Thieme

The Relationship Between Intramural Fat Accumulation and Sarcopenia on MR Enterography Exams in Patients with Crohn's Disease

Der Zusammenhang zwischen intramuraler Fettansammlung und Sarkopenie bei MR-Enterografie-Untersuchungen bei Patienten mit Morbus Crohn

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ABSTRACT

Purpose Research on magnetic resonance enterography (MRE) and sarcopenia for assessing Crohn's disease (CD) is growing. Our study examined the connections between the presence of sarcopenia, intramural fat accumulation (IFA), and clinical, laboratory, and MRE findings.

Materials and Methods This retrospective study was conducted on 112 patients with suspected or diagnosed CD who underwent 3-tesla MRE. The study examined the correlation between sarcopenia-related parameters and MRE findings. Results of MRE exams and clinical and laboratory results were statistically analyzed. The Kruskal-Wallis, Pearson chi-square, and Fisher-Freeman-Halton tests were used for comparison.

Results It was determined that patients with active inflammation on a chronic basis had more IFA than the others ($p < 0.001$). There were positive relationships between IFA and intramural edema ($p < 0.001$). There were positive correlations between IFA and high b-values and negative correlations with apparent diffusion coefficient values ($p < 0.05$). Positively significant relationships were found between IFA and wall thickness, affected segment length, disease duration, and sedimentation values ($p < 0.05$). Strong correlations were found between sarcopenia and the CD activity index as well as wall thickness ($p < 0.001/p = 0.003$). There was no significant relationship between steroid usage and other variables.

Conclusion The presence of IFA is associated with chronic inflammation. There was no clear relationship between steroid use and IFA. Our findings support the idea that sarcopenia is related to the activity of CD. Further comprehensive research is required on these subjects.

Key Points

- The usage of MR enterography for the management of CD is increasing day by day due to its advantages.
- There is a paucity of evidence regarding the relationship between sarcopenia and MR enterography findings in patients with CD.
- Intramural fat accumulation (IFA) is a sign of chronicity in patients with CD.
- The presence of IFA seems to be associated with active inflammation on a chronic basis.
- There was no clear relationship between steroid use and IFA.

Citation Format

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ZUSAMMENFASSUNG

Zweck Die Forschung zur Magnetresonanz-Enterografie (MRE) und Sarkopenie nimmt bei der Beurteilung von Morbus

Crohn (CD) zu. Unsere Studie untersuchte die Zusammenhänge zwischen dem Vorhandensein von Sarkopenie, intramuraler Fettansammlung (IFA) und klinischen, Labor- und MRE-Befunden.

Materialien und Methoden Diese retrospektive Studie wurde an 112 Patienten mit vermuteter oder diagnostizierter Zöliakie durchgeführt, die sich einer 3-Tesla-MRE unterzogen. Die Studie untersuchte die Korrelation zwischen Sarkopenie-bezogenen Parametern und MRE-Befunden. Die Ergebnisse der klinischen und Labor-MRE-Untersuchungen wurden statistisch analysiert. Für Vergleiche wurden die Kruskal-Wallis-, Pearson-Chi-Quadrat- und Fisher-Freeman-Halton-Tests verwendet.

Ergebnisse Es wurde festgestellt, dass Patienten mit aktiver Entzündung auf chronischer Basis mehr IFA hatten als die anderen ($p < 0{,}001$). Es gab positive Beziehungen zwischen IFA und intramuralen Ödemen ($p < 0{,}001$). Es gab positive Korrelationen von IFA mit hohen b-Werten und negative Korrelationen mit scheinbaren Diffusionskoeffizientenwerten ($p < 0{,}05$). Es wurden positiv signifikante Beziehungen zwischen IFA und Wanddicke, der Länge des betroffenen Segments, der Krankheitsdauer oder den Sedimentationswerten gefunden ($p < 0{,}05$). Es wurden starke Korrelationen zwischen Sarkopenie und dem CD-Aktivitätsindex sowie der Wanddicke gefunden ($p < 0{,}001/p = 0{,}003$). Es gab keinen signifikanten Zusammenhang zwischen der Verwendung von Steroiden und anderen Variablen.

Schlussfolgerung Das Vorhandensein von IFA ist mit einer chronischen Entzündung verbunden. Es gab keinen klaren Zusammenhang zwischen Steroidkonsum und IFA. Unsere Ergebnisse stützen die Idee, dass Sarkopenie mit der Aktivität von CD zusammenhängt. Weitere umfassende Forschung zu diesen Themen ist erforderlich.

Kernaussagen

- Der Einsatz der MR-Enterographie bei der Behandlung von Morbus Crohn nimmt aufgrund ihrer Vorteile von Tag zu Tag zu.
- Es gibt nur wenige Belege für den Zusammenhang zwischen Sarkopenie und MR-Enterographie-Befunden bei Patienten mit Morbus Crohn.
- Intramurale Fettansammlung (IFA) ist ein Zeichen für Chronizität bei Patienten mit Morbus Crohn.
- Das Vorhandensein von IFA scheint mit einer aktiven, chronischen Entzündung verbunden zu sein.
- Es gab keinen eindeutigen Zusammenhang zwischen Steroidkonsum und IFA.

Introduction

MR enterography (MRE) has been used for approximately 25 years in the diagnosis, evaluation, and follow-up of patients with Crohn's disease (CD) [1, 2]. The use of MRE for managing CD is increasing due to its advantages, such as radiation-free/functional imaging capabilities and excellent soft-tissue contrast resolution [1, 2, 3]. Sixteen percent of patients with CD have been shown to have a 7 % increase in their risk of cancer due to the use of radiation [4]. MRE is a standard part of imaging protocols for pediatric and young patients, as well as for patients with allergies to iodinated contrast media [2]. MRE is suitable for assessing the extension, manifestations, and complications of CD, and it is typically combined with clinical assessment and ileocolonoscopic exams [2, 4, 5].

Sarcopenia is the loss of muscle mass, strength, quality, performance, and/or function [6, 7]. It is a progressive and generalized skeletal muscle disorder that is associated with an increased likelihood of adverse outcomes including falls, fractures, physical disability, and mortality [8, 9]. Unlike muscle atrophy, sarcopenia involves irreversible muscle changes [10]. Most CD patients (approximately 50 %) had sarcopenia CD because of immobility, chronic inflammation, malnutrition, and fatigue, regardless of disease activity [5, 9, 10]. Sarcopenia is associated with a more complicated disease phenotype and surgical resection with a longer hospital stay [5]. It is graded as 'presarcopenia, sarcopenia, or severe sarcopenia', 'primary (age-related) or secondary', and 'acute (< 6 months) or chronic' [8]. Patients with CD and sarcopenia have a significantly higher risk of disease exacerbation, the need for biological therapy, and major postoperative complications after intestinal resection [9]. There is a paucity of evidence regarding the relationship between sarcopenia and MRE findings in patients with CD [7, 9].

Intramural fat accumulation (IFA) is a sign of chronicity in patients with CD. IFA is a useful parameter for diagnosing the disease and understanding its duration [11]. To the best of our knowledge, there is no research on the relationship between IFA and sarcopenia. We aimed to analyze the relationships between IFA, sarcopenia, and findings of clinical, laboratory, and MRE exams.

Materials and Methods

Between 2017 and 2022, a total of 112 patients with a mean age of 38 and a standard deviation of 13 underwent 3-tesla (3 T) MRE examinations for confirmed or suspected inflammatory bowel disease (IBD). The study was conducted retrospectively. Institutional ethical approval was obtained for the study (approval date: 2024, approval number: T1–24–133). All patients provided informed consent before the MRE examinations. The study group consisted of 49 % women and 51 % men. Patients with suboptimal MRE results, a history of allergy to MR contrast agents, severe organ failure or sepsis, spinal column abnormalities/pathologies, and those who had received steroids for non-IBD reasons were excluded from the study. However, CD patients treated with steroids were not excluded. The diagnosis of CD was confirmed through both histological and clinical assessments.

▶ **Table 1** 3-Tesla MRE protocol of the study.

Sequences / parameters	2 D-T1 W	2 D-T1 W	2 D-DWI	2 D-T2 W (SSFSE)	3 D-T1 W (GRE)
TR/TE (ms)	5.58/1.99	2.91/1.34	6071/61.2	825/175	2.89/1.33
Slice thickness (mm)	4	4	6	6	4
FOV* (mm^2)	360 × 360	400 × 400	360 × 360	380 × 380	400 × 400
NEX	1	1	5	0.607	1
Slice number	22	22	22	22	100
Flip angle (°)	90	90	90	90	10°
Imaging plane	Axial	Coronal	Axial	Axial+coronal	Axial+coronal
Fat saturation	+	+/–	+	+/–	+

Abbreviations: TR/TE: time of repetition/time of echo; NEX: number of excitations; FOV: field of view. Definition of **+/–** represents with and without fat saturation

MRE Protocol

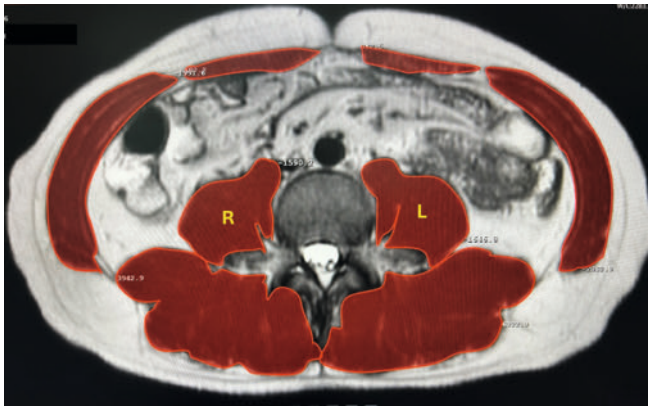
All MRE studies were conducted using a 3 T MR machine (Pioneer, GE Healthcare System, Wisconsin, USA). To ensure the colon is properly cleansed before MRE scans, solid food intake is not allowed 12 hours before the procedures. Patients were advised to consume at least 2 liters of liquid and grain-free watery foods the day before the MRE. The night before the MRE session, patients were instructed to use a laxative diet solution (100 ml, Fleet Phospho-Soda, Kozmed). Patients were given 1500 ml of biphasic oral contrast agent to drink within about 50 minutes for optimal MRE exams. The oral contrast agent was a mixture of 250 ml of lactulose (Duphalac 670 mg/ml, Abbott) with water at room temperature. Additionally, 20 mg of hyoscine-N-butyl bromide (Buscopan, Boehringer, Germany) was administered intravenously as a spasmolytic agent. For post-contrast imaging, 15–20 mL of Dotarem (Gadoterate meglumine, Guerbet, France) was injected intravenously. The MRE acquisition protocol is detailed in ▶ **Table 1**. The final step of the MRE examination involved obtaining a single late-phase (three-minute) fat-suppressed three-dimensional (3 D) T1-weighted (T1 W) acquisition in the axial plane after the injection of the intravenous contrast agent.

Evaluation of the MRE data

The length and wall thickness of the affected bowel segment were measured on fat-suppressed T2-weighted (T2 W) and post-contrast T1 W images. The presence of intramural edema was assessed by examining the presence of intramural hyperintensity in the affected segment on fat-suppressed T2 W images and categorized as either present or absent.

The presence of IFA was evaluated using 3 D Dixon fat images, based on the presence of hyperintense areas within the affected segment(s). The presence of IFA was categorized as either present or absent, as previously described [11].

The presence of restricted diffusion in the affected bowel loops was classified as hyperintense, isointense, or hypointense based on the signal intensity of the affected region on the high b-value images. ADC values in the affected segment were calculated by averaging the values from three distinct circular regions of interest (ROI) positioned in areas exhibiting restricted diffusion. If multiple sites of bowel wall involvement were present, the one with the lowest signal intensity on the ADC images was selected.



▶ **Fig. 1** Demonstration of total psoas area (R+L) and skeletal muscle area calculations on an axial T2 W image (R: right psoas muscle, L: left psoas muscle).

Active disease or active inflammation (AI) is diagnosed by intramural edema with wall thickening, diffusion restriction in the bowel wall, adjacent fat stranding, enlarged lymph nodes (> 5 mm in the shortest diameter), comb sign (prominent vasa recta), and significant contrast enhancement in the affected loops.

The presence of IFA and a long-term disease history accompanying the signs of active inflammation is classified as active disease with a chronic background (chronic active disease, CAI), as previously described [11]. The presence of a long-term CD history without inflammatory findings was accepted as either chronic disease or chronic inflammation (CI).

▶ **Table 2** Relationships between variables analyzed in the study and groups of disease activity.

Variables	N (n = 32)	AI (n = 33)	CAI (n = 44)	CI* (n = 3)	p-value	Pairwise comparison
Age	38 (19:66)	30 (19:57)	41 (19:71)	27 (27:30)	**0.029**[a]	**$p^{AI\text{-}CAI}$ = 0.007**
Weight (kg)	63 (47:82)	68 (45:94)	73 (35:99)	54 (43:70)	0.090[a]	–
Height (cm)	160 (150:180)	170 (155:190)	170 (155:185)	153 (150:155)	**0.004**[a]	**$p^{N\text{-}AI}$ = 0.006** **$p^{N\text{-}CAI}$ = 0.002**
BMI	22.95 (17.4:35.5)	23.3 (17.3:31.2)	24.3 (14.5:32.3)	22.5 (18.3:31.1)	0.185[a]	–
BMI group						
< 18.5	2 (6.3 %)	3 (9.1 %)	2 (4.5 %)	1 (33.3 %)	0.189[b]	–
18.6–25	20 (62.5 %)	21 (63.6 %)	23 (52.3 %)	1 (33.3 %)		
25–30	5 (15.6 %)	8 (24.2 %)	17 (38.6 %)	0		
> 30	5 (15.6 %)	1 (3.1 %)	2 (4.5 %)	1 (33.3 %)		
Sex						
Female	24 (75 %)	13 (39.4 %)	15 (34.1 %)	3 (100 %)	**0.001**[c]	–
Male	8 (25 %)	20 (60.6 %)	29 (65.9 %)	0		
Smoking						
Yes	9 (28.1 %)	13 (39.4 %)	17 (38.6 %)	2 (66.7 %)	0.560[c]	–
No	23 (71.9 %)	20 (60.6 %)	27 (61.4 %)	1 (33.3 %)		

Notes: * is not sufficient for statistical analyses and it is not included in the comparisons. Data are expressed as median (minimum:maximum) or n(%); a: Kruskal Wallis H test; b:Fisher-Freeman Halton test; c: Pearson Chi-Square test

▶ **Table 3** This table shows the distribution of intramural fat accumulation (IFA), intramural edema, and DWI scores according to disease activity.

Variables	N (n = 32)	AI (n = 33)	CAI (n = 44)	CI* (n = 3)	p-value
DWI					
0 (hypointense)	31(96.9 %)	0	0	0	**< 0.001**[c]
1 (isointense)	1(3.1 %)	13(39.4 %)	8(18.2 %)	3(100 %)	
2 (hyperintense)	0	20(60.6 %)	36(81.8 %)	0	
IFA					
0	32(100 %)	32(97 %)	6(13.6 %)	2(66.7 %)	**< 0.001**[b]
1	0	1(3 %)	38(86.4 %)	1(33.3 %)	
Intramural edema					
0	32(100 %)	20(60.6 %)	5(11.4 %)	3(100 %)	**< 0.001**[c]
1	0	13(39.4 %)	39(88.6 %)	0	

Notes: * is not sufficient for statistical analyses and it is not included in the comparisons. Data are expressed as n (%); b: Freeman Halton test; c: Pearson Chi-Square test.

Evaluation of the presence of sarcopenia

Calculations involving sarcopenia were conducted as per the literature (3). Psoas areas (right and left), total psoas area (TPA), and skeletal muscle area (SMA) measurements (excluding main nerve roots) were calculated using the free-hand ROI method on axial T2 W and Dixon water/fat images. An AW Volume Share 7 workstation (GE Healthcare System, Wisconsin, USA) was used for the measurements. The SMA delineates the contours of all abdominal muscles at the L3 vertebrae level (▶ **Fig. 1**). The total psoas area (TPA) was determined by adding the areas of the right

▶ **Table 4** Distribution of quantitative variables according to disease activity groups.

Variables	N (n = 32)	AI (n = 33)	CAI (n = 44)	CI* (n = 3)	p-value	Pairwise comparison
Wall thickness (mm)	0(0:2)	4(2:14)	6.5(2:14)	2(1:6)	**< 0.001**[e]	–
Affected length (mm)	0(0:30)	44(19:352)	89(11:1512)	30(23:90)	**< 0.001**[e]	–
ADC	–	1592(694:3786)	1137(610:3000)	–	**0.008**[e]	–
Disease duration (m)	10(1:156)	4(1:156)	26.5(1:252)	18(1:30)	**0.031**[a]	**$p^{AI\text{-}CAI} = 0.014$**
CRP	3.11(0.4:113)	3.1(0.5:96.1)	7.13(0.5:193)	0.7(0.5:3.9)	**0.009**[a]	**$p^{N\text{-}CAI} = 0.009$** **$p^{AI\text{-}CAI} = 0.011$**
R-psoas area	779(330:2108)	1211(435:2100)	1173(209:2280)	808(244:1282)	**0.009**[a]	**$p^{N\text{-}CAI} = 0.001$**
L-psoas area	793.5(384:2000)	1292(517:2270)	1179(267:1866)	970(719:1532)	**0.008**[a]	**$p^{N\text{-}CAI} = 0.001$**
TPA	15.22(7.14:41.1)	25.93(10.4:42.03)	23.31(4.76:41.39)	17:78(9.63:28.14)	**0.005**[a]	**$p^{N\text{-}AI} = 0.028$** **$p^{N\text{-}CAI} = 0.001$**
SMA	116.09 ± 23.73	131.40 ± 37.66	136.79 ± 34.33	116.1 ± 17.29	**0.025**[d]	**$p^{N\text{-}CAI} = 0.003$**

Notes: Data are expressed as median (minimum:maximum) or mean±standard deviation, a: Kruskal Wallis H test, d: One-way Anova test, e: Mann-Whitney U test

(R) and left (L) psoas muscles (▶ **Fig. 1**). The average of three consecutive manual measurements and the average value of these calculations were taken. Sarcopenia was defined as a skeletal muscle index (SMI) < 38.5 cm^2/m^2 in women and < 52.4 cm^2/m^2 in men [3]. Myosteatosis was considered positive if the ratio of the mean signal intensity of the psoas muscle to that of the cerebrospinal fluid was above 0.107 [3]. ROI measurements were made by Radiologist 1 (Y.C.G.), and the contours were confirmed by Radiologist 2 (O.A.).

Upon accessing the hospital information systems, the clinical and laboratory findings of all patients were recorded in the study worksheet. The radiologists reviewed the MRE examinations without access to the clinical and laboratory results. After evaluating the MRE images and other imaging studies, the patients received a final diagnosis based on a consensus meeting (consisting of radiologists and gastroenterologists). Patients who did not detect any radiological abnormalities on clinical, laboratory, or imaging tests were considered normal or free of CD.

Statistical analysis

The study assessed the normal distribution of variables through the Shapiro-Wilk test. Continuous variables were described using median (minimum: maximum) and mean ± standard deviation. Group comparisons were made using independent sample t-tests or Mann-Whitney U tests based on normality. The Kruskal-Wallis test was used for comparisons among the three groups. Categorical variables were presented as frequency and percentage (n%) and compared using Pearson chi-square or Fisher-Freeman-Halton tests. The relationship between continuous variables is given by the Spearman correlation coefficient and Point Biserial Correlation. Statistical analysis was conducted with SPSS (IBM Corp., released in 2017, IBM SPSS Statistics for Windows, Version 25.0, Armonk, NY: IBM Corp.), with a significance level set at $p < 0.05$.

▶ **Table 5** The relationship between the presence of IFA/the intramural edema and restricted diffusion.

Variables		Restricted diffusion (n = 112)
Wall edema (mm)	r_s	0.732**
	p	< 0.001
IFA	r_s	0.551**
	p	< 0.001

** $p < 0.01$; r_s: Spearmen correlation coefficient

Results

The median age was higher in the CAI group than in the other groups ($p = 0.029$) (▶ **Table 2**). Intramural edema and restricted diffusion were significantly higher in the affected intestinal segments of patients with AI or CAI compared to the other groups ($p < 0.001$) (▶ **Table 3**). It was determined that patients in the CAI group had more IFA than those in the other groups ($p < 0.001$) (▶ **Table 3**).

The median values of wall thickness and affected segment length were higher in the CAI group than in the other groups ($p < 0.001$) (▶ **Table 4**). ADC values were found to be higher in the AI group than in the CAI group ($p = 0.008$) (▶ **Table 4**). The median measurement values for C-reactive protein (CRP) were found to be higher in the CAI group compared to patients in other groups ($p = 0.009$) (▶ **Table 4**). Psoas and skeletal muscle area measurements were found to be higher in the AI and CAI groups than in the CI and normal groups ($p = 0.009$, 0.008, 0.005, and 0.025 for R-psoas area, left psoas area, TPA, and SMA; respectively) (▶ **Table 4**).

▶ **Table 6** The table shows the relationships between the variables analyzed in the study.

Variables		Wall thickness	Affected length	ADC	Disease duration	SMA	TPA	CRP	HBI
Wall thickness	r_s	–							
	p								
	n								
Affected length	r_s	**0.554****	–						
	p	**<0.001**							
	n	**81**							
ADC	r_s	**–0.636****	**–0.508****	–					
	p	**<0.001**	**<0.001**						
	n	**76**	**76**						
Disease duration	r_s	0.166	**0.241***	–0.185	–				
	p	0.138	**0.030**	0.110					
	n	81	**81**	76					
SMA	r_s	–0.136	–0.038	0.092	–0.034	–			
	p	0.227	0.733	0.427	0.720				
	n	81	81	76	112				
TPA	r_s	–0.093	–0.003	0.047	–0.107	**0.727****	–		
	p	0.410	0.976	0.686	0.262	**<0.001**			
	n	81	81	76	112	**112**			
CRP	r_s	**0.436****	**0.438****	**–0.284***	–0.087	0.097	0.182	–	
	p	**<0.001**	**<0.001**	**0.013**	0.361	0.308	0.054		
	n	**81**	**81**	**76**	112	112	112		
HBI	r_s	**0.307****	**0.293****	**–0.252***	–0.094	–0.001	0.080	**0.228***	–
	p	**0.005**	**0.008**	**0.028**	0.325	0.990	0.402	**0.016**	
	n	**81**	**81**	**76**	112	112	112	**112**	
CDAI	r_s	**0.408****	**0.425****	**–0.412****	–0.041	–0.134	0.016	**0.311****	**0.769****
	p	**<0.001**	**<0.001**	**<0.001**	0.669	0.159	0.869	**0.001**	**<0.001**
	n	**81**	**81**	**76**	112	112	112	**112**	**112**
Sedimentation	r_s	**0.236***	0.213	**–0.261***	–0.026	–0.258**	–0.172	**0.494****	0.127
	p	**0.034**	0.056	**0.023**	0.782	0.006	0.069	**<0.001**	0.182
	n	**81**	81	**76**	112	112	112	**112**	112

*p < 0.05; **p < 0.01; r_s: Spearman correlation coefficient; ADC: apparent diffusion coefficient; SMA: skeletal muscle area; TPA: total psoas area; CRP: C-reactive protein; HBI: Harvey-Bradshaw Index; CDAI: CD activity index

A significant relationship was found between restricted diffusion and the presence of intramural edema or IFA (p < 0.001) (▶ **Table 5**). Significant inverse relationships were found between ADC values and intramural edema/CDAI (Spearman correlation coefficients were -0.412 and -0.479, respectively; p < 0.001 for both). Negative relationships were found between ADC measurements and the Harvey–Bradshaw Index (HBI), CRP, or sedimentation values (p ≤ 0.028) (▶ **Table 6**). HBI is a simplification of the CDAI, designed to make data collection and computation easier [12].

Significant positive relationships were found between wall thickness measurements and the length of the affected area, CRP levels, HBI scores, or sedimentation values (p < 0.05). In addition, there was a significant negative relationship between wall thickness measurements and ADC values (p < 0.05) (▶ **Table 6**). Positive significant relationships existed between the affected length and disease duration, CRP, or HBI values (p < 0.05). In addition, a significant inverse relationship was found between the length of affected distances and ADC values (p < 0.05) (▶ **Table 6**). There was a significant negative relationship between ADC measurements and CRP, HBI, or sedimentation values (p < 0.05). There was a significant negative relationship between SMA measurements and sedimentation values (p < 0.05) (▶ **Table 6**).

▶ **Table 7** The table shows the connections between the variables or scores examined in the research.

Variables		IFA	Sarcopenia	Steroid	Wall edema
IFA	r_{pb}	–			
	p				
	n				
Sarcopenia	r_{pb}	0.096	–		
	p	0.314			
	n	112			
Steroid	r_{pb}	0.054	0.012	–	
	p	0.573	0.902		
	n	112	112		
Wall edema	r_{pb}	**0.719****	0.088	0.120	–
	p	**<0.001**	0.361	0.216	
	n	**109**	109	109	
DWI	r_{pb}	**0.548****	0.139	0.077	**0.718****
	p	**<0.001**	0.145	0.422	**<0.001**
	n	**112**	112	112	**109**

**p < 0.01; r_{pb}: Point Biserial Correlation Coefficient. IFA: intramural fat accumulation; DWI: diffusion-weighted imaging

There was a significant positive relationship between the presence of IFA and the severity of intramural edema or restricted diffusion ($p < 0.05$) (▶ **Table 7**). Positive significant relationships were found between the presence of IFA and wall thickness, affected segment length, disease duration, and sedimentation values ($p < 0.05$) (▶ **Table 8**) (▶ **Fig. 2**). There was no significant relationship between steroid usage and other variables ($p > 0.05$) (▶ **Table 7** and ▶ **Table 8**).

There was a significant positive relationship between sarcopenia and wall thickness ($p = 0.003$) (▶ **Table 8**). In addition, there was an inverse relationship between sarcopenia and SMA values ($p < 0.05$) (▶ **Table 8**). We found non-significant negative relationships between SMA and TPA values and wall thickness, affected segment length, and disease duration (▶ **Table 6**). Similarly, non-significant negative relationships were observed between sarcopenia and affected segment length, disease duration, and TPA (▶ **Table 8**). We found a significant positive relationship between myosteatosis and disease duration ($p = 0.047$) (▶ **Table 8**). No statistically significant relationship was found between myosteatosis and other parameters.

Statistically significant positive relationships were found between intramural edema and wall thickness, affected segment length, disease duration, and CRP/CDAI values ($p < 0.05$) (▶ **Table 8**). Similarly, positive relationships were found between restricted diffusion and wall thickness, affected segment length, disease duration, and CRP/CDAI values ($p < 0.05$) (▶ **Table 8**). Significant negative relationships were found between wall edema, restricted diffusion, and ADC values ($p < 0.05$) (▶ **Table 8**).

Discussion

We showed positive correlations between sarcopenia/SMA and bowel wall thickness. Also, we found inverse correlations between sedimentation and SMA or ADC values. These results suggest that the presence of sarcopenia is highly prevalent in patients with high sedimentation values and concomitantly lower ADC values due to an inflammatory background. These correlations should sound the alarm for radiologists to look more thoroughly for signs of active disease in sarcopenic patients, as observed in children with IBD [9].

We found statistically non-significant inverse relationships between myosteatosis and TPA/SMA (▶ **Table 8**). The cause of this situation may be the low number of cases. Only area measurements of the muscles are insufficient to determine the relationship between myosteatosis and/or sarcopenia. In our study, increased muscle areas were generally observed in patients with active inflammatory findings. The cause of this situation may be the presence of myosteatosis or inflammation in patients with active disease. Exact or functional muscle mass in these patients might be overestimated due to myosteatosis, which should be considered in the assessment of sarcopenia in patients with CD. Myosteatosis, a term comprising intermuscular, intramuscular, and/or intramyocellular fat, negatively correlates with muscle strength, quality, or function [13]. Muscle strength and quality are better than mass in predicting the presence of sarcopenia and adverse outcomes [8].

Screening for sarcopenia or myosteatosis is uncommon in CD [9]. We found a significant positive relationship between myosteatosis and disease duration. Myosteatosis is a predictor of mor-

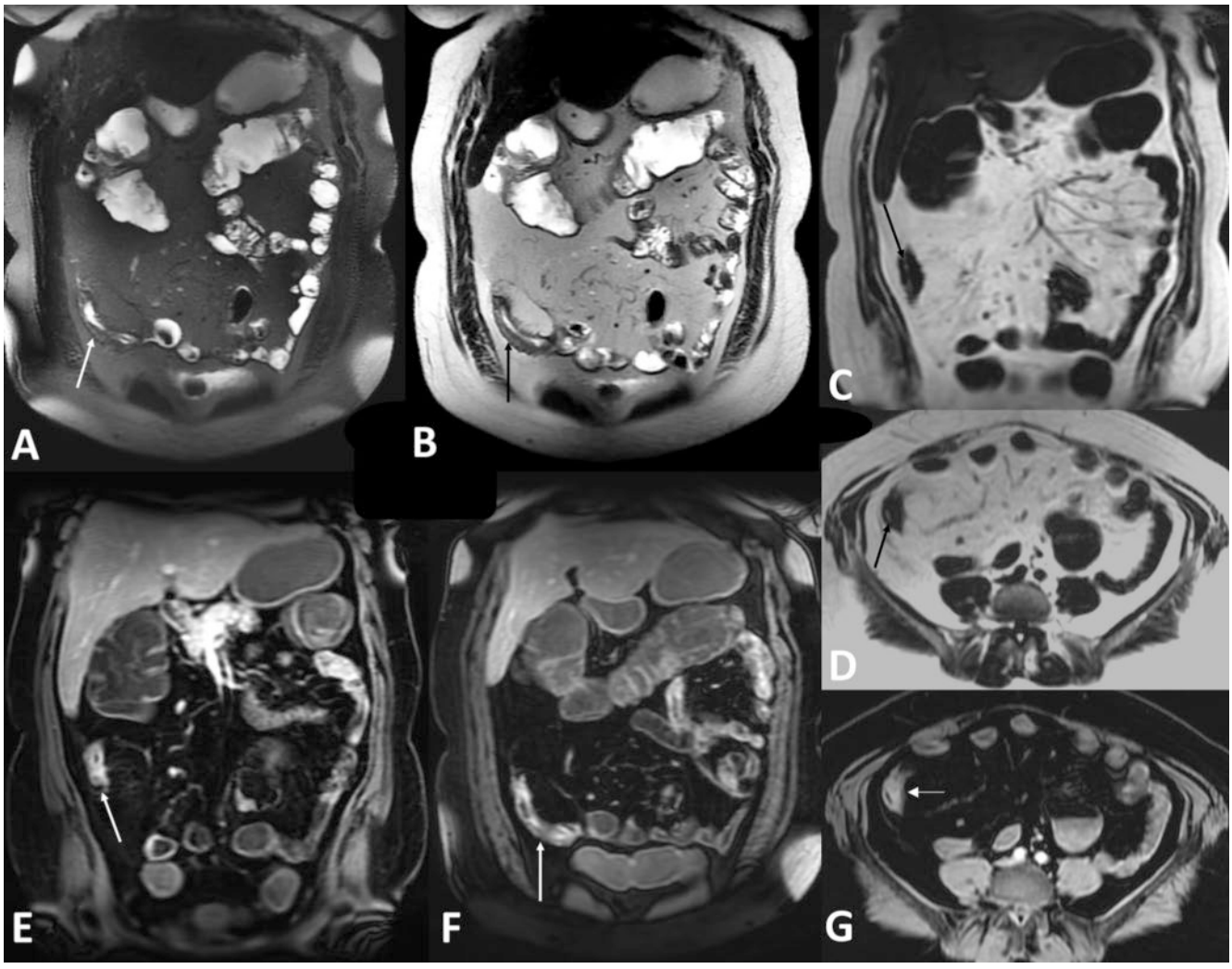
▶ **Table 8** The table displays the relationships between the variables or scores analyzed in the study.

Variables		IFA	Sarcopenia	Steroid usage for IBD treatment	Wall edema	DWI	MYS
Wall thickness (mm)	r_{pb}	**0.379****	**0.323****	0.075	**0.536****	**0.469****	0.155
	p	**<0.001**	**0.003**	0.506	**<0.001**	**<0.001**	0.167
	n	**81**	**81**	81	**79**	**81**	81
Affected length (mm)	r_{pb}	**0.272***	0.185	−0.014	**0.221***	**0.225***	−0.043
	p	**0.014**	0.098	0.905	**0.049**	**0.043**	0.706
	n	**81**	81	81	**79**	**81**	81
ADC	r_{pb}	**−0.302****	−0.029	−0.108	**−0.466****	**−0.487****	−0.182
	p	**0.008**	0.805	0.352	**<0.001**	**<0.001**	0.116
	n	**76**	76	76	**75**	**76**	76
Disease duration (M)	r_{pb}	**0.309****	−0.016	−0.049	**0.229***	0.171	**0.188***
	p	**0.001**	0.868	0.611	**0.017**	0.071	**0.047**
	n	**112**	112	122	**109**	112	**112**
SMA	r_{pb}	0.132	**−0.333****	0.094	0.134	0.177	−0.081
	p	0.167	**<0.001**	0.322	0.165	0.062	0.393
	n	112	**112**	112	109	112	112
TPA	r_{pb}	0.143	−0.011	0.072	0.127	**0.227***	−0.169
	p	0.131	0.912	0.453	0.189	**0.016**	0.075
	n	112	112	112	109	**112**	112
CRP	r_{pb}	0.111	0.161	0.003	**0.232***	0.158	0.025
	p	0.245	0.091	0.971	**0.015**	0.096	0.792
	n	112	112	112	**109**	112	112
HBI	r_{pb}	0.103	0.170	0.094	0.180	0.179	0.034
	p	0.280	0.074	0.324	0.061	0.059	0.718
	n	112	112	112	109	112	112
CDAI	r_{pb}	0.144	**0.317****	0.186	**0.212***	**0.193***	0.120
	p	0.129	**0.001**	0.050	**0.027**	**0.041**	0.206
	n	112	**112**	112	**109**	**112**	112
Sedimentation	r_{pb}	**0.224***	0.119	0.164	0.168	0.109	0.139
	p	**0.017**	0.213	0.084	0.080	0.254	0.145
	n	**112**	112	112	109	112	112

*p<0.05; **p<0.01; r_{pb}: Point Biserial Correlation Coefficient; M: month; ADC: apparent diffusion coefficient; SMA: skeletal muscle area; TPA: total psoas area; CRP: C-reactive protein; HBI: Harvey-Bradshaw index; CDAI: CD activity index; MYS: myosteatosis; IFA: intramural fat accumulation; DWI: diffusion-weighted imaging

bidity/mortality and an independent risk factor for many diseases [13]. Sarcopenia may regress with proper treatment and close follow-up [9]. Sarcopenia should be added to clinical indices or scores investigating disease activity. Unfortunately, sex- or age-specific cut-off values have not yet been determined for parameters of sarcopenia (SMI, skeletal muscle signal intensity or area, etc.) [3, 5, 10]. Opportunistic imaging uses routine imaging exams to obtain new imaging biomarkers and cut-off values and to obtain additional useful information [13]. Routine MRE examinations can also be used to evaluate sarcopenia and myosteatosis as an example of opportunistic imaging. It may be possible to develop better follow-up and preventive approaches or indices based on MRE parameters as a proactive management strategy.

We found non-significant negative relationships between SMA/TPA values and wall thickness, affected segment length, and disease duration (▶ **Table 6**). Similarly, non-significant negative relationships were observed between sarcopenia and affected segment length, disease duration, and TPA (▶ **Table 8**). Patients with CAI were found to have higher muscle mass. The reason for this situation may be the relative increase in muscle volume due to



▶ **Fig. 2** A patient with an active CD with a chronic basis. Intramural edema in the affected segments was observed on the fat-saturated (**A**) and routine (**B**) T2 W coronal plane images (arrows). There was IFA in the affected loops on coronal (**C**) and axial (**D**) planes in Dixon-fat images (arrows). There were contrast material enhancements in these segments on coronal (**E, F**) and axial (**G**) planes fat-suppressed T1 W images (arrows).

myosteatosis. Comprehensive studies are needed with larger patient groups. Only volume, mass, fat, or area measurements of the muscles are insufficient to determine sarcopenia since these measurements do not always correlate with muscle strength [14].

We found more IFA in patients with CAI than in other groups. Positive correlations were observed between IFA and disease duration or restricted diffusion. IFA indicates chronicity, as observed in our study and the literature [11]. We found a negative correlation between the IFA and ADC values. In addition, there were positive correlations between IFA and affected bowel wall thickness, affected segment length, restricted diffusion, or sedimentation values. These results indicate that many patients with IFA had active inflammation based on chronicity. Although a relationship between IFA and long-term steroid usage has been reported in the literature, we did not find a statistically significant relationship between IFA and a history of steroid usage in patients with CD [11].

The DWI component of a routine MRE examination is a reliable tool for evaluating and distinguishing actively inflamed intestinal segments in CD, and it does not require contrast agent administration [15]. In this study, the intensity of the affected bowel loops on high b-value (≥ 800 s/mm2) images and intramural edema on T2 W images were significantly higher in patients with active disease than in those without. We found a statistically significant difference between the ADC values of the AI and CAI groups. In addition, we found a positive correlation between intramural edema and intensity on high b-value images and an inverse correlation between intramural edema and ADC values in the affected regions. Narrowing of the extracellular space and edema within the bowel wall is caused by inflammatory changes, which subsequently lead to restricted diffusion and lower ADC values [16]. Non-contrast MRE with DWI is a suitable option for assessing patients with CD, except for perianal disease [17]. Our findings are consistent with the literature and indicate that both high B-value images but also ADC maps should be considered together to differentiate active disease from chronic disease.

We acknowledge that this study has several limitations. Our study is monocentric and retrospective. We did not evaluate the

efficiency of all parameters (such as calf circumference or mid-thigh assessments), tests (e. g., the chair stand, balance, and/or gait speed tests), and imaging techniques (such as ultrasound-guided measurements of muscle thickness, cross-sectional area, fascicle length, pennation angle, and echogenicity) related to sarcopenia or myosteatosis. There is no ideal method or region for evaluating muscle mass and quality, and cut-off points for low muscle mass are not yet well-defined for sarcopenia measurements [8, 9]. In addition, cross-sectional measurements of the psoas or abdominal muscles from limited slices are not representative of the muscles of the whole body [8]. False-positive results on MRE images may be present due to various factors, such as suboptimal fluid distention, technical factors, or motion artifacts. Zoiko et al. reported a significant association between myosteatosis and myofibrosis [18]. Therefore, both factors should be considered in the development of sarcopenia. A relationship may exist between intramural fibrosis and fat accumulation in the intestinal wall. These issues need to be investigated in prospective and comprehensive studies.

Conclusion

The presence of IFA seems to be linked to chronic inflammation. There was no clear relationship between steroid usage and IFA. Positive relationships were observed between sarcopenia and CDAI or bowel wall thickness in our study. These findings support the idea that sarcopenia is related to CD activity. Further comprehensive research is required on these subjects.

Acknowledgement

Some of the patients analyzed in this study are also included in our previous articles on sarcopenia and MRE. However, the purpose, methodology, and results of this study differ greatly from our previous research.

Conflict of Interest

The authors declare that they have no conflict of interest.

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