Review Article

High-resolution manometry findings with hiatus hernia

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Abstract: The esophagogastric junction (EGJ) is comprised of both the intrinsic lower esophageal sphincter (LES) and extrinsic crural diaphragm (CD) such that intraluminal pressure represents a composite of the two. With type I hiatal hernias there is weakening of the pharyngoesophageal ligament attaching the esophagus to the CD such that the distal esophagus, including the LES, becomes displaced cephalad. High-resolution manometry (HRM), can accurately detect an axial hiatal hernia as confirmed by studies comparing HRM to barium esophagram, upper endoscopy, or intraoperative findings. In HRM studies, hiatus hernia becomes evident by a spatial separation between the pressure signature of the LES and that of the CD; the operative confirmation of hiatus hernia correlates with this separation exceeding 1 cm. With LES-CD separation of <2 cm the HRM pressure signatures of the two overlap, but as the LES-CD separation increases beyond that the two become completely separate. The other progression noted in HRM studies is in the location of the respiratory inversion point (RIP), the axial location at which the inspiratory change in pressure transitions from an inspiratory increase, characteristic of intra-abdominal recordings to an inspiratory decrease, characteristic of intrathoracic recordings. In the normal state and with small hiatal hernias, the location of the RIP correlates with where the CD impinges on the esophagus at inspiration. However, with larger hernias the RIP can localize with either the CD or the LES reflective of whether or not the CD has become incompetent, presumably a result of hiatal dilatation. Consequently, there are three distinct EGJ pressure morphologies in HRM: (I) normal with minimal LES-CD separation, (II) hiatus hernia with LES-CD separation >1 cm and the RIP localized at the CD, and (III) hiatus hernia with LES-CD separation >1 cm and the RIP localized at the LES.

Keywords: Hiatal hernia; high-resolution manometry (HRM); gastroesophageal reflux disease (GERD)

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Introduction

High-resolution manometry (HRM) is usually recommended as a part of the evaluation of gastroesophageal reflux disease (GERD) when a procedural intervention is under consideration, be that a fundoplication, Linx implant, or transoral incisionless fundoplication. Among the objectives of that evaluation is an assessment of the integrity of the esophagogastric junction (EGJ) as an antireflux barrier including the characterization of an axial hiatal hernia. However, there are numerous potential pitfalls in that assessment and consensus is lacking on how to interpret the complex intraluminal pressure signature of both the normal and anatomically disrupted EGJ. Among the technical difficulties encountered are the effects of respiratory variation, the effect of movement of the pressure sensor relative to the sphincter with breathing and swallowing, the recording fidelity of the sensor, distinguishing an intrinsic contraction from extrinsic compression, the effects of pulsations from the heart and aorta, and the extreme radial asymmetry and temporal variability of the EGJ itself. It is from this vantage point that the HRM findings of both the normal EGJ and type I (sliding) hiatus hernia must be explored.

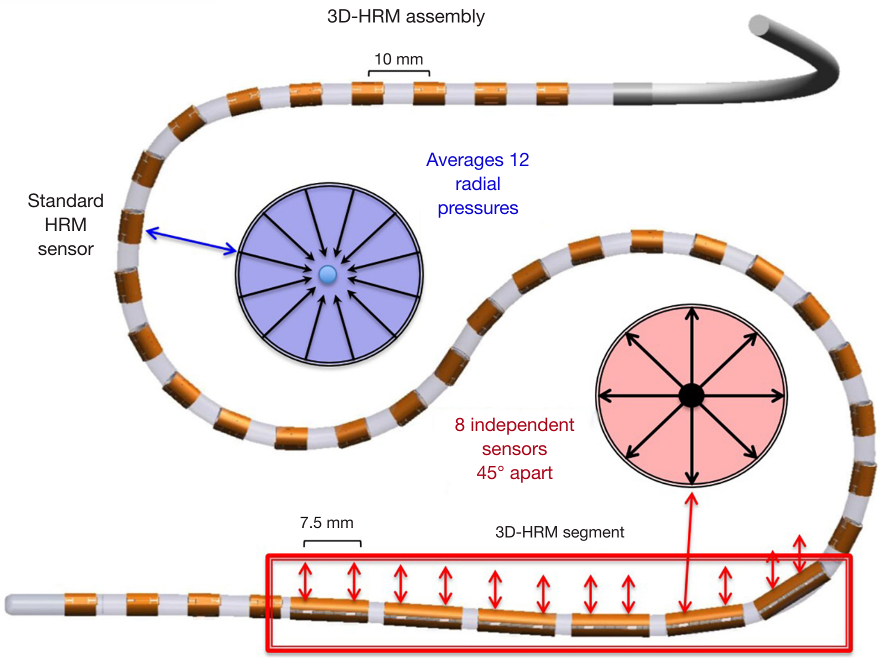

Figure 1 Photograph and schematic of a 3D HRM sensor that incorporates a 6 cm 3D segment designed to record the EGJ along with conventional circumferentially sensitive HRM sensors proximal and distal to the 3D segment for recording within the esophagus and stomach respectively. Each locus along the 3D segment is comprised of 8 independent sensors oriented at 45° increments circumferentially. This in contrast to the conventional HRM sensors that contain 12 elements, but they average those signals to record a single pressure. Figure used with permission from the Esophageal Center at Northwestern.

Normal EGJ pressure morphology: teasing apart the 3D-HRM signal

High among the difficulties encountered in interrogating the EGJ pressure profile are limitations of the pressure sensors themselves. Historically, relatively few sensors were employed, and one needed to repeatedly reposition the manometric catheter or actually pull it across the EGJ to obtain an axial pressure profile. However, with the advent of HRM and the interpolation paradigms that transform HRM into esophageal pressure topography plots, such things are of historical interest only. There is no going back to those archaic techniques. None the less, understanding the HRM pressure signature of the EGJ in a pressure topography format can be quite challenging as it bears no resemblance to recordings obtained with line tracings from 3–8 widely spaced pressure sensors. Adding to the difficulty is that with the current HRM catheter designs each of the closely spaced sensors is circumferentially sensitive such that if it is contacted on one side it can yield a pressure signal that is indistinguishable from the circumferential squeeze of a sphincter. This has profound implications with respect to the EGJ because that pressure signal is comprised of both an extrinsic crural diaphragm (CD) and intrinsic lower esophageal sphincter (LES) component, each of which is subject to independent physiological control mechanisms and pathophysiology. An experimental approach to unraveling this complexity was to develop a 3D HRM device that preserved rather than averaged the circumferentially unequal pressures (1,2). *Figure 1* is an illustration of that device comprised of a 3D segment intended to interrogate the EGJ as well as 'conventional' HRM sensors both proximal and distal to it to record esophageal and intragastric pressure respectively. All told, the 3D-HRM device monitors 128 independent pressure signals in real time, 96 of which are focused on the EGJ. Although this device is not commercially available, recordings obtained from it are very informative with respect to understanding the appearance of recordings obtained with standard HRM devices.

Figure 2 is a sagittal view of an MRI scan in a normal individual selected for illustration because the CD and esophagus outlined in orange and green respectively

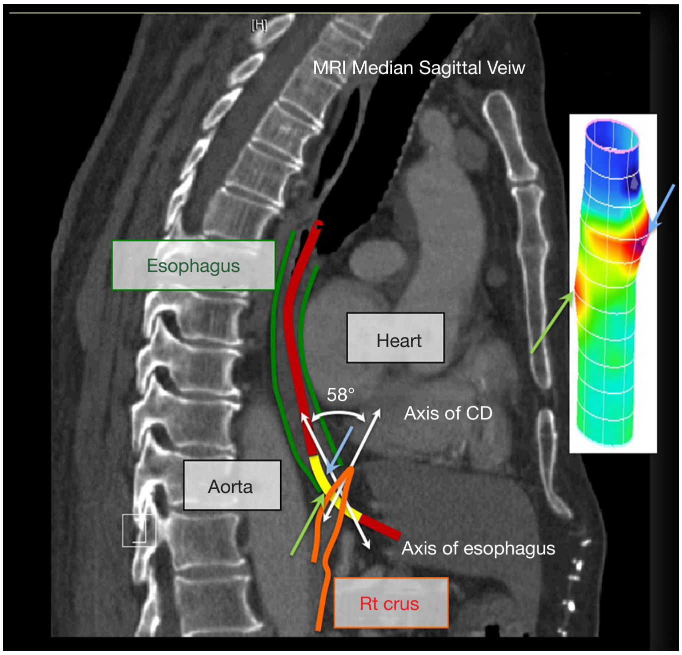

Figure 2 Mid sagittal MRI image highlighting the EGJ with the 3D HRM placed within the lumen of the esophagus. Note the characteristic bend imposed on the HRM catheter as it traverses the EGJ. The CD is outlined in orange while the esophagus is outlined in green. Note that the axis of the CD is not perpendicular to the axis of the esophagus and that wits 3D pressure signature (cylindrical insert) is reflective of this. The insert, taken at peak inspiration shows the CD apex signal largely restricted to the anterolateral walls of the EGJ. Figure used with permission from the Esophageal Center at Northwestern.

were both readily identifiable. Note that the axis of the CD is not perpendicular to the axis of the esophagus; rather, it is at about 58° in this example. Consequently, its pressure signature will be oblique with respect to the axis of the esophagus. Inserted into the esophagus is a 3D HRM catheter with the 3D segment depicted in yellow and the remainder in red. Now consider the cylindrical representation of the 3D segment recording at inspiration inserted onto the MRI. Brighter colors on the cylinder as well as outward deflection depict greater pressure. Note that the CD signal (blue arrow) is the most intense pressure recorded but is largely restricted to the anterolateral wall of the esophagus. Its counterpart, the green arrow is temporally synchronized with it on the opposite wall and likely reflects contact of the HRM device with the opposing wall of the esophagus.

Although the cylindrical representation of the 3D-HRM signal is illustrative, it is difficult to interrogate quantitatively because half or the signals are hidden and the whole recording cannot be viewed without rotating the cylinder. Hence, *Figure 3* shows the technique of unfolding the cylinder and depicting the 3D signal as a rectangle centered on the CD apex as defining the 6 o'clock orientation. When imaged in real time, the CD apex intensifies and then de-intensifies with inspiration and expiration respectively. In fact, the CD signal is so dominant that one wonders where the LES is in *Figure 3*. A key attribute of the LES is that, being a product of circular (or slightly spiral) muscle contraction, it is a circumferential pressure perpendicular to the axis of the esophagus and anatomically localized within the hiatus. However, it is impossible to localize the LES in areas where the pressure topography is obscured by the superimposed CD, so its margins can only be identified in the radial sectors not affected by the CD pressure recording. The horizontal white dashed lines approximate the margins of the LES in *Figure 3*. Note that with the sensors spaced 7.5 mm apart this implies that the intrinsic LES is about 2 cm long, which is consistent with physiological data. Support for this interpretation of the *Figure 3* pressure topography is in *Figure 4*. The left panel of *Figure 4* shows the pressure topography during the LES after-contraction following

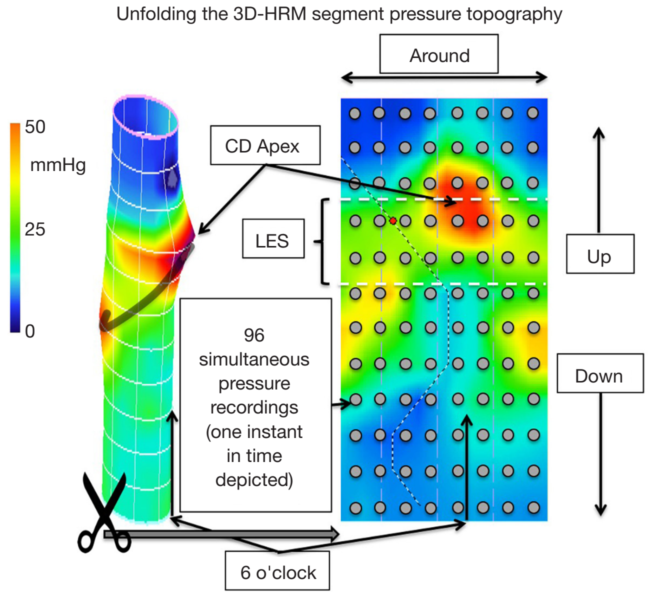

Figure 3 Unfolding the 3D pressure recording from a cylinder to a rectangle. The gray dots signify the locations of the 96 pressure sensors that contributed to generating this pressure topography plot obtained at peak inspiration. The topography plot is created by interpolating between pressure sensors both circumferentially and axially. See text for further detail. Figure used with permission from the Esophageal Center at Northwestern.

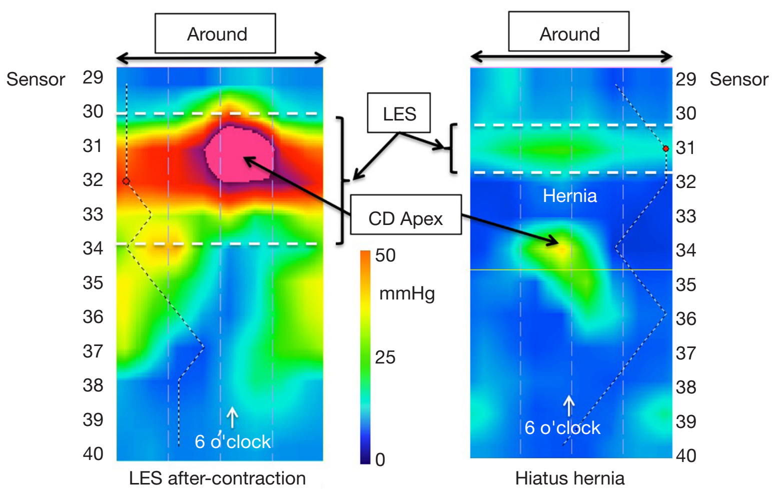

Figure 4 Special circumstances selected to confirm the interpretation in *Figure 3* of the CD and LES contributions to the 3D pressure topography. The left panel illustrates a strong LES after contraction following a test swallow in a person without a hiatal hernia. Note the bright red circumferential band of pressure contributed by the LES. The CD apex, on the other hand, remains largely restricted to the anterolateral aspects of the recording intensifying and de-intensifying with respiration (not shown). The right panel illustrates a normal volunteer who was found to have a hiatus hernia (subsequently confirmed on endoscopy). The CD apex signal is now centered 2.5 cm distal to the center of the LES with a pressure node between the two. Again, the CD apex remains largely restricted to the anterolateral aspects of the recording intensifying and de-intensifying with respiration (not shown). Figure used with permission from the Esophageal Center at Northwestern.

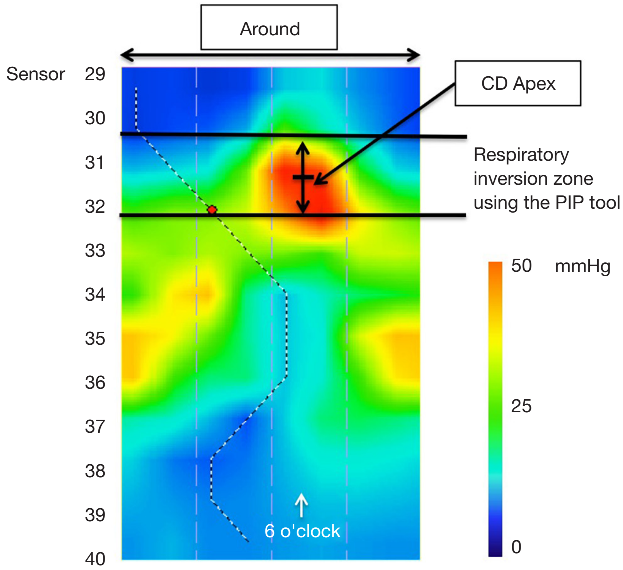

Figure 5 The PIP tool is a feature or Manoview software (Medtronic Inc., Minneapolis, MN) to aid in localizing the RIP, the axial locus at which the inspiratory effect on EGJ pressure transitions from a pressure increase, characteristic of intra-abdominal pressure to a decrease, characteristic of intra-thoracic pressure. The PIP tool is better illustrated in *Figures 6,7,8*, but its output is displayed here to illustrate the relationship to the RIP and the CD apex pressure signal. With normal anatomy, the RIP is defined by the CD occurring toward its upper margin. However, there is sufficient movement of structures and imprecision in its localization so that it is more properly thought of as a respiratory inversion zone. Figure used with permission from the Esophageal Center at Northwestern.

a swallow; this intensity gradually dissipates over the ensuing 5–10 seconds. The panel on the right in *Figure 4* is a recording from a subject with a hiatal hernia wherein the CD is not at all superimposed on the LES and the individual pressure signatures of the LES and CD can be seen. Both are weak, consistent with this individual having an incompetent EGJ, but the pressure signatures of the LES and CD are nonetheless preserved.

Another manometric landmark pertinent to the EGJ is the respiratory inversion point (RIP), also referred to as the pressure inversion point (PIP). The RIP is the location along the axis of the esophagus at which the inspiratory signal transitions from being a pressure increase, characteristic of the abdomen, to a pressure decrease, characteristic of the chest. HRM analysis software (Manoview, Medtronic Inc, Minneapolis, MN) localizes the RIP using the 'PIP tool' which allows the user to scroll up and down over the EGJ pressure complex and find the location at which the pressure signals 1 cm above and 1 cm below a given location most nearly cancel each other out. In essence, the inspiratory increase one cm below that point is negated by the inspiratory decrease one cm above it. The RIP is really more of a zone than an exact point and as illustrated in the 3D-HRM plot shown in *Figure 5*, the RIP zone normally localizes with the CD-apex signal. This is important as we transition to discussing conventional HRM because it provides a mechanism for localizing the CD-apex even when its radially asymmetric signature is obscured by circumferential pressure averaging.

Normal EGJ pressure morphology in HRM

While a strength of 3D-HRM lies in its ability to preserve circumferential pressure asymmetry, a strength of conventional HRM lies in its ability to depict a seamless longitudinal profile of intraesophageally pressure change over time in a single image; this requires a movie with the 3D format. With conventional HRM, the axis used in 3D to depict the radial origin of a pressure is used to show temporal change of a single pressure sensor over time making respiratory changes and vascular pulsations evident by their synchrony with breathing and pulse rate respectively. *Figure 6* illustrates a normal EGJ during quiet respiration including a segment depicting 3 deep

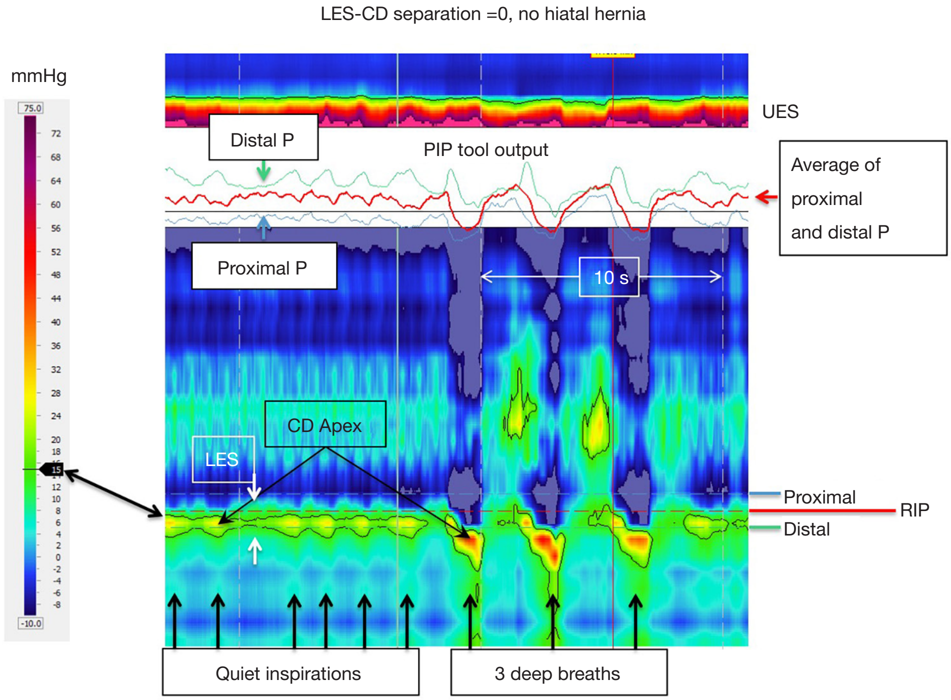

Figure 6 HRM recording of EGJ pressure in an individual without a hiatal hernia as evident by the CD-apex being completely superimposed on the LES pressure signature, i.e., the LES-CD separation is 0. Both during quiet respiration and deep breaths, the LES is only evident between inspirations when the CD signal is minimal. In this example, the PIP tool has been positioned to optimally isolate the RIP as evident by the PIP tool output shown as an insert. Barely visible on the pressure topography are a horizontal blue dashed line and green dashed line indicating the locations of the proximal and distal pressure (P) recordings shown in the PIP tool output. The red line in the PIP tool output box is the computed average of those signals. In using the tool, the area of interrogation is scrolled up and down to find the location at which the red line in the PIP tool output box is most nearly flat, indicative of the site at which the respiratory increases in pressure are offset by the respiratory decreases in pressure seen on the blue line. The area of interest is during quiet respiration and the RIP is seen to localize toward the upper margin of the CD signal, just as it had in the 3D plot of *Figure 5*. This positions the majority of the LES signal within the hiatus, being pulled downward during the three deep breaths. Figure used with permission from the Esophageal Center at Northwestern.

inspirations and an illustration of the PIP tool isolating the RIP, indicative of the location of the CD-apex. The black line indicating the 15 mmHg isobaric contour (referenced to atmospheric pressure) delineates the greatest pressure regions of the LES and CD, which completely overlap in this example with no hiatal hernia. The PIP tool is used to identify the RIP which localizes toward the upper margin of the CD-apex signal (see figure legend for detailed explanation). Refer back to *Figure 3* to conceptualize how the LES and CD contributions to the dynamic EGJ pressure profile in *Figure 6* recognizing that any area of pressure increase in *Figure 3* becomes a band of pressure, fluctuating with respiration, in *Figure 6*.

Hiatus hernia in HRM, i.e., LES-CD separation >1 cm

With a type I (sliding) hiatus hernia there is progressive anatomical disassociation between the CD and the LES attributable to laxity of the phrenoesophageal ligament and intermittent or permanent displacement of the LES into the mediastinum. *Figure 7* illustrates a recording obtained from an individual with a small hiatal hernia, evident by an LES-CD separation of 2 cm. In HRM, this becomes evident with axial separation between the CD and LES signals on the pressure topography plot. EGJ morphology is characterized as type I, II, or III in the Chicago Classification v3.0 (3,4); type 1 with superimposed LES and CD, type 2 with axially

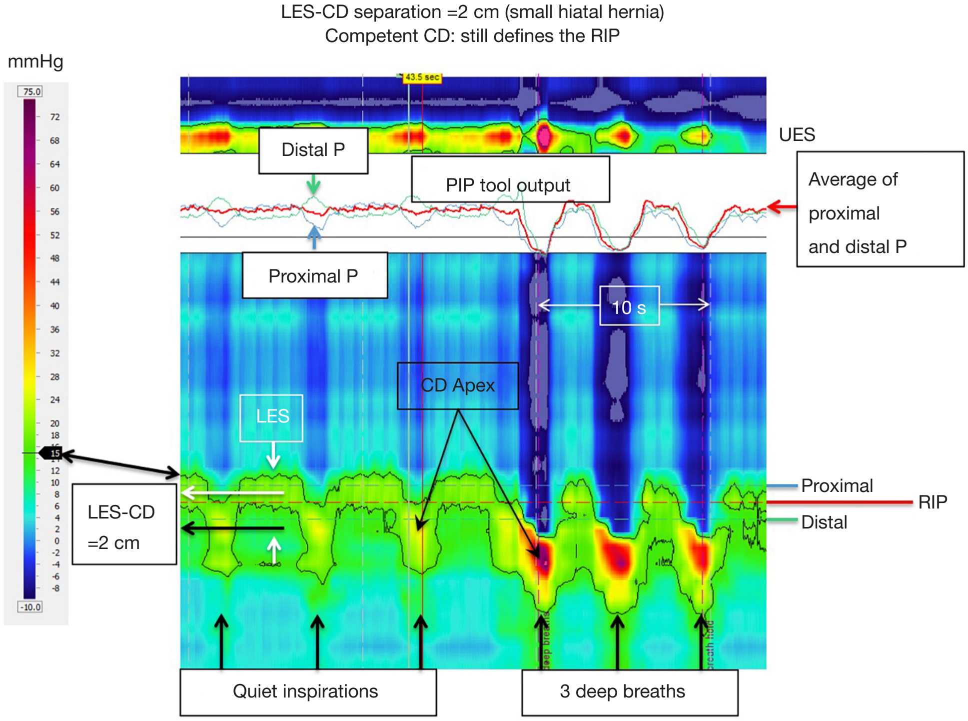

Figure 7 HRM recording of EGJ pressure in an individual with a small hiatal hernia as evident by the CD-apex being only partially superimposed on the LES pressure signature, i.e., the LES-CD separation is 2 cm. Formatting of the figure is identical to that of Figure 6 with the dominant EGJ pressure profile highlighted by the black line (the 15 mmHg isobaric contour) and the PIP tool optimally positioned to isolate the RIP. Note how the LES-CD separation is measured. The center of the LES and CD high pressure zones (white and black horizontal arrows, respectively) are isolated with the help of the isobaric contour tool (set at 15 mmHg in this example) and the separation between the two rounded off to the nearest cm. In this example, the RIP continues to localize toward the upper margin of the CD signal implying that the CD still exerts sufficient sphincteric effect such that it closes the lumen isolating the stomach below from the hernia and LES above. This is particularly evident during the three deep breaths where the strongly negative intrathoracic pressure (deep blue) is seen to abut directly on the CD-apex signal. Figure used with permission from the Esophageal Center at Northwestern.

separated LES and CD pressure signals separated by less than 2 cm, and type 3 with a ≥2 cm separation between the LES and CD pressure signatures. That classification will likely not survive future iterations of the Chicago Classification with the focus instead shifting to whether or not the LES-CD separation exceeds 1 cm (indicative of hiatus hernia) and whether or not the CD-apex pressure signal continues to define the locus of the RIP (indicative of the competence of the CD as a extrinsic sphincter).

In its early stages, a type I hernia is difficult to distinguish from normal, appearing only as an exaggeration of the normal phrenic ampulla on fluoroscopy and a partially overlapping LES and CD on HRM. Furthermore, EGJ pressure morphology can vary over time, even within a single patient study, transitioning between superimposed and separated CD and LES components (5) suggesting that with laxity of the phrenoesophageal ligament the degree of axial separation between the LES and CD can vary in the course of a day based on factors such as patient position or breathing. When such variation is seen, it makes sense to score it as the maximal value (or to report the range), the critical question being whether or not an anatomical hiatal hernia exists. HRM-defined LES-CD separation has been shown to correlate closely with the presence or absence and size of hiatus hernia as determined by endoscopy or barium x-ray with sensitivity and specificity of 88% and 95% respectively (6). LES-CD separation also correlates with reflux severity as determined by pH-metry (3,7,8). True, the Weijenborg *et al.*'s 2015 analysis (6) begs the question of which test is the most appropriate reference standard for

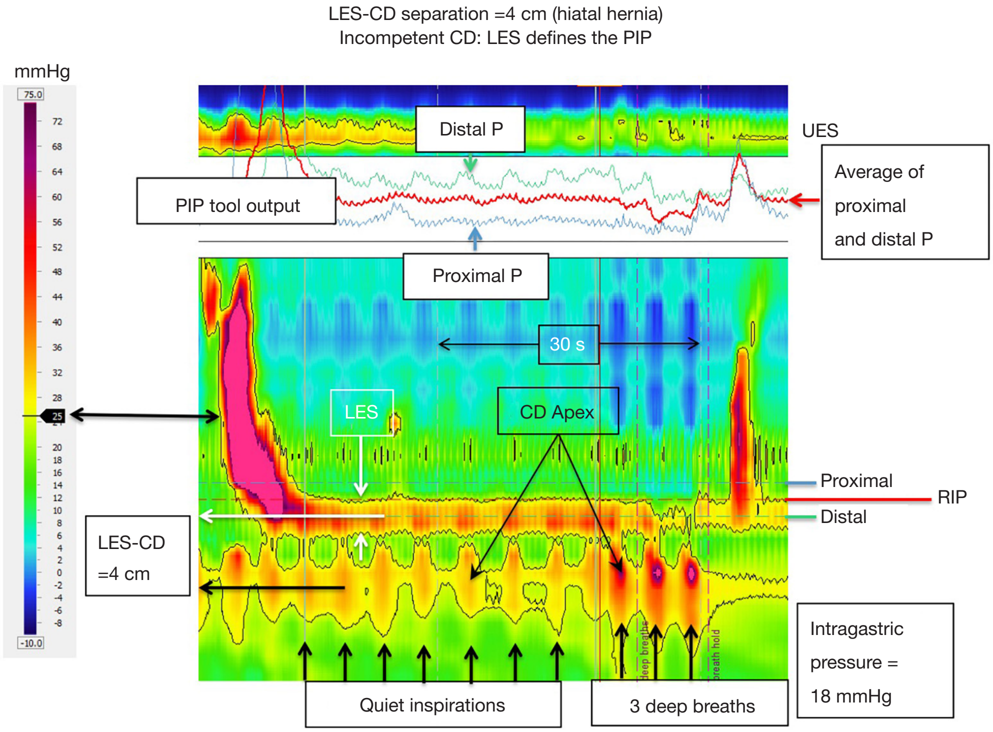

Figure 8 HRM recording of EGJ pressure in an individual with a moderate sized hiatal hernia as evident by the CD-apex being isolated from the LES pressure signature, i.e., the LES-CD separation is 4 cm. Formatting of the figure is identical to that of *Figures 6,7* with the dominant EGJ pressure profile highlighted by the black line (the 25 mmHg isobaric contour in this case) and the PIP tool optimally positioned to isolate the RIP. However, in this example, the RIP no longer localizes the CD-apex signal, instead localizing at the proximal margin of the LES. Even without the aid of the PIP tool, that is evident by the inspiratory bursts of red on the LES recording. Consequently, the CD no longer functions as a competent extrinsic sphincter and the entire hiatal hernia up to the lower margin of the LES is subject to intra-gastric pressure throughout the respiratory cycle. Compounding that issue, this individuals intragastric pressure is quite elevated at 18 mmHg. Figure used with permission from the Esophageal Center at Northwestern.

detecting hiatal hernia because the unequivocal diagnosis of hiatus hernia is ultimately made intraoperatively wherein the spatial relationship between the EGJ and CD and presence or absence of a hernia sac are visually evident. Along that line, a recent analysis compared the accuracy of HRM, endoscopy, and barium radiography to surgery in detecting and sizing hiatus hernia (9). That analysis concluded that HRM, using the LES-CD metric, outperformed the other modalities with a sensitivity of 94%, specificity of 92% and kappa value of 0.85. In that analysis, HRM reached both optimal sensitivity and specificity for detecting hiatus hernia with a threshold LES-CD separation of 1.2 cm. For simplicity, make this 1 cm because, after all, the spatial resolution of a device that measures pressures at 1 cm intervals is 1 cm regardless of how many decimal places the computer spits out.

The RIP

As the LES and CD become spatially separate there is the added issue of whether the RIP remains associated with the CD signal in the EGJ pressure complex or not. Although the precise physiological meaning of the RIP in this context is uncertain, there can be general agreement regarding the observations that: (I) the RIP can never be below the diaphragm; (II) when the CD is superimposed on the LES (i.e., LES-CD separation <1 cm), the RIP localizes above the EGJ pressure complex placing the LES physiologically within and beneath the diaphragmatic hiatus; and (III) with spatial separation of the CD and LES (i.e., LES-CD separation >1 cm), the RIP can localize either at the CD (as in *Figure 7*) or above the CD component placing it either within the hernia or at the LES as in *Figure 8*. Supporting the relevance of this distinction, a recent analysis exploring the relevance of hiatal hernia pressure topography subtyped individuals with LES-CD separation as 'B' or 'C' depending on whether the RIP localized above or below the LES respectively (10). In that analysis, subtype B was less likely to exhibit pathological reflux on pH-metry than subtype C. The authors interpreted this to support the contention that subtype B was indicative of the LES remaining within the abdominal compartment and being advantageous. Of note, the patients associated with *Figures 7,8* both had clear-cut reflux disease. In the case of *Figure 7* they had Barrett's esophagus with high-grade dysplasia and in the case of *Figure 8* a Bravo pH-metry study found pathological reflux on four out of four days with an average esophageal acid exposure time of 10%.

Interpreting the distinction between a competent and an incompetent CD somewhat differently, with greater degrees of LES-CD separation (i.e., >2 cm), there is the additional factor of whether or not the CD effectively compartmentalizes the stomach from the herniated stomach during inspiration. When it does, it is exhibiting greater sphincteric function than when it doesn't, presumably because the hiatal aperture is less dilated (11). Although not precisely addressing this distinction, evidence supporting the relevance of CD competence comes from a logistic regression model of barrier function that simultaneously examined expiratory LES pressure, LES-CD separation, and inspiratory EGJ augmentation while controlling for age and BMI. In that analysis, only inspiratory augmentation had a significant independent association with GERD as defined by pH-metry (3).

Conclusions

Accepting that the presence and size of hiatus hernia is a clinically relevant measurement, it can be concluded that there is strong evidence supporting that LES-CD separation >1 cm evident during quiet respiration during an HRM is indicative of hiatus hernia. With respect to the localization of the RIP, there is less agreement on its clinical significance, but in instances of the LES-CD separation exceeds 1 cm the RIP can localized at or above the CD component. Hence the three possible EGJ morphologies are: (I) no hiatus hernia (LES-CD separation <1 cm); (II) hiatus hernia with a competent crural diaphragm (LES-CD separation >1 cm with the RIP at the CD level); and (III) hiatus hernia with an incompetent CD (LES-CD separation >1 cm with the RIP above the CD component placing it either within the hernia or at the LES). The clinical significance of a competent *vs.* incompetent CD is a matter of continued debate.

Acknowledgments

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Footnote

Conflicts of Interest: The author has completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/ales.2020.03.08). PJK consulting for Ironwood, Bayer. The author has no other conflicts of interest to declare.

Ethical Statement: The author is accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Kwiatek MA, Pandolfino JE, Kahrilas PJ. 3D-high resolution manometry of the esophagogastric junction. Neurogastroenterol Motil 2011;23:e461-9.
2. Nicodème F, Lin Z, Pandolfino JE, Kahrilas PJ. Esophagogastric junction pressure morphology: comparison between a station pull-through and real-time 3D-HRM representation. Neurogastroenterol Motil 2013;25:e591-8.
3. Pandolfino JE, Kim H, Ghosh SK, et al. High-resolution manometry of the EGJ: an analysis of crural diaphragm function in GERD. Am J Gastroenterol 2007;102:1056-63.
4. Kahrilas PJ, Bredenoord AJ, Fox M, et al. The Chicago Classification of esophageal motility disorders, v3.0. Neurogastroenterol Motil 2015;27:160-74.
5. Bredenoord AJ, Weusten BL, Timmer R, et al.

Intermittent spatial separation of diaphragm and lower esophageal sphincter favors acidic and weakly acidic reflux. Gastroenterology 2006;130:334-40.
6. Weijenborg PW, van Hoeij FB, Smout AJ, et al. Accuracy of hiatal hernia detection with esophageal high-resolution manometry. Neurogastroenterol Motil 2015;27:293-9.
7. Ham H, Cho YK, Lee HH, et al. Esophagogastric junction contractile integral and morphology: Two high-resolution manometry metrics of the anti-reflux barrier. J Gastroenterol Hepatol 2017;32:1443-9.
8. Tolone S, de Cassan C, de Bortoli N, et al. Esophagogastric junction morphology is associated with a positive impedance-pH monitoring in patients with GERD. Neurogastroenterol Motil 2015;27:1175-82.
9. Tolone S, Savarino E, Zaninotto G, et al. High-resolution manometry is superior to endoscopy and radiology in assessing and grading sliding hiatal hernia: a comparison with surgical in vivo evaluation. United European Gastroenterol J 2018;6:981-9.
10. Akimoto S, Singhal S, Masuda T, et al. Classification for esophagogastric junction (EGJ) complex based on physiology. Dis Esophagus 2017;30:1-6.
11. Kumar D, Zifan A, Ghahremani G, et al. Morphology of the esophageal hiatus: is it different in 3 types of hiatus hernias. J Neurogastroenterol Motil 2020;26:51-60.

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