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## Research Article

**Keywords:** Crohn's disease, MaRIAs, Inflammatory indicators, SES-CD, Activity

**Posted Date:** April 6th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-386360/v1>

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# Can the Simplified Magnetic Resonance Index of Activity be Used to Evaluate the Degree of Activity in Crohn's Disease?

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## Abstract

*Background and Aims:* A simplified magnetic resonance index of activity (MaRIAs) was proposed recently. Our aim was to verify whether the MaRIAs can accurately assess the activity degree of CD.

*Methods:* We retrospectively analyzed the data of MRI, ileal colonoscopy, fecal calprotectin (FC), erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) of 93 CD patients. With the SES-CD as the gold standard, MaRIAs' accuracy, the correlation of MaRIAs and SES-CD, FC, ESR, CRP, and interevaluator reliability were assessed.

*Results:* MaRIAs  $\geq 1$  detected segments with active CD with 90.80% specificity and 81.37% sensitivity (area under the curve was 0.91, 95% confidence interval 0.87-0.94). MaRIAs score of 2 or more detected severe lesions with 88.89% specificity and 95.12% sensitivity (AUC was 0.96, 95% confidence interval was 0.94-0.98). The MaRIAs score showed a high correlation with the SES-CD in the terminal ileum, transverse colon, right colon, left colon ( $r=0.85, 0.91, 0.88, 0.86, P < 0.001$ ) and a moderate correlation with the SES-CD in the rectum ( $r=0.74, P < 0.001$ ). The global MaRIAs score was highly correlated with the global SES-CD ( $r=0.90, P < 0.001$ ). The global MaRIAs score was positively correlated with the fecal calprotectin (FC) level, erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) level ( $r=0.77, r=0.64, \text{ and } r=0.68$ ). The intra-group correlation coefficient (ICC) of the two physicians in the terminal ileum, right colon, transverse colon, and left colon was 0.91, ICC in the rectum was 0.78, and ICC in the total bowel was 0.95 (95% confidence interval was 0.95-0.98).

*Conclusion:* The MaRIAs can accurately evaluate the disease activity level of CD, high correlated with the SES-CD and biomarker. The interrater reliability of the two physicians was excellent.

*Key words:* Crohn's disease; MaRIAs; Inflammatory indicators; SES-CD; Activity

## 1. Introduction

Crohn's disease (CD) is a chronic transmural inflammatory bowel disease of unknown origin that can involve any part of the digestive tract, especially the terminal ileum and right colon, with symptoms such as abdominal pain, diarrhea, abdominal mass, and perianal fistula. In recent years, with the increasing incidence of and complications associated with CD, it has become an increasingly complex digestive tract disease to diagnose and treat.

Endoscopy is currently considered the gold standard for the diagnosis of CD. The simple endoscopic score for Crohn's disease (SES-CD), including ulcer size, ulcer area, lesion area and intestinal stenosis, can accurately evaluate the disease and is simple to calculate, so it is the most widely used endoscopic scoring system<sup>[1, 2]</sup>. However, extraintestinal conditions cannot be assessed with endoscopy; this procedure is invasive and not suitable for patients with intestinal stenosis and other limitations have been described in a number of studies<sup>[3-5]</sup>.

Magnetic resonance imaging (MRI) has good soft tissue resolution and is nonradioactive and noninvasive. It can be used to observe the whole abdomen pelvic cavity and to evaluate disease activity, mesenteric blood vessels and lymph nodes, and disease-related complications in patients with CD and is particularly attractive because healing of the mucosa and deeper layers of the bowel wall can be assessed<sup>[6]</sup>. Therefore, it is widely used in the diagnosis and long-term follow-up of CD. The magnetic resonance index of activity (MaRIA)<sup>[7]</sup> is currently the most widely used and studied MRI scoring system for CD<sup>[8-10]</sup>.

However, there are some limitations, such as its complicated calculation and the large selection error of the region of interest (ROI), for patients with thin intestinal walls. In March 2019, the Rimola<sup>[11]</sup> team proposed a simplified magnetic resonance index of activity (MaRIAs) for CD.

To better assist clinical work and promote the application of MR in CD, this study took the SES-CD as the gold standard and retrospectively analyzed the ability of the MaRIAs to detect the activity degree of CD patients and the correlation between the MaRIAs score and clinical inflammatory indicators to explore the effectiveness of the MaRIAs score in evaluating the degree of CD activity.

## 2. Methods

### 2.1 Patients:

This was a retrospective study of 107 patients with CD who were treated at the Department of Gastroenterology of the Second Affiliated Hospital of Soochow University between March 2017 and September 2019. Within one week, an MR examination and ileocolonoscopy were performed and the fecal calprotectin (FC) level, erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) level were determined.

The exclusion criteria were as follows: 1) poor quality of endoscopic or magnetic resonance images; 2) incomplete clinical data; 3) history of taking nonsteroidal anti-inflammatory drugs (NSAIDs) within one week before the FC test; and 4) other intestinal lesions. Of a total of 107 CD patients, 14 were excluded: 3 for failed ileocolonoscopy because of severe strictures, 2 for poor-quality MR images, 6 for incomplete clinical data, and 3 for NSAID use. In all, 93 patients were included. The project was approved by the ethics committee of the Second Affiliated Hospital of Soochow University. Because of the retrospective nature of the study, the need for individual consent was waived.

**Table 1 Clinical features of all the patients.**

Variable	
Male, n (%)	63 (68)
Age, years; median (IQR)	29 (25-37)
Disease duration, years; median (IQR)	3 (1-6)

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Montreal classification	
Age at diagnosis (years), n (%)	
A1 (under 16)	2 (2.15)
A2 (17-40)	74 (79.57)
A3 (over 40)	17 (18.28)
Disease location, n (%)	
L1 (terminal ileum)	15 (16.13)
L2 (colon)	12 (12.90)
L3 (ileum plus colon)	66 (70.97)
Disease behavior, n (%)	
B1 (nonstricturing, nonpenetrating)	49 (52.69)
B2 (stricturing)	12 (12.90)
B3 (penetrating)	32 (34.41)
Perianal involvement, n (%)	37 (39.78)
Surgical history, n (%)	
History of perianal surgery	28 (30.11)
History of partial bowel resection	3 (3.23)
Treatment, n (%)	
No treatment	15 (16.13)
Steroids	10 (10.75)
Immunomodulator	31 (33.33)
Anti-TNF inhibitor	37 (39.78)
Abdominal abscess, n (%)	3 (3.23)
Intestinal fistula, n (%)	5 (5.38)
Colovesical fistula, n (%)	1 (1.08)
Ileal bladder fistula, n (%)	1 (1.08)

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IQR: interquartile range

## 2.2 MR examination

The patient fasted for 8 hours before the MR examination and took an oral 2000 ml of 4% mannitol aqueous solution to fill the intestine (500 ml every 15 minutes) 1 hour before the examination. To inhibit bowel peristalsis, intramuscular injection of 10 mg of choline was given 10 minutes prior to examination.

A Philips Ingenia 3.0T magnetic resonance scanner and abdominal phased array coil were used for examination. The patient was placed in the supine position, and the scanning sequence was moved from the head side to the foot side. The conventional MRE scanning sequence and parameters were as follows: (1) BFFE-BH-COR: TR: 3.0 ms, TE: 1.52 ms, layer thickness: 5 mm, layer spacing: 0 mm, flip angle: 40°, and matrix: 268×206; (2) T2WI-TSE-COR: TR: 1100 ms, TE: 80 ms, layer thickness: 5 mm, layer spacing: 0 mm, flip angle: 90°, and matrix: 376×290; (3) T2WI-SPAIR-COR: TR: 869 ms, TE: 80 ms, layer thickness: 5 mm, layer spacing: 0 mm, flip angle: 90°, and matrix: 280×251; (4) T2WI-SPAIR-TRA: TR: 869 ms, TE: 80 ms, layer thickness: 5 mm, layer spacing: 0 mm, flip angle: 90°, and matrix: 232×262; (5) mDIXON-W-BH: TR: 3.8 ms, TE1: 1.32 ms, TE2: 2.4 ms, layer thickness: 5 mm, layer spacing: 0 mm, flip angle: 10°, and matrix: 252×151; (6) transverse diffusion weight imaging (DWI): b values of 0, 300, 600, and 1000 s/mm<sup>2</sup>, TR: 860 ms, TE: 64 ms, layer thickness: 5 mm, layer spacing: 0.5 mm, flip angle: 90°, and matrix: 132×135; and (7) after the IV administration of 0.2 ml/kg of gadolinium chelate(omniscan, 0.5 mmol/ml) at an injection rate of 2-3 ml/s, dynamic images including precontrast, arterial, portal venous and equilibrium phase images were acquired in the coronal plane: TR: 1.32 ms, TE: 3.7 ms, layer thickness: 5 mm, layer spacing: -2 mm, flip angle: 10°, and matrix: 268×235.

### 2.3 Endoscopy and laboratory testing

Each patient consumed liquid food the day before colonoscopy and fasted for 8 hours before the examination. Three bags of compound polyethylene glycol electrolyte were dissolved in 3000 ml of warm water and orally administered 4 hours before the test until the feces were clear. A gastroenterologist with more than 5 years of endoscopy experience performed endoscopic examination of CD patients and reported CD lesions according to the SES-CD. The ileocolon was divided into 5 segments: 1) the terminal ileum (the ileum that can be reached by endoscopy); 2) the right colon (ileocecal, cecum, and ascending colon); 3) the transverse colon; 4) the left colon (descending colon and sigmoid colon); and 5) the rectum. For each intestinal segment, an SES-CD between 0 and 2 is considered as indicated remission, 3-6 as mild disease, and  $\geq 7$  as moderate to severe disease<sup>[2, 12]</sup>. In addition, a classification of severity on a segment basis was performed by considering the presence of severe lesions (ulcers with a diameter  $>5$  mm)<sup>[13]</sup>. The global SES-CD is the sum of the SES-CDs of each intestinal segment: 0-3 indicated remission, 4-10 mild disease, 11-19 moderate disease and  $\geq 20$  severe disease. Therefore, in this study, patients were considered to have active disease if the global SES-CD was  $\geq 4$  and severe disease if the global SES-CD was  $\geq 20$ <sup>[14]</sup>.

**Table 2 Statistical results of the activity degree of each intestinal segment**

Intestinal segment	remission	active disease	severe disease
Terminal ileum	26 (28%)	67(72%)	13 (14%)
Right colon	66 (71%)	27 (29%)	8 (9%)

Transverse colon	64 (69%)	29 (31%)	7 (8%)
Descending colon and sigmoid colon	56 (60%)	37 (40%)	12 (13%)
Rectum	49 (53%)	44 (47%)	6 (6%)
Total	261 (56%)	204 (44%)	46 (10%)

The laboratory indexes included the FC level, ESR and CRP level. The FC level was measured by quantitative enzyme-linked immunosorbent assay (ELISA). The FC level was determined one day before colonoscopy. The ESR and CRP level were determined according to standard laboratory procedures. The normal range of CRP was 0-5 mg/L, and the normal range of the ESR was 0-20 mm/h.

**Table 3 Laboratory examination results**

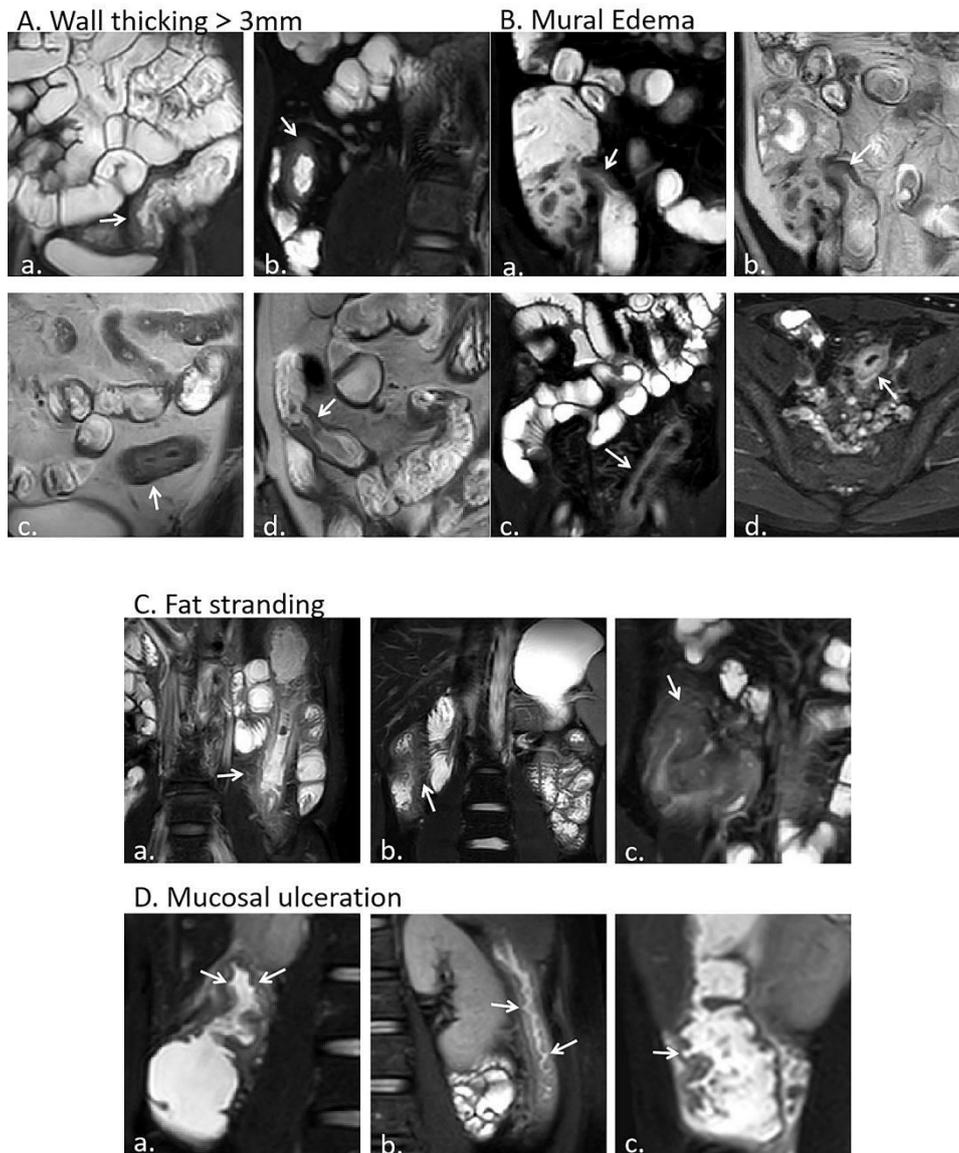
Biomarker	remission (0-3)	mild to moderate active (4-19)	severe active ( $\geq 20$ )	<i>P</i> value
FC ( $\mu\text{g/g}$ )	118 (42-275.25)	589 (267-1369)	1800 (1791.75-1800)	<0.001
CRP (mg/g)	5.6 (5.15-5.6)	6.5 (5.6-24)	87.65 (54-94.75)	<0.001
ESR (mm/h)	4 (2-8)	19 (7-46)	66.5 (53.25-88.5)	<0.001

#### 2.4 MR image analysis

The MR segmentation method is the same as the endoscopic segmentation method. The MaRIAs score in each segment was calculated by the following formula: =thickening ( $>3$  mm) $\times 1$ +edema $\times 1$ +fat stranding $\times 1$ +ulcers $\times 2$  (Figure 1). Two radiologists with more than 5 years of experience in MR abdominal readings scored the MR images separately under the premise that the results of the colonoscopy and laboratory examination were unknown. For the four variables, when the evaluation results of the two experts were inconsistent, the final answer was determined after discussion. The scores of each intestinal segment were determined separately. MaRIAs score  $\geq 1$  indicated intestinal segment activity, and MaRIAs score  $\geq 2$  indicated severe activity. The global MaRIAs score is the sum of the MaRIAs scores of each intestinal segment.

**Table 4 MR score results of the intestinal segments with different activity levels**

Variable	remission	active disease	severe disease	<i>P</i> value
Thickening	50 (19%)	156 (76%)	46 (100%)	<0.001
Edema	40 (15%)	171 (84%)	46 (100%)	<0.001
Fat stranding	1 (0.4%)	44 (22%)	27 (59%)	<0.001
Ulcers	1 (0.4%)	56 (27%)	38 (83%)	<0.001



**Figure 1.** Representative examples of magnetic resonance (MR) lesions:

- (A) Wall thickness >3 mm: coronal T2-weighted images with fat saturation of the descending colon (a) and terminal ileum (b); coronal T2-weighted images of the descending colon (c) and terminal ileum (d) (arrow in image).
- (B) Mural edema (high signal intensity on T2 sequences with fat saturation compared with normal appearing loops): coronal T2-weighted images with fat saturation (a) and without (b) of the terminal ileum from the same patient show high signal intensity. Coronal (c) and axial (d) T2-weighted images with fat saturation of the descending colon from the same patient (arrow in image).
- (C) Fat stranding (loss of the normal sharp interface between the intestinal wall and mesentery, with edema/fluid in the perienteric fat): coronal T2-weighted images with fat saturation of the descending colon (a), sigmoid colon (b) and ascending colon (c) (arrow in image).

(D) Mucosal ulceration: coronal T2-weighted images with fat saturation of the ascending colon (a, c) and descending colon (b) (arrow in image).

## 2.5 Statistical analysis

SPSS 25.0 statistical software was used for data analysis. The intraclass correlation coefficient was used to evaluate the consistency between two physicians. The measurement data were normalized by the Shapiro-Wilk method; the mean  $\pm$  standard deviation is reported for normally distributed data, and the median (interquartile range) is reported for data that did not satisfy a normal distribution. The Kruskal-Wallis test was used to compare the variables among the three groups, and the Bonferroni method was used for correction. A  $p$  value of  $< 0.05$  was considered statistically significant. Receiver operating characteristic curves (ROC) were drawn to evaluate the effectiveness of the MaRIAs for assessing CD activity. Correlations between the MaRIAs score and the SES-CD, FC, CRP, and ESR were measured by Spearman correlation tests.

## Results

### 3.1 Endoscopic evaluation results

A total of 93 patients with 465 intestinal segments were included in this study, including 93 segments of the terminal ileum and 372 segments of the colorectum. Their basic information is shown in Table 1. Three patients had a history of intestinal resection (two partial small bowel resections and one ileocecal resection), which did not affect observation or analysis. SES-CD of the intestinal segments indicated that 261 (56%) segments were associated with remission, 158 (34%) with mild to moderate disease, and 46 (10%) with severe disease; ulcers were found in 46 of the segments (Table 2). The global SES-CD was 14 (15%) for those patients in remission, 61 (66%) for those with mild to moderate disease and 18 (19%) for those with severe disease.

### 3.2 Laboratory evaluation results

The results of the laboratory examination are shown in Table 3. With an increase in CD activity, each index increased to different degrees, and the difference was statistically significant.

### 3.3 MR imaging evaluation results

#### 3.31 Scoring results for the MaRIAs

The MR scores of different activity levels of the intestinal segments are shown in Table 4, and the specific evaluation results are shown in Table 4. Ulcer and fat stranding appeared only one case in the remission group, the incidence of ulcer and fat stranding in the severe active group was significantly increased, and the difference between the three groups was statistically significant. The median global MaRIAs scores for those patients in remission or for those with mild to moderate or severe disease were 0, 3 (1-5) and 11 (8.25-12.75), respectively. The higher the degree of activity was, the higher the MaRIAs score. The difference was statistically significant ( $P < 0.001$ ).

### 3.32 The efficacy of the MaRIAs in assessing the activity of patients with CD

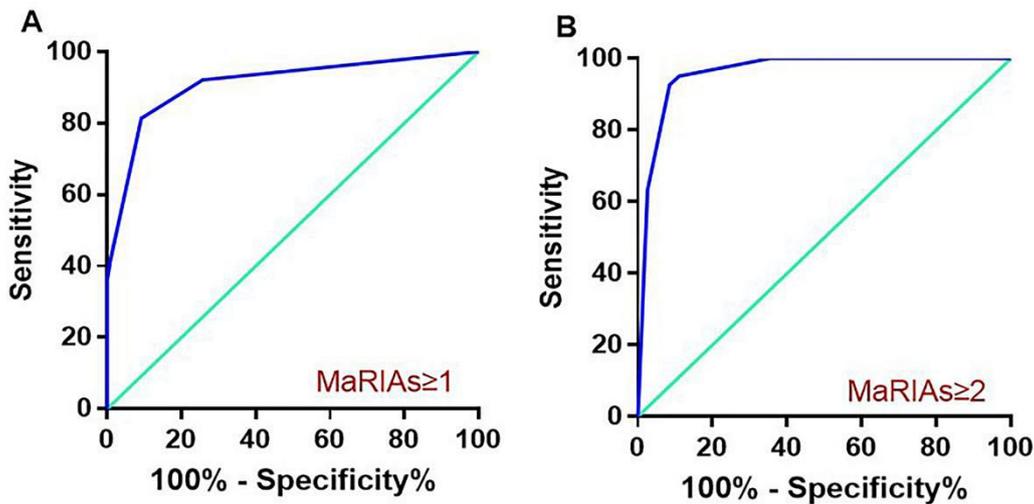
MaRIAs  $\geq 1$  detected segments associated with active CD with 90.8% specificity and 81.37% sensitivity (area under the curve (AUC) was 0.91, 95% confidence interval was 0.87-0.94). MaRIAs score of 2 or more detected severe lesions with 88.89% specificity and 95.12% sensitivity (AUC value was 0.96, 95% confidence interval was 0.94-0.98) (Figure 2). The diagnostic accuracy of the MaRIAs based on separate subanalyses for each intestinal segment is presented in Tables 5 and 6.

**Table 5 Diagnostic accuracy of MaRIAs  $\geq 1$  for the identification of active disease on endoscopy per intestinal segment.**

Intestinal segment	AUC	Sensitivity (%)	Specificity (%)	P Value
terminal ileum	0.97	95.52	92.31	<0.001
right colon	0.87	77.78	90.91	<0.001
transverse colon	0.93	89.66	92.19	<0.001
descending colon and sigmoid colon	0.92	86.49	82.14	<0.001
rectum	0.79	86.36	53.06	<0.001
total	0.91	81.37	90.8	<0.001

**Table 6 Diagnostic accuracy of MaRIAs  $\geq 2$  for the identification of severe disease on endoscopy per intestinal segment.**

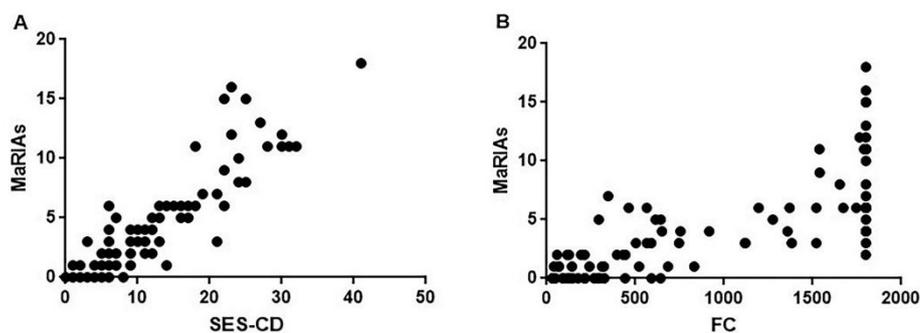
Intestinal segment	AUC	Sensitivity (%)	Specificity (%)	P Value
terminal ileum	0.96	100	78.41	<0.001
right colon	0.98	100	89.41	<0.001
transverse colon	0.97	100	74.7	<0.001
descending colon and sigmoid colon	0.97	73.54	87.65	<0.001
rectum	0.98	100	86.21	<0.001
total	0.96	95.12	88.89	<0.001



**Figure 2.** The ROC curve prediction of disease activity (A) and severe activity (B) associated with each segment showed that the MaRIAs could accurately assess the degree of CD activity.

### 3.33 Correlation analysis between the MaRIAs score and SES-CD

MaRIAs score and SES-CD were highly correlated in the terminal ileum, right colon, transverse colon, and left colon ( $r = 0.85$ ,  $r = 0.91$ ,  $r = 0.88$ ,  $r = 0.86$ ,  $P < 0.001$ ) and moderately correlated in the rectum ( $r = 0.74$ ,  $P < 0.001$ ). The global MaRIAs score was highly correlated with the global SES-CD ( $r = 0.90$ ,  $P < 0.001$ ) (Figure 3A).



**Figure 3.** Correlation between the MaRIAs score and SES-CD in patients (A) and between the MaRIAs score and FC level in patients (B).

### 3.34 Correlation analysis between the MaRIAs score and laboratory indexes

Correlation analysis between the total MaRIAs score and the FC level (Figure 3B), ESR and CRP level showed moderate correlations ( $r = 0.77$ ,  $r = 0.64$ ,  $r = 0.68$ ,  $P < 0.001$ ).

### 3.35 Interrater reliability assessment

The agreement between the two raters was excellent in the terminal ileum, the right colon, the transverse colon, descending colon and sigmoid colon and was fine in the rectum (Table 7).

**Table 7. Interrater agreement analysis between the two raters.**

	Kappa value	Positive(radiologist 1/2)	Agreement proportion	<i>P</i> value
the terminal ileum				
thickening	0.84	74/70	86/93	<0.001
edema	0.83	68/69	85/93	<0.001
fat stranding	0.80	18/18	86/93	<0.001
ulcers	0.78	18/22	84/93	<0.001
MaRIAs	0.91			<0.001
the right colon				
thickening	0.75	25/22	84/93	<0.001
edema	0.71	24/20	83/93	<0.001
fat stranding	0.76	7/4	90/93	<0.001
ulcers	0.86	12/13	90/93	<0.001
MaRIAs	0.91			<0.001
the transverse colon				
thickening	0.80	29/27	85/93	<0.001
edema	0.74	24/28	80/93	<0.001
fat stranding	0.79	5/5	91/93	<0.001
ulcers	0.87	7/9	91/93	<0.001
MaRIAs	0.91			<0.001
descending colon and sigmoid colon				
thickening	0.80	57/58	84/93	<0.001
edema	0.72	49/56	80/93	<0.001
fat stranding	0.80	16/13	88/93	<0.001
ulcers	0.86	21/24	88/93	<0.001

MaRIAs	0.91			<0.001
rectum				
thickening	0.69	50/60	79/93	<0.001
edema	0.68	39/45	77/93	<0.001
fat stranding	0.64	6/9	88/93	<0.001
ulcers	0.60	21/12	82/93	<0.001
MaRIAs	0.78			<0.001
total MaRIAs	0.95			<0.001

#### 4. Discussion

In recent years, with lifestyle changes and improvements in living standards, the incidence rate of CD has increased, and the clinical manifestations in CD patients have been increasingly complicated<sup>[15-18]</sup>. Compared with endoscopy, MR can be used to observe not only the interior of the intestinal cavity but also extraluminal conditions such as mesenteric vessels, perimesenteric lymph nodes and related complications to evaluate the overall situation of the patient. Many methods have been developed to evaluate CD lesions by MR, such as the MaRIAs, Clermont index and London index<sup>[9, 13]</sup>. The most recent evaluation method was proposed by the Rimola team and is the MaRIAs, with the advantages of being simple and convenient. If it can accurately evaluate the activity of CD, the application of MR in CD will be further promoted.

In this study, the SES-CD was used as the gold standard to explore the value of the MaRIAs to evaluate the degree of CD activity. The results suggest that as the activity increases, the probability of wall thickness > 3 mm, edema, fat stranding, and ulcers all showed an upward trend, and the total MaRIAs score increases accordingly. This result indicates that the MaRIAs scores can reflect changes in the degree of lesion activity regardless of whether it is in a single intestinal segment or in the total intestinal.

Mucosal healing is considered a possible treatment endpoint because it can reduce the hospitalization rate, surgery rate, and corticosteroid use in CD patients<sup>[19]</sup>. CD being a transmural disease from a pathophysiological stand-point, achieving MH may not reflect the ongoing inflammation and intestinal damage occurring beneath the surface of an endoscopically healed lumen<sup>[20]</sup>. One case of fat stranding in the remission group of this study may have been cured on the mucosal surface of the intestine but there were lesions on the submucosa and serous surface. MRI can reflect the conditions of the serosal surface of the intestinal wall and the abdominal cavity. More and more studies have shown that MRI can monitor the treatment response. This has led some experts to recommend the use of MRI standards as the treatment endpoint in the clinic.

Adequate patient preparation is a prerequisite for high-quality MRE. A well-filled bowel can more fully show the disease and reduce the probability of missed diagnosis and misdiagnosis. One case of ulcer in

the relief group may be caused by poor intestinal filling and folds of the intestinal wall leading to false positives.

Our study showed that MaRIAs  $\geq 1$  and  $\geq 2$  were the best cut-off values to identify active and severe disease, respectively, which is similar to the results of the Rimola team<sup>[11]</sup>, used the Crohn's Disease Endoscopic Index of Severity (CDEIS) as the gold standard and found that the MaRIAs was significantly correlated with the CDEIS and MaRIA<sup>[11]</sup>.

Inflammatory indicators can reflect the activity of the disease<sup>[21, 22]</sup>. FC is an important marker of intestinal inflammation. Compared with the ESR and CRP, FC is not affected by factors outside the intestinal tract and has high specificity<sup>[23]</sup>, which can better reflect intestinal inflammation. The results showed that there was a moderate correlation between the MaRIAs score and the FC level, ESR and CRP level. FC is a specific indicator of intestinal inflammation, In this study, the correlation analysis between MaRIAs and biological indicators showed that FC and MaRIAs had the strongest correlation, but it didn't show excellent specificity with the MaRIAs, which may be related to the distribution of lesions in the samples and deep ulcers. A number of studies have also shown that the FC level is related to the lesion site<sup>[14, 24]</sup>.

The MaRIA is the most widely used MR scoring system for evaluating the activity and severity of CD. However, The calculation of the relative contrast enhancement is complex and time consuming. Compared with the MaRIA, the MaRIAs have the following three advantages: first, the calculation is simpler and more convenient. CD is a transmural inflammation, and the inflammation situation can be accurately reflected by replacing the relative enhancement degree with fat stranding. Second, the MaRIA score includes the normal intestinal segments, while the MaRIAs score calculates only the diseased segments and can more realistically reflect the pathological changes in the intestine. Third, compared with MaRIA, MaRIAs do not require the use of intravenous contrast, which can shorten the examination time and reduce the examination cost of patients. Without affecting the accuracy, the above advantages make MaRIAs a more favorable tool.

In this experiment, the two radiologists' interrater agreement was moderately good to excellent, per variable and per segment, which indicates that the MaRIAs score is stable and repeatable. The two radiologists' assessment results in the rectum were moderately consistent compared to those in the other segments of the intestine, which may be related to inadequate intestinal expansion<sup>[25]</sup>.

Our study had some limitations. First, since this was a retrospective study, the radiologists were not blinded to gadolinium-enhanced sequences, as its use is currently recommended in guidelines<sup>[26]</sup>. Second, this was a single-center study. Finally, all treated patients were grouped together, but different treatments might have different impacts on the MRI findings.

However, our study has a few strengths. It had a large sample size and evaluated more than 400 intestinal segments by MR and ileocolonoscopy. The calculations of the confidence interval of ROC analysis and interrater agreement analysis between the two radiologists were performed per segment to fully verify the accuracy, stability and repeatability of the MaRIAs. Furthermore, the correlation between inflammatory factors and the MaRIAs score was analyzed to further verify the reliability that the MaRIAs can be used to analyze the activity degree of CD in this study.

In conclusion, our study demonstrated that the MaRIAs can be used to accurately assess the activity degree of CD and were highly correlated with the SES-CD, the gold standard, and moderately to well correlated with three inflammatory indicators. Moreover, the interrater agreement analysis between the two radiologists was stable and repeatable, which demonstrated that the MaRIAs can be applied in the clinic very well.

**Abbreviations:** CD, Crohn's disease; MaRIA, magnetic resonance index of activity; MaRIAs, simplified magnetic resonance index of activity; SES-CD, simple endoscopic score for Crohn's disease; MRI, magnetic resonance imaging; FC, fecal calprotectin; ESR, erythrocyte sedimentation rate; CRP, C-reactive protein; NSAID, nonsteroidal anti-inflammatory drugs; ROI, region of interest; ROC, Receiver operating characteristic curves; ICC, intraclass correlation coefficient; AUC, area under the curve; IQR, interquartile range.

**Acknowledgements:** None.

**Authors' contributions:** Yongli Tao performed radiological interpretations, acquired data, which was analyzed and interpreted, completed statistical analysis, and wrote manuscript. Hong Li conducted MaRIAs scores on MRI images, and performed critical revision of the manuscript for intellectual content; Xiaochun Yang conducted MaRIAs scores on MRI images, and performed critical revision of the manuscript for intellectual content, supervised the investigation, and performed final approval; Wen Tang conducted SES-CD scores on colonoscopy images; Guohua Fan performed critical revision of the manuscript for intellectual content. Han Xu performed critical revision of the manuscript. All authors, approve of have read and approved the manuscript in its current state.

**Funding:** This work was supported by the Preresearch Fund Project for Young Employees

(SDFEYQN1815).

**Availability of data and materials:** The data that support the finding of this study are available from the corresponding author upon reasonable request

**Ethics approval and consent to participate:** The study protocol conforms to the ethical guidelines of the Declaration of Helsinki. The project was approved by the ethics committee of the Second Affiliated Hospital of Soochow University. Because of the retrospective nature of the study, the need for individual consent was waived and this was approved by the ethics committee of the Second Affiliated Hospital of Soochow University. A standardized research protocol for the data collection was utilized.

**Competing interests:** The authors declare they have no competing interests.

**Consent for publication:** All authors approved the publication of this manuscript.

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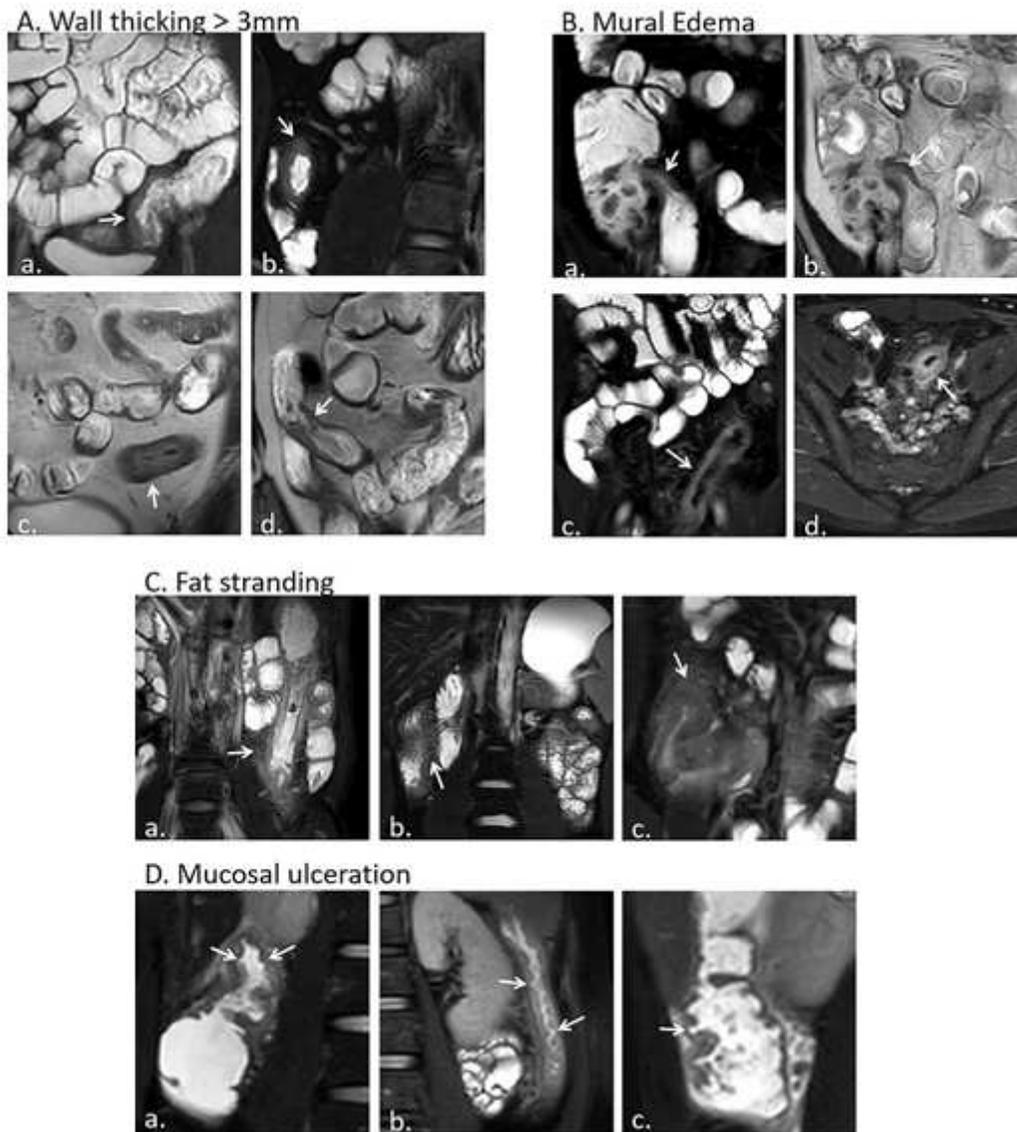
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# Figures



**Figure 1**

Representative examples of magnetic resonance (MR) lesions: (A) Wall thickness >3 mm: coronal T2-weighted images with fat saturation of the descending colon (a) and terminal ileum (b); coronal T2-weighted images of the descending colon (c) and terminal ileum (d) (arrow in image). (B) Mural edema (high signal intensity on T2 sequences with fat saturation compared with normal appearing loops): coronal T2-weighted images with fat saturation (a) and without (b) of the terminal ileum from the same patient show high signal intensity. Coronal (c) and axial (d) T2-weighted images with fat saturation of the descending colon from the same patient (arrow in image). (C) Fat stranding (loss of the normal sharp interface between the intestinal wall and mesentery, with edema/fluid in the perienteric fat): coronal T2-weighted images with fat saturation of the descending colon (a), sigmoid colon (b) and ascending colon

(c) (arrow in image). (D) Mucosal ulceration: coronal T2-weighted images with fat saturation of the ascending colon (a, c) and descending colon (b) (arrow in image).

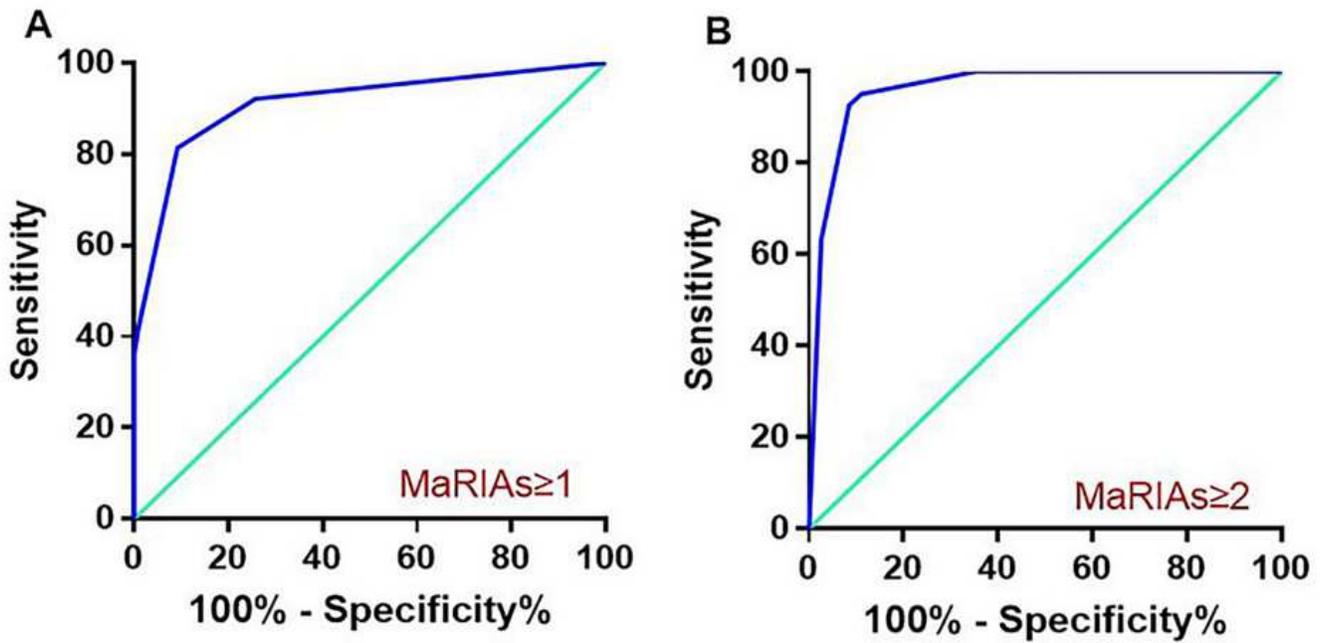


Figure 2

The ROC curve prediction of disease activity (A) and severe activity (B) associated with each segment showed that the MaRIAs could accurately assess the degree of CD activity.

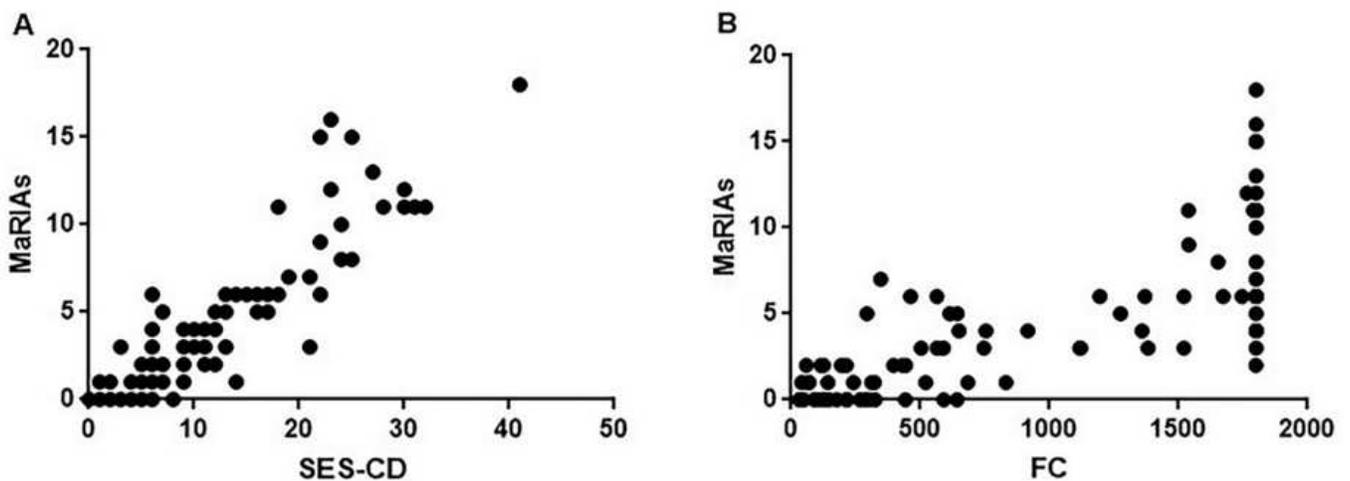


Figure 3

Correlation between the MaRIAs score and SES-CD in patients (A) and between the MaRIAs score and FC level in patients (B).