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FEASIBILITY OF AN OPTIMIZED MR ENTEROGRAPHY PROTOCOL IN THE EVALUATION OF PEDIATRIC INFLAMMATORY BOWEL DISEASE

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Cross-sectional imaging forms an important alternative and complimentary tool to endoscopy in aiding the clinician with diagnosis and management of pediatric inflammatory bowel disease (IBD). The purpose of the study was to evaluate the feasibility of an optimized Magnetic Resonance Enterography (MRE) protocol in the evaluation of patients with suspected IBD. 31 children (18 boys and 13 girls) were evaluated by a pediatric gastroenterologist prior to MRE and given a grading for clinical severity of disease. Imaging was then performed with oral contrast and a tailored protocol using fast T1/T2 weighted pulse sequences. Additionally, contrast and glucagon were administered intravenously. Imaging findings were then correlated with the clinical data. Excellent distension was achieved in the small bowel. The majority of the studies were of diagnostic quality with no motion artifacts. Imaging findings showed statistically significant correlation with disease activity.
An optimized pediatric MRE protocol is feasible and correlates well with clinical disease activity. This in turn aids the clinician in the management of children with this chronic debilitating disease.

Key-words: Crohn disease – Children, gastrointestinal system – MR Enterography.

Cross-sectional imaging forms an important alternative and complimentary tool to endoscopy in aiding the clinician with diagnosis and management of pediatric inflammatory bowel disease (IBD). Inflammatory bowel disease including Crohn's disease (CD) and Ulcerative colitis (UC) are chronic inflammatory diseases of the gastrointestinal tract which may be accompanied by extra-intestinal manifestations (1-3).

Pediatric IBD has been reported to have an overall prevalence of 16.6 cases per 100,000 children and 5.3 cases per 100,000 children younger than 16 years old. CD is twice as common as UC (1). It has a complex disease course with frequent relapses. Next to endoscopy, computed tomography (CT) is frequently used to study IBD. Because IBD often affects young patients who are known to be more sensitive to the deleterious effects of radiation than adults (4), alternative radiation-free diagnostic tests should be explored. The lifetime cancer mortality risk is significantly higher for children than for adults for a given radiation dose (5). This is of additional importance, considering that IBD frequently requires multiple follow up studies, often spanning decades.

Endoscopy frequently fails to evaluate the exact extent of disease because it provides limited access to the small bowel and does not visualize extra luminal complications. Low patient compliance, especially in the pediatric population also remains a concern with endoscopy. Hence, the need for a non- or minimally-invasive, radiation-free and reproducible alternative imaging test. The test should allow to confirm diagnosis, identify complications early and allow monitoring disease activity and response to therapy (6).

Ultrasonography (US) is radiation-free and renders high resolution cross sectional images that can be performed bedside with wide availability. It is relatively cheap, but also has its own limitations. A systematic evaluation of the entire small and large bowel is rather difficult and image quality is typically degraded by endoluminal air. US also remains heavily operator dependent and are not widely accepted by the referring physicians.

Based upon the physical properties, such as lack of radiation, multiplanar capabilities, multiple anatomical and functional image contrasts that can be generated, magnetic resonance imaging (MRI) is a straightforward alternative for cross-sectional imaging of the pediatric gastro-intestinal tract (7-10).

Previous studies have shown that MRI allows to assess both inflammatory changes of the bowel wall and extramural complications in IBD (11). MRI of the bowel also known as MR enterography (MRE) has the potential to impact three important aspects of patient care: diagnosis, management, and treatment monitoring (10, 12, 13). These studies have used a variety of imaging protocols. To facilitate the diagnostic value of MRE, a standard, optimized protocol should be used (12, 13).

The goal of our study is to evaluate a carefully designed imaging protocol which a) takes advantage of all recent MRI developments including fast, high-resolution T1 and T2-weighted sequences, b) uses a biphasic oral, hyperosmolar contrast agent for optimal and complete bowel distension, and c) uses intravenous glucagon to suppress bowel motion. For the purpose of the study, MRE findings were systematically analyzed and correlated with clinical findings.

Material and methods

Thirty one consecutive patients were included in this retrospective study. All patients were referred by the division of pediatric gastroenterology because of clinically suspected IBD. MR Enterography was requested to confirm the clinical diagnosis, to assess the exact extent of disease activity, to look for evidence of recurrence, to identify stenosis, and to exclude extra-intestinal complications. Two patients had multiple follow up studies.

Each patient was seen by a pediatric gastroenterologist with special expertise in the diagnosis and management of IBD. For the purpose of the study, the electronic medical records were again systematically

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reviewed by a pediatric gastroenterologist (MOH). The gastroenterologist was asked to determine if the clinical data confirmed the final diagnosis of IBD; categorize disease as CD, UC, indeterminate colitis or functional symptoms, and differentiate between active and inactive disease. If the clinical data suggested active disease, patients were further subdivided for the degree of disease into mild, moderate or severe symptoms on the basis of a physician global assessment scale. The gastroenterologist was blinded for the MRI findings.

MR Enterography took advantage of an optimized protocol incorporating all recent developments in MR imaging of the small and large bowel.

The majority of studies were performed on a 1.5 Tesla (Avanto, Siemens Medical Systems, Erlangen, Germany) or a 3 Tesla MR scanner (Trio, Siemens Medical Systems, Erlangen, Germany). Two patients were examined on a 3 Tesla Philips MR unit (Phillips Medical Systems, Best, The Netherlands). All patients were examined with multichannel torso phase-array coils. Care was given to ensure that the entire abdomen was imaged reaching from the diaphragm to the lowest point of the pelvic floor. Patients were imaged in the prone position in order to have the majority of the small bowel loops as close as possible to the imaging coils, to increase separation of the small bowel loops and to move residual intraluminal air as far away as possible from the coils. In addition, the prone position typically reduces respiration related intra-abdominal organ motion.

Optimal bowel distension was achieved by oral application of a biphasic (T1-hypointense, T2-hyperintense) hyper-osmolar contrast agent (VoLumen®). The hyperosmolarity enhances distension of the distal ileum. Patients were instructed to drink VoLumen 60 minutes prior to the MR Enterography examination (10 mL/kg of bodyweight). No rectal contrast was administered.

Combinations of fast axial and coronal T1- and T2-weighted sequences were used to cover the entire gastrointestinal tract. Typically, fat saturated thin-sliced T2-weighted true fast imaging with steady-state precession (FISP) sequences (slice thickness: 3-4 mm; interslice gap: 10%; field-of-view (FOV): 420 x 340 – 280 x 250 mm; matrix: 448 x 364 – 320 x 280; TR range: 4.46-4.88 ms; TE: shortest) and 3D T1-weighted fast saturated unenhanced and contrast enhanced (gadolinium based intravenous contrast agents, 0.1 mmol/kg) gradient-echo sequences (slice thickness: 2.5-3 mm; FOV: 420 x 340 – 280 x 250 mm; matrix: 448 x 364 – 256 x 202) were acquired. The FOV and matrix were adapted for each individual patient on the basis of the body size. Post-processing included calculation of subtraction images based upon the matching pre- and post-contrast T1-weighted sequences.

In addition, glucagon was intravenously injected prior to the T1-weighted sequences to suppress bowel motion. In children < 20 kg, 0.5 mg glucagon was injected intravenously; in children > 20 kg, 1 mg glucagon was injected. No parasympatholytic agent was administered to further decrease bowel motion. Contraindications for the use of glucagon included known hypersensitivity to the commercial preparation and known or suspected pheochromocytoma or insulinoma.

Image analysis

All MRE studies were systematically reviewed by two experienced pediatric radiologists in consensus. A standardized evaluation protocol was used for all readings. To facilitate systematical interpretation of images, the bowel was subdivided into the following segments: duodenum, jejunum, proximal ileum, terminal ileum, colon, rectum and anal canal. The terminal ileum was defined as the distal segment of ileum nearest to the ileocecal valve. Distinction among segments of the bowel was based on the readers' visual assessment of their location, the folding pattern, and the estimated distances from the duodenojejunal junction and ileocecal valve.

The overall diagnostic quality and presence of motion artifacts were assessed using a three point scale: 0: non diagnostic, extensive motion artifacts; 1: diagnostic, moderate motion artifacts; 2: highly diagnostic, no motion.

The degree of distension of the different bowel segments were evaluated using a four-point qualitative scale: 0: poor distension; 1: mild distension; 2: moderate distension; 3: excellent distension. In addition, it was recorded if contrast was noted within the lumen of the studied bowel segments.

Five "direct" imaging findings of IBD were studied for each bowel segment. They are as follows: Bowel wall thickening without obvious edema (wall thickness > 3 mm with matching T1 and T2-isointensity); bowel wall edema (wall thickness > 3 mm with matching T2-hyperintensity and T1-hypointensity); bowel wall hyperemia characterized by increased contrast enhancement; focal stricture/stenosis (lumen < 3 mm, simultaneously identified on two timely separated imaging planes); and pre-stenotic dilatation. Bowel wall inflammation was also studied for multifocality or presence of so called "skip lesions". Each "direct" sign was assigned a score of 1, and if present in multiple segments was then multiplied by 2 in order to obtain a total direct score with a possible maximum of 10.

In addition, four "indirect" signs of inflammation were studied: "comb sign" or mesenteric stranding; fibrofatty proliferation; mesenteric lymph nodes; and presence of abscess and/ or fistulae. The "comb sign" relates to an increased mesenteric vascularity as a result of bowel wall inflammation extending beyond the serosa of the bowel. Fibrofatty proliferation, also known as "creeping fat" refers to a fatty deposition along the mesenteric border of inflamed bowel segments, characterized by an increased amount of fat separating adjacent bowel loops. Mesenteric lymph nodes are considered to indicate inflammation if larger than 5 mm in diameter, especially if clustered and contrast enhancing. Finally, presence of intra-abdominal abscesses as well as entero-enteric, entero-colic, entero-cutaneous, entero-vesical or perianal fistulae was studied. Findings were graded as absent or present for each imaging sequences. Each "indirect" sign was assigned a score of 2, with a possible maximum score of 8.

A total radiological score was obtained from the sum of the "direct" and "indirect" sign scores. The maximum total score theoretically achievable was 18. The radiological scores for each patient examination were then correlated with the clinical severity of disease activity to further define and determine the specificity of MRE in disease stratification. The clinical severity of disease activity was obtained on the basis of the physician global assessment scale.

Statistical Analysis

Agreement between clinical and radiological findings of disease, as well as agreement between clinical and radiological determination of involved bowel segments were calculated using the Kappa statistic.

Table I. — Clinical data with distribution of patients and grading of disease.

	N (%)	Active disease	Mild	Moderate	Severe	Inactivity
Clinical diagnosis						
Crohn's disease	24	24	4	15	5	0
Ulcerative colitis	3	3	1	2	0	0
Indeterminate colitis	1	1	0	1	0	0
Functional symptoms	3	0	0	0	1	2

Complete agreement corresponds to $k = 1$, and lack of agreement (i.e. purely random coincidences of rates) corresponds to $k = 0$. $k < 0.20$ correlates with a poor agreement; k <0.20 - 0.40>: fair agreement; k <0.40-0.60>: moderate agreement; k < 0.60-0.80>: good agreement; k <0.80 to 1.00>: very good agreement. A negative kappa value is a sign that the two observers agreed less than would be expected, just by chance and implies that there is no effective agreement.

Pearson's Chi square test was used to determine the association between radiological findings and the degree of disease.

This study was approved by our Institutional Review Board. The study was compliant with the Health Insurance Portability and Accountability Act.

Results

13 boys and 18 girls were included in the study, and their median age was 14 years, with a standard deviation of 4.01 years. The age range was between 1-18 years. In total 34 MRE studies were available for evaluation. Two patients with CD were examined multiple times. Twenty-five patients were imaged in the prone position. The other six patients had to be scanned in the supine position because of intolerance to being in the prone position for the duration of the study.

Of the 31 patients, the final clinical diagnosis was CD in 24 patients, UC in 3, indeterminate colitis in one and the remaining three were deemed to be negative for IBD. All patients with IBD, i.e., 28 of them (100%) presented with active disease based upon clinical presentation and findings during the time of the study. The three patients who were negative for IBD were most likely presenting with functional symptoms on the basis of a clinical diagnosis.

Amongst the 24 CD patients, on the basis of the physician global assessment scale; four, had mild, 15 moderate and four with severe disease grading. Within the three UC patients, one was mild and the other two had moderate disease. One child of the functional group had severe disease and the other two children were clinically inactive. The distribution of patients amongst the groups and clinical grading of disease is summarized (Table I).

Image analysis

The overall diagnostic quality and presence of motion artifacts were assessed. 26/34 (76.5%) of the studies, the majority were graded as "highly diagnostic without motion artifacts". In 7/34 (20.6%), they were "diagnostic with moderate motion artifacts" and "non-diagnostic with extensive motion artifacts" in 1/34 (2.9%).

Excellent distension of the duodenum was present in 29 (85.3%) studies, with contrast in the lumen seen in 32 (94.1%) of the studies (Table II). Distension of the jejunum was graded excellent in 29 (85.3%) studies, with contrast in the lumen in 33 (97%) of the studies. The ileum and terminal ileum showed excellent distension in 31 (91.2%) and 21 (61.8%) of studies, with contrast in the lumen in 32 (94.1%) and 31 (91.2%) respectively. The colon showed excellent distension in 17 (77.3%) of studies with contrast in the lumen in 11 (32.3%) of studies. The cecum and rectum showed excellent distension in 12 (44.4%) and 7 (36.8%) studies, with contrast in the lumen in 20 (58.8%) and 6 (17.6%) respectively.

The direct and indirect imaging findings with visibility on the various pulse sequences were evaluated for the different inflamed bowel segments (Table III). Amongst the direct signs, bowel wall thickening was seen as the leading imaging finding (82.4%), followed closely by bowel wall edema (79.4%) and bowel wall hyperemia (79.4%). Bowel wall thickening was equally well visualized in T1 and T2 weighted images (82.4%) and closely followed by post contrast imaging (79.4%). Bowel wall edema as expected was best appreciated in the T2 weighted images (79.4%). Focal strictures were present in 20/34 (58.8%) examinations

Table II. — Degree of bowel distension with VoLumen.

Bowel Segment	No distension N (%)	Mild distension N (%)	Moderate distension N (%)	Excellent distension N (%)
Duodenum	2 (5.9%)	2 (5.9%)	1 (2.9%)	29 (85.3%)
Jejunum	1 (2.9%)	0 (0%)	4 (11.8%)	29 (85.3%)
Ileum	2 (5.9%)	0 (0%)	1 (2.9%)	31 (91.2%)
Terminal ileum	5 (14.7%)	1 (2.9%)	7 (20.6%)	21 (61.8%)
Cecum	6 (22.2%)	0 (0%)	9 (33.3%)	12 (44.4%)
Colon	5 (22.7%)	0 (0%)	0 (0%)	17 (77.3%)
Rectum	10 (52.6%)	0 (0%)	2 (5.9%)	7 (36.8%)

Table III. — Visibilty of direct and indirect imaging findings on various pulse sequences in the inflamed bowel segments.

	Total visibilty N (%)	T2-W visibility	T1-W visibility	T1-W Post Gad visibility
Direct imaging signs				
Bowel wall thickening	28/34 (82.4%)	28/34 (82.4%)	28/34 (82.4%)	27/34 (79.4%)
Bowel wall edema	27/34 (79.4%)	27/34 (79.4%)	23/34 (67.6%)	22/34 (64.7%)
Bowel wall hyperemia (contrast enhancement)	27/34 (79.4%)	N/A	N/A	27/34 (79.4%)
Focal stricture	20/34 (58.8%)	20/34 (58.8%)	20/34 (58.8%)	19/34 (55.9%)
Prestenotic dilatation	9/34 (26.5%)	9/34 (26.5%)	9/34 (26.5%)	8/34 (23.5%)
Indirect imaging signs				
Comb sign	21/34 (61.8%)	21/34 (61.8%)	21/34 (61.8%)	20/34 (58.8%)
Fibrofatty proliferation	22/34 (64.7%)	22/34 (64.7%)	22/34 (64.7%)	21/34 (61.8%)
Mesenteric lymph nodes	27/34 (79.4%)	27/34 (79.4%)	27/34 (79.4%)	26/34 (76.5%)
Abscesses and/or fistula	0/34 (0%)			

and were nearly equally visible on all sequences. Of the "indirect imaging signs", mesenteric lymph nodes are most frequently seen (79.4%) followed by the fibrofatty proliferation (64.7%) and the "comb sign" (61.8%). Also, all indirect imaging signs were nearly equally well visible amongst all the sequences.

The ileum was predominantly involved as determined by imaging, with 22 of the 34 studies (64.7%), followed by the colon in 17 (50%) and the rectum with 5 (14.7%).

Correlation between clinical and radiological findings

Kappa values were separately calculated for each bowel segment to determine correlation. Involvement of ileum is seen in 64.7% of radiological examinations in contrast to 61.8% clinically. The k value of 0.557 for ileum shows moderate correlation (Table IV). The correlation for colon was fair with a k value of 0.294. Clinical evaluation for colon showed considerably higher positivity with 67.6% and only 50% with MRE. The upper GI tract and anal canal showed no correlation. The upper GI tract did not show any involvement on MRE, however was noted in 20.6% of the examinations to be positive clinically.

The overall correlation between clinical and radiological findings for diagnosis of IBD showed good agreement ($k = 0.61$) for CD, moderate agreement for UC ($k = 0.52$) and again moderate in IBD (both UC and CD together) with a k value of 0.42.

The various direct and indirect radiological findings were correlated with the clinical degree/ severity (mild, moderate and severe) of disease on the basis of the physician's global assessment scale. A Pearson-Chi square test (Table V) shows significant association for most signs, except multiple segment and mesenteric stranding (comb sign) with a p value of 0.215 and 0.182 respectively.

Table VI is a summary of the 31 examinations with specific mention of the radiological scores and the clinical disease severity grading. Also, mean values of the direct, indirect and total radiological scores were obtained for each degree of clinical disease severity. The mean total radiological scores for moderate and severe disease measured 10.2 and 11.9 respectively (Table VII) out of a possible maximum of 18. In the mild grade of disease, the mean total score was 1.75.

Discussion

IBD is a chronic disease with a relapsing and remitting course. In our study, we have evaluated the utilization of an optimized Pediatric MR Enterography protocol. MR Enterography as a technique has been

Table IV. — Bowel segment involvement with clinical and radiological findings and correlation.

	Clinical				Radiology				Kappa
		Yes (n)	No (n)	%		Yes (n)	No (n)	%	
Ileum		21	13	61.8		22	12	64.7	0.557
Colon		23	11	67.6		17	17	50	0.294
Upper GI tract		7	27	20.6		0	34	0	0
Anal canal		2	32	5.9		2	32	5.9	-0.062

Table V. — Association between clinical degree of disease and presence of imaging signs.

Imaging signs	Pearson Chi square X^2	P value
Direct		
Bowel wall thickening	20.62	< 0.001
Bowel wall edema	14.54	0.006
Bowel wall hyperemia	11.73	0.019
Bowel stricture	9.57	0.048
Multiple segment	5.79	0.215
Indirect		
Lymphadenopathy	17.01	0.002
Mesenteric stranding	6.24	0.182
Fatty proliferation	10.12	0.038

described in the literature with reference to its ability in diagnosing IBD. However, to our knowledge, the feasibility and practicality of a well-designed protocol has not been studied enough to consolidate the evidence base, in order to bolster confidence in daily practice. Our patient group, although a relative small number of 31; they were all initially evaluated by a pediatric gastroenterologist for suspicion of IBD. The patient group had comprehensive clinical assessments which included labs, endoscopy and appropriate ancillary tests. The gastroenterologists who were blinded to the MRI findings provided a clinical grading of disease severity on the basis of a

Table VI. — Summary of radiological and clinical scoring.

Patient	Clinical grading	Direct radiological score (Max=10)	Indirect radiological score (Max=8)	Total radiological score (Max=18)	IBD class and activity
1	Severe	3	6	9	CD/ active
2	Moderate	4	4	8	CD/ active
3	Inactive	0	0	0	Functional
4	Mild	0	0	0	UC/ active
5	Moderate	6	6	12	CD/ active
6	Moderate	2	2	4	CD/ active
7	Severe	4	6	10	CD/ active
8	Inactive	0	0	0	Functional
9	Severe	6	2	8	Functional
10	Moderate	0	0	0	CD/ active
11	Moderate	8	6	14	CD/ active
12	Moderate	4	6	10	CD/ active
13	Moderate	3	2	5	CD/ active
14.1	Severe	8	6	14	CD/ active
14.2	Severe	8	6	14	CD/ active
14.3	Severe	6	4	14	CD/ active
15	Moderate	4	6	10	CD/ active
16	Moderate	8	2	10	CD/ active
17	Moderate	8	6	14	CD/ active
18	Mild	3	4	7	CD/ active
19	Mild	0	0	0	CD/ active
20	Moderate	8	4	12	CD/ active
21	Mild	0	0	0	CD/ active
22.1	Moderate	8	6	14	CD/ active
22.2	Severe	8	6	14	CD/ active
23	Moderate	8	6	14	UC/ active
24	Moderate	8	6	14	CD/ active
25	Moderate	6	6	12	UC/ active
26	Moderate	6	6	12	IDC/ active
27	Moderate	6	6	12	CD/ active
28	Moderate	2	4	6	CD/ active
29	Severe	4	6	10	CD/ active
30	Severe	8	6	14	CD/ active
31	Moderate	8	2	10	CD/ active

Table VII. — Correlation between mean radiological scores and clinical severity of disease.

Clinical disease severity	Direct score – Mean value	Indirect score – Mean value	Total score – Mean value
Severe	55/9 = 6.1	48/9 = 5.3	107/9 = 11.9
Moderate	107/19 = 5.6	86/19 = 4.5	193/19 =10.1
Mild	3/4 = 0.75	4/4 = 1	7/4 = 1.75

physician global assessment scale; with a compendium of all clinical symptoms, signs and other supportive data. This comprehensive assessment proved invaluable in the correlation of our MRI findings.

The vast majority (25/31) of the patients were scanned in the ideal prone position. In children, intolerance to the prone position is of particular concern. The benefits of the prone position; with enhanced separation of small bowel loops, displacing intraluminal air and decreasing respiratory motion was achieved in the vast majority, with 26/34 (76.5%) examinations being highly diagnostic without motion artifacts. Only one examination in our study group was non-diagnostic. Our patient age group had a median age of 14 years with 13 boys and 18 girls.

Bowel distension with oral contrast is critical for a high-quality diagnostic examination because collapsed bowel can obscure lesions or create the false appearance of wall thickening (11). In addition, good distension typically suppresses bowel motion. Furthermore, endoluminal contrast material also reduces air in the bowel and consequently minimizes susceptibility artifacts. An ideal oral contrast agent should be absorbed minimally or not at all and should be evacuated completely. VoLumen (E-Z-EM Inc., New York, NY), a low-concentration barium solution (0.1% weight/volume) that contains sorbitol is a hyperosmolar biphasic contrast agent that is minimally absorbed, attracts additional fluid into the bowel lumen and is consequently well suited for optimal distension of the bowel. Our 60 minute interval between start of drinking the contrast agent and imaging achieved excellent distension in 91.2% and 61.8%, in the ileum and terminal ileum respectively. Moderate distension was 20.6% in the terminal ileum. A previous study that used oral mannitol reached very good or excellent distension in 77.3% and 79.2% of respectively the ileum and terminal ileum (14). Putting our moderate and excellent distension groups together for correlation with the aforementioned study, our results for the terminal ileum would remarkably reach 82.4%. Crohn's disease primarily affects the ileum, and hence benefits from the adequate distension of in particular this region of the ileum. Also, the avoidance of nasojejunal tube passage and bowel preparation was of benefit to our patients with no compromise of the diagnostic quality of the examination.

The image quality was further enhanced by taking advantage of several other "imaging optimizing tricks". An antiperistaltic drug was used to transiently reduce peristaltic motion artifacts in MR Enterography. Glucagon was the drug of choice in our study. 26/34 (76.4%) of our examinations were graded as "highly diagnostic without motion artifacts". Moreover, fast sequences that are able to acquire T1- and T2-weighted images within a single breath-hold are essential requisites for high end MRI evaluation of the small bowel. Fat saturation causes an increase in contrast between bowel wall and the surrounding fat tissue. This enhances assessment of bowel wall inflammation and facilitates identification of the inflammatory changes in peritoneal fat tissue. True-FISP (true fast imaging with steady-state precession) is particularly useful in children, as breath holding is generally not required for satisfactory imaging.

Our dedicated method of using direct and indirect imaging findings for the purpose of the study to correlate with clinical disease activity was based on extensive personal experience. This was crucial to obtain a valid dataset in an objective manner for further scrutiny. To our knowledge, there are few studies in the literature on MR imaging of the small bowel in the pediatric population (15-19). Laghi et al. (15) correlated clinical disease activity with contrast enhancement and wall thickening on MRI, whereas, the Alexopoulou group (16) only used contrast enhancement. The clinical activity in our group of patients was determined by the physician global assessment scale. Our total and split radiological score was more comprehensive with 9 factors or entities studied. This in turn was used to obtain a comprehensive dataset for correlation of disease activity.

Bowel wall thickening was the most frequent direct imaging finding seen in 82.4%. Bowel wall edema and bowel wall contrast enhancement were both seen in 79.4% of the examinations (Table III). Focal strictures were present in 20/34 (58.8%). Mesenteric lymphadenopathy was the most frequent indirect imaging finding present in 79.4% of the examinations. Fibrofatty proliferation with 64.7% and Comb sign with 61.8% closely followed suit. A Pearson Chi Square test was performed to determine the association between the clinical severity of disease and the various imaging findings (Table V). Bowel wall thickening, bowel wall edema, bowel wall hyperemia and focal stricture, amongst the direct findings were statistically significant, with p values < 0.05. Mesenteric lymphadenopathy and fibrofatty proliferation were statistically significant amongst the indirect findings. Hence, we have shown that the systematic analysis of various direct and indirect imaging findings, specific for inflammation has a high yield in predicting disease activity or severity.

Correlation between bowel segment involvement on the basis of the MRI and clinical findings showed moderate agreement for ileum ($k = 0.557$), the most significant area for concern in Crohn's disease (Table V). However, the upper GI tract and anal canal showed virtually no agreement, which is a limitation, in spite of excellent distension with oral contrast. This could be partly attributable to the smaller patient group. On further scrutiny, there were seven patient examinations with clinical evidence of disease in the upper GI tract that were not picked up by MRE. Only one of the seven had isolated duodenal disease. The others had ileal or colonic

disease in addition to the upper GI tract. Only fair agreement was noticed with regards to colonic disease ($k = 0.2941$) in our study group. The majority of our patient group had Crohn's disease affecting the ileum (61.8%).

A total radiological score was obtained by the sum of the direct and indirect scores for each patient examination as summarized in Table VI. A maximum total score possible was 18. Mean direct radiological scores of 6.1 and 5.6 for severe and moderate disease was noted. The total scores of 11.9 and 10.1 were present for severe and moderate disease respectively (Table VII). The mild disease group had considerably lower scores of 0.75 (direct) and 1.75 (total). Therefore, imaging findings were helpful in distinguishing between the mild disease group and the others. However, distinction between the moderate and severe clinical grading was not achieved.

Our MR Enterography protocol has been put to the test to fulfill our goal of evaluating a robust, reproducible and child friendly examination. The prudent selection of appropriate pulse sequences, ideal patient preparation, adequate bowel distension and use of glucagon has been validated against clinical findings.

Although a relative small group of patients, we have elucidated the methods for evaluation of disease activity. In contrast to earlier studies, the use of a comprehensive set of imaging findings for clinical correlation demonstrated the advantages and less favorable points. Distinction of the mild disease group from others was a unique finding. Also, this was further reiterated by the fact that most imaging findings, apart from mesenteric stranding and multifocality showed significant statistical association. The upper GI tract fared poorly in our relative small group of patients, perhaps an area to focus upon in the future. Imaging of the ileum, the cornerstone of Crohn's disease remains a very strong point for MR Enterography.

Conclusion

The MR Enterography protocol that we have proposed is a robust, feasible, well-tolerated imaging technique in children permitting assessment of disease activity, particularly in the ileum, free of ionizing radiation.

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