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2009 SSAT POSTER PRESENTATION

# The Value of High-Resolution Manometry in the Assessment of the Resting Characteristics of the Lower Esophageal Sphincter

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**Abstract**

*Introduction* High-resolution manometry (HRM) is faster and easier to perform than conventional water perfused manometry. There is general acceptance of its usefulness in evaluating upper esophageal sphincter and esophageal body. There has been less emphasis on the use of HRM to evaluate the lower esophageal sphincter (LES) resting pressure and length, both factors important in LES barrier function. The aim of this study was to compare the resting characteristics of the LES determined by HRM and conventional manometry in the same patients.

*Methods* We performed both HRM and conventional manometry including a slow motorized pull-through technique in 55 patients with foregut symptoms. The characteristics of the LES analyzed were: resting pressure, total length, and abdominal length. Four available modes of HRM analysis were used to assess resting characteristics of the LES: spatiotemporal mode using both abrupt color change and isobaric contour, line tracing, and pressure profile. The values obtained from these four HRM modes were then compared to the conventional manometry measurements.

*Results* High-resolution manometry and conventional manometry did not differ in their measurement of LES resting pressure. LES overall and abdominal length were consistently overestimated by HRM. A variability up to 4 cm in overall length was observed and was greatest in patients with hiatal hernia (1.8 vs. 0.9 cm, $p=0.027$).

*Conclusion* The current construction of the catheter and software analysis used in high-resolution manometry do not allow precise measurement of LES length. Errors in the identification of the upper border of the sphincter may compromise accurate positioning of a pH probe.

**Keywords** Motility · Esophagus · High-resolution manometry · Pull-through technique · Lower esophageal sphincter · Gastroesophageal reflux disease (GERD)

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## Introduction

Recent advances in catheter and transducer design coupled with improved image processing and display techniques have yielded significant upgrades in technology, cumulating in the development of high-resolution manometry (HRM). The technical advantages of HRM lie in its high density of recording sites, advanced solid-state sensor technology, and intuitive spatiotemporal representation of the data. High-resolution manometry is also faster and easier to perform than conventional water-perfused manometry and has been reported to be superior in the assessment of the upper esophageal sphincter (UES) and esophageal body.[1] However, high-resolution manometry has not been compared to conventional "pull-through" manometry in the assessment of the lower esophageal sphincter (LES). The aim of this study was to compare the resting characteristics of the LES measured by HRM and those measured by a slow motorized pull-through technique (MPT) of conventional manometry in the same group of patients.

## Materials and Methods

Prior to using HRM in our clinical practice, we prospectively evaluated this new technology by comparing it to conventional manometry. Since HRM software allows analysis of esophageal body function in an identical manner to conventional manometry, we focused the evaluation on the resting characteristics of the LES since HRM does not include a traditional pull-through technique.

The study population consisted of 55 consecutive patients with foregut symptoms who had both HRM and conventional manometry performed. All of these patients had a video-esophagram to assess for the presence of a hiatal hernia. This study was approved by the University of Southern California Institutional Review Board.

### Conventional Manometry

Conventional manometry was performed in the supine position using a 12 French eight-channel water-perfused catheter (Arndorfer Medical Specialties, Greendale, WI, USA). The stationary pull-through technique was performed by withdrawing the catheter through the sphincter in 1 cm increments. The upper and lower borders of the LES were identified using the classic definition of 2 mmHg constant rise from the gastric baseline pressure. Values obtained from five individual tracings were averaged.

A slow motorized pull-through technique was also performed for detailed assessment of the LES.[2,3] Motorized pull-through technique was performed in the same setting with the same catheter; a separate intubation was not required. Four radially placed sensors at the same level were used in MPT. The radial sensors were positioned just below the LES, and a mechanical puller was used to withdraw the catheter at a rate of 1 mm/s through the sphincter while the patient breathed normally. If the patient swallowed during this time, the procedure was repeated. The recording was analyzed using the Polygram® software program (version 5.22 Upper GI Edition, Gastrosoft, Medtronic Medical) to determine LES resting pressure, overall length, and abdominal length using the end expiratory gastric pressure as a reference. The lower border of the LES was defined as a persistent rise in pressure ≥2 mmHg above the gastric baseline. The upper border of the LES was defined as the point where the pressure dropped below the gastric baseline. The respiratory inversion point (RIP) was defined as the location where the positive deflections with inspiration recorded in the abdomen changed to negative deflections recorded in the chest. The resting pressure of the sphincter was measured at the RIP during the middle of the respiratory cycle. The overall length was defined as the distance in centimeters between the upper and the lower borders of the LES and the abdominal length as the distance in centimeters between the lower border and the RIP. The values obtained from the four radial channels were averaged.

### High-Resolution Manometry

High-resolution manometry was performed during the same visit in the supine position 30 min after finishing the conventional manometry. A solid-state manometry catheter with 36 circumferential pressure sensors spaced at 1-cm intervals was used (Sierra Scientific Instruments; Los Angeles, CA). The catheter was positioned so that at least four sensors were in the stomach to optimize recording of intragastric pressure. The sensors measured pressure over a length of 0.25 cm, and in the remaining 0.75 cm of space between the sensor recording area, the data was interpolated using an algorithm to generate a pseudo-3-dimensional topographic plot. A 25-s period of recording documented the resting status of the esophagus and determined the location and resting pressure profile of the upper and lower esophageal sphincters. This was followed by ten swallows of 5 cc of water at 20-s intervals to assess upper esophageal sphincter function, esophageal body function, and LES relaxation.

Overall and abdominal lengths of the LES were assessed using ManoView® analysis software (Sierra Scientific Instruments, Los Angeles, CA). The data were first corrected for thermal sensitivity according to the manufacturer's instructions. All pressures were referenced to gastric baseline pressure. The LES reading were analyzed using all four available modes:

1. Spatiotemporal mode using abrupt color change
2. Spatiotemporal mode using isobaric contour=2 mmHg
3. Line tracing mode using constant rise ≥2 mmHg
4. Pressure profile mode

In the spatiotemporal mode, the lower border of LES was defined by a distinct color change from blue (i.e., gastric pressure) to green (i.e., high-pressure zone in distal esophagus).The upper border of the LES was defined by a change back from green to blue (Fig. 1a). In the same mode, the upper and lower borders of the LES were determined using an isobaric contour tool that defined a pressure domain of ≥2 mmHg above gastric pressure (Fig. 1b).

In the line tracing mode, channels can be selected by the user to display tracings in the stomach, the entire gastroesophageal junction, and the distal esophagus. In this display, the most distal line tracing with a constant pressure ≥2 mmHg above gastric baseline represents the lower

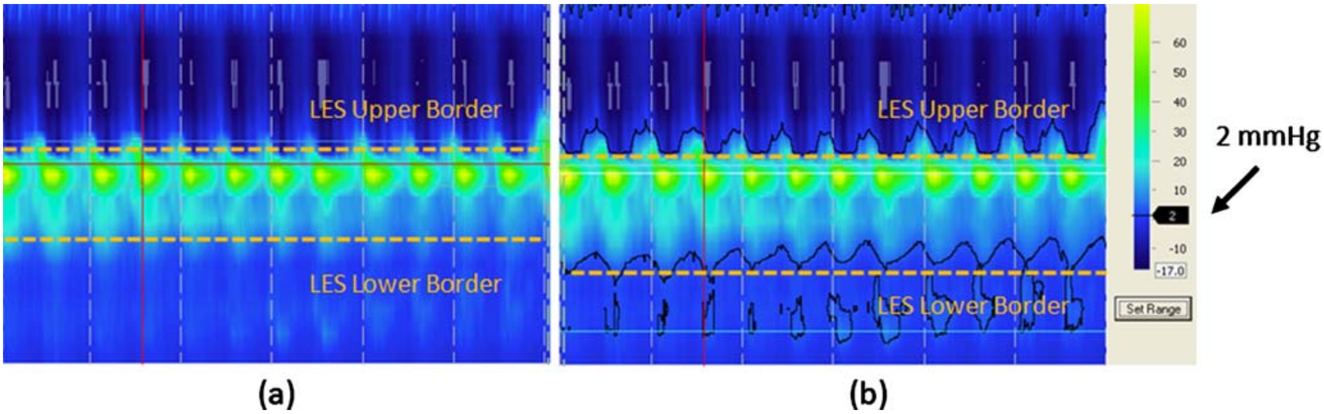


**Figure 1 a** Analysis of the LES in the spatiotemporal mode using abrupt color change. The color changes at the mid respiratory points are identified visually and marked with *horizontal lines* to identify the upper and lower borders of the LES. The software calculates the overall length of the LES as the distance in centimeters between these lines. **b** Analysis of the LES in the spatiotemporal mode using isobaric contour. The user selects a pressure threshold, and the software draws a contour line at this pressure. The upper and lower borders are marked with *horizontal lines* at the mid respiratory point of these contour lines. The software calculates the overall length of the LES as the distance in centimeters between these lines.

border of the LES. The most proximal tracing with a constant pressure ≥2 mmHg above gastric baseline pressure represents the upper border of the LES (Fig. 2).

In the pressure profile mode, the data from the 36 sensors are used to construct a dynamic graph that is shown in the analysis software (Fig. 3). This graph represents the pressure profile along the entire esophagus relative to gastric baseline pressure at any given time during the study. The borders of the LES were defined by the points where the pressure profile line crosses the gastric baseline.

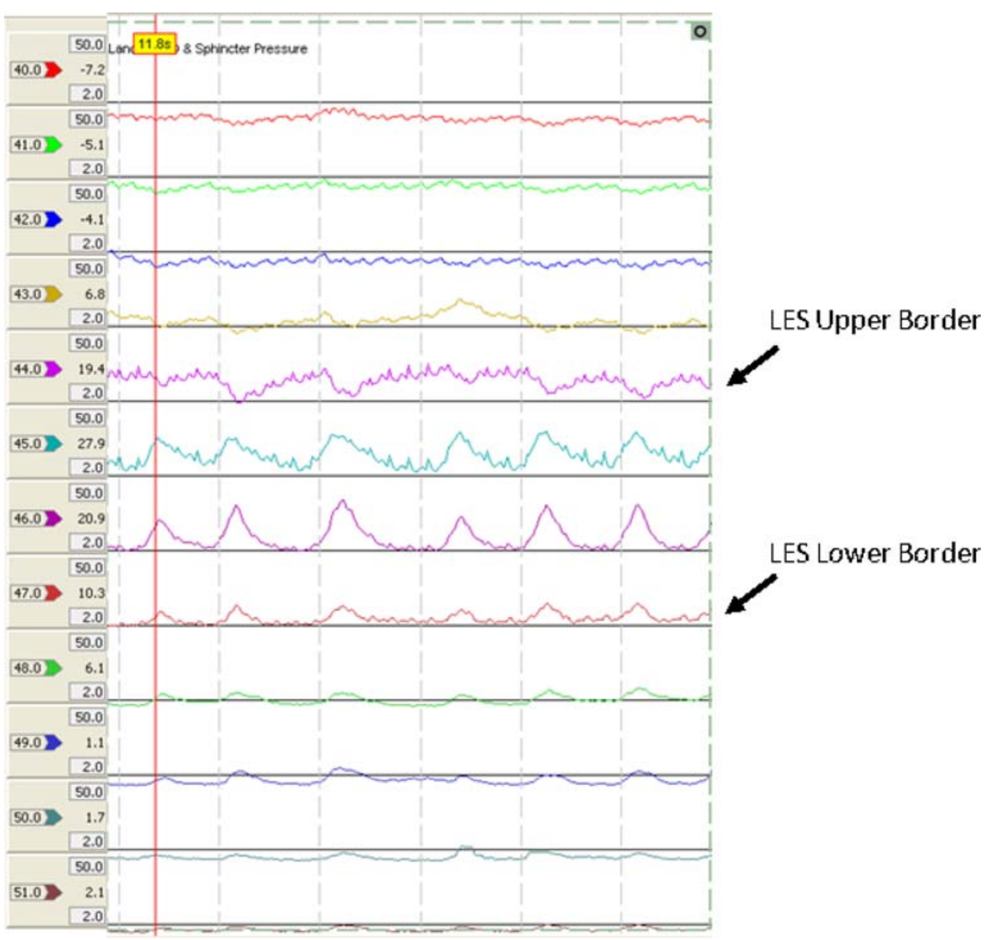


**Figure 2** Analysis of the LES in the line tracing mode. The most distal line tracing with a constant pressure ≥2 mmHg above gastric baseline represents the lower border of the LES. The most proximal tracing with a constant pressure ≥2 mmHg above gastric baseline pressure represents the upper border of the LES. The distance between these sensors is recorded as the overall length of the LES.

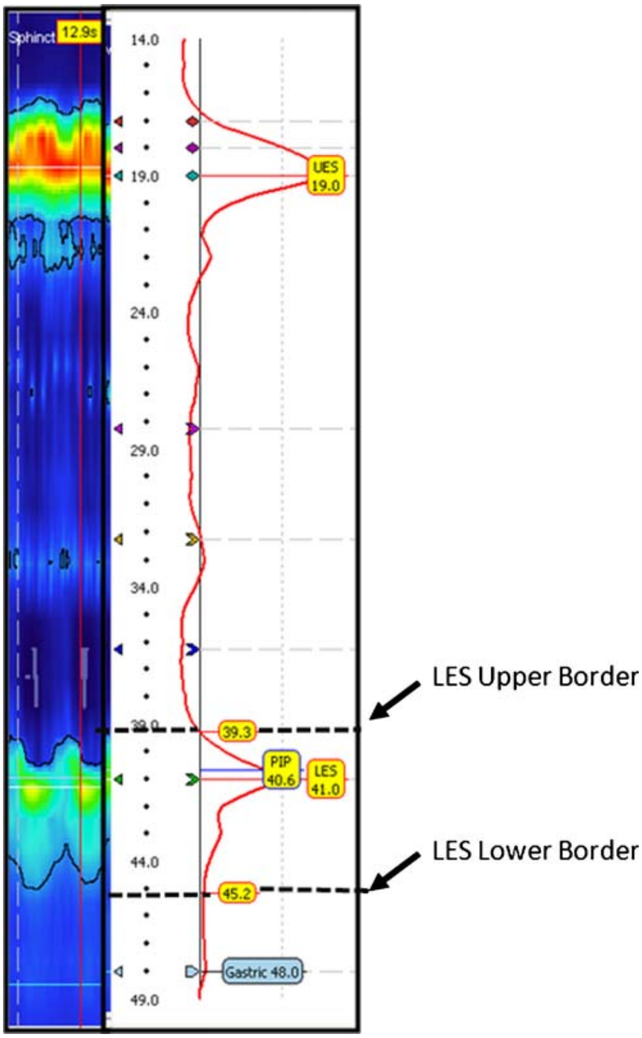


**Figure 3** Analysis of the LES in the pressure profile mode. The pressure profile is displayed for a representative location in the LES at the mid respiratory point. The user places *horizontal lines* where the pressure profile crosses the gastric baseline. The software calculates the overall length of the LES as the distance in centimeters between these lines.

The respiratory inversion point was identified using the pressure inversion point tool provided in the software. The location of the RIP was used to determine the upper extent of the abdominal portion of the LES in order to calculate the abdominal length of the LES in all four modes.

The resting pressure of the LES was determined in two ways. In the spatiotemporal mode, with the upper and lower borders of the LES marked as described above, the E-Sleeve software tool identifies the highest pressure point in the LES. The resting pressure of the LES was also determined by positioning the smart mouse cursor included in the software at the level of RIP at the mid respiratory point to measure the pressure at this location.

### Statistical Analysis

Values are reported as median and interquartile range (IQR). The Wilcoxon signed rank test was used to compare continuous variables. The Spearman test was used to assess correlation between variables reported as the correlation coefficient *R* with 95% confidence intervals (CI). A *p* value less than 0.05 was considered statistically significant. The analysis was performed using Prism 4 statistical software (Graphpad, San Diego, CA, USA).

## Results

There were 29 male and 26 female patients with a median age of 53 years (IQR 45–65). The resting characteristics of the LES measured by the conventional stationary pull-through technique are compared to those obtained by the motorized pull-through technique in Table 1. The LES resting characteristics were similar between these two methods.

Overall lengths of the LES as measured by MPT and the four modes of HRM are compared in Table 2. Overall lengths measured by all modes of HRM were significantly longer compared to the MPT measurements, with the exception of the line-tracing mode. Likewise, the abdominal lengths of the LES measured by HRM were significantly longer than those measured by MPT with the exception of the line tracing mode (Table 3).

The Spearman correlation analyses of overall and abdominal lengths measured by MPT and HRM are shown in Table 4. No correlation was found between overall lengths as measured by MPT and any of the HRM modes. There was a weak correlation between the abdominal length measured by MPT and the pressure profile and spatiotemporal (color change) modes of HRM.

The overall length of the LES was overestimated by all four modes of HRM. This overestimation was maximal for the spatiotemporal mode using color change in which 82% of patients had a longer overall length compared to MPT. The corresponding percentages for other HRM modes

**Table 1** Comparison Between Stationary Pull-through (SPT) and Motorized Pull-through (MPT) Techniques of Conventional Manometry Assessment of the LES Resting Characteristics

| | SPT | MPT | *p* value |
|---|---|---|---|
| Overall length (cm) | 3.0 (2.2–3.4) | 2.8 (2.2–3.8) | 0.55 |
| Abdominal length (cm) | 1.8 (1.1–2.2) | 1.9 (1–2.9) | 0.19 |
| Resting pressure (mmHg) | 13.5 (8–20.2) | 12.8 (8.1–19.5) | 0.69 |

Values expressed as median (IQR)

**Table 2** Comparison of Overall Lengths of the LES Measured by MPT and the Four Modes of HRM, Values Expressed as Median (IQR)

| | Conventional manometry | High-resolution manometry | | | |
|---|---|---|---|---|---|
| | Motorized pull-through | Pressure profile | Spatiotemporal (color change) | Spatiotemporal (isobaric=2mmHg) | Line tracing |
| Overall length (cm) | 2.8 (2.2–3.8) | 4.7 (3.3–5.3) | 3.5 (2.7–4.1) | 4.4 (3.4–5.3) | 3 (2–4) |
| *p* value[a] | – | <0.0001 | 0.0114 | <0.0001 | 0.94 |

[a] For comparison to MPT values using Wilcoxon signed rank test

**Table 3** Comparison of Abdominal Lengths of the LES Measured by MPT and the Four Modes of HRM, Values Expressed as Median (IQR)

| | Conventional manometry | High-resolution manometry | | | |
|---|---|---|---|---|---|
| | Motorized pull-through | Pressure profile | Spatiotemporal (color change) | Spatiotemporal (isobaric=2 mmHg) | Line tracing |
| Abdominal length (cm) | 1.9 (1.0–2.9) | 3.7 (2.6–4.6) | 3.0 (2.1–3.6) | 3.8 (2.7–4.5) | 3 (2–4) |
| *p* value[a] | – | <0.0001 | <0.0001 | <0.0001 | 0.094 |

[a] For comparison to MPT values using Wilcoxon signed rank test

**Table 4** Correlation Between Overall and Abdominal Lengths of the LES Measured by the Four Modes of HRM and the MPT Technique of Conventional Manometry*

| | Pressure profile | Spatiotemporal (color change) | Spatiotemporal (isobaric=2mmHg) | HRM Line tracing |
|---|---|---|---|---|
| Overall length | n.s | n.s | n.s | n.s |
| Abdominal length | 0.31 (0.04–0.53) | 0.40 (0.14–0.61) | n.s | n.s |

*$p<0.05$, Spearman coefficient (95% CI) reported for analyses

*n.s.* not significant

**Table 5** Comparison of Overall and Abdominal Lengths Measured by MPT and the Spatiotemporal Isobaric Contour and Line Tracing Modes of HRM using a Threshold of 5 mmHg, Values expressed as median (IQR)

| | Motorized pull-through | Spatiotemporal (isobaric=5 mmHg) | HRM Line tracing (5 mmHg) |
|---|---|---|---|
| Overall length (cm) | 2.8 (2.2–3.8) | 3.7 (2.7–4.1)* | 2 (1–3) |
| Abdominal length (cm) | 1.9 (1.0–2.9) | 3.5 (2.5–4.3)* | 2 (1–3) |

*$p<0.05$ vs. MPT

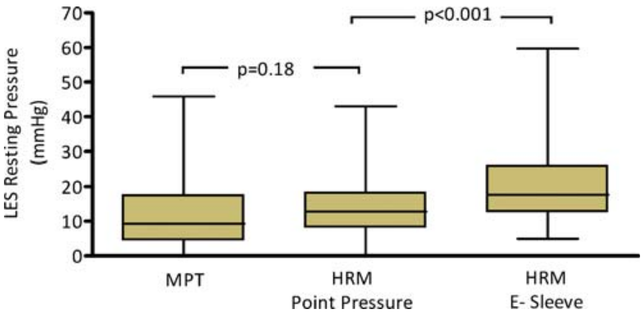


**Figure 4** Comparison of the resting pressure of the LES measured by MPT and two techniques by HRM.

were: 76% for the pressure profile, 60% for the spatiotemporal mode using isobaric contour of 2 mmHg, and 49% for the line tracing using the cut point of 2 mmHg.

We reanalyzed the HRM data using a threshold of 5 mmHg for the isobaric contour in the spatiotemporal mode and a constant rise ≥5 mmHg above gastric pressure in the line tracing mode. Using this higher pressure threshold, the overall and abdominal lengths measured by spatiotemporal mode (using isobaric contour) were shorter but remained significantly different from the values obtained by MPT. With the higher pressure threshold, the lengths measured by the line tracing mode were similar to MPT (Table 5).

Figure 4 compares the resting pressure of the LES measured by MPT and HRM. The pressure measured by the E-sleeve was significantly higher than the MPT pressure. There was no difference between the pressure at the RIP measured by HRM using the smart mouse and the resting pressure measured by MPT.

The location of the upper border of the LES was determined by stationary pull-through during conventional manometry and in the spatiotemporal mode using color change. There was a modest correlation between these measurements with discrepancies as large as 3.4 cm in individual patients (Fig. 5).

Radiologic evidence of a hiatal hernia was present in 38 patients (70%). The presence of a hernia was associated with a greater variability in overall lengths of the LES measured by MPT and the spatiotemporal mode using color change [1.8 cm (1–2.5) vs. 0.9 cm (0.3–2.1), $p$=0.027].

## Discussion

High-resolution manometry has grown in popularity since its introduction in 2000.[4] This has occurred for a number of reasons. It is faster to perform which makes it attractive to both patients and to foregut diagnostic laboratories performing the test. The presence of simultaneous recording channels from the pharynx to the stomach eliminates the need to move the catheter during the study which simplifies the conduct of the procedure and makes it more tolerable for the patients. The solid state catheter eliminates the need for a water perfusion system, which makes the exam technically easier to perform. The sophisticated software package also simplifies the conduct of the study and its analysis. This is especially true when the spatiotemporal mode is used. All of these factors combine to make this HRM popular especially in community-based centers.

High-resolution manometry has been shown to be useful and accurate in the assessment of motor function of the UES[5,6] and esophageal body,[7,8] and it may offer unique insights into assessment of esophageal function particularly in evaluating bolus transport.[9] To date, no studies have assessed the use of HRM in measuring the resting characteristics of the lower esophageal sphincter. In particular, the impact of the elimination of the "pull-through" component of LES analysis has not been studied. We hypothesized that the interpolated data points over the short segment that is the LES may lead to under- or overestimation of the true length of the sphincter by HRM since the pressure sensors are placed at 1 cm intervals.

We have shown that there are significant differences in all measurements of the resting characteristics of the LES between the results obtained using high-resolution manometry and those obtained by the motorized pull-through technique of conventional manometry. We analyzed all four available HRM techniques for assessing the LES using two different pressure thresholds and found that the overall and abdominal lengths of the LES were consistently overestimated. The resting pressure of the LES was also overestimated when the E-sleeve was used as recommended by the manufacturer.

In clinical practice, the spatiotemporal mode of HRM using color change is the most common method used to assess the status of the LES. We have shown that the degree of overestimation of the resting characteristics of the LES was greatest for this mode of analysis. In fact, 82% of

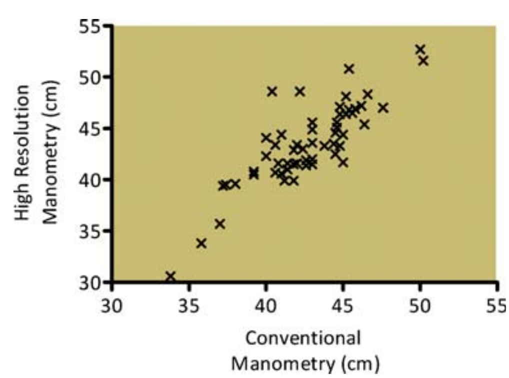


**Figure 5** Correlation between the upper border of the LES determined by conventional manometry and the spatiotemporal mode of HRM using color change ($R^2$=0.45, $p$<0.001).

patients had overestimation of the LES length of up to 4 cm. There are several factors which may explain this discrepancy. First, there is subjectivity in identifying the exact location of the color change to localize the upper and lower borders of the sphincter. Second, the high-pressure zone marked by this method of analysis includes not only the intrinsic sphincter but the impression of the crural diaphragm. As a result, the true length of the LES is overestimated when a hernia is present, which we have also shown. Finally, as a consequence of catheter design, there is the inherent inaccuracy created by mathematical interpolation of the pressure values in the 0.75 cm between recording segments.

Analyses of the LES in the other three modes result in measurements that differ less from those obtained by conventional manometry. This is especially true for the line tracing mode. These methods of analyzing the LES require more experience and considerable adjustment of the software settings, which increases the demands on the technician performing the study. These requirements tend to negate many of the benefits to the diagnostic laboratory performing HRM.

The location of the upper border of the LES is an important landmark for placement of a pH catheter.[10,11] The location of the upper border of the LES determined by HRM was variable when compared to the results of conventional manometry. Overall, there was only a moderate correlation between the two measurements with variation of as much as 3.4 cm noted. This degree of variation in positioning the probe may lead to inconsistencies in pH measurements, given the gradient of acid exposure in the distal esophagus that has been documented in both patients with GERD[12] and in normal subjects.[13] This inconsistency in pH probe placement can affect clinical management by reporting false positive and false negative pH monitoring.

The differences that we have observed between high-resolution manometry and the motorized pull-through technique highlight limitations in the high-resolution technology. Elimination of the pull-through combined with mathematical interpolation of the pressure values between recording segments limits the precision of the length measurements of the LES to 1 cm. It is anticipated that future versions of the analytical software and pending modifications to catheter design will overcome many of the sources of inaccuracy in assessing the LES. In the next generation of HRM currently under development, referred to as high-definition manometry (Sierra Scientific Instruments Inc, Los Angeles, CA), the pressure sensors are more closely spaced such that 128 individual pressure recordings can be made over a distance of 4.8 cm.[14] With this modification, a 3-dimensional representation of the sphincter can be constructed in a manner similar to the sphincter pressure vector volume technique in assessment of LES that we have shown has advantages over conventional manometry in assessing sphincter incompetence.[15]

## Conclusion

For more than half a century, the "pull-through" technique has been the standard means of assessing the resting characteristics of the LES.[16] High-resolution manometry eliminates this procedure and is associated with consistent overestimation of the resting characteristics of the LES and errors in the identification of the upper border of the sphincter and pH probe positioning. It appears that this simplification in the conduct and analysis of esophageal manometry has come at the detriment of accuracy in LES assessment.

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