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Arduino-based Portable Evaluation System for Dysphagia

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One of the most common complications of stroke patients is swallowing difficulty (dysphagia). In addition, such patients with dysphagia often suffer from a variety of clinical challenges, such as malnutrition, significant weight loss, aspiration pneumonia, and so forth. Most previous studies have described the magnitude and duration of swallowing behavior. However, there is no objective and accurate method to assess whether swallowing abnormalities are accompanied by many of the potential factors that affect the risk of future stroke. To evaluate swallowing behavior more accurately, we designed an Arduino-based portable embedded system for evaluating dysphagia to measure several major muscle groups simultaneously during swallowing. With this system, the changes in the relationship between several major muscle groups are explored as an indicator to effectively reflect the differences in the surface electromyography (sEMG) patterns corresponding to the activities of different muscle groups. The results of this study show that there is a significant difference between healthy people and patients with dysphagia. These indicators of abnormality can be used to effectively assess the difference between the left and right groups of swallowing muscles and the potential risk of stroke in the future.

1. Introduction

1.1 Research motivation

Swallowing is a complex neuromuscular activity that involves multiple muscles and nerves working in sequence or in coordination to pass food from the oral cavity through the pharynx and esophagus, and finally to the stomach. Dysphagia is a medical disease usually caused by stroke, structural disease, muscle disease, and other damage to the central nervous system.(1) In the United States, about 15 million patients are affected by dysphagia every year.(2) Clinically, stroke is the most common cause of dysphagia. The incidence of dysphagia after stroke is about

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20–50%, and about 25–35% of unilateral stroke patients also suffer dysphagia symptoms.[3] In the population of stroke patients, oral dysfunction often co-occurs with pharyngeal dysfunction, chewing, and pharyngeal sensory disturbances. Dysphagia can be caused by a stroke with pharyngeal constriction, muscle tissue defects, or damage to the opening of the upper esophageal sphincter.

In these patients, malnutrition, dehydration, and aspiration pneumonia may occur and cause serious medical consequences.[4,5] Difficulty swallowing can also seriously impact the quality of life, because it prevents the patient from interacting with others while eating. Therefore, it is important to identify and minimize the effects of dysphagia as much as possible.

1.2 Research purpose

To diagnose dysphagia, video fluoroscopic swallowing examination [video fluoroscopic swallowing study (VFSS)] is the most common assessment method for evaluating structural lesions and dysphagia at the oral, pharynx, and esophagus stages.[1,6] To diagnose dysphagia,[7,8] during VFSS, the patient is placed in a sitting position and instructed to swallow different liquids and foods in the radiology room. VFSS can provide detailed information regarding the entire swallowing physiology image from the lips to the esophagus. However, VFSS has disadvantages in terms of cost and radiation issues. Recently, the utility of surface electromyography (sEMG) for swallowing research has been extensively studied. sEMG is a simple, non-radioactive, non-invasive inspection tool used to measure the activity patterns of various muscles during swallowing, making it suitable for identifying the occurrence of swallowing and describing the physiology of swallowing. By sEMG, the activity patterns of specific muscles during swallowing can be observed and quantified. Swallowing is a complex process involving the coordination of various muscle groups.[8,9] To more accurately evaluate the swallowing coordination of patients with unilateral stroke dysphagia, a portable system for dysphagia evaluation was designed in this study, using which several muscle groups can be measured simultaneously during swallowing. In this study, the differences between patients with dysphagia and healthy subjects were compared.

1.3 Related research

The sEMG patterns of specific muscle group activities during swallowing can be observed and quantified. In 1997, Crary and Baldwin[9] proposed a method to assess the swallowing coordination of sEMG signals in patients, where a three-channel sEMG model was used to assess the swallowing coordination level. They also pointed out that patients with dysphagia had lower swallow coordination performance in terms of amplitude and time than healthy subjects. In 2004, Vaiman[10] established a standardized sEMG database for different swallowing conditions. In 2006, sEMG was used to evaluate the condition of patients with Zenker's diverticulum.[11] It was also pointed out that patients with Zenker's diverticulum have a specific sEMG pattern. However, the classification of these sEMG patterns is very subjective and not precise. Therefore, in 2007, Vaiman[12] established evaluation criteria based on sEMG for patients with dysphagia, and since 2008, sEMG has been used to study oral and pharyngeal dysphagia and the swallowing patterns of healthy subjects.[13,14] Figure 1 shows three kinds of evaluation using sEMG: (a) evaluation of the rehabilitation effect of neck and shoulder muscles after surgery, (b) evaluation of muscle fatigue, and (c) evaluation of dysphagia.

2. Experiments

The system consists of a microprocessor unit, a front-end physiological signal amplifier, and a Bluetooth wireless transmission circuit. The microprocessor unit has a built-in Arduino-based embedded system, and the sEMG signal processing mainly involves a preamplifier and a bandpass filter sub-system. The sEMG signal is introduced by the sEMG electrode, and it is preprocessed to eliminate frequency interference and amplified by a signal amplifier. Through the Bluetooth wireless transmission module (Bluetooth v2.0 + EDR specification), the sEMG signal is transmitted to the host system for data analysis.

The microprocessor unit used in this system is the well-known Arduino-based microcontroller development board. It is suitable for constructing digital devices and interactive objects that can perceive and control objects in the physical and digital worlds. Because of the open-source code, it is easy to operate and can be used with a wide range of sensor types. It is easy for the measurement system to be integrated into the development board, and the board has a USB power supply for portable usage, or it can be powered with an external 9 V battery or mobile power supply.

The structure of the whole system is shown in Fig. 2. The general voltage signal collected by the electrode on the skin surface is called the sEMG signal and is composed of continuous myoelectric signals. A myoelectric signal refers to the action of a muscle fiber group when it contracts, and is called an action unit, which is expressed in the form of voltage. A portable monitoring device is used in the assessment of dysphagia. sEMG patterns are widely used with diagnosis applications, such as to measure the strength of thigh and arm muscles or the swallowing degree of esophageal muscles. To clarify the detailed changes in muscle potential, our module uses an oscilloscope to measure the basic operation of the surface muscles and generates a voltage signal, which is used to verify the acquisition and correctness of the

(a) (b) (c)

Fig. 1. (Color online) (a) Evaluation of rehabilitation effect of neck and shoulder muscles after surgery, (b) evaluation of muscle fatigue, and (c) evaluation of dysphagia.

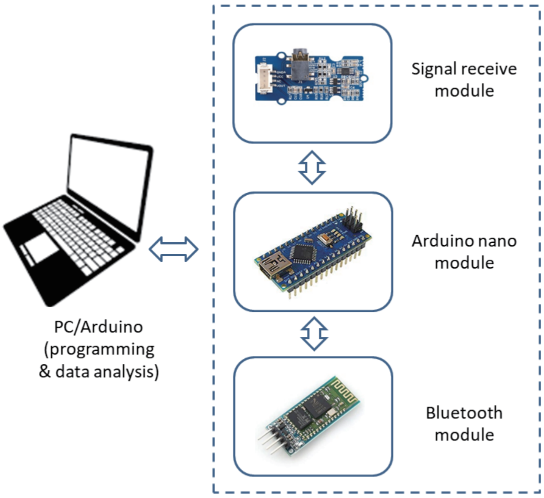

Fig. 2. (Color online) Schematic of the preliminary design of our evaluation system with a signal receive module, Arduino Nano module, and Bluetooth module.

electrophysiological signals of the surface muscles.

In accordance with Vaiman's suggestion, we placed four pairs of sEMG electrodes on the laryngeal band muscle (LSM), masseter muscle (MS), orbicularis oculi muscle (OO), and submental muscle (SUB). The placement of the four pairs of sEMG electrodes is shown in Fig. 3. These bilateral muscle groups are symmetrical and are related to the swallowing process. If patients choked during swallowing or were unable to continue the experiment, the experiment was abandoned.

This study was approved by the institutional review board of Kuang Tien General Hospital. A total of 30 subjects participated in this experiment. The control group consisted of 15 healthy adults (seven men and eight women), and all the members of the control group had no history of swallowing problems or other neurological diseases. The mean age of this group was 60.5 years and the age range was from 45 to 78 years. The experimental group consisted of 15 dysphagic patients (six men and nine women), all with unilateral stroke diagnosed by computer tomography. None of the patients passed swallow screening tests and, moreover, the dysphagia of the patients was confirmed by clinical examination or VFSS. The mean age was 63.4 years and the age range was from 43 to 82 years.

3. Results and Discussion

We observed the four parts of the muscle groups attached to the subject's face, chin, and neck during swallowing, and their incongruity index. Figure 4 shows the means and standard deviations of the duration differences between bilateral sEMG signals corresponding to different muscle groups when swallowing 2 and 5 mL of water.

Each muscle group shows its degree of activation according to its swallowing mechanism. From the experimental results, we can further understand the actions of the left and right muscle groups. The experimental data also show that during the water swallowing test, the action of the

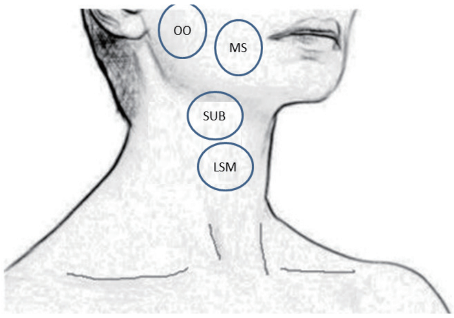

Fig. 3. (Color online) LSM, MS, OO, and SUB activation of the left and right bilateral muscle groups.

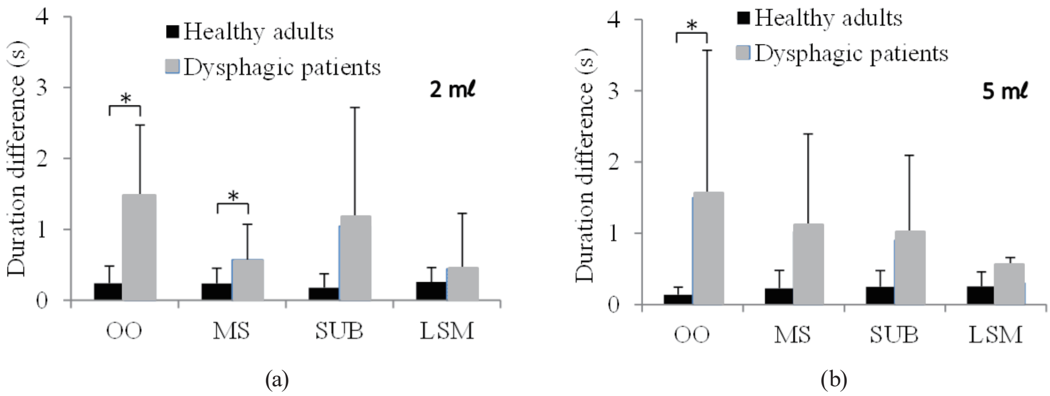

Fig. 4. Means and standard deviations of duration differences between bilateral sEMG signals corresponding to different muscle groups when swallowing (a) 2 and (b) 5 mL of water.

Table 1
Performance comparison of proposed evaluation system and conventional system.

Reference	Basic sensing mechanism	Cost	Selectivity
Conventional system (VFSS)	Optical change	High	Yes
Proposed system (Arduino-based MCU)	Electrical change	Low	Yes

Table 2
BOM list of the proposed system (US$).

Item	Type No.	Quantity	Cost
Embedded system	Arduino Nano	1	< $5
Wireless module	ESP8266	1	< $3
sEMG module	—	1	< $10
Myoelectric sensor	—	8	< $3
Display module	LCD5110	1	< $7
Power module	NORMAL type	1	< $7
Total			< $35

main muscle groups is similar on both sides of the face. Table 1 shows the performance of the proposed evaluation system and a conventional system. Table 2 shows the bill of material (BOM) list of the proposed system in US dollars.

4. Conclusion

In this study, a measurement system for sEMG signals was developed, which can measure the electrophysiological signals of the four main muscle groups, OO, MS, SUB, and LSB, of a healthy person during swallowing. At the same time, the experimental results showed that during the swallowing process, the electromyographic signal amplitudes of the left and right muscle groups of OO, MS, SUB, and LSB of healthy subjects were similar. A preliminary verification of the reliability of the system for measuring the swallowing process was carried out, demonstrating that the system can be used for the clinical diagnosis of dysphagia.

Acknowledgments

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