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Esophageal diverticula are associated with propagating peristalsis: a study utilizing high-resolution manometry

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Abstract

Background—Esophageal diverticula have been associated with esophageal motility disorders, most commonly achalasia. We aimed to evaluate high-resolution manometry (HRM) motility diagnoses and pressurization patterns in patients with esophageal diverticula.

Methods—Patients were retrospectively identified for distal esophageal diverticula and previously completed HRM. HRMs were analyzed according to the Chicago Classification and the pressure slope of the compartmentalization phase (time between upper esophageal sphincter closure and the transition zone) of esophageal bolus transit was measured. Pressure slopes were also measured in 10 asymptomatic volunteers (controls) for comparison.

Results—19 patients (ages 31 – 83) were included. 8 (42%) patients had normal motility, 5 (26%) had esophagogastric junction outflow obstruction, and 2 (11%) had jackhammer esophagus; 4 patients had other motility diagnoses including only one patient with achalasia. A total of 6 patients (32%) had at least one hypercontractile swallow. Greater compartmentalization phase pressure slopes were observed in patients at the mid-esophageal body in both supine [median (IQR): 1.9 mmHg/s (0.9, 3.6)] and upright [1.1 (0.1, 3.1)] positions than in controls [supine: –1.3 (–2.4, –0.11), $p = 0.001$; upright: –0.71 (–2.1, –0.02), $p = 0.005$].

Conclusions—Propagating peristalsis, often with hypercontractility, was commonly seen in our cohort of patients with esophageal diverticula. Abnormal compartmentalization phase pressurization may indicate a relationship of abnormal esophageal wall mechanics and/or compliance with diverticula; however whether these findings are causal or reactionary remains unclear.

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Keywords

diverticula; high-resolution manometry; achalasia; esophageal motility disorder

Introduction

Esophageal diverticula in the epiphrenic and mid-esophageal regions have commonly been associated with esophageal motility disorders.(1, 2) Esophageal diverticula may also be related to an increased risk for aspiration.(3, 4) A common association with achalasia has been reported in numerous previous studies, most utilizing conventional manometry to assess esophageal motility; thus the basis of diverticula formation is often thought to be related to increased intra-esophageal pressures related to esophagogastric junction (EGJ) outflow obstruction.(1–3, 5–9) However, other esophageal motility diagnoses, defined by varying conventional-manometry-based criteria, including non-specific esophageal motility, distal esophageal spasm, and nutcracker esophagus have been reported in varying frequencies in series of patients with esophageal diverticula. (1–10)

The enhanced spatial resolution and color-coded topography plots afforded with high-resolution manometry and esophageal pressure topography (EPT) have improved our ability to evaluate esophageal motor function and pressurization patterns, as well as providing objective metrics of esophageal function that form the basis for a consensus-derived classification scheme of esophageal motility diagnoses.(11) Additionally, a model of esophageal bolus transit was developed using HRM with impedance and concurrent fluoroscopy that identified four distinct phases of the esophageal swallow and their relation to mechanical states of the esophageal wall during each phase.(12) The second phase, compartmentalization, during which both the upper esophageal sphincter (UES) and lower esophageal sphincter (LES) are closed and no trans-sphincteric bolus flow occurs, may represent a period when abnormal esophageal wall mechanics could contribute to increased esophageal wall stress and subsequent diverticula generation.

Therefore, we sought to describe esophageal motility diagnoses based on HRM/EPT assessment among a retrospectively-identified cohort of patients. Additionally, we aimed to assess the pressurization patterns during the compartmentalization phase of esophageal bolus transit in patients with esophageal diverticula as an indirect measure of esophageal mechanical wall states.

Methods

Patients

Patients were identified by billing codes generated between January 2005 and July 2014 using the Northwestern University Enterprise Database Warehouse, a comprehensive database of electronic health records of Northwestern Memorial Hospital and affiliated clinics. Manometries were previously obtained on patients at the discretion of their treating providers. Charts of identified patients were reviewed to confirm presence of mid-esophageal or epiphrenic esophageal diverticula as identified on esophagram and/or upper

endoscopy. Patients with proximal esophageal diverticula, such as Zenker's and patients with foregut surgery prior to diverticula diagnosis were excluded from the analysis. Additional retrospective chart review was conducted to identify other clinical features and medical history.

Ten healthy, asymptomatic volunteers (ages 21–47, 6 women) without history of gastrointestinal symptoms or surgery were included as a control group. These subjects have been previously described. (12) Informed consent was obtained from each control subject. The study protocol was approved by the Northwestern University Institutional Review Board.

High-resolution manometry

Manometry studies were completed after at least a six-hour fast. The HRM studies were completed using a 4.2-mm outer diameter, solid-state assembly with 36 circumferential pressure sensors spaced 1 cm apart (Medtronic Inc, Shoreview, MN). The HRM assembly was placed transnasally and positioned to record from the hypopharynx to the stomach with about three intragastric pressure sensors. Intra-gastric catheter placement was confirmed in all included patients by identification of a pressure-inversion point. For patients, the HRM protocol included a 5-minute baseline recording, ten 5-ml water swallows in a supine position and generally included five 5-ml water swallows in the upright position. In the normal controls, the HRM protocol included two supine and two upright swallows of 5-ml 1:1 barium:normal saline mixture during simultaneous videofluoroscopy.

Study analysis

The HRM studies were analyzed using Manoview Analysis Software v3.0 (Medtronic Inc). The distal contractile integral (DCI), distal latency, and median integrated relaxation pressure (IRP) were measured and applied to the Chicago Classification to provide an esophageal motility diagnosis.(11) Basal EGJ pressures were measured at end-expiration during the baseline HRM recording. Additionally, as illustrated in Figure 1, the pressure slope (i.e. change in pressure divided by time) was calculated during phase 2 (compartmentalization) of esophageal bolus transit, which corresponds to the time period between UES closure and the transition zone. Pressure slopes were measured at the axial levels of the mid-esophagus and at the contractile deceleration point (CDP). If the CDP could not be identified, the pressure slope was measured 3 cm proximal to the EGJ. If the compartmentalization phase could not be identified (as in failed swallows), pressure slope measurement was omitted. The median pressure slope value of five analyzed supine and five upright swallows was used for each patient and the two upright and two supine swallows for each control subject. The median pressure slope value of analyzed supine and upright swallows was used for each subject.

Statistical analysis

Group values are reported as median (interquartile range, IQR), unless otherwise stated. Relationships between continuous variables were assessed using Spearman's correlation. The compartmentalization phase pressure slope measurements were compared between patients and controls using the Mann-Whitney U test. Three group comparison (2 patient

groups based on diverticula location and controls) was performed using the Kruskal-Wallis test and post-hoc testing was applied using a Bonferroni correction.

Results

Patients

The initial medical record search yielded 45 patients with esophageal diverticula and previously completed HRM. Additional review of records and HRM identified 15 patients with proximal esophageal diverticula (e.g. Zenker's) and two patients with technically limited HRM studies that were excluded. Additionally, nine patients had foregut surgery prior to diagnosis of esophageal diverticula and were excluded: 3 laparoscopic Heller myotomy with Dor fundoplasty for achalasia; 2 patients had previous Nissen fundoplication, 1 had lap-band placement, 1 had paraesophageal hernia repair, 1 with esophagojejunostomy following complications of bariatric surgery, and 1 patient had a diverticulectomy of unclear details in the remote past at an outside institution. Thus, 19 patients (median age 66; age range 31 – 83; 11 female) remained to comprise the study population. Clinical characteristics of these patients are displayed in Table 1. Four of the patients (21%) had previous pneumonia suspected from aspiration.

Esophageal motility diagnoses and characteristics

The most common esophageal motility diagnoses was normal motility, which was observed in 8 patients (42%); however, 3 of these patients had a single hypercontractile swallow (i.e. DCI > 8,000 mmHg-s-cm) and thus met criteria for jackhammer esophagus under previous Chicago Classification schemes.(13) Five patients (26%) met criteria for EGJ outflow obstruction (one of which also met criteria for jackhammer esophagus; this was the only patient in the study cohort that reported opiate use, acetaminophen-codeine as-needed for pain, around the time of HRM). Two patients met criteria for jackhammer esophagus. Thus, a total of 6 patients (32%) had at least one hypercontractile swallow. Of the remaining four patients, one was diagnosed with type III achalasia, one (who was treated with pneumatic dilation at an outside institution eight years prior to his HRM) was diagnosed with distal esophageal spasm (DES), one had ineffective esophageal motility, and one had absent contractility.

The basal EGJ pressure was median 18 mmHg (IQR 10 – 26.5). Four patients (three with EGJOO and one with type III achalasia) had basal EGJ pressure > 32 mmHg (95th percentile of normal);(14) thus no patients had normal IRP and abnormal basal EGJ pressure. Five patients had hiatal hernia appreciated on HRM. A peristaltic gap was observed corresponding with the location of the esophageal diverticula in 4/19 (21%) of patients, such as in Figure 1C.

Compartmentalization phase pressure slopes

Compartmentalization pressure slopes were measured in the supine position in 18 patients with diverticula (they were omitted in the patient with absent contractility). Upright swallows were available for analysis in 11 patients. As a group, patients had greater compartmentalization phase pressure slopes in the mid-esophagus in both the upright and

supine positions than the controls (Table 2). Though not meeting statistical significance, there were numeric trends towards greater compartmentalization phase pressure slopes in patients than controls at the CDP in both supine and upright positions. 83% and 91% of patients had a pressure slope in the mid-esophagus greater than the 75th percentile of controls in the supine and upright positions, respectively. The percentages of patients with a pressure slopes greater than the 75th percentile of normal controls by measurement location, swallow position, and motility diagnosis are displayed in Table 3. Although the diverticula patients were older than the controls ($p < 0.001$), the correlation between age and pressure slopes among the diverticula patients was weak for each position: supine, mid-esophagus $\rho = 0.11$, $p = 0.67$; supine, CDP $\rho = -0.317$, $p = 0.20$; upright, mid-esophagus $\rho = -0.032$, $p = 0.93$; upright, CDP $\rho = -0.123$, $p = 0.72$.

Compartmentalization pressure slopes were also compared among patients and with controls based on diverticula location (epiphrenic and/or mid-esophageal). For epiphrenic diverticula, there was a difference in phase pressure slopes at both the mid-esophagus ($p = 0.008$) and CDP ($p = 0.03$) in the supine position and at the mid-esophagus ($p = 0.23$), but not the CDP in the upright position ($p = 0.17$; Table 4). Post-hoc testing demonstrated greater pressure slopes in patients with epiphrenic diverticula than controls at the mid-esophagus in both the supine ($p = 0.003$) and upright ($p = 0.012$) positions and numeric trends towards greater pressure slopes at the CDP in the supine ($p = 0.021$) and upright ($p = 0.068$) positions. Differences in pressure slopes were not detected between patients with and without epiphrenic diverticula. For mid-esophageal diverticula, there was a difference in phase pressure slopes at the mid-esophagus in both the supine ($p = 0.009$) and upright positions ($p = 0.014$), but not the CDP in either position (p -values 0.12 and 0.17; Table 4). Post-hoc testing demonstrated greater pressure slopes in patients with mid-esophageal diverticula than controls at the mid-esophagus in both the supine ($p = 0.004$) and upright ($p = 0.008$), but not at the CDP in neither the supine ($p = 0.41$) nor upright ($p = 0.10$) positions. Differences in pressure slopes were not detected between patients with and without mid-esophageal diverticula.

Discussion

We retrospectively identified patients with esophageal diverticula and HRM/EPT and observed that propagating peristalsis, often with hypercontractility, was commonly observed in our cohort. Additionally, we utilized EPT landmarks related to the compartmentalization (second) phase of esophageal bolus transit and observed abnormal esophageal pressure changes during this phase.

Previous studies examining esophageal motility disorders in patients with esophageal diverticula have observed varying frequencies of esophageal motility diagnoses. Unlike most previous reports, achalasia was rarely observed in our cohort, which may be related to the use of HRM which improves the evaluation of LES relaxation and also allows for more reliable confirmation of catheter placement across the EGJ.⁽¹⁵⁾ Though the majority of previous studies of esophageal motility associated with diverticula have used conventional manometry, one study utilizing HRM included nine patients and though they did not apply a consensus classification scheme (e.g. the Chicago Classification), they reported achalasia in

six (66%) patients (one of whom the manometry catheter was unable to traverse the EGJ).(9) Similarly, a study of 21 patients with esophageal diverticula that used endoscopic placement to ensure traversal of the EGJ with the conventional manometry catheter and also 24-hour ambulatory manometry in six patients, reported achalasia as the most commonly observed motility diagnosis (43%);(3) however, more similarly to our findings, they also reported 5/21 patients with DES (defined as multi-peaked, high-amplitude contractions with > 30% simultaneous pressure waves) and 2/21 with nutcracker (high-amplitude, long-duration contraction); thus potentially patients that may have been classified as jackhammer esophagus with HRM/EPT evaluation.

Abnormal pressurization within the esophagus as the mechanism for diverticula generation has been previously proposed.(3, 6) Additionally, histologic analysis from esophageal muscle obtained during myotomy or esophagectomy in patients with esophageal diverticula demonstrated esophageal myenteric inflammation and fibrosis, as well as ganglion cell abnormalities, in both patients with and without manometrically-identified esophageal motility disorders.(8) Thus, intra-esophageal pressure abnormalities related to esophageal wall properties may be related to esophageal diverticula. By applying concepts from a physiologic model that infers esophageal wall states based on intra-luminal pressure and impedance changes, we observed abnormal pressure changes during the compartmentalization phase of bolus transit in the majority of patients with esophageal diverticula, which appeared to be independent of the overall esophageal motility diagnosis (Table 3).(12) The normal expected response to a swallowed bolus during the compartmentalization phase is a decrease in pressure with a concurrent increase in luminal diameter; thus auxotonic relaxation of the esophageal wall, likely related to deglutitive inhibition.(12, 16) Increasing pressure during the compartmentalization phase represents abnormal accommodation of the swallowed bolus, which may be due to impaired neural inhibition and/or a non-compliant esophageal wall (potentially due to fibrosis and/or muscular hypertrophy) and therefore may subject the esophageal wall to abnormal wall stresses associated with esophageal diverticula. During the compartmentalization phase, the mid-esophageal measurement location likely more accurately measured the intra-bolus pressure (as opposed to the CDP location), which may account for our more consistent findings of differences in pressure changes in the mid-esophagus than at the CDP.

While prospective evaluation is required to better elucidate the contribution of abnormal esophageal wall states to esophageal diverticula formation, given the rarity of esophageal diverticula, other simultaneous factors are likely necessary for diverticula generation. It may be noted that compartmentalization phase pressure slopes were not positive in all diverticula patients, nor negative in all controls. Another potential contributing mechanism for esophageal diverticula formation involving esophageal hypercontractility could be related to asynchrony between esophageal circular and longitudinal muscles (possibly related to cholinergic neural imbalance), which has been reported in patients with nutcracker esophagus evaluated with high-frequency esophageal ultrasound.(17) This asynchrony between muscle layers could provide susceptible locations along the esophageal wall for diverticula formation. In some patients, EGJ outflow obstruction relates to increased intrabolus pressure and increased esophageal wall strain during peristalsis (phase III of esophageal bolus transit) that may contribute to diverticula formation.(12) Thus, although

LES myotomy has been proposed to accompany all surgical diverticulectomy cases, (1, 3) it may be reasonable to tailor the surgical management in patients undergoing diverticulectomy: reserving LES myotomy for patients with elevated LES relaxation pressures and considering a long myotomy for patients with hypercontractility (e.g. jackhammer). However, the sample size and retrospective design limit recommendations to alter management practices based on this study.

The retrospective design of our study limits causal inference between esophageal motility disorders and/or abnormal compartmentalization phase pressures and esophageal diverticula is limited; esophageal pressure abnormalities could also be reactive to the esophageal diverticula. Another limitation is our application of a technique derived using HRM with impedance to HRM studies without impedance; without concurrent impedance, inference regarding concurrent esophageal luminal diameter changes, which can be assessed by the inverse of impedance values, is not possible. Additionally, without impedance, bolus flow across the EGJ could have occurred, though one would expect this to be artificially lower, not raise, the pressure slope during the compartmentalization phase, thus we suspect our measurements are sufficiently accurate.

In conclusion, in our retrospective study of patients with esophageal diverticula evaluated with HRM, we observed propagating peristalsis, often with hypercontractility, (not achalasia) as the primary esophageal motility pattern associated with esophageal diverticula. Additionally, abnormal compartmentalization phase pressurization was frequently observed in diverticula patients, even in those without motility abnormalities, which may indicate a relationship of abnormal esophageal wall mechanics with diverticula. However additional prospective and longitudinal study is required to determine additional causal mechanisms and risk factors for esophageal diverticula.

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Key messages

- Although achalasia has traditionally been considered the primary esophageal motility disorder associated with esophageal diverticula, we found propagating peristalsis, often with hypercontractility, was the predominant motility pattern observed with high-resolution manometry (HRM) in patients with esophageal diverticula. Additionally, changes in intra-bolus pressurization, potentially representing abnormalities in esophageal wall properties, may offer insight into a mechanism of esophageal diverticula formation.
- The aim of this study was to evaluate high-resolution manometry (HRM) motility diagnoses and pressurization patterns in patients with esophageal diverticula.
- 19 patients with esophageal diverticula and HRM were retrospectively evaluated by the Chicago Classification for esophageal motility disorders and for pressure changes during the compartmentalization phase of esophageal bolus transit.
- Normal esophageal motility was the most common motility pattern observed in 42% our cohort of patients with esophageal diverticula; achalasia was the motility diagnosis in only one patient. Compartmentalization phase pressures slopes differed in patients with esophageal diverticula compared with asymptomatic controls suggesting possible abnormal wall mechanics.

Figure 1. Pressure slope during the compartmentalization phase (phase 2) of esophageal bolus transit

Examples of esophageal pressure topography of a supine swallow from a normal control (**A**) and esophageal diverticula patients with normal esophageal motility (**B**, **C**) and EGJ outflow obstruction with jackhammer (**D**) are displayed. The pressure tracings (white lines) at the mid-esophagus and contractile deceleration point are included. The compartmentalization phase pressure slopes (indicated by dashed red lines) were calculated as the change in pressure divided by duration of the compartmentalization phase, which spans from the time of upper esophageal sphincter closure to the transition zone (dashed gray lines). A peristaltic gap with compartmentalized pressurization that corresponded to a mid-esophageal diverticula can be appreciated in **C** (white star). DCI – distal contractile integral. IRP – integrated relaxation pressure. Figure used with permission from the Esophageal Center at Northwestern.

Table 1

Characteristics of study patients with esophageal diverticula.

Characteristic	n (%)
Diverticula location	
Epiphrenic only	11 (58%)
Mid-esophagus only	5 (26%)
Both locations	3 (16%)
Symptoms	
Dysphagia	16 (84%)
Chest pain	4 (21%)
Heartburn	8 (42%)
Regurgitation	9 (47%)

Table 2
Pressure slopes relating to the compartmentalization phase of bolus transit in patients with esophageal diverticula

Values represent median (interquartile range). CDP –contractile deceleration point.

Swallow type	Measurement location	Diverticula patients (mmHg/s)	Control (mmHg/s)	p-value
Supine	Mid-esophagus	1.9 (0.9, 3.6)	−1.3 (−2.4, −0.11)	0.001
	CDP	1.3 (0.06, 2.35)	0.12 (−0.9, 1.3)	0.089
Upright	Mid-esophagus	1.1 (0.1, 3.1)	−0.71 (−2.1, −0.02)	0.005
	CDP	0.6 (−0.8, 4.1)	−0.78 (−1.47, 0.5)	0.085

Table 3
Elevated compartmentalization pressure slopes by esophageal motility diagnosis

Value represent the number of patients (% of patients within the esophageal motility diagnosis with available measures) with a compartmentalization phase pressure slope greater than the 75th percentile of the normal controls. The hypercontractile group represents the patients with at least one supine swallow with a distal contractile integral > 8,000 mmHg-s-cm. CDP - contractile deceleration point. EGJOO – esophagogastric outflow obstruction. DES – distal esophageal spasm. IEM – ineffective esophageal motility.

Motility diagnosis (n)	Supine: Mid-esophagus; n (%)	Supine: CDP; n (%)	Upright: Mid-esophagus; n (%)	Upright: CDP; n (%)
All patients (18)	15 (83)	9 (50)	10 (91)	6 (55)
Normal (8)	7 (88)	6 (75)	4 (100)	4 (100)
EGJOO (5)	4 (80)	2 (40)	4 (80)	1 (20)
Jackhammer (2)	1 (50)	0 (0)	-	-
Type III achalasia (1)	1 (100)	1 (100)	1 (100)	1 (100)
DES (1)	1 (100)	0 (0)	1 (100)	0 (0)
IEM (1)	1 (100)	0 (0)	-	-
<u>Hypercontractile(6)</u>	5 (83)	2 (33)	3 (100)	2 (66)

Table 4
Compartmentalization phases pressure slopes related to esophageal diverticula location

Values represent median (interquartile range) based on presence (+) or absence (–) of diverticula in the epiphrenic or mid-esophageal regions. CDP – contractile deceleration point.

Swallow type	Measurement location	Diverticula Location			
		(+) Epiphrenic (mmHg/s)	(–) Epiphrenic (mmHg/s)	(+) Mid-esophageal (mmHg/s)	(–) Mid-esophageal (mmHg/s)
Supine	Mid-esophagus	2.1 (1.1, 3.7)*	1.0 (0.2, 3.2)	1.5 (0.04, 4.1)*	2.0 (1.2, 3.6)*
	CDP	1.5 (0.96, 2.7)	0 (–0.97, 0.2)	0.22 (–0.3, 2.1)	1.5 (1.0, 2.7)
Upright	Mid-esophagus	1.6 (0.1, 3.1)*	0.44 (0.1, 6.8)	2.9 (0.3, 6.4)*	0.74 (–0.5, 2.3)
	CDP	1.3 (–0.54, 4.1)	–0.64 (–1.3, 4.1)	3.9 (–0.9, 4.9)	0.3 (–1.1, 2.6)

* Comparison with controls, p-value < 0.017.