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Research article

Assessment of esophageal motility disorders by real-time MRI

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ABSTRACT

Purpose: To investigate imaging findings of esophageal motility disorders on dynamic real-time.

Material and methods: 102 patients with GERD-like symptoms were included in this retrospective study between 2015–2018. Dynamic real-time MRI visualized the transit of a 10 mL pineapple juice bolus through the esophagus and EGJ with a temporal resolution of 40 ms. Dynamic and anatomic parameters were measured by consensus reading. Imaging findings were compared to HRM utilizing the Chicago classification of esophageal motility disorders, v3.0.

Results: All 102 patients completed real-time MRI in a median examination time of 15 min. On HRM, 14 patients presented with disorders with EGJ outlet obstruction (EGJOO) (13.7 %), 7 patients with major disorders of peristalsis (6.9 %), and 32 patients with minor disorders of peristalsis (31.4 %). HRM was normal in 49 patients (48.0 %). Incomplete bolus clearance was significantly more frequent in patients with esophageal motility disorders on HRM than in patients with normal HRM ($p = 0.0002$). In patients with motility disorders with EGJOO and major disorders of peristalsis, the esophageal diameter tended to be wider (23.6 ± 8.0 vs. 21.2 ± 3.5 mm, $p = 0.089$) and the sphincter length longer (19.7 ± 7.3 vs. 16.7 ± 3.0 mm, $p = 0.091$) compared to patients with normal HRM. 3/7 patients with achalasia type II were correctly identified by real-time MRI and one further achalasia type II patient was diagnosed with a motility disorder on MRI films. The other 3/7 patients presented no specific imaging features.

Conclusion: Real-time MRI is an auxiliary diagnostic tool for the assessment of swallowing events. Imaging parameters may assist in the detection of esophageal motility disorders.

1. Introduction

Impaired esophageal motility leads to a variety of symptoms, such as dysphagia, regurgitation, and chest pain [1]. High-resolution manometry (HRM) is the gold standard for assessing esophageal motor function and diagnosing esophageal motility disorders [2]. Although HRM measurements enable an exact differenciation of different esophageal motor function disorders, patient symptoms often overlap [3,4]. Moreover, standardized HRM metrics of the internationally recognized Chicago classification do not cover postsurgical conditions after antireflux surgery or myotomy [5]. The fluoroscopic esophagram is another common methodology for assessing esophageal dysmotility [6]. However, poor soft tissue resolution only allows for indirect visualization of the esophageal wall. In addition, fluoroscopic findings frequently differ from modern HRM measurements [7].

Recently, we described the application of real-time MRI for the visualization of the bolus transit through the esophagus and the esophagogastric junction (EGJ) with high soft-tissue resolution at a temporal resolution of 25 frames per second [8,9]. We have also reported that real-time MRI can detect hiatal hernia and evaluate complications after antireflux surgery [10–12]. Real-time MRI showed promising results for the evaluation of oropharyngeal dysphagia in

Abbreviations: DES, Distal esophageal spasm; EGJ, Esophagogastric junction; EGJOO, EGJoutflow obstruction; GERD, Gastroesophageal reflux disease; HRM, High-resolution manometry; IEM, Ineffective motility; LES, Lower esophageal sphincter; NE, Not evaluable.

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patients with inflammatory muscle disease [13]. In this study, we aimed to evaluate the diagnostic accuracy of real-time MRI for assessment of esophageal motility disorders compared to high-resolution manometry.

2. Materials and methods

2.1. Study population

This retrospective cohort study was approved by the local ethics board (NR 14/5/18). All patients included underwent routine high-resolution manometry as part of diagnostics for gastroesophageal reflux disease in the Department of General, Visceral, and Paediatric Surgery and Department of Gastroenterology and Gastrointestinal Oncology of the University Medical Center Göttingen. Further inclusion criteria were GERD-like symptoms for at least 6 months. Patients who aborted HRM and whose HRM pressure plots could not be evaluated were subsequently excluded. All participants gave written informed consent before each examination. General exclusion criteria for MRI were patients with pacemakers/ICDs, prosthetic heart valves, intra-ocular metallic foreign bodies, non-removable insulin pumps and implanted gastric reflux devices. Patients were not considered for real-time MRI in case of known pineapple allergy.

2.2. High-resolution manometry

High-resolution manometry was performed using a UniTip High Resolution Katheter (Unisensor AG, Attikon, Switzerland). After successful transnasal probe placement, all patients performed 10 consecutive swallows of a 5 mL bolus of water in an upright position. Pressure tomography plots were analyzed with ViMeDat™ Version 5.0.0.3117 (Standard Instruments GmbH, Karlsruhe, Germany). Pressure tomography plots were assessed hierarchically according to the Chicago classification of esophageal motility disorders v3.0 [2]: Cutoff value of the integrated relaxation pressure (IRP) of the probe was 28 mmHg. Contraction vigor was assessed by the distal contraction interval (DCI), which is the product of the mean contraction amplitude in the distal esophagus, the duration of the contraction, and the length of the esophageal contraction exceeding 20 mmHg extending from the transition zone to the proximal border of the LES. DCI graded swallows as failed (< 100 mmHg·s cm, weak (100–450 mmHg·s cm, normal (450–8000 mmHg·s cm, and hypercontractile (> 8000 mmHg·s cm. Both failed and weak peristalsis are also subsumed as ineffective peristalsis. A shortened distal latency (DL, time interval from the relaxation of the upper esophageal sphincter to the contractile deceleration point) of less than 4.5 s was defined as premature contraction. Defects > 5 cm of the 20 mmHg isobaric contour with normal DCI values were graded as fragmented peristalsis. The hierarchical analysis of the Chicago classification of esophageal motility disorder, v3.0 and the evaluation of esophageal contractility is summarized in Fig. 1.

2.3. Real-time MRI acquisitions

Real-time MRI was performed using a 3 T scanner (Siemens Skyra, Siemens Healthineers, Erlangen, Germany) with an 18-element thorax coil. Real-time MRI acquisitions were achieved with highly under-sampled radial fast low-angle shot acquisitions and NLINV image reconstruction [14].

Real-time MRI films of the esophagus and esophagogastric junction were continuously obtained with the following parameters: TR = 2.12 ms, TE = 1.31 ms, flip angle 8°, field of view of 256 × 256 mm^2, in-plane resolution of 1.5 × 1.5 mm^2, slice thickness 8 mm. The measurement time was 40 ms resulting in a temporal resolution of 25 frames per second (fps). Real-time MRI films in sagittal and paracoronal view were acquired over a time interval of at least 25 s.

Online reconstruction of real-time images was achieved by a highly parallelized version of the NLINV algorithm and its implementation on a computer (sysGen/TYAN Octuple-GPU, 2 × 123 Intel Westmere E5620 processor, 48 GB RAM, Sysgen, Bremen, Germany) with 8 graphical processing units (GPUs, GeForce GTX TITAN, Nvidia, Santa Clara, CA, USA).

In summary, real-time MRI of the esophagus and EGJ was optimized to visualize the passage of commercially available pineapple juice through the esophagus and EGJ during swallowing act and Valsalva maneuver as described in previous studies [10,11].

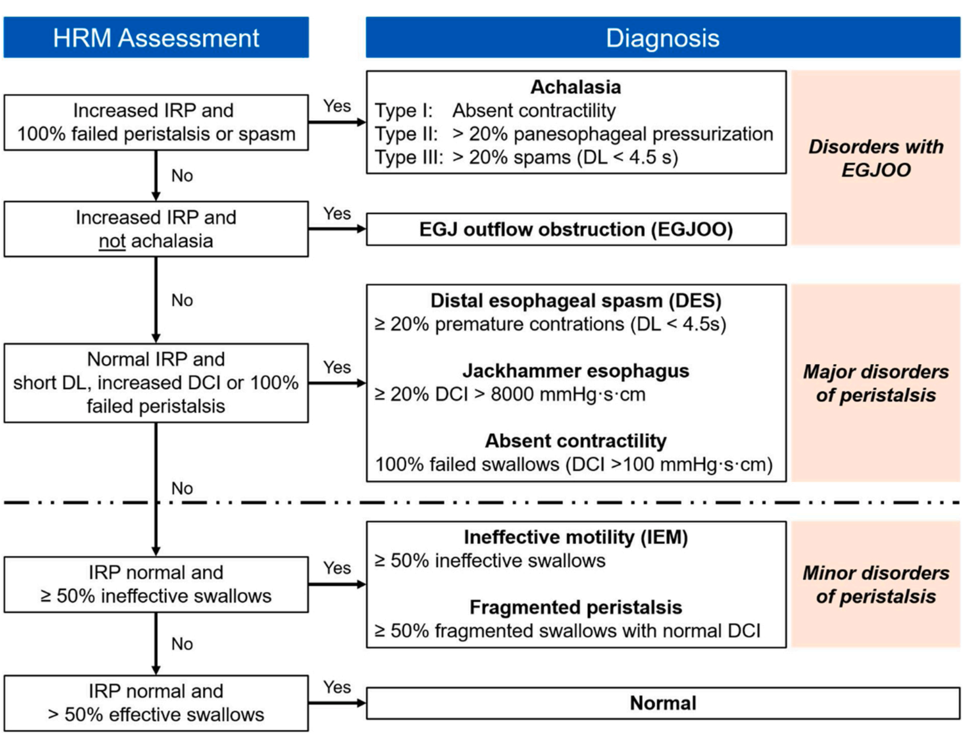

Fig. 1. Hierarchical assessment of esophageal motility disorders by the Chicago classification v3.0, modified after *Kahrilas et al., 2015* [2]. Patients with increased IRP are classified as either having achalasia or EGJOO depending on the presence of peristalsis. Panesophageal pressurization in achalasia type II is defined as uniform pressurization >30 mmHg from the upper esophageal sphincter to the esophagogastric junction. In cases with normal IRP, peristalsis is classified by assessment of DCI, DL and fragmentation. Abnormal findings in patients with normal IRP are divided into major and minor disorders of peristalsis. The dotted line separates major disorders of peristalsis, which are not observed in healthy controls, from minor disorders of peristalsis, which can be seen in patients without symptoms.

2.4. MR image evaluation

Real-time MRI films were analyzed by consensus reading by two experienced abdominal radiologists. Both readers each had 3 years of experience in dedicated real-time MRI of the EGJ. All parameters were assessed for readability by both readers. A parameter was considered not readable if both readers agreed that the anatomic structure or bolus transit was not visualized in its entirety during either the swallowing events or during Valsalva maneuver. All non-readable parameters were marked as “non-evaluable” (NE). In case of disagreement, real-time MRI films were re-read by both readers and the parameter was finally evaluated. Real-time MRI images were assessed on the manufacturer’s software (Syngo B17, Siemens Healthineers, Erlangen, Germany).

2.5. Statistical analysis

Continuous variables are given as mean ± standard deviation (SD), and categorical variables as absolute values and percentage. Continuous variables were compared using the non-parametric Wilcoxon rank-sum test, and categorical variables using the chi-square test. All statistical analyses were performed using R version 3.4.3 and RStudio Version 1.1.414. An alpha level of 0.05 was chosen to indicate statistical significance. All provided p-values are two-sided (Table 1).

3. Results

3.1. Study population

A total of 118 patients underwent real-time MRI of the EGJ and HRM from 2015 to 2018. Sixteen patients were excluded from the study: n = 9 due to aborted HRM; n = 5 due to inability to evaluate HRM according to the standards of the Chicago classification and n = 2 patients withdrew consent to HRM or real-time MRI. Overall, 102 patients were included in this study. A flow chart of patient inclusion and exclusion is provided in Fig. 2. Mean age was 53.0 years (SD ± 15.4, range 21–87). Overall gender distribution was levelled with n = 45 females (44.1 %) and n = 57 males (55.9 %). However, more females presented with disorders with EGJ obstruction and major motility disorders (66.7 % females; 33.3 % males) compared to patients with minor disorders of peristalsis (34.4 % females; 65.6 % males) and normal HRM (40.8 % females; 59.2 % males). Patient characteristics of the study population are summarized in Table 2.

3.2. High-resolution manometry

Overall, 102 out of 118 patients successfully completed HRM. Almost half of the patients presented with normal HRM (n = 49, 48.0 %). A total of 14 patients presented with disorders with EGJ outlet obstruction (EGJOO) (13.7 %): these comprised 7 cases of achalasia type II (6.9 %), one case of achalasia type III (1.0 %), and 6 cases of EGJOO (5.9 %). The collective of patients with major disorders of peristalsis (n = 7, 6.9 %)

Table 1
Characterization of esophageal contractility by high-resolution manometry [2].

Contraction vigor (DCI)	
Failed	<100 mmHg·s·cm
Weak	100–450 mmHg·s·cm
Normal	450–8000 mmHg·s·cm
Hypercontractile	>8000 mmHg·s·cm
Ineffective = failed and weak contractions	
Contraction pattern	
Premature contractions	DL < 4.5 s
Fragmented peristalsis	>5 cm break in the 20-mmHg isobaric contour with normal DCI
Intact	None of the above criteria

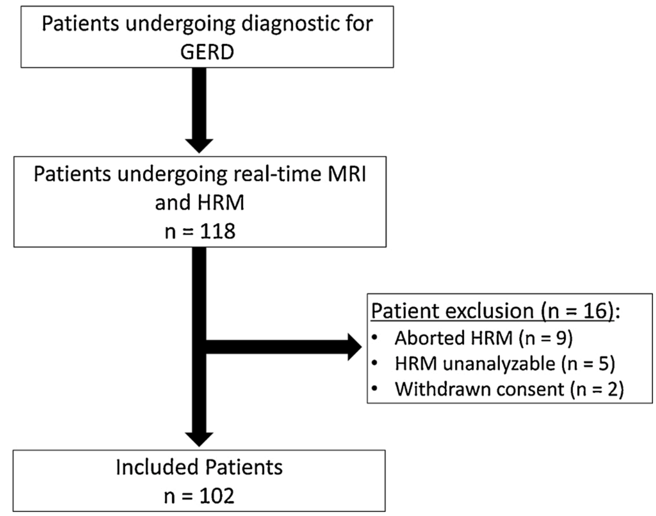

Fig. 2. Patient flow-chart.

consisted of 2 cases of distal esophageal spasms (DES) (2.0 %), one patient with a Jackhammer esophagus (1.0 %), and 4 cases of absent contractility (3.9 %). Thirty-two patients were diagnosed with a minor disorder of peristalsis on HRM (31.4 %): 30 cases with ineffective motility (IEM) (29.4 %) and 2 cases with fragmented peristalsis (2.0 %). The HRM findings are summarized in Table 2.

3.3. Real-time MRI examinations

Real-time MRI examinations were completed successfully at a mean examination time of 15 min with no adverse events in all patients. No patient reported aspiration or coughing during real-time MRI in supine position. MRI films showed a significantly higher rate of incomplete bolus clearance in sagittal plane in patients with disorders with EGJOO or major disorders of peristalsis (47.6 %) and minor disorders of peristalsis (43.8 %) compared to patients with normal HRM (10.2 %). In contrast, bolus clearance was complete in 87.8 % of patients with normal HRM (p = 0.0002). In patients with motility disorders with EGJOO and major disorders of peristalsis, the esophageal diameter tended to be wider with 23.6 ± 8.0 mm and the sphincter length longer with 19.7 ± 7.3 mm compared to patients with normal HRM with measurements of 21.2 ± 3.5 mm and 16.7 ± 3.0 mm, however both parameters were not statistically significant (p = 0.089 and p = 0.091). Patients with motility disorders with EGJOO and major disorders of peristalsis showed no differences regarding the presence of hiatal hernia compared to patients with normal HRM. All MRI parameters and imaging findings are summarized in Tables 3 and 4.

Real-time MRI parameters were similar between patients with normal HRM and minor disorders of peristalsis during swallowing. However, the majority of patients with minor disorders of peristalsis demonstrated visible reflux during Valsalva maneuver (81.2 %).

Of 7 patients with achalasia type II on HRM, 3 (42.0 %) were correctly identified on real-time MRI films with the typical bird beak sign and esophageal dilatation. One patient (14.3 %) with achalasia type II was diagnosed with an unspecified motility disorder on real-time MRI due to fluid stasis, uncoordinated contractions, and an elongated sphincter length. MRI films were not assessed as achalasia in this patient due to the absence of esophageal dilatation with an esophageal diameter of 18 mm. Esophageal clearance at the end of the first swallow maneuver was incomplete in 6/7 cases (85.7 %). In 3 patients, real-time MRI films were not rated as achalasia type II due to the absence of typical imaging features (42.9 %). The single case of achalasia type III showed no specific findings on real-time MRI films.

Of the 6 patients with EGJOO, only one case presented with a dilated

Table 2
Patient characteristics and HRM assessment.

	Total n = 102	EGJOO/ Major disorder of peristalsis n = 21	Minor disorder of peristalsis n = 32	Normal n = 49	P-value
Age	53.0 (±15.4)	60.8 (±17.5)	55.9 (±11.6)	47.8 (±15.0)	0.34
Gender					0.056
Female	45 (44.1 %)	14 (66.7 %)	11 (34.4 %)	20 (40.8 %)	
Male	57 (55.9 %)	7 (33.3 %)	21 (65.6 %)	29 (59.2 %)	
Manometry Assessment					<0.0001
Achalasia type I	0 (0.0 %)	0 (0.0 %)	–	–	
Achalasia type II	7 (6.9 %)	7 (33.3 %)	–	–	
Achalasia type III	1 (1.0 %)	1 (4.8 %)	–	–	
EGJOO	6 (5.9 %)	6 (28.6 %)	–	–	
DES	2 (2.0 %)	2 (9.5 %)	–	–	
Jackhammer esophagus	1 (1.0 %)	1 (4.8 %)	–	–	
Absent contractility	4 (3.9 %)	4 (19.0 %)	–	–	
IEM	30 (29.4 %)	–	30 (93.8 %)	–	
Fragmented peristalsis	2 (2.0 %)	–	2 (6.2 %)	–	
Normal	49 (48.0 %)	–	–	49 (100.0 %)	

Table 3
Real-time MRI parameters.

	Total n = 102	EGJOO/ Major disorder of peristalsis n = 21	Minor disorder of peristalsis n = 32	Normal n = 49	P-value
Esophageal Diameter					0.089
Mean (SD)	22.3 (±5.1)	23.6 (±8.0)	23.1 (±4.5)	21.2 (±3.5)	
NE	2 (2.0 %)	1 (4.8 %)	0 (0 %)	1 (2.0 %)	
Sphincter Length [mm]					0.091
Mean (SD)	17.3 (±4.1)	19.7 (±7.3)	17.3 (±3.5)	16.7 (±3.0)	
NE	23 (22.5 %)	9 (42.9 %)	10 (31.2 %)	4 (8.2 %)	
Hiatal hernia					0.47
Yes	55 (53.9 %)	8 (38.1 %)	20 (62.5 %)	27 (55.1 %)	
No	44 (43.1 %)	10 (47.6 %)	12 (37.5 %)	22 (44.9 %)	
NE	3 (2.9 %)	3 (14.3 %)	0 (0.0 %)	0 (0.0 %)	
Visible Reflux					0.13
Yes	68 (66.7 %)	10 (47.6 %)	26 (81.2 %)	32 (65.3 %)	
No	31 (30.4 %)	8 (38.1 %)	6 (18.8 %)	17 (34.7 %)	
NE	3 (2.9 %)	3 (14.3 %)	0 (0.0 %)	0 (0.0 %)	
Sagittal clearance time [s]					0.28
Mean (SD)	13.8 (±6.0)	16.0 (±7.0)	16.8 (±5.0)	11.0 (±4.8)	
NE	4 (3.9 %)	2 (9.5 %)	1 (3.1 %)	1 (2.0 %)	
Sagittal clearance					0.0002
Complete	69 (67.6 %)	9 (42.9 %)	17 (53.1 %)	43 (87.8 %)	
Incomplete	29 (28.4 %)	10 (47.6 %)	14 (43.8 %)	5 (10.2 %)	
NE	4 (3.9 %)	2 (9.5 %)	1 (3.1 %)	1 (2.0 %)	
Sphincter transit time [s]					0.41
Mean (SD)	7.9 (±4.5)	8.9 (±6.4)	8.6 (±4.7)	7.0 (±3.3)	
NE	8 (7.8 %)	4 (19.0 %)	3 (9.4 %)	1 (2.0 %)	

esophageal diameter of 33 mm, whereas the esophageal diameter of all other patients was between 14–24 mm at maximum distension during bolus passage. Four out of six patients (66.7 %) with EGJOO presented with reflux during Valsava maneuver. Only, 2/6 (33.3 %) presented with incomplete esophageal clearance in sagittal plane.

On real-time MRI, tertiary contractions with concomitant air-fluid level and delayed bolus transit in the middle esophagus were considered pathological in one patient. However, HRM was normal with no signs of DES or Jackhammer esophagus. Example images of patients are presented in Fig. 3.

Table 4
Assessment of real-time MRI films of 7 patients with achalasia type II and 1 patient with achalasia type III on HRM.

	Achalasia	Motility disorder	Non-specific imaging findings	Total
Achalasia type II	3	1	4	7
Achalasia type III	0	0	1	1

4. Discussion

Impaired esophageal motility is associated with several clinical symptoms that can mimic GERD [15]. The current gold standard for esophageal motility assessment is HRM, although HRM measurements do not necessarily correlate with patient symptoms [3,4]. Real-time MRI is an evolving non-invasive imaging technique for the EGJ and distal esophagus, although its role in motility assessment has yet to be determined. The aim of our study was therefore to compare imaging parameters on real-time MRI to esophageal motility assessment by HRM in patients with GERD-like symptoms.

Considering the HRM-based Chicago classification of esophageal motility disorders, real-time MRI parameters showed differences between patient subgroups: sphincter length and esophageal diameter measured on real-time MRI were numerically larger in patients with EGJOO and major disorders of peristalsis, compared to those patients with minor disorders of peristalsis and or normal motility. Although statistical significance was not reached, a statistical trend with $p < 0.1$ was observed for both parameters. Given the small number of patients with EGJOO or major disorders of peristalsis, missing statistical significance might well be attributable to the small sample size and low statistical power. Although incomplete esophageal clearance in sagittal plane was observed significantly more often in patients with abnormal HRM, the majority of patients demonstrated complete esophageal clearance, and incomplete clearance was observed in ca. 10 % of patients with normal HRM, thus limiting the diagnostic potential of this parameter. Still, our data suggest that esophageal motility disorder should be considered in patients with incomplete esophageal clearance, dilated esophagus and a sphincter length well above 20 mm.

On real-time MRI, 4/7 achalasia type II patients were correctly diagnosed with either achalasia or esophageal dysmotility. In spite of incomplete esophageal clearance in the majority of patients with

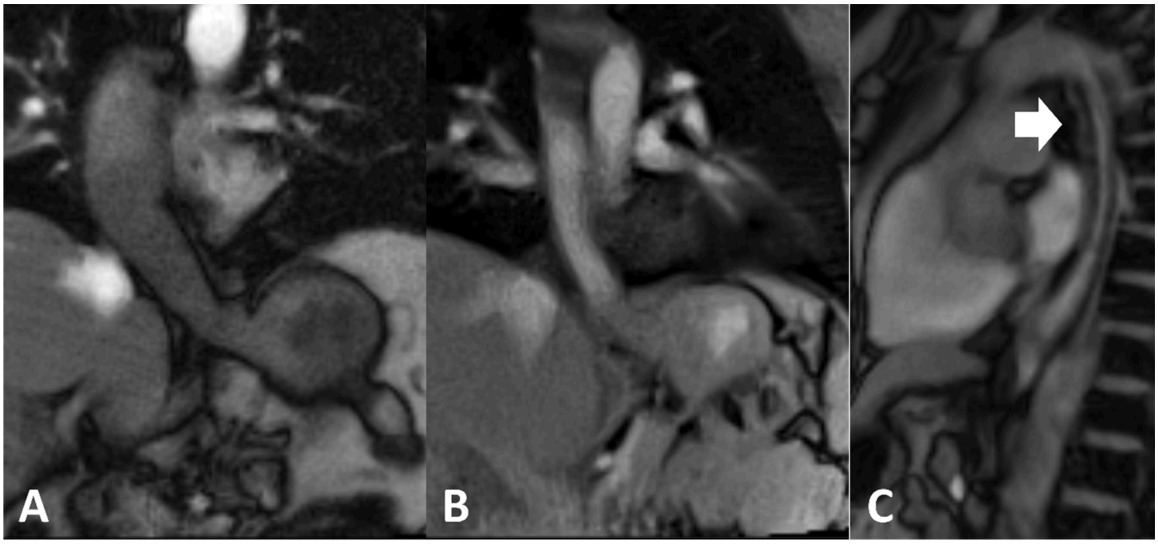

Fig. 3. Real-time MRI examples of 3 patients (A-C). Fig. 3 shows transit of 10 mL bolus of pineapple juice in paracoronal (A and B) and sagittal plane (C). Patient A was diagnosed with achalasia type II due esophageal dilation and incomplete clearance with fluid stasis resulting in low signal in the esophageal lumen. Diagnosis was confirmed by HRM. Patient B was also diagnosed with achalasia type II on HRM, however real-time MRI only revealed esophageal dysmotility without esophageal dilation. Patient C presented with tertiary contractions and bolus stasis in the middle esophagus on real-time MRI films. HRM was normal without a correlate for the imaging findings.

achalasia type II, both readers surprisingly did not correctly identify 3 patients with achalasia type II and one patient with achalasia type III. However, other studies employing fluoroscopy also found imperfect detection of achalasia compared to HRM [16,17]. One reason for the higher diagnostic accuracy of HRM could be that it can detect pathognomonic panesophageal pressurizations of achalasia type II in early stages before characteristic imaging features like the bird beak sign or esophageal dilation manifest. One patient with achalasia type II on HRM only showed signs of esophageal dysmotility including incomplete esophageal clearance but no esophageal dilatation on MRI. Additional endoscopy confirmed imaging findings and the patient did not require pneumatic dilatation. Still, all cases diagnosed with achalasia on real-time MRI were confirmed by HRM, corroborating the positive predictive value of this imaging method.

In the current literature, the application of dynamic MRI imaging for the assessment of esophageal motility is poorly explored: an initial feasibility study in patients with dysphagia showed good correlation between imaging findings and manometric assessment [18]. However, this study employed diagnostic HRM criteria that since have been revised several times [2,18]. Dynamic MRI imaging of the esophagus and swallowing events has shown promising results for detection of reflux and hernias, as well as fundoplication follow-up [11,12,19–21]. Further, patients with secondary motility disorder following fundoplication procedure showed delayed bolus transit and uncoordinated contractions on dynamic MRI imaging [21]. In a previous study, we also correctly identified a patient with secondary esophageal motility disorder after fundoplication procedure [11].

Historically, fluoroscopy has been employed for esophageal motility assessment. Still, the literature remains inconclusive regarding its diagnostic accuracy: a prospective study on patients with dysphagia reported an overall sensitivity of 80 % for fluoroscopy compared to manometry with a perfusion catheter [17]. Ott and colleagues reported a lower overall sensitivity of 56 % compared to manometry [6]. Sensitivity of fluoroscopy compared to manometry only improved after exclusion of nonspecific esophageal motor disorders and nutcracker esophagus [6]. In a more recent study employing modern high-resolution manometry, fluoroscopic sensitivity was 69 % and there was clinically relevant disagreement with HRM assessment [16]. Of all 3 patients with DES in our study, none presented the classical imaging features of a corkscrew esophagus. While the corkscrew esophagus has been considered the typical imaging pattern of DES, it has been shown that only a minority of patients present with its classical appearance [22]. On the contrary, one patient in our study presented with tertiary contractions in the middle esophagus with delayed bolus transit and air-fluid level (see Fig. 3). Although an esophageal motility disorder was suspected on real-time MRI, HRM of this patient was normal with no specific correlate for the imaging findings. False positives have also been described for fluoroscopy and seem to be common among routine evaluation of swallowing studies [16]. Real-time MRI parameters could not differentiate between patients with normal HRM and patients with minor disorders of peristalsis. It remains doubtful that real-time MRI will be able to delineate specific imaging features that will allow to identify IEM and fragmented peristalsis. Still, the clinical relevance of identifying patients with minor disorders of peristalsis has to be questioned as patients generally not only have a favorable prognosis, but these HRM patterns can also be commonly observed in healthy controls [23].

Our study has several limitations: first, the retrospective nature of this study including patients with GERD-like symptoms imposes bias. Second, the small number of patients with EGJOO disorders and major disorders of peristalsis limits the generalizability of our findings. Third, patient positioning in upright position during HRM and supine position during real-time MRI might account for differences especially in esophageal clearance. Finally, real-time MRI would ideally be performed simultaneously to HRM for exact correlation of individual swallowing events. Still, this is the first study to compare real-time MRI to HRM findings using the newest Chicago classification of esophageal motility disorders.

5. Conclusion

Real-time MRI is an auxiliary diagnostic method that shows promising results in the assessment of swallowing events at a high spatial resolution. In the future, anatomical and functional imaging parameters may assist in the detection of esophageal motility disorders. Further studies are needed to verify our results in a prospective manner.

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Stiftung.

CRediT authorship contribution statement

Lorenz Biggemann: Conceptualization, Investigation, Writing - original draft. **Johannes Uhlig:** Formal analysis, Visualization, Writing - review & editing. **Nina Gliem:** Resources, Investigation, Writing - review & editing. **Omar Al-Bourini:** Writing - review & editing, Writing - review & editing. **Edris Wedi:** Resources, Investigation, Writing - review & editing. **Volker Ellenrieder:** Supervision, Resources, Writing - review & editing. **Michael Ghadimi:** Supervision, Resources, Writing - review & editing. **Martin Uecker:** Methodology, Writing - review & editing. **Jens Frahm:** Methodology, Writing - review & editing. **Joachim Lotz:** Supervision, Resources, Writing - review & editing. **Ali Seif Amir Hosseini:** Project administration, Writing - review & editing. **Ulrike Streit:** Project administration, Writing - review & editing.

Declaration of Competing Interest

Jens Frahm and Martin Uecker are co-inventors of a patent covering the real-time MRI technique used in this stud. All other authors have nothing to declare relevant to this project.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ejrad.2020.109265.

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