Reliability of Suprahyoid and Infrahyoid Electromyographic Measurements during Swallowing in Healthy Subjects

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Objective: To evaluate the reliability of suprahyoid and infrahyoid electromyography (EMG) measurement during swallowing.

Methods: In all, 10 healthy volunteers were evaluated for the following surface EMG (sEMG) parameters in the suprahyoid and infrahyoid muscles during swallowing: onset latency, offset latency, duration, peak latency, maximal amplitude during swallowing, and the area under curve (AUC) of the rectified EMG signal. The sEMG was recorded while the participants swallowed five times each of the four fluid volumes (saliva, 2 ml, 5 ml, and 20 ml of water), totaling to 20 swallows. Moreover, the intra-participant variability per parameter was evaluated using the coefficient of variation (CV).

Results: Suprahyoid muscles were activated 0.095 s (95% CI, 0.062-0.128) earlier than the infrahyoid muscles. Maximal amplitudes during the 20 ml swallow were 17.484 (−1.543-36.512) and 13.490 (1.254-25.727) μ V higher than values obtained during the 2 ml swallow in the suprahyoid and infrahyoid muscles, respectively. Furthermore, the AUC of the rectified EMG signal increased with the volume of swallow in both muscle groups ($P=0.003$, suprahyoid; $P<0.002$, infrahyoid). The intra-individual variabilities of offset latency, duration, and maximal amplitude were relatively low ($<30\%$ CV) in both muscle groups with respect to other parameters. The assessment of each parameter using EMG was highly reliable, with an intraclass correlation coefficient of >0.8 .

Conclusion: Among the variable sEMG parameters assessed, the offset latency, duration, and maximal amplitude were the least variable. Although reliability on the rater side showed good results, the swallow-to-swallow variability of the parameters need to be considered in swallowing studies using sEMG. (JKDS 2021;11:128-136)

Keywords: Electromyography, Deglutition disorders, Reliability of results

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INTRODUCTION

Swallowing is a complex process involving a coordinated activation of many muscles, including the oral, pharyngeal, and laryngeal muscles, at different levels of the central nervous system from the cerebral cortex to the medulla oblongata¹. The prevalence of dysphagia is very high in elderly patients, and it affects more than 30% of patients with stroke, 60-80% of patients with neurodegenerative disease, and more than 51% of institutionalized elderly patients². Physicians in various fields frequently encounter patients with these disorders; therefore, a simple and noninvasive screening tool is required for such patients. Currently, videofluoroscopic swallowing study (VFSS) is the gold standard for evaluating patients with dysphagia; however, it uses radiation, requires radiologic equipment and personnel, and is expensive³. With the increasing need for a simple and rapid screening tool for dysphagia, surface electromyography (sEMG) could be considered as a valuable method for evaluating dysphagia because of its noninvasive, radiation-free, inexpensive, and time-saving features. Various studies have used sEMG to evaluate the physiology of swallowing and the pathophysiological mechanisms involved in patients with dysphagia⁴⁻⁷. Despite the advantages of sEMG, there is a paucity of studies with normative data for normal swallowing and the reliability of sEMG for swallowing function evaluation.

This is a preliminary study evaluating the reliability

of sEMG and investigating normative data for suprahyoid and infrahyoid muscle activity during swallowing in healthy adults.

MATERIALS AND METHODS

1. Participants

After obtaining the approval of the Institutional Review Board of Seoul National University Hospital [1406-018-585], we conducted a single-center, prospective, cross-sectional study on 10 consenting healthy participants (9 men and 1 woman) aged 29.50 ± 1.18 (mean $\pm$ standard deviation [SD]) years. None of the participants had a history of major medical problems, such as dysphagia or neurological disorders.

2. Electromyographic techniques

The sEMG study was performed on two muscle groups: (1) suprahyoid muscles and (2) infrahyoid muscles, which are both covered by the platysma. Electrodes were positioned as follows. (Fig. 1) First, electrodes were placed 1 cm away from the midline on both sides of the skin beneath the mandibular body to record suprahyoid muscle group activity. Second, electrodes were placed 1 cm away from the midline on both sides of the thyroid cartilage to record infrahyoid muscle group activity. Third, a single electrode was affixed to the chin as the ground electrode.

The 4-channel sEMG was recorded using an EMG

Fig. 1. Experimental setup. (A) Circles show the location of the electromyography electrodes on suprahyoid and infrahyoid muscle groups. (B) 1 cm away from the midline on both sides of the skin beneath the body of mandible for the suprahyoid muscle group, and thyroid cartilage for the infrahyoid muscle group.

device (Nicolet® EDX; CareFusion, Middleton WI, USA) and software (Synergy v.20.0; CareFusion). We performed sEMG recordings using an EMG device with a bandpass filter frequency of 50-300 Hz, notch filter frequency of 60 Hz, and a sampling rate of 48 kHz.

The raw EMG signal was exported into text files, rectified using the root mean square method, and smoothed with a moving average of 40 ms time constant using in-house MATLAB (version 7.4, MathWorks Inc., Massachusetts, USA) scripts. Traces showing normal swallowing as recorded using sEMG, such as those shown in Fig. 2, were displayed on the computer screen. Cursors were automatically placed on the EMG activity of each muscle at onset and offset points, defined as points where rectified EMG signals exceeded a threshold. The threshold was calculated using the formula presented in a previous study⁸:

$$Threshold = \mu + 2\sigma$$

where μ and σ are the mean and SD, respectively, of the rectified EMG activity during a period of muscle inactivity. To confirm the onset and offset points, automatically placed cursors were adjusted manually by the investigators. Thereafter, the software calculated the duration, peak amplitude, latency of the peak amplitude, and area under the curve of the rectified EMG signal. To evaluate the intra-rater and

inter-rater reliabilities of the measurement, three experienced electromyographers, who were blinded to participant information, independently measured these parameters 3 times for each swallow.

3. Procedures

Participants were seated comfortably on a chair, and four volumes of liquid were swallowed five times each: voluntary single swallow of saliva ("dry" swallow), then 2 ml, 5 ml, and 20 ml of water. There was an interval of 30 s between each trial of the same volume, and 3 min before increasing the volume.

The participants were presented with four different volumes of liquid and asked to hold them until the cue light turned on and to swallow as soon as they saw the cue light on. The sEMG, which was synchronized with the cue light, was recorded for five swallows of each of the four different volumes, totaling to 20 swallows. The participants were blinded to the EMG signals throughout the experiments, and no auditory feedback (EMG sound) was heard during the recording.

4. Synchronization

We manufactured a device that was used to synchronize the swallowing start signal for participants and that on the EMG device.(Fig. 3) When the instructor pressed the 'ON' button of the

Fig. 2. Traces of a normal swallow as recorded on surface electromyography (EMG). (A) Rectified, filtered, (B) and smoothed EMG wave form.

Fig. 3. Experimental setup. (A) The participants start to swallow after the LED light bulb turns on. (B) The electromyography starting signal appears on the screen at the same time.

device, the LED (Light-Emitting Diode) lamp lighted up. Participants were instructed to hold water in their mouths until they see the LED lamp light up, upon which signal they were to swallow. Simultaneously, the starting signal was recorded on the EMG device. The intensity of the starting signal was set to a value greater than 100 μ V for a better signal display.

5. Statistics

Statistical analysis was performed using the Statistical Package for Social Sciences version 19.0 (SPSS 19.0; SPSS Inc., Chicago, IL, USA). To verify the normality of the data, basic descriptive statistics (median, minimum and maximum value) were calculated for every variable. The Mann Whitney U-test was used for paired data to analyze the difference between suprahyoid and infrahyoid muscle activity. The difference in parameters corresponding to different swallow volumes was evaluated using Kruskal Wallis test. Intra-rater and inter-rater reliabilities were assessed using the intraclass correlation coefficient (ICC) for all dependent variables. The coefficient of variation, which is defined as the SD divided by the mean, was used to quantify the intrasubject variability. The level of

significance for all analyses was set at $P < 0.05$.

RESULTS

The basic descriptive statistics of parameters obtained by sEMG during various tests are shown in Tables 1 and 2. The reliability was acceptable (ICC > 0.80) for all dependent variables.(Table 3)

1. Comparison between suprahyoid and infrahyoid muscle activities

The results indicated that the onset and offset latencies of suprahyoid muscles were shorter than those of infrahyoid muscles ($P < 0.001$); moreover, the suprahyoid muscle group had a significantly shorter duration of dry and water swallows than the infrahyoid muscle group. When comparing the results of dry and water swallows by total fluids (2 ml, 5 ml, 50 ml combined) as indicated in Tables 1 and 2 by “total”, there was no significant difference of peak amplitude between the two muscle. The mean of the area under the curve of the rectified EMG signal for all volumes of fluid swallowed was significantly larger in infrahyoid than in suprahyoid muscles.

Table 1. The parameters of suprahyoid surface electromyography.

	Onset (s)	Offset (s)	Duration (s)	Latency of the peak amplitude (s)	Maximal amplitude (μ V)	Area
Swallow of saliva						
Median	0.44	1.46	1.00	0.49	96.66	31.67
(Min.-Max.)	(0.07-1.25)	(0.75-2.67)	(0.63-1.89)	(0.09-0.96)	(47.09-321.63)	(5.74-106.31)
CV (%)	38.0%	14.7%	12.9%	30.1%	17.5%	30.3%
Small amount of fluid (2 ml)						
Median	0.31	1.26	0.85	0.36	96.45	26.49
(Min.-Max.)	(0.07-1.09)	(0.80-2.38)	(0.58-1.84)	(0.05-0.85)	(39.05-320.17)	(6.76-84.39)
CV (%)	37.4%	12.9%	12.0%	25.1%	19.0%	25.9%
Large amount of fluid (5 ml)						
Median	0.30	1.23	0.87	0.356	99.08	28.20
(Min.-Max.)	(0.05-1.44)	(0.68-2.28)	(0.59-1.74)	(0.07-3.90)	(36.65-352.35)	(4.74-74.84)
CV (%)	34.0%	14.3%	12.5%	56.5%	19.0%	26.1%
Cup drinking (20 ml)						
Median	0.33	1.38	0.99	0.45	102.35	36.60
(Min.-Max.)	(0.02-0.88)	(0.78-2.28)	(0.65-1.75)	(0.07-2.96)	(44.85-309.72)	(12.62-76.14)
CV (%)	35.5%	12.8%	13.7%	36.7%	17.7%	26.7%
Total						
Median	0.33	1.32	0.95	0.40	98.76	30.50
(Min.-Max.)	(0.02-1.44)	(0.68-2.67)	(0.58-1.89)	(0.05-3.90)	(36.65-352.35)	(4.74-106.31)
CV (%)	45.7%	17.5%	15.8%	57.6%	24.9%	36.9%

CV: coefficient of variation.

Table 2. The parameters of infrahyoid surface EMG during various tests.

	Onset (s)	Offset (s)	Duration (s)	Latency of the peak amplitude (s)	Maximal amplitude (μ V)	Area
Swallow of saliva						
Median	0.49	1.65	1.11	0.60	103.26	35.56
(Min.-Max.)	(0.05-1.28)	(0.85-2.75)	(0.67-2.10)	(0.17-2.78)	(32.89-261.73)	(6.70-151.90)
CV (%)	33.6%	15.2%	14.7%	33.2%	19.4%	27.5%
Small amount of fluid (2 ml)						
Median	0.41	1.41	0.99	0.46	107.22	36.47
(Min.-Max.)	(0.04-1.09)	(0.76-2.37)	(0.61-1.98)	(0.13-0.91)	(34.24-184.23)	(8.80-70.23)
CV (%)	30.7%	13.5%	14.6%	24.2%	15.2%	25.2%
Large amount of fluid (5 ml)						
Median	0.41	1.47	0.98	0.43	107.86	37.05
(Min.-Max.)	(0.17-1.41)	(0.98-2.41)	(0.65-1.62)	(0.12-2.89)	(33.11-186.89)	(16.39-104.45)
CV (%)	25.4%	12.5%	14.0%	36.0%	18.4%	25.3%
Cup drinking (20 ml)						
Median	0.43	1.54	1.08	0.48	117.49	44.11
(Min.-Max.)	(0.14-1.22)	(0.96-2.49)	(0.71-1.87)	(0.12-3.37)	(36.07-187.98)	(23.34-97.98)
CV (%)	25.7%	12.3%	12.5%	34.1%	14.2%	20.6%
Total						
Median	0.44	1.51	1.05	0.48	107.80	38.00
(Min.-Max.)	(0.04-1.41)	(0.76-2.75)	(0.61-2.10)	(0.12-3.37)	(32.89-261.73)	(6.70-151.90)
CV (%)	33.2%	16.5%	17.2%	44.0%	20.9%	30.9%

CV: coefficient of variation.

Table 3. Intra- and inter-rater reliability using intraclass correlation coefficient for all dependent variables.

	Intra-rater reliability			Inter-rater reliability		
	ICC	95% CI		ICC	95% CI	
		Lower	Upper		Lower	Upper
Right suprahyoid muscles						
Onset (s)	0.994	0.989	0.996	0.977	0.961	0.987
Offset (s)	0.985	0.975	0.992	0.978	0.963	0.988
Duration (s)	0.966	0.942	0.981	0.907	0.842	0.948
Latency to maximum (s)	0.998	0.996	0.999	0.993	0.988	0.996
Area	0.987	0.979	0.993	0.960	0.933	0.978
Left suprahyoid muscles						
Onset (s)	0.988	0.980	0.993	0.971	0.950	0.983
Offset (s)	0.985	0.975	0.992	0.980	0.966	0.989
Duration (s)	0.951	0.918	0.973	0.877	0.792	0.931
Latency to maximum (s)	0.998	0.997	0.999	0.994	0.990	0.997
Area	0.991	0.985	0.995	0.962	0.935	0.978
Right infrahyoid muscles						
Onset (s)	0.978	0.963	0.988	0.970	0.949	0.983
Offset (s)	0.982	0.970	0.990	0.972	0.952	0.984
Duration (s)	0.937	0.893	0.964	0.906	0.841	0.947
Latency to maximum (s)	0.997	0.994	0.998	0.990	0.983	0.994
Area	0.990	0.983	0.994	0.962	0.936	0.979
Left infrahyoid muscles						
Onset (s)	0.977	0.962	0.987	0.968	0.946	0.982
Offset (s)	0.969	0.948	0.983	0.969	0.948	0.983
Duration (s)	0.890	0.814	0.938	0.843	0.735	0.912
Latency to maximum (s)	0.999	0.998	0.999	0.997	0.994	0.998
Area	0.979	0.964	0.988	0.978	0.963	0.988

ICC: intraclass correlation coefficient, CI: confidence interval.

2. Comparison between the different swallowed fluid volumes

In a subgroup analysis wherein saliva swallow was excluded, the peak amplitude of swallow showed a clear linear tendency to increase with the volume of swallowed liquid in the suprahyoid ($P=0.309$) and significant difference in the infrahyoid muscle ($P=0.013$) groups. The area under the curve of the EMG signal increased proportionately with the amount of fluid swallowed in both muscle groups ($P=0.002$, suprahyoid; $P<0.001$, infrahyoid) and was significantly larger in the 20 ml volume swallow of water than in the other volume swallows.

3. Intrasubject variability

The intrasubject variability of the offset latency, duration, and maximal amplitude was lower (less than

30% of the coefficient of variation) than that of the other parameters among the different swallow trials in the same participants.(Table 2)

DISCUSSION

Dysphagia is associated with prolonged hospitalization and a higher risk of mortality in many patients. However, it is difficult to determine the exact prevalence of dysphagia because of its diverse etiologies and the complexity of the evaluation of swallowing. For this reason, the prevalence of dysphagia fluctuates in different published studies. Some studies revealed that the prevalence varies from 0.35% to 55% in the acute care unit^{2,9,10}; moreover, the figures are more pronounced in the nursing home setting with prevalence rates ranging from 55% to 68%^{11,12}. Notably, dysphagia is often present in

individuals with neurological disorders or other general medical problems. Some investigators conducted a study in four European countries and found a high proportion of patients with comorbidities of up to 81%¹³. Hence, a simple screening tool is required to perform a rapid assessment of patients with dysphagia. However, the complex mechanism of swallowing renders the evaluation of dysphagia difficult. Many different diagnostic techniques have been proposed such as computerized axial tomography, magnetic resonance imaging, barium esophagogram, air contrast esophagogram, manometry, fiberoptic endoscopic evaluation of swallowing, bolus scintigraphy, ultrasonography, and VFSS^{3,14}. In current clinical practice, the evaluation of dysphagia is mainly based on VFSS, and it is considered the gold standard in dysphagia assessment³. However, VFSS cannot be performed daily as a simple screening tool due to its use of radiation. Moreover, VFSS cannot evaluate individual muscle activation because it only provides motion recordings.

Swallowing functions have been widely studied using sEMG^{3,8,15-19}. With the recent emphasis on the use of noninvasive techniques for patient evaluation, sEMG emerges as a simple and easy-to-operate, radiation-free, inexpensive, and time-saving screening tool that can provide both qualitative and quantitative data. Despite these advantages, limited information regarding normative data and reliability is available to permit the use of sEMG in clinical practice. Some studies have investigated the normative data and reliability of EMG activity during normal swallowing^{8,15-18,20,21}. The range of normal values presented varies widely because of the large variation in technical factors such as electrode position, examination protocol, or result interpretations among physicians. It is suggested that the procedures and value of sEMG studies may be further improved by international standardization.

This study was undertaken to explore normative data and reliability for several parameters. We sought to investigate possible significant differences in the parameters of EMG activity in the infrahyoid and

suprahyoid muscle groups during swallowing. Moreover, we investigated possible significant differences in parameters of EMG activity during dry, normal (2 ml and 5 ml), and excessive (20 ml) swallow.

We found that the onset and offset latency of the suprahyoid muscles shorter than those of the infrahyoid muscles. Furthermore, the suprahyoid muscle group had a shorter swallowing duration compared with the infrahyoid muscle group. Some authors found that there were no significant differences in offset latency and swallowing duration between the two muscle groups¹⁵; nevertheless, the difference in the definition of the parameters renders direct comparison difficult.

Comparing muscle activity in the different volumes of fluid swallowed, Vaiman et al.^{15,16} found that the duration of swallow increased with volume of swallowed fluid in the suprahyoid muscle group; moreover, there was a significant difference in the duration of swallow between the normal and excessive swallow of water. In our study, the duration of saliva swallow was slightly longer than that of water swallow. This difference is thought to be due to differences in the study procedures. The authors of the previous study¹⁵ performed normal swallow of tap water first followed by dry swallow, whereas dry swallow proceeded water swallow in our study. Differences in the order of swallow resulted in differences in mouth dryness, and an increased muscular effort was required to initiate the dry swallow in our study. This muscular effort could similarly affect the peak EMG amplitude of swallowing. These findings corroborated with those of Hughes et al.²², who showed that the duration of saliva swallow is longer than that of water swallow for all individuals.

In the subgroup analysis wherein saliva swallow was excluded, we found that the peak amplitude increased with volume in both the suprahyoid and infrahyoid muscle groups. This contradicted the finding of Vaiman et al.^{15,16} who found that the range of EMG activity during 20 ml swallow ("stress" test) was significantly lower than that during normal

swallow. We may assume that the adaptation for larger volume accommodation resulted in an increase in muscular effort in our study instead of duration prolongation, as shown in previous studies^{15,16}. However, for participants aged at least 61 years, the results of Vaiman et al.¹⁶ corresponded to those of our study, which showed that the range of submental muscle EMG activity increased with the volume of swallow.

The results of our study showed an excellent agreement for intra-rater and inter-rater reliability. In general, the ICCs for suprahyoid and infrahyoid muscles in this study were in line with the results of previous study²³ that have shown that the intra- and inter-rater reliability using sEMG for monitoring submental muscle activity during swallowing was excellent for all variables and ranged from .98 to .99 and from .88 to .99. In our study, the recording and processing of the sEMG data using MATLAB was carried out by experienced electromyographers in the same settings of our laboratory. Therefore, the results cannot be generalized to other settings. More sEMG studies will be needed in order to assess reliability in different settings.

In our study, intra-individual variability evaluated using the coefficient of variation showed that offset latency, duration, and maximal amplitude of EMG activity were more reliable than the other parameters. Huckabee et al.¹⁹ evaluated the variability in sEMG recording of submental muscle activity during swallowing in healthy participants and found no significant differences across swallow trials within a single session of the same condition on the submental sEMG peak amplitude. Another study²² on the relationship between dysphagia and salivary gland dysfunction revealed that the duration of the third swallow trial was longer than that of the first trial in a series of three saliva swallows. Intra-individual variability could be affected by diverse biological factors such as muscle fatigue or the amount of salivary secretion (which may vary according to the volume of liquid swallowed), time interval between each swallows, the number of trials, and sequence of

the food presentation to the participants. Further research should be performed to evaluate the effect of these factors on the variability.

Our pilot study was conducted to investigate normative data and the reliability of suprahyoid and infrahyoid EMG values during swallowing in a population of apparently healthy people. The use of sEMG for the initial evaluation of swallowing is noninvasive, simple, and reliable. Moreover, sEMG is radiation-free, inexpensive, and time-saving, and it can be used with other evaluation tool such as VFSS simultaneously. We performed this present study with same protocol (voluntary single swallow of saliva, 2 ml, 5 ml, and 20 ml of water) used in VFSS evaluation of our laboratory. As a preliminary study of further research about the relationship between kinematic and electromyographic analysis, we could find that sEMG recordings is reliable tool for evaluating swallow and can be used with VFSS for investigating kinematic and electrophysiologic data.

Nonetheless, our study had the following limitations. First, sEMG could have measured the sum of the activities of all muscles under the skin in the facial area. The muscles evaluated in this study are covered by platysma, and the relaxation of this muscle is essential for reducing the variability. In the present study, only a small number of healthy participants were tested. Further investigations with larger sample sizes are necessary. Furthermore, studies correlating sEMG with videofluoroscopy will provide kinematic information and clarify the relationship between muscle activity and swallowing movement.

In summary, intra-individual swallow-to-swallow variability should be considered when using suprahyoid and infrahyoid sEMG activities as an outcome measure in research. More cautious planning seems warranted, such as taking the average of multiple (>4 times) swallows for each diet, controlling any visual or auditory feedback throughout the experiments, and the consideration of food volume. Among EMG parameters, the offset latency, swallowing duration, and maximal amplitude of the rectified signal seem to be the least variable parameters in terms of

intra-individual variability for multiple trials. Large-scale clinical studies are required to establish the reference range of sEMG parameters for these muscles that are related to swallowing.

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