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MINISYMPOSIUM

CT and MRI of paediatric Crohn disease

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Abstract Over the past two decades there has been considerable evolution in cross-sectional imaging modalities for the evaluation of Crohn disease (CD) in children. CT and MRI have contributed to conventional techniques so that now radiology has an even greater role in the management of CD, monitoring disease progression and detecting complications. The role of CT and MRI, their limitations, and the various imaging features that the radiologist should be aware of are discussed in this review.

Keywords Crohn disease · CT · MRI · Child

Introduction

Crohn disease (CD) is a chronic inflammatory bowel disease (IBD) that may involve any part of the gastrointestinal (GI) tract from mouth to anus and is characterized by recurrent episodes of exacerbation and remission. The distal ileum and colon are the most frequently affected parts. CD is characterized by chronic segmental inflammation that may progressively extend through all layers of the intestinal wall and involve extraintestinal structures.

According to their site, typical CD lesions can be classified as superficial, transmural, or extramural [1]. Superficial lesions represent the early stage of the disease, and include mucosal aphthous erosions, and blunting, flattening, thickening, and distortion of the valvulae conniventes. Transmural abnormalities appear as the disease progresses and include longitudinal and transverse ulcers causing the so-called 'cobblestone' appearance, bowel-wall thickening, stenoses of the intestinal lumen, prestenotic dilations, and increased bowel-wall vascularization. Extramural manifestations include increased mesenteric vascularity causing the so called 'comb' sign, mesenteric fibrofatty proliferation, and complications such as abscesses and fistulae.

Early diagnosis, complete demonstration of the extent of the disease, detection of its extramural complications, periodic reevaluation, and identification of recurrence are the goals of imaging studies in the evaluation of CD. Advances in bowel imaging have greatly improved the service that radiologists are able to offer to paediatric gastroenterologists dealing with children affected by CD. Current diagnostic imaging modalities available to the clinicians include—besides conventional barium studies—sonography, CT, MRI, FDG-PET, and ^{99m}Tc white-cell scintigraphy. The role of CT and MRI, and the variety of abnormalities that can be evaluated with these methods, form the basis of this review.

Imaging modalities

Barium examinations of the GI tract have been the cornerstone of the radiological evaluation of patients with suspected CD. Currently, patients with suspected CD routinely undergo endoscopy of the upper GI tract and colonoscopy with ileoscopy, where direct mucosal visualization and biopsy provide the diagnosis in many cases. Therefore, the upper GI component of a radiological study and the barium enema may be avoided in most cases.

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However, according to the ESPGHAN (European Society for Paediatric Gastroenterology, Hepatology and Nutrition) criteria for diagnosis of CD in children, a small-bowel follow-through or enteroclysis should still be performed when there is endoscopic evidence of CD or inconclusive endoscopic findings to rule out small-bowel disease [2]. Endoscopy and barium studies permit excellent evaluation of bowel mucosa and luminal calibre, but they can provide only indirect information about transmural and extramural extension of the disease. Absence of ionizing radiation and the ability to evaluate both gut wall and extramural extension of the disease make sonography a valuable imaging technique. However, sonography is an operator-dependent technique and even a skilled operator may miss bowel abnormalities if they are located behind air-filled bowel loops. Reliable assessment of disease extension and pathological changes involving bowel wall, mesenteric attachments and adjacent structures is essential to evaluate disease activity and to plan treatment, and it is well accomplished with cross-sectional imaging modalities such as CT and MRI that allow direct evaluation of mural and extramural involvement along the whole bowel.

CT

CT enteroclysis was initially described in Germany and named "CT Sellink", honouring one of the originators of enteroclysis [3]. With this technique it is mandatory to obtain good distension of bowel loops because nondilated loops are a potential source of diagnostic errors; they can be misinterpreted as abscesses, masses, or enlarged lymph nodes [4]. Therefore, as in enteroclysis, CT was initially performed with administration of large quantities of opaque contrast medium via a nasojejunal tube, making it an invasive procedure, especially in children [5]. Furthermore, intraluminal opaque contrast media made it very difficult to evaluate contrast enhancement of bowel wall following intravenous injection of iodinated contrast medium, which is an important indicator of the degree of inflammatory activity of the disease.

More recently, satisfactory small-bowel distension has been reported using a 0.5% solution of hydroxypropylmethylcellulose in water as a low-density oral contrast medium [6], making this method more tolerable for children. Methylcellulose solution is an excellent contrast

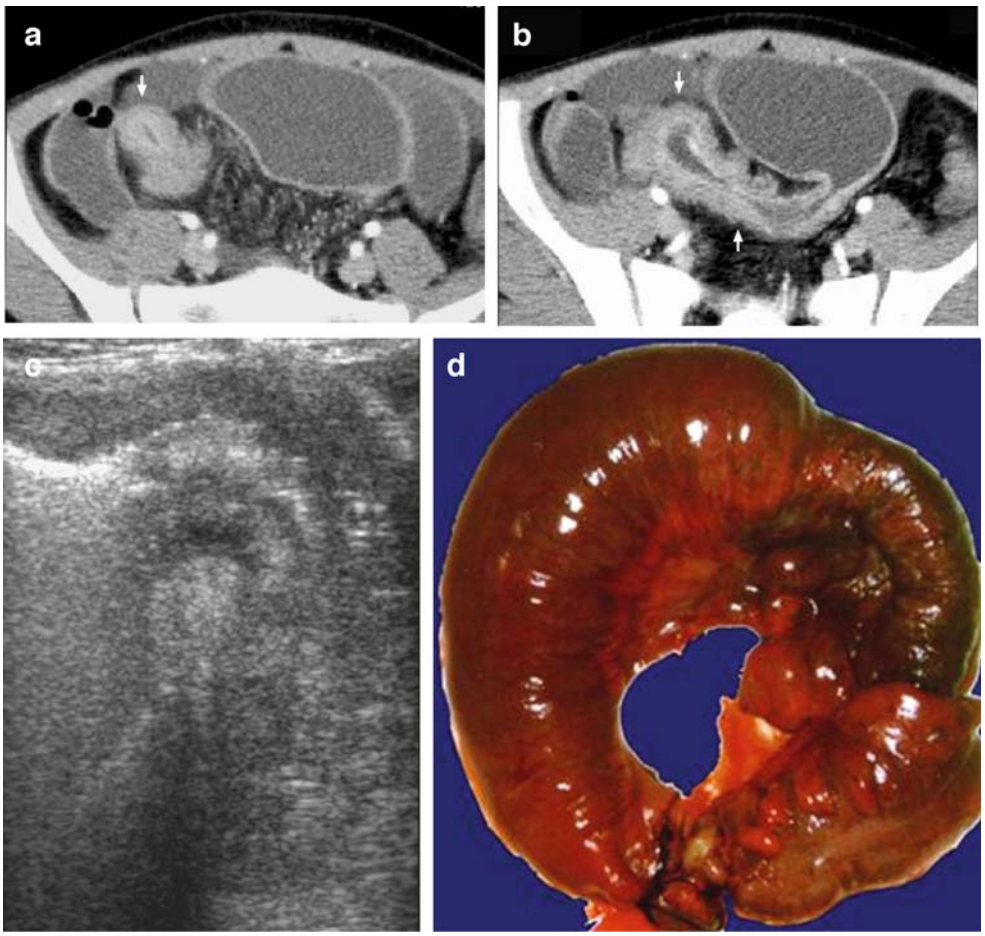

Fig. 1 A 12-year-old child with CD. Contrast-enhanced CT images (single-slice scanner). **a**, **b** The walls of the terminal ileum and caecum (*white arrows*) are diffusely thickened (stratified contrast enhancement) with a luminal stricture that causes obstruction. Dilated fluid-filled loops of bowel are seen proximal to the narrow segment. Enlarged vessels course through prominent mesenteric fat. **c** US of the distal ileum shows bowel-wall thickening, loss of the normal gut signature, and a fixed narrowed lumen, which is seen as an echogenic central line. **d** The resected specimen of terminal ileum

medium for CT enteroclysis: it is nonabsorbable, thus avoiding the risk of haemodilution, and has the same density as water, thus providing good differentiation between the bowel content and the contrast-enhanced intestinal wall [7].

CT imaging may also be limited by motion artefacts from respiration and bowel peristalsis that may impair the quality of the study; breath-hold acquisition and the preliminary administration of hypotonic agents, such as *n*-butyl-joscine or glucagon, are thus recommended. Superficial mucosal lesions are the earliest macroscopic manifestation of CD, but are, in most cases, not detectable with CT. Consequently, when the disease is limited to the mucosa, CT scans are usually normal [4].

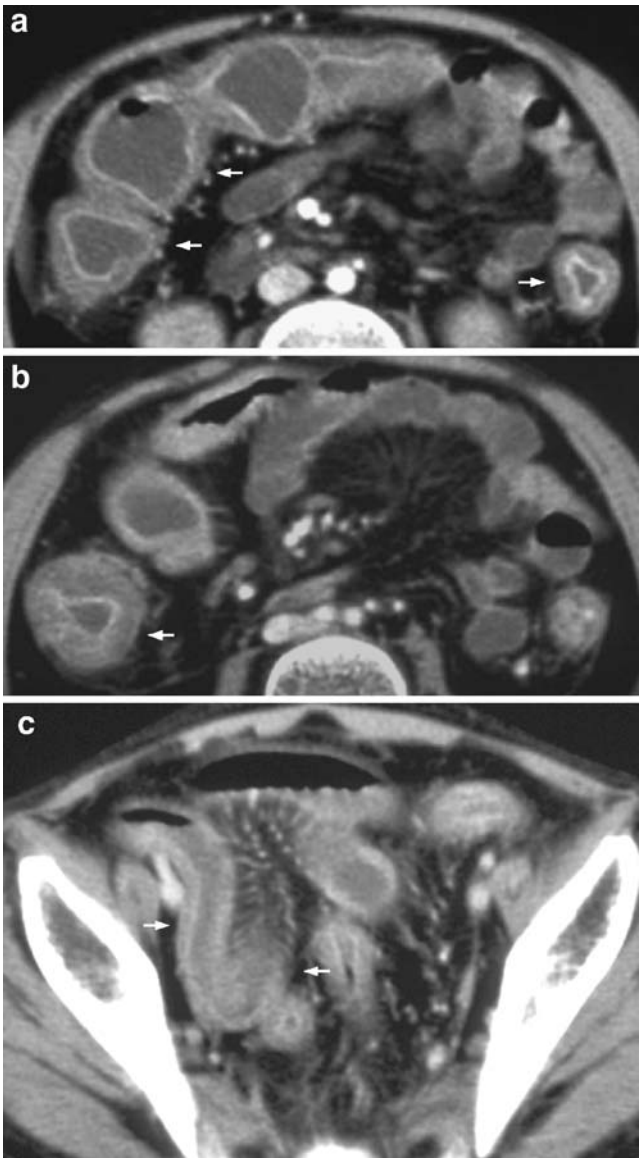

Fig. 2 A 14-year-old child with CD. Contrast-enhanced CT images (single-slice scanner). Circumferential wall thickening of the large bowel (**a**, **b**) and the terminal and distal ileum (**c**). Mural stratification of bowel loops (target sign) is evident due to low attenuation of the oedematous submucosa (*arrows*). Fibrofatty proliferation separates the loops; the comb sign is also evident

Transmural abnormalities are very well depicted with CT. Thickening of the bowel wall (>3 mm) is observed more frequently in the terminal ileum, but other portions of the small bowel, colon, duodenum, and stomach may be similarly affected [8] (Figs. 1 and 2). During the acute phase the affected segment shows mural stratification and often has a target or double-halo appearance. The mucosa appears as a ring of soft-tissue density surrounded by a low-density ring with attenuation near that of water or fat (corresponding to submucosal oedema or fat infiltration), which in turn is surrounded by a higher-density ring representing the muscularis propria [4] (Fig. 2). Inflamed mucosa and serosa may show significant contrast enhancement after an intravenous bolus of contrast medium. In patients with longstanding CD, mural stratification is lost. Homogeneous attenuation of thickened bowel wall after intravenous contrast medium enhancement suggests irreversible fibrosis; the affected segment may appear stenotic, and prestenotic dilation may be observed before the stenotic segment [4].

Fibrofatty proliferation of the mesentery, also known as creeping fat of the mesentery, is an extramural lesion commonly seen in advanced CD that causes separation of small-bowel loops (Fig. 2). On CT scans the sharp interface between bowel and mesentery appears blurred because of the influx of inflammatory cells and oedema [4]. Another extramural lesion involving the mesentery is the so-called comb sign, which is well shown on contrast-enhanced CT scans and appears as hypervascularity characterized by vascular dilatation, tortuosity, and wide spacing of the vasa recta [9]. Enlarged lymph nodes may also be present.

Abscesses, phlegmons, fistulae and sinus tracts may complicate CD. On CT scans, abscesses appear as circumscribed round or oval masses with a hypodense central area that contains necrotic material and a peripheral rim of enhancement when there is a well-formed capsule [4]. Abscesses are most commonly located in the ischiorectal fossa and adjacent to stenotic bowel segments [10]. In 30–50% of cases, bubbles of gas as an air–fluid level within the abscess or dispersed through the collection can be observed (Fig. 3). This gas may be formed by bacteria, but often is secondary to a communication between the GI tract and the skin. If US-guided drainage is not possible, CT is the standard technique for guided drainage [11].

In contradistinction to abscess, a phlegmon is an ill-defined inflammatory mass in the mesentery or omentum. On CT scans it causes loss of definition of adjacent organs and a smudgy or streaky appearance of the adjacent mesenteric or omental fat [4].

Fistulae and sinus tracts affect approximately 20–40% of patients with CD. The involved sites are many: enteroenteric, enterocolic, colocolic, enterovesical, enterovaginal, enter-

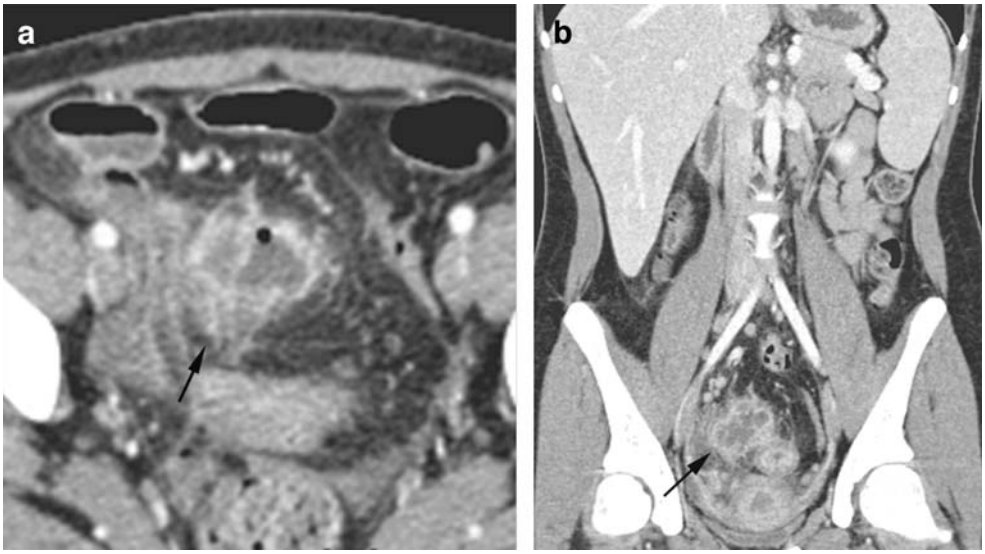

Fig. 3 A 14-year-old child with CD. Contrast-enhanced CT images (64-slice MDCT). **a** Pelvic abscess (*arrow*) with gaseous content surrounded by fibrofatty proliferation. **b** Coronal reformatted image shows the abscess (*arrow*) surrounded by bowel loops with circumferential wall thickening and the target sign

ocutaneous, anorectal, duodenopancreatic, gastrocolic, and, very rarely, colobronchial and enterospinal [12]. When surgical intervention is planned, CT imaging is a very useful diagnostic tool that is superior to conventional techniques in defining precisely the course and anatomic relationships of fistulae and sinus tracts.

A few recent studies in adults have investigated the correlation between signs of "radiologic visible intestinal inflammatory activity" and clinically evaluable disease activity as expressed by parameters such as endoscopic and biopsy findings, or laboratory parameters. Bodily et al. [13] have shown that quantitative measures of mural attenuation and wall thickness on contrast-enhanced CT enterography are strongly correlated with ileoscopy and histological findings, and are sensitive markers of bowel inflammation. Similar results have been reported by Choi et al. [14], and comparable results have been reported by Colombel et al. [15], who also stressed that evidence of fibrofatty proliferation correlates with high levels of C-reactive protein and thus with active inflammation.

The ability of CT to depict activity of CD, its lesions and complications, some of which might be otherwise undetectable with conventional techniques, emphasizes its critical role in the diagnosis and follow-up of patients. Furthermore, the availability of two- and three-dimensional reconstructions with helical multislice CT increases confidence in assessing the presence and extent of the disease. However, it is necessary to consider radiation dose. CD is a chronic condition that may require many radiological investigations over time with a resultant high cumulative dose, especially in children. In defining a protocol for abdominal CT in children, both radiologists and clinicians should realize that image quality is not the only aim when it is known that ionizing radiation may cause cancer in around 1/1,000 of children at a dose close to that of one CT scan. Reducing the dose undoubtedly causes a reduction in the signal-to-noise ratio; it is the radiologist's duty to accept as much noise as will still allow the specific study to be diagnostic [16]. Several scan parameters should be optimized to reduce dose in children. The kVp should be adapted to the diameter of the patient; a lower kVp often allows improved image quality at the same or even lower dose. The tube current (mAs) is the most critical parameter, with different settings suggested according to each scanner, the region to be studied and the age of the patient [17]. The shortest rotation time available should be used in children, as this serves to reduce motion artefacts. In modern scanners, the use of both xy-plane and z-axis dose modulation also plays an important role in dose reduction. A rule of thumb to reduce dose is to acquire relatively noisy thin slices and subsequently to reformat them into thicker images with a better signal-to-noise ratio [18].

$CDTI_w$ is a physical parameter that represents the CT dose index weighted for central and peripheral locations on a round phantom. It reflects the selection of scanning parameters during one rotation and is thus very useful for comparing the relative exposure due to different protocols. Similarly, $CTDI_{vol}$ is another CT dose index and is the ratio $CDTI_w$/pitch. Another fundamental parameter to characterize volume exposure is the dose-length product (DLP), which is the product of $CDTI_w$ or $CTDI_{vol}$ and the length of the scan. DLP can be translated into effective dose by means of factors and methods available in the literature [19]. Recently, the SFIPP (Société Francophone d'Imagerie Pédiatrique et Prénatale) reported acceptable values of $CTDI_{vol}$ and DLP in children imaged with abdominal multislice CT [20] (Table 1).

In March 2007 we acquired a 64-slice CT scanner (Somatom Sensation 64, Siemens, Erlangen, Germany), and we are currently optimizing our CT protocols. Our preliminary results in terms of $CTDI_{vol}$, DLP and effective dose in abdominal CT are shown in Table 1. A comparison

Table 1 Radiation doses in paediatric abdominal CT

Source	Age (years)	$CDTI_{vol}$ (mGy)	DLP (mGy.cm)	Effective dose (mSv)
SFIPP	1	4 (±1.5)	80 (±30)	
	5	5 (±2)	135 (±54)	
	10	7 (±3)	245 (±105)	
Personal experience	7	4.5	150	3
	14	8.6	344	5.2

between abdominal multislice CT and barium meal in children shows that the effective dose of abdominal multislice CT is five- to tenfold higher at least, considering the typical effective dose of a barium meal in children as 0.7 mSv [21].

The relatively high radiation exposure is a limitation to the use of CT enteroclysis in imaging CD in children, and, in fact, most data regarding this method come from studies in adults. Similarly, in our department we do not routinely undertake CT enteroclysis in children with CD. However, we prefer to perform CT when CD is complicated by abscesses and phlegmons because CT is faster and more easily available.

MRI

Lack of ionizing radiation, multiplanar imaging, and superior soft-tissue contrast make MR a potentially ideal technique for studying both the small and large bowel, particularly in children. However, until recently, MR imaging in IBD was impaired by motion artefacts and lack of good oral contrast agents. Nowadays, the availability of fast breath-hold sequences and suitable oral contrast agents has renewed interest in MR as an imaging modality in the study of the bowel [22, 23].

T2-weighted (T2-W) imaging is complemented in most cases by gadolinium-enhanced T1-weighted (T1-W) images in combination with fat saturation. An essential prerequisite for an adequate MR study is optimal distension of bowel loops in order to properly evaluate wall thickness and mural contrast enhancement. In MR enteroclysis, polyethylene glycol (PEG) solution has become a widely used contrast medium [23, 24] as it rapidly progresses along the bowel, is iso-osmotic, and is not absorbable. Furthermore, PEG is ideally suited to children as it can be orally administered thanks to its acceptable taste, thus avoiding the need of duodenojejunal fluoroscopic catheterization [25]. PEG is a biphasic oral contrast agent that produces a dark lumen on T1-W images and a bright lumen on T2-W images. Motion artefacts from bowel peristalsis can be avoided by intravenous injection, just before the examination, of *n*-butylscopolamine [25] or subcutaneous injection of glucagon [23]; both induce intestinal paralysis.

With the possible exception of distortion of mucosal folds, the early superficial lesions of CD are usually not consistently depicted by MRI enteroclysis due to its inadequate spatial resolution [23]. On the contrary, transmural abnormalities, including cobblestoning, thickening, stenosis, prestenotic dilatation and increased parietal enhancement, are well depicted by MRI (Figs. 4, 5, 6 and 7). MRI enteroclysis has an excellent ability to differentiate active inflammation from fibrosis in a thickened bowel segment. Koh et al. [26] observed in adults that the layered pattern of enhancement on gadolinium-enhanced T1-W images is highly specific for active disease. Similarly, bright bowel wall due to increased signal of water on T2-W sequences suggests disease activity. This distinction may have management implications in that the finding of a fibrotic stenosis suggests surgery while inflammation would prompt a more aggressive medical approach. Extramural manifestations and complications such as fibrofatty proliferation, comb sign, mesenteric lymph nodes, abscesses, fistulae and sinus tracts are easily detected (Figs. 8 and 9).

In both adults and children, MRI has been shown to be superior to CT and fistulography in assessing perineal complications of CD, as well as fistulae and sinus tracts, and avoids substantial radiation to the pelvis [27, 28]. Therefore, MRI has become a cornerstone in the evaluation of patients with perianal CD as it is noninvasive and accurate in depiction

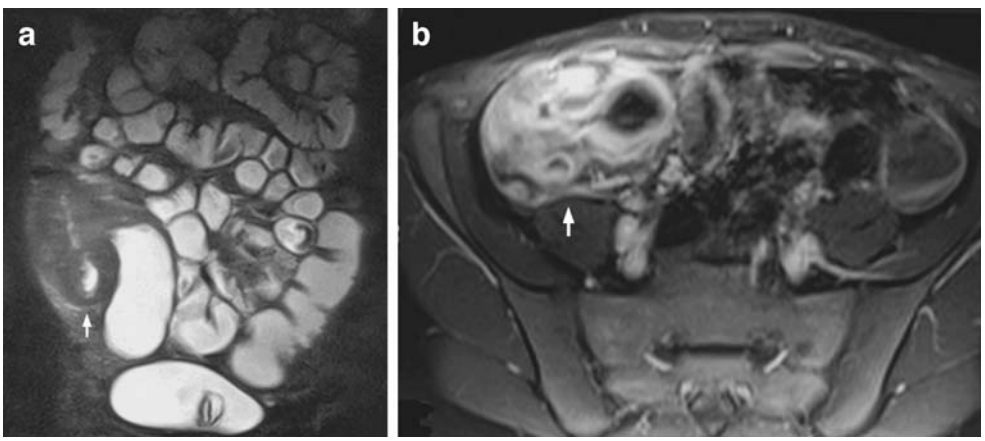

Fig. 4 A 15-year-old child with CD. MRI. **a** Coronal single-shot fast spin-echo T2-W image (EXPRESS) shows severe thickening of the caecal wall (*arrow*) and stenosis of the terminal ileum. **b** Axial T1-W RF spoiled FAST contrast-enhanced image shows marked thickening and intense contrast enhancement in the wall of the caecum (*arrow*) and terminal ileum

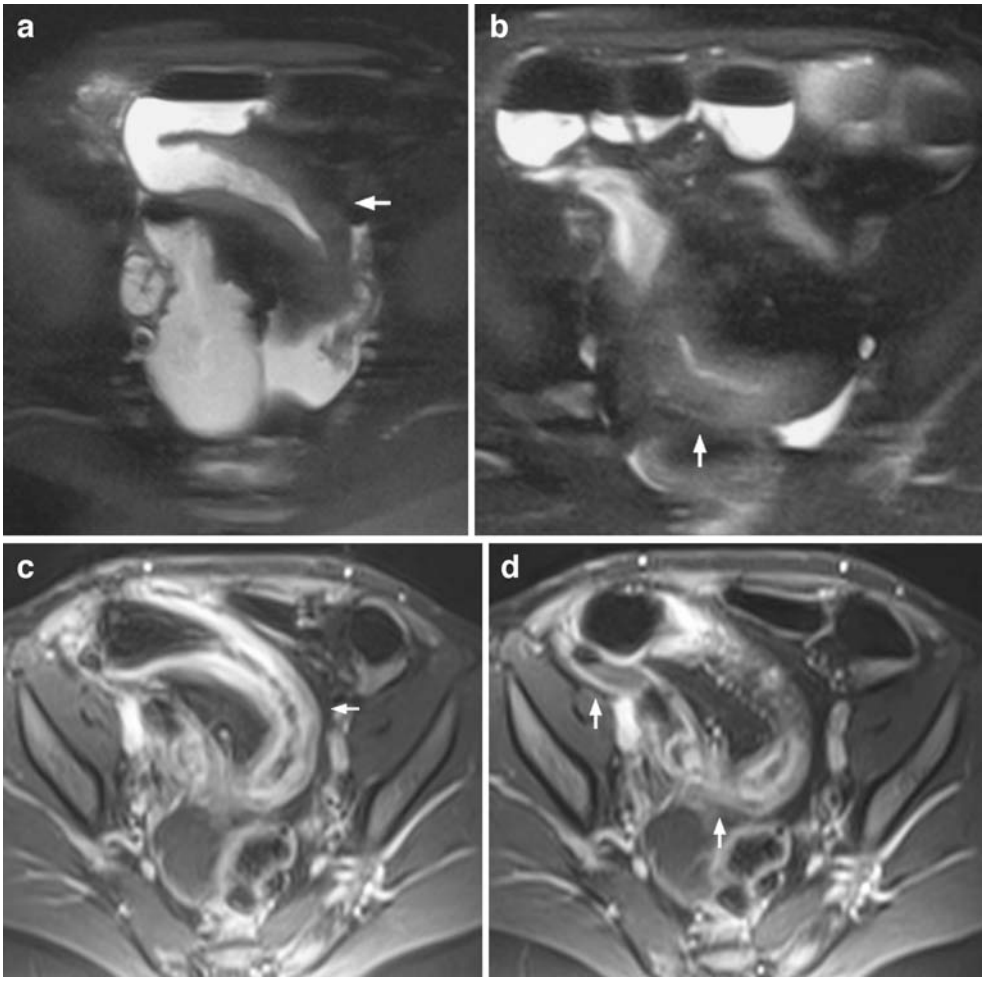

Fig. 5 A 14-year-old child with CD. MRI. **a**, **b** Axial single-shot fast spin-echo T2-W images (EXPRESS) show stenosis and wall thickening of the distal ileum (*arrows*) with preceding dilatation of the prestenotic segment. **c**, **d** Axial RF spoiled FAST contrast-enhanced images. The distal ileum shows wall thickening with stratified contrast enhancement (*arrows*); the mucosa of the bowel wall enhances more strongly than the other layers

of fistulae and abscesses (Figs. 10 and 11). For imaging of perianal CD, external phased-array coils are preferred to endoluminal coils as sinuses and fistulae are often complex and can continue outside the field of view of endoluminal coils. A nonangulated sagittal T2-W sequence is recommended at the beginning of the examination so that the axial and coronal sequences can be orientated perpendicular and parallel to the anal canal, respectively, with the advantage of imaging in surgically relevant planes [29].

The majority of studies concerning the role of MRI in chronic IBD reflect adult practice. A few studies have addressed the comparison between MRI and small-bowel enteroclysis [30, 31]. All these studies have shown markedly higher rates of fistula identification, with evidence in several patients of transmural and/or extramural abnormalities not shown with small-bowel enteroclysis only. Another recent study [32] compared MRI with small-bowel follow-through. MRI was able to provide

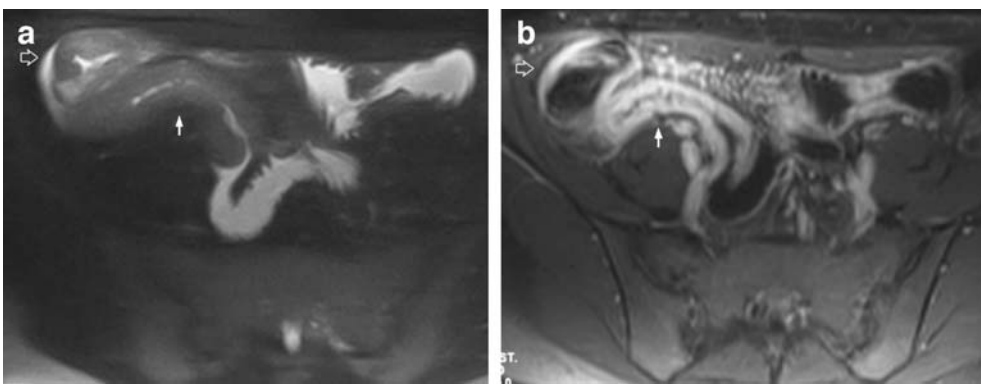

Fig. 6 A 16-year-old child with CD. MRI. **a**, **b** Axial single-shot fast spin-echo T2-W image (**a**) and axial RF spoiled FAST contrast-enhanced image (**b**) show wall thickening (marked contrast enhancement) of the terminal ileum (*white arrows*) and caecum (*white open arrows*)

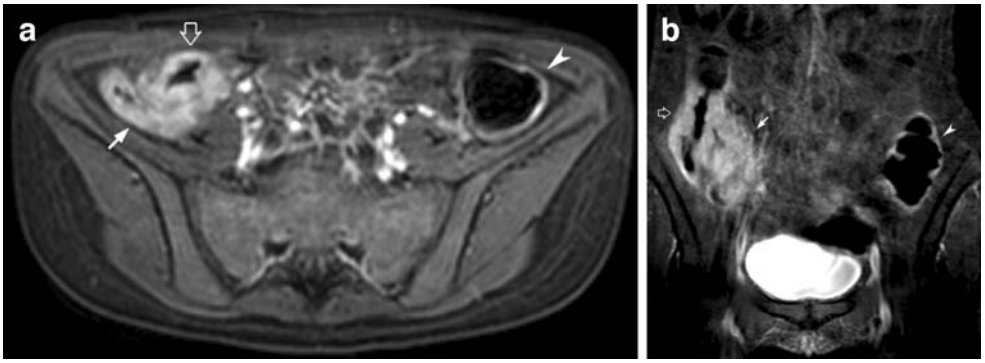

Fig. 7 A 16-year-old child with CD. MRI. **a**, **b** Axial (**a**) and coronal (**b**) gadolinium-enhanced 3-D gradient-echo (THRIVE) images show significant mural thickening with intense contrast enhancement of the terminal ileum (*arrows*) and caecum (*white open arrows*). Marked enhancement of the thickened descending colon is evident (**b** *arrowheads*)

enhanced information in several patients, including active inflammation in stenotic segments based on wall enhancement patterns, vasa recta changes, and lymphadenopathy.

There is just a single study in adults that compared MRI and multidetector spiral CT enteroclysis using well-defined imaging signs in terms of sensitivity, specificity and interobserver agreement [33]. The study included 55 consecutive patients. For bowel-wall thickening, pathological bowel-wall enhancement and lymphadenopathy, sensitivity and interobserver agreement were better with multidetector CT than with MRI, whereas specificity was comparable between the two methods. Sensitivity for intraperitoneal fluid was similar with both methods, with similar specificity and interobserver agreement. The authors of that study concluded that bowel lesions are better detected with multidetector CT thanks to its higher spatial resolution and faster acquisition time, although with the major drawback of a considerable radiation dose.

So far, only a few studies in children affected by chronic IBD have tried to correlate and validate the results of MRI with reference standards. Durno et al. [34] tried to determine whether MRI can differentiate CD from ulcerative colitis (UC) in a very limited number of patients, using ileocolonoscopy with biopsy as the reference. MRI was able to recognize UC in all four children affected, whereas their results in ten children with CD were very disappointing, MRI being able to recognize CD in only five. Furthermore, the degree of parietal enhancement in patients with CD did not correlate with the degree of inflammation determined at endoscopy. Recently, Laghi et al. [35] used MRI to study the terminal ileum in children with CD in order to correlate MRI findings with ileal endoscopy and histology, and with the paediatric CD activity index. Their results in 26 affected children showed a sensitivity and specificity of MRI of 84% and 100%, respectively. In addition, MRI findings correlated markedly with the paediatric CD activity index.

We recently reported our preliminary experience in assessing the ability of MRI enteroclysis to detect bowel abnormalities in children affected by CD. We studied 22 children with a known history of CD and verified the concordance between MRI findings and endoscopy, and B-mode and Doppler sonography. Our results showed that superficial lesions were not detectable with MRI, whereas the MRI findings of stenoses, bowel-wall thickening, bowel-wall hyperaemia, extramural lesions and complications were highly concordant with the findings of endoscopy and sonography. Therefore, our experience suggests that MRI is at least comparable with these techniques in detecting intra- and extramural manifestations of CD [25].

Initially, our MRI studies were carried out using a Marconi-Picker 1.5-T unit (Marconi-Picker, Cleveland, Ohio)

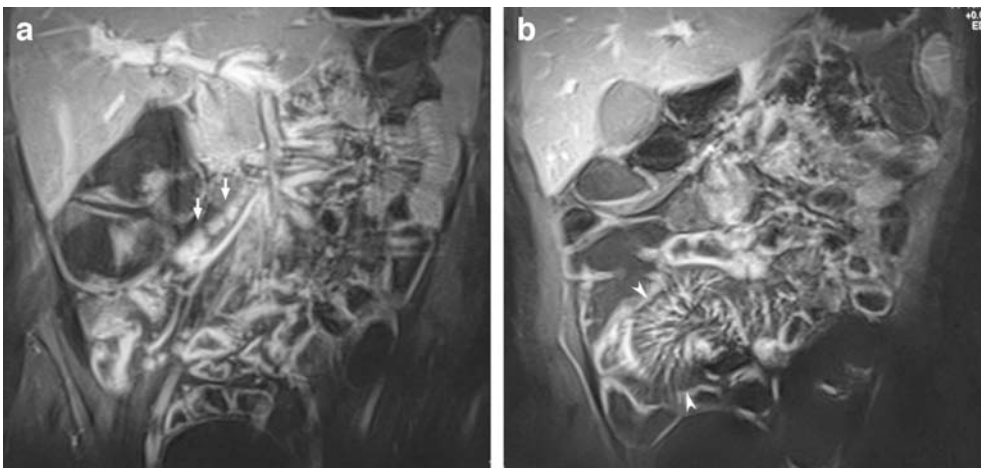

Fig. 8 A 15-year-old child with CD. MRI. **a**, **b** Coronal RF spoiled FAST contrast-enhanced images reveal enlarged mesenteric lymph nodes (*arrows*) and hypertrophied hypervascular mesentery (fibro-fatty proliferation) (*arrowheads*)

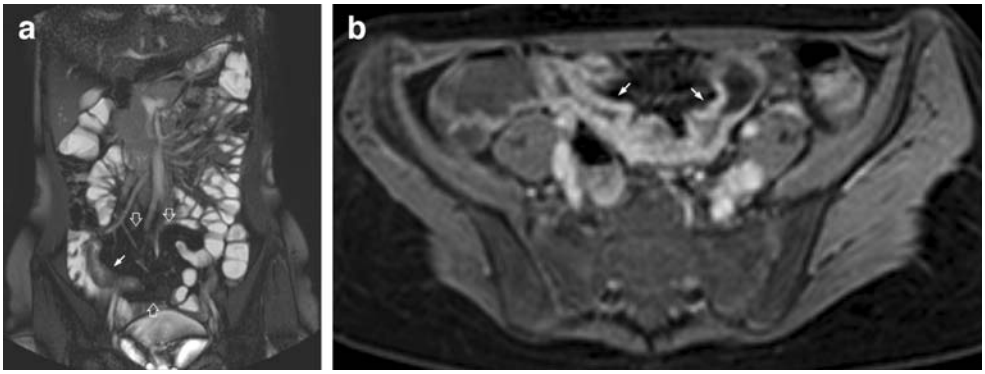

Fig. 9 A 15-year-old child with CD. MRI. **a** Coronal balanced fast-field-echo image shows thickening of the terminal ileum (*arrow*) and fibrofatty proliferation (*white open arrows*). **b** Axial gadolinium-enhanced 3-D gradient-echo (THRIVE) image shows thickened and intensely enhancing walls of the terminal ileum

with a maximum gradient field strength of 16 mT. Patients were studied in the supine position with a phased-array body coil. Breath-hold coronal and axial single-shot fast spin-echo T2-W sequences (proprietary name: EXPRESS) were followed, after intravenous injection of gadolinium chelate (0.3 mmol/kg) for contrast enhancement of the bowel wall, by spoiled gradient-echo (proprietary name: RF Spoiled FAST, *F*ourier *a*cquired *s*teady-state *t*echnique) breath-hold sequences. The lack of artefacts from magnetic susceptibility and bowel peristalsis potentially makes half-Fourier acquisition single-shot fast spin-echo T2-W sequence an ideal acquisition modality for evaluation of abdominal CD. However, a limitation of this sequence is its sensitivity to intraluminal flow voids and the lack of information on the mesentery due to K-space filtering effects [36].

Subsequently, we acquired a Philips 1.5-T Achieva unit (Philips, Best, the Netherlands) with a gradient field strength of 32 mT. For T2-W images, we used initially a single-shot technique (proprietary name: Single Shot Turbo Spin-Echo) with parallel imaging (proprietary name: SENSE). Although parallel imaging techniques allow shorter scan times with shorter breath-holds and a reduction in RF power, the signal-to-noise ratio is adversely affected [29]. For T2-W imaging, we currently use a completely refocused steady-state gradient-echo sequence (proprietary name: Balanced Fast Field Echo). This sequence produces contrast that is a function of the T1/T2 ratio for each tissue. As repetition time and echo time are extremely short, T1 is almost constant so the T1/T2 ratio reflects T2 differences in the tissue. Motion artefacts are minimal as a consequence of the short acquisition time, and there is no sensitivity to intraluminal flow voids thanks to the balanced and symmetrical gradient design. The balanced fast field echo sequence is very effective at showing the bowel wall, mesentery and lymph nodes [29]. For T1-W images, we presently use a T1-W 3-D gradient-echo technique (proprietary name: THRIVE, *T*1 *h*igh-*r*esolution *i*sotropic *v*olume *e*xcitation) and SENSE parallel imaging that provide increased through-plane and in-plane resolution with a higher signal-to-noise ratio than 2-D techniques [29].

Very recently there has been concern that intravenous administration of gadolinium chelates could be linked with the development of nephrogenic systemic fibrosis (NSF) in patients with severe renal function impairment [37]. The main hypothesis is that NSF might occur following systemic gadolinium dechelation causing intoxication with renal dysfunction at the core of this condition. Released gadolinium might overwhelm the cells of the phagocytic system, depressing the reticuloendothelial system and causing activation of a foreign body fibrous reaction. The delayed excretion of these agents in patients with renal impairment increases the contact time in the body and thus

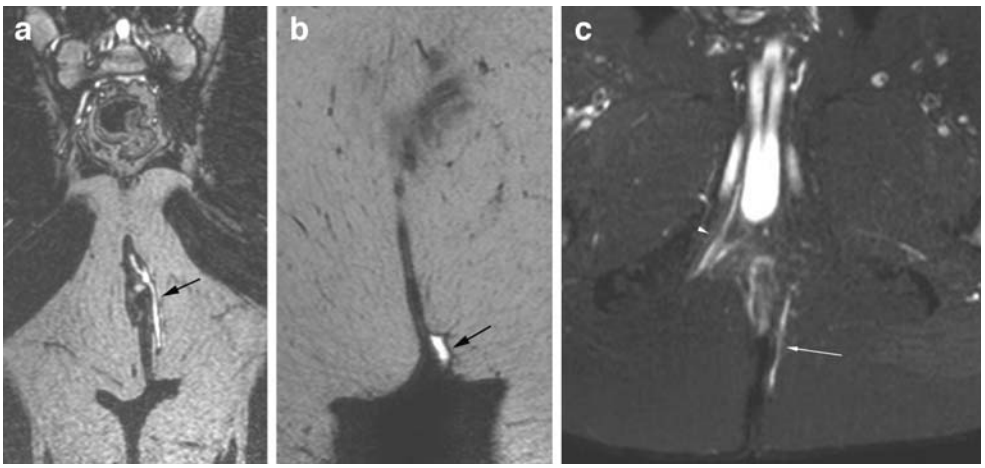

Fig. 10 A 13-year-old child with CD. MRI. **a**, **b** Coronal T2-W images show a transphincteric perianal fistula (*arrow*). **c** Axial T2-W fat-suppressed image demonstrates another fistula that extends superiorly into the right anterior recess of the ischioanal fossa (*arrowhead*)

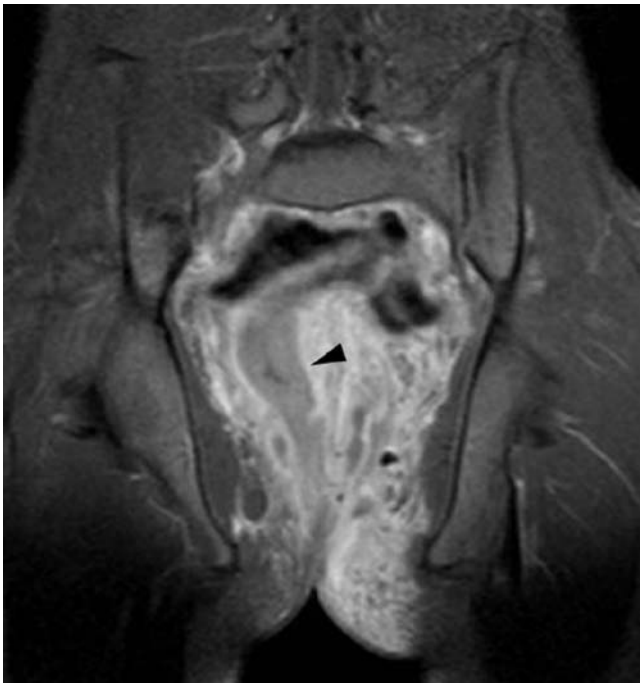

Fig. 11 A 12-year-old child with CD. Coronal gadolinium-enhanced 3-D gradient-echo (THRIVE) MR image shows large abscesses throughout the ischioanal fossa with extension above the laevator ani. The rectum (*arrowhead*) is shifted to the right

the risk of adverse reactions. So far, in over 90% of all those with NSF linked to the use of gadolinium compounds, the NSF occurred after gadodiamide administration. However, there are single cases reports of NSF occurring after gadopentate dimeglumine and gadoversetamide administration. All these gadolinium chelates are characterized by a linear structure that appears to be less stable than the macrocyclic agents such as gadoteridol, gadobutrol and gadoterate meglumine in which Gd^{3+} is caged in a cavity with strong bonds. Therefore, free gadolinium ions might be released more readily from compounds with a linear structure, and this might favour the occurrence of toxic manifestations, although this is not yet proven [38]. Therefore, since April 2007 we have administered a macrocyclic compound such as gadoterate meglumine at a dose reduced from 0.3 mmol/kg to 0.1 mmol/kg (standard dose) and have not experienced significant deterioration of contrast enhancement. Furthermore, we screen kidney function with blood creatinine measurement in each patient in whom contrast-enhanced MRI is planned. Our present protocol for MRI enteroclysis is summarized in Table 2.

Conclusion

The literature on imaging of chronic IBD with CT or MRI has expanded rapidly in the past few years. In comparison with MRI, multidetector CT appears to have an unparalleled sensitivity and specificity in detecting the typical abnormalities of CD. However, the substantial radiation dose makes it an unsuitable method for repeated studies, especially in children. On the other hand, there is increasing evidence that MRI can reliably and accurately show most lesions of CD, with greater accuracy than barium radiographic studies for the detection of extraluminal complications including fistulae and abscesses. Furthermore, lack of ionizing radiation makes it an excellent modality particularly in children who may require repeated studies through their life. Nevertheless, no definite guidelines have been established concerning the role of cross-sectional techniques in children with chronic IBD. A very recent medical position paper from the ESPGHAN on recommendations for diagnosis of IBD in children concludes that MRI may be a promising modality but further validation studies are needed before drawing final conclusions.

Table 2 Authors' protocol for MRI enteroclysis

Stage	Protocol details	
Bowel preparation	Fasting	
	Empty bladder	
	Oral administration of 750–1,000 ml iso-osmotic polyethylene glycol solution, two-thirds 60 min and one-third 15 min before MRI	
	Intravenous administration of 10 mg (patient 8–14 years of age) or 20 mg (patient >14 years of age) of *n*-butylscopolamine to the patient when lying on the MRI table	
MRI study	Body coil, FOV 320 mm (variable according to body size), matrix 256×256	
	T2-W imaging	Axial and coronal completely refocused steady-state gradient-echo sequence (Balanced Fast Field Echo), slice thickness 4 mm, gap 0.4 mm
	T1-W imaging	Axial breath-hold T1-W 3-D gradient-echo technique (THRIVE) with parallel imaging, slice thickness 2 mm, gap 0 mm
	Contrast enhancement	0.1 mmol/kg of gadoterate meglumine (infusion speed 2 ml/s)
	Immediately after contrast medium administration	Two further acquisitions at 1-min intervals using THRIVE and parallel imaging
	After 5 min	Axial, breath-hold, THRIVE with parallel imaging

In our experience, MRI has proved to be a method at least complementary to endoscopy, sonography and barium studies. At our institution, MRI is now routinely performed at diagnosis to evaluate the small bowel in children for better evaluation of disease extension or during follow-up if there is sonographic evidence of relapse or complications, leaving CT and barium radiographic studies for just a very few selected cases.

In the future, the availability of stronger magnetic fields and gradients as well as more advanced reconstruction and acquisition algorithms could further improve resolution of subtle morphological changes that are presently not detectable in most cases, making MRI the preferred method for complete evaluation of the bowel.

References

1. Golberg HI, Caruthers SB, Nelson JA et al (1979) Radiographic findings of the National Cooperative Crohn's disease study. Gastroenterology 77:925–937
2. IBD Working Group of the European Society for Paediatric Gastroenterology, Hepatology and Nutrition (2005) Inflammatory bowel disease in children and adolescents: recommendations for diagnosis – the Porto criteria. J Pediatr Gastroenterol Nutr 41:1–7
3. Thiele J, Kloppel R, Schulz HG (1993) CT-Sellink – a new method of evaluating intestinal wall. Rofo 159:213–217
4. Gore RM, Balthazar EJ, Ghahremani GG et al (1996) CT features of ulcerative colitis and Crohn's disease. AJR 167:3–15
5. Bender GN, Timmons JH, Williard WC et al (1996) Computed tomographic enteroclysis: one methodology. Invest Radiol 31:43–49
6. Reittner P, Goritschnig T, Petritsch W et al (2002) Multiplanar spiral CT enterography in patients with Crohn's disease using a negative oral contrast material: initial results of a non-invasive imaging approach. Eur Radiol 12:2253–2257
7. Rollandi GA, Curone PF, Biscaldi E et al (1999) Spiral CT of the abdomen after distension of small bowel loops with transparent enema in patients with Crohn's disease. Abdom Imaging 24:544–549
8. Klein VHM, Wein B, Adam G et al (1995) Computed tomography of Crohn's disease and ulcerative colitis. Fortschr Rontgenstr 163:9–15
9. Meyers MA, McGuire PV (1995) Spiral CT demonstration of hypervascularity in Crohn disease: "vascular jejunization of the ileum" or the "comb sign". Abdom Imaging 20:327–332
10. Schreyer AG, Seitz J, Feuerbach S et al (2004) Modern imaging using computer tomography and magnetic resonance imaging for inflammatory bowel disease. Inflamm Bowel Dis 10:45–54
11. Horton KM, Corl FM, Fishman EK (2000) CT evaluation of the colon: inflammatory disease. Radiographics 20:399–418
12. Gore RM, Laufer I (1994) Ulcerative and granulomatous colitis: idiopathic inflammatory bowel disease. In: Gore RM, Levine MS, Laufer I (eds) Textbook of gastrointestinal radiology. Saunders, Philadelphia, pp 1098–1141
13. Bodily K, Fletcher J, Solem C et al (2006) Crohn disease: mural attenuation and thickness at contrast-enhanced CT enterography. Correlation with endoscopic and histologic findings of inflammation. Radiology 238:505–516
14. Choi D, Soon JL, Young AC et al (2003) Bowel wall thickening in patients with Crohn's disease: CT patterns and correlation with inflammatory activity. Clin Radiol 58:68–74
15. Colombel JF, Solem CA, Sandbom WJ et al (2006) Quantitative measurement and visual assessment of ileal Crohn's disease activity by computed tomography enterography: correlation with endoscopic severity and C reactive protein. Gut 55:1561–1567
16. Vock P (2005) CT dose reduction in children. Eur Radiol 15: 2330–2340
17. Frush DP (2002) Pediatric CT: practical approach to diminish the radiation dose. Pediatr Radiol 32:714–717
18. Vock P, Wolf R (2007) Dose optimization and reduction in CT of children. In: Tack D, Gevenois PA (eds) Radiation dose from adult and pediatric multidetector computed tomography. Springer, Berlin, pp 223–236
19. Chapple CL, Willis S, Frame J (2002) Effective dose in pediatric computed tomography. Phys Med Biol 47:107–115
20. Brisse H (2006) Guide des procedures radiologiques SFR/INRS Scanographie Pédiatrique. http://www.sfip-radiopediatrie.org
21. European Guidelines for the Optimisation of Fluoroscopic Imaging in Paediatrics (1999) Research contract FIP4-CT00092. Draft final report. DG XII, Brussels
22. Debatin JF, Patak MA (1999) MRI of the small and large bowel. Eur Radiol 9:1523–1534
23. Prassopoulos P, Papanikolau N, Grammatikakis J et al (2001) MR enteroclysis imaging of Crohn disease. Radiographics 21:161–172
24. Potthast S, Rieber A, von Tirpitz C et al (2002) Ultrasound and magnetic resonance imaging in Crohn's disease: a comparison. Eur Radiol 12:1416–1422
25. Magnano GM, Granata C, Barabino A et al (2003) Polyethylene glycol and contrast-enhanced MRI of Crohn's disease in children: preliminary experience. Pediatr Radiol 33:385–391
26. Koh DM, Miao Y, Chinn RJ et al (2001) MR imaging evaluation of the activity of Crohn's disease. AJR 177:1325–1332
27. Koelbel G, Schmiedl U, Majer MC et al (1989) Diagnosis of fistulae and sinus tracts in patients with Crohn disease: value of MR imaging. AJR 152:999–1003
28. Essary B, Kim J, Anupindi S et al (2007) Pelvic MRI in children with Crohn disease and suspected perianal involvement. Pediatr Radiol 37:201–208
29. Horsthuis K, Lavini C, Phil M et al (2005) MRI in Crohn's disease. J Magn Reson Imaging 22:1–12
30. Rieber A, Wruk D, Potthast S et al (2000) Diagnostic imaging in Crohn's disease: comparison of magnetic resonance imaging and conventional techniques. Int J Colorectal Dis 15:176–181
31. Ochsenkuhn T, Herrmann K, Schoenberg SO et al (2004) Crohn disease of the small bowel proximal to the terminal ileum: detection by MR-enteroclysis. Scand J Gastroenterol 39:953–960
32. Bernstein CN, Greenberg H, Boult I et al (2005) A prospective comparison of MRI versus small bowel follow through in recurrent Crohn's disease. Am J Gastroenterol 100:2493–2502
33. Schmidt S, Lepori D, Meuwly JY et al (2003) Prospective comparison of MR enteroclysis with multidetector spiral-CT enteroclysis: interobserver agreement and sensitivity by means of "sign-by-sign" correlation. Eur Radiol 13:1303–1311
34. Durno CA, Sherman P, Williams T et al (2000) Magnetic resonance imaging to distinguish the type and severity of pediatric inflammatory bowel disease. J Pediatr Gastroenterol Nutr 30: 170–174
35. Laghi A, Borrelli O, Paolantonio P et al (2003) Contrast enhanced magnetic resonance imaging of the terminal ileum in children with Crohn's disease. Gut 52:393–397
36. Masselli G, Brizi GM, Parrella A et al (2004) Crohn disease: magnetic resonance enteroclysis. Abdom Imaging 29:326–334
37. Grobner T (2006) Gadolinium – a specific trigger for the development of nephrogenic fibrosing dermopathy and nephrogenic systemic fibrosis? Nephrol Dial Transplant 21:1104–1108
38. Bongartz G (2007) Imaging in the time of NFD/NFS: do we have to change our routines concerning renal insufficiency? MAGMA 20:57–62