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Chapter

Role of Imaging in Small Bowel Crohn's Disease

Bilal Imširović, Enver Zerem and Emir Gušo

Abstract

The small intestine is a challenging organ for clinical and radiological evaluation. The introduction of radiological imaging techniques, which do not significantly disturb patients' comfort and safety, attempts to obtain an adequate diagnosis and valuable information. The aim is to determine the capabilities and potential of ultrasound, computed tomography (CT), diffusion-weighted imaging (DWI), and contrast-enhanced magnetic resonance (MR) enterography to establish the diagnosis and to evaluate the severity and activity of intestinal inflammation. Conventional ultrasound is a suitable orientation method in the initial evaluation of patients with Crohn's disease. At the same time, contrast-enhanced MR enterography provides an excellent assessment of disease activity, as well as the complications that accompany it. Contrast-enhanced MR enterography, combined with DWI, allows for excellent evaluation of disease activity and problems or difficulties following it. The examination can be repeated, controlled and can monitor patients with this disease.

Keywords: ultrasound, computed tomography, diffusion, inflammatory bowel disease, magnetic resonance imaging

1. Introduction

Crohn's disease or enteritis regionalis is a chronic inflammatory disease of the digestive tract, predominantly of the small intestine. It is the most common small bowel disease in the United States and Europe: (3.1–14.6/100,000 in the United States and 0.7–9.8/100,000 in Europe, respectively) [1]. It occurs more frequently in the White population than in African-American and Asian ones, and is particularly common in certain ethnic groups [2]. The disease is equally present in both sexes and most often occurs between twenty and forty years of age [3].

Research into the epidemiology of IBD in areas with a sharply increased incidence may discover important etiological factors associated with the disease development [4].

Although the process most commonly affects the terminal ileum (60–80% of cases), the disease can occur in any part of the digestive tract, from the mouth to the anus [5].

Crohn's disease is a disease of segmental nature, in which healthy parts of the intestine are located between the affected ones. The inflammatory process spreads to all layers of the wall and affects the mesentery and local lymph glands [5, 6].

Many patients have lesions on the terminal ileum and the colon; in many cases, it is challenging to distinguish Crohn's disease from ulcerative colitis by differential

diagnosis. Therefore, for ulcerative colitis and Crohn's disease, there is a common name - inflammatory bowel disease (IBD) [6, 7].

Inflammatory changes in the early stage of the disease are more pronounced in the submucosa than in the mucosa due to lymphedema [8]. The mucosa's lamina propria is infiltrated by polymorphonuclear leukocytes, forming crypt abscesses as a sign of the earliest lesion; this is followed by an enlargement of the lymphoid follicles surrounded by a red ring. Aphthoid ulceration appears on the mucosa, which progresses to deep, most often longitudinal ulcers in the disease's further course. As the disease progresses, the inflammation spreads transmurally with the formation of deep fissures and ulcerations along with the entire wall thickness.

In the advanced stage of the disease, fibrous strictures and extramural fistulas and abscesses develop [9].

Complications in Crohn's disease are common and can be local and extraintestinal [10].

2. Diagnosis of the disease

Inflammatory bowel diseases, especially small bowel diseases, have always posed a diagnostic challenge [11]. The small intestine is a very challenging organ for clinical and radiological evaluation. Detecting the disease and determining its prevalence are two important clinical and diagnostic tasks.

In addition to the above, an important question to be answered is the degree of the disease's inflammatory activity. Although the medical issue was defined in the last century, diagnostic problems are still present. Advances in technology and the introduction of new diagnostic procedures promise better results.

2.1 Imaging techniques in the diagnosis of Crohn's disease

Ultrasound, computed tomography, and MRI are the techniques often used in the diagnosis of abdominal disease.

2.1.1 Ultrasound

Ultrasound is a widely used diagnostic modality that, due to its availability, simplicity, absence of harmful effects, and low cost of the examination, is the first diagnostic method used to diagnose abdominal diseases [12].

Ultrasound is generally performed without the use of a contrast agent. Some studies indicate greater sensitivity after the administration of an ultrasound contrast agent [13].

Technological advances and the growing experience of radiologists make ultrasound an increasingly valuable modality in diagnosing diseases of the gastrointestinal tract. The gradual compression technique and high-resolution multifrequency linear probes enable the displaying of changes in the intestinal wall [14]. Ultrasound plays an essential role in diagnosing diseases of the digestive tract, such as inflammatory bowel disease, small bowel obstruction, appendicitis, intussusception, and hypertrophic pyloric stenosis in newborns [15]. Factors that limit ultrasound examination of the abdominal organs, especially assessment of the digestive tract, are pain, pronounced flatulence, low spatial resolution, inability to display the rectum, and the distal part of the sigmoid colon. Recent studies, which compare Ultrasound and MRI in assessing the enlargement and inflammatory activity of Crohn's disease, indicate that ultrasound can localize the affected intestinal segments to some extent and the complications that accompany them [16, 17].

Sonographic lines of the intestinal wall correspond more to the interfaces than the wall's real histological layers. The central, thickened layer corresponds to the lamina submucosa, while the outer and inner hypoechoic layers correspond to the lamina mucosa and lamina muscularis respectively [18]. The wall is usually stratified if the lamina mucosa, submucosa, and muscularis propria are visible as separate layers. Loss of stratification is the inability to distinguish these layers or distinguish lamina mucosa from submucosa with visible muscularis.

The stomach wall's standard thickness is up to 5 mm, the small intestine up to 2 mm, and the large intestine up to 3 mm.

2.1.1.1 Examination technique and ultrasound findings

After the conventional abdominal ultrasound with a convex probe within the range of 2–5 MHz, the gastrointestinal tract examination is continued with high-frequency linear probes in the field of 5–10 MHz.

When inspecting the intestinal vortices, the gradual compression technique is used to expel air from the intestines.

Incompressibility and thickening are vital signs of a pathomorphological change of the wall. The intestine's pathomorphological altered segment is characterized by concentric wall thickening, absence or reduction of peristalsis, and lack of compressibility under pressure with an ultrasound probe [19] (**Figure 1**).

A wall thickness above 3 mm can be considered a pathological finding [20]. The discovery of a "pseudo-kidney" or "target sign" is the thickened, relatively hypoechoic intestinal wall surrounding the hyperechoic lumen, which is not specific and can be caused by other pathological conditions (neoplasms, intussusception, wall hematomas, hypertrophic pyloric ischemia, appendicitis, diverticulitis, etc.) [21]. A longitudinal view shows the tubular structure.

Some authors report a high percentage of detection of thickened intestinal convolutions (up to 90%) by high-resolution ultrasound, making it more challenging to determine the affected segment's exact length [22].

Therefore, the determination of the affected segment's length is estimated more reliably by other radiological methods [20].

An increasing number of authors emphasize the value of ultrasound in detecting and monitoring chronic inflammatory bowel disease, and in evaluating drug therapy

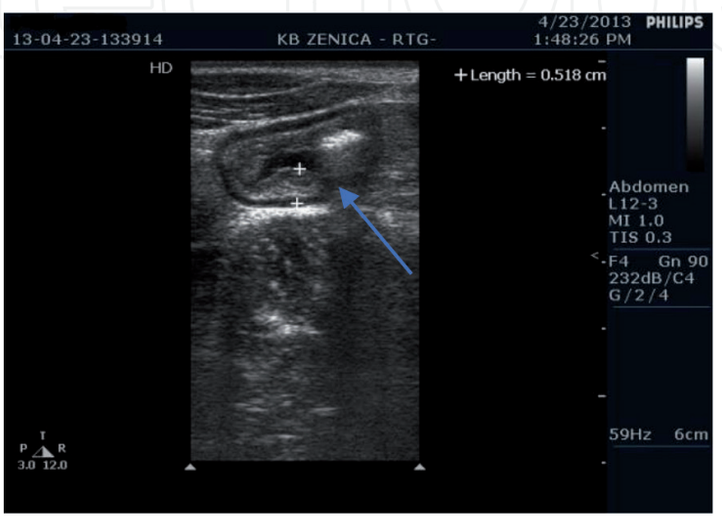


Figure 1.
Thickening of the terminal ileum wall.

effectiveness and presenting extramural complications (fistulas, abscesses, lymph nodes, free fluid) [23, 24] (**Figures 2** and **3**).

There are observations related to Crohn's disease that the loss of stratification due to wall edema correlates with the disease's active phase. In contrast, in the subacute and chronic phases, due to fibrosis, recognizable stratification from all five layers prevails [25].

2.1.2 CT enterography

It is a fast, non-invasive technique that uses a large amount of intestinal contrast material to better display the small intestine wall and lumen [26, 27].

CT enterography is not as sensitive as standard radiological methods in detecting mucosal damage. In comparison between them, it is superior in showing intramural and extraluminal changes [28] (**Figure 4**).

CT-proven mural thickening of the intestinal wall is the most crucial indicator of a pathological finding [29].

In the active inflammatory phase of the disease, contrast imbibition shows CT thickening of the wall and "stratification", which is indicated by a double halo - the "target sign" [29].

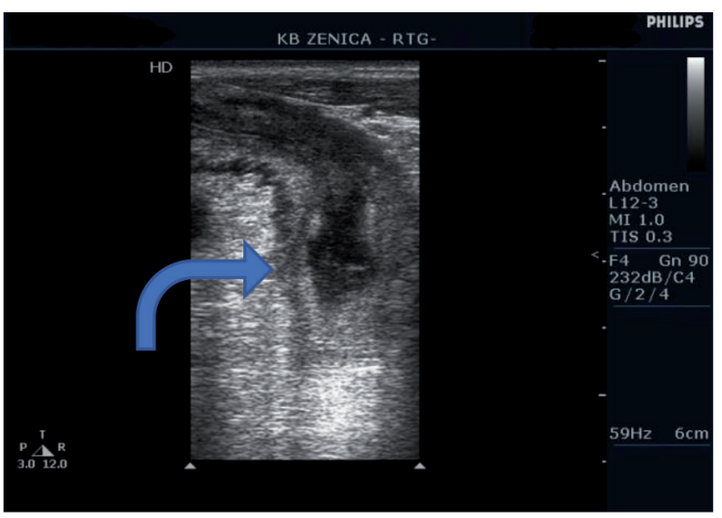


Figure 2.
Enterocutaneous fistula.

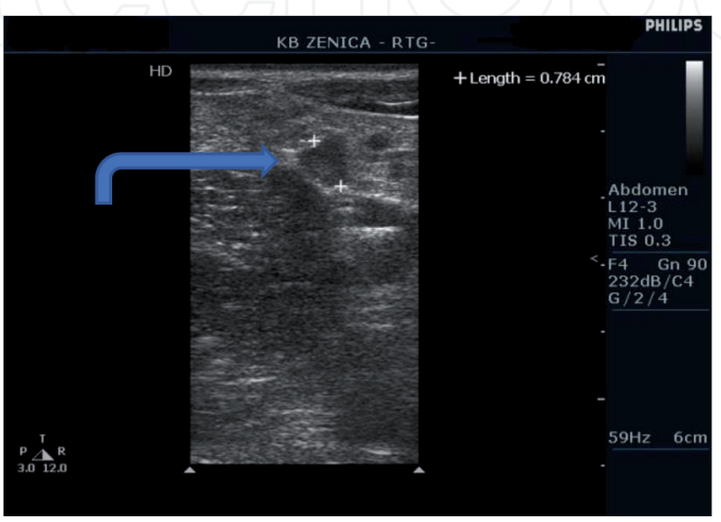


Figure 3.
Hypoechogenic, reactively altered lymph nodes.



Figure 4.
CT enterography - thickening of the terminal ileum wall.

The main limiting factor in CT enterography is ionizing radiation, and it is unsuitable for the follow-up of patients with Crohn's disease.

2.1.3 Contrast MR enterography

Magnetic resonance imaging was introduced as an alternative method for detecting Crohn's disease and can be performed as MR enterography, or as MR enteroclysis [30–34].

MR enteroclysis is more demanding to perform and uncomfortable for the patient because it involves using a nasojejunal tube, and nowadays it is being avoided [35].

Technical advances with rapid sequences (GRE and EPI sequences, particularly HASTE) have minimized artifacts problem due to respiration and peristalsis [36]. Fat signal suppression is one of the technical modifications to better contrast the MR image [37].

The examination involves applying a more considerable amount of fluid orally to ensure the distension of the intestinal vortices, after which the MRI imaging itself is approached. Before the native and contrast sequences, an antispasmodic is administered intravenously to slow down the peristalsis and avoid bowel movement artifacts. After that, axial and coronal T1 and T2 sequences are recorded, as well as dynamic post-contrast recordings.

The fair spatial and temporal resolution of MR images, combined with a large amount of oral contrast agent that provides intestinal curvature distension, allows good visualization of the intestinal wall thickening, and edema thereof, which is useful for assessing Crohn's disease activity [38] (**Figure 5**).

A high signal in the T2 measured image as a well-known indicator of inflammation in human tissue should be a good indicator of inflammation in Crohn's disease.

The inflamed bowel wall in the T2-weighted image has a low-contrast resolution because the inflamed wall is more difficult to distinguish from the high signal of intraluminal fluid and perivisceral fatty tissue T2W sequence.

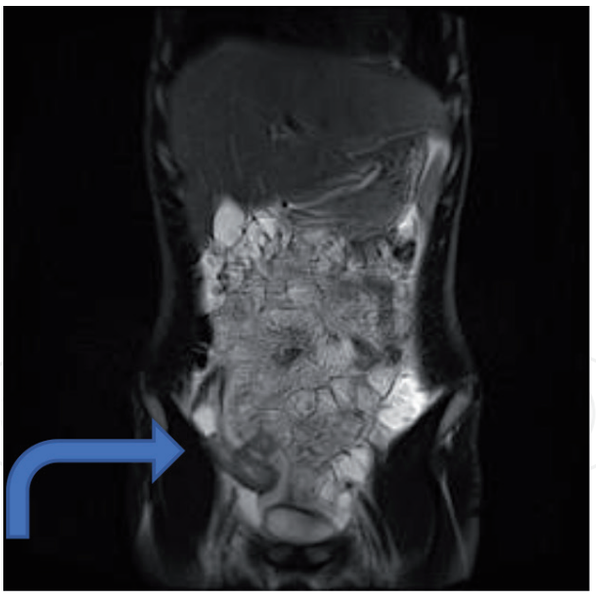


Figure 5.
T2 blade coronal mbh sequence: Distended intestinal loops with visible thickening of the terminal ileal wall.

Suppression of perivisceral adipose tissue signals with the "fat suppression" technique amplifies signal intensity of the inflamed intestine level. Also, superparamagnetic contrast (iron oxide particles) reduces the high intraluminal signal in the T2W-measured image.

Combining the above (fat suppression and superparamagnetic contrast) maximally improves the intestinal wall's high T2 signal. In other words, the mesenteric adipose tissue signal and the intraluminal content signal are "subtracted" from the display, which amplifies the inflamed intestinal wall signal in the T2W sequence.

Wall thickening, length of inflamed bowel and mural signal enhancement after intravenous administration of gadolinium correlate with Crohn's disease activity [39] (**Figure 6**).

MR enterography is easy to perform and has been proven to be useful for detecting active ileitis, assessing disease activity in the area of anastomoses, and identifying extraenteric complications [40–44] (**Figures 7–13**).

One of the earliest papers indicated a high sensitivity of over 90% in detecting fistulas in Crohn's disease [45].

The advantages of MRI imaging are:

- absence of ionizing radiation, which is especially crucial for the young population,
- possibility of using different parameters for the evaluation of inflammatory activity (T2 sequence),
- potential for making multiplanar and coronal representations,
- high signal intensity after the application of gadolinium in pathological changes of the intestinal wall,
- fair contrast resolution (display of wall edema) using fat suppression technique,
- high reliability to show fistulas.

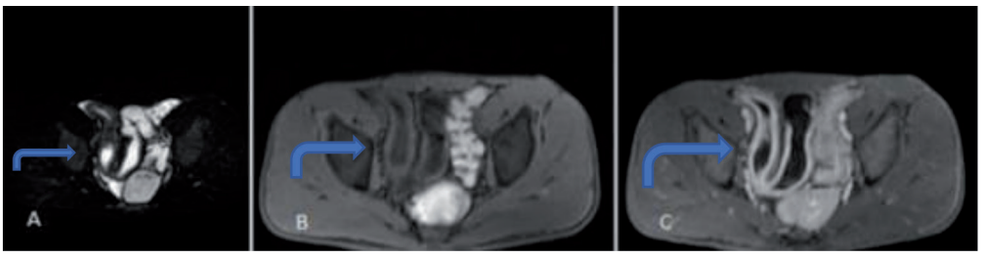


Figure 6.
(A) T2 blade fs axial multi breathe hold (mbh), (B) T1 vibe fs axial mbh, and (C) T1 vibe fs axial mbh postcontrast: Thickening of the ileal wall in Crohn's disease.

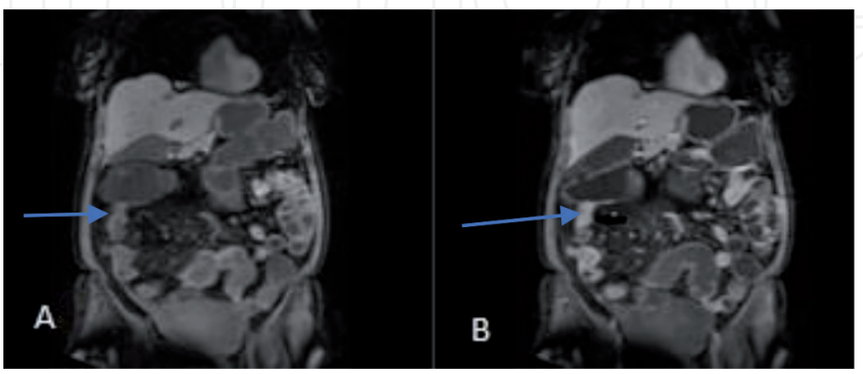


Figure 7.
(A) T1 vibe fs coronal mbh native and (B) T1 vibe fs coronal mbh after paramagnetic contrast agent application: Thickening of the ileal wall in the area of ileotransverso anastomosis.

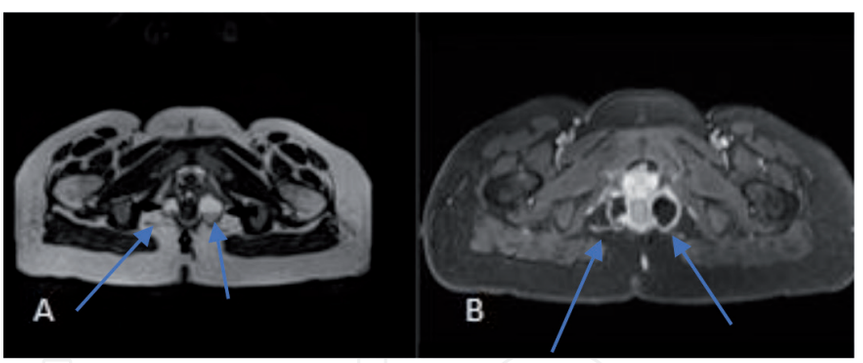


Figure 8.
(A) T2 blade transverse mbh and (B) T1 vibe transverse mbhpostcontrast: Perianal abscesses fused by retroanal fistula.

The disadvantages of MRI imaging are:

- high search price, and difficult availability,
- prolonged search time, and related claustrophobia,
- metal side of the body,
- lower spatial resolution.

2.1.4 Diffusion-weighted magnetic resonance imaging (DW MRI) and apparent diffusion coefficient (ADC)

Diffusion-weighted imaging (DWI) provides unique information about the observed tissue because the image contrast between different structures

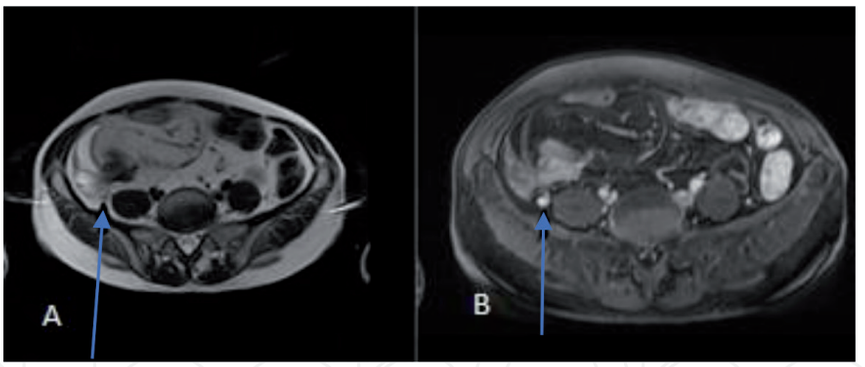


Figure 9.
(A) T2 blade transverse mbh and (B) T1 vibe transverse mbhpostcontrast: Significant lymph node along the Bauchini valve region.

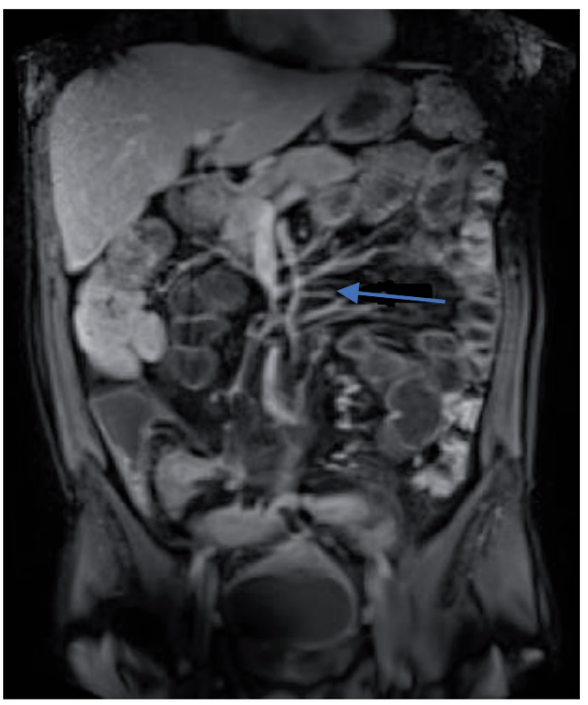


Figure 10.
T1 vibe coronal mbh postcontrast: Indicated blood vessels (vasa recta) as an indirect sign of inflammation.

in this technique depends on water molecules' local diffusion properties (**Figure 14**).

Diffusion-weighted imaging is a method by which we can accurately and non-invasively monitor proton diffusion of water molecules.

Diffusion is a physical term that describes the random movement of molecules without specific transport mechanisms [46].

Diffusion imaging of water is based on the natural sensitivity of MR signals to movement. In the presence of a magnetic field gradient, protons carried by water molecules' movement receive a phase shift of transverse magnetization.

Since other types of intravoxel incoherent movements, such as capillary perfusion, can produce effects similar to those of real diffusion, it has been proposed that the term ADC (Apparent Diffusion Coefficient) be used to quantify the results of in vivo diffusion imaging experiments.

The apparent diffusion coefficient (ADC) is calculated by comparing images with two or more different b-factor values allowing the diffusion to be quantified.

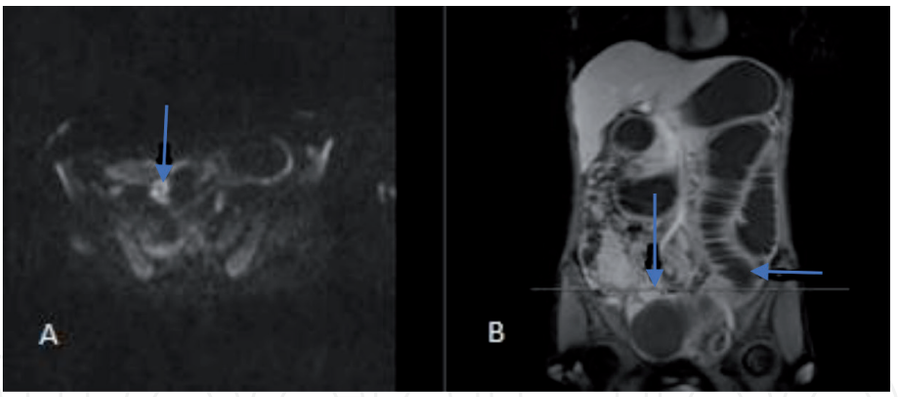


Figure 11.
(A) DWI and (B) T1 vibe fs coronal mbhpostcontrast sequence: Stenosis of the ileal segment with consequent distension of the proximal part of the small intestine - an indirect sign of affection.

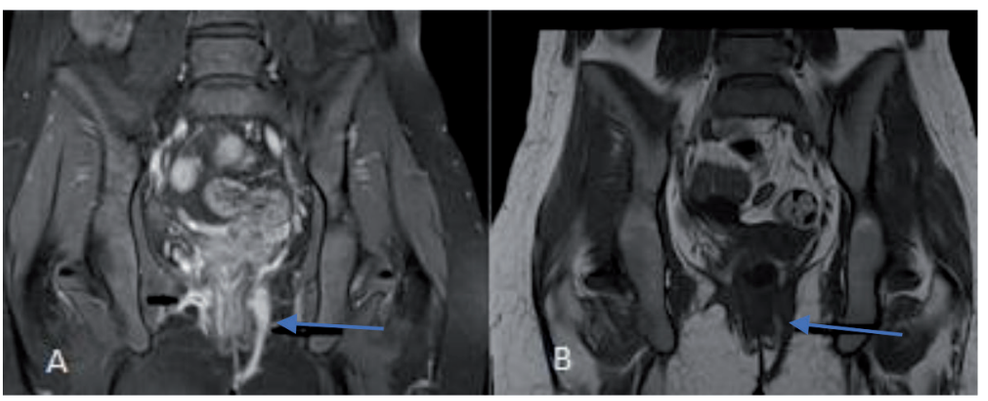


Figure 12.
(A) T1 vibe fs coronal mbh after and (B) pre-application of paramagnetic contrast agent (B): Perianal fistulas.

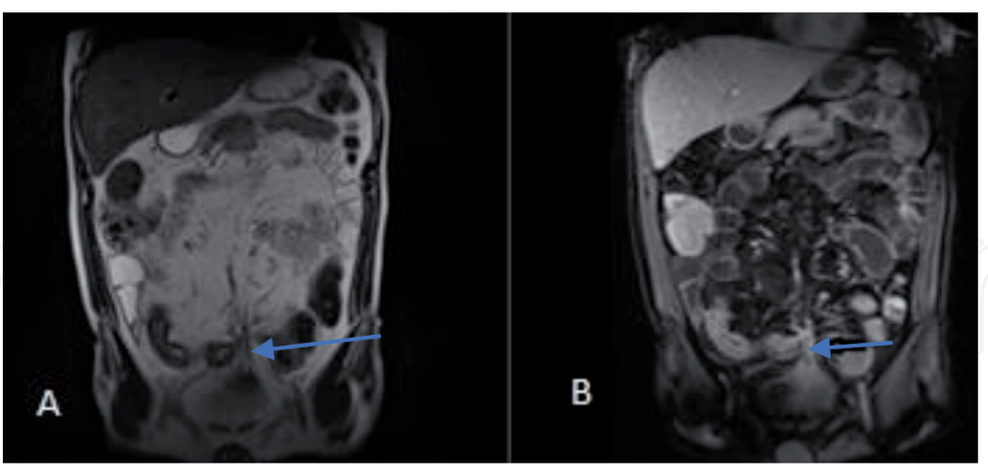


Figure 13.
(A) T2 blade coronal mbh and (B) T1 vibe fs coronal mbhpostcontrast: Enterovesical fistula.

Images in which the shade of the grayscale of an individual image element (pixel) is proportional to the apparent diffusion coefficient value are ADC maps.

Its high sensitivity limits clinical use of diffusion MR imaging to motion artifacts and limited hardware on conventional MR scanners.

The single-shot technique directly improves diffusion recording because it significantly reduces motion artifacts and increases the measured diffusion coefficient reliability by allowing many diffusion images to be obtained in a brief time interval. Thus, this technique is compatible with the clinical protocol [47].

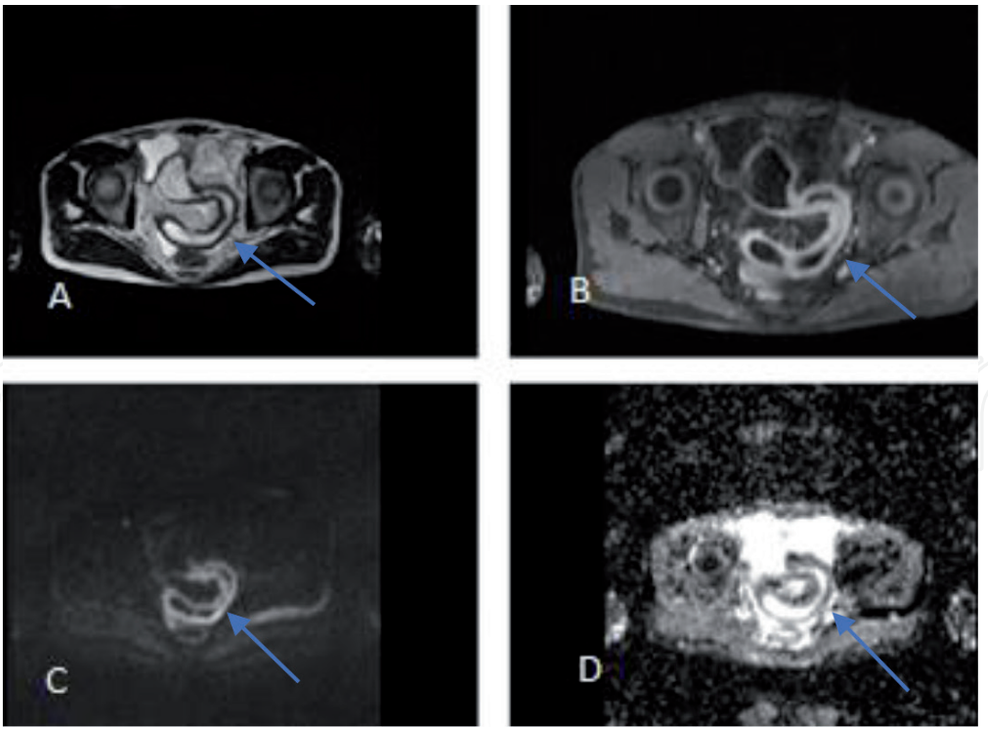


Figure 14.
(A) T2 blade transverse mbh, (B) T1 vibe fs transverse mbh, (C) DWI and (D) ADC map: Thickening of the ileal wall with visible free water diffusion restriction.

With this imaging technique, the whole signal from the tissue is canceled, so that only the signal of the molecules moving due to diffusion is displayed. The method is very demanding for the device, and only devices with good, strong, and fast gradients can cancel the signal enough not to see the "illumination of the T2 image", which can be sensed even with robust devices. These images are used daily to show the brain tissue that has experienced ischemia or stroke. Although the information obtained by diffusion measurements requires new studies, several reports have shown that diffusion imaging could become a powerful principle for the diagnosis of abdominal diseases [48–54].

3. What is the new gold standard?

Barium contrast tests and isotopes have been used to show inflammatory bowel disease, but they carry a risk of ionizing radiation exposure. Barium use is declining to result in fewer radiologists having the expertise and experience for such examinations - the lack of anatomical localizations limits isotopic studies.

CT is beneficial for assessing Crohn's disease complications, but it is burdened with high radiation.

CT enterography improves the visualization of the small bowel disease and allows the assessment of the disease activity.

Ultrasound has been increasingly used for the preliminary assessment of patients with potential IBD [55–59]. Although it is widely available and inexpensive, it depends on the experience of the doctor.

Finally, MRI is the most accurate tool for assessing the disease, its severity, and its prevalence [42–44, 60]. Pelvic MRI completely suppressed other techniques in the assessment of perianal fistulas [61].

According to the latest ECCO guidelines for the diagnosis of Crohn's disease, endoscopy and radiology are complementary techniques to define the site and extension of the disease so that optimal therapy can be planned [62].

4. Conclusions

Conventional ultrasound is a suitable orientation method in the initial evaluation of the patients with Crohn's disease. It can be used as an initial method for the patients who will subsequently undergo MRI enterography. CT is beneficial for assessing Crohn's disease complications, but it is burdened with high radiation.

Contrast MRI enterography provides an excellent assessment of disease activity, as well as the complications that accompany it. The method has a high sensitivity to changes seen in the patients with Crohn's disease; it offers detailed morphological and functional data on the small bowel disease and reliable evidence of normalcy; thus, it facilitates the final diagnosis of early or subtle structural abnormalities and helps to guide treatment and decisions on a further follow-up of patients. Contrast MRI enterography, in combination with DWI, is a comprehensive and safe method compared to reference - endoscopic examinations, and it should be considered as the preliminary examination for the detection of lesions in Crohn's disease, especially in children. Given the convenience and considering the safety and ease of the analysis, MRI enterography combined with DWI is suitable for repeated follow-up examinations, i.e. it can contribute to the follow-up of patients with Crohn's disease. Contrast MRI enterography combined with DWI is an excellent tool for evaluating complications of the underlying condition, especially for detecting fistulas, perianal fistulas in particular.

Conflict of interest

The authors declare no conflict of interest.

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