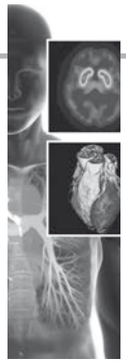

MRI of the bowel

"[MRI] is the only imaging modality able to produce excellent images of the small and large bowel, on all the spatial planes, using different image parameters, without any restriction and without radiation exposure."

KEYWORDS: bowel ■ Crohn's disease ■ inflammatory bowel disease ■ MR enterography ■ MRI ■ small bowel

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The challenge of small bowel evaluation

The capability of evaluating the entire abdomen with adequate anatomical details and fast sequences nowadays makes MRI a successful and effective diagnostic tool for investigating the entire bowel, from the esophagus to the anal canal. The stomach and the colon, however, owing to their large caliber and relatively fixed position, can be effectively studied both with endoscopic and radiological examinations, while the exploration of the small intestine is more complex and challenging for any investigation, including MRI. This is due to the physiological intestinal peristalsis and specific morphofunctional features, such as the length, convolution of bowel loops, mobility of the mesentery, frequency and distribution of mucosal folds, and thin thickness of the intestinal wall. An ideal investigation of the small intestine should be able to assess its entire length, from the duodenum to the terminal ileum, its caliber, intraluminal profile, wall structure and mesenteric fat, as well as its peristalsis. None of the currently available investigations for the small bowel (SB), including conventional endoscopy and capsule endoscopy, ultrasonography, barium studies and CT, either with oral contrast or enteroclysis, is alone able to evaluate all these features. Is MRI the ideal investigative tool for the SB?

MRI of the bowel: major advantages

The clinical introduction of MRI in the evaluation of bowel dates back approximately two decades. In early phases, however, the long acquisition times produced blurred images, due to motion artifacts related to peristalsis and respiratory movements. The spatial resolution was inadequate to image the thin bowel wall and to detect subtle intestinal abnormalities. More recently, thanks to the significant technical advances in the hardware and software components that have mostly occurred during the last decade, MRI has emerged in the evaluation of the bowel, particularly the SB, like no other diagnostic modality [1–3]. Highly performing gradients and new software led to the development of fast imaging, with significant reduction of motion artifacts. Nowadays, fast and ultra-fast sequences are widely used in MRI of the SB: by using breath-hold sequences up to 15–20 slices are acquired during an apnea of 15–20 s, whereas with breath-hold free sequences a slice is acquired in less than 1 s, not requiring any stop of respiratory movements during acquisition. Furthermore, the availability of multichannel phased array MR coils has enabled evaluation of the entire abdomen with higher resolution and wider fields of view, a compromise that was not possible only a few years ago. The association of short acquisition times, high spatial resolution and larger fields of view are the three major requirements for imaging the bowel and definitely the major challenge for any MRI system too [1–3]. The evaluation of the intestine remains one of the frontiers of MRI, so that it may only be offered by advanced and updated MRI systems.

The increasing use of MRI for the evaluation of the bowel is related to its specific well-known advantages over other imaging modalities. First of all, the lack of ionizing radiations. Most SB diseases, including the most frequent ones, Crohn's disease (CD) and Celiac disease, are chronic and benign, with frequent onset at pediatric age. In Europe the use of MRI in the evaluation of these diseases is growing rapidly, leading to a complete replacement of CT and barium studies in pediatric and young patients. Moreover, the multiplanar capability

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and panoramicity of MRI are extremely helpful to image bowel loops in their full length. Finally, the possibility of evaluating intestinal diseases with high soft-tissue contrast and different parameters is probably the major advantage of MRI over other imaging modalities. Specific parameters used for intestinal MRI include: T_1-weighted parameters, before and after intravenous gadolinium injection, to detect tissue vascularization; and T_2-weighted fluid-sensitive parameters, to detect tissue edema, with or without selective suppression of the fat signal. The newest parameters introduced in abdominal and intestinal imaging, which are still in large part experimental, include diffusion weighted imaging (DWI), which provides information regarding the motility water molecules in human tissues, and MR spectroscopy, which analyzes the distribution of specific biological molecules *in vivo*.

Technical aspects, difficulties & limits

One of the main difficulties of bowel MRI lies in the complexity and variety of available imaging parameters and heterogeneity of techniques, differing for intestinal contrast agents, routes of administration, sequences and coils. Furthermore, imaging techniques may vary greatly according to the clinical indications. To assess both the small or large bowel with MRI, five variables have to be properly chosen and associated: sequences, intestinal contrast agent, intravenous contrast agent, way of administration of the intestinal contrast agent and selective suppression of the fat tissue signal. An inadequate or wrong association of these five variables may cause artifacts and reduce the diagnostic value of the examination, while the correct association produces, in different ways, the highest image quality and diagnostic performance.

The most widely used intestinal contrast agents are the biphasic and negative superparamagnetic ones [1–5]. Negative contrast agents produce a black lumen on both T_1- and T_2-weighted images, due to the presence of iron [1,4,5]. Biphasic contrast agents, consisting of nonabsorbable iso-osmolar solutions, produce a black lumen on T_1-weighted and white lumen on T_2-weighted images [1,5]. Both can be administered either orally (MR enterography) or by enteroclysis (MR enteroclysis) [1,6]. MR enteroclysis is primarily addressed to evaluate the inner mucosal profile of the SB, in order to detect polyps, ulcers and circular folds abnormalities [6]. MR enterography, on the other hand, is mainly focused to investigate the transmural and extramural involvement of inflammatory and neoplastic diseases, rather than mucosal changes, since it does not produce excessive bowel distension. Similarly, MRI techniques focused to evaluate the colon (MR colonography) can be performed with retrograde administration of a negative or biphasic contrast agent or with fecal tagging, achievable with the oral ingestion of a contrast agent [7].

Therefore, a standardized MRI technique to image the bowel does not exist. MRI techniques used for evaluating celiac disease [8] or polypoid syndromes [9] are usually different from those focused to evaluate CD in the small or large bowel [1,3,5,6], or polyps in the colon [7]. At the moment, MRI of the bowel should be considered an 'open' imaging procedure that may be structured in different ways according to the specific clinical question. The wide diagnostic potential is certainly the strength and major advantage of MRI. On the other hand, it requires a radiologist with specific experience, who should always be directly and fully involved in the clinical problem. MRI of the bowel is an operator-dependent imaging technique, probably more so than intestinal ultrasonography.

Well-known limits of MRI include the relatively high examination costs, low availability and accessibility. Furthermore, performances of bowel MRI are strongly affected by the quality of MR systems that should be continuously upgraded. Usually, 1- or 1.5-Tesla systems are preferred for bowel imaging, while the newest 3-Tesla Units, to date, have not provided great advantages, but rather some disadvantages in bowel imaging, due to technical artifacts. MRI of the bowel is therefore a technology-dependent imaging technique. Since MRI of the bowel requires a specific radiologist's experience and technologically advanced MRI units, it is likely that in the coming years it will be preferably performed in specialized imaging centers, as will neuroimaging or cardioimaging.

Indications for bowel MRI

■ MRI in CD

The hallmark of CD is uncontrolled transmural inflammation of the intestinal wall, usually affecting the SB and colon, with a segmental distribution. Several studies reported a great accuracy in assessing all the major features of CD, both in the small and large bowel. CD features detectable by MRI include mural features (wall thickening, mural hypervascularity, edema and fibrosis) extramural features, (fibrofatty proliferation, increased number of local lymph nodes and

increased mesenteric vascularity) and complications, such as sinus tracts, fistulas, adhesions, abscesses, urinary and biliary complications and perianal disease, all identified both on T_1- and T_2-weighted images [1,5]. While Gd-enhanced sequences are able to detect the mural hypervascularity, T_2-weighted sequences allow detection of the amount of edema and fluid components in the inflamed wall [2,3,5,6,10–15]. Increased wall thickening, wall Gd-enhancement, wall and mesenteric edema, and number and enhancement of local lymph nodes [15] are the main findings of active CD and direct expressions of its typical transmural inflammation, which involves all wall layers, the serosa and the fat, immediately outside the intestinal wall. The correlation between T_1- and T_2-related activity parameters and disease activity has been proven by several studies [10–16]. Recently, an MRI index of inflammation well correlated with the CD Endoscopic Index of Severity (CDEIS) has been proposed [16]. T_2-weighted images, moreover, seem effective in characterizing wall structure, by differentiating wall edema from wall fibrosis [5]. The capability of MRI in characterizing the disease and evaluating the degree of inflammation is crucial in therapeutic planning and in monitoring drug effects. Several MR techniques have been proposed for the evaluation of CD, including MR enteroclysis [6] and MR enterography, either with biphasic or negative contrast agents [13,16]. Whether it is preferable to choose MR enterography or MR enteroclysis for evaluation of CD is still an open question. Currently, most studies are in favor of oral administration, which is better tolerated by patients and capable of assessing intestinal lesion extent and activity both in the small and large bowel with accuracy comparable to ME enteroclysis [1,3–5].

■ MRI in benign diseases of the SB & colon

MRI has proven very effective in assessing SB changes in celiac disease. Specific signs of celiac disease detectable at MRI include abnormalities of the intestinal fold pattern and lumen [8]. Ulcerative colitis, affecting predominantly the colon, can be completely evaluated by means of colonoscopy, leaving a limited space for other diagnostic tools. MRI may be useful when endoscopy is at high risk or contraindicated, for example in severe flare-ups, or in the presence of tight strictures. In these cases, MRI may evaluate the extent and severity of the disease, similarly to CD [17]. Other severe infectious colitis, particularly the pseudo-membranous colitis, may be reasonably assessed and monitored during the treatment by a noninvasive investigation such as MRI, due to the very high risk of colonic endoscopic perforation.

■ Oncologic imaging

In the local staging of colonic and gastric neoplasms, despite the high accuracy of MRI, multislice CT still remains the reference examination, being able to assess the entire body in the shortest time. On the other hand, for rectal cancer staging MRI is widely used, due to the higher tissue contrast and spatial resolution compared with multislice CT. High-resolution sequences are available, in fact, exclusively for the evaluation of the anorectal tract, either with endoanal or external coils. High resolution MRI, providing an excellent anatomical detail, is widely considered a primary diagnostic tool for staging both neoplastic and inflammatory lesions of the anorectal region, including perianal fistulas [18]. The role of MRI in the detection and staging of the very rare SB neoplasms has not yet been established. Recently, however, MRI has shown to be a useful and valuable tool for periodic controls in patients with polypoid syndromes of the SB, particularly the Peutz–Jeghers syndrome [9]. In these patients in fact, there is an increasing need for monitoring of the SB with a noninvasive, well-tolerated diagnostic modality. The use of MR colonography for the screening of colonic polyps has been proposed by several studies as an appealing alternative to CT colonography [11]. Although extremely promising due to the lack of radiation exposure and invasiveness, MR colonography is still difficult to apply in the clinical practice, due to the still lower spatial and temporal resolution as compared with CT colonography.

■ Functional imaging

Several MRI studies have demonstrated the possibility of evaluating intestinal motility with real-time imaging or MR fluoroscopy. Esophageal and gastric functional disorders are increasingly investigated by MRI. The gastric emptying time, the frequency of peristaltic waves, and the initial and final stomach volume can be easily assessed with MRI without invasiveness. Dynamic imaging of the pelvic floor and defeco-MRI are currently widely used in clinical practice in the evaluation of defecatory disorders, progressively replacing conventional evacuation proctography. Motility studies have recently been introduced to assess peristalsis of the SB as well, particularly in CD, with interesting preliminary results [19].

Future perspective

The newest MR applications, such as MR spectroscopy, DWI and molecular imaging, still have unknown potential in the evaluation of the bowel wall [18]. MR spectroscopy is able to identify different biological molecules *in vivo*. To date, it has been mainly used for the characterization of brain and prostate tumors, but it may have great potential in the detection and characterization of intestinal neoplasms and inflammatory diseases. Firstly, DWI, which is applied to neurologic and oncologic diseases, is being increasingly used in abdominal and intestinal imaging. In rectal cancer, DWI increases the confidence of the radiologists to rule out a recurrence, particularly in the presence of fibrous scar tissue [20]. A potential role in the evaluation of inflammatory bowel diseases has been suggested in early preliminary studies both on CD and ulcerative colitis, showing differences in apparent diffusion coefficient values between active and inactive disease [21]. Finally, it is possible that further developments of MR molecular imaging and PET-MRI, which nowadays is purely experimental, could provide relevant information on active inflammatory cells in CD [18].

Conclusion

MRI offers both morphologic and functional information regarding bowel caliber, distribution, bowel peristalsis, wall thickness, vascularization and characterization, like no other imaging modality. MRI has nowadays reached such a high technological and technical evolution to be able to successfully face the challenging study of the small intestine. It is, at the moment, the only imaging modality able to produce excellent images of the small and large bowel, on all the spatial planes, using different image parameters, without any restriction and without radiation exposure. The association of different MR techniques (MR enterography, MR enteroclysis, MR colonography and high-resolution imaging of the anorectal region) can offer the full range of morphologic information currently available with conventional cross-sectional or radiographic barium studies.

MRI of the bowel is destined to progress in the coming years, due to expected technical evolution of MRI systems. *In vivo* information on the molecular structure of both benign and malignant intestinal diseases will be achieved by MR spectroscopy, MR molecular imaging and PET-MRI, whose impact on therapeutic planning and scientific knowledge is, so far, unpredictable.

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