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Surface Electromyographic Characteristics of Swallowing in Dysphagia Secondary to Brainstem Stroke

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Abstract. Surface electromyography (SEMG) provides an noninvasive avenue for evaluating swallowing physiology. This report describes SEMG characteristics associated with swallow attempts in 6 dysphagic patients who had suffered brainstem stroke compared with 6 age- and gender-matched controls. Results indicated that patients with dysphagia secondary to brainstem stroke differed in both amplitude and timing aspects of swallowing attempts from asymptomatic controls. Specifically, the results indicated that during swallow attempts, dysphagic patients produced more muscle activity over a shorter duration and with less coordination than controls. Potential physiological mechanisms of these results are discussed.

Key words: Dysphagia — Swallowing — Surface electromyography — Neurological — Stroke — Deglutition — Deglutition disorders.

Damage to brainstem structures via stroke or other neurotrauma may impair swallowing function in two ways: paresis within the corticobulbar musculature active during swallowing and impaired central control of swallowing resulting from damage to brainstem swallowing centers [1–3]. Descriptions of swallowing patterns in patients with dysphagia secondary to brainstem stroke typically rely on analysis of videofluorographic studies [4,5]. Patterns of swallowing deficit are expected to be variable among patients, but common descriptors include pharyngeal asymmetry, unilateral laryngeal weakness, reduced duration and extent of laryngeal excursion, and reduced cricopharyngeal opening. Crary [6] has referred to the pattern seen in such patients as the ‘‘incomplete swallow’’ noting that it is often seen in combination with temporal incoordination among components of the oropharyngeal swallow.

Surface electromyography (SEMG) has recently received increased attention in the evaluation of swallowing physiology and in the rehabilitation of swallowing deficits [6–11]. In this report, certain SEMG characteristics of swallowing activity in patients presenting dysphagia secondary to brainstem stroke are contrasted with those obtained from age- and gender-matched asymptomatic controls.

Methods

Subjects

Twelve adults participated in this study. Six presented with dysphagia secondary to brainstem stroke. This group included 4 males and 2 females, aged 59–78 years, a mean 66.8 years. Months postonset ranged from 2 to 54 and all patients had participated in prior swallowing rehabilitation efforts that were unsuccessful. All patients were receiving total nutrition and hydration via gastrostomy or jejunostomy tubes and all had difficulty managing oral secretions. One patient had a cuffless tracheostomy tube in place at the time of testing. Unilateral brainstem stroke was confirmed from review of medical records including diagnostic imaging and neurological evaluation reports. No patient had a history of neurological deficit prior to the stroke. Pattern of neurological involvement was variable but all subjects were medically stable and had completed post-acute rehabilitation at the time of testing. Tables 1 and 2 summarize patient characteristics.

Control subjects included 4 males and 2 females aged 58–81 years, a mean 66.8 years. None of these volunteers had a history of dysphagia or other neurological deficits.

Surface Electromyographic Measurements

Myoelectric activity was monitored from three surface electrode placement sites: perioral, masseter, and infrahyoid. The unimpaired side of the face was used for perioral and masseter placements. Care was taken

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Table 1. Patient characteristics

Patient/ gender	Age	Side of lesion	Months post-onset	Clinical examination	Oral intake	Expectorating saliva	Prior therapy
1/M	66	Left	2	Ataxia			
				CN 7, 9, 10	None	Yes	Swallow exercises
				Face			
				Pharynx			Swallow exercises
				Larynx			
2/F	61	Left	14	Hemiplegia	None	Yes	Thermal stimulation
				CN 7, 9, 10, 12			Swallow exercises
				Face			
				Pharynx			
				Velum			
				Tongue			
3/F	59	Right/SC	13	Hemiplegia	None	Yes	Thermal stimulation
				Oral incoordination			Swallow exercises
				CN 9, 10, 12			
				Pharynx			
				Velum			
				Tongue			
4/M	78	Right	5	Mild ataxia	None	Yes	Thermal stimulation
				CN 9, 10			Swallow exercises
				Pharynx			
				Larynx			
				Velum			
5/M	72	Left/SC	54	CN 9, 10	None	Yes	Thermal stimulation
				Pharynx			Swallow exercises
							Myotomy
6/M	66	Right/SC	20	Hemiplegia	None	Yes	Thermal stimulation
		Left frontal		CN 7, 9, 10			Swallow exercises
		Thrombus		Face			Myotomy
				Pharynx			
				Larynx			

SC = subcortical, CN = cranial nerve.

Table 2. Patient characteristics: Results of videofluorographic swallowing examinations

Patient	''Incomplete'' swallow	Residue		Laryngeal penetration	Aspiration	Cough/ clear	Passage through PES	Pharyngeal paresis
		Valleculae	Piriforms					
1	+	+	+	+	During	+	+	R
2	+	+	+	+	No	+	+	L
3	+	+	+	+	No	+	+	R
4	+	+	+	+	Post-swallow	+	+	R
5	+	+	+	+	No	+	+	L
6	+	+	+	+	Post-swallow	+	+	B (R > L)

PES = pharyngoesophageal segment, R = right, L = left, B = bilateral, + = yes, − = no.

to position all electrodes similarly on each subject. Three perioral electrodes were placed at the corner of the mouth with the center of the ground electrode 10 mm lateral to the vermilion border, level with the corner of the mouth. The remaining electrodes were spaced 20 mm center to center from the ground, on the upper and lower lip, with the electrode centers 10 mm from the vermilion border. Electrodes were placed longitudinally, 20 mm center to center along the masseter muscle with the ground in the center position. Infrahyoid electrodes were placed horizontally along the anterior neck. The ground was placed just inferior to the thyroid cartilage notch and the remaining electrodes were placed equidistant from the ground between the superior border of the thyroid cartilage and the hyoid bone. Miniature Beckman electrodes with an inside diameter of 4 mm were used.

SEMG signals were amplified, filtered (wide band: 100-1 kHz), rectified, and integrated for 20 msec. The integrated signal was digitized with a sampling rate of 10 Hz and stored in an interactive software program for subsequent analysis. A 4-sec sampling window was used to evaluate each swallowing attempt.

Swallow Conditions

SEMG data were obtained in each of the following conditions: (1) two trials of a resting baseline (mouth empty); (2–3) two trials each of an ''active baseline'' (holding 5 or 10 ml of water in the mouth without swallowing); (4) five no bolus (saliva) swallows; (5) five attempts to swallow 5 ml of water; and (6) five attempts to swallow 10 ml of water. The same sequence of swallow attempts was used for each subject. The procedure was discontinued for any dysphagic patient who demonstrated coughing during any three water swallow attempts. Number of completed swallow attempts was analyzed as part of results. Patients were free to discontinue participation at any time, however, none elected to do so.

Data Analysis

Microvolt and time values for each condition were transferred from a numerical spreadsheet to a graphics program to generate a three-channel graph of each baseline trial or swallowing attempt (Fig. 1). Using a combination of the tabled numerical values and the graphic depictions of SEMG activity during swallowing, onset and offset of swallowing events were identified. Onset was defined as a point where baseline activity increased into a characteristic swallow pattern. The specific point chosen as the onset was the microvolt value exceeding 2 standard deviations (SDs) above the baseline activity preceding the swallow attempt. Offset was determined as that point when myoelectric activity returned to within 2 SDs of average baseline levels. Once the swallowing event was identified, amplitude and timing measures were obtained from each SEMG channel. Amplitude measures included the average microvolt value during each baseline condition, the average microvolt value during each swallow attempt, and the peak microvolt value during each swallow attempt. Timing measures (sec) included duration of the swallowing event and the latency between the onset of the swallow and the peak microvolt value within the swallow event in each measurement channel. Finally, the degree of swallowing coordination was rated from the amplitude by time plot of each swallow attempt using a 4-point ordinal scale in which ''0'' represented identifiable swallow event, ''1'' represented a poorly defined event with at least two of the three channels showing swallowing activity, ''2'' represented well-defined swallowing but with missing onset or offset, and ''3'' represented well-defined swallowing activity for all three channels. Type 3 patterns were considered to reflect the most normal swallowing events based on evaluation of over 700 swallow attempts obtained from nearly 50 normal swallowing adults between the ages of 20 and 80 years. These ratings depicted the amplitude and timing coordination among the three SEMG channels. Figure 2 shows examples of each of the four types of swallow patterns. These patterns were rated separately for no bolus (saliva) swallows, 5-ml swallows, and 10-ml swallows.

To estimate interobserver agreement for coordination ratings, two judges with experience in the technique and in the area of swallowing disorders rated 24 SEMG traces. The traces chosen for reliability analysis were counterbalanced to represent all conditions (no bolus, 5-ml, 10-ml) and both subject groups. The kappa statistic was used to assess the degree of perfect and ''within-1'' (judges differ by only a single scale score) percent agreement between the two judges above what would be expected by chance. Perfect agreement (67%) was significantly greater than chance (k $=$ 0.52, p $=$ 0.0001) with the magnitude of the kappa statistic indicating a moderate level of agreement [12]. Agreement within one scale score (92%) also was significantly greater than chance (k $=$ 0.71, p $=$ 0.003) with the magnitude of the kappa statistic indicating moderate to excellent agreement.

All results except coordination ratings were evaluated statistically using 2-factor analyses of variance to examine differences attributed to group or bolus condition for each of the three channels. Post hoc Scheffe' contrasts among conditions were performed as required. The Wilcoxon signed rank test, a nonparametric analogue of the paired *t*-test, was used to compare coordination ratings within-subjects pairwise between treatment conditions (no bolus, 5 ml, 10 ml). The Wilcoxon rank sum test, a nonparametric analogue of the independent-sample *t*-test, was used to compare groups within each treatment condition and also to compare median within-subject treatment differences (e.g., 5 ml vs. no bolus or 10 ml vs. no bolus) between groups. This last type of comparison assesses interaction between group and treatment condition.

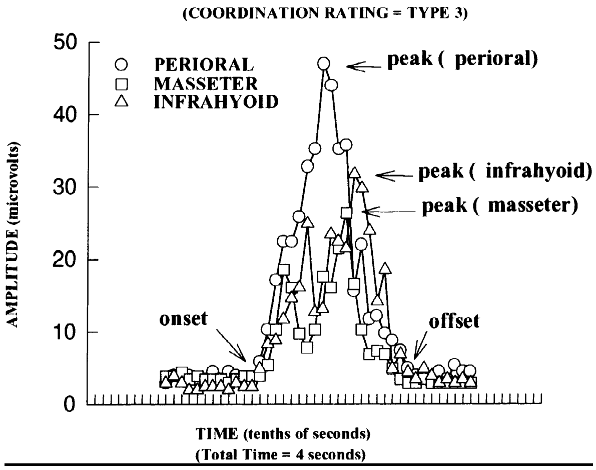

Fig. 1. Amplitude by time plot of three-channel SEMG activity during swallowing attempt from an asymptomatic adult. Onset and offset are marked for swallow event in addition to peak microvolt values for each channel.

Results

Analyzed Swallow Attempts

Both groups completed all of the no bolus (saliva) swallow attempts. The control group completed all of the 5- and 10-ml swallows, but the dysphagic subjects completed only 80% (24/30) of the 5-ml swallow trials and 27% (8/30) of the 10-ml swallow attempts because of discontinuation secondary to coughing after swallow attempts. Fisher's exact test for comparing proportions indicated that the patient group had significantly fewer swallow attempts for both the 5 ml (p $=$ 0.024) and the 10 ml ($p < 0.0001$) conditions.

Discrete swallowing events were not always identifiable from the SEMG results. From the control group, 93% of no bolus swallow attempts and 100% of 5- and 10-ml swallow attempts produced recognizable SEMG swallow patterns which included an amplitude increase from baseline in at least two of the three channels that produced a peak and returned to baseline. From the dysphagia group, 90% of no-bolus swallow attempts, 71% of 5-ml swallow attempts, and 100% of completed 10-ml swallow attempts produced recognizable SEMG patterns. Attempts with no identifiable swallow pattern

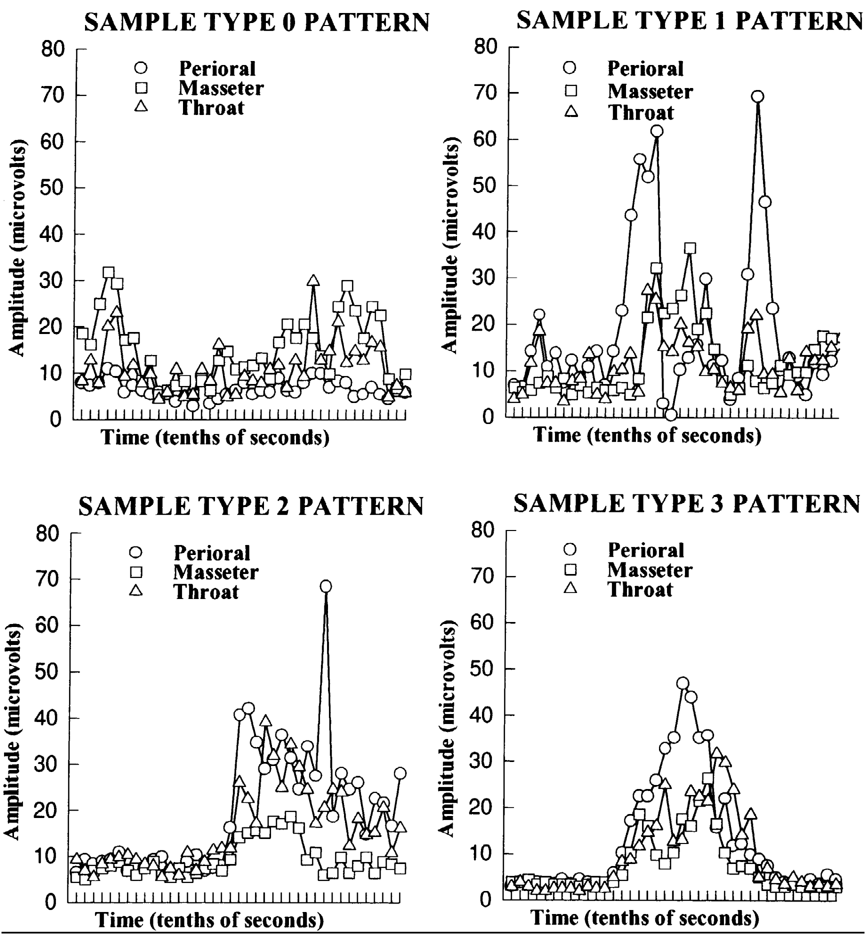

Fig. 2. Examples of SEMG patterns reflecting four degrees of amplitude and timing coordination during swallow attempts. Degree of coordination increases from type 0 to type 3 patterns.

were included in the coordination ratings, but they were not included in other measures of SEMG activity.

Baseline Activity

Baseline activity was measured to evaluate resting levels of myoelectric activity with no oral bolus and to determine if the loading effect created by holding an oral bolus would differentially influence the two groups of subjects.

Table 3 presents baseline SEMG results from each measurement site for the respective bolus conditions for each subject group. A significant bolus condition effect (no bolus vs. 5 ml or 10 ml) was obtained only from the perioral musculature. Myoelectric activity was greater in both groups when subjects were holding an oral bolus vs. no bolus ($p = 0.01$). No significant difference was obtained between the 5-ml and 10-ml conditions.

A significant group effect (dysphagia patients vs. controls) was obtained from the infrahyoid measurement site. Dysphagic subjects demonstrated significantly higher baseline activity than the control subjects in all three bolus conditions ($p = 0.002$).

Peak SEMG Values

Peak microvolt values during the swallowing attempts represent the maximum myoelectric activity observed during swallowing. Table 4 presents data for peak SEMG activity during swallow attempts. No significant bolus condition effects were obtained. Significant group differences were identified from the perioral ($p = 0.018$) and the infrahyoid ($p = 0.019$) measurement sites. In each instance, dysphagia subjects demonstrated greater SEMG activity than the control group.

Average SEMG Activity

Average SEMG activity during each swallow attempt was calculated as the mathematical average of all microvolt values between the onset and offset of the swallow

Table 3. Baseline SEMG activity (mV) from dysphagic stroke patients and controls in three bolus conditions (no bolus, 5 ml water, and 10 ml water) at each measurement site

Group	Condition	Measurement sites		
		Perioral	Masseter	Infrahyoid
Dysphagia/stroke	No bolus	4.27 (1.81)	6.54 (2.93)	4.52 (1.92)
	5 ml	6.66 (2.34)	5.44 (2.28)	4.51 (1.44)
	10 ml	6.68 (1.90)	7.66 (3.09)	5.13 (4.40)
Control	No bolus	3.30 (1.68)	2.17 (0.64)	1.95 (1.37)
	5 ml	7.08 (2.60)	4.69 (4.73)	2.74 (1.25)
	10 ml	8.44 (4.31)	4.60 (4.76)	2.56 (1.50)

Means and SDs ().

Table 4. Peak SEMG value (mV) during swallow event from dysphagic stroke patients and controls under three bolus conditions (no bolus, 5 ml water, and 10 ml water) at each measurement site

Group	Condition	Measurement sites		
		Perioral	Masseter	Infrahyoid
Dysphagia/stroke	No bolus	76.55 (103.17)	25.05 (10.53)	37.65 (24.53)
	5 ml	83.85 (80.85)	40.37 (18.27)	44.98 (30.97)
	10 ml	187.71 (110.65)	50.80 (26.68)	57.02 (45.97)
Control	No bolus	47.23 (35.86)	48.28 (48.01)	29.58 (7.64)
	5 ml	47.23 (35.86)	27.90 (32.66)	25.78 (3.10)
	10 ml	62.04 (27.34)	35.17 (45.49)	27.00 (6.12)

Means and SDs ().

event. Table 5 shows average SEMG activity during swallow attempts. No significant bolus condition effects were identified. Significant group differences were obtained from the perioral ($p = 0.008$) and infrahyoid ($p = 0.003$) measurement sites. Similar to the results of peak SEMG values, the average SEMG activity during swallow attempts from these measurement sites was greater among the dysphagic subjects.

Duration

Duration of swallow attempts for each electrode site was measured only for those attempts in which an onset and an offset could be identified. Swallow durations were highly similar across the three measurement channels. Therefore, the infrahyoid channel was chosen as representative of duration of swallow attempts. Table 6 shows the swallow durations measured from the respective groups in each bolus condition. No significant effects of bolus size were obtained in either group. Significant group differences were identified ($p = 0.0002$). In each instance swallow durations in the dysphagic patients were shorter than those obtained from the control subjects.

Peak Latency

Table 7 presents results of peak latency measures from each measurement site. No significant bolus condition effects were identified in either group. Significant group effects were identified in the perioral ($p = 0.001$) and the masseter ($p = 0.002$) channels. No significant group differences were obtained from the infrahyoid channel.

Coordination Measures

Table 8 shows the median coordination ratings for each subject group in each bolus condition. Only eight swallows were rated from the dysphagic subjects in the 10-ml condition. All eight were rated as ‘‘2,’’ resulting in no variation around the median. Within-subject comparison of scores between bolus conditions indicated no significant differences in either group of subjects. Comparison between groups indicated that the patient group coordination scores were significantly lower than the control group scores in both the no bolus ($p < 0.0001$) and 5 ml ($p < 0.0001$) conditions. Within-subject differences between the bolus conditions did not differ significantly between groups for any pair of bolus conditions, indicating no significant interactions between group and bolus condition.

Discussion

The results of this study indicate that patients with dysphagia secondary to brainstem stroke differed in both

Table 5. Average SEMG activity (mV) during swallow event from dysphagic stroke patients and controls under three bolus conditions (no bolus, 5 ml water, and 10 ml water) at each measurement site

		Measurement sites		
Group	Condition	Perioral	Masseter	Infrahyoid
Dysphagia/stroke	No bolus	36.77 (51.72)	12.79 (5.81)	17.37 (12.07)
	5 ml	33.64 (29.17)	19.05 (8.33)	22.12 (13.80)
	10 ml	89.52 (64.47)	21.73 (10.27)	26.69 (19.09)
Control	No bolus	17.72 (11.47)	16.57 (15.55)	10.75 (2.39)
	5 ml	17.28 (7.60)	11.02 (10.35)	10.43 (1.87)
	10 ml	23.71 (8.54)	13.32 (15.19)	11.15 (2.46)

Means and SDs ().

Table 6. Duration of swallow event (sec) measured from the infrahyoid site from dysphagic stroke patients and controls under three bolus conditions (no bolus, 5 ml water, and 10 ml water)

	Condition		
Group	No bolus	5 ml	10 ml
Dysphagia/stroke	1.22 (0.20)	1.20 (0.28)	1.32 (0.06)
Control	1.85 (0.37)	1.69 (0.30)	1.58 (0.22)

Means and SDs ().

amplitude and timing aspects of swallowing attempts from asymptomatic age- and gender-matched controls. Swallow attempts from dysphagic patients reflected higher and more variable amplitude characteristics and shorter durations. In addition, coordination ratings were lower in dysphagic patients indicating poorer amplitude and timing coordination in the SEMG traces. This finding suggests poorer swallow coordination for the patient group specifically for the no bolus and 5-ml bolus conditions. Significant differences were most prominent for perioral and infrahyoid measurement sites. Few significant differences were attributed to bolus size. Collectively, these findings suggest that, during swallow attempts, patients with dysphagia secondary to brainstem stroke produced more muscle activity over a shorter duration with less coordination than asymptomatic controls.

Several observations of this study may have implications for understanding the physiology of oropharyngeal dysphagia secondary to brainstem stroke and/or clinical implications pertinent to dysphagia management. Though the SEMG correlates of swallowing attempts revealed few bolus size influences, certain observations of bolus size were relevant. Dysphagic patients completed only 80% (24/30) of their 5-ml swallow attempts and only 27% (8/30) of their 10-ml swallow attempts compared with 100% completion among the control subjects. Thus, at this level of description, the patient group had more difficulty with a water bolus. This difficulty was enhanced with the larger water bolus. Still, for those patients who could swallow a 10-ml water bolus, coordination ratings did not differ significantly from those of the control subjects. This would suggest that even among dysphagia patients taking no oral food or liquid, swallow attempts revealing some similarities to age-matched controls may be identified at a physiological level of description using SEMG techniques.

Another similarity between the two groups was identified among the baseline measures. Perioral myoelectric activity increased in both groups when subjects held a bolus in the mouth. This is an anticipated reaction to increased lip seal activity resulting from holding an oral liquid bolus. Both groups demonstrated similar patterns of physiological response in the perioral musculature when holding an oral bolus.

Differences between the two groups were more pronounced than similarities. In general, amplitude measures were higher among dysphagic subjects, suggesting more muscle activity at both rest and during swallowing attempts. Several possibilities may be offered to account for this observation. Anxiety may contribute to increased myoelectric activity [13]. Considering that none of the dysphagic patients were swallowing any food or even their own saliva at the time of this study, it is conceivable that the enhanced infrahyoid baseline levels and other amplitude measures resulted in part from anxiety influences. In fact, many of the patients expressed anxiety at swallowing attempts. This factor has been addressed clinically in using biofeedback approaches to treat dysphagia [6,11]. Another possible influence might be increased tone in the muscle groups being evaluated. Hypertonicity would be an expected sequelae to upper motor neuron deficit and could contribute to increased myoelectric activity at rest. Still, it is unlikely that anxiety and/or hypertonicity influences would account for the total pattern of differences between the groups. For example, only the infrahyoid channel revealed baseline differences between the two groups. Furthermore, myoelectric activity from the masseter did not differ between the two groups on any amplitude measure.

Table 7. Latency of peak SEMG value (sec) from swallow onset in dysphagic stroke patients and controls under three bolus conditions (no bolus, 5 ml water, and 10 ml water) at each measurement site

		Measurement sites		
Group	Condition	Perioral	Masseter	Infrahyoid
Dysphagia/stroke	No bolus	0.58 (0.11)	0.56 (0.09)	0.62 (0.11)
	5 ml	0.49 (0.22)	0.53 (0.28)	0.68 (0.33)
	10 ml	0.45 (0.28)	0.62 (0.03)	0.89 (0.16)
Control	No bolus	0.74 (0.30)	0.95 (0.14)	0.89 (0.12)
	5 ml	0.81 (0.27)	0.77 (0.24)	0.81 (0.19)
	10 ml	0.69 (0.13)	0.81 (0.25)	0.81 (0.26)

Means and SDs ().

Table 8. Coordination ratings of SEMG traces of swallow event from dysphagic stroke patients and controls under three bolus conditions (no bolus, 5 ml water, and 10 ml water) at each measurement site

	Condition		
Group	No bolus	5 ml	10 ml
Dysphagia/stroke			
Median	2.00	1.00	2.00
25%	1.00	1.00	2.00
75%	2.00	2.00	2.00
Control			
Median	2.00	2.50	2.00
25%	2.00	2.00	2.00
75%	3.00	3.00	3.00

A potential explanation for the increased infrahyoid baseline activity might be a form of compensation. Buchholz et al. [14] described compensation as an adjustment of swallowing behaviors to overcome deficiency in deglutition. Crary [6] observed that in some patients receiving therapy, infrahyoid myoelectric activity would increase dramatically from a resting baseline once an oral bolus was placed. This could be interpreted as an anxiety response but it could also be interpreted as an airway protective response in which laryngeal/pharyngeal musculature actively attempt to protect against early entrance of a bolus into the pharynx/larynx. Additional study using both physiological and direct imaging techniques will be necessary to evaluate this possibility.

Temporal characteristics of swallow attempts also differed between dysphagic and control subjects; swallow durations were shorter in dysphagic subjects. However, it is important to note that only those swallow attempts in which a clear onset and offset were identified were included in duration measurements. In this respect, the more impaired swallow attempts from the dysphagia group were not included among duration measures. Since swallow attempts with a discrete onset and offset were rated higher on the coordination scale it may be more appropriate to state that the more coordinated swallow attempts from the dysphagic subjects were shorter in duration than those of the control subjects.

Temporal characteristics of impaired swallowing have been measured in various ways. In describing the ''incomplete swallow'' demonstrated by brainstem stroke dysphagic patients, Crary [6] implicated shorter durations and temporal incoordination among swallowing components. In that report as well as in a case report described by Logemann and Kahrilas [15], durational aspects of swallowing increased in brainstem stroke patients subsequent to therapy. Still, other reports suggest that duration of swallowing may overlap between brainstem stroke patients and control subjects [16].

Peak latencies were shorter in the dysphagic patients only for the perioral and masseter musculature. This pattern along with shorter durations would suggest an acceleration of the oral component of swallow attempts among the dysphagic subjects. Conversely, the lack of significant difference between the groups in the infrahyoid channel compared with the shorter latencies in the other two channels might suggest a delay in the pharyngeal component of swallowing in these patients. This observation is consistent with descriptions of swallowing in brainstem stroke patients from videofluorographic analysis [4,15].

In summary, SEMG characteristics of swallowing attempts depict multiple differences between patients with dysphagia secondary to brainstem stroke and age- and gender-matched controls. The pattern of results suggests that the stroke patients use more myoelectric activity over a shorter time period with poorer coordination in the swallowing attempts. Bolus size effects were minimal among these results. The noninvasive techniques of surface electromyography offer the possibility of studying swallowing physiology at a different level of description than radiographic imaging techniques or more invasive intramuscular electromyography. However, additional study is warranted combining both physiological and direct imaging technologies.

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