Magnetic Resonance Imaging of the Bowel: Today and Tomorrow

Magnetresonanztomografie des Darms: Altbewährtes und Innovatives

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- small bowel
- MR-imaging
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- imaging sequences

Abstract
Magnetic resonance imaging of the small bowel has been feasible for more than 15 years. This review is meant to give an overview of typical techniques, sequences and indications. Furthermore, newly evaluated promising techniques are presented, which have an impact on the advance of MR imaging of the small and large bowel.

Key Points:
- T2-weighted sequences both with and without fat saturation and T1-weighted fat saturated sequences prior to and following intravenous injection of a gadolinium-based contrast medium constitute the basics for bowel MR imaging.
- Newer MR applications, such as diffusion-weighted imaging or contrast-enhanced dynamic sequences supply additional information; they should thus be integrated in a regular sequence protocol for bowel MRI.
- Additional new modalities like motility imaging and PET/MRI have to be evaluated in future studies.

Introduction
Magnetic resonance imaging (MRI) has been used for examining the small and large intestines for over 15 years [1, 2]. During this period, new techniques and sequences have provided imaging with consistency and have ensured ongoing improvement and innovation.

This survey article provides a summary of time-tested principles of imaging and sequence protocols and the known and typical indications. It also presents new and future applications and techniques.

Time-tested

Indications
The typical indications for magnetic resonance imaging (MRI) of the bowel are inflammatory or tumorous changes [3]. MRI of the bowel, in particular the large intestine, was and is still discussed as a screening method for colorectal cancers, which are frequently treatable and even curable if detected at an early stage [4, 5]. An article recently published by Graser et al. demonstrates that MR colonography at 3 Tesla detects colorectal adenomas $\geq 6$ mm and advanced neoplasia with greater sensitivity and specificity, yet still remains inferior to colonoscopy when it comes to colorectal neoplasia [6].

A suspected diagnosis in the large intestine can be routinely confirmed through endoscopy and histological study. In cases of incomplete colonoscopy, e.g. when there are stenotic colon tumors or unfavorable anatomy as...
well as following infections, MRI makes it possible to evaluate sections of the colon more proximal [7]. For diseases of the small intestine, capsule endoscopy currently provides image-based morphological confirmation of a diagnosis, yet is still used on a limited basis because of its costliness. MRI of the small bowel constitutes a more cost-effective and very good diagnostic method for confirming or excluding diseases in this section of the bowel. MRI of the small intestine is performed primarily in cases of chronic inflammatory bowel disease in children and adults [8, 9]. The advantage of MRI over computed tomography is that it involves no exposure to radiation, which is particularly important given the young patient age and the necessity of repeated examinations for monitoring therapy. MRI has the advantage over endoscopy in that it can also examine extra-intestinal areas, which is especially important when dealing with transmural inflammatory diseases such as Crohn’s disease and when assessing local and remote metastases of intestinal tumors (Fig. 1). In addition, MRI of the small intestine is an observer-independent method as Schleder et al. demonstrated in an analysis of MR enterographies performed on patients with Crohn’s disease [10].

Examination prerequisites, protocol and sequences
To achieve diagnostic image quality and to facilitate performing the selected sequences within one breathhold, the bowel should be examined at least on a 1.5 Tesla MRI machine. Thus far, higher field strengths have not been found to be superior in detecting polyps when used in MR colonography [11, 12] and have exhibited only minor advantages in diagnosing mucosal ulcerations in Crohn’s patients [13]. Therefore, 1.5-Tesla scanners, which are the most commonly available in clinical settings, continue to be the standard for imaging. The distension of the cleansed and evacuated bowel is another prerequisite for optimal imaging. The distension of the cleansed and evacuated bowel should be examined at least on a 1.5 Tesla MRI machine. Thus far, higher field strengths have not been found to be superior in detecting polyps when used in MR colonography [11, 12] and have exhibited only minor advantages in diagnosing mucosal ulcerations in Crohn’s patients [13]. Therefore, 1.5-Tesla scanners, which are the most commonly available in clinical settings, continue to be the standard for imaging. The distension of the cleansed and evacuated bowel is another prerequisite for optimal imaging. The distension of the cleansed and evacuated bowel includes axial and coronal T1- and T2-weighted sequences as well as the acquisition of dynamic contrast enhanced T1-weighted sequences [25]. To keep the motion-related artefacts to a minimum, the examination should be performed with the patient lying prone, since this reduces respiratory excursion, and an antispasmodic should be administered to suspend or significantly reduce intestinal motility. The appropriate antispasmodics are hyoscine butylbromide, (Buscopan, Boehringer Ingel-
heim Pharma GmbH & Co KG, Germany) and glucagon, with studies showing glucagon to induce a longer period of spasmolysis [26]. Intravenous administration results in a faster and more reliable onset of effect [27].

One of the relevant sequences is an axial or coronal T2-weighted sequence (half-fourier single-shot turbo spin echo, HASTE with Siemens; single-shot fast spin echo, SSFSE with General Electric or ultra-fast spin echo, UFSE with Philips), which offers a good overview of the wall thickness of the intestinal segments as well as of any existing edema. A balanced Steady State Free Precession (bSSFP) sequence (True fast imaging with steady state precession, TrueFISP with Siemens; Fast Imaging Employing Steady-state Acquisition, FIESTA with General Electric or Balanced Fast Field Echo, b-FFE with Philips) in coronal acquisition facilitates good clarification of mural pathologies such as ulcerations as well as extraintestinal changes such as mesenteric lymph nodes or vascular injections (comb signs) as signs of inflammatory changes. This sequence is not sensitive to movements and can thus be used as a basic sequence on patients with reduced compliance. In addition, coronal T1-weighted, fat-saturated rapid gradient echo sequences are performed for dynamic contrast-enhanced acquisition (volume-interpolated breath hold examination, VIBE with Siemens, liver acquisition with volume acquisition, LAVA with General Electric, enhanced T1 High Resolution Isotropic Volume Excitation, eTHRIVE with Philips). Finally, a fat-saturated T1 Turbo Spin Echo (TSE) sequence is performed in axial and coronal acquisition during the late phase following administration of contrast medium to allow the surrounding organs and soft tissues to be examined for pathologies once again. In their evaluation of the specified sequences, Schleder et al. concluded that a non-contrast T1-weighted sequences can be omitted from the MRI-supported diagnostic investigation of Crohn’s disease [28]. However, this type of sequence plays an important role in the diagnostic investigation of the large intestine since it allows possible contrast-enhanced polyps to be differentiated from stool residue, which is already hyperintense in non-contrast sequences [29] as Fig. 2 shows. By prompting subsequent endoscopic removal, polyp detection is important, since a polyp may result in a later intestinal tumor in the course of an adenoma-carcinoma sequence (see also Fig. 1). Non-enhanced T1-sequences should therefore be part of in a conclusive bowel protocol. Fig. 3 provides an overview of a typical basic protocol for bowel diagnostics.

**Diffusion-weighted imaging**

Diffusion-weighted sequences were first used in the neuroradiological MR diagnostic investigation of strokes [30] as well as in the differentiation of brain tumors [31]. In the meantime, this technique has also been used for full body diagnostics, in particular to answer oncological clinical requests [32, 33]. Diffusion weighted imaging (DWI) essentially takes advantage of the limited diffusion (random thermal motion of the water molecules / Brownian molecular motion) caused by, for example, damaged membranes in infarcted areas. Limited diffusion is also present in inflamed or tumorous tissue. In tumors, the cells are more densely packed, resulting in less extracellular space and thus limited diffusion. Active inflammatory processes exhibit swelling or edematous changes in the cellular structure and likewise bring about a reduction in normal diffusion. Active inflammatory processes exhibit swelling or edematous changes in the cellular structure and likewise bring about a reduction in normal diffusion. Initial examinations in patients with chronic inflammatory bowel diseases were able to differentiate healthy segments of the bowel and grade the severity of the disease on the basis of apparent diffusion coefficients (ADC) using DWI [34–36] (Fig. 4). It was also shown that adding diffusion-weighted sequences to the clinical examination protocol improved diagnostic certainty.

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Fig. 2  MR colonography in a 46 year old female patient with anemia due to iron deficiency. Two lesions can be depicted in the TrueFISP images A in the descending colon (arrows). The proximal lesion is hyperintense in an unenhanced T1-weighted sequence A and cannot be depicted after contrast C leading to the diagnosis of residual stool. The second lesion is only visible after contrast (arrow head): Subsequent colonoscopy confirmed a polyp.
Both small and large intestine examinations were included in different clinical requests, reflecting the reality of clinical examinations. Diagnostic certainty was improved not only for inflammatory but also for tumorous lesions. Klickesmez et al. showed that for examining the rectosigmoid colon of patients with inflammatory and neoplastic changes, DWI is able to differentiate normal from pathologically changed findings and could thus facilitate differentiating inflammation from tumor growth. Schmid-Tannwald et al. discovered additional benefits of DWI for differentiating fistulas. In their publication, these authors discussed the use of DWI on patients with contraindications for contrast medium (e.g., renal failure). An already published study as well as additional current studies compare the diagnostic accuracy of DWI with that of conventional contrast-enhanced bowel imaging in patients with chronic inflammatory bowel diseases. As mentioned above, the fact that DWI makes it possible to omit the use of contrast medium would be beneficial not only in cases of kidney dysfunctions but also when repeated examinations are required in pediatric diagnostics.

Diffusion-weighted imaging allows the detection of accessory inflammatory or tumorous lesions, while increasing diagnostic certainty. Because it does not require the use of contrast medium, it can additionally be used particularly for examining patients with impaired kidney function and, because of the brief examination time involved, it can be used on pediatric patients, e.g., for evaluating response to therapy.

**MRI of bowel motility**

Because intestinal peristalsis is typically antegrade, chyme is propelled forward from the oral cavity to the rectum, being intensely mixed and processed along the way. Propulsion is facilitated by a contraction of the intestinal wall musculature. The presence of an intestinal disease also affecting deeper layers of the intestinal wall can be manifested in this segment by a reduction or suspension of bowel motility. More recent studies have concerned themselves with these motility examinations, which are typically performed following the overview sequences and prior to administration of an antispasmodic. A T2-weighted real-time cine sequence can be employed to generate repetitive images, thereby representing bowel motility. Comparison of the motility of individual intestinal segments can expose initial pathologies, since small intestinal segments in particularly normally exhibit a regular, uniform contraction. Fröhlich et al. measured the changes in intestinal segment diameter over time during this process. Current software solutions make it possible to quantify the reduced or sus-

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**Fig. 3** A MR bowel protocol should include TrueFISP images in coronal acquisition, T2 HASTE in axial or coronal acquisition as well as dynamic fat saturated T1 weighted gradient echo sequences (VIBE, C, D) in coronal acquisition.
Dynamic contrast enhanced (DCE) MRI

Dynamic contrast-enhanced imaging has long been employed in oncology as a non-invasive method for evaluating tumor blood perfusion [48]. The potential of DCE-MRI as a biomarker for measuring antiangiogenic effects of cancer therapy can also be used in bowel imaging for evaluating the vascularization of intestinal segments and likewise for evaluating therapy response in both chronic inflammatory bowel diseases and in tumors of the bowel [49, 50]. In a study involving 18 patients, Oto et al. showed that combining DCE-MRI with new methods of diffusion-weighted imaging (DWI) provides a good quantitative measure for differentiating acutely inflammatory changes in the small intestine from normal intestinal segments [35]. However, DWI was even superior to DCE-MRT in this endeavor. Nevertheless, the combination of ADC values and perfusion parameters makes it possible to improve specificity. In their study of children with chronic inflammatory bowel disease, Alexopoulou et al. showed that the percentage-based enhancement of the intestinal wall was significantly higher in patients with abnormal C-reactive protein (CRP) values, i.e. with acute inflammation parameters, than in patients with normal CRP values [51]. DCE-MRI requires contrast medium administration within a strictly defined timeframe to allow the quantitative and qualitative analysis of time-signal-
curves. In the future, 4-dimensional MR angiography sequences could also be beneficial here. DCE-MRI is used particularly for evaluating acute inflammatory as well as tumorous processes and monitoring the response to therapy thereof. Its benefits appear to still be inferior to DWI in particular, and future studies are needed to establish its relative value.

**Hybrid imaging: PET/MR**

Positron emission tomography (PET) is a form of functional imaging. Using 18-F-fluorodeoxyglucose (18-F-FDG), this imaging technique takes advantage of glucose metabolism, since inflammatory and tumorous processes in the body have elevated glucose consumption and store 18-F-FDG at a greater rate. Combining computed tomography (CT) with PET/CT makes it possible to detect chronic inflammatory bowel diseases at higher sensitivity and specificity [52]. With its greater soft tissue contrast, MRI would appear to be ideal for being combined with the metabolic information of PET and thus achieving even better results than that of PET/CT as the first images from PET/MR examination highlight (Fig. 6). In addition, PET/MRI exposes patients to less radiation than PET/CT. A study conducted by Lenze et al. already demonstrated that the combination of individual examinations yielded better results than 18-F-FDG PET/CT, MR enteroclysis and transabdominal ultrasound alone in the detection and differentiation of acute inflammatory changes over fibrotic strictures in Crohn’s disease patients alone [53]. It is expedient for PET and MR data to be acquired simultaneously when PET/MRI is employed. This method is particularly relevant if the position of the intestinal loops shows drastic change within a brief period and offers in combination the highest accuracy for detecting pathologies. The nuclear medicine component of PET/MRI cannot rely just on 18-F-FDG as tracer. It is conceivable that additional, radiotracer-

Conclusions

T2-weighted sequences both with and without fat saturation and T1-weighted fat saturated sequences prior to and following intravenous injection of a gadolinium-based contrast medium constitute basic diagnostic approaches in the magnetic resonance imaging of the bowel. Newer MR applications, such as diffusion-weighted imaging or contrast-enhanced dynamic sequences supply additional information in the diagnosing of chronic inflammatory bowel diseases as well as bowel tumors and should thus be integrated into the regular sequence protocol. Additional new imaging modalities such as motility imaging or the combination with PET in the form of PET/MRI must continue to be evaluated in the future and are very likely to become valuable tools in diagnosing chronic inflammatory bowel diseases. These innovative imaging modalities could provide deeper understanding of the underlying diseases and allow the possibility of functional, non-invasive therapy monitoring.

References

1 Luboldt W, Debatin JF. Virtual endoscopic colonography based on 3D MRI. Abdom Imaging 1998; 23: 568–572
3 Platzler IA, Neubauer H, Beer M. Mittels Hydro-Sonografie und Hydro-MRT juvenilen Kolonpolypen auf die Spur kommen. Fortschr Röntgenstr 2012; 183: 744–745

MRI will be used as functional imaging modalities among these patients.

labelled cells or receptors can be used in the future for both inflammatory changes and tumorous processes.

Future studies on both patients with chronic inflammatory bowel diseases and patients with gastrointestinal tumors are still needed to shed light on the current value of PET/MRI. In addition to the conventional morphological sequences, the other innovative sequences such as DWI and DCE-MRI seem to be promising.

Fat saturated. Imaging patients with inflammatory bowel disease therefore tended, non-prepared bowel show only slight mural edema (Fig. 6). T2-weighted images of non-dis-tended, non-prepared bowel show only slight mural edema (A T1w FLASH after contrast, arrow). PET images show enhanced glucose uptake (B). T2-weighted images of non-dis-tended, non-prepared bowel show only slight mural edema (C T2 HASTE fat saturated). Imaging patients with inflammatory bowel disease therefore seems to be promising.

Fig. 6 28 year old female patient with initial diagnosis of breast cancer and whole-body PET MR imaging with 18F-FDG for staging and known crohn’s disease. Contrast enhancement and slight wall thickening can be seen in the rectosigmoid colon (A T1w FLASH after contrast, arrow). PET images show enhanced glucose uptake (B). T2-weighted images of non-dis-tended, non-prepared bowel show only slight mural edema (C T2 HASTE fat saturated). Imaging patients with inflammatory bowel disease therefore seems to be promising.
16 Kinner S, Kuehle C, Herbig S et al. MRI of the small bowel: can sufficient bowel distension be achieved with small volumes of oral contrast? Eur Radiol 2008; 18: 2542 – 2548
37 Kinner S, Blex S, Maderwald S et al. Addition of diffusion-weighted imaging can improve diagnostic confidence in bowel MRI. Clinical radiology 2013
43 Bickelhaupt S, Froehlich JM, Cattin R et al. Software-assisted quantitative analysis of small bowel motility compared to manual measurements. Clinical radiology 2014