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A Pilot Study of High-Density Electromyographic Maps of Muscle Activity in Normal Deglutition

Bin Yu, Mingxing Zhu, Lisheng Xu, and Guanglin Li, *Senior Member, IEEE*

Abstract — **While various methods have been used to study physiological aspects of swallowing, few studies have been conducted to investigate the dynamics of a swallowing procedure with the activation pattern of swallowing muscles. In this pilot study we investigated the feasibility of surface electromyographic (sEMG) dynamic topography as a new approach for continuously visualizing muscle activity of normal swallowing. The dynamic sEMG topographies (or potential mappings) of swallowing were constructed with high-density sEMG recordings from three subjects without any swallowing disorders. The root mean square (RMS) of the sEMG signals was calculated as a function of both position and time to produce two-dimension dynamic sEMG maps of the muscle activity during swallowing. The sEMG maps could provide the information about the dynamic characteristics of swallowing muscles, which is accordance with physiological and biomechanical laws of a normal swallowing. With the results of the present study, we might conclude that the dynamic topography would provide a noninvasive means to continuously visualize the distribution of surface EMG signals of complex muscle activities of normal deglutition.**

Keywords: **Normal deglutition, high-density surface, electromyography, sEMG maps, deglutition disorders**

I. Introduction

Swallowing in human or animal has a complex mechanism using both skeletal muscle (tongue) and smooth muscles of the pharynx and esophagus, where the autonomic nervous system (ANS) would coordinate this process in the pharyngeal and esophageal phases. The difficulty in swallowing or dysphagia is a common disorder among all age groups of human, especially the elderly. So understanding the dynamics of normal swallowing would be helpful in recognizing a swallowing disorder and be critical in developing a proper and efficient treatment protocol.

A variety of techniques have been proposed in many previous studies with an attempt to understand the physiology and biomechanism of normal swallowing and/or dysphagia. For example, both videofluoroscopy and endoscopy [1] can provide the information on the movement of anatomic structures during swallowing. Pharyngeal manometry [2] can be used to assess esophageal motor activity during the pharyngeal stage of swallowing. While these techniques could provide some inferential information about the activities of swallowing muscles, the best way to explore the muscle activities during swallowing should be electromyography. The sEMG outperforms radiographic, manometric, and endoscopic procedures for the study of deglutition since it directly corresponds to the physiological response of muscle contraction in deglutition and could be non-invasively acquired from neck surface.

Most of the previous studies used intramuscular EMG signals from a single muscle or a muscle pair [3-5] to explore the muscle activities in deglutition. A few -channels (generally from 1 to 4 electrodes) EMG recordings may provide some valuable information about the properties of the muscles related to deglutition. However, the EMG recordings from a limited number of channels may not provide the complete information about the dynamics of a whole swallowing procedure since a normal deglutition may involve 26 muscles and five cranial nerves [6]. Obviously, with a whole swallowing procedure that requires a complex sequence of oral and pharyngeal events for the passage of a bolus into the esophagus, studying the dynamics of swallowing-related muscles would be important and helpful for evaluation of deglutition ability and/or swallowing disorders. This requires a method to simultaneously observe the activities of all the muscles related to a swallowing procedure.

High-density electrodes array technique is a recently proposed and used method for investigation of whole and fine information on activities of muscles [7-11]. The sEMG recordings with two-dimension (2D) arrays on a wide area of muscles [7] and the processing of signals in the space dimension could overcome some of the drawbacks of single-channel approaches, providing the spatial properties of the electrical muscle activity [8]. This new approach have been applied in several neurorehabilitation fields, such as the diagnosis of neuromuscular disorders [9], assessment of muscle conditions[10], and sport medicine[11]. Based on our knowledge, there is no report on utilizing high-density sEMG technique in the study of deglutition. In this study, the feasibility of high-density sEMG dynamic topography as a new approach for continuously visualizing muscle activity of the normal swallowing would be investigated. The high-density sEMG signals were recorded with an array of closely spaced electrodes from neck muscles and were used to construct sEMG topography or maps during a normal swallowing. These EMG maps would provide rich

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B. Yu, M. Zhu, and G. Li are with the Key Laboratory of Health Informatics of Chinese Academy of Sciences (CAS), Shenzhen Institutes of Advanced Technology, CAS, Shenzhen, Guangdong 518055 China (Phone: 86-755-86392219; e-mail: gl.li@)siat.ac.cn.).

L. Xu is with the Sino-Dutch Biomedical and information Engineering School, Northeastern University, Shenyang, Liaoning 100044 China.

information about the dynamics of muscle activities in deglutition. Furthermore, these EMG maps might be used as a potential means for the evaluation and/or diagnosis of swallowing capability and disorders.

II. Methodology

A. Subjects

Three young volunteers (one female and two males, age range: 23 to 25) participated in the pilot investigation. The subjects reported no history of dysphagia or any medical problems or took medications that might affect swallowing. The protocol of this study was approved by the Institutional Review Board of the Shenzhen Institutes of Advanced Technology, China. All subjects gave the written informed consent and provided the permission for publication of photographs with a scientific and educational purpose.

B. sEMG Acquisition

For each subject, a grid of monopolar surface EMG electrodes was evenly placed over the front of neck region (covering submental and infrahyoid muscle complexes) for sEMG acquisition. Fig. 1 shows the electrode-array placement on a subject and the alignment in the neck region. Each electrode had a circular recording surface with 5-mm diameter. The two-dimension (2D) electrodes grid was composed of 96 electrodes (16×6 array) with a center-to-center distance between adjacent electrodes of around 10 mm. A reference electrode was affixed to the right wrist. The subject's skin was scrubbed with alcohol and electrodes were coated with conductive gel prior to the electrode placement (Fig. 1). The sEMG signals were acquired using a TMSi system (*TMSi, the Netherlands*) with a sampling rate of 1 kHz and a band-pass filtering (10–500Hz).

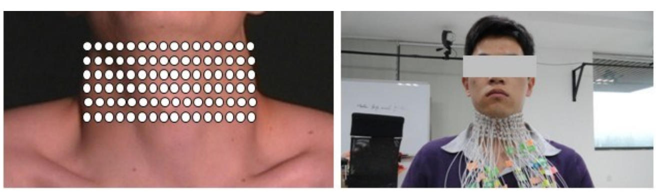

Figure 1. Electrode array alignment on neck region.

C. Experimental Procedures

During the experiment, subjects were seated comfortably and instructed to perform different swallowing tasks. Firstly, the sEMG signals were collected without swallow, which was used for sEMG normalization. And then, three successive swallowing tests, voluntary single swallow of saliva ("dry" swallow), voluntary single swallow of 5 ml water from an open cup ("normal test"), and voluntary single swallow of 15ml water from an open cup ("stress test"), were performed for each subject. The subjects did the same swallowing task three times for each test. For a water swallowing test, subjects were asked to hold the water bolus in the mouth for a while and then to get started swallowing normally. During swallowing, the subjects retained their head forward and avoided any head and facial movements.

D. Signal processing and data analysis

In the analysis of high-density sEMG signals, the raw sEMG recordings were rectified and filtered initially. An independent component analysis (ICA) was used to remove 50 Hz powerline influence and ECG artefacts. The EMG recordings were segmented into a series of 100-ms analysis windows and the RMS value, which represented the averaged power of EMG signals over each analysis window, was calculated for each of 96 channels. The 96-channel RMS values were reformed to a 16×6 matrix for each analysis window. Then each 16×6 matrix of RMS values were extended into a 1500×500 matrix using a linear cubic spline interpolation method and the extended matrix was used to construct a 2D color topography for each analysis window using different color tones (cold to hot color). In sEMG topography, the distribution of sEMG intensities and myoelectrical activities on the surface of the neck muscle area were visually inspected. By displaying the topography slide by slide, the streaming topography would represent the spatial distribution of muscle activities during swallowing.

III. Results

A. Dynamic sEMG topography in a swallowing process

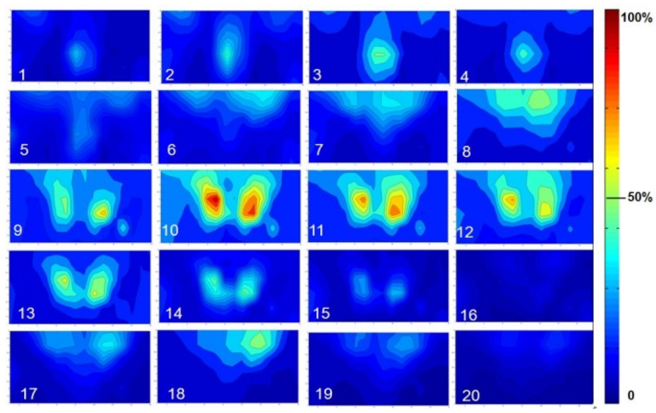

Figure 2. The sEMG RMS topography of swallowing(15ml water). The color bar shows the percentage of the global maximum value of EMG RMS.

For each subject, twenty consecutive frames of sEMG RMS maps were constructed from the sEMG recordings during a swallowing process with a time interval of 100ms in the study. Fig.2 shows the typical sEMG RMS maps during a normal swallowing of 15ml water for subject #1. These sEMG maps were globally normalized with the maximum value of EMG RMS values in all 20 frames. The dynamic sEMG topography could reflect the information about the dynamics of swallowing and presents muscle contraction coordination related to swallowing. In the early stages of swallowing (numbered 1-4 frames), in which the subject just held the water in his mouth, the EMG maps show a single activity area around the center of maps. With an actual swallowing start, the EMG activities were split into two parts in the EMG maps (Frames#5 to #16). The two symmetric EMG activity areas were located at the top of maps near the palate at the beginning of swallowing, and then moved downward and the intensity of EMG activities were gradually increasing along swallowing progress. The EMG activities achieved the peak in the middle of deglutition (Frame# 10).

After that, the intensity of EMG activities was weakening and finally disappeared at Frame#20. These typical dynamic patterns of muscle activation also were seen consistently in other two subjects.

B. *Comparison of sEMG topography in different swallowing tasks*

The comparison for the dynamic EMG maps of three swallowing tests revealed no significant differences between 5 ml water swallow and 15 ml water swallow, but both were significantly different from dry swallow. Figs.3-4 show the dynamic swallowing sEMG maps of 5ml and 15ml water from the same subject (subject #1).

The dynamic EMG maps for swallowing of 5ml water exhibited similar patterns of muscle activity (Fig. 3). The high sEMG activity was present in the center of maps in the early stages of swallowing (numbered 2-3 frames). In the actual process of swallowing (Frames#5 to #15), the location of high intensity sEMG activity was moving down gradually from the upper edge to central area of maps and then disappeared. These results are remarkably similar to those found in swallow of 15 ml water (Fig. 2).

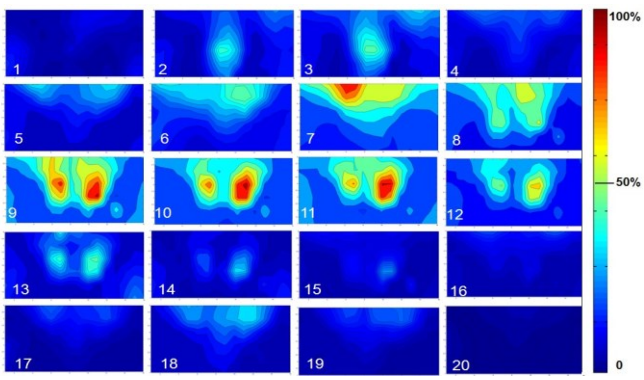

Figure 3. The sEMG RMS topography of swallowing (5ml water)

The difference in sEMG maps of dry swallow was mainly embodied in the early and final stages of swallowing (Fig. 4). In the early stages (numbered 1-4 frames), there was no obvious high sEMG activity presented on maps. In the final stages (numbered 17-20 frames), long-lasting high intensity sEMG activity could be observed in the center of maps. The maps for actual process of swallowing (From frames#5 to #16) demonstrated the similar patterns of muscle activity as the swallows of water.

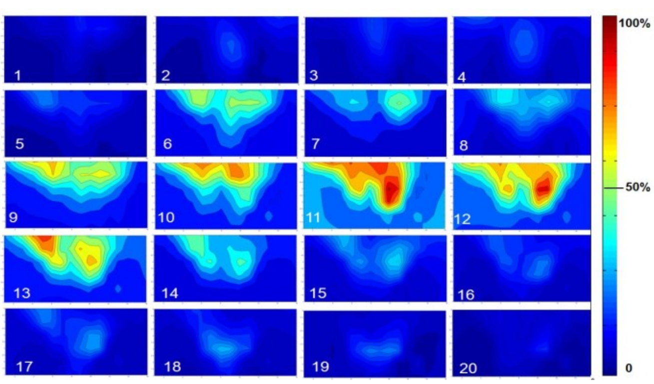

Figure 4. The sEMG RMS topography of swallowing (dry swallow)

C. *Comparison of sEMG topography in different subjects*

For a swallowing task, the distribution patterns of sEMG signals revealed overall consistency for all the subjects, as shown in Figs. 2-4. However, some difference of sEMG maps also could be seen among subjects. The RMS of 25 continuous intervals during the entire swalloiwng process was averaged. Fig. 5 shows the averaged sEMG RMS maps over a complete swallowing procedure of 15ml water in the three subjects. These sEMG maps showed symmetric muscle activities on both the left and right sides and the high intensity at the upper edge and the center of the maps, representing two major muscle groups involved in swallowing (submental and infrahyoid muscle complexes).The major differences among the three subjects were the locations and the values of highest activity in sEMG maps .

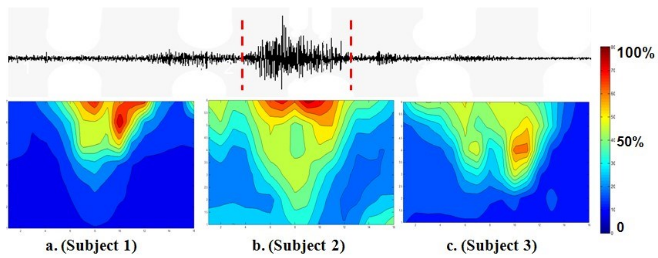

Figure 5. Average sEMG topography over a complete swallowing of 15ml water in three subjects (the muscle activity between the two red vertical lines)

IV. Discussion

Surface EMG is well known as a non-invasive and ease-to-measure means for evaluation of muscle electric activities. sEMG signals also have been used for the assessment of deglutition with/without disorders [3-5]. However, these previous studies for sEMG evaluation of deglutition have some limitations [12]. One of major issues is that a limited number of EMG electrodes were used to evaluate the complex muscle electric activities in deglutition. High-density surface EMG technique could overcome some of the drawbacks of few-channels approaches, providing dynamic visual maps of global distribution of electrical muscle activity during swallowing. The major advantage of using high-density sEMG map may be related to its ability to visualize muscle activity during dynamic swallowing process.

In the present study, the feasibility of high-density sEMG maps to visualize neck muscle myoelectric activity in normal deglutition was investigated in the subjects using the high-density sEMG maps that might provided a new view to analyze the dynamics of swallowing. The major objective of this study was to provide a basis of the dynamic sEMG topography of complex muscle activities in a normal swallowing for the comparison of swallowing ability between normal deglutition and dysphagia.

From the results of this study, we can know that high-density sEMG topography could provide the information about the spatial properties of the electrical muscle activity and present a global distribution of sEMG activities from many muscle groups related to swallowing, as shown in Figs. 2-5. Different from a previous study [13] which investigated only the sEMG of an individual muscle, the present study, for the first time, evaluated the dynamic activities of swallowing-related muscles by using a high-density EMG recording method. The topographic technique applied in this study was intended to identify the contour of myoelectric activity, thus comparison of activities was made in the topography but not individual channels through time. The RMS value was used to describe myoelectric potential of the neck region in this study. With the RMS calculation of sEMG signals from the electrode array, the distribution of EMG activity was obtained. To visualize the EMG activity, topography of RMS distribution was plotted to interpret the coordination of muscles. However, single topography is limited with a static representation of muscle contraction distribution. Through concatenating sequent topographies, a streaming topography can be played to present the muscle contraction synergy during the swallowing. So we conclude that the application of the high-density electrode-array technique might enable the assessment of global muscular activities in the neck region.

In this study, dynamic sEMG topography provides information about the dynamics of swallowing, which is accordance with physiological and biomechanical laws of swallowing described by Koichiro[14]. In the actual swallowing process, the soft palate elevate to push bolus to palatoglossal arch of the oropharynx, submental muscles begin contracting, the location of high intensity sEMG activity rise gradually in the top portion of maps(Fig. 3, frames#5 to #7). Then the pharyngeal reflex began, bolus entered the esophagus, and the much higher intensity sEMG activity produced by infrahyoid muscle complexes in the central area of maps(Fig. 3, frames#9 to #13). EMG activity in the submental muscles most often initiated the swallow whereas the infrahyoid muscle activity most frequently terminated the swallow.

Note that the present study was conducted only for three subjects with normal deglutition. To establish a solid basis of EMG maps of normal muscle activities in deglutition, more subjects with normal deglutition will be involved in the future investigation. In addition, the results of the present study were based on the evaluation of a single material (water) or dry swallowing from a healthy cohort of young adults. Because age and swallowing material would impact the swallowing physiology, further investigations will be conducted for the evaluation of EMG maps in these factors. Again, the purpose of this pilot study was to evaluate the ability of dynamic sEMG topography to represent the dynamics of normal swallowing. Furthermore, we will also perform the studies to explore the possibility and performance of the presently proposed method in evaluation and/or diagnosis of abnormal swallowing or dysphagia in following investigations.

V. Conclusion

The dynamic sEMG maps could be a novel method of continuously visualizing overall muscular activity associated with swallowing. With a series of visual maps of global muscle activity, the information about the dynamic characteristics of swallowing muscles would be understood. The advantage of using the dynamic topography technique is its ability to provide the spatial properties of the electrical muscle activity, which allow the continuous visualization of the distribution of surface EMG signals and the coordination of muscular contractions during swallowing. With further investigation, the dynamic sEMG maps might be useful tool for assessment or evaluation of swallowing disorders and dysphagia.

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