Chapter 2

Colonography by Magnetic Resonance Imaging (MRI).

Adapted from:

F.M. Zijta
J.Stoker

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M.P. van der Paardt
F.M. Zijta
J. Stoker
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MR colonography

The second chapter of this thesis focuses on the evaluation of the colon using Magnetic Resonance (MR) imaging, which has been increasingly applied over the last decade. Recent advances in MR technology, particularly the advent of faster T1 pulse sequences, resulted in reduced physiological artefacts and consequently facilitated bowel imaging and assessment.

When applying colonic distension (i.e. MR colonography), MRI offers a method for colon imaging comparable to computed tomography (CT) colonography. MR colonography can be regarded as a minimally invasive tool for evaluating the entire colon, permitting multiplanar imaging and potentially enables three-dimensional (3D) rendering during post-processing. Additionally, it provides information of the extra colonic organs which are not perceptible during colonoscopy. Advantages of MR colonography over CT colonography is the lack of the use of ionizing radiation and the high inherent soft tissue contrast, which allows the use of a wide range of ‘faecal tagging’ regimes for bowel preparation. Whereas colonic distension in CT colonography typically entails the rectal administration of carbon dioxide or air, in MR colonography colonic distension is often acquired with the administration of a water-based enema and only few studies have reported on the usage of gaseous agents for colonic distension.

Since the introduction of MR colonography [1], research in this field is mainly focused to outline its role in the detection of colorectal masses and subsequently describe the future potentials of this modality in screening for colorectal carcinoma (CRC) as it has proved to be accurate in detecting clinical relevant precursors of CRC [2]. However, the clinical indications for performing MR colonography reach beyond and cover indications which are applied for both colonoscopy and CT colonography.

A variety of acquisition methods are described to perform MR colonography, but to date none of the different approaches have been shown to be superior. Regardless of the applied technique, prerequisite is a well distended colon which is either cleansed or homogenously tagged, in order to permit an adequate assessment in a MR colonography setting.

When to perform MRI of the large bowel

The indications for performing MRI of the colon merely cover the indications which are applied for colonoscopy and / or CT colonography and has been proposed in the diagnostic assessment of the colorectum of symptomatic patients for colorectal carcinoma (CRC), the colorectal assessment of asymptomatic
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individuals who are at average or increased risk for CRC, clinical staging evaluation in patients with CRC, assessment of colorectal involvement in patients with recognized or suspected inflammatory bowel disease (IBD), the evaluation of patients with incomplete or failed colonoscopy and the evaluation of patients with suspected diverticular disease (DD).

Detection of precursors of colorectal cancer
In many western countries, colorectal cancer (CRC) is currently one of the leading causes of cancer-related death in both men and women. If the disease is diagnosed at a low stage, the five-year survival is high. However the five-year survival rate drops to less than 10% if distant metastases are present [3]. Primary goals of colorectal cancer screening programs are to reduce both morbidity and mortality through reducing the incidence of the advanced staged disease and prevention of colorectal cancer by removal of benign precursors (adenomas) [4,5]. Histologically, colorectal polyps primarily can be divided into adenomatous and hyperplastic, in which adenomatous polyps comprise nearly two-third of all colorectal polyps. According to the adenoma-carcinoma sequence hypothesis, adenomatous polyps have the potential to progress to CRC.

The potential risk for developing CRC from colorectal adenomas is related to both size and histology. Colonography enables the detection and size estimation of colorectal polyps and can therefore trigger future polypectomy at colonoscopy. Importantly, no histological distinction can be applied using colonography and size remains the most important criterion to estimate the potential to evolve into malignancy. Therefore it is essential to define the potential CRC risk associated with each polyp size category before data on MR colonography polyp detection rates can be interpreted in their context.

Irrespective of histology, colorectal polyps can be stratified into three generally accepted size thresholds, reflecting the potential risk to contain or progress into cancer. Large polyps are defined as polyps with a size of 10 mm or larger (≥10mm) and a recent study demonstrated advanced histology in 30.6% of all polyps ≥10mm. Of the 13,992 asymptomatic patients who underwent colonoscopy malignancy was demonstrated in 2.6% of the large polyps (≥10mm), 0.2% of the intermediate polyps (6-9mm), and the likelihood that polyps smaller than 5 mm ('diminutive' lesions) harboured malignancy was less than 0.1% [6].

A recently published simulation, which has inherent limitations, estimated the associated risk for a large colorectal adenomatous polyp (≥10mm) to evolve
into CRC, as approximately 16% in ten years. The estimated risk potential for intermediate (6-9 mm) and diminutive lesions is substantially smaller (0.7 % and 0.08%, respectively) [7]. Histological features which have been associated with a higher risk for CRC include high-grade of dysplasia (HGD) and villous element [8]. Neoplasia can therefore be classified into ‘advanced’ (i.e. adenocarcinoma and advanced adenomas, the latter being all adenomas ≥ 10mm, adenomas with HGD or containing villous element (>25%)) and therefore clinically significant, or ‘non advanced’.

General guidelines regarding relevance of lesion size for colonography are presented by the recently published consensus proposal for CT colonography. These recommendations propose that patients with polyps ≥ 10mm as found with colonography, should be referred for polypectomy at colonoscopy. In addition, patients with intermediate polyps (6-9 mm) should either be referred for colonoscopy or undergo CT colonography on a custom basis [9]. Though, in daily practice frequently a more stringent approach is applied, resulting in the colonoscopy for any CT colonography with one of more polyps > 6mm. Small polyps (≤ 5 mm) are considered clinically not important, because of their very low risk for development of CRC. Recommendations have been proposed concerning data reporting in colonography, which encompasses the presentation of outcomes regarding different polyp size categories and additional data for histological subset analyses [10].

**Image interpretation**

Accurate colonic distension is the key element for adequate visualization of colorectal polyps and cancers. Inferior distension or segmental collapse will ultimately lead to false-positive and false-negative findings. This as the observer is not optimal able to detect lesions that may protrude into the colonic lumen, and otherwise a segment which is collapsed may simulate pathological bowel wall thickening. Similar to CT colonography, in MR colonography the post-procedural display techniques for detecting colorectal lesions distinguishes two reading techniques and is performed on a post processing workstation with dedicated software.

Firstly, two-dimensional data sets will be evaluated using a two-dimensional method, which facilitates the evaluation of both the colon and extracolonic organs. Three-dimensional (3D) data sets can be evaluated two-dimensionally in each orthogonal anatomical plane (i.e. transverse, sagittal and coronal), using multiplanar reformation (MPR). If detected, colorectal lesions can
be described by the location and morphological features, also it can be measured and consequently be classified into one of the three predefined polyp categories [9]. Again, solitary colorectal polyps smaller than 6 mm can be ignored in this setting, as the likelihood for the presence of advanced neoplasia is extremely low [7].

Most MR colonography studies report the solitary use of MPR data set interpretation. An additional principle of data evaluation entails the application of virtual colonoscopy, in which the MR colonography dataset is used to construct a 3D rendering. However, current technical limitations hamper the application of this method in MR colonography, which is widely applied in CT colonography. Whereas in CT colonography this endoluminal view is typically based on data thresholding, high variation in signal value precludes such a straightforward approach for MRI data. These fluctuations in MRI signal might originate both from global (e.g. distance to the antenna) as well as from local effects (inhomogeneities in bowel content), and are difficult to overcome. Nonetheless, several authors report on the use of a local 3D surface rendering during review and might be used for problem solving [11, 12].

**MR-colonography techniques in relation to prevalence**

As in CT-colonography, different groups with a different prevalence of disease can be identified: (1) asymptomatic subjects at increased risk for CRC (e.g. family history of familial adenomatous polyposis (FAP), first degree relative with CRC, personal and/or family history of colorectal cancer or polyps, inflammatory bowel disease (IBD)) and (2) asymptomatic subject at average risk for CRC (age >50yrs). The first group is considered as individuals with a high prevalence of disease and the latter is considered a screening population with a relatively low prevalence of disease. The results of MR-colonography will be described taking these different groups with different disease prevalence and disease spectrum into account.

**High prevalence population**

*Bright lumen strategy*

In the late 1990’s and early 2000’s several investigators identified MR colonography as a potential diagnostic method for the detection of colorectal polyps and cancer in asymptomatic patients and patients at increased risk for CRC [13, 14]. Initial research was performed with the use of bright lumen MR colonography in which the colonic lumen appears hyper intense on T1w sequences by the rectal administration of a gadolinium based enema (*Figure 1*).
Figure 1. (a) T1 w three-dimensional (3D) coronal Fast Field Echo (FFE) image of a 56 year old patient with suspicion of a hyperplastic polyposis syndrome. MR colonography visualized a hypo-intense lesion which protrudes into the ‘bright’ colonic lumen (arrow), in the distal part of the transverse colon. Suspicious of a pedunculated polyp.  **(b)** The presence of a lesion is also confirmed at an axial T2 w two-dimensional (2D) Fast Spin Echo (FSE) image, with relative high signal intensity on this sequence (arrow).  **(c)** The presence of a 15 mm pedunculated polyp was confirmed at colonoscopy. Histology analysis confirmed the diagnosis of a hyperplastic polyp. (Adapted from Zijla FM, Stoker J. *MRI of the Colon (Colonography): Results, Medical Radiology Diagn. Imaging, MRI of the Gastrointestinal Tract – J. Stoker (Ed). 185-204, With kind permission of Springer Science + Business Media*)

Among the first prospective studies using bright lumen MR colonography was a paper by Luboldt et al, who reported a high sensitivity (93%) and a high specificity (99%) for detecting patients with large colorectal lesions. 1.5T MR
colonography was compared with colonoscopy in 117 symptomatic patients referred for colonoscopy, using a rectal enema which contained 3L of water and 60mL of 0.5 mol/L Magnevist (gadopentetate dimeglumine). However a moderate sensitivity was demonstrated (75%) when a cut-off value of 7 mm was applied [13]. Pappalardo and colleagues studied 70 patients at increased risk for CRC, who underwent 1.0T MR colonography using a comparable bright lumen approach. High diagnostic outcomes were found (sensitivity 96% and specificity 93%) for detecting patients with polyps of all sizes [15]. In this study 125 endoluminal lesions were found in 54 patients of which 94 lesions were larger than 10 mm in size. These results demonstrated the ability of MR colonography to detect colorectal lesions exceeding the size of 10 mm with acceptable diagnostic accuracy. This encouraged study groups to investigate MR colonography as alternative diagnostic tool in this field, particularly the value of this modality in detecting intermediate polyps (6-9 mm).

While earlier studies typically used the bright lumen variant with promising outcomes, currently the dark lumen method is mostly applied. This change in acquisition method however was more based on practical reasons (costs of contrast agent) than on extensive series. Some research was performed on different type of MR colonography regimes by Florie et al., who studied diagnostic yield for the bright lumen strategy [16]. In this study, three different MR colonography strategies, which consisted of two dark lumen (water-based and air-based colonic distension) and one bright lumen strategy with faecal tagging strategy as bowel preparation, were compared. Forty-five subjects at increased risk for CRC were subjected to both MR colonography and colonoscopy. While the diagnostic confidence of both the bright lumen and dark lumen strategy using air for colonic distension was rated best by two independent observers, patient acceptance in the bright lumen method proved less burdensome as compared to the other two dark lumen strategies. The latter was mainly due to the better tolerance of the bowel preparation method.

In a further prospective study in 200 patients at increased risk for CRC bright lumen MR colonography using gadolinium/water mixture for colonic distension was compared to findings with colonoscopy [17]. Results in this study showed only moderate sensitivity in detecting patients with polyps ≥ 10 mm (75%). Specificity for these clinical significant polyps was 93%, however a high number of false positive findings reduced specificity for polyps ≥ 6 mm to 67%. The latter was mostly related to both air pockets and motion artefacts. This study
Figure 2. (a) Supine T1w 3D axial FFE image of an 84-year old male with multiple polyps in the right colon. ‘Bright lumen’ MR colonography visualizes a lesion in the transverse colon (arrow) and a lesion in the proximal aspect of the ascending colon (arrow). Several air collections are visible, potentially leading to false negative findings in this position (curved arrows). (b) The presence of the polyps is also visualized on the corresponding axial T2w 2D FSE image in supine position, which shows relative high signal on this sequence (arrows). Hydronephrosis of the right kidney (curved open arrow). (c) Corresponding prone T1w 3D axial FFE image shows the somewhat elongated polyp on the anterior aspect of the transverse colon. (d) Colonoscopy confirmed the presence of a pedunculated 10 mm polyp in the proximal aspect of the transverse colon. The presence of a polyp in the ascending colon was confirmed at colonoscopy (not shown). (Adapted from Zijla FM, Stoker J. MRI of the Colon: Colonography: Results. Medical Radiology Diagn. Imaging. MRI of the Gastrointestinal Tract – J. Stoker (Ed). 185-204. With kind permission of Springer Science + Business Media)

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was performed in primarily high-risk patients for CRC who took part in a surveillance program. Interestingly the prevalence of patients with polyps larger
than 10 mm in this cohort who underwent colonoscopy surveillance was only 6%,
which might have influenced test outcome.

Another prospective study, conducted in 120 symptomatic patients and
patients at increased risk, using the ‘bright lumen’ approach with standard bowel
preparation, showed adequate detection rates for patients with present polyps or
lesions with any size. Forty-seven of 56 patients with colonoscopically confirmed
colorectal lesions, were correctly identified to have lesions using bright lumen MR
colonography, and 94% of lesions ≥10 mm were depicted [18]. Additionally, MR
colonography was able to detect all seven colorectal carcinomas.

Limitations in these studies concern the technical ability of the used
technique to correctly identify flat polyps / adenomas and small polyps which is
also frequently reported in CT colonography in surveillance populations [19, 20].
But more importantly, small air pockets and non-tagged faecal residue are
reported as a constant source of false positive findings in recent bright lumen MR
colonography studies (Figure 2).

Dark lumen strategy
The first published article on the use of dark lumen MR colonography appeared in
2001 and suggested promising results regarding diagnostic accuracy, acquisition
time and review time. Initially following a standard preparation for bowel
cleansing, a water enema was used which consisted of the rectal administration of
3000 mL of warm tap water followed by a pre- and post-(IV) contrast T1w three-
dimensional gradient echo data acquisition [21]. The use of water results in a
homogenously low signal throughout the colonic lumen at T1w sequences and
allows depiction of enhancing abnormalities originating from the colonic wall
after the intravenous administration of contrast agent (Figure 3 - 5).

As the increase in signal-to-noise ratio (SNR) is significant between pre-
and post contrast series, this technique will in theory lead to better diagnostic
accuracy. Interestingly, three of twelve patients included in this study underwent
additional bright lumen MR colonography in a further session, which in turn
resulted in two false-positive findings in one patient. In contrast, in dark lumen
MR imaging no false-negative findings were reported.

Studies specifically evaluating the value of dark lumen MR colonography,
using standardized bowel cleansing and water-based enema for colonic bowel
distension, have been conducted. In one study, 122 subjects underwent MR
colonography prior to colonoscopy. Adequate colonic distension and the absence
of significant disturbing artefacts resulted in a high diagnostic confidence in
practically all acquired examinations. All nine carcinomas, and 89% (16/18) of all intermediate polyps (5-10 mm) and 100% (2/2) of polyps ≥ 10 mm at colonoscopy were detected with MR colonography performed in prone position [22].

A more recent prospective study by Hartmann et al. found comparable results for the detection of intermediate, large adenomatous polyps and colorectal carcinomas (84%, 100% and 100%, respectively). Ninety-two patients underwent both dark lumen colonography and colonoscopy, using standard bowel preparation and colonic distension method [23]. Yet, these studies have reported on populations which are characterized with a relatively high prevalence of colorectal polyps and malignancy and the results therefore apply to these populations only. Clinical application of this technique is far from established and prospective studies with predefined end points are necessary to validate its use.

Figure 3. Dark lumen MR colonography using 3DT1 turbo field echo (TFE) sequence with additional fat saturation. Sequential parameters: TR/TE=4.6/2.2 ms; FOV=420mm; FA = 10; slice thickness = 3mm. (a) 60 year old male patient who presented with weight loss and rectal bleeding. MR colonography visualized the presence of a 5-6 cm large intraluminal, enhancing tumor just above the recto-sigmoid junction (arrows). (Adapted from Zijla FM, Stoker J. MRI of the Colon (Colonography): Results. Medical Radiology Diagn. Imaging. MRI of the Gastrointestinal Tract – J. Stoker (Ed). 185-204. With kind permission of Springer Science + Business Media)

So far only few studies focused on the use of gaseous agents for colonic distension, which subsequently results in a dark appearing colonic lumen at both T1w and T2w sequences. For this purpose both room air and carbon dioxide (CO2) are applicable agents (Figure 6). If comparing these two entities, diffusion through
the bowel wall favours the application of CO₂ as this ultimately leads to better patient acceptance [24]. Overall, the use gas insufflation is considered less burdensome, if compared to a water-enema. Also, gas distension is thought to allow better colonic distension, but this assumption has not been established in MR colonography [25, 26].

In a study of 156 patients at average and increased risk of CRC, MR colonography correctly depicted only four out of 31 colorectal polyps of any size which resulted in poor overall diagnostic outcomes. In this study room air was manually inflated for luminal distension and was compared with colonoscopy findings. Factors which negatively affected MR colonography performance included physiological artefacts, moderate colonic distension and the presence of faecal residue [27]. Whereas carbon dioxide (CO₂) for colonic distension is now standard in CT colonography [28], in MR colonography it has been reported in a series of six patients with known colorectal cancer [29]. Although the included population in this study was small, the results are encouraging on applied T2w sequences.

Faecal tagging
As previously outlined, one of the key elements for performing MR colonography is an optimal differentiation between bowel wall and lumen. In order to correctly identify colonic wall-related pathology, adequate cleansing or homogenous tagging of residual faeces of the bowel is essential. In most earlier studies a standardized polyethylene glycol electrolyte lavage solution was orally administered for proper cleansing, which goes together with abdominal discomfort and nausea and eventually leads to limited patient acceptance and compliance.

Faecal tagging refers to the labelling of the faecal residue and is similar to the method as applied in CT colonography. The administration of an oral tagging agent results in either low or high signal intensity of the bowel in MR colonography allowing an improved differentiation between bowel wall and bowel content and ultimately results in less false-positive findings. Importantly, this enables the use of a limited bowel preparation regime and thus obviates cathartic preparation [11, 30]. Faecal tagging can be applied in bright-lumen and dark-lumen techniques and has been evaluated both on diagnostic outcomes and patient acceptance, in MR colonography literature.
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Figure 4. 58 Year old male who presented with fatigue and changed bowel habits. Dark lumen MR colonography visualized an enhancing lesion in the sigmoid colon (arrow). The presence of a 12 mm polyp was confirmed at colonoscopy. Adapted from Zijto FM, Stoker J. MRI of the Colon (Colonography): Results. Medical Radiology Diagn. Imaging. MRI of the Gastrointestinal Tract – J. Stoker (Ed). 185-204. With kind permission of Springer Science + Business Media

Lauenstein et al. proposed a concentrated barium sulphate contrast agent for faecal tagging, which resulted in a homogenously low signal intensity of the colonic lumen, and additionally high contrast-to-noise ratios were measured following to the intravenous administration of T1-shortening paramagnetic contrast agent. Twenty-four symptomatic patients were included in this prospective study, presenting with only mild symptoms. MR colonography demonstrated a high sensitivity (91%) for detecting patients with any sized colorectal lesions and the absence of false-positive findings resulted in an excellent specificity. Though these study results were substantially biased by the high prevalence of large abnormalities as >90% of the colorectal lesions consisted of polyps >8 mm and carcinomas [11].

Initial optimism regarding the barium-based faecal tagging approach was tempered by a study reported by Goehde et al. In this study, inclusion of patients was stopped owing to inferior MR performance. The diagnostic performance was mainly affected by the high signal intensity of faecal residue throughout the colon on the T1w sequences, which hampered reliable polyp detection in 1 out of every 5 included patients. This is reflected in the low sensitivity of lesions >10mm (50%) [31]. Adjusting the barium-based faecal tagging protocol thereby reducing the amount of barium sulphate and add ferumoxsil (GastroMark®, Lumirem®), has been
reported to improve patient acceptance. This preparation technique was compared with colonoscopy in 56 patients. For intermediate and large polyps MR colonography had a sensitivity of 86% and 81%, respectively. The results improved if these were calculated on a per-patient bases, resulting in a high sensitivity (100%) and specificity (91.4%) for depicting patients with polyps ≥ 10 mm [32]. In summary, diagnostic outcomes in studies using barium sulphate-based faecal tagging method vary considerably and are therefore difficult to interpret. This emphasizes the necessity to further investigate and optimize this approach.

**Figure 5.** MR colonography in a patient with incomplete endoscopy due to an elongated colon. **(a)** Coronal 3DT1 w sequence with additional fat saturation after administration of intravenous contrast agent. A circumferential enhancing tumor was found in the proximal part of the ascending colon (arrows). **(b)** True FISP sequence of the same patient, showing a bright lumen appearance with evident filling defect on the level of the tumor. (Adapted from Zijta FM, Stoker J. MRI of the Colon (Colonography): Results. Medical Radiology Diagn. Imaging. MRI of the Gastrointestinal Tract – J. Stoker (Ed). 185-204. With kind permission of Springer Science + Business Media)

**Low prevalence population**

**Screening MR colonography**

Whereas most investigators evaluated MR colonography in relatively high prevalence populations, to date one study solely has evaluated MR colonography
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in a screening population. In this single centre prospective study, dark lumen MR colonography without bowel cleansing was compared to colonoscopy in an asymptomatic average risk population of 315 subjects [12]. The overall prevalence of patients with polyps ≥ 10 mm within this population was 6.3 percent (20 / 315). In this study faecal tagging was applied using a modified barium-based solution (5% Gastrografin / 1% barium / 0.2% locust bean gum). Sensitivity for the detection of patients with polyps ≥ 10 mm and patients with intermediate polyps (5-10 mm) was 70% and 60%, respectively. The sensitivity of MR colonography for the detection of patients with adenomatous polyps at least 10 mm in diameter was 87% and 81% for patients with intermediate polyps. Specificity for polyps ≥ 10 mm and polyps 5-10 mm was 100% and 98%, respectively. Recently published data of a multicenter CT colonography screening study [33], reported a comparable sensitivity in identifying asymptomatic patients with adenomas with a size of 10 mm or more, and 6 mm in size or more (90% and 78%, respectively).

Evidence on MR colonography in screening is very limited, and only concerns the aforementioned single centre study. Current limited evidence, the lack of an established technique, the costs and rather limited access make MR colonography at the moment of writing less suited for screening. Still the use of non-ionizing radiation and the wide range of possible limited bowel preparation schemes make MR colonography a potential diagnostic alternative to CT colonography.

Patient acceptance in MR colonography
Several investigators have focused on the degree of comfort, acceptance and future preferences of MR colonography, if compared to conventional colonoscopy. Here we focus on two aspects of the examination, namely patient acceptance regarding bowel preparation and colonic distension.

Bowel Preparation
As previously outlined, prerequisite for a high quality MR colonography is a clean or homogeneously tagged colon. This as residual faeces can both conceal and simulate bowel wall pathology, which potentially leads to false-negative and false-positive findings. In the earlier studies patient preparation for MR colonography was similar to the bowel preparation as applied for conventional colonoscopy. This ultimately could influence future preferences for this modality, since bowel purgation is rated as one of the most unpleasant parts during conventional colonoscopy.
colonoscopy. With the introduction of faecal tagging in MR colonography a method was described which obviated the application of a complete bowel cleansing approach.

Figure 6. MR colonography after the automatic insufflation of carbon-dioxide (CO₂) in a normal volunteer, results in an optimal distension in all colonic segments. The lumen shows a low signal on both T2w (a) and T1w (b) images, without the presence of disturbing artefacts. This method allows adequate differentiation between the colonic lumen and colonic wall, even without the administration of an intravenous paramagnetic contrast agent (b). (Adapted from Zijta FM, Stoker J. MRI of the Colon (Colonography): Results. Medical Radiology Diagn. Imaging. MRI of the Gastrointestinal Tract – J. Stoker (Ed). 185-204. With kind permission of Springer Science + Business Media)

Since 1999 several faecal tagging strategies have been evaluated, for both bright lumen and dark lumen approach [14, 30]. Initial approach in dark lumen MR colonography, as reported by Lauenstein et al, was the oral administration of 200mL barium-based contrast agent with each meal, starting 36 hrs for the examination and proved feasible. In this study patient acceptance was thought to improve, however this was not thoroughly investigated [14]. From the same research group, Goehde et al. used a comparable bowel preparation strategy,
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which consisted of the administration of 150mL barium-sulphate in six consecutive oral intakes. Opposite conclusions were drawn from this study as this technical approach resulted in only moderate diagnostic accuracy, poor image quality in approximately 20% of the MR examinations, and moreover the total MR colonography examination was graded more uncomfortable than conventional colonoscopy. The barium intake was graded as most disturbing factor [31]. The taste of barium sulphate is generally considered unpleasant, and especially the viscous texture might lead to some degree of discomfort. Adjustments in this barium-sulphate regime have been reported. Adding ferumoxsil (GastroMark®, Lumirem®) and reducing the amount of barium sulphate results in improved patient acceptance of the bowel preparation [34].

A modified barium based faecal-tagging protocol - consisting of 5% Gastrografine, 1% barium and 0.2% locust bean gum - has been described by a research group in two different studies. In 29 patients with IBD, this faecal tagging preparation was rated significantly less bothersome than bowel purgation [35]. However, overall patient acceptance based on preparation protocol and examination procedures was in favour of colonoscopy. Patient acceptance of MR colonography in a screening population was reported for a series of 248 patients using the modified barium faecal tagging regime with colonoscopy as the reference standard [36]. Important conclusions in this study entailed the comparable patient acceptance of MR colonography and colonoscopy and the comparable future patient preferences for MR colonography and colonoscopy. A better patient acceptance than colonoscopy would be a major factor favouring MR colonography for screening. Given the wide range of possible limited bowel strategies for MR colonography, efforts should be made to study regimes with a lower burden to be applied for screening.

A prospective study was performed comparing three different faecal tagging strategies with respect to image quality and patient acceptance in a series of 45 patients at increased risk (surveillance)[16]. The study was executed using two dark lumen approaches with barium-based (3 x 200mL) faecal tagging strategy and one bright lumen approach with gadolinium (3 x 10mL) as oral tagging agent, in combination with a low-fibre diet. The bright lumen strategy resulted in better outcomes regarding the diagnostic confidence and acceptance of bowel preparation and therefore this protocol was used in the following study in which MR colonography was preferred above conventional colonoscopy [37]. Experience from 209 patients regarding bowel preparation and the overall
procedure were rated better directly after finishing the examinations, and five weeks after both examinations.

**Colonic Distension**

Another important aspect which influence patient acceptance is the colonic distension method. A frequently used method for colonic distension is the administration of a water-based enema, which mostly consists of warm tap-water (*dark lumen*) or gadolinium/water mixture (*bright lumen*). However, enemas are relative uncomfortable. Insufflation of gas for colonic distension most likely leads to less patient burden, as is common practice in CT colonography. Initial studies did not use gaseous distending agents because of substantial susceptibility artefacts at gas soft tissue interfaces and motion artefacts. Improved techniques with data acquisition with short echo times has enabled the performance of MR colonography without important susceptibility artefacts and/or motion artefacts. Considering these factors, gaseous based distension methods are evaluated in order to improve image quality and patient acceptance in MR colonography.

In a single prospective experience in 165 individuals at both high risk and average risk for CRC, no significant differences in discomfort was found between MR colonography using air for colonic distension and colonoscopy with identical bowel preparation [38]. Yet a significant proportion of the individuals preferred colonoscopy to MR colonography. The authors suggest that this finding might be related to the fact that all individuals received sedation during colonoscopy and the examination time was shorter for colonoscopy.

Other authors used air-based MR colonography to compare feasibility and patients acceptance with both water-based colonic distension and colonoscopy in a randomized study, studying 50 patients at high risk for CRC with similar bowel preparation technique [25]. Water-based and air-based colonic distension were rated comparable, regarding the degree of discomfort. This is rather in contrast with studies evaluating patient acceptance in CT colonography and double-contrast barium enema [39], as resulted a better tolerance of air based colonic distension.

Another feasible way to improve patient acceptance might be a combined faecal tagging strategy and air-based colonic distension. However comparable patient acceptance with the water-based alternative and significant better examination tolerance compared to colonoscopy, was combined with inferior image quality of air-based MR colonography [26].
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Considering patient acceptance, the potential better tolerance of using gas for colonic distension instead of a water based enema has not been evidently demonstrated in MR colonography literature. Moreover so far there is no available evidence on the patient acceptance of carbon-dioxide in MR colonography, the colonic distension method frequently applied in CT colonography.

3.0T MR colonography
During the last decade, high-field imaging has become increasingly studied and the application is widely implemented [40]. In 3.0T MR imaging, the high-field strength permits an increase in spatial resolution and/or a decrease in acquisition time [41, 42] and this might improve image quality considerably. However straight adoption of sequences used at 1.5T is not feasible. At high-field strength tissue T1 and T2 relaxation parameters are different than at 1.5T, as well as specific absorption rate (SAR) and changes in chemical shift - and susceptibility effects [41, 43] which are especially perceptible at soft tissue-air interfaces (e.g. residual gas in the colonic lumen [42]). Magnetic susceptibility artefacts are more prominent at 3.0T if compared to low-field strength MRI and might therefore potentially disadvantage the use of air-based distension in 3.0T MR colonography.

Although high-field imaging is promising, there is limited evidence concerning the role of 3.0T MRI in MR colonography [41]. Saar and colleagues, proved feasibility of 3.0T MR colonography in 34 symptomatic patients, demonstrating good diagnostic quality and high overall diagnostic accuracy (per-patient sensitivity and specificity was 83% and 100%, respectively) [44]. A study in 40 patients demonstrated no significant difference in image quality at 3.0T compared to 1.5T in two sequences (T1w fat-suppressed GRE and T2w single-shot fast spin-echo) [45] and in a phantom study no significant difference in detection of polyps larger than 6 mm at 1.5T and 3.0T were demonstrated [46].

Extracolonic findings
In contrast to colonoscopy, MRI also provides information of the extra colonic organs. Reported data on extracolonic findings in MR colonography are limited [47, 48]. Recently, Yusuf et al. [47] reported on the prevalence of extra-colonic findings in 210 patients at increased risk for CRC who underwent bright lumen MR colonography. The study demonstrated a wide range of extra-colonic findings in 125 (59.5%) patients (e.g. lymphadenopathy, aortic aneurysm, gallbladder stones, hepatic and renal cysts). Ten (4.8%) findings were clinically significant (as
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scored according to the CRADS Reporting System [9]) of which two revealed to be malignant (1.0%) [47]. It was concluded that in MR colonography extra-colonic findings are common, but the majority are of low clinical significance. Ajaj et al. [48] demonstrated extracolonic findings in 69% of 375 subjects who underwent dark lumen MR colonography for suspected colonic disease of which 27 subjects were subjected to an additional examination which confirmed the MRI findings. They concluded that dark lumen MR colonography has a high accuracy for the assessment of extracolonic findings [48].

**MR colonography perspectives**

MR imaging of the colon can be applied for a wide spectrum of indications. The current available evidence however is rather limited, and therefore its role for detecting different types of colonic disorders is far from established. Whereas additional administration of a rectal enema seems legitimated for improving detection of colorectal polyps, the beneficial effect for other indications, in particular inflammatory bowel disease, remains unclear.

To date most of the MR colonography research is aimed at the detection of (precursors of) CRC. Although no consensus has been reached regarding important elements of the exam, current evidence suggests sufficient accuracy in detecting significant large polyps. Yet at this point we are far from the implementation of an established diagnostic tool, such as presently observed in CT colonography for screening.
Chapter 2

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