Dysphagia (2011) 26:392–398
DOI 10.1007/s00455-011-9325-5

ORIGINAL ARTICLE

Kinematic Analysis of Dysphagia: Significant Parameters of Aspiration Related to Bolus Viscosity

Kyoung Hyo Choi · Ju Seok Ryu · Min Young Kim · Jin Young Kang · Seung Don Yoo

Received: 1 September 2010 / Accepted: 5 January 2011 / Published online: 26 January 2011
© Springer Science+Business Media, LLC 2011

Abstract The purpose of this study was to investigate the mechanisms of aspiration with respect to the viscosity of ingested material in patients with dysphagia. Seventy patients with dysphagia underwent videofluoroscopic swallow studies (VFSS) between May 1, 2009 and September 30, 2009. Based on the findings of the VFSS, patients were divided into three groups: a thick-fluid aspiration group, a thin-fluid aspiration group, and a no-aspiration group. Kinematic analyses were performed during thick-fluid swallowing. Among our 70 patients, 23 had thick-fluid aspiration, 20 had thin-fluid aspiration, and 27 had no aspiration. A shortened duration of upper esophageal sphincter (UES) opening, a shorter interval between UES opening and peak pharyngeal constriction, and a diminished extent of laryngeal elevation were all significant risk factors for thick-fluid aspiration. A prolonged latency of the swallowing reflex, pharyngeal transit time, and the interval between bolus arrival at the vallecula and laryngeal elevation were all significant risk factors for thin-fluid aspiration. Our kinematic analysis of dysphagia employing the VFSS indicated that the mechanisms relevant to aspiration differed with respect to food viscosity.

Keywords Swallowing · Bolus viscosity · Kinematic analysis · Videofluoroscopic swallowing study · Deglutition · Deglutition disorders

K. H. Choi
Department of Rehabilitation Medicine, University of Ulsan College of Medicine, Songpa-ku, Seoul 138-736, Korea

J. S. Ryu (✉) · M. Y. Kim · J. Y. Kang
Department of Rehabilitation Medicine, CHA Bundang Medical Center, CHA University, 351 Yatap-dong, Bundang-gu, Seongnam-si, Gyeonggi-do 463-712, Korea
e-mail: jseok337@cha.ac.kr

S. D. Yoo
Department of Physical Medicine and Rehabilitation, Kyung Hee University College of Medicine, Dongdaemun-gu, Seoul 130-701, Korea

A videofluoroscopic swallow study (VFSS), an X-ray-based analysis of swallowing function, is a well-established tool used to analyze swallowing function in patients with dysphagia. The kinematic analysis provided by VFSS can reveal subtle abnormalities of swallowing and allows improved data interpretation [1]. Moreover, VFSS provides objective data permitting meaningful comparisons between the swallowing function of normal and abnormal subjects, between groups of patients, and for an individual patient studied at different times.

Previous kinematic analyses of swallowing in normal subjects have documented differences in oropharyngeal muscle activity and pressure changes as bolus viscosity varied, but few studies have explored changes in the timing and extent of swallowing gestures as they relate directly to bolus transit [2, 3]. Most previous reports on kinematic analysis of VFSS focused on normative data, but published research has not been based on VFSS for identifying pathophysiologic features [2, 4, 5]. For example, Kendall et al. [1] analyzed, in detail, the timing of bolus pharyngeal transit, soft palate elevation, aryepiglottic fold elevation, supraglottic closure, arrival of the bolus in the vallecula, hyoid bone displacement onset and duration, arrival of the bolus at the pharyngoesophageal sphincter, maximum pharyngeal constriction, and pharyngoesophageal sphincter opening. However, they did not study any of the pathophysiology of dysphagia, the causes of aspiration, or differences in aspiration with variation in food viscosity.

In the present study, we compare the kinematics of a no-aspiration group, a thick-fluid aspiration group, and a thin-fluid aspiration group to identify clinically significant measures that can be used to identify such patients. We expect that data obtained from our analysis of 21 swallowing parameters will provide insight into the pathophysiology of dysphagia and that identification of the most significant parameters of aspiration related to bolus viscosity will allow better identification and evaluation of patients with dysphagia.

Methods

Participants

Our study was a prospective observational project conducted between May 1, 2009, and September 30, 2009. A total of 132 patients underwent VFSS at a tertiary hospital for evaluation of dysphagia. The study protocol was approved by the Institutional Review Board of the Bundang Cha Hospital. All participating patients provided written informed consent.

All initially enrolled patients suffered from dysphagia, had evaluable VFSS, had stable vital signs, and were physically able to participate in our study. We excluded patients with severe cognitive dysfunctions, serious psychiatric disorders, younger than 20 years, had cervical surgery, and were uncooperative for various reasons. Many patients were evaluated more than once, and only the results from the first examination are included in the present analysis. Causes of exclusion were nonvisualization of VFSS ($n = 3$), incomplete evaluation ($n = 12$), abnormal posture (such as chin-down or chin-up) ($n = 12$), cognitive dysfunction ($n = 18$), cervical fusion surgery ($n = 3$), and complete cricopharyngeal dysfunction ($n = 4$).

Methods

Thick fluid (viscosity $>$ 1750 cP), dysphagia I (viscosity range = 351-1750 cP, pureed diet), dysphagia II (same viscosity, mechanically altered), dysphagia III (same viscosity, regular texture), nectar like (51-350 cP), and thin fluid (1-50 cP) boluses were swallowed sequentially [6, 7]. Each subject received one 3-ml bolus, followed by two boluses each of 5 ml. Fluid (thick, nectar like, and thin) was delivered using 10-ml syringes, whereas patients with dysphagia of grades I, II, and III were fed using spoons. Patients were asked to hold the liquid briefly in the oral cavity before swallowing on command. Artificial inflation in tracheostomy patients was discontinued during VFSS. The patients swallowed a thick-fluid bolus first. If any patient demonstrated aspiration with this first bolus category, the study was stopped and no further trials with boluses of other consistencies were done. The patients that aspirated on this first bolus category were grouped together into the thick-fluid aspiration group (Rosenbek penetration-aspiration scale: 6, 7, 8). If the patient did not aspirate on the thick fluid, he/she was given thin fluid. Those that aspirated on the thin fluid were grouped as thin-fluid aspiration group (Rosenbek penetration-aspiration scale: 6, 7, 8) and those that did not aspirate at all were grouped into a no-aspiration group (Rosenbek penetration aspiration scale: 1, 2, 3, 4, 5) [8].

The thick-fluid aspiration group included patients with dysphagia after ingestion of thick fluid, dysphagia I, II, and III, and showed accumulation of fluid below the vocal cords. The thin-fluid aspiration group included patients who, after ingestion, showed a pool composed of both thin and honey-like fluid below the vocal cords. The no-aspiration group comprised patients in whom no ingested material was evident below the vocal cords.

Figure 1 shows the swallowing processes of a normal person, i.e., one without dysphagia [1, 9]. The definition of the pharyngeal phase varies in different studies [1, 10]; we used the posterior nasal spine as a landmark for the beginning of the pharyngeal phase of a swallow, and closure of the pharyngoesophageal sphincter (PES), with entrance of the bolus tail into the esophagus, as the end point of the pharyngeal phase [1, 9]. The larynx is visible on a lateral projection of a radiograph because of the hypodensity of the tracheal air column. Thus, it is possible to identify when the vocal cord begins to elevate [2, 6]. The latency of laryngeal elevation is defined as the time from the initiation of the pharyngeal phase to the initiation of laryngeal elevation. Peak laryngeal elevation is defined by measuring the point of maximal anterior and superior excursion of the larynx during a swallow [5]. It is also possible to identify the constriction of the pharyngeal wall and the soft palate. The latency of pharyngeal constriction is defined as the time from the initiation of the pharyngeal phase to the initiation of constriction of the pharyngeal wall and the soft palate. As the bolus is propelled into the upper esophagus, the pharynx is typically completely obliterated by the tongue, which pushes against the contracting posterior pharyngeal wall. The peak pharyngeal constriction is the narrowest observed anterior-posterior diameter, as measured in a lateral view [11]. The upper esophageal sphincter (UES) opening was identified as the moment at which the narrowest part of the upper esophagus between C4 and C6 opened, because this opening is functionally the most significant [1, 12, 13].

To account for magnification during fluoroscopy, a token (23 mm in diameter) was placed under the mandible to measure the extent of laryngeal elevation, which was assessed at the midportion of the vocal cord.

We measured various time intervals during the swallowing process (pharyngeal phase), including that

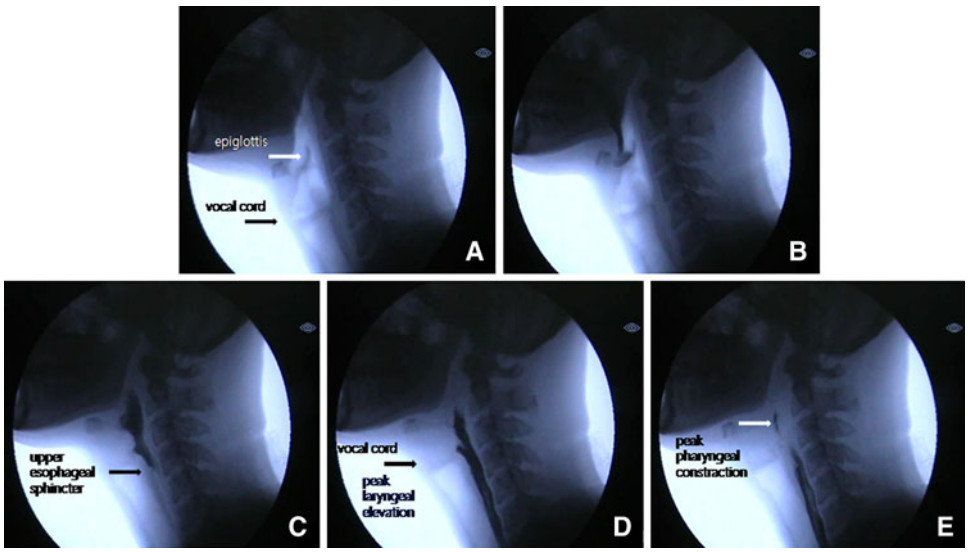

Fig. 1 Swallowing processes of a normal person. **a** Initiation of pharyngeal phase. **b** Latency of epiglottis contact. **c** Latency of UES opening. **d** Latency of peak laryngeal elevation. **e** Latency of peak pharyngeal constriction

of epiglottis contact with the bolus, laryngeal elevation, pharyngeal constriction, and UES opening. Thus, 21 variables were measured in the present study (Table 1).

VFSS was recorded using a camcorder (Samsung SMX-C14®) running at 30 frames per second [3]. The images were saved on a personal computer and analyzed by one of the authors on a multimedia player (Gomplayer; Gretech®); this author was blinded to subject identity. Timing measures were reported in 1/100 s. Kinematic analyses were performed among the three groups by swallowing 5 cc of thick fluid to minimize the effect of viscosity and volume.

Statistical Analysis

SPSS for Windows 12.0 (SPSS Inc., Chicago, IL) was used for statistical analysis. Initial comparisons were performed

Table 1 Abbreviations and definitions

Variables	Definition
LEC	Interval between the initiation of pharyngeal phase and epiglottis contact (arrival at vallecula)
LLE	Interval between the initiation of pharyngeal phase and the initiation of laryngeal elevation
LPC	Interval between the initiation of pharyngeal phase and the initiation of pharyngeal contraction
LUEO	Interval between the initiation of pharyngeal phase and the initiation of UES opening
LPLE	Interval between the initiation of pharyngeal phase and the peak laryngeal elevation
LPPC	Interval between the initiation of pharyngeal phase and the peak pharyngeal contraction
PTT	Interval between the initiation of pharyngeal phase and closure of pharyngoesohageal sphincter
LLE-LEC	Interval between latency of epiglottis contact and latency of laryngeal elevation
LPC-LLE	Interval between latency of laryngeal elevation and latency of pharyngeal contraction
LPPC-LLE	Interval between latency of laryngeal elevation and latency of peak pharyngeal contraction
LUEO-LLE	Interval between latency of laryngeal elevation and latency of UES opening
LPLE-LPC	Interval between latency of pharyngeal contraction and latency of peak laryngeal elevation
LPPC-LPLE	Interval between latency of peak laryngeal elevation and latency of peak pharyngeal contraction
LPLE-LUEO	Interval between latency of UES opening and latency of peak laryngeal elevation
LPLE-LLE	Rise time of laryngeal elevation
DLE	Interval between the initiation and the end of laryngeal elevation
LPPC-LPC	Rise time of pharyngeal contraction
DUEO	Interval between the opening and closing of UES opening
LUEO-LPC	Interval between latency of pharyngeal contraction and latency of UES opening
LUEO-LPPC	Interval between latency of peak pharyngeal contraction and latency of UES opening
DisLE	Extent of laryngeal elevation

among the three groups. Data are expressed as mean ± standard deviation. Data were analyzed by multifactorial analysis of variance (ANOVA). Post-hoc paired comparisons were performed using Tukey's and/or Duncan's adjustment for multiple comparisons. A $p \leq 0.05$ was considered statistically significant. An interrater reliability test was not necessary because all analyses were performed by a single author. Intrarater reliability was established over ten swallowing studies and was over 90% for each measure assessed.

Results

A total of 70 patients (41 men, 29 women; average age = 67.8 ± 14.1 years) were enrolled in the study. Among these 70 patients, the etiologies of dysphagia were stroke ($n = 60$), brain tumor ($n = 1$), otolaryngologic disorder ($n = 2$), Parkinson's disease ($n = 2$), and other medical diseases ($n = 5$) (Table 2). Of the 60 stroke patients, the average time since the stroke was 683 ± 1661 days. Nineteen were evaluated within 1 month of stroke, 16 between 1 and 3 months, and 25 patients later than 3 months.

A total of 23 patients showed aspiration with thick fluid during VFSS and were placed in the thick-fluid aspiration group, 20 demonstrated aspiration with thin fluid during VFSS and were placed in the thin-fluid aspiration group, and 27 had no aspiration with either thick or thin fluid and were placed in the no-aspiration group.

Table 3 defines the 21 measured variables. LLE, LPC, LUEO, LPLE, LPPC, PTT, LLE-LEC, DUEO, LUEO-LPPC, and DisLE differed significantly among the three groups ($p < 0.05$). Further analysis indicated that DUEO varied significantly between the thick-fluid aspiration group and the no-aspiration group, whereas both LUEO-LPPC and DisLE in thick-fluid aspiration patients were significantly different from those in both the thin-fluid aspiration and no-aspiration groups (Table 4, $p < 0.05$). LLE, LPC, LUEO, LPLE, LPPC, PTT, and LLE-LEC differed significantly between the thin-fluid aspiration group and the no-aspiration group (Table 5, $p < 0.05$).

Discussion

We sought to determine the mechanisms and predictors of aspiration in patients with dysphagia using VFSS. Our results indicate that particular variables are strongly associated with aspiration and further show that aspiration is related to food viscosity. These findings have potentially significant clinical implications.

Previous studies have provided detailed kinesiologic descriptions of the swallowing mechanism [3, 14, 15]. Motions of the hyoid bone depend on the position of the jaw and contraction of the suprahyoid and infrahyoid muscles. During swallowing, contraction of these muscles pulls the hyoid bone, larynx, and adjacent anterior pharyngeal wall upward and forward, opening the pharyngoesophageal sphincter (PES) [14]. Displacement of the hyoid bone and larynx were highly correlated, suggesting that these structures share a common muscular mechanism of movement. Although elevation of the PES may be aided by laryngeal elevation, contraction of the suspensory muscles of the pharynx above the PES also contributes to a greater PES vertical displacement [3, 14, 15]. Disruption of this mechanism may result in dysphagia and aspiration.

In the present study we found that a short duration of the UES opening, a shortened interval between peak pharyngeal constriction and the onset of UES opening, and a decrease in the extent of laryngeal elevation were all significant risk factors for thick-fluid aspiration. According to previous studies, a more viscous bolus has been shown to

Table 2 Demographic data

	Thick-fluid aspiration	Thin-fluid aspiration	No aspiration	Total
Number	23	20	27	70
Age (year)	65.0 ± 15.1	73.7 ± 10.1	66.0 ± 15.0	67.8 ± 14.1
Sex (M/F)	14/9	12/8	15/12	41/29
Tracheostomy (Yes/No)	6/17	2/18	5/22	13/57
Causes				
Cerebral infarction	14	15	13	42
Cerebral hemorrhage	4	4	5	13
Subachronoid hemorrhage	1	0	4	5
Brain tumor	1	0	0	1
Parkinson disease	1	1	0	2
Medical disease	1	0	4	5
Head and neck cancer	1	0	3	2

Table 3 Descriptive analyses of variables

	Thick-fluid aspiration	Thin-fluid aspiration	No aspiration	*p* value
LEC	0.61 ± 1.01	0.36 ± 0.18	0.24 ± 0.11	0.087
LLE*	1.67 ± 2.07	2.44 ± 3.02	0.46 ± 0.78	0.006
LPC*	1.71 ± 2.04	2.49 ± 3.03	0.52 ± 0.79	0.006
LUEO*	1.96 ± 2.06	2.72 ± 3.03	0.73 ± 0.81	0.006
LPLE*	2.05 ± 2.07	2.88 ± 3.02	0.85 ± 0.82	0.005
LPPC*	2.07 ± 2.06	2.93 ± 3.07	0.93 ± 0.78	0.006
PTT*	2.35 ± 2.00	3.21 ± 3.07	1.23 ± 0.82	0.006
LLE-LEC*	1.06 ± 1.32	2.08 ± 3.01	0.22 ± 0.74	0.004
LPC-LLE	0.04 ± 0.12	0.05 ± 0.05	0.06 ± 0.13	0.852
LPPC-LLE	0.41 ± 0.14	0.49 ± 0.15	0.48 ± 0.11	0.097
LUEO-LLE	0.29 ± 0.12	0.29 ± 0.07	0.27 ± 0.11	0.759
LPLE-LPC	0.35 ± 0.15	0.39 ± 0.12	0.34 ± 0.16	0.431
LPPC-LPLE	0.02 ± 0.13	0.05 ± 0.14	0.08 ± 0.15	0.318
LPLE-LUEO	0.09 ± 0.15	0.16 ± 0.11	0.12 ± 0.13	0.291
LPLE-LLE	0.39 ± 0.13	0.44 ± 0.12	0.40 ± 0.14	0.344
DLE	1.25 ± 0.46	1.30 ± 0.28	1.24 ± 0.25	0.852
LPPC-LPC	0.37 ± 0.13	0.44 ± 0.137	0.42 ± 0.12	0.162
DUEO*	0.39 ± 0.21	0.49 ± 0.13	0.50 ± 0.12	0.043
LUEO-LPC	0.25 ± 0.09	0.24 ± 0.06	0.21 ± 0.12	0.370
LUEO-LPPC*	0.11 ± 0.11	0.21 ± 0.12	0.20 ± 0.077	0.003
DisLE*	0.37 ± 0.17	0.57 ± 0.13	0.59 ± 0.13	<0.001

For definition of abbreviations see Table 1

Unit of measure is seconds

* $p < 0.05$

Table 4 Main determinant of thick-fluid aspiration

	Thick-fluid aspiration (A)	Thin-fluid aspiration (B)	No aspiration (C)	*p* value	Tukey
DUEO*	0.39 ± 0.21	0.49 ± 0.13	0.50 ± 0.12	0.043	A vs. C: 0.055
LUEO-LPPC*	0.11 ± 0.11	0.21 ± 0.12	0.20 ± 0.08	0.003	A vs. C: 0.007
					A vs. B: 0.011
DisLE*	0.37 ± 0.17	0.57 ± 0.13	0.59 ± 0.13	<0.001	A vs. B: 0.000
					A vs. C: 0.000

For definition of abbreviations see Table 1

A thick-fluid aspiration group; *B* thin-fluid aspiration group; *C* no-aspiration group

Unit of measure is seconds

* $p < 0.05$

Table 5 Main determinant of thin-fluid aspiration

	Thick-fluid aspiration (A)	Thin-fluid aspiration (B)	No aspiration (C)	*p* value	Tukey
LLE*	1.67 ± 2.07	2.44 ± 3.02	0.46 ± 0.78	0.006	B vs. C: 0.005
LPC*	1.71 ± 2.04	2.49 ± 3.03	0.52 ± 0.79	0.006	B vs. C: 0.005
LUEO*	1.96 ± 2.06	2.72 ± 3.03	0.73 ± 0.81	0.006	B vs. C: 0.005
LPLE*	2.05 ± 2.07	2.88 ± 3.02	0.85 ± 0.82	0.005	B vs. C: 0.004
LPPC*	2.073 ± 2.06	2.93 ± 3.07	0.93 ± 0.78	0.006	B vs. C: 0.005
PTT*	2.35 ± 2.00	3.21 ± 3.07	1.23 ± 0.82	0.006	B vs. C: 0.005
LLE-LEC*	1.06 ± 1.32	2.08 ± 3.01	0.22 ± 0.74	0.004	B vs. C: 0.003

For definition of abbreviations see Table 1

A thick-fluid aspiration group; *B* thin-fluid aspiration group; *C* no-aspiration group

Unit of measure is seconds

* $p < 0.05$

elicit increased strength and duration of contractile activity in the suprahyoid muscles [9] and a slowing and prolongation of the PES opening [16]. In line with the longer duration of the PES opening, Dantas et al. [16] found that the anterior movement of the hyoid bone-larynx complex was more marked during swallowing of a thick-fluid bolus. These data suggest that both insufficient pharyngeal pressure and inadequate laryngeal elevation are important in compromising the swallowing of thick fluid. Our data show that insufficient pharyngeal constriction and diminished laryngeal elevation were significant risk factors for thick-fluid aspiration.

Our thorough investigation of the time course of swallowing a thick fluid indicated that on average, larynx-to-hyoid approximation achieves a maximum value after the PES has opened. These results are consistent with those of previous studies [5]. This may reflect a secondary protective mechanism of the airway, which becomes more tightly sealed during the time of greatest pressure in the pharynx [5]. Kendall et al. [2] showed that the onset of hyoid bone elevation relative to the start of a swallow did not vary with a change in bolus consistency but that the timing of other parameters was different. Kendall and Leonard [11] also examined the timing of maximum constriction relative to arrival of the bolus at the UES and found that the relationship between maximum constriction time and UES arrival of the bolus was the same in elderly and young groups for both thick- and thin-bolus categories. However, after maximum pharyngeal constriction, the bolus took much longer to pass completely through the UES in elderly patients. Our data tended to show that elderly patients demonstrated pharyngeal weakness that correlated with a longer duration of pharyngeal transit. In other words, weakness of the pharyngeal muscles and/or a fall in the duration of pharyngeal constriction reduced the length of time during which the UES was open. Although the duration of pharyngeal constriction per se was not a significant risk factor for aspiration, UES was indeed significant in this regard. Reductions in the durations of UES and diminished laryngeal elevation may have a common clinical cause, e.g., poor hyolaryngeal elevation.

In the present study we identified the following parameters as significant risk factors for thin-fluid aspiration: increased latency of the swallowing reflex (latency of laryngeal elevation, latency of pharyngeal constriction, latency of UES opening, peak latency of laryngeal elevation, peak latency of pharyngeal constriction); pharyngeal transit time; and the interval between arrival of the bolus at the vallecula and laryngeal elevation. These were all timing measures of swallowing gestures relative to the onset of bolus pharyngeal transit. In other words, the onset of laryngeal elevation, the onset of pharyngeal constriction, the onset of UES opening, peak laryngeal elevation, and peak pharyngeal constriction were significantly delayed in patients who aspirated thick fluid and more delayed in patients who aspirated only thin fluid, compared to the nonaspirating group. Furthermore, we found delays in overall bolus pharyngeal transit timing that demonstrated a pattern similar to that of gesture timing with regard to patient category. This finding is the opposite of what one might expect. In general, thick fluids are considered to be less likely to be aspirated because they hold together better. The study results indicate that patients who aspirated only thin fluid and not thick fluid were more delayed/abnormal than the patients who aspirated thick fluid (and presumably would have also aspirated the thin fluid).

It is notable that LEC was found to be the first event to occur during the swallow, and it was significantly delayed in patients who aspirated compared to those who did not, but in a pattern opposite to all subsequent variables. In other words, LEC was more delayed in patients who aspirated thick fluid than in patients who aspirated only thin fluid. In addition, LLE-LEC was significantly prolonged in patients who aspirated compared to those who did not, but in a pattern similar to the delays in gesture timing relative to the onset of the swallow. According to these results, we might conclude that those individuals who demonstrate significant delays in the movement of the bolus through the first part of the swallow are at higher risk of aspirating only thick fluid. On the other hand, aspirators of thin fluid but not thick fluid tend to demonstrate a further delay in the onset of gestures required for adequate airway protection relative to the movement of the bolus.

A previous study on predictors of aspiration indicated that delayed pharyngeal swallowing and reduced laryngeal elevation were both significant risk factors for aspiration [17]. Prolonged pharyngeal transit times have been associated with an increased incidence of aspiration pneumonia in several patient populations [18–20]. However, the cited studies did not evaluate thick fluid and thin fluid separately and did not employ quantitative kinematic analysis.

When we compared the timing of several swallowing gestures to one another, in other words, the coordination of the swallowing gestures, there was no difference between the groups. This indicates that the coordination of swallowing gestures did not deteriorate further in the patient population who aspirated compared to the patient population that did not aspirate.

We enrolled only 70 patients who had diverse disorders, and future studies with larger patient numbers are thus required to explore kinematic differences in swallowing with respect to disease entity. Because a manometer was not used in this study, we could not evaluate the role of lingual pressure generation which has been shown to increase as viscosity increases.

Summary

Our kinematic analysis of patients with dysphagia allowed us to identify factors associated with aspiration. The duration of the UES opening, the interval between LUES and LPPC, and the extent of laryngeal elevation were all significant risk factors for thick-fluid aspiration. In addition, the latency of the swallowing reflex (latency of laryngeal elevation, latency of pharyngeal constriction, latency of UES opening, peak latency of laryngeal elevation, peak latency of pharyngeal constriction); pharyngeal transit time; and the interval between latency of epiglottis contact and latency of laryngeal elevation were all significant risk factors for thin fluid aspiration.

References

1. Kendall KA, McKenzie S, Leonard RJ, Goncalves MI, Walker A. Timing of events in normal swallowing: a videofluoroscopic study. Dysphagia. 2000;15:74–83.
2. Kendall KA, Leonard RJ, McKenzie SW. Accommodation to changes in bolus viscosity in normal deglutition: a videofluoroscopic study. Ann Otol Rhinol Laryngol. 2001;110:1059–65.
3. Palmer JB, Tanaka E, Ensrud E. Motions of the posterior pharyngeal wall in human swallowing: a quantitative videofluorographic study. Arch Phys Med Rehabil. 2000;81:1520–6.
4. Kendall KA, McKenzie SW, Leonard RJ, Jones CU. Timing of swallowing events after single-modality treatment of head and neck carcinomas with radiotherapy. Ann Otol Rhinol Laryngol. 2000;109:767–75.
5. Leonard RJ, Kendall KA, McKenzie S, Goncalves MI, Walker A. Structural displacements in normal swallowing: a videofluoroscopic study. Dysphagia. 2000;15:146–52.
6. The National Dysphagia Diet Task Force. The National Diet Dysphagia Diet: standardization for optimal care. Chicago, IL: American Dietetic Association; 2002.
7. Strowd L, Kyzima J, Pillsbury D, Valley T, Rubin B. Dysphagia dietary guidelines and the rheology of nutritional feeds and barium test feeds. Chest. 2008;133:1397–401.
8. Rosenbek JC, Robbins JA, Roecker EB, Coyle JL, Wood JL. A penetration-aspiration scale. Dysphagia. 1996;11:93–8.
9. Leonard R, Kendall K. Dysphagia assessment and treatment planning. 2nd ed. San Diego, CA: Plural Publishing, Inc.; 2008.
10. Rademaker AW, Pauloski BR, Logemann JA, Shanahan TK. Oropharyngeal swallow efficiency as a representative measure of swallowing function. J Speech Hear Res. 1994;37:314–25.
11. Kendall KA, Leonard RJ. Pharyngeal constriction in elderly dysphagic patients compared with young and elderly nondysphagic controls. Dysphagia. 2001;16:272–8.
12. Pauloski BR, Rademaker AW, Logemann JA, Colangelo LA. Speech and swallowing in irradiated and nonirradiated postsurgical oral cancer patients. Otolaryngol Head Neck Surg. 1998;118:616–24.
13. Dantas RO, Dodds WJ. Effect of bolus volume and consistency on swallow-induced submental and infrahyoid electromyographic activity. Bras J Med Biol Res. 1990;23:37–44.
14. Palmer JB, Rudin NJ, Lara G, Crompton AW. Coordination of mastication and swallowing. Dysphagia. 1992;7:187–200.
15. Donner MW, Bosma JF, Robertson DL. Anatomy and physiology of the pharynx. Gastrointest Radiol. 1985;10:196–212.
16. Dantas RO, Kern MK, Massey BT, Dodds WJ, Kahrilas PJ, Brasseur JG, Cook IJ, Lang IM. Effect of swallowed bolus variables on oral and pharyngeal phases of swallowing. Am J Physiol. 1990;258:G675–81.
17. Perlman AL, Booth BM, Grayhack JP. Videofluoroscopic predictors of aspiration in patients with oropharyngeal dysphagia. Dysphagia. 1994;9:90–5.
18. Johnson ER, McKenzie SW, Sievers A. Aspiration pneumonia in stroke. Arch Phys Med Rehabil. 1993;74:973–6.
19. Johnson ER, McKenzie SW, Rosenquist CJ, Lieberman JS, Sievers AE. Dysphagia following stroke: quantitative evaluation of pharyngeal transit times. Arch Phys Med Rehabil. 1992;73:419–23.
20. Bisch EM, Logemann JA, Rademaker AW, Kahrilas PJ, Lazarus CL. Pharyngeal effects of bolus volume, viscosity, and temperature in patients with dysphagia resulting from neurologic impairment and in normal subjects. J Speech Hear Res. 1994;37:1041–59.

Kyoung Hyo Choi MD, PhD

Ju Seok Ryu MD

Min Young Kim MD, PhD

Jin Young Kang MD

Seung Don Yoo MD, PhD