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High-resolution manometry: Reliability of automated analysis of upper esophageal sphincter relaxation parameters

ESOPHAGUS

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Original Article

ABSTRACT

Background/Aims: At present, automated analysis of high-resolution manometry (HRM) provides details of upper esophageal sphincter (UES) relaxation parameters. The aim of this study was to assess the accuracy of automatic analysis of UES relaxation parameters.

Materials and Methods: One hundred and fifty three subjects (78 males, mean age 68.6 years, range 26-97) underwent HRM. UES relaxation parameters were interpreted twice, once visually (V) by two experts and once automatically (AS) using the ManoView ESO analysis software. Agreement between the two analysis methods was assessed using Bland-Altman plots and Lin's concordance correlation coefficient (CCC).

Results: The agreement between V and AS analyses of basal UES pressure (CCC 0.996; 95% confidence interval (CI) 0.994-0.997) and residual UES pressure (CCC 0.918; 95% CI 0.895-0.936) was good to excellent. Agreement for time to UES relaxation nadir (CCC 0.208; 95% CI 0.068-0.339) and UES relaxation duration (CCC 0.286; 95% CI 0.148-0.413) between V and AS analyses was poor. There was moderate agreement for recovery time of UES relaxation (CCC 0.522; 95% CI 0.397-0.627) and peak pharyngeal pressure (CCC 0.695; 95% CI 0.605-0.767) between V and AS analysis.

Conclusion: AS analysis was unreliable, especially regarding the time variables of UES relaxation. Due to the difference in the clinical interpretation of pharyngoesophageal dysfunction between V and AS analysis, the use of visual analysis is justified.

Keywords: Automatic analysis, human study, high-resolution manometry

INTRODUCTION

Oropharyngeal dysphagia (OPD) is significantly associated with nutritional deficiency and aspiration pneumonia, which can lead to death (1,2). A videofluoroscopic swallowing study (VFSS) is currently the most common clinical tool used to assess OPD (3). However, it does not allow for quantification of pharyngeal contractile forces or detection of incomplete upper esophageal sphincter (UES) relaxation. VFSS not only requires considerable examiner experience but is also not easy to interpret, particularly in terms of the timing of swallow onset and the adequacy of velopharyngeal apposition, laryngeal elevation, epiglottic tilt, pharyngeal contraction, and UES opening (4).

The pressure sensors used for high-resolution manometry (HRM) are placed close together (usually 1 cm apart), and therefore a greater number is required. Thus, HRM has an increased ability to accurately assess pharyngeal pressure events during swallowing (5). We have reported previously that HRM facilitates a comprehensive assessment of OPD mechanisms and aids in the recognition of subtle abnormalities not visible to the naked eye using VFSS (6). More recently, high-res-

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olution impedance manometry (HRIM) has been introduced; this technique combines the benefits of HRM and impedance-based bolus transit assessments. Several studies have reported the utility of high-resolution impedance manometry (HRIM) in the evaluation of OPD (7-15).

At present, automated HRM analysis provides information such as the mean basal UES pressure, mean residual UES pressure, UES relaxation time to nadir, UES relaxation duration, UES recovery time, and peak pharyngeal pressure. These parameters of UES relaxation could provide useful information for the management of OPD patients. However, the reliability of automated HRM analysis has not been assessed. Moreover, inaccurate analysis of UES relaxation parameters frequently occurs in the setting of incomplete UES relaxation, resulting in provision of misinformation to the clinician (16). Therefore, the aim of this study was to assess the reliability of automated HRM analysis of UES relaxation parameters in OPD. We also determined whether the presence of OPD or aspiration affects the reliability of automated analysis.

MATERIALS AND METHODS

Subjects

One hundred and fifty-three subjects (78 males, mean age 68.6 years, range 26-97) underwent HRM at Soonchunhyang University Seoul Hospital between January 2012 and June 2012. One hundred and twenty-two (79.7%) subjects had OPD symptoms. OPD symptoms included difficulty swallowing food or pills, a change in swallowing ability, coughing or choking when eating, shortness of breath during swallowing, food backing up into the mouth or nasal passage, fever or voice changes after swallowing, pain when swallowing, and unexplained weight loss. The remaining 31 subjects (20.3%) were asymptomatic and referred for assessment of normal HRIM UES relaxation parameters within the same period. The study protocol was approved by the Institutional Review Board of Soonchunhyang University Seoul Hospital, College of Medicine, Seoul, Korea.

All subjects underwent an HRM study by two independent examiners (LJS and LTH) after at least a 6-h fast. The HRM catheter was 4.2 mm in diameter, with 36 circumferential pressure sensors at 1-cm intervals and 18 impedance channels at 2-cm intervals (Given Imaging, Los Angeles, CA). The catheter was passed transnasally into the esophagus to a depth of 60 cm. The tip was in the cardia of the stomach, and the zero mark on the probe was located at the channel used for lower esophageal sphincter (LES) analysis. After 5 min of adaptation in the sitting position, subjects were asked to perform 10 saline swallows (5 mL each) at 20-s intervals.

Data analysis

Upper esophageal sphincter relaxation parameters were recorded using computer software (ManoScan™ system, Given Imaging, Los Angeles, CA) and analyzed twice, first automatically (AS) using the ManoView ESO version 3.0 software and then visually (V) by two experts (LTH and LJS). To improve the reliability of V analysis, a consensus reading was performed by two experts (THL and JSL), who had focused on study of UES disorders for 4 years.

The HRM files of each subject, which had been edited by the motility nurse, were reviewed by the two experts. The data were first corrected for thermal sensitivity using an internal compensation function. Spatial markers for the UES, LES upper and lower boundaries, and stomach were adjusted manually on the graphical display. A specialized window was used to determine the pressure inversion point. The software automatically placed markers at the beginning peak and the end of each esophageal peristaltic contraction wave. Each swallow was reviewed to ensure that the marker for esophageal peristaltic contraction was placed in an accurate position. Adjustments were made as required. The software assessed the UES relaxation parameters for each swallow automatically and provided a summary.

For visual analysis, the frames of each swallow were magnified either with the zoom button or by right clicking and dragging to the main display. Each swallow was reviewed using two display mode options to ensure that the markers of pharyngeal contraction and UES relaxation were positioned accurately. The two display mode options were "Enable Pressure Traces on Contour" and "Pressure Traces" (Figure 1). We then adjusted the locations of the Start (UES-1), Nadir (UES-2), and End Relaxation (UES-3) for UES and the Start (^{Upper}Pharynx-1 or ^{Lower}Pharynx-1), Peak (^{Upper}Pharynx-2 or ^{Lower}Pharynx-2), and End Waves (^{Upper}Pharynx-3 or ^{Lower}Pharynx-3) for the pharyngeal channel above the UES. Finally a summary of the UES relaxation parameter data was acquired.

The following parameters were examined: mean basal pressure, mean residual pressure, relaxation time to nadir, relaxation duration, recovery time, and peak pharyngeal pressure.

Types of pharyngeal and UES location marker errors

An error was defined as a change in the location markers of pharyngeal or UES relaxation in the swallow frame after visual analysis. The error was classified as type 1 to 4 based on etiology. In a type 1 error (Figure 2a), the incorrect positioning of the pharyngeal or UES wave marker on each swallow frame was due to a double or multiple swallow. Type 2 error (Figure 2b) was inaccurate positioning of a pharyngeal or UES marker due to a sudden change in UES pressure, such as belching. A type 3 error (Figure 2c) was identification of a different UES location in each swallowing frame. A type 4 error (Figure 2d) was one of unclear etiology.

Flexible endoscopic evaluation of swallowing (FEES) protocol

In all subjects, flexible endoscopic evaluation of swallowing (FEES) was performed by an experienced endoscopist

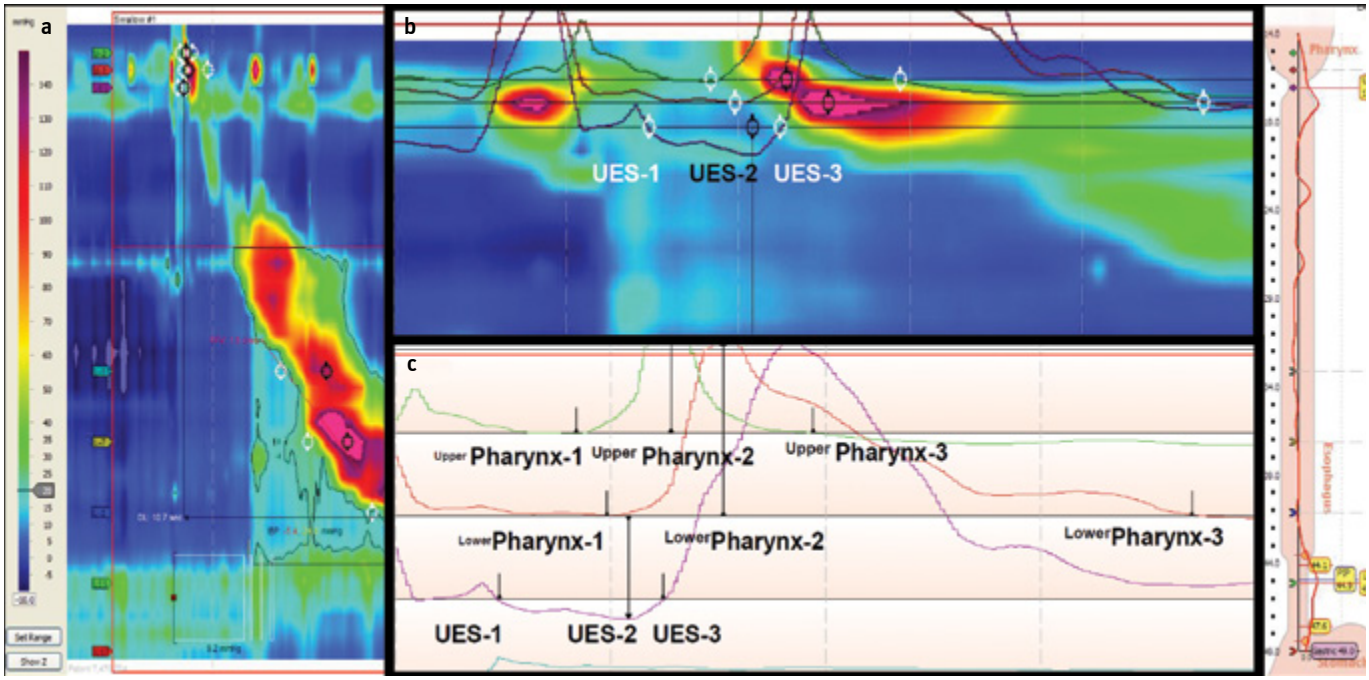

Figure 1. a-c. Visual analysis using two display modes in the magnified display. The main contour mode before magnification shows the location markers of UES relaxation and pharyngeal contraction. However, it is impossible to determine whether the markers are located appropriately **(a)**. In the "Enable Pressure Traces on Contour" display mode, the two upper empty, black circles are markers of peak pharyngeal contraction, and the lower empty, black circle is a marker of UES relaxation nadir **(b)**. In the "Pressure Traces" display mode, the Start (^{Upper}Pharynx-1 or ^{Lower}Pharynx-1), Peak (^{Upper}Pharynx-2 or ^{Lower}Pharynx-2), and End Waves (^{Upper}Pharynx-3 or ^{Lower}Pharynx-3) of the pharyngeal channel above the UES were reviewed to ensure the accurate location of the UES Start (UES-1), Nadir (UES-2), and End Relaxation (UES-3) **(c)**.

(THL). A thin video gastroscope (Olympus GIF-XP 260, Olympus, Tokyo, Japan), with a 6.5-mm insertion tube, 2.0-mm channel, and a working length of 1030 mm was used during FEES. The endoscope was inserted through the nostril and placed between the end of the soft palate and the epiglottis. The patient was then allowed a 1-min rest to adapt to the presence of the laryngoscope and prepare for testing. The examination consisted of an anatomic and physiologic assessment, including velar and laryngopharyngeal anatomy, movement, and sensation, and the direct examination of swallowing various test foods. When clinically indicated, an entire anatomic assessment of the esophagus and stomach was performed. For the FEES test diets, we first used 5 mL of yogurt to represent a viscous food, followed by 5 mL of indigo carmine dye mixed with water as a liquid food, which allowed for visualization during the FEES protocol adopted in the hospital. The entire clinical procedure was recorded on video for analysis by the endoscopist (THL). Original eight-point Penetration-Aspiration Scale (PAS)(17) considers not only invasive depth but also clearance and response. However, there are considerable difficulties in accurately determining elimination of the ingesta by the cough reflex. It is also unclear whether the different levels have clinically different meanings. It was necessary to facilitate statistical analysis and encourage observers to provide a definite statement. Therefore, we reconstructed the scale and redefined level 1 as normal, levels 2-5 as penetration (when material remained above the vocal cord or reached the vocal cord), and levels 6-8 as aspiration (when material passed the glottis).

Statistical analysis

Results were expressed as medians (interquartile range) and compared using the Wilcoxon signed-rank test. A p-value <0.05 was considered to indicate statistical significance. Agreement between the two methods of analysis (visual and automated) was evaluated using Lin's concordance correlation coefficient (CCC). A CCC value of 1 indicates perfect agreement, values <0.5 poor agreement, values of 0.5-0.7 moderate agreement, and values >0.7 good-to-excellent agreement (18).

Bland-Altman plots (19) were used to assess agreement between the two analysis methods. Briefly, for each subject the difference between the values of the two analysis methods is plotted on the y-axis and the mean of the two analysis methods on the x-axis. If the difference between the two analyses is small, data points are scattered close to the x-axis. Agreement between the two analysis methods is considered to be adequate when all data points are located within two standard deviations (SD), and the mean of differences is not significantly different from zero.

To assess whether OPD or aspiration affects the agreement between the two analysis methods, Lin's CCCs were evaluated based on the presence of OPD, liquid aspiration, or viscous aspiration. In subgroup analysis, the median rate of error was compared using Wilcoxon's signed-rank test.

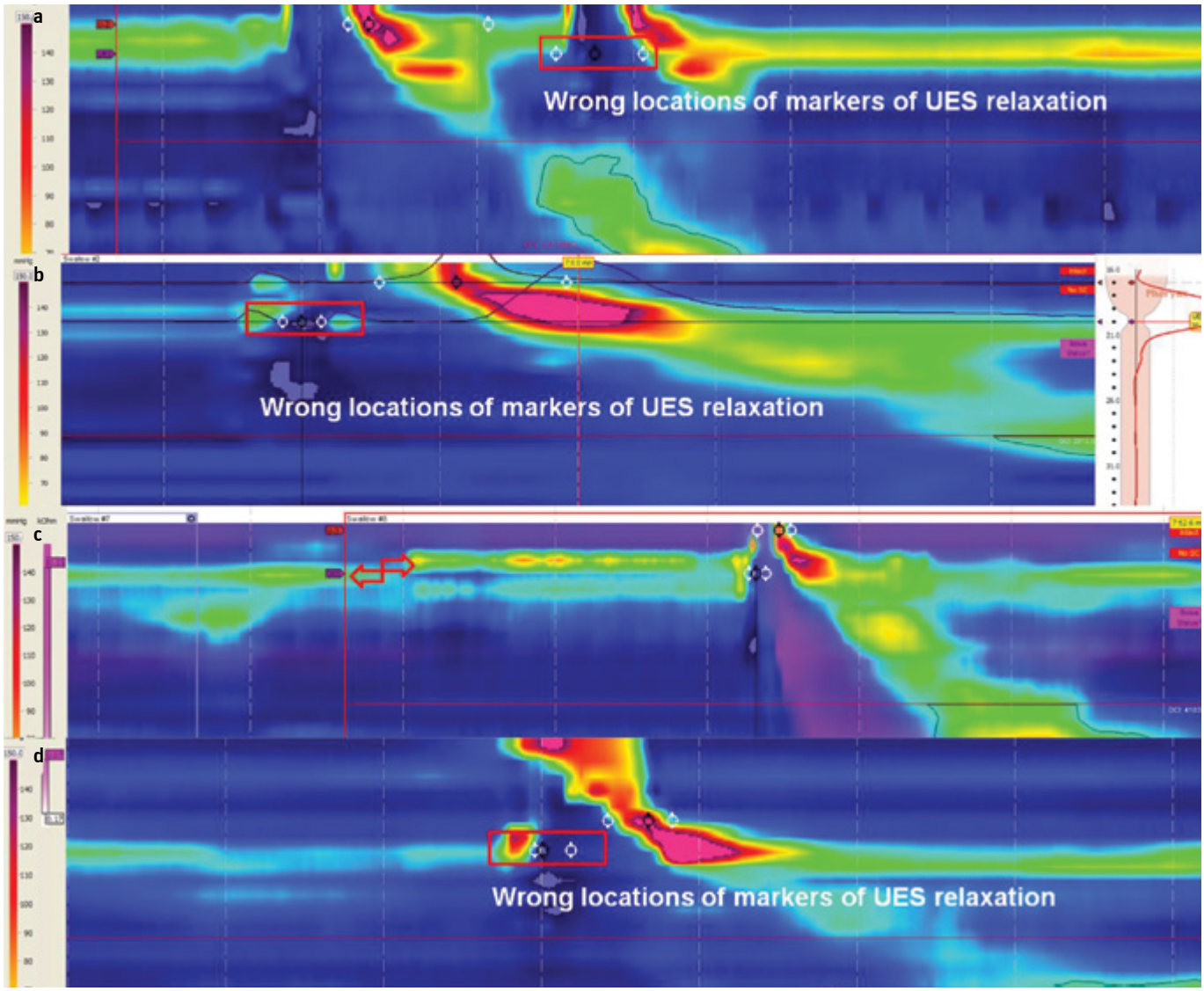

Figure 2. a-d. The four types of error in pharyngeal and UES markers. Incorrect location of the UES wave markers resulting from double swallow (type 1 error) **(a)**. Inaccurate location of the UES wave markers as a result of a sudden UES pressure change (type 2 error) **(b)**. Different location of the UES in each frame (see both red arrows), resulting in incorrect location of the UES wave markers (type 3 error) **(c)**.
Inappropriate location of the UES wave markers due to an unknown etiology (type 4 error) **(d)**.

Statistical analyses were performed using the SAS version 9.3 software (SAS Institute Inc., Cary, NC, USA). Bland-Altman plots were created using the MedCalc statistics software (version 13.0.2.0, MedCalc Software, Mariakerke, Belgium).

RESULTS

Agreement between visual and automated analysis

In all subjects, the agreement between V and AS analysis for basal UES pressure (CCC 0.996; 95% confidence interval (CI) 0.994-0.997) and residual UES pressure (CCC 0.918; 95% CI 0.895-0.936) was good to excellent (Table 1). Agreement for time to UES relaxation nadir (CCC 0.208; 95% CI 0.068-0.339) and UES relaxation duration (CCC 0.286; 95% CI 0.148-0.413) between V and AS analysis was poor. There was moderate agreement for recovery time of UES relaxation (CCC 0.522; 95% CI 0.397-0.627) and peak pharyngeal pressure (CCC 0.695; 95% CI 0.605-0.767) between V and AS analysis.

Figure 3 shows the Bland-Altman plots for UES relaxation parameters in all subjects. The 95% limits of agreement were -3.7 and 3.7 for basal UES pressure (Figure 3a) and -7.5 to 5.1 for residual UES pressure (Figure 3b). Basal UES pressure and residual UES pressure values determined by both analysis methods lie between the upper and lower 95% limits of agreement, indicating good-to-excellent agreement. The 95% limits of agreement for UES relaxation time to nadir were -0.34 and .44, (Figure 3c) and -0.54 to 0.63 for UES relaxation duration (Figure 3d). In contrast to basal and residual UES pressure, the values for UES relaxation time to nadir and UES relaxation duration basal lay beyond the 95% limits of agreement. The 95% limits of agreement for the recovery time of UES relaxation duration were

-0.37 and 0.35 (Figure 3e), and the 95% limits of agreement for peak pharyngeal pressure were -109.3 and 127.3 (Figure 3f).

Subgroup analysis based on the presence of OPD

When subgroup analysis was performed according to the presence of OPD (Table 1), the controls had good-to-excellent agreement in all parameters, with the exception of peak pharyngeal pressure (CCC 0.168; 95% CI -0.135-0.442). In OPD patients, good-to-excellent agreement was observed for basal UES pressure, residual UES pressure, and peak pharyngeal pressure. Moderate agreement was observed for recovery time of UES relaxation in OPD patients, and poor agreement was observed for UES relaxation time to nadir and UES relaxation duration.

Subgroup analysis based on the presence of aspiration

Agreement between the two analysis methods in the presence of aspiration during FEES is shown in Table 2. In subjects without liquid aspiration, good-to-excellent agreement was observed in all parameters, with the exception of peak pharyngeal pressure (CCC 0.605; 95% CI 0.456-0.720). However, in subjects with liquid aspiration, all parameters demonstrated poor agreement between the two analysis methods, with the exception of peak pharyngeal pressure (CCC 0.751; 95% CI 0.629-0.838).

In subjects without viscous aspiration, good-to-excellent agreement was noted for basal UES pressure (CCC 0.996; 95% CI 0.995-0.998) and residual UES pressure (CCC 0.939; 95% CI 0.915-0.957). The remaining parameters had moderate agreements between the two analysis methods. In subjects with viscous aspiration, poor agreement was observed for UES relaxation time to nadir (CCC 0.037; 95% CI -0.219-0.288), UES relaxation duration (CCC 0.029; 95% CI -0.170-0.225), and recovery time of UES relaxation (CCC 0.090; 95% CI -0.200-0.365), but agreement was good-to-excellent for all remaining parameters.

Table 1. Agreement between automated and visual analysis in all subjects (controls and patients with oropharyngeal dysphagia)

		AS analysis			V analysis			p value	Concordance correlation coefficient (95% CI)		
Basal UES pressure (mmHg)											
Total		25.80	[14.80	41.20]	26.90	[14.10	42.30]	0.879	0.996	(0.994	0.997)
	Control	41.20	[24.60	53.20]	42.30	[25.20	53.20]	0.250	0.999	(0.997	0.999)
	OPD	23.85	[12.80	34.50]	24.05	[12.80	34.50]	0.602	0.995	(0.992	0.996)
Residual UES pressure (mmHg)											
Total		-1.60	-[4.80	2.00]	-0.90	-[4.50	2.90]	<0.001	0.918	(0.895	0.936)
	Control	-0.90	-[3.70	1.90]	-0.70	-[3.80	2.30]	0.033	0.974	(0.947	0.987)
	OPD	-1.80	-[5.20	2.30]	-1.15	-[4.80	3.30]	<0.001	0.915	(0.888	0.935)
UES relaxation time to nadir (s)											
Total		0.17	[0.10	0.25]	0.15	[0.10	0.22]	<0.001	0.208	(0.068	0.340)
	Control	0.20	[0.09	0.24]	0.19	[0.10	0.24]	0.197	0.802	(0.650	0.892)
	OPD	0.16	[0.10	0.26]	0.15	[0.10	0.22]	<0.001	0.171	(0.014	0.320)
UES relaxation duration (s)											
Total		0.58	[0.42	0.74]	0.57	[0.44	0.69]	0.439	0.286	(0.148	0.413)
	Control	0.57	[0.48	0.78]	0.60	[0.48	0.78]	0.626	0.729	(0.525	0.854)
	OPD	0.58	[0.38	0.73]	0.55	[0.40	0.67]	0.323	0.234	(0.078	0.378)
Recover duration of UES (s)											
Total		0.36	[0.26	0.51]	0.38	[0.26	0.53]	0.844	0.522	(0.397	0.627)
	Control	0.41	[0.28	0.61]	0.44	[0.28	0.65]	0.502	0.889	(0.784	0.944)
	OPD	0.36	[0.26	0.51]	0.37	[0.25	0.52]	0.939	0.418	(0.261	0.553)
Pharynx peak pressure (mmHg)											
Total		154.90	[107.10	204.40]	150.10	[102.40	202.20]	0.083	0.695	(0.605	0.768)
	Control	153.20	[109.00	194.90]	147.90	[108.70	184.80]	0.129	0.168	-(0.135	0.442)
	OPD	154.90	[101.90	207.80]	154.15	[97.60	205.20]	0.207	0.803	(0.731	0.858)

AS: automated; V: visual; OPD: oropharyngeal dysphagia; UES: upper esophageal sphincter; CI: confidence interval
Values are medians (interquartile range).
p value by Wilcoxon signed-rank test.

Table 2. Agreement between automated and visual analysis with liquid or viscous aspiration during a flexible endoscopic swallow study

		AS analysis			V analysis			p value	Concordance correlation coefficient (95% CI)		
Basal UES pressure (mmHg)											
Aspiration liquid											
	None	30.00	[17.95	43.20]	30.00	[17.95	43.55]	0.219	0.998	(0.997	0.999)
	Present	23.30	[12.60	34.80]	24.00	[11.90	34.80]	0.636	0.993	(0.988	0.995)
Aspiration viscous											
	None	28.05	[17.00	43.20]	28.65	[16.40	43.20]	0.275	0.996	(0.995	0.998)
	Present	24.00	[10.50	33.80]	24.00	[10.00	33.80]	0.262	0.994	(0.989	0.997)
Residual UES pressure (mmHg)											
Aspiration liquid											
	None	-1.95	-[4.50	0.85]	-1.20	-[4.30	1.25]	<0.001	0.938	(0.910	0.957)
	Present	-1.10	-[5.20	5.30]	-0.40	-[4.80	5.90]	<0.001	0.906	(0.870	0.935)
Aspiration viscous											
	None	-2.35	-[5.20	0.90]	-1.50	-[5.20	1.80]	<0.001	0.939	(0.915	0.957)
	Present	0.80	-[4.30	8.80]	3.00	-[2.30	9.70]	<0.001	0.884	(0.819	0.927)
UES relaxation time to nadir (s)											
Aspiration liquid											
	None	0.16	[0.10	0.24]	0.16	[0.11	0.23]	0.170	0.765	(0.662	0.839)
	Present	0.17	[0.11	0.26]	0.13	[0.09	0.19]	<0.001	0.044	-(0.153	0.236)
Aspiration viscous											
	None	0.16	[0.10	0.24]	0.16	[0.10	0.22]	0.103	0.467	(0.327	0.587)
	Present	0.20	[0.11	0.35]	0.13	[0.09	0.22]	<0.001	0.037	-(0.219	0.288)
UES Relaxation duration (s)											
Aspiration liquid											
	None	0.59	[0.45	0.76]	0.61	[0.49	0.75]	0.311	0.709	(0.591	0.797)
	Present	0.55	[0.35	0.73]	0.49	[0.35	0.60]	0.058	0.002	-(0.180	0.184)
Aspiration viscous											
	None	0.58	[0.43	0.73]	0.61	[0.48	0.72]	0.175	0.563	(0.431	0.672)
	Present	0.55	[0.35	0.84]	0.42	[0.30	0.58]	0.007	0.029	-(0.170	0.225)
Recover duration of UES (s)											
Aspiration liquid											
	None	0.40	[0.30	0.57]	0.44	[0.31	0.59]	0.170	0.758	(0.653	0.835)
	Present	0.34	[0.21	0.46]	0.35	[0.21	0.43]	0.421	0.120	-(0.117	0.344)
Aspiration viscous											
	None	0.40	[0.28	0.52]	0.43	[0.30	0.58]	0.101	0.637	(0.515	0.733)
	Present	0.34	[0.20	0.44]	0.30	[0.19	0.38]	0.065	0.090	-(0.200	0.365)
Pharynx peak pressure (mmHg)											
Aspiration liquid											
	None	153.05	[108.85	189.75]	144.65	[108.40	192.20]	0.358	0.605	(0.456	0.720)
	Present	164.90	[101.90	224.30]	156.70	[97.60	207.40]	0.175	0.751	(0.629	0.838)
Aspiration viscous											
	None	154.90	[108.60	209.00]	151.50	[109.00	202.20]	0.177	0.669	(0.555	0.758)
	Present	153.70	[93.30	195.10]	142.70	[72.50	204.40]	0.261	0.731	(0.558	0.843)

Values are medians (interquartile range).
AS: automated; V: visual; UES: upper esophageal sphincter; CI: confidence interval

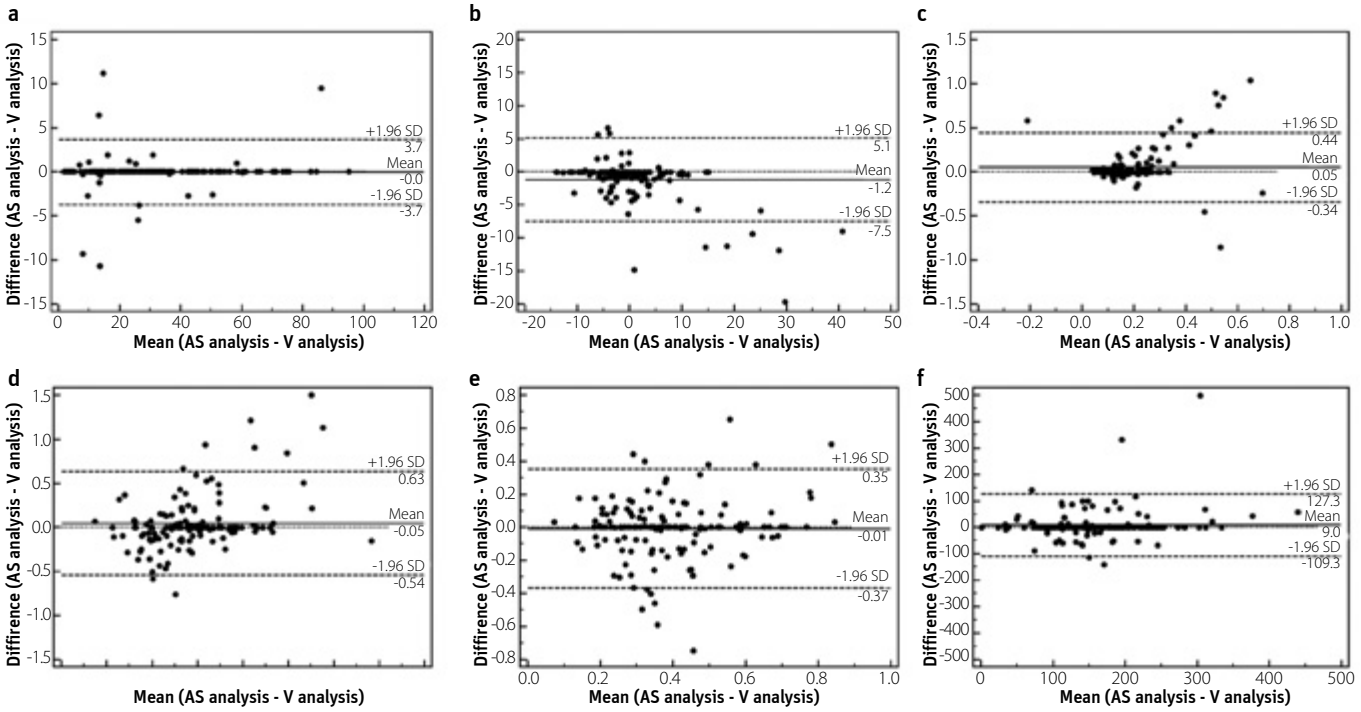

Figure 3. a-f. Bland-Altman representation of the agreement between visual (V) and automated (AS) analysis. Agreement between V and AS analysis for the measurement of basal UES pressure **(a)**, mean residual UES pressure **(b)**, UES relaxation time to nadir **(c)**, UES relaxation duration **(d)**, UES recovery duration **(e)**, and peak pharyngeal pressure **(f)**. For each subject, the graph reports the mean of the values determined by the two analysis methods, as well as the difference between these vales. The heavy lines represent the difference between the values determined by the two analysis methods, and the broken lines represent the means ±1.96 SD of the two values.

Errors in the localization of pharyngeal and UES wave markers

The median rate of errors in pharyngeal and UES location markers was 60% in all subjects. No errors were observed in 37 (24.2%) subjects. The most common type of error was type 2 (41.8%; 64/153), followed by type 4 (26.1%; 40/153), type 3 (19.6%; 30/153), and type 1 (15.0%) errors. The rate of error was significantly higher in OPD patients (median 80%) than controls (median 10%) ($p<0.0001$). The rate of error was significantly higher in subjects with liquid aspiration (median 90%) than in those without (median 40%) ($p=0.021$). The rate of error was significantly higher in subjects with viscous aspiration (median 100%) than in those without (median 40%) ($p=0.001$).

DISCUSSION

This was the first large study to assess the reliability of automated HRM UES relaxation parameter analysis in controls and OPD patients. The results of the present study are important because of the increased role of HRM in the assessment of pharyngoesophageal dysfunction.

Mielens et al. (12) reported a strong correlation between data extracted with automated and manual methods in 12 control and 3 OPD patients, and they believed that automated analysis of pharyngeal and UES manometry would be valuable. However, it should be noted that the automated analysis used by Mielens et al. (12) is not feasible with the current HRM software system, because their analysis used the MATLAB software. In that study, the HRM protocol was similar to our modified method (6), during which the HRM catheter is pulled back 10 cm for the assessment of the entire pharyngoesophageal segment. HRM findings in the segment were also not addressed according to the current Chicago classification criteria (20). Therefore, the automated analysis incorporated in the current HRM software might be valuable for the evaluation of pharyngoesophageal dysfunction in clinical practice, and knowledge of the reliability of automated analysis by the HRM software package is important.

In the current study, the agreement between V and AS analyses for UES relaxation time to nadir and UES relaxation was poor. Moderate agreement for recovery time of UES relaxation and peak pharyngeal pressure was observed. Importantly, the number of UES relaxation parameters with poor agreement was greater in OPD patients, compared to controls. The number of UES relaxation parameters with poor agreement was also greater in subjects with aspiration compared to those without. The median rate of error was also higher in subjects with OPD, liquid aspiration, or viscous aspiration, compared to those without. These results indicate that automated analysis is unreliable, especially in patients with suspected pharyngoesophageal dysfunction.

The results of the present study were not surprising, because abnormal HRM contours are observed more frequently in OPD patients. Also, the incorrect location of pharyngeal and UES

markers is frequently observed in patients with incomplete UES relaxation. Therefore, automated analysis can provide misinformation, especially regarding UES relaxation duration, since correct adjustment of UES wave markers is difficult in these patients.

A new approach to quantitative assessment of UES relaxation should be considered. Previously we reported that using isobaric contours of 20 mmHg might provide more robust localization of wave markers and provide additional information regarding UES relaxation measurements.(16) The duration of UES relaxation seems to correlate well with the "UES relaxation interval isobaric 20 mmHg", which is defined as the shortest horizontal distance from the ending contour of pre-swallow UES peak to the starting contour of post-swallow UES peak. However, the clinical usefulness of "UES relaxation interval isobaric 20 mmHg" should be validated by additional large studies.

In conclusion, automated HRM UES relaxation parameter analysis is not accurate, especially in patients with OPD or aspiration, and therefore, visual analysis is mandatory in the assessment of pharyngoesophageal dysfunction.

Ethics Committee Approval: Ethics committee approval was received for this study from Institutional Review Board of Soonchunhyang University Seoul Hospital.

Informed Consent: Written informed consent was obtained from patients who participated in this study.

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