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Manometry of the Lower Esophageal Sphincter

Inter- and Intraindividual Variability of Slow Motorized Pull-Through Versus Station Pull-Through Manometry

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The purpose of this study was to evaluate the interindividual and intraindividual variability of slow motorized pull-through lower esophageal sphincter (LES) manometry compared to standard station pull-through LES manometry to measure LES overall length, abdominal length, and pressure and to report normal values for the slow motorized pull-through method. The slow motorized pull-through had significantly smaller coefficient of variation, indicating closer agreement between different examiners in analyzing a given tracing. The correlation coefficients for each parameter in normal subjects and symptomatic patients was significantly higher when using slow motorized pull-through for both patients and normal subjects for all three parameters. The 5th percentile of normal values obtained from 41 volunteers for LES overall length, abdominal length, and pressure was 2.7 cm, 1.4 cm, 5.1 mm Hg, respectively. The results indicate that the slow motorized pull-through method is more reproducible than the standard station pull-through method both between different observers and when the same examiner measures the same tracing on two different occasions.

KEY WORDS: manometry; esophagus; esophagogastric junction; automatic data processing; gastrointestinal motility; gastroesophageal reflux.

The principal barrier protecting the esophagus from reflux of gastric juice is the lower esophageal sphincter (LES). Failure of the LES to exercise this protective function can occur in several ways. These include structural failure, when the resting resistance of the LES is subnormal, and dynamic failure, when the LES resistance transiently falls to zero in response to gastric distension. Hiatal herniation may alter the geometry of the LES and render it more likely to fail in the face of a gastric challenge (1).

The quantification of resting LES resistance depends on accurate assessment of the LES pressure, the length over which the pressure is exerted, and the length of the LES subjected to intraabdominal pressure. These three measurements, the pressure, overall length, and abdominal length, when found subnormal at manometry have been associated with a high prevalence of gastroesophageal reflux disease (2–4) and also to be predictive of more severe disease (5). The interpretation and analysis of manometric tracings of the LES are not automated and demand a lot of time and experience on the part of the analyst. Surprisingly, little attention has been paid to the agreement betwen experts in the analysis of LES records (6). We recently introduced a new method using a slow continuous motorized method to pull the catheter through the LES rather than the convetional stepwise (station pull-through) method (7). The perceived advantages of the slow motorized pull-through method include reduced discomfort for the patient, shorter performance time, and reduction in swallow-induced artifacts leading to clearer tracings more

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amenable to computer-assisted analysis. The subjective judgment required for conventional LES analysis creates the potential for two different sources of variability: differences between different observers analyzing the same tracing (interindividual variability) and the same observer analyzing the same tracing on two different occasions (intraindividual variability).

The purpose of this study was to evaluate the interindividual and intraindividual variability of slow motorized pull-through LES manometry compared to standard station pull-through LES manometry and to report normal values for the slow motorized pull-through method.

MATERIALS AND METHODS

To study the interindividual and intraindividual variability, 10 healthy asymptomatic volunteers (5 women, 5 men; median age 30, range 22–54) and 20 patients (12 women, 8 men; median age 42, range 24–73) with symptoms suggestive of gastroesophageal reflux disease (GERD) were studied by manometry and the tracings analyzed by five physicians experienced in esophageal manometry on two separate occasions. Patients with previous upper gastrointestinal surgery or with named motility disorders were excluded.

For establishment of normal ranges, a separate cohort of 41 healthy asymptomatic volunteers (14 women, 27 men; median age 28, range 20–57) underwent LES and esophageal manometry (LES manometry using both slow motorized pull-through and standard station pull-through) and 24-hr esophageal pH monitoring. The results were analyzed by the first author. All asymptomatic volunteers had normal 24-hr esophageal pH scores.

LES Manometry Study. Both slow motorized pull-through and station pull-through were performed in the same setting with the same catheter: a separate intubation was not required. A 12 French 8-channel water-perfused motility catheter (Arndorfer Medical Specialties, Greendale, Wisconsin, USA) was passed through the anesthetized nostril into the esophagus and into the stomach. The eight side holes on the catheter for each channel were arranged so that four were at the same level at 90° to each other, and the other four side holes were positioned at 5-cm intervals along the catheter, also at 90° to one another. The channels were perfused with sterile distilled water at a constant rate of 0.6 ml/min. Each channel was connected to an external pressure transducer positioned at the level of the midaxillary line and connected to an eight-channel recorder (PC Polygraf HR; Medtronic Synectics Medical, Minneapolis, Minnesota, USA).

Station Pull-Through. The catheter was pulled back in 1-cm steps as previously described until all side holes had passed from the stomach into the esophageal body. The four side holes at 5-cm intervals, and one of the circumferential side holes, were used, so that each parameter of the LES was the mean of five readings. The resting pressure, overall length, and abdominal length were measured as previously described (4).

Slow Motorized Pull-Through. The catheter was repositioned so that all side holes were in the stomach, and slowly pulled until the side hole 5 cm above the four cicumferential ports had entered the LES. The catheter was connected to a custom motorized puller that pulled it out at 1 mm/sec while the patient breathed normally. This took up to 90 sec to perform. The rate of the catheter movement was imperceptible to the patient. If the patient swallowed during this time, the procedure was repeated.

Tracing analysis was performed with the software Polygram Version 5.22 Upper GI Edition (Gastrosoft, Medtronic Synectics Medical) in which the analyst was required to mark the lower border of the LES (the breath in which the tracing first rose above gastric baseline in end-expiration) and the upper border of the LES (the first breath in which the tracing fell below esophageal baseline in end-expiration) for each channel. The respiratory inversion point (RIP) was defined as the first inspiration in which the pressure was decreased rather than increased and the analyst marked the end-expiratory pressure in the last breath before and the first breath after the RIP. The RIP for the sphincter as a whole was the first inspiration in which three of the four tracings showed a downward deflection with inspiration. The overall length was defined as the distance in millimeters between the upper and lower borders of the LES, and the abdominal length as the distance between the lower border and the RIP. When the analyst had marked these points on the computer screen, the overall length, abdominal length, and end-expiratory pressure were all calculated automatically by the software (Figure 1).

The tracings from each patient using each method were stored on computer. Five physicians experienced in motility analysis independently analyzed the results of the Slow Motorized Pull Through and the Stationary pull through for each subject. One week later, each physician analyzed the same tracings. The names of the subjects were removed from their records and the order of the subjects on the computer disk were scrambled to reduce bias due to recall of individual features from the first analysis.

Data Analysis. The three standard parameters (overall length, abdominal length, and pressure) were measured by each observer. The coefficient of variation between observers (interindividual variation) for each parameter was calculated for the slow motorized pull-through and the station pull-through methods. Intraindividual variation was expressed as the correlation between the value measured by each observer on the first occasion and the same parameter on the same tracing one week later, by calculating Spearman's correlation coefficient. Interindividual and intraindividual variation was calculated separately for normal subjects and symptomatic patients. Statistical significance was considered at the $\alpha \leq 0.05$ level.

The lower limit of normal was assessed using the 5th percentile based on the analysis of 41 normal volunteers.

RESULTS

Interobserver Variation. The coefficient of variation between each method demonstrating the agreement between examiners for each parameter is shown in Figure 2. For each parameter, the slow motorized pull-through had a significantly smaller coefficient of variation, indicating closer agreement between different examiners in analyzing a given tracing. In normal volunteers, the slow motorized pull-through was superior to the stationary pull through method due to a lesser variation in all

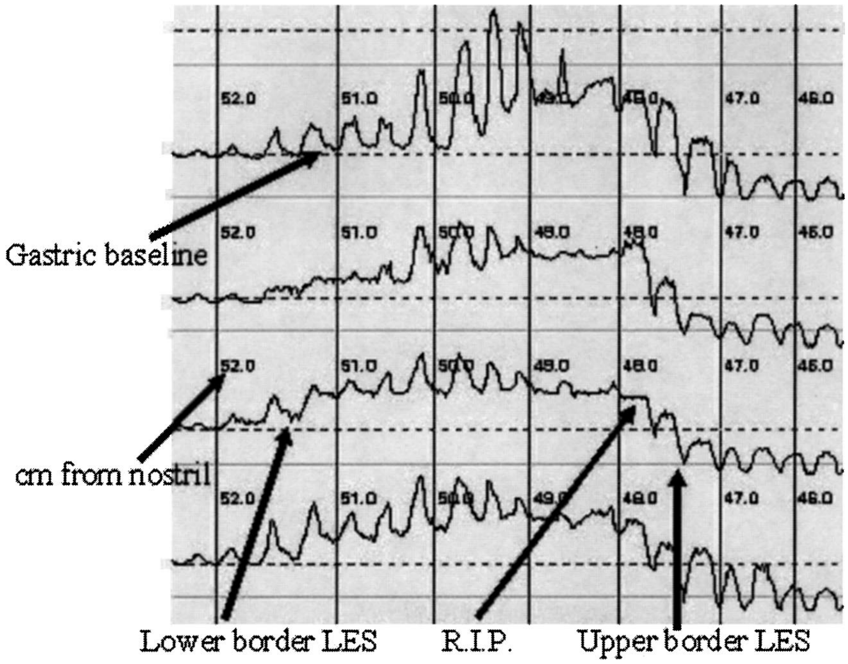

Fig 1. Slow motorized pull-through sample tracing. The examiner sets the baseline and identifies the respiratory inversion point and the lower and upper border of the LES in each channel. The software will automatically calculate LES pressure and abdominal and total length.

three measured parameters and when applied to patients the same advantage was observed for the parameters of pressure and abdominal length.

Intraobserver Variation. Correlation coefficients for each parameter in normal subjects and symptomatic patients when measured by slow motorized pull-through and station pull through manometry are shown in Figures 3–5. The agreement between the same examiner's assessments on two different occasions was significantly higher when using slow motorized pull-through for both patients and normal subjects for all three parameters.

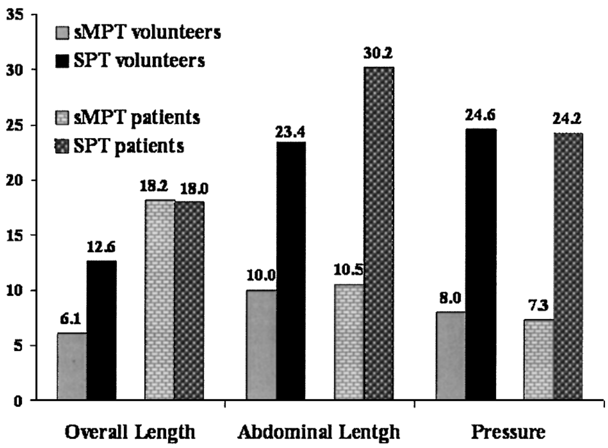

Fig 2. Interobserver variability: comparison of coefficient of variation for slow motorized pull-through and station pull-through in normal volunteers and in symptomatic patients.

Normal Ranges. Based on the measurement of 41 normal volunteers, normal values and ranges for the motorized pull through method are shown in Table 1. These closely approximate to the ranges published for the station pull-through method.

DISCUSSION

The results of this study clearly indicate that analysis of tracings obtained by the slow motorized pull-through method are more reproducible both between different observers and when the same examiner measures the same tracing on two different occasions. The differences were most marked when studying normal subjects, but even when studying patients with a wider spectrum of abnormalities, the slow motorized pull-through was superior.

These results were obtained despite taking less time to perform and less time to analyze than the standard station pull-through method. Patient comfort was also noticeably improved, since the slow rate of catheter

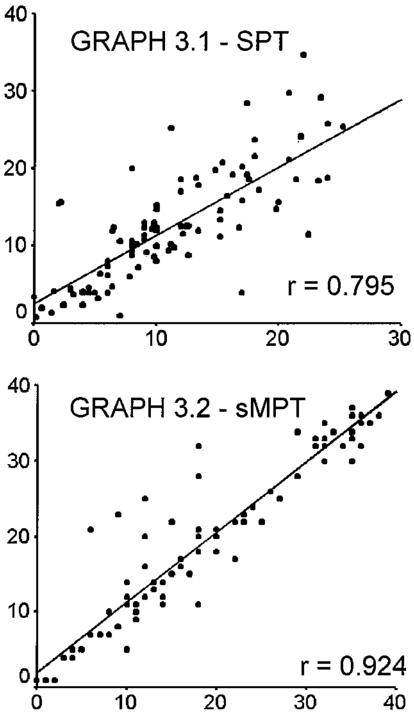

Fig 3. Intraobserver variation in LES pressure measurement for station pull-through (graph 3.1) vs Slow Motorized Pull Through (graph 3.2).

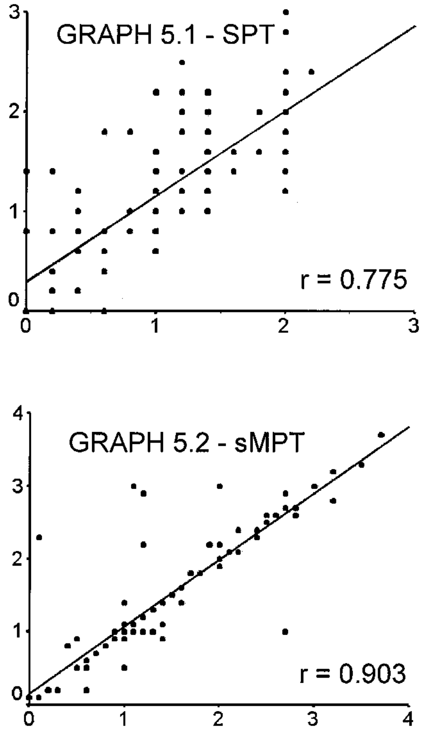

Fig 5. Intraobserver variation in LES abdominal length measurement for station pull through (graph 5.1) vs slow motorized pull-through (graph 5.2).

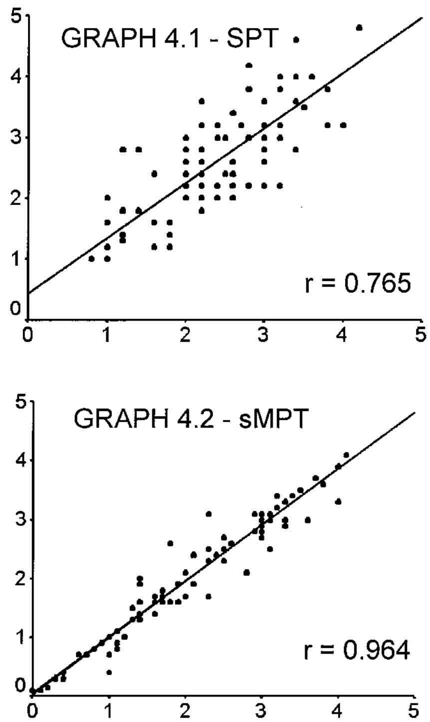

Fig 4. Intraobserver variation in LES overall length measurement for station pull through (graph 4.1) vs slow motorized pull-through (graph 4.2).

pull through created minimal stimulation to swallow, in contrast to the station pull-through when the patient often swallows as the catheter is retracted at each centimeter station.

It is important to distinguish the current method of slow motorized pull-through from the so-called rapid pull-through method popular in the 1980s. The latter method, despite its touted advantages, proved to be less reproducible than station pull-through (8). It gave no indication of diaphragmatic activity, did not allow the calculation of

TABLE 1. NORMAL RANGES: LES OVERALL LENGTH, ABDOMINAL LENGTH, MID-CYCLE PRESSURE, AND END-EXPIRATORY CYCLE PRESSURE, IN 41 NORMAL VOLUNTEERS

	Mean	*SD*	*Median*	*Min*	*Max*	*5th percentile*
Overall length (cm)	4.4	1.14	4.4	2.7	6.9	2.7
Abdominal length (cm)	3.0	1.09	2.9	1.1	5.4	1.4
Mid-respiratory pressure (mm Hg)	15.8	7.49	16	4.3	37	5.1
End-expiratory pressure (mm Hg)	18.8	8.89	18.3	5.3	41.3	6.7

intraabdominal length, and patient's breath holding was often inconstant. The current study of slow motorized pull-through allows the patient to breathe normally and the rate of catheter movement is so slow that it is quite imperceptible to the subject.

It is surprising that so few investigators have considered the potential sources of inaccuracy in motility tracings. Use of the Dent sleeve has indicated that the LES pressure varies considerably throughout the day, tending to change with posture and with the consumption of meals (9). The current study did not investigate variability of LES parameters when measured on different occasions. Rather, we concentrated on assessing the potential sources of error in analyzing a given record.

The importance of the LES resting parameters has been downgraded in the minds of some investigators who consider that transient loss of the reflux barrier, often described as transient lower esophageal sphincter relaxations, are the dominant mechanism permitting gastroesophageal reflux (10, 11). Adoption of this view regards the resting parameters of the LES as of minor relevance. However, it is established that the frequency of such transient loss of the reflux barrier is similar in normal subjects and patients with GERD, and consequently other mechanisms must be invoked to explain the increased esophageal acid exposure in patients with GERD. Reflux during prolonged hypotonia of the LES or in response to abrupt rises in intraabdominal pressure are two such potential mechanisms. These conditions are likely to apply in patients with reduced resting parameters of the LES, especially under conditions of LES stress such as after a meal. We recently showed that ingestion of carbonated beverages produced sustained reduction of LES pressure and length, often into the abnormal range (12). In addition, previous studies consistently indicated that defective LES pressure was associated with a poorer response to medical treatment (13–15) and is associated with more severe manifestations of GERD, such as Barretts esophagus (5). Consequently, a patient with GERD and a truly defective LES may be a good candidate to consider for surgical referral.

A further study of a large number of symptomatic patients is now being completed in our department. The utility of the new method in detecting abnormalities of significance will be assessed in this study. However, in view of the reduced time, cost, and discomfort in performing the study and the reduced variability in its analysis, the slow motorized pull-through method has the potential to replace conventional station pull-through in the study of LES function.

REFERENCES

1. Fein M, Ritter MP, DeMeester TR, Oberg S, Peters JH, Hagen JA, Bremner CG: Role of the lower esophageal sphincter and hiatal hernia in the pathogenesis of gastr oesophageal reflux disease. J Gastrointest Surg 4:405–410, 1999
2. O'Sullivan GC, DeMeester TR, Joelsson BE, Smith RB, Blough RR, Johnson LF, Skinner DB: Interaction of lower esophageal sphincter pressure and length of sphincter in the abdomen as determinants of gastroesophageal competence. Am J Surg 143:40–47, 1982
3. Bonavina L, Evander A, DeMeester TR, Walther B, Cheng S-C, Palazzo L, Concannon JL: Length of the distal esophageal sphincter and competency of the cardia. Am J Surg 151:25–34, 1986
4. Zaninotto G, DeMeester TR, Schwizer W, Johansson K-E, Cheng S-C: The lower esophageal sphincter in health and disease. Am J Surg 155:104–111, 1988
5. Campos GM, DeMeester SR, Peters JH, Oberg S, Crookes PF, Hagen JA, Bremner CG, Sillin LF 3rd, Mason RJ, DeMeester TR: Predictive factors of Barrett esophagus: multivariate analysis of 502 patients with gastroesophageal reflux disease. Arch Surg 136(11):1267–1273, 2001
6. Fox JE, Vidins EI. Beck IT: Observer variation in esophageal pressure assessment. Gastroenterology. 65:884–888, 1973
7. Campos GM, Crookes PF, Oberg S, Gastal OL, Theisen J, Nigro J, Bremner CG, Peters JH, DeMeester TR: A New standardized method for measurement of the lower esophageal sphincter. Gastroenterology 114:A730, 1998
8. Welch RW, Drake ST: Normal lower esophageal sphincter pressure: a comparison of rapid vs slow pull-through techniques. Gastroenterology 78:1446–1451, 1980
9. Schoeman MN, Tippet MD, Akkermans LM, Dent J, Holloway RH: Mechanisms of gastroesophageal reflux in ambulant healthy human subjects. Gastroenterology 108:83–91, 1995
10. Dent J, Dodds WJ, Friedman RH, Sekiguchi T, Hogan WJ, Arndorfer RC, Petrie DJ: Mechanism of gastroesophageal reflux in recumbent asymptomatic human subjects. J Clin Invest 65:256–267, 1980
11. Dodds WJ, Dent J, Hogan WJ, Helm JF, Hauser R, Patel GK, Egide MS: Mechanisms of gastroesophageal reflux in patients with reflux esophagitis. N. Engl J Med 307:1547–1552, 1982
12. Crookes PF, Hamoui N, Theisen J, Johansson J, Lord RV, Gastal O, Corkill S, DeMeester TR: Response of the lower esophageal sphincter to ingestion of carbonated beverages. Gastroenterology 116:A140, 1999
13. Liebermann DA: Medical therapy for chronic reflux esophagitis; long-term follow-up. Arch Intern Med 147:1717–1720, 1987
14. Kuster E, Ros D, Toledo-Pimental V, Pujol A, Bordas JM, Grande L, Pera C: Predictive factors of the long term outcome in gastro-oesophageal reflux disease: six year follow up of 107 patients. Gut 35:8–14, 1994
15. Costantini M, Zaninotto G, Anselmino M, Boccu C, Nicoletti L, Ancona E: The role of a defecive lower esophageal sphincter in the clinical outcome of treatment for gastroesophageal reflux disease. Arch Surg 131:659–659, 1996