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ORIGINAL ARTICLE

Cine magnetic resonance imaging for quantitative assessment of healthy volunteers and patients with organic small bowel disease*

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Abstract

Objective The aim of the study was to use dynamic magnetic resonance imaging (MRI) to compare quantitative parameters of small bowel motility between healthy volunteers and patients with small bowel diseases in order to investigate the characteristics of normal and impaired bowel peristalsis.

Methods A total of 44 healthy volunteers (20 men, 24 women; mean age: 36 years; range: 20–61 years) and 42 patients (28 men, 14 women; mean age: 44 years; range: 15–72 years) with organic small bowel disease were recruited in our hospital (Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China) in this prospective study approved by the hospital institutional review board. Imaging was performed using a 3.0-T scanner 45 minutes after standardized oral administration of 1500 mL non-absorbable fluid (2.5% mannitol). A serial coronal scan was performed at selected planes for two minutes without breath-hold. Time-caliber curves were plotted at two well-distended small bowel loops in both healthy and patient groups regardless of location. Luminal diameter (LD), contraction period (CP), frequency of contraction (FC), and amplitude-diameter ratio (ADR) were measured based on the graph.

Results The characteristics of abnormal peristaltic parameters were assessed in different patients and compared to normal curves from healthy volunteers. A total of 37 segments with abnormal motility were confirmed by two readers in consensus, based on curve patterns and the presence of a stationary phase. Compared to normal peristalsis in healthy volunteers, five different patterns of impaired peristalsis were identified: I, consecutive; II, slow; III, giant type; IV, uncoordinated; and V, akinetic. Dilated LDs were detected in all instances of abnormal peristalsis ($P < 0.05$). Increased frequency was found in type I [(8.73 ± 1.15) /min], while decreased frequency was detected in type III peristalsis [(0.67 ± 0.29) /min]. There were no significant differences in frequency between type II [(3.19 ± 0.43) /min] and normal peristalsis [(3.45 ± 0.57) /min]. Apart from type I [(8.70 ± 0.75) /min], increased FCs were found in all other abnormal patterns. In type II peristalsis, the average ADR value was 0.82 ± 0.08, comparable to the ADR value in the healthy group (0.83 ± 0.13).

Conclusion MR cine is an effective method for differentiating normal and abnormal small bowel peristalsis. Plotting time-caliber curves and measuring quantitative MR cine parameters such as LD, CP, FC, and ADR offers more precise information about small bowel motility.

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Key words: small bowel; magnetic resonance (MR) cine; quantitative assessment

Small bowel motility is an essential activity for life [1]. Because much of the digestion and absorption of food takes place in the small intestine, motility function is of great importance, especially in patients with conditions that could lead to impaired motility, such as inflammation, tumor, or ischemia. In previous decades, small bowel motility patterns and periods were detected using techniques such as intraluminal manometry and impedancemetry [2]. However, these methods are invasive, requiring intubation or exposure to ionizing radiation. These tests also involve complicated procedures that patients with small bowel diseases may be unable to tolerate. Assessment of orocecal transit time (OCTT) can also be used to evaluate the motility function of the small bowel [3]; however,

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the limited information provided by this test may not offer clinicians a comprehensive understanding of the impaired bowel segments.

Recently, magnetic resonance imaging (MRI) cine has been increasingly proposed as a noninvasive modality for assessing bowel motility function. It is a real-time technique that offers high resolution imaging to clearly display endoluminal, mural, and extramural details, and can also record luminal diameter (LD) plotted over time to produce peristaltic contraction curves [4]. In addition, several software-assisted analysis methods have been recently developed that offer semiautomatic breath correction, parametric maps, and tagged imaging in order to improve measurement reproducibility and efficiency [5–7]. Subjects in these previous studies were mostly healthy volunteers and patients with Crohn's disease or extremely severe motility disorders such as chronic intestinal pseudo-obstruction (CIPO) [8–10], and the indicators of small bowel motility used in these studies were confined to frequency and contraction amplitude. However, impaired small bowel motility remains uncharacterized, which makes identification of abnormal segmental small bowel peristalsis difficult in patients with small bowel diseases. The purpose of our study was to compare the quantitative parameters of small bowel motility provided by dynamic MRI between healthy volunteers and patients with various organic small bowel diseases in order to investigate the characteristics of normal and various patterns of impaired bowel peristalsis.

Patients and methods

Participants

The institutional ethics committee approved the study protocol. Written informed consent was obtained from each participant prior to entering the study. From December 2012 to December 2014, 44 healthy volunteers [20 men and 24 women, mean age (36.05 ± 13.01) years, range 20–61 years] without history of surgery, ongoing gastrointestinal disease, medication use in the previous month, or gastrointestinal symptoms, were enrolled in this study, along with 42 patients [28 men and 14 women, mean age (44.14 ± 18.31) years, range 15–72 years] with suspected small bowel disease confirmed by endoscopic biopsy or surgery (Fig. 1).

Preparation

Participant preparation for MR enterography (MRE) included: (a) fasting for at least 8 hours, (b) oral uptake of 1000–1500 mL 2.5% mannitol solution (depending on physical status), (c) urination and defecation before MR scan, (d) clysis if feces were not defecated within 12 hours before examination, and (e) training to breath regularly during the scanning process.

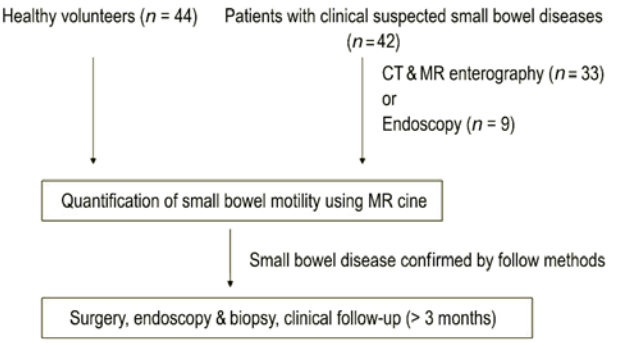

Fig. 1 Flowchart showing patients suspected of having organic small bowel diseases who had previously received CT, MR, or endoscopic examinations

MRI technique

All MR images were acquired with a 3.0-T system (Discovery 750, GE Medical System) using a 32-channel torso-coil covering the entire abdomen. No anti-peristaltic drugs were injected before examination. All volunteers and patients were scanned in a supine position. Free-breathing coronal 2D-fast imaging employing steady state acquisition (FIESTA) and respiratory-triggered single shot fast spin echo (SSFSE) sequences were obtained for a global view of bowel distribution. Cine MRI (TR = 3.2 ms, TE = 1.1 ms, flip angle = 75°; field of view = 48 cm × 48 cm; matrix = 256 × 256; slice thickness = 4 mm; spacing = 1 mm) was performed with a temporal resolution of 565 ms. The total scan time was less than 15 minutes, and a standard static MRE protocol was performed later if required (Table 1).

Data analysis and statistical methods

All MR imaging data were transferred to an Advantage Workstation 4.5. In healthy volunteers, two well-distend-

Table 1 MR imaging sequences and parameters

	SSFSE-ARC	FIESTA	FIESTA-CINE
Repetition time (ms)	4000	3.2	3.2
Echo time (ms)	20	1.1	1.1
Flip angle (degrees)	83.3	75	75
Thickness (mm)	4	8	8
Spacing (mm)	1	1	1
Matrix	256 × 256	256 × 256	256 × 256
FOV (mm)	440	440	440
Breath-type	Respiratory trigger	Free-breathing	Free-breathing
Direction	Coronal/Axial	Coronal	Coronal
Fat suppression type	Fat	Special	Special
Scan time (s)	90–120	17–20	120

Note: SSFSE-ARC, Single shot fast spine echo – auto calibrating reconstruction for cartesian sampling; FIESTA, Fast imaging employing steady state acquisition

ed bowel loops were chosen from the left upper and right lower quadrants. Repeated acquisitions over the same location were used to measure the undulating LD, and a graph of the temporal changes of bowel luminal diameter was then plotted manually. The quantitative parameters of bowel motility, including the LD, contraction period (CP), frequency (FC) and amplitude diameter ratio (ADR) were measured by consensus of two radiologists with 3 years of MRE experience, using graphs of the two selected bowel segments. In the patient group, both an affected and one well-distended bowel segment at the proximal side were measured. Finally, we characterized abnormal peristaltic graphs from different patients by comparing them to normal curves from healthy volunteers. Aside from descriptive analyses, we applied the Shapiro-Wilk test for normality to compare quantitative parameters between healthy volunteers and patients. Paired *t*-tests were used to compare recorded data between two bowel segments. All data were analyzed using SPSS Statistics for Window, Version 17.0 software.

Results

The oral ingestion of 1500 mL 2.5% mannitol solution was well tolerated in all 44 healthy individuals and 39 patients with small bowel diseases, providing sufficient distended small bowel segments for motility assessment. Intraluminal fluid was present in three patients with obstructive gastrointestinal symptoms, which also provided well-distended small bowel segments for functional evaluation.

Healthy group

There were no statistical differences in quantitative parameters (LD, FC, CP, and ADR) between the two bowel segments in healthy volunteers. Normal peristalsis was characterized by the following features: (a) a cluster of sinusoid phasic contraction waves, (b) a cluster of contractions propagated from the proximal to distal segments, (c) a pause; although the duration differed widely between healthy individuals, it did exist in every analyzed small bowel segment in this group (Fig. 2).

Table 2 Distribution of different types abnormal small bowel peristalsis

Variety of disease	Distal segment	Proximal segment	Type
Adenocarcinoma	6/6	6/6	III
Stromal tumor	0/6	0/6	/
Lymphoma	3/6	1/6	V
Chronic inflammation	1/1	1/1	I, III
Crohn's	8/13	0/13	II
Portal mesenteric venous thrombosis	3/4	3/4	IV, V
Henoch-Schonlein purpura	2/2	0/2	V
Adhesion	2/3	1/3	I
Stercoral obstruction	1/1	1/1	I, V
Total	25/42	12/42	37

Patient group

A total of 37 segments with abnormal motility were confirmed by two readers in consensus based on curve patterns and the presence of a stationary phase. Compared to normal peristalsis in normal volunteers, five different patterns of impaired peristalsis were identified: I, consecutive (Fig. 3); II, slow (Fig. 4); III, giant (Fig. 5); IV, uncoordinated (Fig. 6); and V, akinetic (Fig. 7). The distribution of abnormal motility types was shown in Table 2. Paired *t*-tests were used to compare quantitative parameters between healthy volunteers and patients (Table 3). Dilated LDs were detected in all types of abnormal peristalsis ($P < 0.05$). Increased FC was found in type I [(8.73 ± 1.15) /min], while decreased frequency was detected in type III [(0.67 ± 0.29) /min]. There was no significant difference in frequency between type II [(3.19 ± 0.43) /min] and normal peristalsis [(3.45 ± 0.57) /min]. Except for type I peristalsis [(8.70 ± 0.75) /min], higher CPs were found in all other abnormal patterns. In type II peristalsis, the average ADR value was 0.82 ± 0.08, comparable to that of the healthy group (0.83 ± 0.13). Decreased ADR values were observed in patients with types III, IV, and V peristalsis.

Discussion

Until now, there have been few studies on small bowel motility. Computed tomography (CT) and double-con-

Table 3 Quantitative parameters of normal and abnormal small bowel motility

		Diameter (mm)	Frequency (/min)	Period (s)	Amplitude diameter ratio
Healthy group		17.54 ± 2.07	3.45 ± 0.57	8.70 ± 0.75	0.83 ± 0.13
Patients group	I. Consecutive	28.44 ± 4.32*	8.73 ± 1.15*	8.53 ± 0.27**	0.51 ± 0.23*
	II. Slow	35.90 ± 5.56*	3.19 ± 0.43**	15.41 ± 1.42*	0.82 ± 0.08**
	III. Giant	60.58 ± 4.79*	0.67 ± 0.29*	27.36 ± 5.77*	1.00 ± 0.00*
	IV. Uncoordinated	37.23 ± 10.54*	/	/	0.00 ± 0.00*
	V. Akinetic	41.74 ± 12.33*	/	/	0.00 ± 0.00*

* significant difference to healthy volunteers; ** no significant difference to healthy volunteers

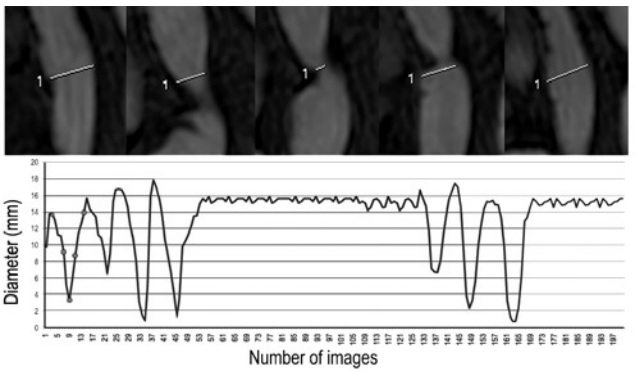

Fig. 2 Time caliber curve of normal small bowel motility. Plotting caliber over time on MR cine images revealed normal peristalsis as a sinusoid phasic contraction wave with intervals

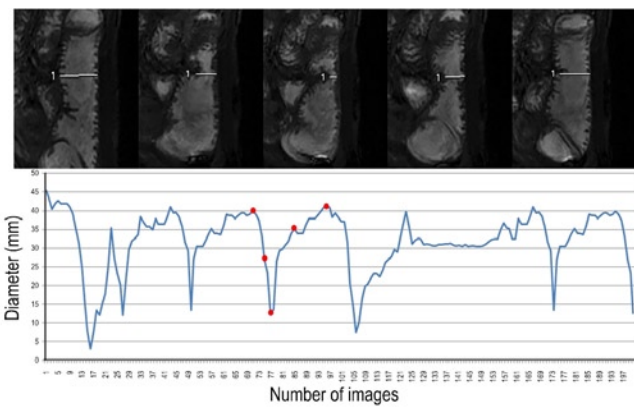

Fig. 4 Slow contraction (Type II). MR cine images in a 48-year-old man with confirmed active Crohn's disease. Dilated bowel segments were visible on MR cine images. Time-caliber curve showed a longer contraction period than normal

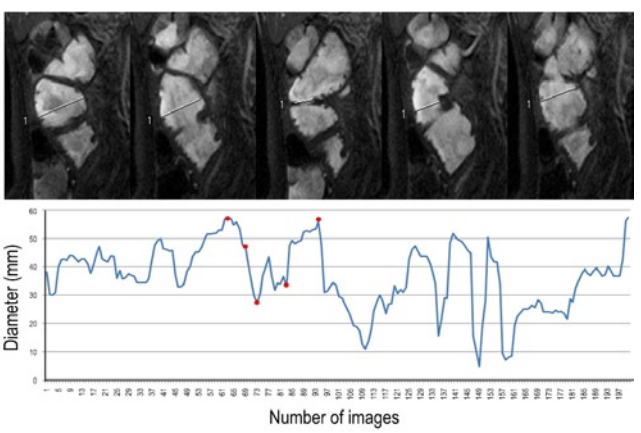

Fig. 6 Uncoordinated contraction (Type IV). Portal-mesenteric venous thrombosis (PMVT) was confirmed by CT angiography in a 20-year-old man two weeks prior. MR cines showed dilated lumen and thickened small bowel wall. Uncoordinated contraction waves were observed on the time-caliber curve, with inconsistent contraction parameters including contraction period, frequency, and amplitude-diameter ratio

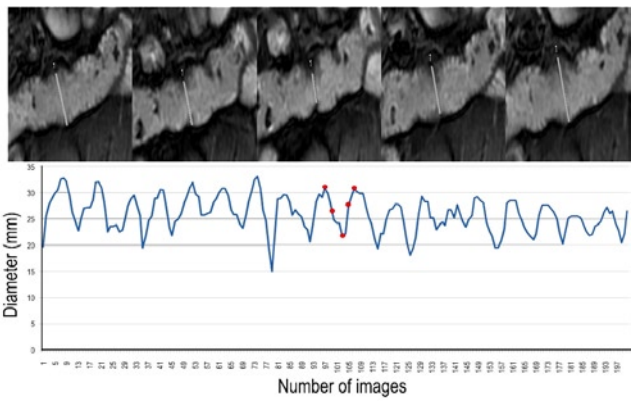

Fig. 3 Consecutive contraction (Type I). MR cine images in a 37-year-old man with confirmed stenosis after appendicectomy. A total of 18 consecutive contractions and decreased ADR in small bowel segments adjacent to the stenosis region were visible on a 2-min MR cine sequence

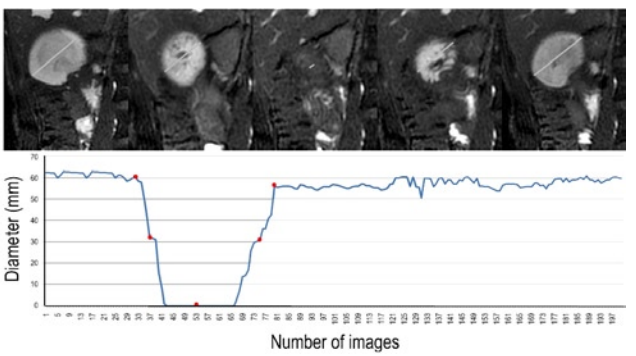

Fig. 5 Giant contraction (Type III). Severe stenosis occurred in the descending part of the duodenum, resulting in recurrent inflammation in a 42-year-old man. MR cines images showed dilated first and second part of the duodenum, proximal to the obstruction. A giant contraction wave was detected on a plotted graph of the time-caliber curve, characterized by longer contraction periods, elevated ADR values, and reduced contraction frequency

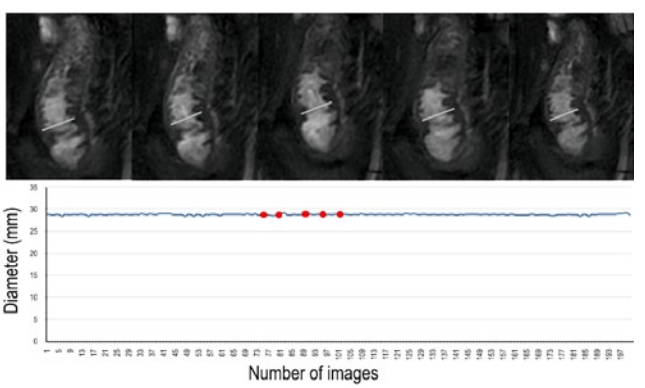

Fig. 7 Akinetic contraction (Type V). A 35-year-old patient with Henoch-Schonlein purpura and intermittent hematochezia. Mucosal edema and mildly dilated bowel lumen were visible in MR cine images. Paralyzed movement of local small bowel segments was found on a plotted time-caliber curve

trast barium enteroclysis are useful techniques for evaluation of small bowel diseases, providing detailed information about the mucosal and space distribution of the entire small bowel. These methods also allow identification of dilated bowel lumen with indirect signs of small bowel obstruction such as dilated bowel lumen with multiple air fluid levels. However, due to concerns about radiation dose, this method can only be performed at a few time points; thus, it is limited for use as a dynamic scan protocol to assess small bowel motility.

Traditional methods such as manometry and impedancemetry are efficient methods for quantitative assessment of small bowel motility; however, ionizing radiation and the complexity of multiple procedures limit their widespread clinical use. With high temporal and soft tissue resolution, MR cine images can provide not only morphological information, but also real-time data on small bowel movement.

In the present study, normal peristalsis was defined as a sinusoid phasic contraction wave in the time-caliber curve (Fig. 2). Periods of stationary phase existed in all small bowel segments during the 2-min MR cine series. There was no statistical difference in diameter, contraction period, or amplitude-caliber ratio between left upper and right lower quadrants. The normal pattern of small bowel peristalsis is characterized by a phasic contraction with intervals using manometry [11–14]. MR cine has been introduced recently by several researchers to evaluate abnormal small bowel peristalsis. Patak *et al* [15] were the first to report using ultrafast MRI as a non-invasive method for measurement of small bowel motility in 30 patients after abdominal surgery. This study shows that by plotting time-caliber curve, non-invasive MRI assessment of bowel motion allows highly rapid and reliable localization and diagnosis of motility problems and thus could have a beneficial impact on treatment and recovery [15]. In addition, Heye *et al* [16] used MR cine to evaluate 91 patients with suspected adhesion or stenosis. They reported 96% and 85% accuracy using MR cine to detect reduced peristalsis and stenosis, respectively, compared to surgical findings [16]. Another study assessed small bowel motility in 12 patients with CIPO compared to healthy volunteers and patients with irritable bowel syndrome (IBS). Plotting time-caliber curves from cine MRI clearly revealed contractility impairments in patients with CIPO [10]. However, the breath-hold MR cine scan protocol used in these previous studies allowed at most 2–3 contractions to be acquired in a single scan. The current study obtained two minute-long MR cine images without breath-holds. In healthy volunteers, a set of contraction waves with a distinct pause can be completely recorded, consistent with results acquired from manometry. In addition, plotting time-caliber curves allowed characterization of different small bowel diseases in this study. Based on a comparative analysis of quantitative parameters (LD, FC, CP, and ADR) between participants in the healthy group and those with small bowel disease, five different patterns of impaired peristalsis were identified in this study (I. consecutive; II. slow; III. giant; IV. uncoordinated; and V. akinetic types).

Identification of abnormal time-caliber curves first calls for analysis of the LD during the resting phase: like the pressure value in manometry, this value represents tension in the bowel lumen. In this study, most patients with different small bowl diseases had larger diameters than healthy volunteers [(17.54 ± 2.07) mm], except for patients with stromal tumors. While the causes of increased diameter vary according to pathological physiological condition, they are mainly divided into two categories: 1. Increased intraluminal pressure due to mechanical obstruction, such as adenocarcinoma, Cohn's disease, or chronic recurrent inflammation, which can result in local bowel wall thickening [17]; 2. Decreased tension of the intestinal smooth muscle cells, which are affected by various pathological factors such as inflammation and ischemia. In the patient group, we noted that all four patients with portal-mesenteric venous thrombosis (PMVT) revealed dilated bowels without stenosis on MRI analysis. In addition, there were no diameter differences between patients with stromal tumor and healthy volunteers. This may be related to the serous origin of the lesion, which has no impact on the bowel lumen or pacemaker cells in the muscular layer; in addition, the largest stromal tumor lesions are less than 3 cm in diameter.

ADR is another important indicator for assessment of small bowel motility; this factor determines the pushing volume of each contraction. In the healthy group, normal peristalsis was defined as a sinusoid phasic contraction wave with a duration of pause. The amplitude-diameter ratio was 0.83 ± 0.13 in this group. In the present study, consecutive contractions characterized by no resting phase were detected in three patients with incomplete small bowel obstruction. Although there appeared to be no differences in the shapes of contraction waves on the plotted graph, the ADR value was lower in these patients (0.51 ± 0.23), representing reduced propulsion due to increased LD compared to normal peristalsis. These features are obvious in type IV and V peristalsis due to mechanical obstruction, with ADR value near zero, which indicates paralyzed small bowel motility.

FC determines the velocity of small bowel peristalsis. The FC in patients with consecutive contraction (8.73 ± 0.11) was significantly higher than the normal group (3.45 ± 0.57). A previous study [18] using manometry in patients with mechanical small bowel obstruction reported clustered and retrograde peristaltic contractions during the resting phase in the time-pressure curve that lasted more than one minute; this was correlated with clinical

manifestations such as nausea and vomiting. This may explain the increased frequency in patients with consecutive contractions.

This study also found that abnormal CPs were associated with impaired small bowel movement. Previous studies have shown that quantified terminal ileal motility is negatively correlated with histopathological measures of disease activity and existing anatomical MRI activity biomarkers [19–20]. Other researchers have noted increased CP and reduced FC in patients with active Crohn's disease [9]. In our study, slow contraction, which is characterized by a longer contraction period [(15.44 ± 1.42) s] compared to the normal group [(8.70 ± 0.75) s], only appeared in segments proximal to the affected locations in patients with active Crohn's disease. Meanwhile, there was no significant difference in FC and ADR between patients with type II peristalsis and healthy volunteers. This might be related to our small sample and individual differences. In type III peristalsis, a giant contraction wave was detected on plotted graphs of time-caliber curve, with increased contraction periods [(27.36 ± 5.77) s], elevated ADR (almost 1.0) value, and reduced FC. As described by Husebye and Frank *et al* [13, 21], in their manometry studies on abnormal small bowel motility, giant migrating contractions or non-propagated prolonged contractions were highly correlated to mechanical obstruction. The abnormal contraction periods described in these two studies were more than 20 s; the giant contractions observed in our study were similar to those observed in these previous studies. In addition, the bowel segments in the four patients with PMVT in this study showed varying degrees of dilated bowel in MRI analysis. According to the previous studies, PMVT is closely related to bowel infarction. As patients with PMVT often may or may not present with nonspecific abdominal pain or peritonitis, it is of great importance to choose the most effective imaging modality to make a timely and accurate diagnosis [22–23]. In the present study, PMVT was confirmed through contrast-enhance CT examination. After months of anticoagulant therapy, however, the impaired bowel segments demonstrated uncoordinated or akinetic contractions in plotted graphs of time-caliber curves, which were caused by ischemia that was confirmed during surgery. Akinetic contractions exist in patients with stercoral obstructions due to ischemic necrosis caused by local oppression by an intraluminal fecalith. Two patients in our study were diagnosed with Henoch-Schonlein purpura (HSP). It is a multisystem small vessel vasculitis with gastrointestinal symptoms that occur in up to 85% of patients [24–25], intussusception, ischemia, and infarction of the small bowel are the most severe manifestations in patients with HSP [26]. Chang *et al* [27] conducted a retrospective study of 261 patients with HSP. They showed that ultrasound plays an important role in direct visualization of decreased motility associated with ischemia, and is also able to monitor vital signs for complications such as intussusception and perforation [27]. In the present study, two patients with HSP had gastrointestinal bleeding; akinetic contractions were detected on the plotted graphs of their time-caliber curves, which may be associated with ischemia in the involved bowel segments. Therefore, the MR cine technique is an effective method for distinguishing various kinds of abnormal peristalsis and may offer insight into the effects of various small bowel organic diseases on motility, especially when ischemia and obstruction occurs, which is often characterized by severe dysfunction of small bowel movement.

This study had several limitations. First, drawing the time-caliber curve is time consuming. In this study, we attempted to summarize information from time-caliber curve plots as quantitative parameters in order to characterize impaired small bowel motility. Another limitation is that respiratory movement may affect the diameter; however, respiratory training results in less than 10 mm sagittal displacement of bowel loops, and the tiny fluctuation caused by respiratory movement on time-caliber curves did not affect measurement of quantitative parameters or the shape of contraction wave.

Conclusion

Cine MRI is a noninvasive, radiation free, and feasible method for evaluation of impaired small bowel peristalsis. Plotting time-caliber curves and measuring quantitative parameters allows sub-classification of various diseases associated with small bowel motility. These findings provide a new aspect of diagnostic information for assessing organic small bowel diseases; they may also be useful as a research basis for future studies on functional small bowel disease.

Conflicts of interest

The authors indicated no potential conflicts of interest.

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