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High Resolution Manometry and Esophageal Pressure Topography: Filling the Gaps of Convention Manometry

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Abstract

The goal of any diagnostic scheme is to objectively classify patients with similar symptoms into appropriate clinical categories that ultimately direct specific therapies. Classification schemes for esophageal motility disorders were developed initially using conventional manometry which displayed the data in a line tracing format. While conventional manometry set the basis for the diagnosis of esophageal motility disorders, the large axial spacing between recording sites leaves large portions of the esophagus unevaluated and vulnerable to movement artifact. On the other hand, the continuous spatiotemporal representations of pressure through the entire esophagus recorded with high resolution manometry offers greater detail and improved accuracy for many of the most important measurements of esophageal motor function. This review will describe how the new classification schemes for esophageal pressure topography have evolved from conventional criteria. Additionally, we will also focus on how esophageal pressure topography has improved our ability to subcategorize conventional manometric diagnoses into new functional phenotypes.

Keywords

Esophageal motility disorders; high-resolution manometry; achalasia; distal esophageal spasm

INTRODUCTION

In 2001, based on a review of the literature to date, Spechler and Castell proposed a classification scheme for esophageal motility disorders incorporating defined conventional manometry (CM) criteria[1]. This was the state of the art description of manometry with conventional manometry, however, the authors accepted that the clinical significance of the observed manometric findings may be limited as the abnormalities were often reported to occur with poor correlation to symptoms and therapeutic corrections of manometric findings often did not lead to improvement in symptoms[2].

A few years after that review was published, high resolution manometry (HRM) and esophageal pressure topography (EPT) started to appear on the scene, both in research and clinical practice. High resolution manometry is composed of multiple, closely-spaced pressure sensors (usually 1 cm apart) that records pressure without significant gaps in data along the length of the entire esophagus. This data can be modified using interpolation to generate EPT plots that are color-coded, spatiotemporal representations of pressure recordings in the esophagus (Clouse Plots). This technology lends itself to an objective assessment of EPT metrics that have been integrated into a new classification scheme for esophageal motility disorders, referred to as the Chicago Classification scheme [3]. As

clinical and research experience grows with HRM, the Chicago classification scheme has been intermittently updated in an attempt to improve its representation of clinically relevant phenotypes [4–7]. The goal of this review is to compare conventional and high resolution manometric classification schemes for esophageal motility disorders and to illustrate how these new clinical phenotypes on EPT have evolved from previous definitions utilized by Spechler and Castell for conventional manometry.

METHODOLOGY: CONVENTIONAL AND HIGH RESOLUTION MANOMETRY

The procedure for both types of manometry begins with the placement of the manometry catheter transnasally until the distal pressure sensors cross the esophagogastric junction (EGJ) and enter the stomach. The comparative measurements made with CM and HRM are displayed in Table 1.

In CM, a pull-through technique is utilized to determine the position of the lower esophageal sphincter (LES) pressure by identifying the pressure inversion point and a high-pressure zone. The pressure sensor is then left positioned in the LES and basal pressure is recorded over at least 2 minutes with minimal swallowing. Once the baseline recording is complete, LES relaxation is measured during at least five wet (5mL water) swallows with the pressure sensor maintained at the position where the middle of the LES high-pressure zone was recorded. Peristaltic function is typically assessed with pressure sensors spaced anywhere from 3 to 5 cm apart with a repositioning of the pressure sensors into the body or by simultaneous pressure recording at the LES using a sleeve or single sensor.

In HRM, the distal end of the catheter is passed into the gastric compartment below the LES and hiatal canal and no pull-through is required as the catheter can provide recording from the stomach through the esophagus into the oropharynx. During an HRM study, EPT plots, also known as “Clouse” plots, are generated by computer software during ten wet (5mL water) swallows and there is no need to perform different steps in the evaluation because all variables can be assessed during the single swallows[8, 9].

Analysis of an EPT study is performed using a stepwise approach that focuses on an algorithm based scheme that first defines the patient based on EGJ relaxation pressures and subsequently uses individual swallow patterns defined by EPT metrics to further subclassify the patient into specific categories.

- **Step1: Assessment of EGJ pressure morphology at baseline**
  - The first step of the analysis process focuses on describing the pressure morphology of the EGJ to determine whether a hiatus hernia is present and where the pressure inversion point is located as this can have dramatic effects on the measures of EGJ function. The baseline end-expiratory pressure and inspiratory augmentation are recorded to assess integrity of the crural diaphragm as an extrinsic sphincter.
- **Step 2: Assessing EGJ relaxation and bolus pressure dynamics through the EGJ.**
  - Patients are defined as having normal or abnormal EGJ relaxation using the integrated relaxation pressure (IRP). The IRP is the lowest mean EGJ pressure for 4 contiguous or non-contiguous seconds during the deglutitive period. As demonstrated in figure 1, the IRP has replaced the conventional measures of nadir or end-expiratory LES relaxation pressure on conventional manometry as EPT evaluation made it quite clear that the pressure measured through the EGJ during swallowing was heavily reliant

on intrabolus pressure and was not a pure measure of LES relaxation[10, 11].

- **Step 3: Assess integrity of the peristaltic wave**
  - Once the IRP is measured, esophageal peristaltic integrity is characterized to determine if the peristaltic activity is intact, failed, or associated with small (2–5 cm) or large (>5 cm) peristaltic breaks in the 20 mmHg isobaric contour. This step is performed before any other measurements are made as the subsequent measurements are dependent on the presence of intact or preserved peristaltic integrity in the distal esophagus. This metric is similar to utilizing a 30 mmHg threshold at 3 and 8cm above the proximal border of the LES to define effective swallows[12]. However, the isobaric contour tool provides a more complete assessment of the entire swallow as demonstrated in Figure 2.
- **Step 4: Determine the location of the contractile deceleration point (CDP)**
  - The CDP is defined as the inflection point along the contractile wavefront defined by the 30 mmHg isobaric contour tool where the greatest deceleration occurs and the function of the esophagus converts from a stripping wave to a compartmentalized ampulla to promote emptying of the remaining bolus (Fig. 3). This landmark is in close proximity to the proximal border of the LES during maximal shortening and is usually associated with maximal concurrent axial contraction of the esophageal body [13]. The CDP should be localized within the 3rd contractile segment defined by Clouse and there is no method or measure on conventional manometry that localizes the CDP[8].
- **Step 5: Assess propagation**
  - Propagation and timing of peristalsis is defined by assessing the distal latency to determine whether the swallow is premature and possibly associated with impaired inhibitory function of the esophageal body. It is defined as the interval between upper esophageal relaxation and the CDP, as demonstrated in Figure 3. There is no correlate to this metric in conventional manometry.
  - Velocity of the stripping wave is determined by an assessment of the Contractile Front Velocity (CFV). It is defined as the slope of the tangent approximating the 30 mmHg isobaric contour between the proximal pressure trough and the contractile deceleration point. This is akin to the measurement of velocity using the pressure sensor located 3 and 8 cm above the proximal aspect of the LES on conventional manometry. It is interesting that the 3 cm point utilized on conventional manometry closely approximates the CDP and thus, this measure has good correlation with CFV.
- **Step 6: Measure contractile vigor**
  - Contractile vigor has been revised to objectively measure all of the contractile activity within the domain of the distal smooth muscle esophagus below the transition zone. The transition zone is typically localized approximately 6cm below the lower border of the UES and represents the first pressure trough between segments 1 and 2 on the Clouse plot. The metric utilized to quantify the contractile activity between the transition zone and proximal aspect of the EGJ is termed the

Distal Contractile Integral (DCI) and it utilizes the space time domain of the 2nd and 3rd contractile segments to provide a single number that quantifies contractile vigor (Figure 4). This is utilized in place of measuring the mean value of the highest wave amplitude at 3 and 8 cm above the proximal aspect of the LES on conventional manometry. The EPT plots also allow a qualitative assessment of the contraction that helps define focal contractile abnormalities and disorders associated with LES after-contraction.

- **Step 7: Determine whether abnormal pressure patterns are present**
  - Abnormal intrabolar pressure is a sign of abnormal mechanics of bolus transit related to either an outflow obstruction in the distal esophagus/EGJ or a poorly compliant esophageal wall. It is measured using the isobaric contour tool that is referenced to atmospheric pressure to identify pressurization patterns. These patterns can be compartmentalized between a propagating peristaltic wavefront and the EGJ or between the two sphincters (panesophageal pressurization). There is no correlate for this measure on conventional manometry, however, astute clinicians can assess the initial ramp pressure on tracings (see Figure 5) or identify isobaric pressure patterns on tracings (see Figure 6B).

EPT CORRELATES OF CONVENTIONAL MANOMETRIC DEFINITIONS

Disorders with abnormal lower esophageal sphincter relaxation

Abnormal LES relaxation is the hallmark of achalasia, the most well defined of the esophageal motility disorders and the one with the most effective therapies [1, 14]. Classically, achalasia also demonstrates a lack of esophageal peristalsis on manometry, though other manometric findings and sub-classifications have been described and proposed.

Conventional criteria—The proposed criteria for a diagnosis of classic achalasia by CM criteria included incomplete relaxation of the LES (defined as a mean LES relaxation pressure during swallowing > 8mmHg above gastric pressure) and aperistalsis of the esophageal body (either simultaneous contractions with amplitudes < 40 mmHg or no apparent esophageal contraction) [1]. “Atypical disorders of LES relaxation” are also described that exclude a diagnosis of classic achalasia with some preserved peristalsis and/or esophageal contractions with amplitudes greater than 40 mmHg, the latter situation often being referred to as “vigorous achalasia.”

Achalasia Phenotypes—The classification of achalasia has evolved with the updated revisions of the Chicago classification to reflect different achalasia subtypes that have demonstrated varying symptom profiles and responses to different treatment modalities. The achalasia subtypes are all associated with abnormal EGJ relaxation and are categorized based on the pattern of esophageal body contraction and pressurization: Type I - absent peristalsis, Type II - achalasia with panesophageal pressurization in 20% of swallows, and Type III - spastic achalasia (no normal peristalsis and premature contractions in 20% of swallows) [6, 7]. Representative Clouse plots with overlying CM line tracings are displayed in Figure 6. This sub-classification of achalasia distinguishes separate clinical phenotypes that are helpful in predicting response to therapy and this scheme is supported by three separate retrospective studies [15–17].

Our initial study analyzed 99 newly diagnosed achalasia patients with EPT, who underwent balloon dilation, Heller myotomy, and/or Botox injection [15]. Another study analyzed 246 patients with achalasia, 230 with conventional manometry and 16 with EPT, and followed

patients after undergoing Heller-Dor myotomy [16]. A third study analyzed 51 patients with EPT, 45 of which underwent pneumatic dilation [17]. In each study, pre-treatment symptom assessment suggested that chest pain may be more common in patients with Type III (spastic) achalasia. Response to treatment was consistent across all three studies, with Type II patients having the best and Type III patients having the worst response to treatment. The study assessing response to dilation, myotomy, and/or Botox even suggested that Type I patients may have a better response to myotomy (compared with dilation or Botox injection) as the initial treatment [15]. While prospective treatment trials are needed for further evaluation, these initial studies suggest that achalasia subtypes represent unique clinical phenotypes and may have predictive benefits in treatment planning for achalasia patients.

EGJ outflow obstruction—EPT analysis also demonstrates a population of patients with abnormal EGJ relaxation with remaining peristaltic activity that fails to meet criteria for a diagnosis of achalasia, similar to those with “atypical disorders of LES relaxation” in the conventional criteria. This pattern was termed functional obstruction in the early Chicago Classification schemes [4–6]. However, further analysis of patients with these EPT findings displayed similar characteristics, including an elevated intrabolar pressure, as patients with a known mechanical obstruction (such as post-fundoplication). Thus, this entity is now categorized as EGJ outflow obstruction [7, 18]. A representative swallow is displayed in Figure 5. Again, these manometric findings appear to reflect a clinical phenotype that frequently present with dysphagia and/or chest pain, may respond poorly to balloon dilation or Botox injection overall, and may have a favorable outcome in response to treatment with myotomy [19]. While additional study is needed to further characterize this group, it is possible that patients with this manometric profile may represent undetected inflammatory or infiltrating malignant disorders, or may be a variant or earlier form of achalasia. Given this heterogeneous differential diagnosis, it may be helpful if these findings are correlated with either endoscopic ultrasound or other imaging modalities.

Diffuse esophageal spasm

Diffuse esophageal spasm (DES) is often implicated as the etiology of non-cardiac chest pain or dysphagia, however the manometric criteria for the diagnosis of DES has frequently been questioned. While differences in the requirements for repetitive, spontaneous, high amplitude, or rapid contractions have varied in the previous literature, simultaneous esophageal contractions are nearly universally described as manometric criteria for DES and have been proposed to be the essential criteria in the diagnosis of DES.

Conventional criteria—Spechler and Castel proposed that a diagnosis of DES should require 1.) simultaneous contractions with >10% of wet swallows and 2.) a mean simultaneous contraction amplitude >30mmHg[1]. They reported that other common, but not required, features may include spontaneous contractions, repetitive contractions, multiple peaked contractions, and intermittent normal peristalsis. They also stated that if LES pressure is abnormal, the disorder is better classified as an atypical disorder of LES relaxation.

Distal Esophageal Spasm—“Simultaneous contractions” was interpreted in the early versions of the Chicago Classification, as rapid contractions, which were defined by a CFV > 8 mm/s [3, 5, 6]. The CFV, however, has been demonstrated to be susceptible to regional variability in contractile velocity within the swallow and thus may be a nonspecific finding of unknown significance [20]. The Distal Latency (DL), however, seems to be a more reliable measure of premature contractions that likely represents a clinical phenotype defined by dysphagia and chest pain.

A study that analyzed 1070 consecutive interpretable EPT studies found 24 patients that exhibited premature contraction (defined by DL <4.5s) and 67 patients that were found to have rapid contractions alone (defined as CFV > 9m/s, but normal DL[20]. A review of medical records revealed that all 24 of the patients with premature contractions had a dominant symptom of dysphagia or chest pain and were diagnosed and managed as DES (6 patients) or spastic achalasia (18 patients). The 67 patients with rapid contractions with normal latency had a more heterogeneous dominant symptom (56% dysphagia, 34% GERD, and 10% other) and were ultimately diagnosed and managed with an array of manometric diagnoses (14 normal, 39 weak, 5 hypertensive, 7 EGJ outflow obstruction, and another two patients had rapid contraction with normal latency that could potentially have been described as weak peristalsis given large breaks in the 20mmHg isobaric contour plot). Thus, the current version of the Chicago criteria requires 20% of swallows to have a reduced DL(Fig. 7A), defined as <4.5s, to meet criteria for a diagnosis of DES[7]. Patients with 20% of swallows with a rapid CFV (>9cm/s), but with normal DL (Fig. 7B) are categorized as rapid contraction; a diagnosis without known clinical significance.

While further study of treatment outcomes using DL as the diagnostic criterion for DES is needed for additional support for the use of DL, this study suggests that the diagnosis of DES based on an abnormal DL defines a more distinct clinical phenotype and in agreement with Spechler and Castell, is likely an uncommon disorder.

Esophageal hypercontraction

Another disorder frequently associated with non-cardiac chest pain and dysphagia is Nutcracker esophagus, a disorder usually defined by elevated intensity of esophageal peristaltic contractions. Nutcracker esophagus is the primary disorder of esophageal hypercontractility described by Spechler and Castell, and the early versions of the Chicago criteria. However, further evaluation with EPT has again refined this spectrum of esophageal hypercontractile disorders to distinguish borderline motor function from a primary abnormality of peristalsis.

Conventional criteria—Previous studies on nutcracker esophagus with CM have generally defined the disorder by distal wave amplitude > 2 standard deviations above the normal. However, normal values and location of high amplitude contractions (e.g. diffuse or segmental) have varied. Thus, Spechler and Castell proposed that the diagnostic criteria for Nutcracker esophagus be focused on a mean distal esophageal peristaltic wave amplitude >180mmHg, measured as the average amplitude of the ten swallows at recording sites 3 and 8 cm above the LES [1]. Increased contraction duration was an inconsistently described characteristic of nutcracker esophagus and thus was not required for manometric diagnosis.

Phenotypes of Hypercontractile disorders—While the elevated wave amplitude has persistently been a part of the diagnostic criteria of nutcracker esophagus, its occurrence is not always associated with the characteristic symptoms of dysphagia and chest pain [21]. EPT utilizes the metric of DCI to measure peristaltic contractile vigor, which accounts for both contractile intensity (akin to wave amplitude) and duration. EPT analysis of normal subjects (N= 75) and patients (N=400) defined a mean normal (95th percentile) DCI value of <5000 mmHg-s-cm, though there was substantial heterogeneity in the group of patients with mean DCI of 5000–8000 mmHg-s-cm (a group classified as “hypertensive peristalsis” or “nutcracker esophagus”) [4]. In addition, a mean DCI > 8000 mg-s-cm (defined in the early Chicago classifications as “spastic nutcracker esophagus”) was a rare finding, seemed to exhibit a distinct pattern with repetitive high amplitude contractions (Fig. 8), and was universally associated with dysphagia and/or chest pain [4–6].

Further evaluation of EPT studies of 72 asymptomatic controls and 1070 patients led to refinement of this classification [22]. Examination of individual swallows, as opposed to the *mean* DCI, found that within the control group, subjects often had individual swallows with DCIs >5000 mmHg-s-cm (median DCI 2073 mmHg-s-cm, 5–95th percentile 757–5946); the highest single DCI value seen in the control group was 7732 mmHg-s-cm. On the other hand, 44 patients (4.1%) were found to have at least one swallow with a DCI > 8000 mmHg-cm-s, the majority (75%) of whom presented with dysphagia, and generally had a positive response to a variety of treatments (including antireflux, anticholinergic, and endoscopic Botox injection). Classifying patients based on a *single* swallow with a DCI > 8000mmHg-s-cm, a group whose *mean* DCI had an interquartile range of approximately 3900 – 8700, had a high proportion of patients that presented with symptoms of chest pain and dysphagia, thus deterring the use of the previous arbitrarily set use of the *mean* DCI.

Multipeaked contractions were frequently seen in the patients with DCI > 8000 mg-s-cm (36/44, 86%), and thus the term “Jackhammer esophagus” was coined to describe this pattern. The patients that displayed multipeaked hypertensive contractions were more likely to have a normal IRP than hypertensive patients without multipeaked contractions. While the presence or absence of these multipeaked contractions did not seem to have an association with the symptom profile or to have an association with response to treatment, this was a retrospective report of an uncontrolled data set with a wide variety of treatments. Further systematic treatment trials classifying patients with hypertensive (DCI >8000 mmHg-cm-s) peristaltic contractions based on the presence or absence of multipeaked, “Jackhammer”-like contractions may lend additional insight of the clinical phenotype of this manometric pattern.

Based upon this study, the current version of the Chicago classification describes the diagnostic criteria for determining hypercontractile (“Jackhammer”) esophagus based on at least one swallow with a DCI > 8000 mmHg-cm-s (with or without multipeaked contractions), while hypertensive peristalsis (nutcracker esophagus) is defined as mean DCI >5000 mmHg-s-cm but not meeting criteria for hypercontractile esophagus [7].

Hypocontractile disorders: Ineffective esophageal motility

Spechler and Castell classified a group of disorders with hypocontractile characteristics as ineffective esophageal motility disorders (IEM) [1]. These disorders had previously often been referred to as “scleroderma esophagus” and “non-specific esophageal motility disorders,” though many other disorders other than scleroderma (GERD) may demonstrate similar motility patterns.

Conventional criteria—The CM diagnostic criterion for IEM proposed in the 2001 review was ineffective wet swallows in 30% of swallows. Ineffective swallows could be demonstrated manometrically by any combination of 1.) distal esophageal peristaltic wave amplitude 30mmHg, 2.) simultaneous contractions with amplitudes 30mmHg, 3.) failed peristalsis (the peristaltic wave does not traverse the entire length of the distal esophagus, and/or 4.) absent peristalsis. These criteria were based on previous findings that similar esophageal conventional manometry metrics were associated with impaired bolus transport or ineffective esophageal acid clearance [1, 23]. An additional study utilizing impedance-manometry to assess esophageal bolus clearance refined the criteria of IEM, demonstrating that a cutoff of 50% of ineffective swallows improved identification of patients with abnormal esophageal bolus transport and had a trend towards representation of a group of patients more likely to demonstrate dysphagia and/or heartburn [24, 25].

EPT: Weak and failed peristalsis—EPT allows one to characterize the contractile activity of the entire esophagus, as opposed to separated axial measurements as used in studies utilizing CM. Thus, EPT offers improved detection of breaks in the peristaltic wavefront (Figure 9). Studies utilizing EPT and intraluminal impedance have demonstrated that peristaltic breaks > 2cm in the 20mmHg isobaric contour plot may be associated with impaired bolus transport [26, 27]. The Chicago Criteria, describes “hypocontractile disorders” as “weak peristalsis” and “frequent failed peristalsis” in regards to peristaltic breaks in the isobaric contour (>30% of swallows with small (2–5cm) or >20% of swallows with large (>5cm) breaks in the isobaric contour] or frequent failed peristalsis (>30%, but <100% of swallows with failed peristalsis), respectively [7]. A comparison of EPT characteristics of 75 normal controls and 113 patients with nonobstructive dysphagia demonstrated that weak peristalsis with small (2–5cm) and large (>5cm) peristaltic breaks (but not failed peristalsis) were all seen more commonly in the patients than the controls [27]. However, the peristaltic breaks were only seen in approximately one third of the patients and were occasionally present in the normal controls as well.

Although hypocontractile peristalsis could be defined adequately using weak peristalsis and frequent failed peristalsis on EPT, many clinicians and investigators were hesitant to adopt this new terminology and continued to utilize IEM. This was the impetus for a recent study that sought to correlate the CM diagnosis of IEM (a diagnosis not included in the Chicago Classification) with EPT findings. They compared individual swallows and manometric classifications (based on a complete 10 swallow study) in terms of CM line tracings (taken at 3 and 8 cm from the LES) and EPT [12]. IEM was defined by the updated CM criteria (>50% ineffective swallows) and EPT studies were analyzed according to the Chicago Classification diagnoses of weak peristalsis and frequent-failed peristalsis (defined as above). EPT abnormalities (individual swallows with peristaltic break or failed swallow; classification of weak or frequent failed peristalsis) were found in more than 25% of swallows deemed normal by CM and more than 35% of studies classified as normal. By removing comparison with EPT studies with proximal pressure trough (transition zone) defects, the agreement in manometric characterization between the two methods rose appreciably. Addition of a CM line tracing at 13cm from the LES considerably increased the ability of CM line tracings to detect the presence of a transition zone defect (Fig. 9a); a defect that’s size may have an association with symptoms such as heartburn or dysphagia [28]

The same study described above also suggests that DCI had a strong correlation with mean wave amplitudes at 3 and 8 cm from the LES [12]. Low DCI, a measure not previously included in the Chicago, was shown to be a strong predictor of ineffective (DCI < 450mmHg-s-cm) or failed (DCI < 50 mmHg-s-cm) peristalsis and thus could potentially be incorporated into automated manometry diagnostic software and possibly future revisions of the Chicago Classification.

As expected, the additional data of peristaltic integrity generated by EPT is able to increase characterization of disorders of esophageal hypocontraction, though a correlation could be made between the CM diagnosis of IEM and the combined EPT classifications of weak peristalsis with small or large defects, and frequent-failed peristalsis. Nonetheless, the clinical significance of any of these disorders or findings is not completely clear and further manometric pattern assessment and clinical treatment trials may offer additional insight into their contribution to heartburn and/or dysphagia.

Conclusion

Increased clinical experience with EPT has helped identify specific patterns that appear to distinguish clinically relevant phenotypes within the classical description of esophageal

motility disorders using conventional manometry. The Chicago Criteria has attempted to bridge the gap between the previous diagnostic experience with conventional manometry and the new technology and has primarily focused on using the enhanced information available with high resolution manometry to better define abnormal motor function. The objective metrics of esophageal peristaltic and sphincter function available with EPT analysis also facilitate utilization of a diagnostic scheme that utilizes an algorithm-based diagnostic model that can be incorporated into analytic software programs.

Ultimately, as is initially apparent with achalasia sub-type designations, further characterization of clinical phenotypes represented by manometric patterns hopes to offer improved ability to tailor therapy to specific clinical entities and enhance our ability to care for patients with esophageal motility disorders.

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Abbreviations

CM	conventional manometry
HRM	high resolution manometry
EPT	esophageal pressure topography
EGJ	esophagogastric junction
LES	lower esophageal sphincter
IRP	integrated relaxation pressure
CDP	Contractile Deceleration Point
DL	Distal latency
CFV	Contractile Front Velocity
DCI	Distal Contractile Integral
DES	Diffuse esophageal spasm
IEM	ineffective esophageal motility disorders

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Key points

- Diagnostic schemes for conventional manometry and esophageal pressure topography (EPT) rely on measurements of key variables and descriptions of patterns of contractile activity. However, the enhanced assessment of esophageal motility and sphincter function available with EPT has led to further characterization of clinically relevant phenotypes.
- Differentiation of achalasia into sub-types provides a method to predict response to treatment.
- A diagnosis of diffuse esophageal spasm represents a unique clinical phenotype when defined by premature esophageal contraction (measured via distal latency) instead of when defined by rapid contraction (measured by contractile front velocity and/or wave progression) alone.
- Defining hypercontractile esophagus with a single swallow with a significantly elevated distal contractile integral (DCI), as opposed to using a mean value above a predetermined 95th percentile, may define a more specific clinical syndrome characterized by chest pain and/or dysphagia.
- Esophageal pressure topography correlates of the conventional manometric diagnosis of ineffective esophageal motility include weak and frequent-failed peristalsis, however, the clinical significance of these diagnoses is not completely understood.

Figure 1.

Assessment of EGJ relaxation. Nadir LES pressure (CM line tracing - purple) and IRP (dotted white boxes indicating lowest LES pressure segments over 4 non-contiguous seconds) are demonstrated in a normal swallow. IRP = 4.8 mmHg. Nadir LES pressure = 0.3 mmHg above gastric pressure. The nadir pressure is likely a measurement of intra-gastric pressure.

Figure 2. Peristaltic Integrity. A Clouse plot of a swallow with a large (5.1cm axial length) peristaltic defect in the 20mmHg isobaric contour is displayed. CM line tracings at 3 and 8 cm do not detect this defect in the transition zone. Black lines indicate the CM recording sites with their position from the LES, e.g. 3cm, as labeled.

Figure 3.

Propagation of peristalsis. The EPT metrics of CDP, DL, CFV, as well as the CM wavefront progression are displayed on a normal swallow. The CDP (red circle) is located at the intersection of the CFV tangent (white dashed line) and the velocity tangent of the terminal segment of esophageal peristalsis (solid white line), which correlates with emptying of the esophageal ampulla. The DL (purple arrow) is defined as the time from the initiation of the swallow to the CDP and measures 7s in the above swallow. The wavefront progression (black dashed line) is determined from CM line tracings (above, measuring 5.0cm/s) and is comparable to the CFV (above, 3.4cm/s) in EPT.

Figure 4.

Contractile vigor. The DCI is the software-generated sum of the esophageal body contractile activity from the transition zone to the distal pressure trough (area within the transparent box). CM assessment of contractile vigor is depicted by the mean of the peak wave amplitudes at 3 and 8cm from the LES (white dashed lines). In the above hypertensive swallow, the DCI is 7195 mmHg-s-cm and the mean peak amplitude is 214 mmHg.

Figure 5.

Compartmentalized pressure. Compartmentalized intrabulbar pressure (X) visualized on EPT can also be implicated via assessment of ramp pressure (black dashed portion of line tracing at 3cm from the LES) on CM line tracings. This Clouse plot is an example of a swallow characteristic of EGJ outflow obstruction with abnormal EGJ relaxation (IRP = 25.6mmHg; nadir LES pressure = 28.9) and evidence of intact peristalsis.

Figure 6a.

Figure 6b.

Figure 6c.

Figure 6.

Achalasia Phenotypes. Once abnormal EGJ relaxation is determined (A: IRP 17.6mmHg, nadir LES pressure = 23.3mmHg; B: IRP 26.5mmHg, nadir LES pressure 25.3mmHg; C: IRP 46.5mmHg, nadir LES pressure 42.3mmHg), these disorders can be further classified based on their esophageal body contractility patterns. Type I (A), “classic” achalasia, is characterized by absent peristalsis. Type II (B), achalasia with esophageal compartmentalization, demonstrates pressurization spanning the entire length of the esophagus without intact peristalsis. Panesophageal pressurization can be identified with CM by noting the isobaric pressure tracings, as seen here. Type III (C), “spastic” achalasia, can demonstrate fragments of distal peristalsis and/or premature esophageal contractions, as demonstrated here with a shorter than normal latency (white arrow) of 3.1s. Elevated wave amplitudes are also present on the CM line tracings, which has previously prompted labeling as “vigorous achalasia.”

Figure 7a

Figure 7b.

Figure 7.

Distal Esophageal Spasm. A.) DES, when defined by premature contractions ($DL < 4s$) is nearly uniformly associated with chest pain or dysphagia. Above (A) $DL = 3.8s$; $CFV = 12.1cm/s$. B.) Rapid contraction ($CFV > 9cm/s$) with normal latency ($DL = 5.3s$, $CFV = 14.1cm/s$), is associated with various clinical symptoms, as well as in normal control. The EGJ relaxation is normal in both panels (A: $IRP = 12.3mmHg$; B: $IRP = 0 mmHg$). DL (purple arrow). CDP (red circle). CFV (red dashed line).

Figure 8. “Jackhammer” esophagus. Clouse plot with overlying CM line tracings of a hypertensive swallow with significantly elevated DCI (15,025 mmHg-s-cm), mean wave amplitude (260 mmHg), and displaying multi-peaked esophageal body contractions.

Figure 9a.

Figure 9b.

Figure 9.

Ineffective esophageal motility. EPT correlates of IEM included failed (not pictured) and weak (A, B) peristalsis. Axial separation of CM pressure sensors limits the assessment of esophageal peristaltic integrity as demonstrated with the Clouse plots with overlying CM line tracings from recording sites at 3, 8, and 13cm from the LES of a swallow with a large transition zone peristaltic defect (A) and another swallow with both proximal and distal defects (B). Of note, the DCIs of swallows in A and B are 820 and 316 mmHg-s-cm, respectively.

Table 1

displays a comparison of CM and HRM metrics

Esophageal motility characteristic	CM measurement	HRM measurement
LES relaxation		
	LES relaxation with swallow	IRP
Normal *	Complete (<8mmHg above gastric pressure)	<15mmHg
Peristaltic propagation		
	Wave progression between pressure sensors 8 and 3 cm above the LES	CFV
Normal *	2–8 cm/s (UES to LES)	<9 cm/s
	<i>(no corresponding CM metric)</i>	DL
Normal *		4.5s
Contractile vigor		
	Mean distal wave maximum amplitude of pressure sensors 8 and 3 cm above the LES	DCI
Normal *	30–180 mmHg	450–5000 mmHg-cm-s

* Normal values as stated in references 1, 6.

CM - conventional manometry; HRM – high resolution manometry; IRP - Integrated relaxation pressure; CFV - Contractile front velocity; DL – Distal latency; DCI - Distal Contractile integer