Hindawi Publishing Corporation
ISRN Pathology
Volume 2013, Article ID 419542, 13 pages
http://dx.doi.org/10.1155/2013/419542

Review Article

Small Bowel Imaging: Clinical Applications of the Different Imaging Modalities—A Comprehensive Review

Gabriele Masselli

Radiology Department, First Faculty of Medicine, Università di Roma Sapienza, Viale del Policlinico 155, 00161 Rome, Italy

Correspondence should be addressed to Gabriele Masselli; gabrielemasselli@libero.it

Received 14 January 2013; Accepted 6 February 2013

Academic Editors: F. Shimamoto and A. Wincewicz

In the last years, MR and CT techniques have been optimized for small bowel imaging and are playing an increasing role in the evaluation of small bowel disorders. In comparison to traditional barium fluoroscopic examinations, spatial and temporal resolution is now much more improved partially thanks to modern bowel distending agents. However, there is a global interest in implementing techniques that either reduce or eliminate radiation exposure. This is especially important in patients with chronic diseases such as inflammatory bowel disease who may require multiple studies over a lifetime. Owing to the excellent soft tissue contrast, direct multiplanar imaging capabilities, new ultrafast breath-holding pulse sequences, lack of ionizing radiation, and availability of a variety of oral contrast agents, MR is well suited to play a critical role in the imaging of small bowel disorders.

1. Introduction

The small bowel remains a challenging anatomical site to image accurately [1, 2]. Nonspecific clinical presentations from a wide range of localized and systemic disorders confound successful imaging approaches. However, over recent years there have been significant advances in a number of new radiological techniques, which combine with more established approaches to better define small bowel lesions [3–8].

A successful imaging strategy is dependent on using the most appropriate radiology to answer the right clinical question. A number of conventional imaging strategies, such as barium follow-through, have been successfully used to characterize small bowel pathology, but newer techniques, including CT enteroclysis or MR enteroclysis (CTE or MRE), have been introduced and are gaining popularity; moreover, the development of enteric agents to distend the bowel have led to routine visualization of the small bowel lumen, wall, and perienteric tissues using CT and MR modalities [9–15].

For these reasons, CT and MR enterography have been shown to offer improved sensitivity and are replacing barium studies as the preferred diagnostic tests.

Cross-sectional imaging techniques overcome the principal disadvantages of conventional enteroclysis that are the limited indirect information on the state of the bowel wall and extramural extension of Crohn's disease (CD), and its effectiveness may be hindered owing to overlapping bowel loops [16–20].

CT and MRI of the small bowel have become widely accepted at centers dedicated to the diagnosis and treatment of inflammatory bowel disease (IBD), due to the method's diagnostic efficacy; CT and MR can help to confirm the diagnosis; localize lesions and assess their severity, extent, and inflammatory activity; and identify the presence of extraintestinal complications and other entities that require surgical intervention [21–42].

We describe and illustrate the different imaging modalities and techniques currently available in the investigation of small bowel diseases.

2. Barium Studies

Barium examinations are still the first-line examination in most departments in the investigation of small bowel disease

[1, 34]. They are readily available, relatively well tolerated by the patient, easy to perform, consistent, and reproducible. There are two main barium techniques: the follow-through and the small bowel enema (SBE). Both examinations can be aided by bowel preparation, with fasting only, or a low-residue diet with or without a laxative taken the day before the test with nothing to eat on the day of the examination. The former technique is often adequate preparation and should be used in suspected cases of CD or in patients with profuse diarrhoea.

In a small bowel follow-through, patients drink an approximately 40% weight/volume (w/v) barium suspension with prone films taken every 20–30 min until barium reaches the terminal ileum. Fluoroscopic spot views of the terminal ileum are then obtained. When the terminal ileum is collapsed, per-rectal air insufflation may occasionally aid its distension and visualization.

An SBE requires nasojejunal intubation with a 10 Fr catheter and infusion of approximately 20% w/v barium suspension to achieve optimal small bowel distension. Spot films of the small bowel with compression views to separate small bowel loops and visualize the terminal ileum are taken. Transit of barium through the small bowel with either techniques may be improved by the administration of 10 mg of metoclopramide orally or intravenously, or 10–20 mL of Gastrografin orally.

The advantage of a small bowel barium study is that it achieves good mucosal detail, and the distension achieved with enteroclysis is reported to improve visualization of fistulae, sites of small bowel obstruction, and mural or intraluminal filling defects such as small bowel neoplasms [1]. Barium studies have a limited role in the diagnosis of acute small bowel obstruction or ileus [2] and in the assessment of extraluminal disease, and patients are often referred for additional CT studies to help characterize small bowel lesions or stage small bowel tumours. Lastly, the radiologist should give consideration to a radiation dose of approximately 1 mSv for each barium study [2]. Patients investigated are often young and can require multiple investigations. There is a need in this group to find a low- or no-dose study which is accurate, reproducible and looks at the whole of the small bowel.

3. Ultrasound

Ultrasonography has been successfully used to evaluate patients with CD. Ultrasound does not involve radiation and is widely available; however, successful evaluation using this technique depends on the skill and experience of each individual operator.

Mural thickening is the most common abnormality seen in patients with Crohn's disease of the small bowel. It is typically concentric, and the mural echogenicity depends on the degree of inflammatory infiltration and fibrosis [36]. In early acute disease, mural stratification is retained; with long-standing disease, most commonly seen in elderly patients, a target or pseudokidney appearance may be identified. In patients with inactive longstanding disease, fat deposition in the submucosal may be present. Actively inflamed gut appears rigid and fixed with decreased or absent peristalsis. Color Doppler imaging typically shows hyperemia. Findings on spectral Doppler analysis include increased superior mesenteric and/or inferior mesenteric artery blood flow, increased portal vein velocity.

In patients with IBDs, ultrasound findings are nonspecific but can be used to guide further studies and to evaluate the effects of treatment. When peroral techniques are used to distend the bowel, the sensitivity and specificity of ultrasound in detection of IBDs range from 78% to 90% and 83% to 95%, respectively [37].

Ultrasound is the most effective at detecting IBD in the terminal ileum and less effective elsewhere in the small and large bowel. Ultrasonography (US) is a useful radiation-free alternative for demonstrating focal bowel wall thickening in inflammatory bowel disease (IBD), but it is reliant on operator skill and experience and may also fail to fully delineate complications and exclude disease in deep abdominal loops.

A meta-analysis of studies on the use of ultrasound to diagnose CD reported sensitivity and specificity between 75%–94% and 67%–100%, respectively [36].

Compared with a reference standard consisting of a combination of clinical and conventional enteroclysis findings, the specificity and sensitivity of ultrasound in the diagnosis of CD have been reported to be 88.4% and 93.3%, respectively [36].

However, ultrasound was less reliable in patients with early stage CD of the small bowel (sensitivity 66.7%) [37]. Therefore, if ultrasound is used as the initial modality to examine the small bowel in patients with suspected CD, a negative result warrants further evaluation.

Differentiation between inactive disease and normal small bowel was not possible using Doppler US, making this technique unsuitable for diagnosis of CD. A major limitation is that while hypervascularization and thus the presence of inflammatory activity can be visualized, it is not possible to ascertain which segment of bowel is associated with this sign of inflammation. Another drawback of this technique is that the left colon cannot be assessed with this technique as blood supply is not provided by the superior mesenteric artery. All in all, this technique is not frequently used in evaluation of CD because it has a limited role in management of suspected complications of CD.

4. Computed Tomography

Technical advances of MDCT scanners as the use of imaging workstations that allow multiplanar and 3D evaluation of isotropic data sets, oral contrast agents, and administration techniques that improve small bowel distention, have allowed improved detection and characterization of small bowel pathology [5–7].

Conventional abdominal and pelvic CT with iv and oral contrast is widely used to investigate Nonspecific abdominal symptoms. It is not uncommon for the underlying cause to be an occult small bowel disease can often be the cause of. In addition, asymptomatic small bowel abnormalities may be identified on CT. Commonly identified abnormalities

include inflammatory and neoplastic diseases. CT lacks the mucosal detail of small bowel barium studies but is able to identify small bowel wall thickening and is excellent at identifying associated extraluminal diseases such as inflammatory change, fat wrapping, fistulae, abscess formation, lymphadenopathy, or local and metastatic tumour spread from small bowel neoplasms.

CT has proven to have a very high sensitivity (81%–94%) and specificity (96%) for determining the level and cause of high-grade small bowel obstruction and is now the investigation of choice for this indication [6]. Those values are also improved in the detection of partial small bowel obstruction and intraluminal small bowel lesions, combining CT with enteral volume challenge of CT enteroclysis or enterography. Those techniques have proved to be particularly useful in the assessment of the activity and complications of CD, the identification of causes of occult GI bleeding or anaemia and the detection and staging of small bowel neoplasms.

CT enteroclysis has become an increasingly popular examination for small bowel disorders. The technique combines the advantages of an enteral volume challenge with the multiplanar reformatting capabilities of cross-sectional imaging. Patients undergo bowel cleansing for a small bowel barium study or are fasted for 8–12 h prior to the study.

A nasojejunal tube (typically 8 or 10 Fr) is inserted under fluoroscopic guidance, and enteral contrast is infused at a controlled rate of 120–200 mL/min using an enteroclysis pump until 1500–2000 mL has been delivered. Increasing the rate of infusion to 150–200 mL/min after 500–1000 mL induces a reflex atony in the bowel, improving distension. Prior to scanning, an antiperistaltic agent is given, either 20 mg buscopan or 1 mg glucagon iv. Slice acquisition at 2.5 mm with a pitch of 1.5 for a four-row multidetector CT (MDCT) and 1 mm with pitch of 0.8 for a 64-row MDCT is standard [7].

Dilute barium and iodinated positive oral contrast agents are optimal in the evaluation of intraperitoneal adipose tissues. However, positive oral contrast agents tend to obscure mucosal enhancement impairing the pattern of enhancement which is relevant in the differential diagnosis of an abnormal small bowel segment.

Neutral oral contrast agents better allow full visualization the analysis of the degree and pattern of small bowel enhancement [8]. "Neutral contrast" refers to agents that have an attenuation value similar to that of water (10–30 H). For neutral contrast agents to be effective, they must be used with IV contrast material and the small bowel distention must be optimal.

Several neutral contrast agents have been evaluated for small bowel distention, including water, water in combination with methylcellulose, polyethylene glycol solutions (PEG), and a commercially available low-density barium solution (Volumen) [8]. Volumen and polyethylene glycol solutions are less rapidly absorbed then water and they achieve a better small bowel distention [10].

Peroral CT enterography differs from CT enteroclysis in that the latter technique is performed after placement of a nasojejunal tube in conjunction with active small bowel distention. Neutral enteral contrast agent is administered orally (enterography), although the degree of small bowel distension achieved may be more variable than with enteroclysis. PEG produces better small bowel distension than water or methylcellulose when taken orally but may induce abdominal cramps and diarrhoea. Volumen seems to be better tolerated by patients whilst achieving reasonable distension. Although CT enterography is inferior to CT enteroclysis in achieving small bowel distention, the noninvasive nature and speed of CT enterography make it well suited as a first-line technique for the evaluation of suspected small bowel disease [5, 8].

CTE and CT enterography combine luminal imaging with an examination of extraintestinal disease in a single study and can be applied to investigate a spectrum of small bowel pathologies that include inflammatory disease, GI bleeding, coeliac disease, low-grade small bowel obstruction, small bowel tumours, or causes of malabsorption.

The limitations of CTE are represented by poor toleration of the high volume of enteral contrast material and by the high radiation dose involved, between 6 and 12 mSv for CTE studies (depending on the number of sequences acquired) compared with 1.5 mSv for an SBE [9].

PET/CT has been having an emergent role in evaluating patients with IBD.

Advantages of PET-CT with FDG include improved spatial localization (compared with PET-FDG without CT); reduced FDG uptake in fibrous strictures (indicating failure of medical therapy), compared with nonfibrous areas; and improved performance for detecting colon inflammation compared to CT and MR enterography.

Physiologic uptake of FDG by the intestine can lead to false positive results, and the low radiation dose of the correlative CT limits evaluation of the collapsed small bowel and mesentery. Combinations of PET and CT enterography or enteroclysis techniques might improve bowel distension, anatomic detail, and potential to predict failure of therapy.

Limitations of PET-CT include the cost of the examination and the dose of radiation applied. The approximate radiation dose from the CT portion of the examination is 10 mSv and from the FDG administration is 5.7–7 mSv. Further studies are needed to better define the role of PET-CT in evaluating CD.

5. Magnetic Resonance Imaging

Owing to the excellent soft tissue contrast, direct multiplanar imaging capabilities, new ultrafast breath-holding pulse sequences, lack of ionizing radiation, and availability of a variety of oral contrast agents, MR is well suited to play a critical role in the imaging of small bowel disorders.

The preference of MR versus CT has been geographical and based on expertise and public policy. With the increasing awareness of radiation exposure, there has been a more global interest in implementing techniques that either reduce or eliminate radiation exposure [42]. This is especially important in patients with chronic diseases such as inflammatory bowel disease who may require multiple studies over a lifetime or in studies that require sequential imaging time points such as in assessment of gastrointestinal motility [43].

MRI also has improved soft tissue resolution over any other radiological modality.

Two major techniques are used to achieve bowel distention using MR: MR enteroclysis (MRE) with infusion of the contrast through a nasojejunal tube and MR enterography with oral contrast administration [44–50].

Several enteric contrast agents have been investigated for MR enterography and enteroclysis. These can be classified into one of three types: negative contrast agents (low signal intensity on T1- and T2-weighted images), positive contrast agents (high signal intensity on both T1- and T2-weighted sequences), and biphasic agents (low signal intensity on one sequence and high signal intensity on the opposite) [51–60].

The biphasic category consists of the largest number of available agents. The majority of these agents are low signal intensity on T1-weighted images and high signal intensity on T2-weighted images. The low signal intensity of these agents on T1-weighted imaging improves the contrast between bowel lumen and hyperenhancing wall inflammation or masses following intravenous contrast (water, methylcellulose and water mixture, polyethylene glycol, and Volumen) [61–63].

MR enteroclysis provides a superior small bowel distention, and the optimal distention of small bowel loops is crucial to evaluate bowel wall pathologies correctly, because collapsed bowel loops can hide lesions or mimic disease by suggesting pathologically thickened bowel wall in collapsed segments, and the visualization of small polypoid masses that do not produce obstruction is difficult.

MR enteroclysis delineates superficial changes better than MR enterography in patients with CD, and this aspect has to influence the revealing and localizing of the disease in patients with only superficial manifestations [51]. Evaluation of superficial abnormalities is of particular importance in the depiction of small bowel neoplasm in an early stage. MR enteroclysis with fluoroscopic sequences can help to determine the distensibility of narrowed areas and to improve the differentiation of contractions from strictures and differentiation between a fixed and an unfixed stenosis. Combing the functional and morphologic capabilities in evaluating intraluminal, mural, and extraparietal findings MR enteroclysis could be the one stop shop modality in the majority of the cases. For these reasons, we prefer to perform MR enteroclysis as the initial evaluation in patients with suspicion of a small bowel neoplastic versus inflammatory diseases or with obscure gastrointestinal bleeding, whereas MR enterography approach is used for the follow-up of the patients with CD.

Several different pulse sequences are available for imaging the small bowel. The main diagnostic sequences can be divided into the T2-weighted sequences that consist of the single-shot HASTE techniques (single-shot fast spin echo (SSFSE), HASTE, single-shot turbo spin echo) and the balanced gradient echo (fast imaging employing steady-state acquisition, true fast imaging with steady-state precession (FISP), balanced fast field echo) sequences.

Contrast enhanced T1-weighted gradient echo sequences with fat suppression also are routinely performed to look for areas of increased enhancement.

Combining T2-weighted half-Fourier rapid acquisition with relaxation enhancement (RARE) or half-Fourier acquisition single-shot turbo spin echo (HASTE) and T1-weighted gadolinium-enhanced spoiled gradient echo (SGE) sequences, it is possible to assess small bowel diseases, because these sequences complement each other for the evaluation of location, extent, and severity of the small bowel diseases. The lack of magnetic susceptibility artefacts and lack of artefacts from bowel peristalsis theoretically makes the HASTE sequence ideal for imaging bowel. A limitation of HASTE is its sensitivity to intraluminal flow voids, while another disadvantage is that no information on mesenteries can be obtained due to K-space filtering effects. Another sequence promoted for the evaluation of small bowel diseases is the true fast imaging with steady-state precession (true-FISP) sequence, which is the proprietary name of a completely refocused steady-state gradient echo sequence (also called balanced fast field echo and FIESTA by other vendors). The true-FISP sequence is particularly good for obtaining information about the mural and extraintestinal complications; the mural ulcers and mesenteries are very well visualized, and lymph nodes are very conspicuous with this technique. The black boundary artefact encountered with the true-FISP sequence at fat water interfaces may hamper the perception of subtle thickening of the bowel wall. While steady-state sequence with fat saturation has an advantage over the same sequence without fat saturation, because of the elimination of black boundary artefacts. The detection of subtle bowel wall thickness is therefore improved. Malignant peritoneal tissue enhances moderately to substantially on interstitial phase gadolinium-enhanced images and appears as nodular or irregular thickened peritoneal or serosal diseases. Gadolinium-enhanced fat suppressed imaging has been shown to be more sensitive than CT imaging in detecting small tumor nodules [63, 64].

The absence of radiation and the inherent excellent soft tissue contrast make MRE an attractive choice in the investigation of inflammatory bowel disease, with the pattern of enhancement and the presence of enhancing lymph nodes potentially capable of predicting disease activity.

Compared with an SBE, an MRE can be considered a more expensive study. However, patients often require both barium and CT to define the extent of their abdominal and pelvic disease and, therefore, true costs for this one-stop test may be favourable. There remains limited experience at present in the use of MRE in investigating other small bowel abnormalities.

6. Crohn's Disease

The abnormalities associated with early Crohn's disease (CD), visualizing at barium studies, include a coarse villous pattern, fold thickening, and aphthous ulcers. These findings alone are not pathognomonic of CD and can be seen in other diseases, but their presence can provide firm evidence of an early stage of the disease. Linear ulcers along the mesenteric border constitute one of the most important diagnostic features of small bowel CD.

The ulcers run parallel to the shortened, concave, or straightened (and somewhat rigid) mesenteric border. The adjacent mesentery is thickened and retracted, especially at its junction with the affected bowel segment.

The rigidity of the mesenteric border is due to transmural inflammation that extends from the linear ulcer into the mesentery. As ulceration proceeds, spasms and irritability increase, the folds become more coarse and thickened, and the gastrointestinal string sign may be seen. The bowel proximal to the sign may or may not be dilated, depending on the stage of the disease. In the nonstenotic phase, the proximal intestinal lumen is generally not dilated [2], despite the narrowing associated with the string sign, which indicates the importance of edema, spasm, and inflammation in producing this characteristic appearance.

This spasm is usually inconstant. Repeated spot radiographs demonstrate that some distensibility is present in this segment. However, when the spasm is persistent, temporary proximal dilatation may occur with symptoms of obstruction.

In the stenotic phase, there is a constant proximal dilatation that may be accentuated by spasms secondary to ulceration.

Despite the narrowing, complete intestinal obstruction is rare.

Several studies have found MR enteroclysis to be superior to the double-contrast methylcellulose technique, the most commonly enteroclysis method (Figure 1) [50–55].

MRE and conventional enteroclysis were comparable in the evaluation of patients with CD, and both were superior to MR enterography when evaluating the intraluminal abnormalities, whereas there were no statistical differences in the assessment of parietal stenosis and fistulae between the three techniques. Both MR techniques were better than conventional enteroclysis in evaluating mesenteric manifestations and colonic skip lesions [3].

There are no studies in the literature that have compared MR enteroclysis with air (CO_2) double-contrast barium enteroclysis [3, 43]. The latter has been shown to detect mucosal alterations in early small bowel disease more effectively than other radiologic investigations. However, the clinical use of air (CO_2) double-contrast barium enteroclysis is limited because it is technically demanding for radiologists and it is a less comfortable procedure for the patient. Moreover, like conventional enteroclysis, this modality does not reliably assess extraluminal findings.

A meta-analysis of studies on the use of ultrasound to diagnose CD reported sensitivity and specificity between 75%–94% and 67%–100%, respectively [17].

Compared with a reference standard consisting of a combination of clinical and conventional enteroclysis findings, the specificity and sensitivity of ultrasound in the diagnosis of CD have been reported to be 88.4% and 93.3%, respectively.

However, ultrasound was less reliable in patients with early stage CD of the small bowel (sensitivity 66.7%). Therefore, if ultrasound is used as the initial modality to examine the small bowel in patients with suspected CD, a negative result warrants further evaluation.

Contrast-enhanced ultrasound nicely demonstrates mural enhancement after intravenous injection of hexafluoride-filled microbubbles [11, 14]. Quantitative analysis of bowel wall vascularization shows a significant higher peak of signal intensity and a higher regional blood volume for CD in comparison with healthy volunteers. However, at the moment contrast-enhanced ultrasound is not widely used. Moreover, it is a subjective method that depends on the investigator's expertise. Another limitation is the fact that ultrasound contrast materials are not approved in the USA.

Ultrasonography (US) is a useful radiation-free alternative for demonstrating focal bowel wall thickening in inflammatory bowel disease (IBD), but it is reliant on operator skill and experience and may also fail to fully delineate complications and exclude disease in deep abdominal loops [56, 57].

MR modalities have several advantages over CT: the first is that MRI does not use ionizing radiation to produce images. because imaging of the small bowel in patients with CD during the lifelong course of the disease often has to be repeated, MR for its absence of ionizing radiation and its easy comparability would be the preferable diagnostic procedure [27, 28].

This is especially important in pediatric patients, in pregnant women, and in patients with chronic inflammatory bowel disease who may require multiple studies over a lifetime.

Moreover, MR imaging also offers the opportunity to perform a functional or real-time examination of the bowel, whereas CT imaging can only be performed at a few points in time because of ionizing radiation exposure. This limitation may cause difficulty in determining whether areas of bowel narrowing are secondary to contractions or to fixed strictures.

There are few data comparing state-of-the-art MR enteroclysis and capsule endoscopy; moreover, few studies have compared MR enterography and capsule endoscopy in patients with CD [8]. Some authors have stated that CE seems to be a better method for assessing the severity and extent of small bowel inflammation, although its use apparently does not change the therapy received [8]. In another study [16], CE was compared with MR enterography in 27 patients with established CD and 25 with suspected CD. In the group with established CD, the yield for CE was 93% compared with 79% for MRI. In those with suspected CD, CE was more sensitive and specific than MRI (92% and 100% versus 77% and 80%, resp.).

In patients with suspected or newly diagnosed CD, CE had a sensitivity of 100% for detection of CD in the terminal ileum, compared with 81% for MRE [16].

Endoscopy allows the clinician to obtain a better view of the mucosal layer. On the other hand, MR imaging allows the clinician to see beyond the mucosa; with MRI, the clinician obtains a full transmural view of the entire bowel wall and can see whether the patient has any extraenteric complications, such as fistulas or abscesses.

There are some basic problems with capsule endoscopy. The first is that it is very sensitive, especially in CD, but this is offset by low specificity. Furthermore, evidence suggests

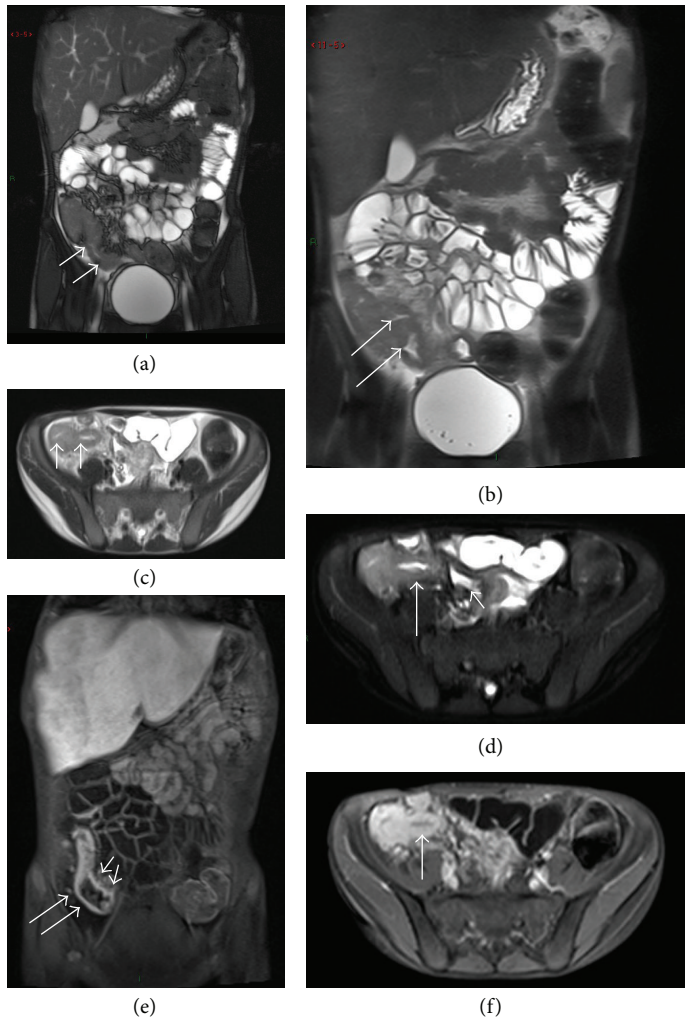

Figure 1: MR enteroclysis in a 21-year-old man with active Crohn's disease. Coronal true-FISP (a) and Haste (b) images show mucosal irregularity (arrows) as thin lines of high signal intensity, longitudinally, or transversely (fissure ulcers) orientated within the thickened in the terminal ileum consistent with diffuse ulcerations in Crohn's ileitis. Axial true-FISP sequence (c) detects wall thickening of terminal ileum as well as the cecal wall (arrows). Axial fat-suppressed T2 Haste sequence (d) MR image shows high signal intensity bowel wall (arrows) and fluid surrounding the distal ileum (small arrow). Coronal (e) and axial (f) contrasts GRE T1 with fat saturated images show marked contrast enhancement, with avid enhancement of the mucosa of the terminal ileum and cecal walls. Note the high signal intensity linear structure due to increased vascularity (small arrows in (e)) close to the mesenteric border of the involved small bowel segment, the so-called comb sign. These MR findings are indicative of active Crohn's disease.

that up to 13% of normal, asymptomatic individuals may have mucosal breaks and other minor lesions of the small bowel detected by CE [8].

Therefore, capsule endoscopic findings of mucosal lesions of the small bowel are alone not sufficient for a diagnosis of CD. The other major problem with the use of capsule endoscopy is that significant small bowel strictures will obstruct the capsule passage, requiring surgical removal of the capsule MR enteroclysis can be used as the initial evaluation in patients with suspected CD because it is accurate in assessing both jejunal and ileal loops and in distinguishing Crohn's disease from other small bowel diseases. When it is normal videocapsule endoscopy could be performed to detect more subtle disease.

MR enterography should be the follow up examination in patients with CD with no proximal disease and for pediatric-age patients.

Conventional enteroclysis is superior in comparison to CT and MR in visualizing early superficial mucosal lesions, but capsule endoscopy is probably the best method to assess mucosal changes. However, since the inflammatory process in CD does not stop at the mucosa, cross-sectional modalities can answer all major clinical questions relevant to patient management.

6.1. Small Bowel Neoplasms. MR enteroclysis has been shown to be more sensitive than CT enteroclysis for detecting mucosal lesions of the small bowel [65–67], and it appears to

facilitate superior detection of segments with only superficial abnormalities. These findings may be due to the better soft tissue contrast that can be achieved with MR imaging, which may be important for tissue characterization and the detection of subtle areas of abnormality (Figure 2) [68–70].

CT represents a useful modality in the investigation of bowel masses [7]; however, if the lesion is isoattenuating, the distension of the lumen is suboptimal, or a positive (iperattenuating) enteric contrast is used, small lesion could be very difficult to detect [6]. Moreover, the inability to monitor small bowel filling in real time without exposing the patient to ionizing radiation is a limitation of CT, as is the limited number of time points in which the small bowel can be imaged, thus precluding the assessment of small bowel peristaltic activity. Besides, an intermittent spasm or peristaltic contraction during the examination can also be misdiagnosed as a small bowel neoplasm on the CT study [6].

These limits are overcome by MR imaging that allows functional evaluation of the small bowel mobility and the detection of intraluminal, intramural, and extramural manifestations in small bowel diseases [71–84].

It is recognized that this proximal region is the least well visualized by capsule endoscopy, probably because of rapid capsule transit, bile and/or bubble artifact, and relatively poor luminal distension [85–90].

However, it is likely that the unidirectional views and relatively slow image capture rate (2 frames/s) of the current generation of small bowel capsule results in less reliable identification of lesions in this segment. Adequate image capture of a very large lesions located more distally can also be problematic during CE and, often, only fleeting views of the edge of the lesion may be recorded [91–94], highlighting the importance of considering newer cross-sectional radiologic techniques, such as CTE and MRE, for the detection of SBMLs, which have a predominantly extraluminal rather than intraluminal component. It is difficult to identify pathology and tumor type based on the capsule endoscopic appearance of lesions. The miss rate of CE in neoplastic disease can reach 18,9%. There are several reasons contributing to that miss rate, but probably the crucial one is related, in this particular subset of patients, to the fact that sometime it is arduous, on the ground of CE findings, to discriminate masses from bulges [95]. A bulge is defined as a round smooth, large base protrusion in the lumen having an ill-defined edge on the surrounding mucosa; it can be a prominent normal fold or the luminal expression of intestinal loop angulation and stiffness, and sometimes it can be virtually indistinguishable from a small submucosal tumor. Pennazio et al. [96] described 51 patients with polypoid lesions revealed at CE that were not confirmed at further examinations (false positive capsule endoscopy).

This problem, highlighted also in other studies [97, 98], can significantly influence the subsequent management; in fact a positive CE requires further invasive examinations (PPE or surgical interventions). It is not reliable for accurate sizing of polyps.

Another important limitation of wireless capsule endoscopy includes capsule retention in approximately 10%–25% of cases of small bowel tumors [95–98], which may require surgery because of acute small bowel obstruction in a subset of patients [95]. Consequently, small bowel tumor is now considered as a risk factor for capsule retention [96]. This risk correlates with luminal protrusion of the tumor. For these reasons MR enteroclysis should be used for patients suspected of having small bowel neoplasms.

In patients with suspected small bowel tumors, MR enteroclysis might be used as the first modality of choice. If the presence of a tumor is confirmed, DBE is used to allow histologic determination. In addition, MR enteroclysis helps in the choice of the preferred route of insertion of the DBE endoscope.

MR and CT enteroclysis have the benefit of being able to depict small bowel diverticula (because distension of the small bowel prevents collapse of diverticular segments) and the extraluminal abnormalities encountered with inflammation.

In patients with obscure gastrointestinal bleeding endoscopic modalities are more accurate than MR modalities in detecting flat mucosal lesions, which most vascular lesions are.

MR enteroclysis has a high accuracy in excluding inflammatory and neoplastic disease; therefore, in case of a negative MR enteroclysis, an arteriovenous malformation is likely to be the cause of bleeding, and enteroscopy may be required for diagnosis and treatment of these vascular malformations [3]. Thus, we believe that MR enteroclysis should precede enteroscopic modalities in the examination of patients with obscure gastrointestinal bleeding.

The radiologist most frequently encounters inflammatory and infectious diseases of the small intestine during the work-up of patients with suspected small bowel diseases, and identification of disease-specific features is therefore important for the differential diagnosis with small bowel neoplasms [24–26].

Specific characteristics of inflammatory small bowel diseases are the presence of bowel wall edema, ulcerations, increased mesenteric vascularization (comb sign), enhancing mesenteric lymphnodes, and increased mesenteric fat. In acute inflammation, the bowel wall can have a layered pattern due to submucosal edema, that is not seen in neoplastic diseases.

Functional information can be used to assess the grade of bowel wall stenosis and the distensibility of the stenosis that can occur in inflammatory conditions. An increased prevalence of small bowel carcinoma has been reported in patients with Crohn's long-standing disease involving the small bowel mostly in the terminal ileum. A preoperative radiologic diagnosis of Crohn's cancers is almost always impossible because of absence of characteristic features.

Infectious diseases usually cause a diffuse involvement of jejunum and ileum and are characterized by thickening of all jejunal wall layers with wall edema; the findings resolve completely after therapy.

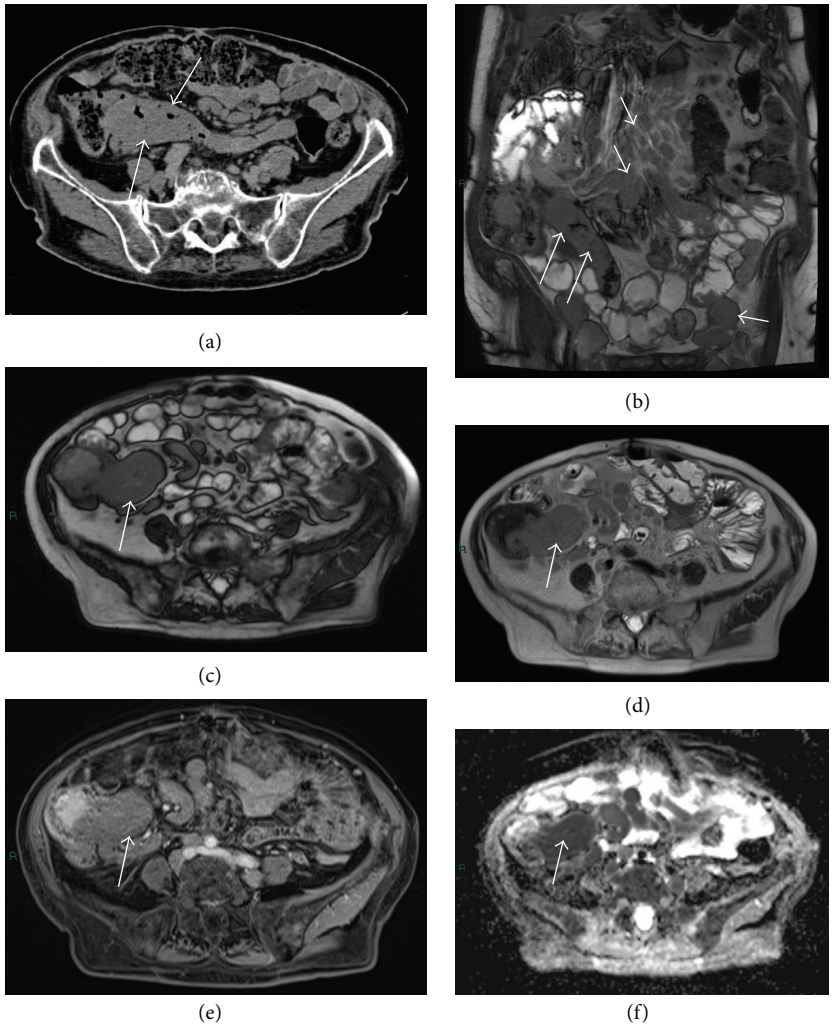

Figure 2: CT and MR enterography in a 68-year-old patient with ileal lymphoma. Axial CT image (a) shows abnormal thickening of terminal ileum (arrows), with aneurysmal pseudo-dilatation. Coronal true fisp (b) shows abnormal thickening of terminal ileum (arrows) multiple mesenteric lymph nodes (short arrows). Axial true fisp (c) and Haste sequence (d) show a long segment of terminal ileum with abnormal thickening, smooth margins, and luminal narrowing with loss of normal mucosal folds (arrows). Axial contrast T1-LAVA (e) sequence shows minimal enhancement of the mass (arrow) infiltrating the small bowel loop, with restriction of the diffusion (ADC) (f) indicative of high cellularity tissue. The morphologic and functional data are suggestive of small bowel lymphoma.

In intestinal tuberculosis, MR images may show circumferential wall thickening of the cecum and terminal ileum associated with adjacent mesenteric lymphadenopathy. wall ulcerations and peritoneal involvement can be seen; moreover, the lymph nodes demonstrate central areas of colliquative necrosis.

Meckel diverticulum may present with gastrointestinal bleeding and obstruction and should be differentiated from small bowel neoplasms. CT and ultrasound have a poor sensitivity for diagnosis of Meckel's diverticulum; MR is able to visualize the characteristic blind-ending cystic sac in communication with the border of distal ileum. For its high soft tissue contrast MR is able to visualize blood products inside the diverticulum, without evidence of neoplastic nodules.

Sclerosing mesenteritis most commonly appears as a soft tissue mass in the small bowel mesentery, that mass may envelop the mesenteric vessels, and collateral vessels may develop over time. There may be preservation of fat around the mesenteric vessels, a phenomenon that is called the "fat ring sign." This finding may help distinguish sclerosing mesenteritis from other mesenteric processes such as lymphoma, carcinoid tumor, or carcinomatosis.

7. GI Tract Bleeding

As defined by the American Gastroenterological Association, obscure gastrointestinal bleeding (OGIB) is a persistent or

recurring condition of unknown origin after negative upper and lower endoscopies.

The cause of OGIB has been described to exist in the small bowel in 5% to 10% up to 27% of patients [48].

Wireless endoscopy is the most sensitive examination for detecting sources of OGIB, with reported sensitivities ranging from 42% to 80% [48]. However, this method is not able to show submucosal or serosal abnormalities and has long reporting times [48, 49].

Triple phase (arterial, enteric, and delayed phases) CT enterography was recently reported to be of value for detecting GI tract bleeding and identifying the source [50].

The sensitivity of multiphase CT enterography in the detection of small bowel lesions causing obscure gastrointestinal bleeding was significantly greater than that of capsule endoscopy (88% versus 38%, resp.; $P = 0.008$), largely because CT enterography depicted more small bowel masses (nine of nine patients (100%) versus three of nine patients (33%), resp.; $P = 0.03$) [98].

Active small bowel bleeding at multiphase CT enterography is observed as a gradual accumulation of contrast material within the bowel lumen.

Most cases of OGIB are due to benign vascular abnormalities, such as angiodysplasia.

Bleeding in the GI tract has many possible causes, including ulcers, vascular malformations, and tumors.

Patients in whom the presence of GI tract bleeding is suspected usually undergo upper and lower GI tract endoscopy for initial evaluation. If the result of endoscopy is negative or inconclusive, multiphase CT may be helpful.

Angiodysplasia is the most common cause of occult GI tract bleeding. The structural abnormality usually appears as an avidly enhancing plaque or nodule during the enteric phase and fades during the delayed phase.

Less commonly, it might manifest as a focal area of enhancement or an associated early draining vein during the arterial phase. Other causes of GI tract bleeding that may be detected at CT enterography include various types of vascular malformations, neoplasms, and Meckel's diverticulum. Small bowel tumors such as leiomyoma and gastrointestinal stromal tumor (GIST) also may be sources of occult GI tract bleeding.

In patients with clinical suspicion of small bowel neoplasms, MR enteroclysis may also be used to distinguish neoplasms from inflammatory diseases, as well as other conditions that cause obscure gastrointestinal bleeding, such as Meckel's diverticulum.

8. Celiac Disease

Celiac disease is characterized by malabsorption of the intestine which develops due to gluten and/or gluten-related protein intake through wheat, barley, and rye; this chronic intolerance of gluten induces intestinal mucosal lesions in genetically predisposed patients and is the most frequently seen enteropathy in western countries, and its prevalence is 0.7%–2% [99]. This disease affects both children and adults, may be more prevalent than reported, and the reported cases are described as the tip of the celiac iceberg [99]. The pathologic changes of celiac disease are predominantly seen in the duodenum and proximal jejunum. However, the extent of the disease is extremely variable, ranging from segmental to full involvement of the small bowel.

The most specific sign of celiac disease is represented by fold pattern abnormalities [100]. Abnormalities of the intestinal fold pattern are defined qualitatively as a decreased number of jejunal folds.

The pathologic changes of celiac disease are predominantly seen in the duodenum and proximal jejunum. However, the extent of the disease is extremely variable, ranging from segmental to full involvement of the small bowel.

The most specific sign of celiac disease is represented by fold pattern abnormalities [101]. Valvulae conniventes may exhibit five patterns. (1) Normal: in most patients valvulae look normal, (2) squared ends: ends at the margin are squared off rather than rounded, (3) reversed jejunal fold pattern: decreased jejunal folds with increased ileal folds, and (4) absence of valvulae: "Moulage sign," characteristic of sprue, due to total villous atrophy.

The small bowel findings in celiac disease reflect the underlying villous atrophy. With extensive villous atrophy, there is loss of the surface area of the mucosa. This loss of mucosa in celiac disease is manifested by a decreased number of folds in the proximal jejunum, the portion of the small bowel that is mostly severely involved in the disease.

Jejunal folds should be considered decreased in number if <3 folds per inch. In severe celiac disease, a complete flattening of jejunal folds can be observed. An increased number of ileal folds (>5 per inch) represents another specific sign of celiac disease.

A reversed jejunoileal fold pattern, which presumably is caused by a compensatory response of the ileum to severe villous atrophy of the proximal small bowel, is highly suggestive of celiac disease. Small bowel dilatation, affecting particularly the jejunum, is commonly found in celiac patients and is felt to occur secondary to intestinal hypomobility.

Alteration of bowel wall thickness represents an uncommon and Nonspecific sign of celiac disease. Mural thickening in the setting of celiac disease may reflect submucosal edema and varying degrees of inflammation. Bowel wall is considered thickened when it measures more than 4 mm. Usually bowel wall thickening is diffused and not associated with reduction of intestinal caliber. Intestinal strictures are not common in celiac disease and do not represent a specific sign of disease.

Although endoscopic biopsy is required for a definitive diagnosis of celiac disease, MR studies may also be performed to establish the diagnosis in patients with atypical symptoms.

The ability to visualize a variety of small bowel diseases with MRI was previously described [50]. CT is a good modality for visualizing the small bowel. However, MRI has certain advantages over CT, including the superb soft tissue contrast resolution, multiplanar imaging capabilities, and the lack of associated ionizing radiation exposure that allow repeated data acquisition over time. Moreover, the lack of ionizing radiation in patients who may require serial follow up studies is an important issue. MR enterography is particularly of value for detecting complications in patients

with known celiac disease and a poor response to medical therapy or in patients with recurrent symptoms despite gluten withdrawal.

9. Summary

A successful approach for the radiologist depends on the local availability of different services and clinical expertise. Consideration should always be given to new investigations with the utility benefit of reduced radiation exposure, single study techniques, or those with increased diagnostic sensitivity. A number of these newer techniques still require further peer evaluation before they can be considered for routine practice. Ultimately, diagnostic yield is determined by accurate clinical assessment and the appropriate choice of investigation. Endoscopy provides the advantage of obtaining biopsies, but only the terminal ileum, the duodenum, and the proximal ileum can be sufficiently explored in routine procedures. DBE/SBE can cover all length of the small intestine but are not commonly available [102–104]. Wireless capsule endoscopy (WCE) is probably the best method for visualizing mucosal abnormalities [102]. However, it is not very accurate in the estimation of location and size of the intraluminal abnormalities and, it is contraindicated in patients suspected with bowel stricture, history of prior small bowel surgery, swallowing disorders, motility disorders, and intestinal obstruction. One of the most important limitations of all endoscopic methods is the inability to visualize submucosal or extramural manifestations of small bowel diseases. For many years, "conventional" double contrast enteroclysis has been suggested as the technique of choice for the evaluation of the small intestine. Adequate distention of the small bowel allows imaging of mucosal abnormalities and provides functional information by defining free peristaltic contraction or fixation of the small bowel loops. The principal disadvantage of conventional enteroclysis is the limited information about the state of the bowel wall and extramural extension of tumor disease. MDCT enteroclysis shows a good accuracy in the evaluation of small bowel diseases. MR enteroclysis was more sensitive in detecting lesions of the small bowel than CT enteroclysis in patients with CD and for these reasons MR seems superior in the detection of segments with only superficial abnormalities [105, 106]. Moreover, because of ionizing radiation exposure at CT, imaging can be obtained at only a few points in time, precluding repeated temporal imaging and hence assessment of small bowel peristaltic activity. In the author's opinion, MR enteroclysis could be superior in comparison of MDCT for the better soft tissue contrast, that may be important for detecting subtle areas of pathology, and for the tissue characterization. MR fluoroscopy sequences provide useful information in determining the distensibility of narrowed areas and improve differentiation of contractions from strictures, the evaluation of the prestenotic dilatation, and small bowel mobility, and in the visualization of findings similar to that obtained with barium studies useful in the differentiation between mucosal, submucosal, and extramural origin. For these reasons, MRE is an accurate method that allows the visualization of small bowel diseases in the majority of the cases.

References

[1] D. J. Nolan, "Enteroclysis of non-neoplastic disorders of the small intestine," *European Radiology*, vol. 10, no. 2, pp. 342–353, 2000.

[2] J. R. Bessette, D. D. T. Maglinte, F. M. Kelvin, and S. M. Chernish, "Primary malignant tumors in the small bowel: 4 comparison of the small-bowel enema and conventional follow-through examination," *American Journal of Roentgenology*, vol. 153, no. 4, pp. 741–744, 1989.

[3] A. Furukawa, M. Yamasaki, K. Furuichi et al., "Helical CT in the diagnosis of small bowel obstruction," *RadioGraphics*, vol. 21, no. 2, pp. 341–355, 2001.

[4] R. Ruiz-Cruces, F. Ruiz, and M. Perez-Martinez, "Patient dose from barium procedures," *British Journal of Radiology*, vol. 73, pp. 752–761, 2000.

[5] S. R. Paulsen, J. E. Huprich, J. G. Fletcher et al., "CT enterography as a diagnostic tool in evaluating small bowel disorders: review of clinical experience with over 700 cases," *RadioGraphics*, vol. 26, no. 3, pp. 641–657, 2006.

[6] D. W. Walsh, G. N. Bender, and H. Timmons, "Comparison of computed tomography-enteroclysis and traditional computed tomography in the setting of suspected partial small bowel obstruction," *Emergency Radiology*, vol. 5, no. 1, pp. 29–37, 1998.

[7] S. Schmidt, C. Felley, J. Y. Meuwly, P. Schnyder, and A. Denys, "CT enteroclysis: technique and clinical applications," *European Radiology*, vol. 16, no. 3, pp. 648–660, 2006.

[8] A. K. Hara, J. A. Leighton, V. K. Sharma, R. I. Heigh, and D. E. Fleischer, "Imaging of small bowel disease: comparison of capsule endoscopy, standard endoscopy, barium examination, and CT," *RadioGraphics*, vol. 25, no. 3, pp. 697–711, 2005.

[9] A. C. Planner, A. Phillips, and H. K. Bungay, "The role of imaging in small bowel disease," *Imaging*, vol. 18, no. 4, pp. 228–256, 2006.

[10] M. Macari, A. J. Megibow, and E. J. Balthazar, "A pattern approach to the abnormal small bowel: observations at MDCT and CT enterography," *American Journal of Roentgenology*, vol. 188, no. 5, pp. 1344–1355, 2007.

[11] D. J. Brenner and E. J. Hall, "Computed tomography—an increasing source of radiation exposure," *The New England Journal of Medicine*, vol. 357, pp. 2277–2284, 2007.

[12] J. M. Froehlich, M. A. Patak, C. von Weymarn, C. F. Juli, C. L. Zollikofer, and K. U. Wentz, "Small bowel motility assessment with magnetic resonance imaging," *Journal of Magnetic Resonance Imaging*, vol. 21, no. 4, pp. 370–375, 2005.

[13] H. Siddiki and J. Fidler, "MR imaging of the small bowel in Crohn's disease," *European Journal of Radiology*, vol. 69, no. 3, pp. 409–417, 2008.

[14] D. D. T. Maglinte and J. E. Huprich, "Invited commentary," *RadioGraphics*, vol. 26, no. 3, pp. 657–662, 2006.

[15] J. L. Goldstein, G. M. Eisen, B. Lewis, I. M. Gralnek, S. Zlotnick, and J. G. Fort, "Video capsule endoscopy to prospectively assess small bowel injury with celecoxib, naproxen plus omeprazole, and placebo," *Clinical Gastroenterology and Hepatology*, vol. 3, no. 2, pp. 133–141, 2005.

[16] D. D. T. Maglinte, "Capsule imaging and the role of radiology in the investigation of diseases of the small bowel," *Radiology*, vol. 236, no. 3, pp. 763–767, 2005.

[17] J. L. Fidler, L. Guimaraes, and D. M. Einstein, "MR imaging of the small bowel," *RadioGraphics*, vol. 29, no. 6, pp. 1811–1825, 2009.

[18] B. M. Wiarda, E. J. Kuipers, M. A. Heitbrink, A. van Oijen, and J. Stoker, "MR enteroclysis of inflammatory small-bowel diseases," *American Journal of Roentgenology*, vol. 187, no. 2, pp. 522–531, 2006.

[19] H. W. Umschaden, D. Szolar, J. Gasser, M. Umschaden, and H. Haselbach, "Small-bowel disease: comparison of MR enteroclysis images with conventional enteroclysis and surgical findings," *Radiology*, vol. 215, no. 3, pp. 717–725, 2000.

[20] N. C. Gourtsoyiannis, J. Grammatikakis, G. Papamastorakis et al., "Imaging of small intestinal Crohn's disease: comparison between MR enteroclysis and conventional enteroclysis," *European Radiology*, vol. 16, no. 9, pp. 1915–1925, 2006.

[21] P. Prassopoulos, N. Papanikolaou, J. Grammatikakis, M. Rousomoustakaki, T. Maris, and N. Gourtsoyiannis, "MR enteroclysis imaging of crohn disease," *RadioGraphics*, vol. 21, pp. S161–S172, 2001.

[22] D. D. T. Maglinte, E. S. Siegelman, and F. M. Kelvin, "MR enteroclysis: the future of small-bowel imaging?" *Radiology*, vol. 215, no. 3, pp. 639–641, 2000.

[23] A. Laghi, P. Paolantonio, F. Iafrate, F. Altomari, C. Miglio, and R. Passariello, "Oral contrast agents for magnetic resonance imaging of the bowel," *Topics in Magnetic Resonance Imaging*, vol. 13, no. 6, pp. 389–396, 2002.

[24] A. Rieber, A. Aschoff, K. Nüssle et al., "MRI in the diagnosis of small bowel disease: use of positive and negative oral contrast media in combination with enteroclysis," *European Radiology*, vol. 10, no. 9, pp. 1377–1382, 2000.

[25] W. C. Small, D. DeSimone-Macchi, J. R. Parker et al., "A multisite phase III study of the safety and efficacy of a new manganese chloride-based gastrointestinal contrast agent for MRI of the abdomen and pelvis," *Journal of Magnetic Resonance Imaging*, vol. 10, pp. 15–24, 1999.

[26] D. Kivelitz, H. B. Gehl, A. Heuck et al., "Ferric ammonium citrate as a positive bowel contrast agent for MR imaging of the upper abdomen: safety and diagnostic efficacy," *Acta Radiologica*, vol. 40, no. 4, pp. 429–435, 1999.

[27] A. H. Karantanas, N. Papanikolaou, J. Kalef-Ezra, A. Challa, and N. Gourtsoyiannis, "Blueberry juice used per os in upper abdominal MR imaging: composition and initial clinical data," *European Radiology*, vol. 10, no. 6, pp. 909–913, 2000.

[28] A. Rieber, K. Nüssle, M. Reinshagen, H. J. Brambs, and A. Gabelmann, "MRI of the abdomen with positive oral contrast agents for the diagnosis of inflammatory small bowel disease," *Abdominal Imaging*, vol. 27, no. 4, pp. 394–399, 2002.

[29] A. G. Schreyer, S. Gölder, K. Scheibl et al., "Dark lumen magnetic resonance enteroclysis in combination with MRI colonography for whole bowel assessment in patients with Crohn's disease: first clinical experience," *Inflammatory Bowel Diseases*, vol. 11, no. 4, pp. 388–394, 2005.

[30] J. Fidler, "MR imaging of the small bowel," *Radiologic Clinics of North America*, vol. 45, no. 2, pp. 317–331, 2007.

[31] R. R. Sood, I. Joubert, H. Franklin, T. Doyle, and D. J. Lomas, "Small bowel MRI: comparison of a polyethylene glycol preparation and water as oral contrast media," *Journal of Magnetic Resonance Imaging*, vol. 15, no. 4, pp. 401–408, 2002.

[32] A. Laghi, I. Carbone, C. Catalano et al., "Polyethylene glycol solution as an oral contrast agent for MR imaging of the small bowel," *American Journal of Roentgenology*, vol. 177, no. 6, pp. 1333–1334, 2001.

[33] M. F. Lin and V. Narra, "Developing role of magnetic resonance imaging in Crohn's disease," *Current Opinion in Gastroenterology*, vol. 24, no. 2, pp. 135–140, 2008.

[34] R. Gore, G. Masselli, and D. Caroline, "Crohn's disease of thesmall bowel," in *Textbook of Gastrointestinal Radiology*, R. Gore and M. Levine, Eds., pp. 781–806, Saunders Elsevier, Philadelphia, Pa, USA, 3rd edition, 2008.

[35] H. W. Umschaden and J. Gasser, "MR enteroclysis," *Radiologic Clinics of North America*, vol. 41, no. 2, pp. 231–248, 2003.

[36] Z. Tarjan, G. Toth, T. Gyorke et al., "Ultrasound in Crohn's disease of the small bowel," *European Journal of Radiology*, vol. 35, no. 3, pp. 176–182, 2000.

[37] R. Di Mizio, G. Maconi, S. Romano, F. D'Amario, G. B. Porro, and R. Grassi, "Small bowel Crohn disease: sonographic features," *Abdominal Imaging*, vol. 29, no. 1, pp. 23–35, 2004.

[38] D. J. Lomas and M. J. Graves, "Small bowel MRI using water as a contrast medium," *British Journal of Radiology*, vol. 72, pp. 994–997, 1999.

[39] W. Ajaj, M. Goyen, H. Schneemann et al., "Oral contrast agents for small bowel distension in MRI: influence of the osmolarity for small bowel distention," *European Radiology*, vol. 15, no. 7, pp. 1400–1406, 2005.

[40] D. A. McKenna, C. J. Roche, J. M. P. Murphy, and P. A. McCarthy, "Polyethylene glycol solution as an oral contrast agent for MRI of the small bowel in a patient population," *Clinical Radiology*, vol. 61, no. 11, pp. 966–970, 2006.

[41] C. A. Kuehle, W. Ajaj, S. C. Ladd, S. Massing, J. Barkhausen, and T. C. Lauenstein, "Hydro-MRI of the small bowel: effect of contrast volume, timing of contrast administration, and data acquisition on bowel distention," *American Journal of Roentgenology*, vol. 187, no. 4, pp. W375–W385, 2006.

[42] B. M. Young, J. G. Fletcher, F. Booya et al., "Head-to-head comparison of oral contrast agents for cross-sectional enterography: small bowel distention, timing, and side effects," *Journal of Computer Assisted Tomography*, vol. 32, no. 1, pp. 32–38, 2008.

[43] N. C. Gourtsoyiannis and N. Papanikolaou, "Magnetic resonance enteroclysis," *Seminars in Ultrasound, CT and MRI*, vol. 26, no. 4, pp. 237–246, 2005.

[44] G. Masselli, E. Casciani, E. Polettini, S. Lanciotti, L. Bertini, and G. Gualdi, "Assessment of Crohn's disease in the small bowel: prospective comparison of magnetic resonance enteroclysis with conventional enteroclysis," *European Radiology*, vol. 16, no. 12, pp. 2817–2827, 2006.

[45] J. Zhu, J. R. Xu, H. X. Gong, and Y. Zhou, "Updating magnetic resonance imaging of small bowel: imaging protocols and clinical indications," *World Journal of Gastroenterology*, vol. 14, no. 21, pp. 3403–3409, 2008.

[46] A. Negaard, V. Paulsen, L. Sandvik et al., "A prospective randomized comparison between two MRI studies of the small bowel in Crohn's disease, the oral contrast method and MR enteroclysis," *European Radiology*, vol. 17, no. 9, pp. 2294–2301, 2007.

[47] A. G. Schreyer, A. Geissler, H. Albrich et al., "Abdominal MRI after enteroclysis or with oral contrast in patients with suspected or proven Crohn's disease," *Clinical Gastroenterology and Hepatology*, vol. 2, no. 6, pp. 491–497, 2004.

[48] C. G. Cronin, D. G. Lohan, A. M. Browne, C. Roche, and J. M. Murphy, "Magnetic resonance enterography in the evaluation of the small bowel," *Seminars in Roentgenology*, vol. 44, no. 4, pp. 237–243, 2009.

[49] W. Ajaj, S. C. Goehde, H. Schneemann, S. G. Ruehm, J. F. Debatin, and T. C. Lauenstein, "Dose optimization of mannitol solution for small bowel distension in MRI," *Journal of Magnetic Resonance Imaging*, vol. 20, no. 4, pp. 648–653, 2004.

[50] D. Lohan, C. Cronin, C. Meehan, A. N. Alhajeri, C. Roche, and J. Murphy, "MR small bowel enterography: optimization of imaging timing," *Clinical Radiology*, vol. 62, no. 8, pp. 804–807, 2007.

[51] G. Masselli, E. Casciani, E. Polettini, and G. Gualdi, "Comparison of MR enteroclysis with MR enterography and conventional enteroclysis in patients with Crohn's disease," *European Radiology*, vol. 18, no. 3, pp. 438–447, 2008.

[52] U. Korman, S. Kurugoglu, and G. Ogut, "Conventional enteroclysis with complementary MR enteroclysis: a combination of small bowel imaging," *Abdominal Imaging*, vol. 30, no. 5, pp. 564–575, 2005.

[53] D. J. M. Tolan, R. Greenhalgh, I. A. Zealley, S. Halligan, and S. A. Taylor, "MR enterographic manifestations of small bowel crohn disease," *RadioGraphics*, vol. 30, no. 2, pp. 367–384, 2010.

[54] N. Gourtsoyiannis, N. Papanikolaou, J. Grammatikakis, and P. Prassopoulos, "MR enteroclysis: technical considerations and clinical applications," *European Radiology*, vol. 12, no. 11, pp. 2651–2658, 2002.

[55] C. G. Cronin, D. G. Lohan, J. Ni Mhuircheartaigh et al., "MRI small-bowel follow-through: prone versus supine patient positioning for best small-bowel distention and lesion detection," *American Journal of Roentgenology*, vol. 191, no. 2, pp. 502–506, 2008.

[56] M. A. Patak, C. von Weymarn, and J. M. Froehlich, "Small bowel MR imaging: 1.5T versus 3T," *Magnetic Resonance Imaging Clinics of North America*, vol. 15, no. 3, pp. 383–393, 2007.

[57] B. M. Wiarda, K. Horsthuis, A. C. Dobben et al., "Magnetic resonance imaging of the small bowel with the true FISP sequence: intra- and interobserver agreement of enteroclysis and imaging without contrast material," *Clinical Imaging*, vol. 33, no. 4, pp. 267–273, 2009.

[58] J. R. Leyendecker, R. S. Bloomfeld, D. J. DiSantis, G. S. Waters, R. Mott, and R. E. Bechtold, "MR enterography in the management of patients with Crohn disease," *RadioGraphics*, vol. 29, no. 6, pp. 1827–1846, 2009.

[59] A. Oto, F. Zhu, K. Kulkarni, G. S. Karczmar, J. R. Turner, and D. Rubin, "Evaluation of diffusion-weighted MR imaging for detection of bowel inflammation in patients with Crohn's disease," *Academic Radiology*, vol. 16, no. 5, pp. 597–603, 2009.

[60] T. C. Lauenstein, W. Ajaj, B. Narin et al., "MR imaging of apparent small-bowel perfusion for diagnosing mesenteric ischemia: feasibility study," *Radiology*, vol. 234, no. 2, pp. 569–575, 2005.

[61] R. N. Low, C. P. Sebrechts, D. A. Politoske et al., "Crohn disease with endoscopic correlation: single-shot fast spin-echo and gadolinium-enhanced fat-suppressed spoiled gradient-echo MR imaging," *Radiology*, vol. 222, no. 3, pp. 652–660, 2002.

[62] A. Sharman, I. A. Zealley, R. Greenhalgh, P. Bassett, and S. A. Taylor, "MRI of small bowel Crohn's disease: determining the reproducibility of bowel wall gadolinium enhancement measurements," *European Radiology*, vol. 19, no. 8, pp. 1960–1967, 2009.

[63] M. Zappa, C. Stefanescu, D. Cazals-Hatem et al., "Which magnetic resonance imaging findings accurately evaluate inflammation in small bowel Crohn's disease? A retrospective comparison with surgical pathologic analysis," *Inflammatory Bowel Diseases*, vol. 17, no. 4, pp. 984–993, 2011.

[64] S. A. Taylor, S. Punwani, M. Rodriguez-Justo et al., "Mural Crohn disease: correlation of dynamic contrast-enhanced MR imaging findings with angiogenesis and inflammation at histologic examination—pilot study," *Radiology*, vol. 251, no. 2, pp. 369–379, 2009.

[65] G. Masselli, E. Polettini, E. Casciani, L. Bertini, A. Vecchioli, and G. Gualdi, "Small-bowel neoplasms: prospective evaluation of MR enteroclysis," *Radiology*, vol. 251, no. 3, pp. 743–750, 2009.

[66] S. J. B. van Weyenberg, M. R. Meijerink, M. A. J. M. Jacobs et al., "MR enteroclysis in the diagnosis of small-bowel neoplasms," *Radiology*, vol. 254, no. 3, pp. 765–773, 2010.

[67] D. D. Maglinte, J. C. Lappas, and K. Sandrasegaran, "Malignant tumors of the small bowel," in *Textbook of Gastrointestinal Radiology*, R. Gore and M. Levine, Eds., pp. 853–869, Saunders Elsevier, Philadelphia, Pa, USA, 3rd edition, 2008.

[68] G. Masselli, A. Picarelli, M. Di Tola et al., "Celiac disease: evaluation with dynamic contrast-enhanced MR imaging," *Radiology*, vol. 256, no. 3, pp. 783–790, 2010.

[69] R. N. Low, S. C. Chen, and R. Barone, "Distinguishing benign from malignant bowel obstruction in patients with malignancy: findings at MR imaging," *Radiology*, vol. 228, no. 1, pp. 157–165, 2003.

[70] M. S. Gee and M. G. Harisinghani, "MRI in patients with inflammatory bowel disease," *Journal of Magnetic Resonance Imaging*, vol. 33, no. 3, pp. 527–534, 2011.

[71] F. Maccioni, A. Bruni, A. Viscido et al., "MR imaging in patients with Crohn disease: value of T2- versus T1-weighted gadolinium-enhanced MR sequences with use of an oral superparamagnetic contrast agent," *Radiology*, vol. 238, no. 2, pp. 517–530, 2006.

[72] C. G. Cronin, E. Delappe, D. G. Lohan, C. Roche, and J. M. Murphy, "Normal small bowel wall characteristics on MR enterography," *European Journal of Radiology*, vol. 75, no. 2, pp. 207–211, 2010.

[73] R. Sinha, R. Verma, S. Verma, and A. Rajesh, "MR enterography of Crohn disease: part 2, imaging and pathologic findings," *American Journal of Roentgenology*, vol. 197, no. 1, pp. 80–85, 2011.

[74] D. D. T. Maglinte, N. Gourtsoyiannis, D. Rex, T. J. Howard, and F. M. Kelvin, "Classification of small bowel Crohn's subtypes based on multimodality imaging," *Radiologic Clinics of North America*, vol. 41, no. 2, pp. 285–303, 2003.

[75] J. G. Fletcher, J. L. Fidler, D. H. Bruining, and J. E. Huprich, "New concepts in intestinal imaging for inflammatory bowel diseases," *Gastroenterology*, vol. 140, no. 6, pp. 1795–1806, 2011.

[76] K. Horsthuis, S. Bipat, R. J. Bennink, and J. Stoker, "Inflammatory bowel disease diagnosed with US, MR, scintigraphy, and CT: meta-analysis of prospective studies," *Radiology*, vol. 247, no. 1, pp. 64–79, 2008.

[77] A. Negaard, L. Sandvik, A. Mulahasanovic, A. E. Berstad, and N. E. Klöw, "Magnetic resonance enteroclysis in the diagnosis of small-intestinal Crohn's disease: diagnostic accuracy and inter- and intra-observer agreement," *Acta Radiologica*, vol. 47, no. 10, pp. 1008–1016, 2006.

[78] J. M. Froehlich, C. Waldherr, C. Stoupis, S. M. Erturk, and M. A. Patak, "MR motility imaging in Crohn's disease improves lesion detection compared with standard MR imaging," *European Radiology*, vol. 20, no. 8, pp. 1945–1951, 2010.

[79] D. H. Winship, R. W. Summers, and J. W. Singleton, "National cooperative Crohn's disease study: study design and conduct of the study," *Gastroenterology*, vol. 77, no. 4, pp. 829–842, 1979.

[80] R. F. Harvey and J. M. Bradshaw, "A simple index of Crohn's-disease activity," *The Lancet*, vol. 1, no. 8167, article 514, 1980.

[81] D. M. Koh, Y. Miao, R. J. Chinn et al., "MR imaging evaluation of the activity of Crohn's disease," *American Journal of Roentgenology*, vol. 177, pp. 1325–1332, 2001.

[82] J. Rimola, S. Rodriguez, O. García-Bosch et al., "Magnetic resonance for assessment of disease activity and severity in ileocolonic Crohn's disease," *Gut*, vol. 58, no. 8, pp. 1113–1120, 2009.

[83] R. del Vescovo, I. Sansoni, R. Caviglia et al., "Dynamic contrast enhanced magnetic resonance imaging of the terminal ileum: differentiation of activity of Crohn's disease," *Abdominal Imaging*, vol. 33, no. 4, pp. 417–424, 2008.

[84] A. J. Madureira, "The comb sign," *Radiology*, vol. 230, no. 3, pp. 783–784, 2004.

[85] G. Masselli, "The gastrointestinal string sign," *Radiology*, vol. 242, no. 2, pp. 632–633, 2007.

[86] L. E. Cipriano, B. G. Levesque, G. Zaric, E. Loftus, and W. Sandborn, "Cost-effectiveness of imaging strategies to reduce radiation-induced cancer risk in Crohn's disease," *Inflammatory Bowel Disease*, vol. 18, no. 7, pp. 1240–1248, 2012.

[87] S. S. Lee, A. Y. Kim, S.-K. Yang et al., "Crohn disease of the small bowel: comparison of CT enterography, MR enterography, and small-bowel follow-through as diagnostic techniques," *Radiology*, vol. 251, no. 3, pp. 751–761, 2009.

[88] H. A. Siddiki, J. L. Fidler, J. G. Fletcher et al., "Prospective comparison of state-of-the-art MR enterography and CT enterography in small-bowel Crohn's disease," *American Journal of Roentgenology*, vol. 193, no. 1, pp. 113–121, 2009.

[89] S. Schmidt, D. Lepori, J. Y. Meuwly et al., "Prospective comparison of MR enteroclysis with multidetector spiral-CT enteroclysis: interobserver agreement and sensitivity by means of "sign-by-sign" correlation," *European Radiology*, vol. 13, no. 6, pp. 1303–1311, 2003.

[90] P. Soyer, M. Boudiaf, E. K. Fishman et al., "Imaging of malignant neoplasms of the mesenteric small bowel: new trends and perspectives," *Critical Reviews in Oncology / Hematology*, vol. 80, no. 1, pp. 10–30, 2011.

[91] R. Caspari, M. von Falkenhausen, C. Krautmacher, H. Schild, J. Heller, and T. Sauerbruch, "Comparison of capsule endoscopy and magnetic resonance imaging for the detection of polyps of the small intestine in patients with familial adenomatous polyposis or with Peutz-Jeghers' syndrome," *Endoscopy*, vol. 36, no. 12, pp. 1054–1059, 2004.

[92] J. G. Albert, F. Martiny, A. Krummenerl et al., "Diagnosis of small bowel Crohn's disease: a prospective comparison of capsule endoscopy with magnetic resonance imaging and fluoroscopic enteroclysis," *Gut*, vol. 54, no. 12, pp. 1721–1727, 2005.

[93] R. C. Semelka, G. John, N. L. Kelekis, D. A. Burdeny, and S. M. Ascher, "Small bowel neoplastic disease: demonstration by MRI," *Journal of Magnetic Resonance Imaging*, vol. 6, no. 6, pp. 855–860, 1996.

[94] A. Postgate, E. Despott, D. Burling et al., "Significant small-bowel lesions detected by alternative diagnostic modalities after negative capsule endoscopy," *Gastrointestinal Endoscopy*, vol. 68, no. 6, pp. 1209–1214, 2008.

[95] M. M. Baichi, R. M. Arifuddin, and P. S. Mantry, "Small-bowel masses found and missed on capsule endoscopy for obscure bleeding," *Scandinavian Journal of Gastroenterology*, vol. 42, no. 9, pp. 1127–1132, 2007.

[96] M. Pennazio, E. Rondonotti, and R. de Franchis, "Capsule endoscopy in neoplastic diseases," *World Journal of Gastroenterology*, vol. 14, no. 34, pp. 5245–5253, 2008.

[97] E. Estévez, B. González-Conde, J. L. Vázquez-Iglesias, P. A. Alonso, M. D. L. A. Vázquez-Millán, and R. Pardeiro, "Incidence of tumoral pathology according to study using capsule endoscopy for patients with obscure gastrointestinal bleeding," *Surgical Endoscopy and Other Interventional Techniques*, vol. 21, no. 10, pp. 1776–1780, 2007.

[98] S. J. B. van Weyenberg, M. R. Meijerink, M. A. J. M. Jacobs, C. van Kuijk, C. J. Mulder, and J. H. T. M. van Waesberghe, "MR enteroclysis in refractory celiac disease: proposal and validation of a severity scoring system," *Radiology*, vol. 259, no. 1, pp. 151–161, 2011.

[99] P. H. R. Green and C. Cellier, "Medical progress: celiac disease," *New England Journal of Medicine*, vol. 357, no. 17, pp. 1731–1743, 2007.

[100] E. Tomei, R. C. Semelka, L. Braga et al., "Adult celiac disease: what is the role of MRI?" *Journal of Magnetic Resonance Imaging*, vol. 24, no. 3, pp. 625–629, 2006.

[101] D. G. Lohan, A. N. Alhajeri, C. G. Cronin, C. J. Roche, and J. M. Murphy, "MR enterography of small-bowel lymphoma: potential for suggestion of histologic subtype and the presence of underlying celiac disease," *American Journal of Roentgenology*, vol. 190, no. 2, pp. 287–293, 2008.

[102] S. J. B. van Weyenberg, J. H. T. M. van Waesberghe, C. Ell, and J. Pohl, "Enteroscopy and its relationship to radiological small bowel imaging," *Gastrointestinal Endoscopy Clinics of North America*, vol. 19, no. 3, pp. 389–407, 2009.

[103] D. P. Beall, B. J. Fortman, B. C. Lawler, and F. Regan, "Imaging bowel obstruction: a comparison between fast magnetic resonance imaging and helical computed tomography," *Clinical Radiology*, vol. 57, no. 8, pp. 719–724, 2002.

[104] A. Lienemann, D. Sprenger, H. O. Steitz, M. Korell, and M. Reiser, "Detection and mapping of intraabdominal adhesions by using functional cine MR imaging: preliminary results," *Radiology*, vol. 217, no. 2, pp. 421–425, 2000.

[105] G. Masselli and G. Gualdi, "MR imaging of the small bowel," *Radiology*, vol. 264, no. 2, pp. 333–348, 2012.

[106] G. Masselli and G. Gualdi, "CT and MR enterography in evaluating small bowel diseases: when to use which modality?" *Abdominal Imaging*, vol. 38, no. 2, pp. 249–259, 2013.