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Three-Dimensional Imaging of the Lower Esophageal Sphincter in Healthy Subjects and Gastroesophageal Reflux

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The resting pressure and intraabdominal length are the most important factors which determine competence of the lower esophageal sphincter (LES). The intraabdominal sphincter vector volume (ISVV) is a single value which takes into account both of these measurements. Normal values of ISVV and of the total sphincter vector volume (TSVV) were established in 20 normal subjects. The sensitivity and the specificity of ISVV and TSVV were then evaluated in 81 patients with gastroesophageal reflux disease (GERD) and in 19 normal subjects and were compared with the usual stepwise pullback manometry (SPM) measuring the resting pressure of the LES at the respiratory inversion point. The motorized pullthrough technique was used to perform the vector volume procedure. Normal values of ISVV were 1870–10740 mm $Hg^2 \times$ mm, and of TSVV 2200–13110 mm $Hg^2 \times$ mm. The sensitivity of ISVV was 93.8% ($p < 0.05$), of TSVV 80.2%, and of SPM 81.5%. The specificity of ISVV and TSVV was 89.5% and of SPM 78.9% (not significant). Analysis of the intraabdominal sphincter vector volume is more sensitive than the total sphincter vector volume or standard stationary manometry in establishing a defective LES in patients with GERD. Intraabdominal sphincter vector volume analysis will allow surgeons better to identify patients with a defective LES who may be suitable for antireflux surgery.

KEY WORDS: lower esophageal sphincter; vector volume; gastroesophageal reflux disease.

The lower esophageal sphincter (LES) is the primary barrier against reflux of gastric and/or duodenal juice into the esophagus. Factors which may influence the function of the LES are the resting pressure, the intraabdominal length, and the overall length of the sphincter (1). Especially the intraabdominal length is of great importance since an increase in the intraabdominal pressure under straining conditions is passively transmitted onto the intraabdominal part of the LES and may therefore strengthen the antireflux barrier (2). Dislocation of the LES into the chest, as seen in hiatal hernia, shortens the intraabdominal sphincter portion and may therefore result in LES incompetence even in the case of a normal resting pressure and a normal overall sphincter length (3). On esophageal manometry performed by the usual stepwise pullback technique, the resting pressure and the overall and the intraabdominal sphincter length can be evaluated. However, even when all three components of sphincter competence are taken into account, the sensitivity of esophageal manometry to detect an incompetent LES is only 58% (4). Patients with low normal values of each component can still have a defective LES.

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The sphincter vector volume, originally introduced by Bombeck *et al.* (5) and further evaluated by Stein *et al.* (3), is a measure which describes the three-dimensional distribution of the sphincter pressure at each point over the sphincter length. Since this measure is an integration of sphincter pressure and length into one parameter it should be more accurate in the evaluation of the defective LES than the usual stepwise pullback technique. However, due to the lack of sophisticated software programs to calculate the sphincter vector volume, the clinical application of this technique has been limited so far. Calculation without the support of software programs is time-consuming and prone to errors. This may be the reason why no data on the sensitivity and specificity of this technique have been quoted in previous studies. Due to this fact it is not clear if the sphincter vector volume may improve the evaluation of the defective LES. With the introduction of reliable software programs, the calculation of the sphincter vector volume became clinically more practicable and it was therefore the aim of this study to investigate if the sphincter vector volume is a useful contribution in the assessment of the incompetent LES.

MATERIALS AND METHODS

In 20 healthy subjects the normal values of the total sphincter vector volume (TSVV) and the intraabdominal sphincter vector volume (ISVV) were evaluated. The lower and upper limits of normal were obtained by calculating the 5th and 95th percentiles. Eighty-one consecutive patients with gastroesophageal reflux disease (GERD) and 19 normal subjects were used to calculate the sensitivity and specificity of TSVV and ISVV. In these 81 patients and 19 normals also the usual stepwise pullback manometry (SPM) was performed measuring the resting pressure of the LES and its overall and intraabdominal length. The sensitivity and specificity of this technique were compared with the values obtained with TSVV and ISVV. GERD was proven in all patients by a positive history of heartburn and a DeMeester score above 14.8 on 24-hr pH monitoring (6, 7) or the presence of esophagitis on endoscopy. Esophagitis was graded according to the Savary Miller classification system (8). There were 11 patients with esophagitis grade 0, 21 patients with grade 1, 16 patients with grade 2, 7 with grade 3, and 26 patients with grade 4 esophagitis. All of the GERD patients except three had a hiatal hernia 3 to 7 cm in length diagnosed by radiography. In normals GERD was excluded by a negative history of heartburn, no presence of a hiatal hernia and esophagitis on endoscopy or barium study, and normal 24-hr pH-monitoring.

Esophageal Manometry. A low-compliance, pneumohydraulic capillary infusion system (Arndorfer Medical Specialties, Greendale, WI) and an eight-channel water-perfused catheter was used for the manometric evaluation of the LES. The catheter consisted of four openings at its tip in a radial orientation and four further openings above the tip at a 5-cm spacing. This allowed for the performance of the vector volume procedure and the usual stepwise pullback procedure in the same session without changing the catheter. The manometric evaluation of the LES was started with the stepwise pullback procedure. Five channels of the water-perfused catheter at a 5-cm spacing were pulled through the LES at 1-cm intervals. The LES pressure was measured in each channel as the difference between the gastric baseline and the pressure at the respiratory inversion point (RIP) during the middle of the respiratory cycle. Data were recorded using a polygraph (Synectics, Irving, TX), which transferred the data to an IBM personal computer. The data were analyzed with the help of a commercially available software program (Polygram, Gastrosoft, Version 5.05C3, Irving, TX). The mean of the pressures obtained from all five channels was recorded as the resting pressure of the LES. In addition, the mean intraabdominal length and the overall length of the LES were evaluated. The intraabdominal sphincter length was defined as the distance between the point where the LES pressure rose above the gastric baseline (lower border of the LES) and the RIP. The overall sphincter length was defined as the distance between the lower border of the LES and the point where the pressure dropped to the esophageal baseline (upper border of the LES). The LES was defined as incompetent when the pressure was below 8 mm Hg and/or the intraabdominal length below 1.2 cm and/or the overall length below 2.4 cm. These normals have been evaluated in our laboratory on 50 healthy subjects by calculation of the fifth percentiles (1).

For the performance of the vector volume procedure the four radially oriented openings of the water-perfused catheter were used. The catheter was pulled through the LES at a constant speed of 3 mm/sec by means of a motorized catheter puller (Synectics, Version 1.3, Irving, TX). The patients were allowed to breathe quietly but were restricted to swallow. The lower and upper border of the LES and the RIP were identified in each channel and marked on the computer screen (Figure 1). The lower border was defined as the point where the pressure rose above the gastric baseline; the upper border of the LES was defined as the point where the pressure dropped below the gastric baseline. With the help of the computer program (Polygram, Gastrosoft, Version 5.05C3, Irving, TX), the three-dimensional distribution of the pressure over the intraabdominal and the total sphincter length was depicted on the computer screen and the intraabdominal (ISVV) and total vector volume (TSVV) were calculated from the obtained figures using the trigonometric formula for an irregular tetragon (Figures 2–4) as previously described (3, 5). All calculations were performed by the computer program. Data are expressed as mm Hg^2 × mm. The motorized pullback procedure was repeated twice in each patient and the lowest values of ISVV and TSVV of all three pullback maneuvers were reported.

Statistical Analysis. The sensitivity of ISVV, TSVV, and SPM was defined as the probability of a positive result in a GERD patient and was calculated by means of the following formula: sensitivity = No. of true positives/total No. of GERD patients expressed as a percentage. The specificity of ISVV, TSVV, and SPM was defined as the probability of a negative result in those without GERD and was calcu-

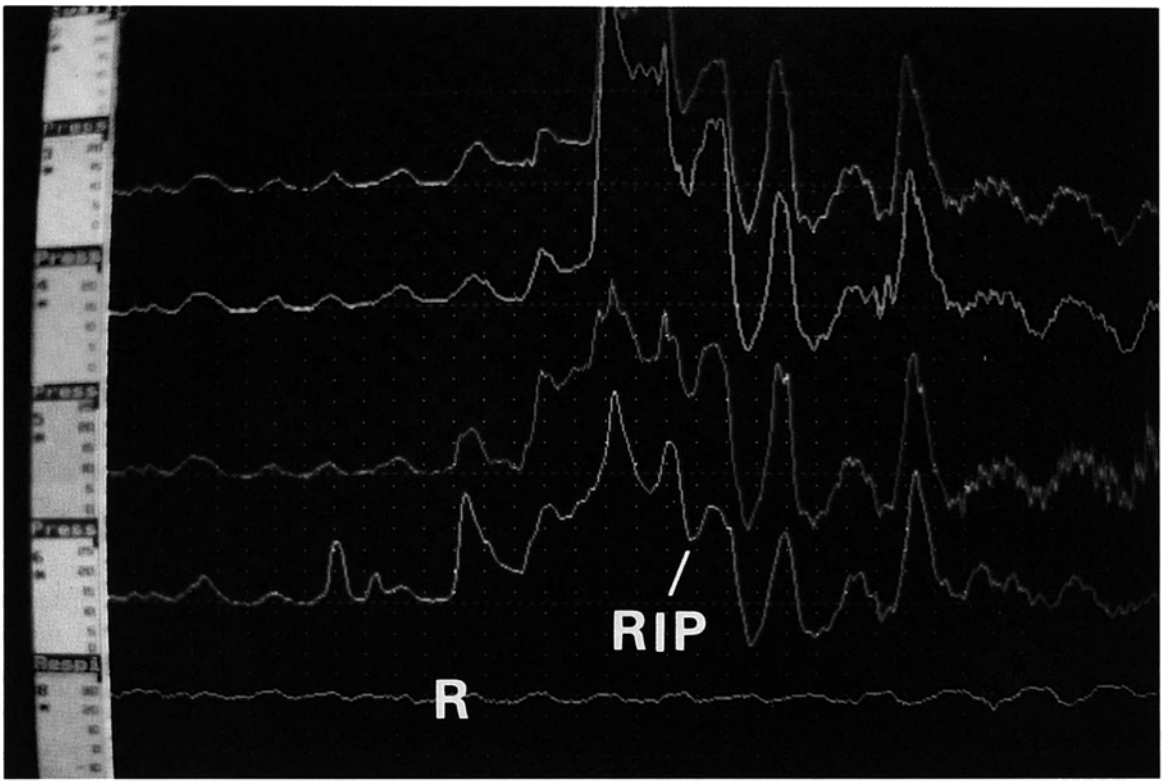

Fig 1. Pressure tracing on the computer screen during the vector volume procedure. The upper four channels are the pressure channels; the lowest channel is the respiratory channel. The respiratory inversion point (RIP), which marks the end of the intraabdominal sphincter length, is clearly identified. R, respiratory channel.

lated using the following formula: specificity = No. of true negatives/total No. of patients without GERD expressed in percent.

The sensitivity and specificity of ISVV, TSVV, and SPM were compared by means of the chi-square test. A p value of less than 0.05 was considered to be significant. TSVV and ISVV were correlated with the grade of esophagitis by means of the Spearman test. The Spearman rank correlation coefficient r_s was quoted.

RESULTS

Values of SPM and data of 24-hr pH monitoring in normals and GERD patients are shown in Table 1. Normal values of ISVV were 1870–10,740 mm $Hg^2 \times$ mm, and of TSVV 2200–13,110 mm $Hg^2 \times$ mm. The mean ISVV of patients was 954.8 mm $Hg^2 \times$ mm (range: 60–5910) and the mean TSVV was 2009 mm

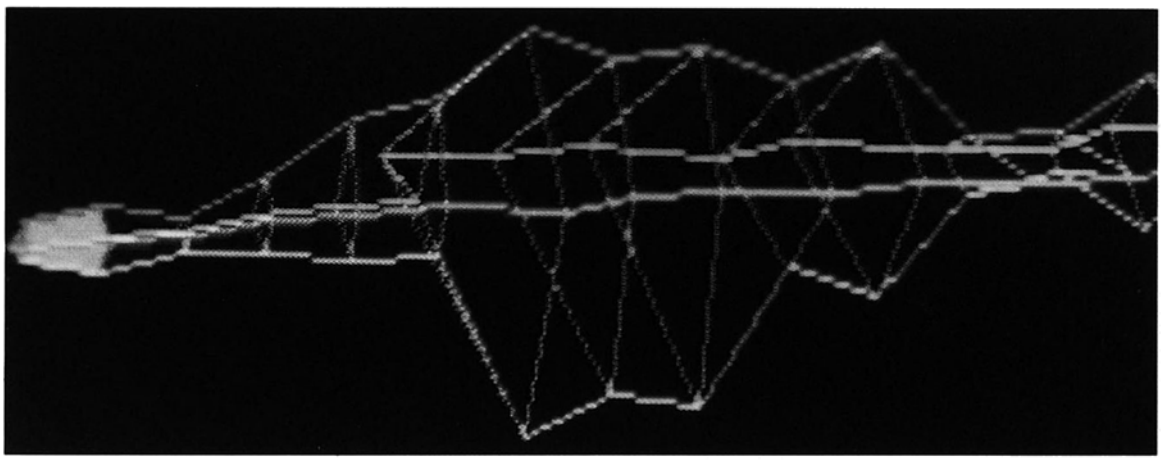

Fig 2. Three-dimensional pressure figure of a normal LES obtained by the computer program.

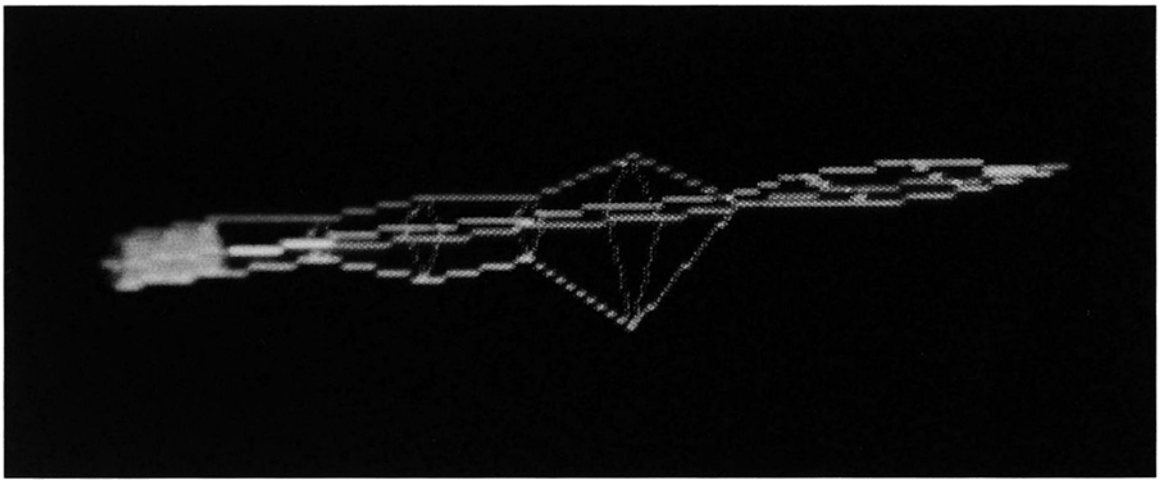

Fig 3. Three-dimensional pressure figure of a pathologic LES of a GERD patient obtained by the computer program. The pressure is decreased over the entire length of the sphincter.

$Hg^2 \times$ mm (range: 90–12,030). The number of true positive results of ISVV was 76, of TSVV 65, and of SPM 66. The number of true negative results of ISVV and of TSVV was 17, and of SPM 15. The sensitivity of ISVV was 93.8%, of TSVV 80.2%, and of SPM 81.5%. There was a significant difference between ISVV and TSVV or SPM but not between TSVV and SPM. The specificity of ISVV and TSVV was 89.5%, and of SPM 78.9% (no significant difference). There was no correlation between the grade of esophagitis and ISVV ($r_s = -0.22$) or TSVV ($r_s = -0.14$).

DISCUSSION

Gastroesophageal reflux disease is the most common foregut disorder and may lead to complications such as ulceration, stricture or Barrett's esophagus in about 50% of patients (9). Although gastric acid is a major part of the gastroesophageal refluxate, long-term results aimed on suppression of gastric acid production are poor (10–12). The relapse rate of esophagitis after discontinuation of omeprazole or H_2 blocker therapy is about 90% within a year, and even

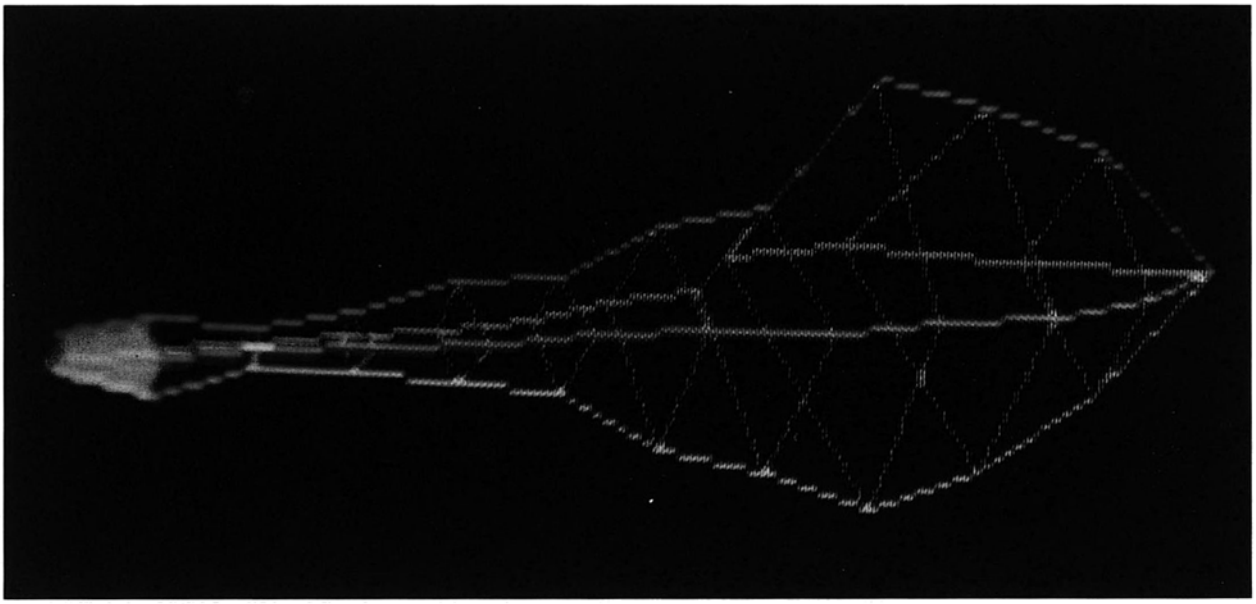

Fig 4. Three-dimensional pressure figure of a pathologic LES of a GERD patient obtained by the computer program. Pressure is noted only in the proximal (intrathoracic) part of the sphincter, whereas the intraabdominal sphincter is defective.

TABLE 1. DATA ON THE LES OBTAINED BY THE USUAL PULLBACK MANOMETRY AND DATA ON 24-hr pH MONITORING IN NORMALS AND GERD PATIENTS*

	Normals	*GERD patients*
Resting pressure (mm Hg)	15.4 (4.6–36.1)	5.8 (0–24.8)
Intraabdominal sphincter length (cm)	2.8 (1.0–4.4)	1.8 (0.4–3.4)
Total sphincter length (cm)	5.0 (3.2–6.8)	5.1 (1.8–10.8)
DeMeester score	4.4 (0.2–14.1)	35.4 (0.4–143.9)

* Mean (range).

under maintenance therapy with 20 mg omeprazole daily the recurrence rate is about 40% within a year and may reach more than 50% in patients with severe esophagitis. Moreover, there is also some evidence that gastric acid suppression does not prevent GERD complications effectively (4). This is due to the fact that gastric acid suppression does not improve the sphincter function and other noxious ingredients of gastric and/or duodenal content such as pepsin, trypsin, and bile salts may still reflux into the esophagus resulting in persistent mucosal damage even when patients are free of reflux symptoms.

Antireflux surgery restores the function of the antireflux barrier by increasing the resting pressure and the intraabdominal length of the LES and can effectively prevent reflux of any gastric and duodenal content (13). It should be performed before severe damage of the esophageal mucosa with the development of complications occurs. Therefore it is important to identify patients with a defective LES at an early stage of mucosal damage.

Our study demonstrates that the analysis of the intraabdominal sphincter vector volume improves the evaluation of the defective LES compared with standard techniques, although in our series of patients a high sensitivity was also achieved with the usual stepwise pullback technique. In other studies the sensitivity of the stepwise pullback procedure was only 58% (4). However, in these studies the competence of the LES was defined only by means of the resting pressure, whereas in our study also the intraabdominal and overall sphincter length were taken into account to evaluate the competence of the LES. This may explain the higher sensitivity of the stepwise pullback technique seen in our series of patients compared with other studies.

The measurement of the sphincter vector volume using the motorized pullthrough technique was established by Bombeck *et al.* (5). In this study they demonstrated the effect of antireflux surgery on the sphincter vector volume. There was on average a 100-fold increase in the total sphincter vector volume, even in patients where the resting pressure of the LES decreased postoperatively. He furthermore demonstrated that, with analysis of the total sphincter vector volume, it is possible to predict accurately patients in whom medical therapy will eventually fail. Since Bombeck did not record respiration during the motorized pullback procedure, he could not identify the respiratory inversion point and was therefore unable to calculate the intraabdominal sphincter vector volume (ISVV). In our series of patients the analysis of the total sphincter vector volume was not superior to the usual stepwise pullback. This is due to the fact that, in the case of a hiatal hernia, the resting pressure of the lower esophageal sphincter may be still in the normal range and may therefore result in a normal total sphincter vector volume. However, in hiatal hernias the sphincter is dislocated into the chest and therefore has a decreased intraabdominal portion with a decreased intraabdominal sphincter vector volume. This indicates that the LES is incompetent if it is dislocated into the chest and it is the intraabdominal sphincter portion which mainly determines the sphincter function.

The analysis of the intraabdominal vector volume was introduced by Stein *et al.* (3). The procedure in this study was performed in a stepwise pullback fashion using catheters with four or eight channels in radially orientation at the tip. The manometry catheter was pulled through the sphincter at 1-cm intervals. At each point the cross-sectional sphincter pressure area was calculated and multiplied by 1 cm. The obtained 1-cm vector volume slices were then added. Since it is possible to identify the respiratory inversion point with the stepwise pullback technique, Stein was able to calculate the intraabdominal sphincter vector volume. However, he did not calculate the sensitivity and specificity of this procedure, therefore it is not known if this technique is an improvement in the evaluation of the defective LES. In our experience it is difficult accurately to pull back the catheter at 1-cm intervals in a stepwise fashion and therefore this technique may be prone to errors. Moreover, this procedure is tedious and time-consuming and therefore not recommendable for the practical use. Stein *et al.* also studied the motorized pullback technique, but as in Bombeck's series patients were not allowed to breathe and therefore the calculation of the intraabdominal sphincter vector volume was not possible using this procedure. In our study patients were allowed to breathe, enabling the calculation of the

intraabdominal sphincter vector volume. Our technique also takes into account the inspiratory pressure decrease in the intrathoracic sphincter portion and the inspiratory pressure increase in the intraabdominal sphincter portion, which influence the sphincter function to some degree. Stein *et al.* found that both the intraabdominal and the total sphincter vector volume decrease with the severity of esophagitis. In our series of patients there was no strong correlation between the grade of esophagitis and the sphincter vector volumes, suggesting that factors other than the sole sphincter function are determining the severity of esophagitis (14–16).

In summary we have found that calculation of the intraabdominal sphincter vector volume using the motorized pullback procedure with constant speed is a simple and reliable method to evaluate the defective LES. This technique is superior to the usual stepwise pullback procedure, calculating only the sphincter resting pressure and its overall and intraabdominal length, and it is also superior to the total sphincter vector volume.

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