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Dysphagia Evaluation by Using Cross-correlation coefficient of Surface Electromyography

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Abstract: *Swallowing disorder, also called dysphagia, is a common complication caused by strokes. The dysphagic patients usually have clinical problems such as choking, malnutrition, significant weight loss, and aspiration pneumonia. Surface electromyography(EMG) provides a simple, non-radioactive, and non-invasive method to measure the muscle activity patterns during swallowing to describe physiology of swallowing behavior. Most of previous studies described the swallowing behavior by the terms of amplitude and latency. However, there is no objective and precise approach to evaluate swallowing coordination. In order to evaluate swallowing coordination more precisely, surface EMG of bilateral muscles involving in swallowing were recorded and the cross-correlation analysis was used. The variations of the cross correlation coefficients were defined as the discoordination index (DI), which reflects the difference between the surface EMG patterns of the bilateral muscle groups. Dysphagia stroke patients and healthy subjects were recruited for sEMG recording. The result shows that the discoordination indexes for dysphagic patients were significantly larger than those for healthy subjects in submental muscles and can be used as an effective way for quantification of the coordination between bilateral swallowing muscles in future studies.*

Keywords: *Discoordination index, dysphagia, surface electromyography*

1. INTRODUCTION

Dysphagia is a common medical disorder caused by strokes, structural lesions, muscular disorders, and other central neurological impairments [1]. In the United States, about 15 million patients are affected by swallowing disorder every year [2]. Swallowing is a complex neuromuscular activity, which involves multiple muscles and nerves working in sequence or in coordination to process food from oral cavity, through pharynx and esophagus, and finally to the stomach.

Clinically, stroke is the most common cause of dysphagia. The incidence of dysphagia after stroke is around 23% to 50% [1], and even in unilateral stroke patients, there are 30 % of patients suffered from dysphagia [3]. In stroke patients, dysfunction of the oral cavity is common along with pharyngeal dysfunction. Deficits in mastication, sensory impairment in the oral and pharynx, weakness of the pharyngeal constrictor musculature, or impaired opening of the upper esophagus sphincter can all contribute to dysphagia after stroke. In these patients, malnutrition, dehydration and aspiration pneumonia can occur and lead to serious medical consequence. [4, 5]

Numerous ways were established to evaluate swallowing dysfunction. These include bedside swallow evaluation, 3-ounce water swallow test, videofluorography swallow study, fiberoptic endoscopic evaluation of swallowing, esophagoscopy, manometry and electromyography. To date, videofluoroscopic swallow study (VFSS) is the criterion standard in dysphagia diagnosis and a very helpful tool in evaluating the efficacy of postural or behavior compensatory strategies being applied. [1, 6, 7]. However, VFSS has disadvantage of cost and radiation issues [6].

Recently, the utility of surface electromyography (sEMG) has been widely developed and used as an assistance in swallowing evaluation and biofeedback therapy. sEMG is a simple, non-radioactive, non-invasive screening tool to measure activity patterns of muscles among various muscles during swallowing [6, 8-14], and is suitable for identifying the occurrence of swallowing, and describing physiology of swallowing. In 1997, Crary and Baldwin [10] proposed a method to evaluate swallowing coordination from sEMG signals of patients with brainstem stroke. The patterns of three-channel sEMG were used to evaluate the level of swallowing coordination. They also indicated that the swallowing coordination of dysphagic patients in amplitude and timing were more mismatched than that of healthy subjects. In 2004, Vaiman et al. attempted to establish normative sEMG database for different swallowing conditions [12]. However, the classification of these sEMG patterns was by using subjectively observation of sEMG pattern and lack of a comparable and quantificable measure.

During a swallowing process, orbicularis oris (OO) and masseter (MS) primarily contribute to labial musculature for ensuring adequate seal and chewing in the oral phase respectively. Submental muscle groups (SUB) and laryngeal strap muscles (LSM), on the other hand, contribute to the elevation and anterior movement of the hyoid and larynx, and subsequently opening the upper esophageal sphincter. In normal swallowing, these muscles work in sequence and synergic bilaterally to help propelling the food, whereas, such mechanism can be impaired after cerebral vascular event [15]. When sEMG is recorded during swallowing, amplitude and duration of muscle activity can be recorded, i.e., we can get all the information, such as the peak and occurrence time of muscle contraction.

In our study, sEMG of bilateral orbicularis oris, masseter, submental muscle groups, and laryngeal strap muscles were recorded and further analyzed in order to investigate the discoordination between bilateral sides in dysphagic patients. Cross-correlation analysis [16,17] was used to determine the correlation between the sEMG patterns of bilateral muscle groups (OO, MS, SUB, and LSM muscles) during swallowing process. The variations of the cross correlation analysis were defined as the discoordination index, which could reflect the difference between the sEMG patterns of the bilateral muscle groups. We hypothesized that the discoordination index would be larger in the dysphagic patients than the healthy subjects, which means that greater discoordination between bilateral muscles in dysphagic patients. We also proposed this discoordination index as an analyzed tool to evaluate the original signals of amplitude and duration seen in sEMG and in hope to provide a quantificable and measurable information of the coordination in swallowing muscles.

2. METHODS

2.1 Experiment Procedures

A total of 31 subjects participated in this experiment. The control group contained nineteen healthy adults, including seven men and twelve women with no history of swallowing problems or other neurological diseases. The mean age is 59.7 years old, varying from 44 to 76 years old. The experimental group contained twelve dysphagic stroke patients, including eight males and four females, with the mean age of 64.5 years old. These were all first-ever, unilateral stroke occurred in recent one year and were proven by magnetic resonance imaging with four right hemisphere stroke, three left hemisphere stroke, one right brainstem stroke, and four left brainstem stroke. The dysphagia condition were all confirmed by Videofluoroscopic swallowing study (VFSS) as well, including delayed of trigger, excessive residual in piriformis sinus or velleculae, insufficient opening of upper esophageal sphincter, penetration and aspiration. This study was approved by the institutional review board of the Chi-Mei medical center.

According to Vaiman's suggestion [11], four pairs of sEMG electrodes were placed on bilateral muscle groups of OO, MS, SUB, and LSM muscles respectively. A wireless multi-channel EMG acquisition module [18,19] was designed and implemented to collect sEMG data. The gain of amplifiers were set to 5000 times with the frequency band of 100 Hz ~ 1000 Hz, and the sampling rate was set to 2000 Hz. The system resolution was set to 12 bits. The data collected from the electrodes were transmitted to the computer via Bluetooth connections. The muscles are symmetrical and related to the swallowing process [6, 11]. Before the test, the participant was instructed to sit on a chair, and his/ her skin was cleaned by 75% alcohol. During the experiment, the participant was instructed to hold 5 mL water in his/ her month, and then swallow water as the instructor performed the swallowing command. The participant was instructed to stop the swallowing experiment, if aspiration occurred. Each participant was recorded only once. Here, the approach of independent t test was used to analyze data in this study. The significance is defined by $p < 0.05$.

2.2 Coordination Evaluation Approach by Using Cross-correlation Coefficient

In the pre-processing procedure of the coordination evaluation approach (Fig. 1), the raw sEMG signal was full-wave rectified first [8], and the root mean square (RMS) of sEMG signal was calculated from the rectified sEMG signal with the window length of 400 millisecond. Next, the onset and offset of the sEMG corresponding to the swallowing activity was obtained.

Here, the onset is defined as the point where sEMG signal begins a sustained increase from baseline [10]. The offset is defined as the point where sEMG signal returns to the baseline. In order to determine the onset and offset of sEMG, the threshold defined as the 3 standard deviation above the sEMG baseline is used. When the sEMG exceeds the threshold from the sEMG baseline and stay above the threshold for 200 milliseconds, the time point is the onset point. When the sEMG return to the threshold and stay below the threshold for 200 milliseconds, the time point is the offset point [10]. Fig. 2 and 3 demonstrated surface EMG signals and cross-correlation coefficient of (a) OO, (b) MS, (c) SUB, and (d) LSM obtained from healthy subject and dysphagic patient respectively. After calculating the RMS of sEMG and its onset and offset point for swallowing process, the cross correlation between the RMS of one-second bilateral sEMG signals was calculated.

Cross correlation is widely used to estimate the correlation between two signals. Let $\mathbf{x}(t) = [x(t), x(t-1), \ldots, x(t-N+1)]$ and $\mathbf{y}(t) = [y(t), y(t-1), \ldots, y(t-N+1)]$ denote the vectors of the RMS of one-second right-side and left-side sEMG signals at iteration t, respectively. Then, the value $r(t)$ of the cross-correlation coefficient between $\mathbf{x}(t)$ and $\mathbf{y}(t)$ at iteration t can be calculated by

$$r(t) = \frac{\sum_{l=0}^{N-1}(x(t-l)-\bar{x})(y(t-l)-\bar{y})}{\sqrt{\sum_{l=0}^{N-1}(x(t-l)-\bar{x})^2 \sum_{l=0}^{N-1}(y(t-l)-\bar{y})^2}} \qquad (1)$$

where $\bar{x}$ and $\bar{y}$ denote the mean RMS values of the right-side and the left-side sEMG signals, respectively. $r(t)$ describes the similarity between the two signals, with a value of 1 indicating the signals are identical and 0 indicating completely disassociated signals. The small magnitude variation in signals during that time might be electrical interference and equally present on both sEMG recordings. Therefore, the variation of cross-correlation coefficient between the onset point and the offset point was used as a discoordination index δ to estimate the difference between the bilateral sEMG patterns over time. The discoordination index δ is defined as the deviation from the value 1 of the cross-correlation coefficient during a sEMG activity, and can be given by

$$\delta = \frac{\sum_{k=t_{onset}}^{t_{offset}}(1-r(k))}{t_{offset}-t_{onset}} \qquad (2)$$

where t_{onset} and t_{offset} are defined as the first onset point and the last offset point between the two bilateral sEMG signals, respectively.

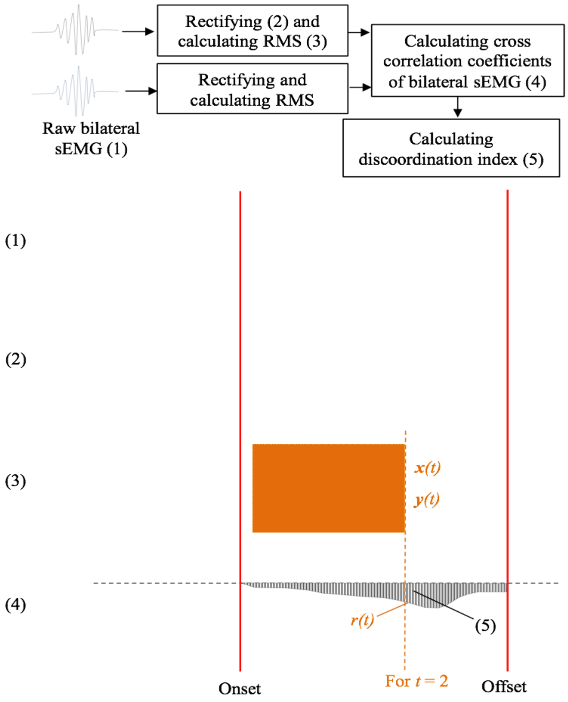

Figure 1: *Procedure of coordination evaluation approach.*

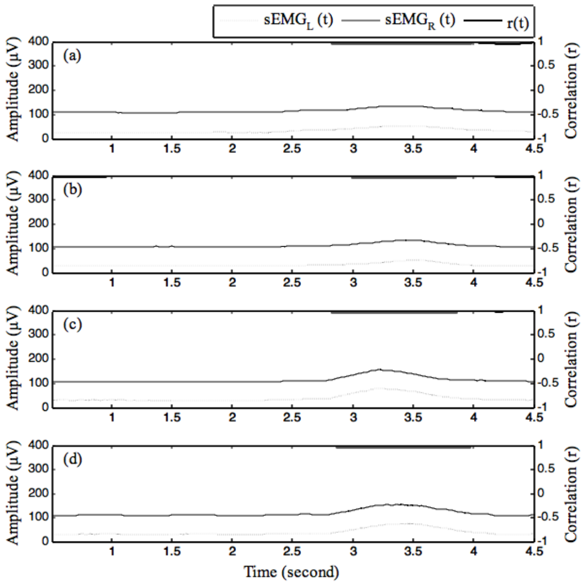

Fig 2: *Surface EMG signals and cross-correlation coefficient of (a) OO, (b) MS, (c) SUB, and (d) LSM obtained from one of healthy subjects.*

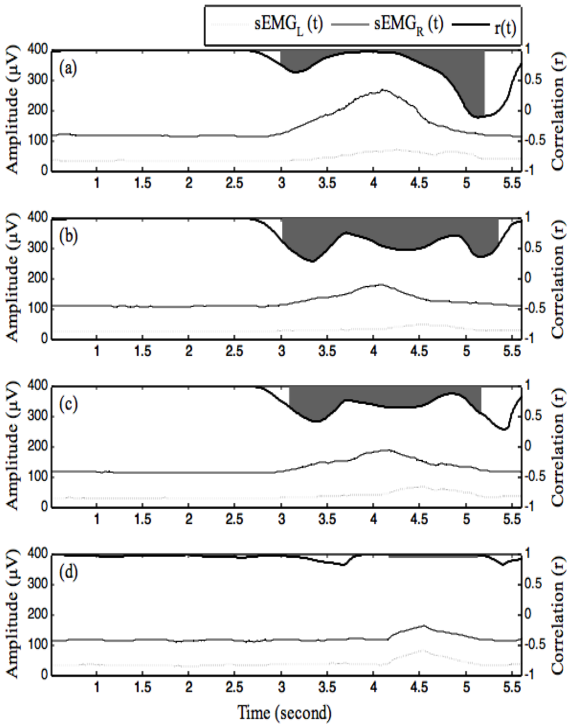

Fig 3: *Surface EMG signals and cross-correlation coefficient of (a) OO, (b) MS, (c) SUB, and (d) LSM obtained from one of dysphagic patients.*

3. RESULTS

In this section, the statistics analysis of the four discoordination indexes for the experimental and control groups were investigated. Table 1 presented the mean values and the standard deviations (SD) of the discoordination indexes for the experimental and control groups, corresponding to the activities of swallowing 5 mL water. It showed that, for all of the four muscle groups, the mean values of the discoordination indexes in the experimental group were larger than those in the control group. For the muscle groups of OO, MS, and SUB, their differences of the discoordination indexes between the experimental and control groups were significant.

4. DISCUSSION

From the result of our study, discoordination index was significantly larger in the muscle groups of OO, MS and SUB among stroke patients. The discoordination shown in the dysphagia group came from the disparity of sEMG signals including onset and offset, amplitude and duration obtained from both sides. With the discoordination index, all these differences were summed up into one amount for better interpretation.

Furthermore, in our study, four sets of muscles were targeted for sEMG recording, including OO, MS, SUB and LSM. These muscles were chosen partly because sEMG can only detect muscles that are superficial and easily attached by the surface adhesive electrodes. The other reason is that previous studies suggested swallowing is a synergistic response therefore these muscles can be treated as representative targets when assessing swallowing [20]-[23].

Physiologically, OO and MS primarily contribute to labial musculature for ensuring adequate seal and chewing in the oral phase respectively. SUB and LSM, on the other hand, contribute to the elevation and anterior movement of the hyoid and larynx, and subsequently opening the upper esophageal sphincter. From our result, only OO, MS and SUB were shown to be increased in the discoordination index with the exception of LSM in the dysphagic group. The discoordination shown in the dysphagic group is compatible with previous study [24, 25]. The reason of the exception of LSM, in the discoordination index, might be related to the anatomical position of the LSM. LSM are composed of thyrohyoid, sternohyoid, sternothyroid and omohyoid which are close to the midline of the larynx. However, during sEMG recording, at least 2cm of spacing is recommended between each sensor for preventing cross-talk contamination, i.e., preventing signal interference with each other. Due to the close distance of LSM from the sound and lesion side, signal interference is inevitable and contribute to the insignificant finding shown up in the discoordination index [26].

5. CONCLUSSION

A novel approach by using cross-correlation coefficient was proposed to evaluate the coordination of the bilateral muscle groups for dysphagic patients with unilateral stroke and healthy adults in this study. The experimental result showed that the discoordination indexes of OO, MS, and SUB muscle groups for dysphagic patients were significantly larger than those for healthy subjects under different swallowing conditions. Different from other previous studies which used the terms of amplitude and latency to describe the swallowing coordination, the proposed approach can provide a more objective perspective on the swallowing coordination.

6. STUDY LIMITATION

A very large distribution of the discoordination index with a high SD was found in the dysphagic group. A small sample size and different ischemic location of our dysphagic patients could contribute to this. Further studies with larger sample size are required. Nevertheless, marked increased of discoordination index were found in the dysphagic group when compared with the normal group showing that the method we use are effective to discriminate the discoordination of swallowing muscles.

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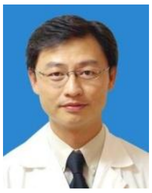
AUTHORS' BIOGRAPHIES



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