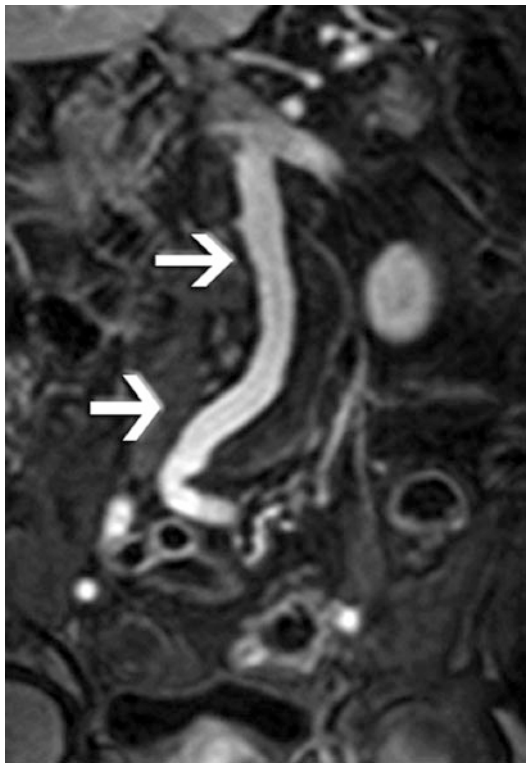

Fig. 50.8 Dark lumen MRC: Coronal T1-weighted SPGR image post IV contrast shows a 4 cm infrarenal aortic aneurysm (*arrows*) (Courtesy of Sonia Rodríguez-Gomez, MD, Hospital Clínico, Barcelona, Spain)

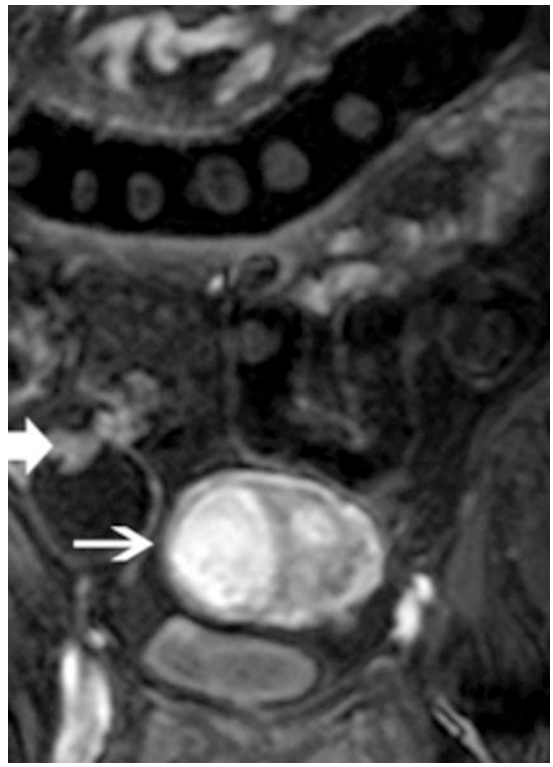

Fig. 50.9 Dark lumen MRC: Coronal T1-weighted SPGR image post IV shows concerning enhancement with the mural nodule within a right adnexal mass (*block arrow*). The uterine lesion (*small arrow*) was shown to represent a leiomyoma (Courtesy of Sonia Rodriguez-Gomez, MD, Hospital Clinico, Barcelona, Spain)

in increased cost as well as possible distress to patients. Only two studies have been performed to date evaluating the incidence, and category of incidental findings on MRC; one with bright lumen MRC, and the other with dark lumen MRC (Yusuf et al. (2011); Ajaj et al. 2007). The studies were performed on different cohorts of patients; Yusuf et al. studied patients at increased risk of colorectal cancer who were undergoing a screening MRC, while Ajaj et al. studied a mixed group of patients including screening patients (23%), symptomatic patients, patients with elevated liver function tests, as well as those with previous history of colon cancer. As a result, the rate of clinically significant/therapeutically relevant findings was higher in the mixed group of patients (12%) than the screening group alone (4.8%). Further diagnostic work-up was performed in 7.2% and 6.7% of patients, respectively, in these studies (Yusuf et al. (2011); Ajaj et al. 2007). The cost of the additional work-up was not calculated in either study. Ultimately, the cost-effectiveness of MRC as a screening tool should be evaluated in a manner similar to that, which has previously been performed for CT Colonography (Yee et al. 2005).

Incidental findings on MRC should be reported in a standardized manner, similar to the CT colonography Reporting And Data System, (C-RADS) used in CT colonography (Zalis et al. 2005). Standardized reports assist referring physicians in management decisions on the basis of the results of MRC, as well as allow direct comparison of reports of examinations performed at difference centers.

Future of MRC

1. Parallel Imaging
   Advances in MR technology, such as parallel imaging, facilitates imaging using thinner slices as well

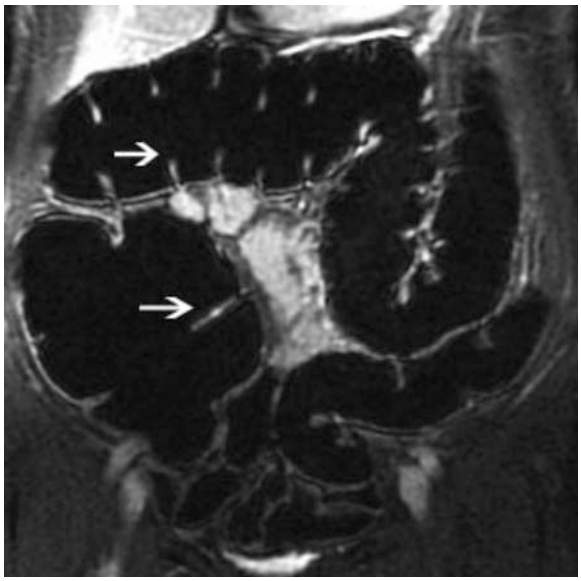

Fig. 50.10 Dark lumen MRC: Coronal T1-weighted SPGR with twofold acceleration using ASSET post IV shows a well-distended colon with excellent visualization of the haustral folds (*arrows*). This image was acquired in 13 s

as acquisition of near isotropic voxels that allow multiplanar reconstructions to be carried out (Fig. 50.10). Parallel imaging facilitates faster image acquisition so that image quality can be maintained with a reduced breath-hold duration. Alternatively, if breath-hold duration is unchanged, increased spatial resolution may be obtained. Promising results have been demonstrated using this technique with a phantom model, with 100% sensitivity and specificity for detection of polyps 5 mm or larger (Morrin et al. 2008).

2. MRC at 3.0 T
   With the advent of 3.0-T MR imaging, it is anticipated that the diagnostic performance of MRC would be further improved. Spatial resolution can be considerably greater at 3.0 T than at 1.5 T with thinner sections and 1.6 mm isotropic voxels possible with 3.0 T. There is no consensus currently that imaging with a stronger magnetic field increases sensitivity and specificity for detection of polyps. Saar et al. demonstrated a sensitivity of 100% for all colon cancers, and polyps great than 6 mm in a small cohort of 34 patients with 3.0 T MRC. However, increased artifacts can degrade image quality in 3.0 T MRC.

Conclusion

While MRC is not in widespread use currently, it is a promising tool for evaluating the colon in a noninvasive manner. Its main advantage is the lack of ionizing radiation, and superior soft tissue contrast. Its use is particularly attractive in younger patients or in patients who require regular colonic evaluation with cross-sectional imaging. In the screening setting, is has shown to be accurate in the detection of colon cancer and large polyps (>10 mm). Failure to detect polyps less than 5 mm in size, is not clinically significant due to the fact that there is a low risk of malignant transformation associated with polyps of this size (Nusko et al. 1997). There have been mixed results for the detection of polyps measuring between 6 and 9 mm. There is currently significant heterogeneity of the methods used with regard to MRC and data reporting particularly in the setting of polyp detection. Consensus reporting recommendations regarding study design characteristics, such as definition of an experienced reader in MRC, and standardized per-patient and per-polyp data presentation, should be introduced for future studies. The methodology that has been used in CTC could potentially be used as a framework for subsequent studies in MRC.

Pearls to Remember

- MRC is currently only used in routine clinical practice in a small number of specialized centers.
- The main advantages of MRC are the lack of ionizing radiation and superior soft tissue contrast.
- Bright lumen MRC relies on visualization of polyps and masses as filling defects against a bright contrast material-filled lumen. A gadolinium-spiked enema is usually used.
- Dark lumen MRC uses a negative contrast agent, such as water, room air, or carbon dioxide, to distend the colon. Intravenous gadolinium chelate is usually administered with this technique and abnormalities in the colonic wall enhance and become more conspicuous.
- Indications for MRC include incomplete colonoscopy, inflammatory bowel disease monitoring, endometriosis detection, diverticulitis, assessment of colonic anastomoses, and potentially colorectal cancer screening.

- MRC is accurate in detecting colon cancer (100% sensitive) and polyps greater than 10 mm (per patient sensitivity of 88%). Variable sensitivities and specificities have been found for the detection of polyps measuring 6–9 mm.
- Extracolonic abnormalities may be detected during MRC examinations, which can result in the early detection of malignancy involving other organs in the abdomen and pelvis or metastatic disease from colon cancer. However, detection of incidental findings may result in further investigations with an associated cost, as well as unnecessary anxiety for patients.

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