Original Article

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High-resolution manometry is superior to endoscopy and radiology in assessing and grading sliding hiatal hernia: A comparison with surgical in vivo evaluation

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Abstract

Background: Hiatal hernia is diagnosed by barium-swallow esophagogram or esophagogastroduodenoscopy, with possible suboptimal results. High-resolution manometry clearly identifies crural diaphragm and lower esophageal sphincter.

Objectives: To assess the diagnostic accuracy of high-resolution manometry in detecting hiatal hernia compared to esophagogram and esophagogastroduodenoscopy, using as reference the surgical in vivo measurement.

Methods: Patients were studied with esophagogram, esophagogastroduodenoscopy, high-resolution manometry and in vivo evaluation of the esophago-gastric junction. Esophago-gastric junction was classified as type I (no separation between crural diaphragm and lower esophageal sphincter); type II ($\geq 1, \leq 2$ cm separation); type III (>2 cm). During in vivo measurement, distance between the esophago-gastric junction and crural diaphragm proximal border was recorded.

Results: Surgery identified 53 hiatal hernias in 100 patients. Forty-seven percent were classified as type I esophago-gastric junction, 35% type II and 18% type III. Referenced to in vivo evaluation, high-resolution manometry showed superior diagnostic sensitivity and specificity (94.3% and 91.5%, respectively) to esophagogram and esophagogastroduodenoscopy, with 92.6% predictive value of a positive test and 93.5% predictive value of a negative test. The kappa value for high-resolution manometry and in vivo evaluation was 0.85. High-resolution manometry showed optimal sensitivity and specificity in detecting types I, II and III esophago-gastric junction.

Conclusions: High-resolution manometry enables an accurate diagnosis of hiatal hernia and a better classification than endoscopy and radiology, reaching optimal agreement with in vivo assessment.

Keywords

Hiatal hernia, esophagogastric junction, high resolution manometry, upper endoscopy, barium esophagogram

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Key summary

Summarise the established knowledge on this subject

- Sliding HH presence is more frequently observed with the increasing severity of GERD and it has been associated with abnormal esophageal acid exposure, prolonged esophageal clearance and increased number of reflux episodes.
- HHs can be diagnosed by barium swallow esophagogram and EGD; however, these two methods are impaired by the subjective and indirect evaluation of EGJ components.
- A better diagnostic evaluation of HH presence and axial dislocation may be useful in the management of GERD patients.

What are the significant and/or new findings of this study?

- HRM showed the highest correlation with surgical in vivo evaluation of HHs.
- Referenced to in vivo evaluation, HRM showed superior diagnostic sensitivity and specificity (94.3% and 91.5%, respectively) than esophagogram and EGD.
- HRM showed optimal sensitivity and specificity in detecting types I, II and III EGJ.

Introduction

Hiatal hernia (HH) occurs when the stability of the esophagogastric junction (EGJ) is impaired, allowing upward dislocation of the lower esophageal sphincter (LES) and stomach through the crural diaphragm (CD). Generally, four types of HH are described: sliding HH (type I), paraesophageal (type II), mixed (type III) and massive (type IV). Type I HH is by far the most common type, accounting for 95% of instances.

Sliding HH has been associated with increased reflux exposure[1–3] and increasing severity of gastroesophageal reflux disease (GERD), from non-erosive compared to erosive esophagitis and Barrett's esophagus.[4–12] Sliding HH diagnosis is classically made by barium-swallow esophagogram,[13] and/or during esophagogastroduodenoscopy (EGD).[14] However, these methods are impaired by subjective and indirect evaluation of LES and CD location.

Previous studies with conventional manometry documented two separate pressure zones at the EGJ level in HH patients, representing the spatial separation of LES and CD, but failed to reach optimal sensitivity.[9,15] High-resolution manometry (HRM) clearly identifies CD and LES and evaluates their anatomical relationship. At HRM, three EGJ subtypes are described based on LES–CD separation.[16] However, its diagnostic accuracy has been poorly investigated. Only two studies have measured the agreement between HRM and conventional techniques, i.e. esophagogram and EGD, in detecting HH,[17,18] and HRM findings were never compared with in vivo measurements.

We aimed to assess the HRM diagnostic value in HH detection, in comparison with esophagogram and EGD, assuming the in vivo direct measurement during open surgery of the distance between EGJ and diaphragmatic hiatus as the golden standard for a sliding HH presence.

Materials and methods

Study population

We enrolled at the University of Campania consecutive patients undergoing open foregut surgery, between May 2009 and December 2015. The study protocol was approved by the internal review board (University of Campania, part of protocol no. 608/26-10-2017).

Exclusion criteria were: the presence of paraesophageal, mixed and type IV HH, a past history of thoracic, esophageal, or gastric surgery; primary motility disorders; pregnancy.

All subjects underwent esophagogram, EGD, HRM (anatomical preoperative assessment) and EGJ morphology in vivo evaluation during surgery in which EGJ needed to be dissected (total fundoplication for refractory GERD, Barrett's esophagus, bariatric surgery). At first visit, demographics and clinical history were recorded. Patients were asked to discontinue any medication influencing esophageal motor function 5–7 days prior to testing.

EGJ appearance

In order to optimise concordance between HH grades assessed by different exams, we arbitrarily decided to adopt a unique nomenclature, as follows: type I, type II and type III EGJ appearance.

Barium esophagogram

Esophagogram was performed in fasting conditions, following a standardised protocol (drinking 200 ml of diluted barium, in upright, supine, and prone positions, with and without gas powders). Determination of sliding HH presence was based on the EGJ appearance determined by two skilled radiologists blinded to the patient's symptoms and other findings. A radiological B ring was defined as a smooth, symmetric ring-like indentation at

EGJ. The HH axial length was measured in centimetres. We classified radiological appearance as follows: type I, normal EGJ without B ring or gastric fold evidence; type II, sliding HH 2 cm or less; type III, sliding HH greater than 2 cm, when B ring or gastric folds demarcated the EGJ displaced above the diaphragm proximal border.

Esophagogastroduodenoscopy

During EGD, two landmarks were recorded: the position of the crural impression proximal border and EGJ. Proximal gastric rugal folds end defined EGJ.[19] The distance in centimetres from incisors to the diaphragmatic pinch proximal border and to the top of proximal gastric folds was recorded. Endoscopic type I morphology indicated a normal position of EGJ (superimposed to diaphragmatic pinch); type II, a HH diagnosed with a difference of 1 cm or greater and 2 cm or less between the position of the crural impression proximal border and EGJ and type III, with a difference greater than 2 cm.

High-resolution manometry

HRM was performed with a 4.2 mm diameter solid-state assembly with 32 circumferential sensors spaced at 1-cm intervals (HRiM catheter InSight; Sandhill Scientific Inc., USA). Examinations were done in the supine position after fasting and manometric assemblies were positioned with at least five intragastric sensors. EGJ was assessed during a 5-minute baseline recording, then at least 10 single water swallows (5 mL) evaluated esophageal peristalsis.[20–22]

Analysis was performed using Sandhill Bioview software, after thermal compensation. EGJ was localised and its pressure and relaxations evaluated; proximal and distal borders were marked according to intraesophageal and intragastric pressures. CD was marked as the axial level characterised by maximal inspiratory pressure augmentation. The distance in centimetres between the maximal LES pressure peak and the maximal CD pressure peak was measured directly from isocontour plots. Two blinded investigators independently analysed EGJ morphology for each subject. Patients were then classified to have three morphological types of EGJ, based on LES–CD axial separation, measured in centimetres, and classified as: type I, no separation between LES and CD; type II, minimal separation (>1 and ≤ 2 cm); type III, greater than 2 cm of separation (Figure 1).[23]

In vivo measurement

In vivo HH measurement was performed during elective open surgery; laparoscopic measurements were not considered to exclude diaphragmatic overdistension due to pneumoperitoneum. After phrenoesophageal membrane incision, complete EGJ and CD isolation was obtained. When necessary, hernia sac and anterior fat pad resection was performed. Mediastinal esophageal dissection was strictly avoided before measurement and no gastric tension was applied. Then, an endoscope was inserted orally up to the proximal gastric folds (EGJ level). A large hemoclip marked the EGJ position. Endoscope deflated the stomach and then retracted to the clip (Figure 2). Surgeons measured the distance in centimetres between the clip (helped by endoscopical trans-illumination) and CD proximal border (apex), with a ruler. We classified in vivo EGJ morphology as follows: type I, EGJ placed below or overlapping the CD, type II, EGJ above CD greater than 1 cm but 2 cm or less, and type III, EGJ laid down above CD greater than 2 cm, respectively.

Statistical analysis

Statistical analysis was performed using SPSS (version 22; SPSS Inc.). Continuous data were expressed as median and interquartile (25–75th) range, unless otherwise indicated. To determine HRM, endoscopy and radiology diagnostic value in identifying HHs we used the EGJ morphology detected during an in vivo measurement as the reference standard. Sensitivity, specificity and predictive value of a positive test (PVPT) and a negative test (PVNT) were determined for each technique, using Baye's theorem for the observed HH prevalence during in vivo study. Comparisons of probability of concordance (agreement between the positive results of two tests among the same patients) between the three tests were made using McNemar's test. The chi-square test was used to compare the proportion of false positive and false negative results between the diagnostic tests. Receiver operating characteristic (ROC) analysis was used to determine the optimal length of LES–CD separation on HRM to predict HH presence at in vivo measurement, and to compare HRM to EGD and esophagogram in predicting HH presence. P values of 0.05 or less were considered statistically significant.

Results

We enrolled one hundred consecutive patients who all underwent surgery, and prior esophagogram, EGD and HRM. The baseline characteristics of patients are shown in Table 1.

In vivo

During surgery, 53 (53%) patients had HHs. Forty-seven (47%) patients were classified as type I EGJ, 35 (35%) type II and 18 (18%) type III. The mean LES–CD axial separation in HH patients was

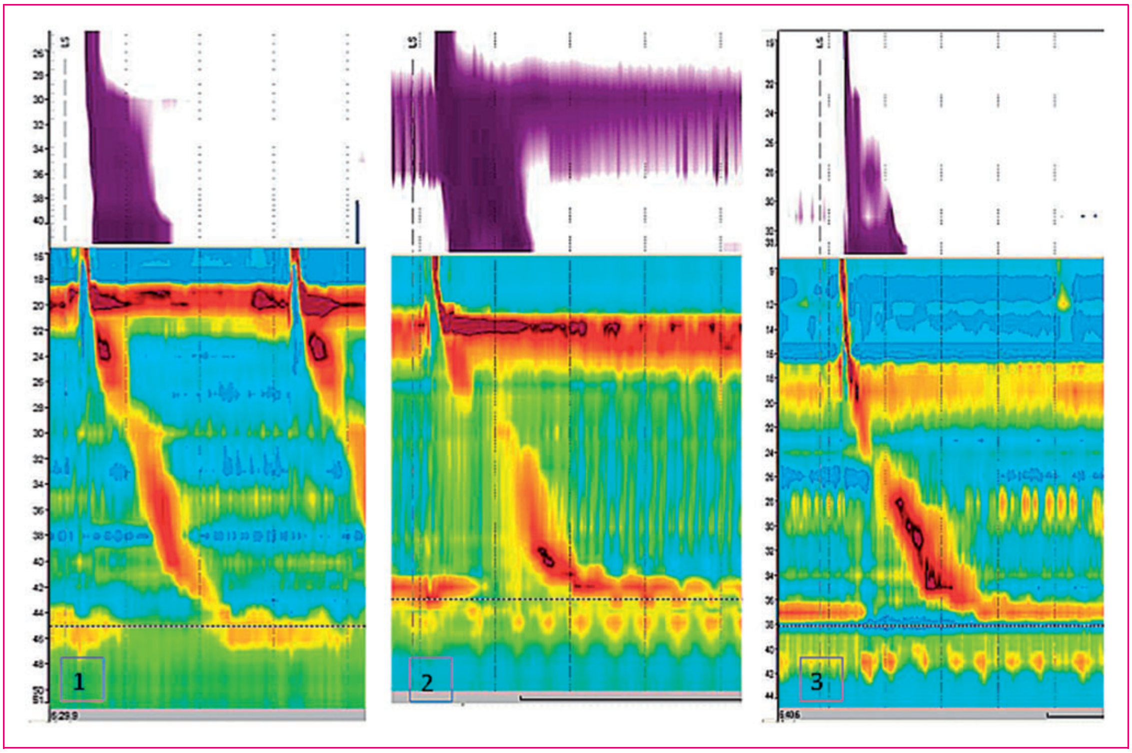

Figure 1. Examples of high resolution manometry traces in (1) esophagogastric junction (EGJ) morphology type I (complete overlap between lower esophageal sphincter and crural diaphragm); (2) EGJ morphology type II (separation > 1 but ≤ 2 cm); (3) EGJ morphology type III (separation > 2 cm).

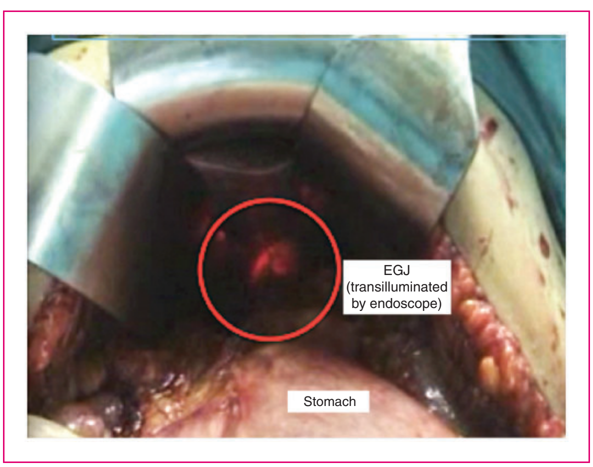

Figure 2. Intraoperative recording of esophagogastric junction (EGJ) landmarks (proximal rugal fold and crural diaphragm) by means of intraoperative endoscopy.

2.13 ± 1.14 cm. HH patients were older than type I EGJ patients ($P < 0.01$).

High-resolution manometry

Fifty-four (54%) patients had a LES–CD axial separation higher than 1 cm, whereas the remaining 46 patients had a type I EGJ. Among the HHs identified, 36 (36%) were type II, and 18 (18%) type III EGJ. The mean LES–CD axial separation in HH patients was 2.11 ± 1.14 cm. Compared to in vivo evaluation, HRM showed a diagnostic sensitivity and specificity of 94.3% and 91.5%, respectively, in detecting HH presence, with 92.6% PVPT and 93.5% PVNT. The kappa value for HRM and in vivo evaluation was 0.85. McNemar's test demonstrated a statistically significant concordance ($P = 1.0$). HRM showed optimal diagnostic sensitivity and specificity in detecting types I, II and III EGJ morphology (Figure 3). Detailed findings are shown in Tables 2 and 3. ROC analysis determined a cu-off value of LES–CD axial separation of 1.2 cm, as this yielded the optimal performance (sensitivity and specificity of 95.7% and 90.6%, respectively) in diagnosing HH presence (Figure 4).

Esophagogastroduodenoscopy

EGD identified 63 (63%) patients with HH. Thirty-one (31%) had type II and 32 (32%) type III EGJ. Sensitivity was similar to HRM (96.2%), but specificity was lower (74.5%), with a 0.716 kappa value. McNemar's test demonstrated a statistically significant discordance ($P = 0.022$) between endoscopy and HRM.

Table 1. Baseline characteristics of study population classified according to presence of a hiatal hernia identified during surgery.

Features	Whole population	Patients with HH	Patients without HH	*P* value
Patients, *n*	100	53	47	
Male patients, *n* (%)	42 (42%)	22 (41.5%)	20 (42.5%)	NS
Mean age (range)	48.4 (37–71)	53 (38–71)	46 (37–67)	0.032
Mean BMI (range)	25 (17–33)	25 (19–33)	24 (17–31)	NS
Alcohol consumption, *n* (%)	20 (20%)	12 (22.6%)	8 (17%)	NS
Coffee consumption, *n* (%)	47 (47%)	24 (45.3%)	23 (48.9%)	NS
Smoking, *n* (%)	18 (18%)	9 (16.9%)	9 (19.1%)	NS
H. pylori infection, *n* (%)	24 (24%)	13 (24.5%)	11 (23.4%)	NS
Esophagitis grade A, B (sec. Los Angeles), *n* (%)	26 (26%)	19 (35.8%)	7 (14.8%)	0.031
Esophagitis grade C, D (sec. Los Angeles), *n* (%)	6 (6%)	5 (9.4%)	1 (2.1%)	NS
Barrett's esophagus (any), *n* (%)	4 (4%)	4 (7.5%)	0 (0%)	NS

HH: hiatal hernia; BMI: body mass index; NS: not significant.

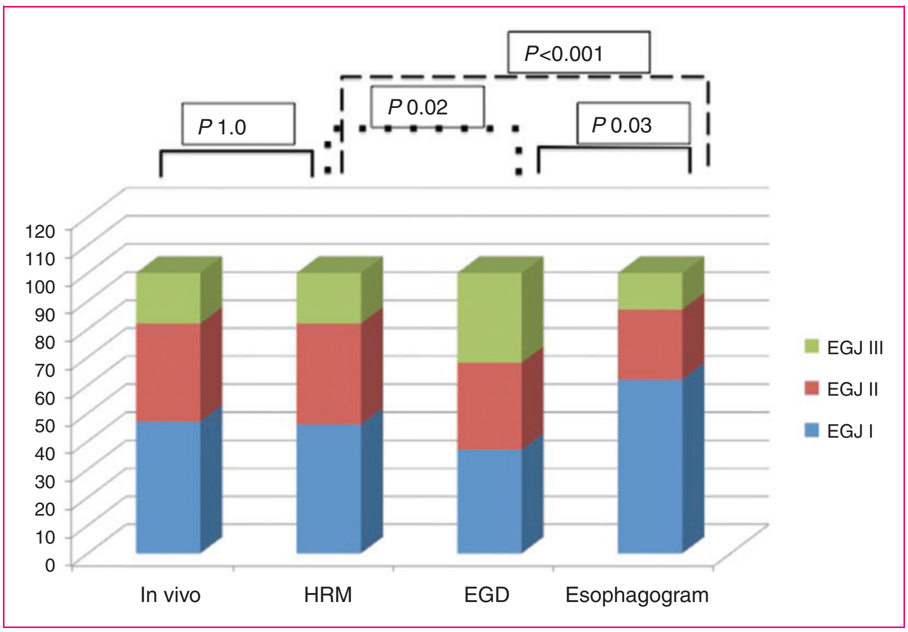

Figure 3. Hiatal hernia presence and esophagogastric junction appearance during in vivo examinations and during different diagnostic testing.
EGJ: esophagogastric junction; HRM: high-resolution manometry; EGD: esophagogastroduodenoscopy.

EGD produced lower sensitivity in detecting type I EGJ, lower specificity in type III EGJ and both lower sensitivity and specificity in type II EGJ than HRM (Tables 2 and 3).

Barium esophagogram

In 38 (38%) patients a B ring was documented as sign of HH presence. Twenty-five (25%) patients were categorised as type II EGJ, whereas 13 (13%) were considered type III EGJ. The esophagogram ability in detecting HHs was similar to HRM, with a specificity of 97.9% but with lower sensitivity (69.8%). Compared to EGD, radiology showed higher specificity and lower sensitivity. McNemar's test demonstrated a statistically significant discordance ($P < 0.001$) between radiology and HRM. According to morphological EGJ groups, esophagogram had similar specificity in identifying types II and III, and lower specificity in type I EGJ than HRM, whereas sensitivity was lower for types II and III than HRM. Compared to EGD, radiology had similar sensitivity for type II, but discordant values for both types I and III (Table 2 and 3).

Table 2. Sensitivity, specificity, predictive values of positive and negative tests, and Cohen's kappa agreement for HRM, endoscopy and barium esophagogram, using in vivo assessment as gold standard diagnostic reference for hiatal hernia.

	HRM	Endoscopy	Esophagogram
Sensitivity (%)	94.3	96.2	69.8
Specificity (%)	91.5	74.5	97.9
PVPT (%)	92.6	81	97.4
PVNT (%)	93.5	94.6	74.2
Kappa values	0.85	0.716	0.661

HRM: high-resolution manometry; PVPT: predictive value of a positive test; PVNT: predictive value of a negative test.

Area under receiver operating characteristic comparison

Using HRM as reference standard, the predictability of HH presence was higher than endoscopy and esophagogram, even if there was an absence of statistical significance (Figure 4(b)).

Discussion

Recent studies demonstrated that HRM has a high sensitivity and specificity for sliding HH detection.[13,14] In this study, we confirmed that HRM seems to detect HH presence accurately. In particular, we proved this ability using a reference standard, the surgical in vivo

Table 3. Sensitivity, specificity, predictive values of PVPT and PVNT, and Cohen's kappa agreement for HRM, endoscopy and barium esophagogram, using in vivo assessment as gold standard diagnostic reference for HH with subgroups according to EGJ morphology.

	HRM type I	HRM type II	HRM type III	Endoscopy type I	Endoscopy type II	Endoscopy type III	Barium type I	Barium type II	Barium type III
Sensitivity (%)	91.5	91.4	100	74.5	54.3	100	97.9	54.3	72.2
Specificity (%)	94.3	93.8	100	96.2	81.5	82.9	69.8	90.8	100
PVPT (%)	93.5	88.9	100	94.6	61.3	56.3	74.2	76	100
PVNT (%)	92.6	95.3	100	81	76.8	100	97.4	78.7	94.3
Kappa	0.86	0.847	1.0	0.716	0.368	0.636	0.665	0.482	0.81

HH: hiatus hernia; EGJ: esophagogastric junction; HRM: high-resolution manometry; PVPT: predictive value of a positive test; PVNT: predictive value of a negative test.

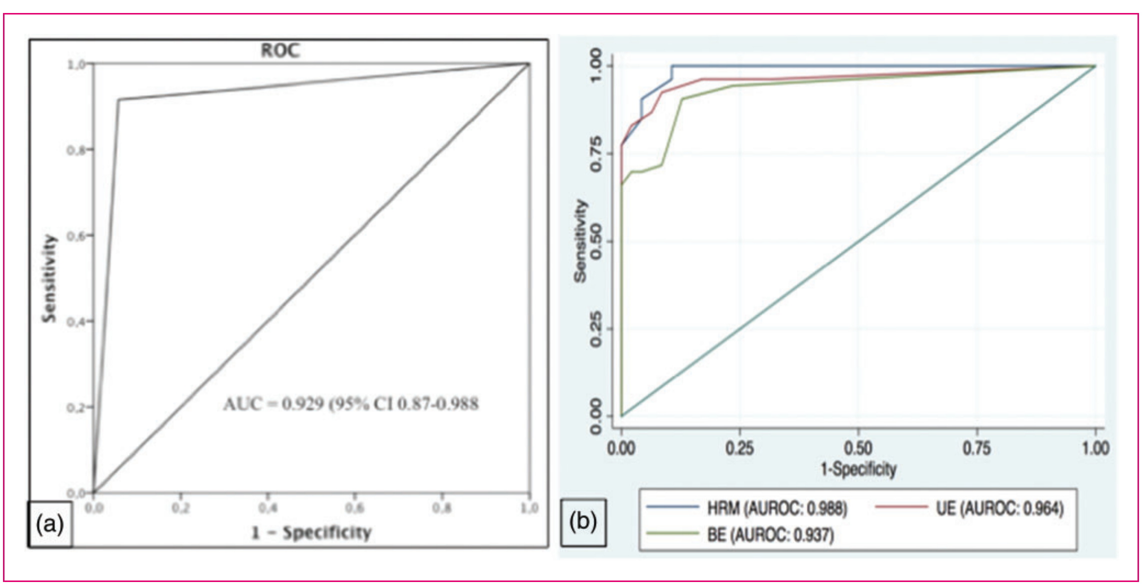

Figure 4. (a) Receiver operating characteristic (ROC) curve for the presence of hiatal hernia by high resolution manometry (HRM), using in vivo surgical assessment as diagnostic reference. AUC: area under the curve. (b) Area under receiver operating characteristic(AUROC) curve for the presence of hiatal hernia by the measurements of lower esophageal sphincter to crural diaphragm (LES–CD) length at high-resolution manometry (HRM), upper endoscopy (UE) and barium esophagogram (BE).

evaluation of LES–CD axial dislocation. HRM reached a sensitivity and specificity of HH diagnosis of 94.3% and 91.5%, respectively, exceeding the diagnostic ability of both endoscopy and radiography. HRM showed a 'substantial' agreement (kappa 0.85) and a statistically significant concordance ($P = 1.0$) with the in vivo assessment. Furthermore, we demonstrated that HRM could accurately define HH size (i.e. small when > 1 but ≤ 2 cm, and large when > 2 cm).

The HH role in GERD patients has been extensively investigated.[24] EGJ migration can be responsible for a decreased barrier function,[25–31] dysphagia[4] and hernia symptoms. Also, HH axial extension is considered an important parameter to plan pharmacological, endoscopic or surgical therapies.[32]

Usually, HH diagnosis is performed during EGD or esophagogram, but the reported data on the sensitivity, specificity or reproducibility of these tests are limited,[12,27] and are affected by various drawbacks, such as EGJ mobility.[32–34] This makes it difficult to standardise the assessment and measurement of a sliding HH with snapshot techniques. EGD is influenced by additional confounding factors such as difficulty in marking the squamo-columnar junction in Barrett's metaplasia, an extremely patulous hiatus, and excess gastric insufflation.[35] In this study, endoscopy showed a lower specificity than HRM, whereas radiology had a lower sensitivity. This is in agreement with the limitations of these two techniques; a lower specificity of EGD can be explained by exaggerated gastric inflation or by low patient compliance that might exaggerate the apparent HH size. Instead, radiology was very accurate in excluding HH presence, but was unable to identify small hernias.

HRM allows a more dynamic evaluation of EGJ and its components and, theoretically, is not influenced by subjective landmarks (such as a damaged mucosa) or by position or exaggerated gastric filling. Also, HRM protocol is well standardised and is rigorous worldwide. We demonstrated that HRM reached both optimal sensitivity and specificity when a LES–CD axial separation greater than 1.2 cm was present, with optimal PVPT and PVNT values, suggesting its major role in HH diagnosis. These findings are consistent with a recent study by Weijenborg et al.,[17] in which the authors compared HRM diagnostic power in identifying HHs with endoscopy and radiology either alone or combined. HRM showed 92% sensitivity and 93% specificity, exceeding the diagnostic power of the other two techniques alone. However, their study presented two important limitations: the reference standard applied was a subjective one, made by the combination of HH presence at endoscopy or radiology, and data from endoscopies and esophagograms were retrospectively collected.

In contrast to our results, Khajanchee et al.[18] often reported false negative results with HRM (low sensitivity, 52.38%, but high specificity, 95.12%). Interestingly, they evaluated HH length assessment during laparoscopic surgery and established this measurement as the reference. However, as stated by the authors themselves, creating a pneumoperitoneum may have exaggerated the HH size. Pneumoperitoneum could also reduce LES–CD axial separation, due to the well-known induced diaphragmatic proximal overdistension.

A major strength of our study is that we used an in vivo assessment of HHs during open surgery as the reference standard, avoiding increasing the abdominal pressure and diaphragmatic overdistension. Also, all measurements, both in vivo and during all tests, were easily reproducible and performed according to standardised protocols under the same circumstances. Finally, we performed a diagnostic power analysis for detecting both small and large sliding HH. It is worthy of note that the lowest diagnostic test values belonged to endoscopy and radiology in classifying small HHs (>1 cm but ≤ 2 cm), whereas both techniques showed optimal diagnostic power in large HHs. These data seem to support the hypothesis that endoscopy usually tends to exaggerate HH size, while radiology underestimates small hernias. HRM, instead, showed an optimal performance in classifying various EGJ morphologies. Another potential reason for the better correlation of the surgically measured HHs with HRM measurements is that both these measurements are performed in the basal state of the EGJ, without swallows (as with barium studies) or air insufflation causing secondary peristalsis (as with EGD).

This study has some limitations. The patients were enrolled during a 5-year interval, in which software analyses were probably ameliorated. However, this long time lapse was due to the wide use of laparoscopy for upper gastrointestinal surgery, and this caused difficulty in enrolling an adequate number of subjects. This is the first study using in vivo evaluation as the reference for HH presence (even if classic reports in early 1900 verified the presence of HHs during surgical procedures after diagnostic attempts with X-rays), thus there is not yet a real validation. Another possible limitation is the subjective definition of small and large HHs. It is intuitive that with a strict definition of 1 cm and 2 cm as landmarks, some HHs (i.e. HHs measuring 0.9 cm or 1.9 cm) can be erroneously classified as no HH or both small and large HHs. However, we had a very low frequency of these 'borderline' cases. The role of a constant presence of LES–CD axial separation greater than 0 cm but less than 1 cm was not investigated. This can be explained by the catheter spatial sensor configuration (1 cm each apart), which renders it actually impossible to detect exact separations lower than 1 cm. Finally, this study was not intended to compare the pathophysiological significance of HH measured with any of the testing modalities. However, as the surgically identified HH is subject to repair during anti-reflux surgery, we feel that knowing which non-surgical measurement most accurately predicts surgical HH size is relevant to the treating physician and surgeon. Thus, in this context, our findings indicate that HH measurements on HRM best predict what the surgeon encounters during anti-reflux surgery.

In conclusion, HRM can accurately diagnose a sliding HH presence, with high sensitivity and specificity. HRM seems to classify HHs better (no HH, small or large size) than endoscopy and radiology, and reaches an optimal agreement with surgical in vivo assessment, thus suggesting its use in combination with esophagogram and EGD for HH evaluation, particularly when anti-reflux surgery is considered.

Author contribution

ST, ES and GZ: data collection and analysis, writing of the manuscript, approving final version. MF and NdB: writing of the manuscript; LF, GdG, GB and MF: data collection and analysis; VS and LD: approving final version.

Declaration of conflicting interests

The authors declared that there is no conflict of interest.

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Ethics approval

The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a prior approval by the institution's human research committee.

Informed consent

Written informed consent was obtained from each patient included in the study.

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