Pediatric Gastrointestinal Imaging - Enhancing Diagnostic Accuracy while Minimizing Radiation Exposure

Dr. Kunj Shah*

*MD Radiologist

Assistant Professor Government medical College Bhavnagar, radiantdiagnostics23@gmail.com

Abstract
Diagnostic imaging was identified to have a highly significant role in assessing pediatric gastrointestinal disorders. However, there are worries that imaging associated with radiation may be damaging especially in children who are more sensitive to radiation. This paper aims to review the existing management of pediatric gastrointestinal radiology with special emphasis on radiation dose optimization while preserving image quality. A literature review was carried out on low-dose methods, other modalities and image-appropriate image utilization. Flexible low-dose protocols with iterative reconstruction can decrease dose by 65-90% with minimal degradation of image quality. MRI is gradually becoming another valuable non-radiation diagnostic modality especially since it offers complementary information to CT, with high soft tissue contrast. Clinical decision rules for ordering imaging to be appropriate ensure that there is little over-reliance on imaging, and this ensures that radiation exposure is limited among people in the population. Appropriate scanning parameters, which include a low dose, wider adoption of MRI as a complementary method, and more rational utilization of imaging procedures can significantly reduce radiation doses while improving or at least preserving the diagnostic outcomes. More studies investigating the enhancement of pediatric protocols for the current scanner generation should be carried out.

Keywords: Pediatrics; Gastrointestinal; Diagnostic Imaging; Radiation dose; Protocol optimization.

Introduction
The growth of a distinctive medical sub-specialty called pediatric gastroenterology is due to children having peculiar gastrointestinal tract problems that are not found in adults. At the beginning of the twentieth century, gastroenterologists had a meager number of tools at their disposal to diagnose the disorders in the digestive system and its treatments [1]. Radiography was discovered in 1895 and it boosted the development of clinical gastroenterology. Although the history and physical examination are still valid components of diagnosing ascites, descriptive words have transitioned from euphonious 'succession splash' and 'fluid wave' to those with a more technical resonance that relates to imaging [2]. The alimentary canal is a tubular structure that runs from the mouth to the anus and is commonly divided into the upper and lower gastrointestinal tract, despite certain controversy in terms of demarcation [3]. Some of the signs that may be observed in gastrointestinal disease include vomiting – with or without bile, dysphagia, acute or chronic abdominal pain, jaundice, gastrointestinal haemorrhage, constipation, choking, cyanosis, etc. [4].

In diagnosing and sometimes managing gastrointestinal disorders in children, medical imaging is an important tool in Figure 1. Like any other imaging modality, there are dangers associated with radiation and sedation for children, and these must be balanced with the benefits that the modality offers [5]. In the case of children, they are very vulnerable to radiation; hence, in the imaging of children, the dose should be as low as is reasonably achievable without reducing the quality of the images. Similarly, sedation and anesthesia have unavoidable risks regardless of their infrequency [6]. Besides, there are cases when children have an allergic reaction to contrast media. Some of these risks include the following; Heavily reduced by having a child-friendly environment and specialized Pediatric transport teams [7].

The spectrum of pediatric gastrointestinal disorders is broad, encompassing conditions like EA with or without fistula, congenital hypertrophic pyloric stenosis, duodenal atresia, jejunal and ileal atresias Meconium ileus and peritonitis, midgut volvulus and malrotation, inflammation such as appendicitis, colon polyps, necrotizing enterocolitis, intussusception, bowel obstruction, mesenteric cysts, irschsprung's disease [8].

Especially in cases with high gastrointestinal obstruction, plain film X-rays are adequate to assess the diagnosis and management of neonates. Partial obstructions should be evaluated with an upper GI series [9]. Ultrasound is the preferred first form of imaging in some congenital anomalies including hypertrophic pyloric stenosis, enteric duplication cysts, mesenteric cysts, meconium ileus with peritonitis, midgut volvulus and malrotation. Detailed imaging using CT and MRI is also essential in the assessment of esophageal duplications, vascular rings around anatomical structures, and anorectal malformations [10]. Nevertheless, it is crucial to recall that there are always certain dangers connected with radiation, and thus, the utilization of medical imaging should remain careful.

To practice patient-centered care, one has to consider imaging techniques in a manner that will reduce radiation dose and patients' discomfort yet achieve the intended imaging goals. Knowledge of a broad range of possibilities becomes valuable for clinicians to make an appropriate choice for every case [11]. Looking to further progress, imaging is expected to be an even more prominent component of pediatric gastroenterology in the future. However, it is crucial to remember that history and physical exams will always remain the foundation for decision-making. The knowledge of descriptive terms and constant sharpening of clinical skills is still essential for the correct diagnosis and management of cases [12]. Thus, in the case of pediatric care in particular, the potential benefits and harms of each decision at different stages of diagnostics and treatment must be considered.

Imaging Modalities in Pediatric GI Diagnosis

Ultrasound (US) is frequently the first choice of imaging for gastrointestinal (GI) pathology in children because of its non-invasive method without using ionizing radiation and also for real-time examination [13]. The US stands for high-frequency sound waves that are used to produce images of internal body structures in Table 1. Specific indications for Pediatric Abdominal US are appendicitis, intussusception, pyloric stenosis, and liver/biliary pathology.

Advantages of Ultrasound

Many advantages of the US allow it to be most suitable to be applied in pediatric abdominal imaging. Notably, in the US, the technique does not involve the use of ionizing radiation, thus ruling out exposure issues in children [14]. It also enables live demonstration and illustration of anatomical structures and pathological conditions. Other benefits are the fact that the technique is not invasive, less costly compared to other diagnostic techniques and it has high contrast resolution of soft tissues [15]. Further, advancements such as in transducer technology or harmonic imaging have helped in making drastic changes to the image quality.

Clinical Applications

Several common indications for pediatric GI ultrasound are outlined below:

Appendicitis: USG is most employed as the first-line investigation of likely appendicitis in children, and it is highly accurate when practiced by experienced operators [16]. Some important observations seen in appendicitis are the inability to compress the appendiceal, the size of the appendix being greater than 6mm and increased vascularity.

Intussusception: Imaging in children US is the preferred method for diagnosis and assessment of reduction in pediatric intussusception [17]. The sign that is present on the USG is the “target sign” which is pathognomonic of the condition.

Pyloric Stenosis: About the US in diagnosing hypertrophic pyloric stenosis: It is possible to measure pyloric muscle thickness and channel length with enough accuracy in the US [15]. It can also evaluate the outcome of the operation known as pyloromyotomy.

Liver/Biliary Pathology: US offers a more detailed assessment of the overall liver texture and echo transcript, the biliary tree, and the ductal anatomy. It is highly beneficial in locating space-occupying lesions in the liver, distinguishing between intrahepatic biliary obstruction and extrahepatic, and in gallbladder pathology.

Table 1. Imaging Protocols for Common Pediatric GI Conditions

Modality	Condition	Recommended Protocol
Ultrasound	Appendicitis	High-frequency linear transducer, graded compression
MRI	Crohn's Disease	MR enterography, T1/T2-weighted sequences, gadolinium contrast
CT	Acute Abdomen	Low-dose CT, oral and IV contrast as needed

Figure 1. Imaging Modalities in Pediatric GI Diagnosis

X-ray/Fluoroscopy

Application in Pediatric Gastrointestinal Imaging

Radiology and contrast fluoroscopy are very useful in the diagnosis of gastrointestinal disorders in children. These modalities can give helpful diagnostic information in a shorter time and with a smaller cost as compared to other cross-sectional imaging [18]. Nevertheless, it is imperative to consider the risks posed by ionizing radiation, especially when used in children and adolescents and weigh the risk against the clinical needs of the patients in Figure 2.

Bowel Obstruction

An abdominal X-ray is done as the initial imaging modality when assessing for any mechanical small bowel obstruction [19]. They can confirm obstruction by showing sight of distended small bowel loops along with air-fluid level. Fluoroscopy can also be done where the area of obstruction and the extent of obstruction can be seen and distinguishing between partial and complete obstruction made depending on if or how much contrast passed through the obstruction. Plain films and fluoroscopy exposure are less than CT scans [20].

Malrotation

Fluoroscopic examination using barium contrast is preferable for diagnosing malrotation and midgut volvulus in children than radiographic studies [21]. These kinematic investigations can depict the duodenojejunal flexure to be in an incorrect place and look for volvulus. Early diagnosis is, therefore, mandatory to avoid the development of intestinal ischemia and necrosis.

Dysmotility Disorders

Fluoroscopy in a standing position can assess gastrointestinal dysmotility in pediatric patients. Some of them are barium swallow for patients with disorders in the esophagus and upper GI tract, and kontrast enemas for studying colonic dysmotility [22]. Conditions like gastroparesis, chronic intestinal pseudo-obstruction and Hirschsprung's disease are some of the functional disorders that can be examined. The amount of radiation should be kept to a minimum by using screening that is not continuous but instead done in intervals.

Figure 2. X-ray/Fluoroscopy in Pediatric Gastrointestinal Imaging

Computed Tomography (CT)

Abdominopelvic CT is a significant imaging modality in the assessment of the GI tract and the diagnosis of a multitude of abdominal diseases. CT offers sectional images of the GI organs and is sensitive to diseases and lesions in this region [23]. However, CT also has its limitations such as the ability to expose patients to ionizing radiation and the dangers associated with IV contrast in Figure 3.

Clinical Focus of CT in Imaging the Gastrointestinal Tract

Appendicitis in Obese Patients

CT has been widely employed in patients who are believed to have appendicitis, especially in those with obesity where physical exams and ultrasound may not reveal the pathology [24]. CT can identify an inflamed appendix and any relevant complications like perforation or formation of an abscess.

Small Bowel Obstruction

Using CT angiography, visualization of the superior mesenteric artery and vein allows us to determine the location of the small bowel obstruction and its cause [25]. The clinical findings that are suggestive of bowel obstruction are a dilated small bowel with an apple core sign, an empty colon and the presence of a line demarcating dilated and non-dilated bowel.

Trauma Imaging

CT is useful for initial imaging in the evaluation of suspected abdominopelvic injuries due to blunt or penetrating mechanisms [26]. MR images of planar and reformation injury accurately define solid organ injury, bowel and mesenteric injury and vascular injury.

The benefits of CT when used in the assessment of the GI tract are as follows.

High Spatial Resolution

CT provides better spatial resolution than ultrasound, barium studies, and MRI because of its narrow X-ray beam. CT is superior in visualizing fine structures and small pathology in the GI tract [27].

Rapid Scan Times

It is very fast to acquire the images with the help of the CT technique. Variably, the scan time can take as little as a few seconds when only one or two areas of the body are scanned and at most less than a minute when scanning the whole of the abdomen and pelvis. High-speed capabilities of the acquisition allow imaging of patients with acute pathology and reduce motion-related artifacts.

Limitations in the use of CT for imaging the gastrointestinal system.

Ionizing Radiation

Sub-CT radiation risks are relatively small but the accumulation of those risks from multiple CT scans over the entire life span is rather large [28]. They have also used scans to show increased future cancer risks in children who undergo CT scans. Consequently, CT scans should not be performed gratuitously and should be optimized when they are indicated.

Risks of Contrast Administration

Iodinated contrast use for CT scans also involves rare risks such as allergic reactions when administered intravenously. Another risk factor includes contrast-induced nephrotoxicity which is common in patients suffering from altered renal function [29].

Motion Degradation

Gross cardiac and respiratory movements can cause motion-related blur and artifacts although these may be reduced using other scanners and scanning protocols. Abdominal wall pulsation and peristalsis of the bowel can hinder the visibility of the bowel wall and mucosa without using an antispasmodic agent.

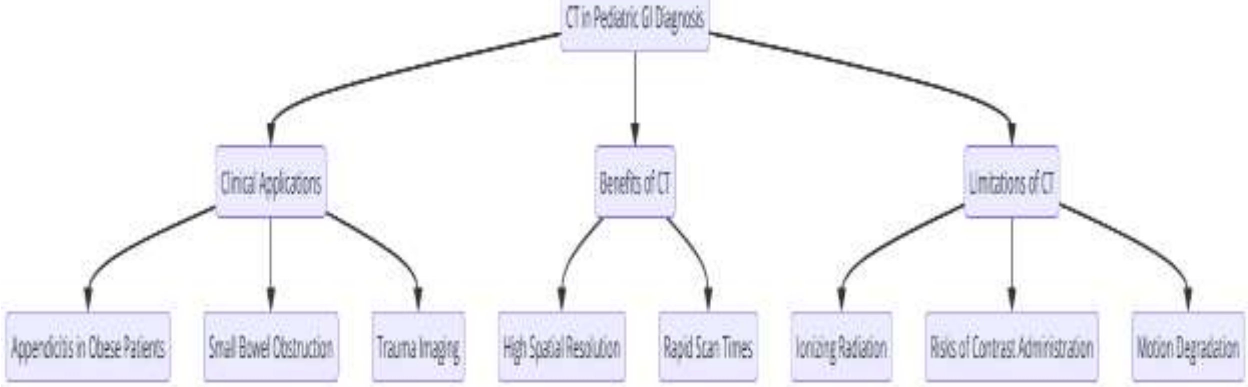

Figure 3. CT in Pediatric GI Diagnosis

MRI Case Reviews and Imaging Strategies in Pediatric Radiology
The use of MRI is advantageous in the assessment of pediatric patients for the following reasons: As a result, MRI is a valuable imaging modality in diverse clinical applications. Below are some of the specific uses of MRI's in children:

Central Nervous System Applications
MRI should be preferred in pediatric neurological disorders due to the lack of ionizing radiation in its use. MRI remains an invaluable tool in imaging soft tissues to assess developmental, inflammatory, vascular, traumatic, infectious, and neoplastic changes affecting the brain and spinal cord [30]. For instance, MRI is particularly useful in showing malformation of cortical development, white matter diseases such as demyelination and posterior fossa tumors like medulloblastoma and brain stem gliomas, vascular lesions including arteriovenous malformations and fistulae, abscesses in meningitis and injuries to the spinal cord [31]. Contrast-enhanced MRI can identify even minimal enhancement that suggests brain or leptomeningeal spread. Functional MRI outlines eloquent cortex to direct neurosurgical maneuvers [32,33]. As for the white matter organization and development, there are diffusion tensor imaging and tractography. Thus, MRI is a valuable tool in diagnosis, preoperative planning, and follow-up of the various central nervous system pathologies in children without the risks associated with radiation.

Body Imaging Applications
Although ultrasound and CT are applied in the study of body images in children more frequently, MRI is essential in evaluating some of the important characteristics in children [34]. MRI is helpful in the assessment of the liver and lesions, pancreatic tumors, adrenals and retroperitoneal disorders [35]. MRI offers excellent soft tissue contrast and distinguishes benign processes from more sinister pathology without using ionizing radiation in the management of the child's condition [36]. Other pediatric indications for MRI involve evaluation of musculoskeletal abnormalities to better define the location and extent of bony or soft tissue changes which may inform the next course of management [37]. Finally, although not as real-time as ultrasound and not possessing the high spatial resolution of CT, MRI allows the assessment of several organ systems in children with no detrimental effects of Multiple passages of radiation in Figure 4.

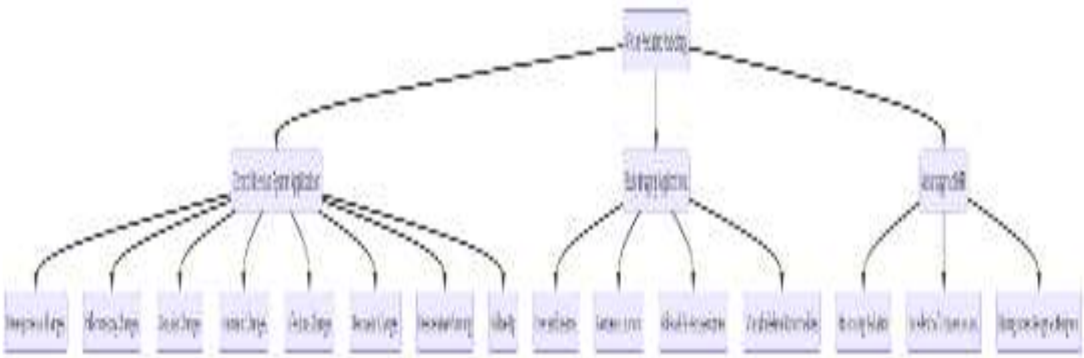

Figure 4. MRI Case Reviews and Imaging Strategies in Pediatric Radiology

MRI offers high contrast and provides a detailed depiction of the soft tissue and visceral structures by distinguishing between the normal and pathologic tissues.

Cardiovascular Imaging
Cardiac MRI has emerged in the past few years as a valuable imaging technique in several aspects of congenital and acquired cardiac disease in children [38]. CMRI is commonly used as the gold standard

for assessment of the cardiac chamber volumes, ventricular function, and cavity dimensions [39]. It is also worth noting that owing to the excellent tissue characterization possible with CMRI, one is also able to map velocities and tissue pathology to a T. Such makes CMRI helpful in the evaluation of diseases such as cardiomyopathies [40]. CMRI also offers high spatial resolution to facilitate the assessment of great vessel anomalies. Besides, CMRI is the imaging test of choice for assessing the viability of myocardial tissue in ischemic heart disease as well as in patients who have experienced myocardial infarction [41]. This is because, unlike other imaging techniques that use ionizing radiation, CMRI does not employ any form of radiation making it ideal for serial imaging on children.

Gastrointestinal Imaging

MRI is increasingly used in the evaluation of Crohn's disease extent and activity in children [42]. It could also assess bowel wall edema, ulceration, and enhancement all in a non-invasive manner and without using ionizing radiation [43]. MRI is useful for appendicitis, especially when utilized as a cross-sectional imaging modality for the appendix and to rule out other diseases in cases of inconclusive clinical or ultrasound findings [44]. MRI is also helpful when increasing the specificity of abdominal masses detected on ultrasound, with features such as diffusion-weighted imaging helping to differentiate between cystic and solid lesions [45]. However, MRI is yet to replace ultrasound as the first-line imaging modality in intussusception because of its availability and lack of radiation, but it can reliably demonstrate the characteristic bowel-within-bowel appearance and should be used in cases that are inconclusive on ultrasound in Figure 5.

MRI is noninvasive and does not employ ionizing radiation, which allows for multiple evaluations in children with chronic gastrointestinal disorders.

Musculoskeletal Imaging

In musculoskeletal concerns, MRI helps assess bone marrow, ligaments, tendons, cartilage, as well as soft tissues. That is for the diagnosis and assessment of the extent of infection, inflammation, trauma, tumor as well as congenital limb anomalies and spinal abnormalities in children [46].

Other Applications

Some of the other specific areas where the use of pediatric MRI is appropriate are in imaging the neck and chest, pelvis and renal and genital regions. Contrast-enhanced MRI is also done to assess certain types of lesions [47]. MRI is, therefore, an essential component of the imaging armory for the evaluation of children with the disease across body systems, in conjunction with CT and ultrasound.

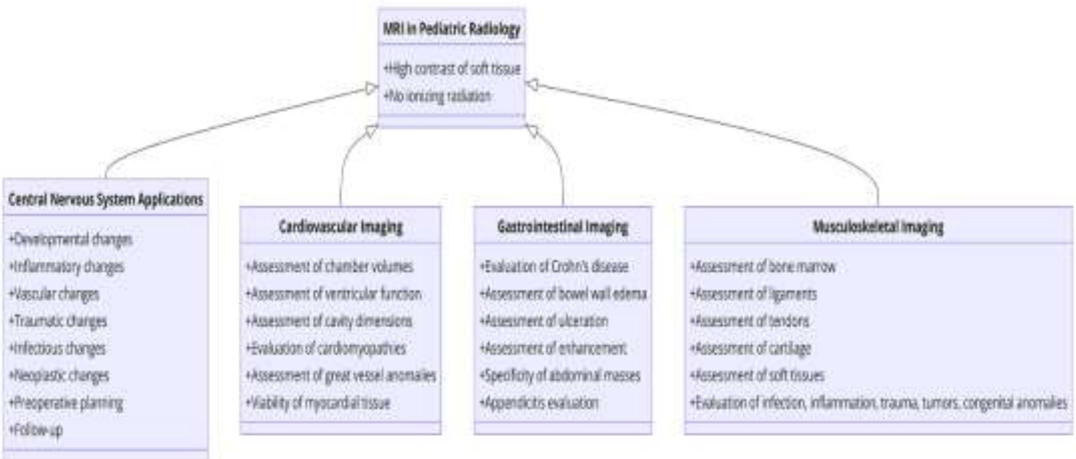

Figure 5. MRI Applications in Pediatric Radiology

Nuclear Medicine

Two common methods of nuclear imaging applied to assess gastrointestinal structure and function include the use of tracer agents that emit radiation. Other typical scans are gastric emptying scans assessing motility [48], gastroesophageal reflux scans to assess abnormal reflux [49], Meckel's scan to identify ectopic gastric mucosa [50], and liver-spleen scans evaluating the reticuloendothelial system [41]. These physiologic tests have high sensitivity in identifying pathology and offer useful information in disorders such as gastroparesis and reflux diseases. Nonetheless, nuclear imaging has relatively low spatial resolution of the body compared to cross-sectional imaging in Table 2. However, a drawback of using this treatment method is the exposure of the patient to radiation, particularly in a young patient or women in their childbearing ages. Measures that may need to be taken, and reasons for exposing radiation in such circumstances, must be discussed as and when required in Figure 6. However, nuclear gastrointestinal imaging still has its role in diagnostic evaluation in certain case settings.

Table 2: Common Pediatric GI Conditions Diagnosed by Ultrasound

Condition	Sensitivity	Specificity	Typical Findings
Appendicitis	85-90%	92-95%	Enlarged appendix, non-compressible, peri-appendiceal fluid
Intussusception	98-100%	98-100%	Target sign, pseudo-kidney sign
Pyloric Stenosis	90-95%	95-98%	Thickened pyloric muscle, elongated pylorus

Figure 6. MRI Image of Pediatric Crohn's Disease. (a) A transverse image through the right lower quadrant demonstrates normal, collapsed small bowel loops. (b) A transverse image through the mid abdomen in a 14-month-old boy reveals multiple distended, fluid-filled loops of bowel

Minimizing Radiation Exposure

1. Protocol Optimization

Radiation protection in children: Techniques for avoiding unnecessary exposure

As CT, X-ray and other imaging modalities are used more frequently in the assessment and treatment of children, the potential dangers of biological damage from ionizing radiation at low to moderate doses over the long term need to be lessened [51]. Given that children are likely to have longer life spans and are considered to suffer the most from the effects of radiation harm, all possible efforts should be made to ensure that radiation exposures are kept to the lowest possible levels [52]. In this light, perfecting a protocol along with the help of appropriate technologies, and staff training can largely reduce doses.

1. Implies the general enhancement of this protocol for pediatric patients.
The management should therefore be in a way that would be suited for children due to their relatively small size compared to adults [53]. Adjustments can include:
Reduced exposure – Reducing tube voltage to 80 or 100 kVp if the patient is under 12 years old also improves contrast by better penetration and reduces the dose as there is better beam attenuation in these settings. Special care should be taken with regions that are larger than the rest of the body, such as the torso [54].
Lower tube current – Employing low tube current, for instance reducing it from 300mA to 40-60mA could be possible without the need to affect the image quality of the X-ray.
Faster rotation times – The modern scanner's rotation time of 0.35s to 0.4s nearly stops motion.
Beam collimation – Source collimation to the body part anatomy reduces radiation to surrounding structures.
Automatic exposure control – Current is adjusted according to the patient's linear attenuation coefficient to achieve a dose reduction of up to 40%.
Any adjustment entails ascertaining the quality of diagnostic images on the scout views before moving forward.

2. The 'Technical Parameter and Reconstruction Developments' subheading deals with the following:
EB-IR methods allow an approximate reduction of the radiation dose by 30-90% in comparison with FBP methods, taking into account photon statistics and noise more accurately [55]. These compute-intensive techniques have been made reasonable in terms of reconstruction time through the help of graphics processing units. Sinogram affirmed iterative reconstruction methods such as model-based methods like incorporating anatomical a priori information to generate images from low-dose data.
Iterative techniques based on statistical and model methods require optimization for the making of the scanner and the pediatric protocols applied [56]. We should learn how to set noise reduction filters so that the images do not look overly smoothed.

3. Staff Training
Achieving an ALARA culture therefore necessitates education and training of imaging staff. Due to the importance of pediatric imaging, protocols have to be well-defined and set for each application on scanners. Technologists are required to maintain prescribed technical parameters and cannot vary from set default values without advice from a medical physicist [57]. Concerning radiation dose-related indices such as CTDIvol, these can be used to measure safety enhancement.
Pediatric imaging can be done safely and effectively by proper justification and optimization that can minimize doses, particularly for CT and interventional procedures that have greater cumulative risks per examination.

Table 2: Radiation Dose Reduction Techniques

Technique	**Description**	**Dose Reduction (%)**
Low-dose protocols	Adjusting CT parameters	20-50%
Iterative reconstruction	Advanced image processing	30-70%
Automated exposure control	Adjusts dose based on patient size and density	20-40%

2. Alternative Modalities
Diagnostic imaging techniques, which involve irradiation, include X-ray and computed tomography, which are also very useful in medical diagnosis. However, being exposed to ionizing radiation is not completely harmless and can cause some harm to human health. Consequently, it is valuable to

consider other diagnostic methods that do not involve ionizing radiation whenever possible [58]. The two such alternatives are ultrasound and MRI exams which can partially or completely replace the use of radiation in many situations.

Illustrating, ultrasound makes use of sound waves of a high frequency to create images. Since it is noninvasive and does not use radiation, ultrasound is commonly used as the first line of imaging, particularly when looking for pediatric pathology and abdominal pain [59]. Ultrasound is therefore portable, does not involve using any probes or instruments on the body, and is inexpensive. It also makes it possible to assess the structures and circulation at the time of intervention. Drawbacks include user dependency, low field of view, and diminished capabilities in evaluating air-bearing structures or bones. In sum, ultrasound is a first-line, all-purpose imaging modality that can be utilized in most medical and surgical disciplines.

MRI also has the added advantage of not exposing the body to ionizing radiation like the X-rays and CT scans may [60]. Unlike radiation, MRI uses magnetic fields and radio waves to produce quality images of the soft tissue and the organs. Some of the benefits of using CT are that it gives excellent contrast resolution and can be visualized in different planes. MRI is done where one needs to investigate joints, ligaments or tendons, spinal cord or brain, some cancers and other diseases. Some of the disadvantages are increased cost, longer time taken to perform an exam and the motion artifacts that are likely to occur, incompatibility with implants or devices as well as scarcity in some healthcare facilities. However, MRI can still increase its functions due to such matters as functional MRI techniques.

In many cases, just an ultrasound or MRI is sufficient to give the necessary clinical information. Nevertheless, ionizing radiation modalities such as CT or plain films could remain necessary depending on the clinical scenario and first assessments [61]. A synergistic, sequential imaging strategy that first employs non-radiation ultrasound or MRI and then uses CT only if more detailed information is needed after the first examination. This enables the strengths of CT in defining the outcomes that are otherwise difficult or ambiguous to express to be maintained while avoiding radiation.

Intravenous contrast agents for CT and MRI also improve diagnostic performance in many instances. As such, contrast enhancement makes it possible to evaluate the vessels, pathologies in various organs or tissues, inflammation, tumors, and functional activity. Contrast agents enhance the sensitivity and specificity of imaging studies as they improve the identification and delineation of lesions. It may also help in clinical decision-making in the patient and decrease the amount of retesting that is done. As such, comparison with contrast CT or MRI is often preferred over non-contrast scans.
To sum up, avoiding ionizing ultrasound and MRI equipment wherever possible is one of the best approaches to managing risks associated with medical radiation. Stationary imaging protocols and contrast enhancement of the scans also enhance radiation dose. Physicians and other healthcare providers need to continue to practice ionizing modalities responsibly and appropriately for enhanced patient safety.

Innovations in Pediatric GI Imaging

1. Contrast-Enhanced Ultrasound (CEUS)

Contrast-enhanced ultrasound (CEUS), on the other hand, is an ultrasound technique that uses microbubble contrast agents to help visualize blood flow and the perfusion of tissues. CEUS consists of microbubbles with a diameter of less than a red blood cell that is injected intravenously and circulated through the vascular space [62]. Based on the nonlinear oscillation of microbubbles exposed to an ultrasound beam, CEUS provides moving images of the enhancement pattern in real-time, thereby reflecting tissue vascularity at both the macroscopic and microscopic levels [63].

Some of the most common uses of CEUS include evaluation of liver lesions to determine their nature, differentiation between the active and the quiescent phase of inflammatory bowel disease such as Crohn's disease, and assessment of relationships between complex vascular structures. CEUS provides nearly 5 times more vascular detail than conventional ultrasound which may lead to better delineation of the lesion and better characterization of the lesion [64]. For example, it can help distinguish between a benign liver lesion such as hemangioma from a malignant mass because they are supplied differently in Figure 7. Moreover, CEUS does not involve the use of ionizing radiation as in contrast CT and the examination is true to dynamic as opposed to static examination such as contrast MRI.

The following are some of the advantages that CEUS holds out over other imaging techniques. CEUS is also relatively safer in cases that require repeated examinations and assessment of diseases in young patients, such as children and pregnant women.4 Although microbubble agents are used, they are associated with fewer serious adverse effects compared with iodinated CT contrast and gadolinium MRI agents [65]. CEUS generates fewer images, in contrast to USG, which may alter the results' clarity. CEUS allows the assessment of temporal perfusion changes that cannot be evaluated with CT or MRI due to its real-time imaging technique. The aforementioned benefits underpin the growing application of CEUS in a myriad of clinical interventions.

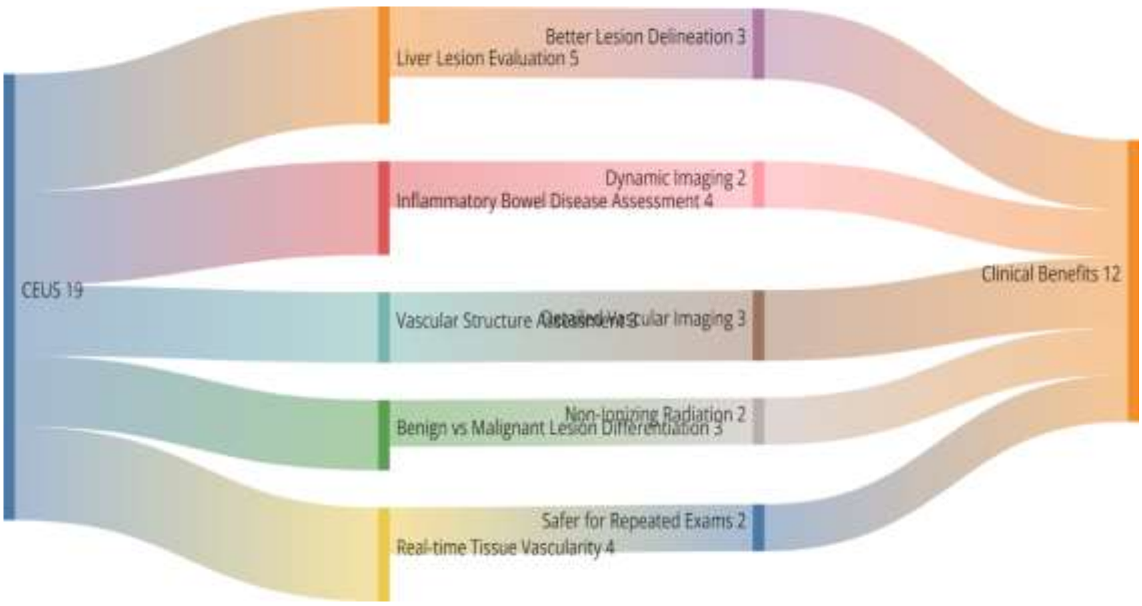

Figure 7. Contrast-Enhanced Ultrasound (CEUS)

2. MR Enterography

MR enterography (MRE) is an MRI modality designed specifically for the visualization of the small bowel based on the MRI sequences optimized for this purpose, particularly in children with IBD [66]. It gives good soft tissue contrast and motion that enables high-resolution imaging of the bowel, wall and other pathologies.

The first step of the process involves the administration of an oral contrast agent which helps to fill the small bowel lumen [67]. The patient is then imaged under a supine position and using specific MRI sequences that provide better bowel contrast. The main MRE sequences include fast imaging employing steady-state acquisition (FIESTA) or balanced steady-state free precession (SSFP) to show the structure of the bowel; diffusion-weighted imaging (DWI) and dynamic contrast-enhanced (DCE) MRI to quantify the disease activity and inflammation [68]. The primary advantages of MRE over CT

enterography are the absence of ionizing radiation and the ability to obtain complementary functional data [69].
Some of the major advantages of MRE over the other modalities include the fact that it involves no ionizing radiation, thus, making the technique ideal for imaging children, and for serial studies in assessing the progression of the disease and response to treatment. MRE also offers superior contrast resolution of soft tissues over CT and ultrasonography; it enables a depiction of bowel wall layers and surrounding structures. Since the post-contrast images are obtained dynamically, there is further delineation of the bowel wall vasculature and enhancement kinetics [56]. For this reason, MRE is non-invasive and only involves minimal risks associated with MRI physical precautions and the use of intravenous contrast agents if any.

The major disadvantages of MRE include increased examination time and the need for the patient to remain still and cooperate during imaging; this is more challenging when managing children. MRE also is slightly less spatial resolution as compared to CT [69]. However, contemporary methods using parallel imaging and new MRI systems which have a higher and faster gradient are promising to increase the efficiency and accuracy of MRE.

Conclusion

To sum up, it is crucial to introduce effective diagnostic strategies and avoid radiation harm when imaging children who have been referred for gastrointestinal disorders. As discussed in this paper, it is now crucial to address strategies /technical aspects on improving diagnostic accuracy in this population. These are; use of ultrasonography as an initial imaging technique to assess intestinal pathology, inflammation and other causes of abdominal pain without using radiation. MRI is a second-line imaging modality as a structural and IBD evaluation of the bowel without the use of ionizing radiation. Where ionizing techniques are necessary, enormous care is required in ensuring compliance with ALARA principles to minimize dose. It entails the use of lead shielding, digital detector technology, pulsed fluoroscopy and dose modulation in order to minimize the amount of radiation exposure. Furthermore, there must be diagnostic reference levels for weight-based pediatric groups that should be defining acceptable doses. Last but not the least; education campaigns for the providers, technical staff and families on the range of relative radiation exposure for different examinations as compared to background exposure may help to minimize unnecessary imaging orders. By being more vigilant, extending the available technology, and using standardized zero exposure protocols, the general aim of obtaining high accuracy in diagnosing gastrointestinal abnormalities at a minimum exposure to radiation in the sensitive pediatric population can be attained. More of such comparative effectiveness research in this particular area should be carried out.

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