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ORIGINAL ARTICLE

Impact of Thickened Liquids on Laryngeal Movement Velocity in Patients with Dysphagia

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Abstract
Considering that thickened liquids are frequently used for patients with dysphagia, elucidating their impact on laryngeal dynamics is important. Although studies have investigated the impact of thickened liquids on laryngeal movement velocity among healthy young adults, no study has examined the same among patients with dysphagia. We aimed to elucidate the influence of bolus consistency on laryngeal movement velocity and surface electromyographic activity of the suprahyoid muscles in patients with dysphagia. Participants included 18 male, poststroke patients with dysphagia, whereas patients with true bulbar paralysis, head and neck cancer, neuromuscular disease, or recurrent nerve paralysis were excluded. A video fluoroscopic swallowing study (VFSS) was performed while swallowing 3 mL of moderately thick and thin liquids. Quantitative VFSS analysis, including factors such as laryngeal peak velocity, laryngeal mean velocity, laryngeal movement distance, duration of the laryngeal elevation movement, and the temporal location of laryngeal vestibule closure within the laryngeal elevation movement was performed. Muscle activity was evaluated using integrated muscles activity values obtained from electromyography (iEMG) of the suprahyoid muscle during swallowing. VFSS analysis showed that laryngeal peak velocity and laryngeal mean velocity were significantly faster while swallowing moderately thick than while swallowing thin liquids. Laryngeal movement distance was significantly greater while swallowing moderately thick than while swallowing thin liquids. iEMG was significantly higher while swallowing moderately thick liquids than while swallowing thin liquids. Compared to thin liquids, moderately thick induced an increase in laryngeal movement velocity and in suprahyoid muscle activity among patients with dysphagia, a finding consistent with that of a previous study among healthy adults.

Keywords Video fluoroscopic swallowing study · Laryngeal peak velocity · Bolus consistency · Suprahyoid muscle activity · Deglutition · Deglutition disorders

Introduction

Dysphagia is an abnormality of the swallowing mechanism that may lead to aspiration pneumonia; therefore, its management has been considered important in clinical settings [1]. Patients with dysphagia frequently have trouble controlling rapid liquid flow through the pharynx [2, 3], which may result in aspiration while swallowing liquids. Because thickened liquids have been found to help in controlling bolus speed [4], they have been widely used to prevent aspiration in patients with dysphagia [5, 6] in hospitals and long-term care facilities [7].

The video fluoroscopic swallowing study (VFSS), which has been extensively used worldwide, is the gold standard method for diagnosing dysphagia. Several studies have evaluated the impact of thickened liquids on

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hyoid and laryngeal movements using quantitative VFSS analysis [4, 8–15]. Although most of these studies analyzed hyolaryngeal excursion and duration, Nagy et al. [14] analyzed hyolaryngeal movement velocity among healthy young adults. Nagy and colleagues suggested that increased bolus thickness led to greater laryngeal movement velocity among healthy young adults and assumed that hyolaryngeal movement velocity was related to suprahyoid muscle strength. However, considering the fact that thickened liquids help in controlling bolus speed, we hypothesized that hyolaryngeal movement velocity might decrease with increased bolus thickness. Therefore, we undertook a study to confirm the impact of thickened liquids on hyolaryngeal movement velocity in healthy adults [15], which corroborated the study results of Nagy et al. [14]. Thus, research suggests that thicker bolus consistencies elicit faster laryngeal movement velocity in healthy adults. However, no study has yet investigated the impact of thickened liquids on hyolaryngeal movement velocity in patients with dysphagia. Previous studies have suggested that thickened liquids elicit greater hyolaryngeal movement distance [8] and reduced hyolaryngeal elevation movement duration in patients with dysphagia [12] compared with thin liquids. We hypothesized that thicker bolus consistency would induce increased laryngeal peak velocity in patients with dysphagia. Additionally, as suprahyoid muscle contraction promotes laryngeal elevation, we hypothesized that suprahyoid muscle activity would be affected by bolus consistency. Because thickened liquids are frequently used for patients with dysphagia, elucidating their impact on hyolaryngeal dynamics is crucial. Therefore, the current study aimed to elucidate the influence of bolus consistency on laryngeal movement velocity and surface electromyographic activity of the suprahyoid muscles in patients with dysphagia.

Materials and Methods

Participants

Participants included 18 male, poststroke patients with dysphagia (mean age: 67.1 ± 12.8 years) who had a VFSS in Hyogo College of Medicine hospital. All patients underwent VFSS because aspiration was suspected based on a prior water swallowing test. Patients with true bulbar paralysis, head and neck cancer, neuromuscular disease, or recurrent nerve paralysis were excluded. Additionally, those with severe or moderate dysphagia (such as those with clinical signs of aspiration of moderately thick liquids) were excluded. This study was approved by the institutional ethics committee of Hyogo College of Medicine. All patients provided written informed consent before VFSS.

Video Fluoroscopic Swallowing Study

A VFSS was performed with the patient in a sitting position. Lateral projections were obtained for swallowing with two liquid consistencies (thin and moderately thick), and two trials per type of consistency were attempted. However, when aspiration was observed, data collection was terminated. For example, if aspiration was identified while swallowing the first trial of thin liquid, the second trial of thin liquid was not performed. The test liquid was infused into the floor of the mouth using a syringe, and the patient held the test liquid in their mouth until cued to swallow. The test liquid was 3 mL of barium liquid whose properties were adjusted to produce thin and moderately thick liquids. The test liquid was prepared as follows: barium sulfate powder (Baritop P®, 99% w/w; Kaigen Pharram Co., Ltd., Osaka, Japan) was mixed with water to obtain 40% weight/volume barium sulfate. The moderately thick liquid was prepared by mixing 200 mL of the thin liquid with a xanthan gum based thickener (6 g; Softia-1SOL, Nutri Co., Ltd., Mie, Japan). Consistency measurements of the test liquids were conducted using the IDDSI Flow Test [16], with thin and moderately thick liquid identified as IDDSI level 0 (thin) and 3 (moderately thick), respectively.

The VFSS was recorded using an HDD recorder (DIGA DMR-XP200; Panasonic Corporation, Japan) running at 30 fps. VFSS images were analyzed using image analysis software (Dipp-Motion V2D; Int. DITECT) by a speech therapist. The anterior inferior margin of the C2 vertebra (C2), the anterior inferior margin of the C4 vertebra (C4), and the anterior commissure of the vocal cords were identified on each frame of the sequence (Fig. 1). Laryngeal movement was defined as vocal cord motion. The reference plane for analysis was determined by defining C4 as the origin and connecting C2 and C4 as the *Y*-axis and the line perpendicular to the *Y*-axis as the *X*-axis. Based on a previous study [17], the positional data were scaled in units using an internal anatomical scalar (%C2-4 spine length). The frame-by-frame CSV data output of position history from the image analysis software was used to index the onset and end positions of the anterosuperior laryngeal movement for each swallow. Subsequently, measures of laryngeal elevation movement distance, duration, velocity and peak velocity were made, as well as identifying the temporal location of laryngeal vestibule closure within the laryngeal elevation movement.

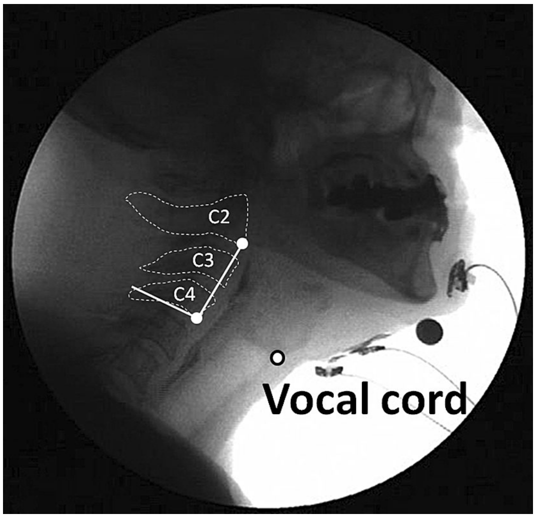

Fig. 1 Plots for quantitative video fluoroscopic swallowing study analysis. The anterior inferior margin of C2, the anterior inferior margin of C4, and vocal cords were identified to determine the origin, *X* and *Y* axis, and laryngeal movements

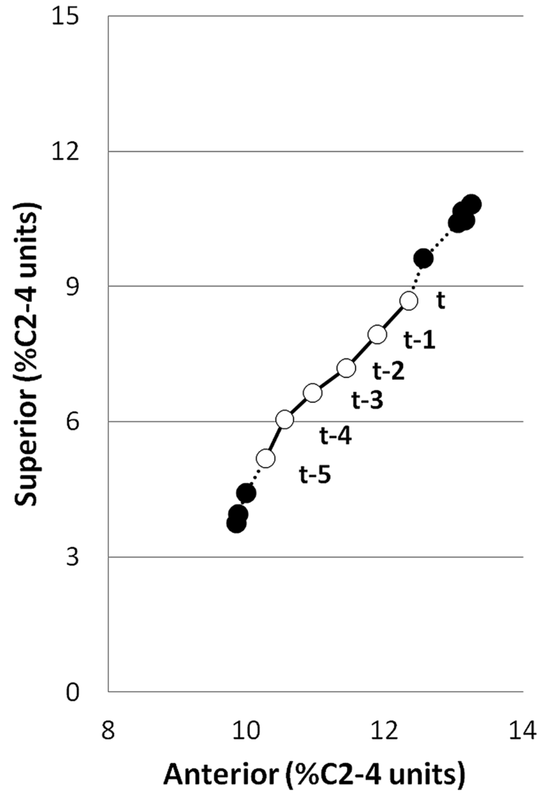

Fig. 2 Peak velocity calculation. To avoid measurement errors, laryngeal movement velocity was calculated frame-by-frame by dividing the distance tracked in five frames by 5/30 s. The highest among the obtained velocities was defined as the peak velocity

Duration(s)

Duration was defined as the duration from the onset until the highest position of anterosuperior laryngeal movement.

Distance (%C2-4 units)

Distance was defined as the displacement from rest to peak position of the larynx, measured separately in the anterior, superior and anterosuperior planes of movement.

$$\text{Peak velocity/speed}(\%C2-4\text{units/s}) = \frac{\text{The distance tracked from frame t}-5 \text{ to t}(\%C2-4\text{units})}{5/30(\text{s}) = 0.17(\text{s})}$$

Mean Velocity and Mean Speed (%C2-4 units/s)

Mean velocity was defined as distance of laryngeal movement from onset to highest position along the anterior and superior planes of movement, divided by movement duration. Mean speed was similarly defined as the distance of laryngeal movement from onset to highest position along the anterosuperior plane of movement, divided by movement duration [14].

Peak Velocity and Peak Speed (%C2-4 units/s)

Instantaneous laryngeal movement velocity and speed were calculated across successive 5-frame windows, by dividing distance moved along the anterior, superior or anterosuperior planes of movement by 5/30s (Fig. 2). The highest among the obtained velocities (speed) was defined as the peak velocity (speed).

To our best knowledge, there are two methods to calculate peak velocity: the first is to divide the distance tracked across successive windows containing five frames (five frames method) [18], and the second is to divide the distance tracked per frame (1 frame method) [14]. We evaluated the reproducibility of anterior peak velocity, superior peak velocity, and anterosuperior peak speed. The intraclass correlation coefficients using the five frames method were 0.82, 0.94, and 0.90 ($p < 0.001$), respectively; the intraclass correlation coefficients using the one frame method were 0.57, 0.90, and 0.84 ($p < 0.001$), respectively. To avoid measurement error, we used the five frames method to calculate the peak velocity and peak speed in this study.

Temporal Location of Laryngeal Vestibule Closure (LVC, % Duration)

The temporal location of LVC was identified according to the method reported by Nagy et al. [19]. The first frame showing LVC was defined as a seal between the laryngeal surface of the epiglottis and the arytenoids, which was tracked for each swallow. Next, its temporal location was calculated as a % of the duration of laryngeal movement. For example, values of 30% and 70% would reflect earlier and later laryngeal vestibule closure, respectively, whereas a value of 50% would indicate that the LVC occurred halfway through the laryngeal movement.

Aspiration Status and Pharyngeal Residue

Aspiration status was evaluated using the penetration–aspiration scale (PAS) [20]. The PAS assesses the depth to which the material passes in the airway and whether the material entering the airway is ejected during swallowing; PAS scores of 1–5 = no aspiration and 6–8 = aspiration. The pharyngeal residue was measured using the normalized residue ratio scale (NRRS) [21], which assesses residue severity by pixel-based measurements using an anatomically referenced scale. Residue was measured separately for the valleculae (NRRS V) and pyriform sinuses (NRRS P).

Electromyographic Activity (%μV*s)

Among the 18 participants, seven underwent muscle activity evaluation with the VFSS. Surface EMG activity was analyzed using the myo TRACE 400 (Noraxon Inc.). Before attaching the electrodes (Ambu® Blue Sensor N-00-S), the electrode sites were swabbed with alcohol-soaked cotton to reduce skin resistance. Two electrodes were attached in the submental area with an interelectrode distance of 20 mm to record suprahyoid muscle activity. A reference electrode was affixed to the mandible.

A speech therapist analyzed the EMG data using the MyoResearch Master Edition 1.06 XP software (sampling rate: 1000 Hz; band pass filter: 20–400 Hz; notch filter: 60 Hz) and processed into the root mean square. Muscle activity was evaluated using integrated muscle activity values obtained from an electromyographic examination of the suprahyoid muscles during swallowing (Fig. 3). The onset and offset of swallowing were identified using VFSS images. To normalize the muscle activity values, we divided such values by the maximum peak values during swallowing of the thin liquid.

Statistical Analysis

The mean of the results of two boluses per consistency was used for statistical analysis. However, in cases where only a single trial of thin liquid was administered due to aspiration ($n = 4$), single data was used for statistical analysis. Shapiro–Wilk tests were used to determine normal data distribution. Paired *t*-test and Wilcoxon signed-rank sum test were used to determine statistical differences between swallowing thin and moderately thick liquids. Student's *t* test and Mann–Whitney *U* test were used to determine statistical differences between no-aspiration and aspiration groups. Spearman's rank correlation coefficient was used to determine the coefficients between laryngeal movements and NRRSV/NRRSP. All statistical analyses were conducted using SPSS ver.24 (IBM SPSS Statistics) with statistical significance set at $p < 0.05$.

Results

Table 1 shows the participants' clinical characteristics. Table 2 shows the results of VFSS analysis and suprahyoid muscle activity. VFSS analysis revealed significant effects of liquid thickness on laryngeal elevation peak velocity, mean velocity, and distance. Peak velocity and mean velocity were significantly faster on superior movement and anterosuperior movement when swallowing moderately thick liquid than when swallowing thin liquid. Moreover, the distances of superior movement and anterosuperior movement were significantly greater when swallowing moderately thick than when swallowing thin liquid. No significant differences in other parameters were observed between swallowing moderately thick and thin liquids. iEMG was significantly stronger while swallowing moderately thick than while swallowing thin liquid. Table 3 shows the comparison of laryngeal movements while swallowing thin liquid between aspiration and no-aspiration groups. The distance of anterior movement was significantly larger and measures of mean and peak anterior movement velocity was significantly faster in the no-aspiration group than in the aspiration group. No significant differences in other parameters were observed between the aspiration and no-aspiration groups. Table 4 shows the relationship between laryngeal movement and residue measured with the NRRS. Residue following moderately thick liquid swallows showed significant negative correlations with superior laryngeal elevation mean velocity and anterosuperior mean speed ($r = -0.49$, $p = 0.04$ and $r = -0.62$, $p = 0.01$, respectively). No statistically significant coefficients in other parameters were observed.

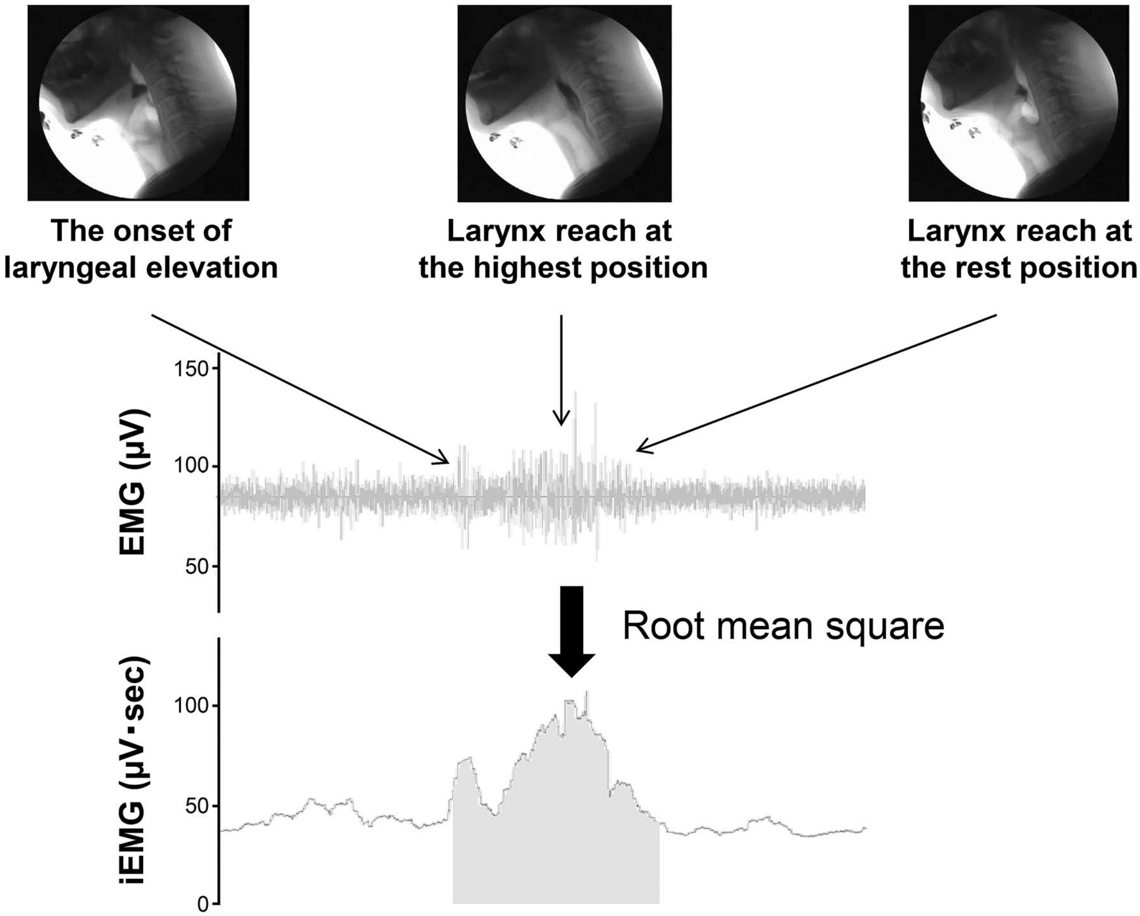

Fig. 3 Electromyographic analysis of the suprahyoid muscle. Suprahyoid muscle electromyography (EMG) was conducted simultaneously with VFSS. EMG data was processed into the root mean square. Muscle activity was evaluated using integrated muscle activity values obtained from suprahyoid muscle electromyography during swallowing

Table 1 Participant characteristics

Characteristics	$N = 18$
Age	67.1 ± 12.8
Medical diagnoses	
Cerebral infarction	$N = 15$
Cerebral hemorrhage	$N = 2$
Subarachnoid hemorrhage	$N = 1$
Days after stroke	21.2 ± 20.3
Modified Rankin Scale	3.3 ± 0.9
VFSS while swallowing thin liquids	
Aspiration (PAS = 6-8)	$N = 7$
NRRS V	0.09 ± 0.15
NRRS P	0.19 ± 0.52
VFSS while swallowing moderately thick	
Aspiration (PAS = 6–8)	$N = 0$
NRRS V	0.10 ± 0.15
NRRS P	0.18 ± 0.39

Values expressed as mean ± standard deviation

Discussion

The current prospective study elucidated the impact of different thicknesses of liquids on swallowing function and suprahyoid muscle activity in a sample of patients with dysphagia. The main findings were that laryngeal peak velocity was significantly faster and iEMG was significantly stronger while swallowing moderately thick than while swallowing thin liquids.

Impact of Moderately Thick Liquids on Laryngeal Movement Velocity

Thickened liquids have been frequently used for patients with dysphagia to prevent aspiration [5, 6]. Many studies have analyzed the impact of thickened liquids on hyolaryngeal excursion and duration. Previous studies have suggested that swallowing thickened liquids elicited shorter durations of hyolaryngeal elevation [12, 13] and greater

Table 2 Video fluoroscopic swallowing study analysis and surface electromyographic activity

	Thin liquid	Moderately thick	*d*	*p* value
Duration of anterosuperior movement (*s*)	0.5 ± 0.1	0.5 ± 0.1	0.17	0.52
Distance of anterior movement (*%C2-4 units*)	11.4 ± 7.7	13.7 ± 11.4	0.24	0.35
Distance of superior movement (*%C2-4 units*)	59.8 ± 11.5	65.1 ± 11.7	0.45	0.02
Distance of anterosuperior movement (*%C2-4 units*)	61.5 ± 11.7	67.4 ± 12.2	0.50	0.01
Anterior mean velocity (*%C2-4 units/s*)	23.9 ± 16.9	31.9 ± 27.9	0.35	0.16
Superior mean velocity (*%C2-4 units/s*)	124.3 ± 21.7	143.7 ± 26.9	0.80	0.006
Anterosuperior mean speed (*%C2-4 units/s*)	127.8 ± 22.2	149.45 ± 29.8	0.83	0.004
Anterior peak velocity (*%C2-4 units/s*)	34.7 ± 23.7	41.2 ± 28.8	0.25	0.23
Superior peak velocity (*%C2-4 units/s*)	216.6 ± 49.9	255.5 ± 52.4	0.76	0.005
Anterosuperior peak speed (*%C2-4 units/s*)	218.9 ± 47.5	259.0 ± 51.9	0.81	0.003
Laryngeal vestibule closure *(% duration)*	73.7 ± 12.9	77.9 ± 16.2	0.28	0.24
Suprahyoid muscle activity (*%μV*s*)	73.3 ± 27.6	96.6 ± 35.5	0.73	0.03

Values expressed as mean ± standard deviation; effect size is expressed as *d* (Cohen's *d*)

Table 3 Comparisons of laryngeal movements while swallowing thin liquid between aspiration and no-aspiration groups

	No-aspiration	Aspiration	*d*	*p* value
Duration of anterosuperior movement (*s*)	0.5 ± 0.1	0.5 ± 0.1	0.11	0.82
Distance of anterior movement (*%C2-4 units*)	14.1 ± 8.0	7.1 ± 4.9	1.06	0.04
Distance of superior movement (*%C2-4 units*)	63.2 ± 10.9	54.5 ± 11.0	0.79	0.26
Distance of anterosuperior movement (*%C2-4 units*)	65.5 ± 10.5	55.1 ± 11.4	0.95	0.08
Anterior mean velocity (*%C2-4 units/s*)	29.9 ± 17.8	14.4 ± 10.4	1.07	0.03
Superior mean velocity (*%C2-4 units/s*)	129.6 ± 19.7	115.9 ± 23.3	0.63	0.22
Anterosuperior mean speed (*%C2-4 units/s*)	134.5 ± 19.1	117.1 ± 24.1	0.80	0.14
Anterior peak velocity (*%C2-4 units/s*)	43.6 ± 22.6	20.8 ± 19.1	1.09	0.04
Superior peak velocity (*%C2-4 units/s*)	228.6 ± 51.8	197.9 ± 43.5	0.64	0.20
Anterosuperior peak speed (*%C2-4 units/s*)	232.0 ± 46.9	198.3 ± 43.7	0.75	0.14
Laryngeal vestibule closure *(% duration)*	71.2 ± 11.8	77.5 ± 14.6	-0.47	0.36

Values expressed as mean ± standard deviation; effect size is expressed as *d* (Cohen's *d*)

Table 4 Correlation coefficients between laryngeal movements and NRRS

	Thin liquid				Moderately thick			
	NRRS V		NRRS P		NRRS V		NRRS P	
	r	*p* value	*r*	*p* value	*r*	*p* value	*R*	*p* value
Duration of anterosuperior movement (*s*)	−0.15	0.56	−0.11	0.68	0.29	0.24	0.26	0.30
Distance of anterior movement (*%C2-4 units*)	−0.67	0.79	−0.37	0.13	−0.27	0.24	0.01	0.98
Distance of superior movement (*%C2-4 units*)	−0.34	0.17	−0.25	0.32	0.05	0.84	0.13	0.62
Distance of anterosuperior movement (*%C2-4 units*)	−0.37	0.13	−0.31	0.21	−0.08	0.74	0.07	0.79
Anterior mean velocity (*%C2-4 units/s*)	−0.12	0.64	−0.37	0.14	−0.40	0.10	−0.08	0.74
Superior mean velocity (*%C2-4 units/s*)	−0.27	0.28	−0.22	0.39	−0.49	0.04	−0.41	0.09
Anterosuperior mean speed (*%C2-4 units/s*)	−0.27	0.29	−0.21	0.40	−0.62	0.01	−0.40	0.14
Anterior peak velocity (*%C2-4 units/s*)	−0.18	0.48	0.01	0.99	−0.25	0.32	−0.09	0.71
Superior peak velocity (*%C2-4 units/s*)	−0.12	0.64	−0.08	0.75	−0.39	0.11	−0.39	0.11
Anterosuperior peak speed (*%C2-4 units/s*)	−0.17	0.51	−0.08	0.75	−0.30	0.23	−0.28	0.26
Laryngeal vestibule closure *(% duration)*	−0.06	0.82	0.12	0.64	−0.15	0.54	−0.25	0.31

Values expressed as correlation coefficient hyolaryngeal movement distance [4, 8, 9] than swallowing thin liquids. Moreover, Nagy et al. [14] and our previous study [15] suggested that thicker bolus consistencies induced greater hyolaryngeal movement velocity among healthy adults. However, no study has yet investigated the impact of thickened liquids on hyolaryngeal movement velocity in patients with dysphagia.

After investigating the impact of thickened liquids on swallowing dynamics in patients with dysphagia, our results showed that laryngeal peak velocity and suprahyoid muscle activity were significantly greater when swallowing moderately thick than while swallowing thin liquids. This indicated that the impact of thickened liquids on laryngeal movement velocity in patients with dysphagia was consistent with that in healthy young adults [14, 15] wherein swallowing moderately thick liquids induced faster peak laryngeal movement velocity and suprahyoid muscle activity.

Laryngeal vestibule closure, which plays an important function in preventing aspiration, is achieved by the coordinated movement of the laryngeal vestibule, epiglottis, and true vocal folds. Among such movements, those of the laryngeal vestibule and epiglottis have been associated with laryngeal elevation while swallowing. Thickened liquids create a setting in which there is less urgency to quickly move the larynx considering that liquids with thicker consistencies flow more slowly. Therefore, it would be reasonable to expect slower laryngeal movement with increased bolus consistency. However, our results showed that thickened liquids elicited faster laryngeal movement velocity but did not affect LVC. Inamoto et al. [22], who investigated the effect of bolus consistency on laryngeal closure during swallowing, suggested that only the timing of true vocal cord closure differed significantly between thin and thickened liquids. Moreover, our results showed that laryngeal movement velocity is associated with pharyngeal residue and aspiration status. Therefore, we speculated that laryngeal movement velocity is associated with another mechanism through which thickened liquids facilitate safe swallowing rather than laryngeal closure. Raut et al. [23] and Sia et al. [24] reported that pharyngeal clearing constriction increased with bolus consistency. Because thickened liquids required not only greater peak laryngeal movement velocity but also pharyngeal constriction, we speculate that laryngeal movement velocity may be associated with ejection fraction while swallowing. However, to date, there is little evidence upon which to base this hypothesis; thus, further study is needed to elucidate the functional importance of laryngeal movement velocity.

Association between Laryngeal Peak Velocity and Suprahyoid Muscle Activity

Laryngeal peak velocity is a recently developed parameter that evaluates instantaneous laryngeal movement velocity while swallowing, with some studies assuming a relationship between laryngeal peak velocity and suprahyoid muscle strength [14, 18]. After simultaneously measuring both laryngeal peak velocity and suprahyoid muscle activity, the present study indicated that thicker bolus consistency elicits increases in both laryngeal peak velocity and suprahyoid muscles activity. Several previous studies have indicated that suprahyoid muscle activity increases with thicker bolus consistency in healthy adults [25–27] and poststroke patients with dysphagia [28]. Because suprahyoid muscle contraction promotes laryngeal elevation while swallowing [29], suprahyoid muscle activity has been considered important for laryngeal movements. Accordingly, we surmised that increased suprahyoid muscle activity promoted greater laryngeal peak velocity when swallowing thickened liquids.

A systematic review by Steele et al. [30] identified previous studies suggesting that thickened liquids not only reduced the risk of aspiration but may also increase the risk of pharyngeal residue. Moreover, the previous and present study both revealed that liquids with excessive thickening elicited increased laryngeal peak velocity [14, 15] and suprahyoid muscle activity [25–28]. Thus, patients with low laryngeal peak velocity and suprahyoid muscle activity may be at greater risk for having pharyngeal residue after swallowing thickened liquids.

Limitations

The current study does not investigate the impact of thickened liquids on hyoid movements. Considering that several previous studies that quantitatively analyzed VFSS evaluated hyoid movements, we have attempted to evaluate not only laryngeal but also hyoid movements. However, hyoid movement could not be evaluated in some of our patients given that the *hyoid* is masked by the *mandible at its highest position. Considering that the larynx can be visualized in all our patients, the VFSS analysis focuses on evaluating laryngeal movement.*

The test liquid in this study involved 3 mL boluses of barium liquid whose properties were adjusted to thin and moderately thick liquids, and two measurements of both viscosities were obtained. The mean of the results of the two boluses per consistency were used for statistical analysis. However, this is a limitation of this study because calculating an average measure across three or more task repetitions is considered ideal. Thus, VFSS should be examined for three or more task repetitions. Moreover, in a recent study by Steele et al. in 2019 [31], reference values of sip volumes in healthy individuals were identified. The volume for thin liquid was 12 mL and that for moderately thick liquid was 5 mL. Both volumes are larger than the 3 mL boluses used in this study; therefore, we cannot compare laryngeal movement with those reference values. This suggests that one of the limitations may be a lack of representation of functional swallowing physiology.

This study included a small cohort of participants who had only mild swallowing disability. Patients with moderate or severe dysphagia may show different results considering the influence of dysphagia severity on swallowing dynamics. As such, future studies including a larger cohort with moderate and severe dysphagia should be conducted. Moreover, given that some participants in our study could not undergo EMG activity evaluation because of equipment failure, future research on this matter is needed.

Conclusion

This study elucidated the influence of thickened liquids on laryngeal movement velocity and suprahyoid muscle activity among patients with dysphagia. Accordingly, our results showed that increasing bolus thickness promoted increased laryngeal movement velocity and suprahyoid muscle activity among patients with mild dysphagia.

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Author Contributions Conceptualization—YN, HO, TH, OS, and KD. Data curation—YN, SS, TN, and YU. Formal analysis—YN. Funding acquisition—YN. Investigation; Methodology—YN, HO, TH, and OS. Roles/Writing—original draft—YN. Writing—review & editing—YN, HO, TH, OS, YU, and KD.

Compliance with Ethical Standards

Conflict of interest The authors have no conflicts of interest to disclose.

Ethical Approval This study was approved by the institutional ethics committee of Hyogo College of Medicine. All patients provided their written informed consent before VFSS.

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