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Use of sEMG for Swallowing Muscles Activity Quantification in Acute Phase of Stroke

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Abstract

Early diagnosis of dysphagia and aspiration risk is very important in minimizing the risk of various medical consequences. This study aimed to establish a scientific database for future sEMG-based dysphagia screening investigations by examining the electrical activity of swallowing muscles in acute stroke cases. A quantitative cross-sectional study was conducted on 61 stroke inpatients admitted to Dr. Hasan Sadikin General Hospital, Bandung, Indonesia, from July to November 2019. The objective of this study was to quantify electrical activities of the suprahyoid (SH) and infrahyoid (IH) muscles during swallowing. Patients participated in both dry swallowing and a 3 mL water swallowing task, with the sEMG used to measure electrical activity parameters (duration, swallowing initiation, time-to-peak, and amplitude) on both paretic and normal sides. The Wilcoxon test was used to compare the electrical activity parameters between the patients paretic and normal sides. Only amplitude showed a significant difference between the paretic and normal side (p=0.023) when performing the 3 mL water swallowing test. Other parameters did not exhibit significant differences in activity between muscle groups during both swallowing tests (p>0.05), although varying water volumes led to distinct activities in both muscles. Despite the absence of a clear pattern in SH and IH contractions during swallowing, the result showed that the sEMG quantification method might become a promising method for screening dysphagia, complementary to FEES and VFSS. The non-invasive and cost-effective sEMG method can serve as an early screening tool for dysphagia in stroke patients. This study underscores the importance of further investigation on sEMG use, incorporating a larger sample size and diverse cohort results with various swallowing exercises (varying in volume and viscosity) to validate the use of sEMG in dysphagia screening.

Keywords: Deglutition, electromyography, stroke

Introduction

Stroke is a neurological deficit that can cause many functional disturbances, including swallowing disorders (dysphagia), which affects 44–63% of acute stroke cases. However, most cases of dysphagia in this stage of stroke are rarely found with simple clinical examinations.[1] This condition can significantly diminish post-stroke patients quality of life, leading to increased morbidities such as pneumonia, malnutrition, dehydration, and mortality.[2] Early identification of dysphagia and aspiration risk is crucial as it can reduce the incidence of various medical complications, such as aspiration-related medical complications, prevent long-term hospitalization, reduce medical costs in general, and precision of rehabilitation plans, particularly for stroke patients.[3]

Early screening for dysphagia is crucial, typically initiated with non-instrumental tests. If the screening shows suspicion of dysphagia, a more comprehensive test using instruments will be carried out. This instrumental screening test can directly evaluate the impaired swallowing mechanism, significantly improving the accuracy of the diagnosis of swallowing disorder. Despite its diagnostic benefits, challenges persist in conducting instrumental screening tests on acute stroke patients.[3]

The elaborate process of swallowing engages over 50 head and neck muscles, with crucial

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roles played by muscles like the suprahyoid and infrahyoid. Weakness and coordination disorder of these muscles post-stroke can cause aspiration during swallowing.[3] This abnormality can be detected through surface electromyography (sEMG). This device has been proven safe, and it can measure the capability of swallowing muscles in healthy and dysphagic populations.[4]

sEMG is relatively affordable, non-invasive, and sensitive enough for dysphagia screening. It provides a semi-quantitative measurement of dysphagia caused by pharyngeal muscle dysfunction.[5] Subsequently, sEMG measurement of the muscles engaged in swallowing has been used to assess swallowing capability in sub-acute stroke. Patients with infarct stroke, as observed through sEMG, exhibited delayed onset, longer pre-trigger duration, and shorter electrical swallowing muscle activity than healthy people, which describes an impaired larynx protection mechanism.[6]

There is a scarcity of studies conducting instrumental dysphagia screening in acute stroke patients. However, in Italy, Giannantoni et al. used sEMG in the acute stroke population in 2016 and described decreased pharyngeal muscle motility.[5] The suprahyoid (SH) and infrahyoid (IH) muscles have been widely studied among the muscles included in swallowing. The positioning of the hyoid is the mutual function of SH and IH muscle contraction. The SH muscles can lift the hyoid bone in anterosuperior motions, which elevate the floor of the mouth to facilitate deglutition. The suprahyoid (SH) muscles play a role in depressing the jaw and aiding in a broad opening of the mouth, while the infrahyoid (IH) muscles stabilize the hyoid bone. The IH muscles depress the hyolaryngeal complex, and the thyrohyoid muscle, one of the four IH muscles, moves the larynx anterior-superiorly during swallowing. Moreover, the SH and IH muscles help the upper esophageal sphincter (UES) open by elevating the hyoid bone.[6]

Many studies using sEMG have primarily focused on evaluating swallowing only by measuring SH muscle activity in healthy patients or those already experiencing swallowing problems. Only a limited number of studies have included stroke patients and measured the activity of infrahyoid IH muscles. Therefore, this study aimed to quantitatively describe the electrical activities of SH and IH muscles in acute stroke patients to provide a scientific database for future investigation on dysphagia screening using sEMG.

Methods

A cross-sectional, analytic descriptive, observational study of the electrical signals of SH and IH muscles during swallowing was carried out in 61 patients with acute-phase stroke who were selected by consecutive sampling and obtained informed consent. Subsequently, this study was carried out in the neurological ward of Dr. Hasan Sadikin General Hospital, Bandung, West Java, Indonesia, from July to November 2019 after obtaining approval from the ethics committee (LB.02.01/X.6.5/62/2019).

Patients were included if diagnosed with the acute phase (day 1–2 weeks after onset) hemiparesis due to the first stroke or a recurrent stroke that occurred on the same side (proven by CT scan), aged 18-69 years old, and consented to participate. Patients were excluded if they showed an inability to follow simple instructions, were hemodynamically unstable, or still had impaired consciousness after two weeks following the stroke onset, had a history of trauma or surgery in the head or neck region, exhibited Parkinson's symptoms, had a pacemaker, or taken muscle-relaxing drugs in two weeks before the measurement.

The variables collected were the characteristics of the patients and sEMG parameters, including duration, swallowing onset, time-to-peak, and amplitude. A neurologist initially evaluated the patients stroke using the NIHSS score. Subsequently, patients were divided into three groups based on the severity of their strokes: mild stroke, defined as an NIHSS score of 8 or less; moderate stroke, defined as an NIHSS score of 9 to 15; and severe stroke, defined as an NIHSS score of 16 or more. sEMG data were obtained from SH and IH muscles in dry swallowing and 3-ml-water swallowing tests. In this study, sEMG (myoscan sEMG T9503M)

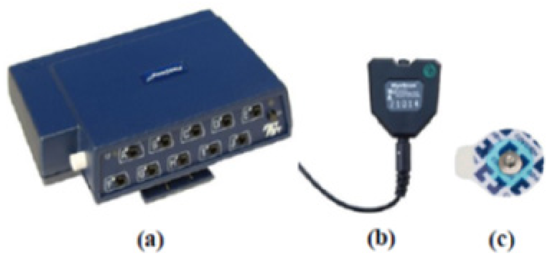

Figure 1 (a) Instrument Flex Comp Infiniti, (b) EMG sensor Myoscan, (c) Disposable EMG Electrodes

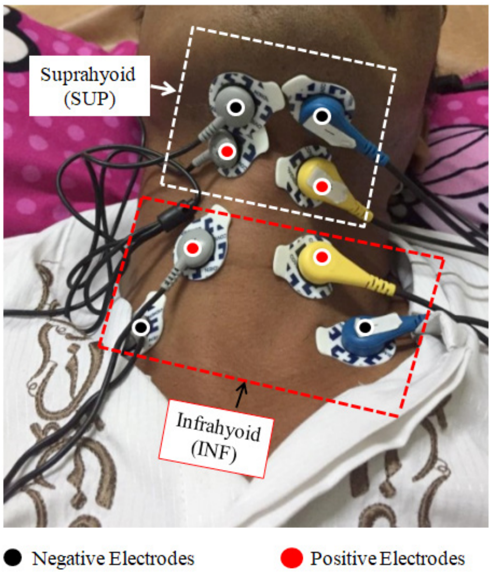

Figure 2 Illustration of the Placement of sEMG Electrodes[7]

was used in recording the measurements while connected to a bio-amplifier (FlexComp System with BioGraph Infiniti Software version 6.1.4 developed and manufactured by Thought Technology Ltd, Montreal, Canada) that has ten measurement canals with high sampling speed (2048 sample/second) and 14-bit resolution (data range 0-16383) (Figure 1).

This device has an internal calibration scheme which was activated to ensure the signal was in high resolution. The triangular head sensor on sEMG represents the two bipolar active electrodes (positive and negative) and one reference electrode (ground). The sensors specifications are as follows: a pre-amplifier that can detect a potential difference of 0–2000 µV accurate to ±5% and ±0.3iV; a high input impedance value (1,000,000 MΩ); a sensitivity of ≥0.1 iVRMS; CMRR at 50-60Hz:-180dB; and CMRR at 10-1000 Hz: -130dB. Disposable EMG Ag/AgCl electrodes were then attached to the skin on the area between the two innervation zones and reference points (Figure 2).

The EMG signals obtained from FlexComp, representing the four muscle groups included in swallowing, were processed using BioGraph Infiniti before being recorded on a computer, and the problem of study guided the data analysis process. The Sapiro-Wilk test was applied to verify the normality of the data first, statistical analysis was in line with the study objectives and hypotheses. Finally, the Wilcoxon test was used to compare the electrical activity parameters between the patients paretic and normal sides because the data were not normally distributed. The p-value is the commonly used significance value; if $p \leq 0.05$, the data is considered significant. All data were then processed using the SPSS 17.0 version for Windows (Figure 3).

Results

As shown in Table 1, the majority of patients were male (51%), aged 60-69 years (21%), with

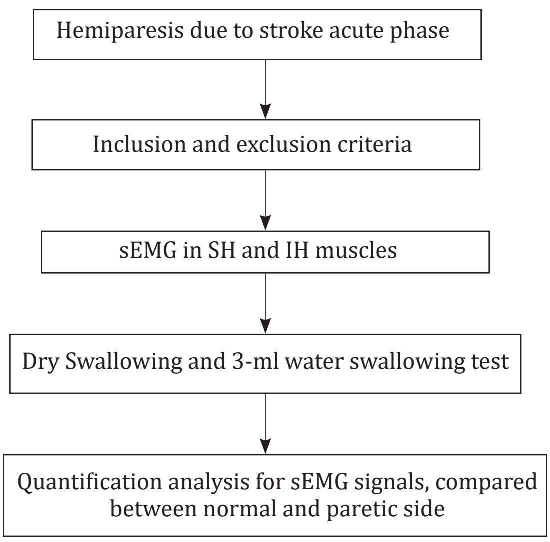

Figure 3 Research Flow

Table 1 Characteristics of Subjects

Variable	(n=61)	%
Gender		
Male	31	51
Female	30	49
Age (years)		
20–29	2	3
30–39	4	7
40–49	17	28
50–59	25	41
60–69	13	21
Site of Lesion		
Cortical	11	18
Subcortical	40	66
Cortical, Subcortical	10	16
Level severity of the stroke (NIHSS score)		
Mild	25	41
Moderate	36	59

NIHSS: National Institutes of Health Stroke Scale

subcortical lesions (66%) and moderate severity of stroke (59%). In two swallowing tests, the data were not normally distributed, and there were no significantly different patterns in electrical activity parameters between the paretic compared to the normal side except in amplitude when performing dry swallowing and 3-mL water swallowing tests, where paretic side have higher amplitude compared to normal side (Table 2).

Discussion

The SH and IH muscles contribute to hyoid bone stability, generating a neutral resultant force through their contractions. Motoric deficit caused by stroke is frequently followed by skeletal muscle flaccidity. Reduced suprahyoid tension due to flaccidity prompts an increase in infrahyoid tension, maintaining a neutral resultant force.[8] A previous study found that in dysphagia, there was a delayed onset of SH in the starting pharyngeal phase followed by delayed laryngeal excursion.[9]

An impartial quantitative assessment of stroke patients prone to dysphagia is crucial. Among various methods used for evaluating dysphagia, the gold standard for diagnosing and formulating a plan for proper care and its treatment is the fiberoptic endoscopic evaluation of swallowing (FEES) and the videofluoroscopic swallowing study (VFSS), subjectivity remains due to qualitative assessments by doctors. In addition, the VFSS has limitations, such as its high cost, radiation impact, and the need for special equipment and skilled operators.[10]

The active participation of specific muscles in swallowing has been studied by surface electromyography (sEMG). Electrodes on the skin capture the motor unit action potentials generated by muscle contraction. Due to the sequential activation of motor units and an increase in the firing rate of all motor units recruited, sEMG signal's amplitude, which can be graphically represented, increases with an elevated muscular contraction force.[11] sEMG signal can be used to study dysphagia as it serves as an effective indicator of essential mechanical events in swallowing. Consequently, it can be employed to screen for swallowing disorders, including oropharyngeal dysphagia post-stroke.[12]

In sEMG examination, swallowing onset represents the initial contraction of muscles during the swallowing activity. The onset parameter shows the sequence of muscle contractions, showing which muscle group contracts earlier and which experiences delayed contraction during swallowing. This study found that the onset of SH and IH was not significantly different on the paretic side compared to the normal side in dry-swallowing and the 3-mL water test. However, when the volume is increased, the onset tends to be earlier (Table 2). This is in line with the result of the earlier study that bolus volume significantly affects pharyngeal pressure and swallowing timing.[13]

Duration is a parameter used in evaluating the length of the muscle contraction period when swallowing. The tendency of prolonged duration in SH and IH in stroke patients compared to those that are healthy may show a slow reaction in the swallowing process, specifically during the pharyngeal phase. In this study, the duration of SH and IH contractions was not statistically different between the paretic and the normal side when performing a dry and 3-ml-water test (Table 2). The duration of both groups muscle contractions in the dry swallowing test showed a shorter duration than 3-ml-water swallowing, which discovered that the amount of water swallowed affects how long swallowing muscles contract.[14]

Table 2 Electrical Activity Parameters of Suprahyoid and Infrahyoid Muscles in Dry Swallowing and 3-mL Swallowing Test

Electrical Activity Parameters Median Minimum			Suprahyoid				Infrahyoid			
			Median	Min.	Max.	p-value	Median	Min.	Max.	p-value
Dry swallowing	Onset (seconds)	paretic side	0.17	0.01	1.14	0.483	0.05	0.01	1.16	0.328
		normal side	0.17	0.01	1.01		0.06	0.01	3.53	
	Duration (seconds)	paretic side	2.51	1.08	4.51	0.900	2.79	0.55	4.56	0.906
		normal side	2.59	0.71	4.55		2.76	0.00	4.59	
	Time-to-Peak (seconds)	paretic side	1.23	0.33	3.50	0.318	1.20	0.45	3.40	0.399
		normal side	1.23	0.39	2.91		1.29	0.33	3.53	
	Amplitude (mV)	paretic side	20.78	4.08	69.98	0.201	13.98	3.95	51.02	0.301
		normal side	20.73	0.13	393.51		14.43	3.83	53.11	
3-ml-water swallowing	Onset (seconds)	paretic side	0.04	0.01	1.08	0.710	0.04	0.01	0.94	0.495
		normal side	0.07	0.01	1.18		0.06	0.01	0.93	
	Duration (seconds)	paretic side	2.83	0.89	3.74	0.163	2.83	0.99	3.99	0.390
		normal side	2.79	0.55	3.84		2.83	0.99	3.98	
	Time-to-Peak (seconds)	paretic side	1.16	0.35	3.25	0.991	1.22	0.44	3.15	0.186
		normal side	1.22	0.19	2.91		1.33	0.35	3.08	
	Amplitude (mV)	paretic side	22.33	4.51	64.08	**0.023***	13.35	5.54	64.84	0.407
		normal side	20.81	0.12	82.52		14.69	3.64	92.67	

*Significant (p≤0.05); max: maximum; min.:minimum

Time-to-peak is needed for muscle to reach maximal contraction in one swallowing action. This parameter refers to the duration between the onset and the amplitude of the electric signal. In both swallowing tests, this study showed that the time-to-peak for both SH and IH muscles was not significantly different. Subsequently, the same was true with another result in the time parameter variables, showing that the bolus volume was included in the result. The result showed that if the volume increases, the paretic side reaches maximal contraction faster than the normal side.

The time parameters of the electrical signal, which include duration, onset, and time-to-peak, used in sEMG study for swallowing evaluation have lower reliability than the amplitude parameter.[4,15] Studies using time parameters have yielded varied results, influenced by factors such as the limited number of electrodes used for muscle examination and the characteristics of the patients included. This prevents a complete picture of the sequential activity of all the muscles included in swallowing.

Aging can induce physiological changes, potentially affecting swallowing timing. Showing age-related alterations in timing measures has proven challenging, but the literature suggests a correlation with diminished tongue muscular strength. Timing is crucial because a safe and effective swallow depends on careful timing and coordinated contraction of several muscles in the oropharynx. Although it was already clear that older individuals' swallowing mechanisms differed from those of younger adults and the elderly, studies found that many swallow timing characteristics seemed unaffected by aging.[16] The majority of participants in this study were 50 to 59, which may have influenced the result, although the cut-off age for older patients was 60, the characteristics could have affected the results.

Apart from aging, the investigation into potential gender differences in the typical physiological swallowing process has gained recent attention. However, this area requires further study to draw conclusive results. An earlier study showed a gender difference in the length of the cricopharyngeal opening for a 10 mL bolus, with the opening persisting longer in women. Age-related disparities in hyolaryngeal excursion between men and women were likely connected. The proposal suggested that women retained more muscle reserve than men. In addition, it has been observed that variations in the pharyngeal phase of swallowing are due to anatomical differences between men and women, in which the pharynx is more extended in men than women. However, this conclusion is still subject to debate, as a recent study suggested that age and gender did not significantly impact the oral transition of the bolus. Earlier studies showed that age and gender have a significant effect on the bolus's oropharyngeal transition and could vary depending on the bolus volume. In Table 1, data showed that the patients gender proportion was almost the same between men and women, minimizing potential influence on the results.[17]

Studies have indicated that crucial factors in determining the prognosis or severity of dysphagia include the location and severity of the initial stroke. Previous studies showed that dysphagia may be influenced by brainstem or posterior circulation abnormalities. However, in some studies, the site of the stroke was not associated with dysphagia, which means that the initial severity of the stroke was found to be the leading risk factor for dysphagia.[18] There is a need for further due to the discrepancies in the studies about the relationship between these parameters and sEMG in patients with dysphagia.

The oropharyngeal sensory receptors modulate the swallowing motor response, which controls the physiological swallowing reaction. A higher amplitude of the electrical signal of a contracting muscle is caused by an increased release rate of motor units or an increased number of recruited motor units.[19] As shown in Table 2, this study found the SH amplitude to be higher than the IH amplitude in both maneuvers. Physiologically, SH and IH muscle groups work together in elevating the larynx and hyoid bone. Previous investigations have shown that the IH muscles are engaged during the oropharyngeal motor response sequence after the SH muscle. Subsequently, IH having a lower amplitude than SH shows that SH muscle is more dominant in keeping the larynges elevated during swallowing.[19] In the dry swallowing test, the amplitude did not significantly differ between the paretic and the normal side. The amplitude was significantly different in the 3-mL water swallowing test. If the bolus is bigger, the amplitude increases, showing SH needs more effort to swallow in line with the higher bolus.

The swallowing function may be accurately and objectively estimated using sEMG. This procedure was reliable, non-invasive, radiation-free, affordable, effective, and easy to use. The widespread adoption of sEMG as a dysphagia screening method faces challenges due to the need for anatomical expertise, as accurate electrode placement in specific regions is crucial.[20] This study method uses four electrodes to record different muscle activities (suprahyoid and infrahyoid muscles) associated with swallowing to make it a simple and non-invasive tool to quantify muscle activity during swallowing.

An earlier study using the same sEMG procedure has successfully showed the evaluation of muscle activity in swallowing using quantification methods in the time domain. In comparison between healthy patients and post-stroke patients, the result showed that contraction duration and time to peak of maximum contraction in healthy patients were shorter than in stroke patients. This study found that the evaluation using the time domain method for swallowing analysis is promising and holds the potential to support dysphagia screening.[7] Further analysis in the time domain for the pattern of SH and IH contraction in the dysphagia sample showed no specific pattern, except for the amplitude, where some limitations may come into play.

This study used sEMG on suprahyoid and infrahyoid muscles to compare the muscle activity during swallowing and tried to explore all available parameters in detail. However, some limitations need to be addressed in further studies. This study did not measure sensibility in oral, pharyngeal, and laryngeal areas that may influence motoric control when swallowing in stroke patients. The swallowing test only used a small volume of water, which may not give an accurate picture of muscle electrical activity during daily swallowing activity.

This study has limitations, as it exclusively used stroke patients without healthy control patients, preventing a comparison of electrical activity parameters between the two groups. Further studies with a control group that matches the age, gender, and other comorbidities should be carried out to minimize bias that may become confounding factors. Besides that, to evaluate anatomical active participation in the swallowing process, standard tools such as Flexible Endoscopic Evaluation of Swallowing (FEES) or videofluoroscopy are also needed as objective tools for dysphagia diagnosis.

In conclusion, quantifying SH and IH contractions in swallowing in the acute phase of stroke using sEMG resulted in varied outcomes with no specific pattern. This shows that, except for amplitude, the contraction of the SH and IH muscles on the paretic side did not differ significantly from the normal side. Despite the significant difference in amplitude, the results showed the potential use of sEMG in screening dysphagia during the early phase. The quantification through sEMG results showed that SH-dominated and varied volume boluses produced different results. Subsequently, future studies should use a larger sample in a cohort study, more diverse swallowing activities (different volume and viscosity), and a control group (healthy patient group) that matches the age, gender, and other comorbidities that may become confounding factors. This study serves as a preliminary analysis, and future study is essential to uncover additional parameters in muscle activity for screening dysphagia. Establishing a cut-off value for the electrical activity of swallowing muscles using sEMG in the early phase of dysphagia can be explored as a complementary procedure alongside FEES and VFSS.

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