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Measurement of Swallowing Using Flexible Polymer Sensor

Yusuke Sakaue, Takahiro Shimizu, Motomi Matsushima, Mikiya Matsuura, Katsuei Takahashi, Kazuhiko Asahara, Shima Okada, *Member, IEEE* and Masaaki Makikawa, *Member, IEEE*

Abstract— **We proposed a new method to measure swallowing in this study. A flexible polymer sensor was used to measure human swallowing. Electromyogram (EMG) of suprahyoid muscles were measured as a reference of swallowing. We also developed a measurement system for the flexible polymer sensor, which consists of two measurement circuits; the 1st one measures the voltage of flexible polymer sensor, and the 2nd one EMG of suprahyoid muscles. We conducted measurement experiments focused on human swallowing to confirm the ability of this sensor. At the experiment one subject was asked to sit in three different postures and to drink a cup of water. Results show that human swallowing can be detected by this flexible polymer sensor.**

I. Introduction

Ingestion is very important for human by which energy and sustenance are obtained to maintain healthy body and promote growth of body [1]. Many people feel happy when eating with their own mouth, and disorder of ingestion makes it impossible to maintain the good physical and mental health. Ingestion has possibility to improve quality of life (QOL) and pathology. Therefore in many hospitals and care facilities patients are required to eat with their own mouth as long as possible.

Ingestion consists of two processes: mastication and swallowing. In mastication solid food or semisolid food are changed into small particles by teeth. During mastication saliva is mixed with food particles to make coherent bolus. This is preparation for swallowing and coherent bolus can be easily swallowed [2]. Finally, food is transported from mouth to stomach by swallowing.

Swallowing is the transportation of food bolus and/or saliva from mouth to stomach. Swallowing of bolus is considered conscious movement of esophagus because this swallowing can be occurred by one's own will during eating. On the other hand many swallowing of saliva is considered unconscious motion because this swallowing can be occurred even during sleep. Swallowing can be divided into four stages according to the position of bolus; the first is preparatory stage, the second is oral stage, the third is pharyngeal stage and the fourth is esophagus stage [3]. Of these the preparatory and oral stages are considered voluntary movement and the pharyngeal and esophagus stages are considered involuntary movement. In the preparatory stage, food bolus or saliva is led into mouth and is prepared for swallowing. Hence mastication can be regarded as the first part of swallowing. After mastication, bolus is positioned on tongue. In the oral stage, bolus is rolled into pharynx by tongue. Therefore tongue movement is very important for swallowing. During the bolus transportation into the pharynx, the soft palate is elevated to prevent the bolus flowing in nasal cavity. In the pharyngeal stage, bolus is transported from pharynx to esophagus by swallowing reflex.

Food cannot be transported to stomach when swallowing ability is decreased, and this ability is decreased due to advancing age or diseases. It is generally recognized that a lot of elderly people have swallowing problem. The strength of musculature and ligament tend to decline according to aging and the elderly people ordinarily lose their swallowing ability. Additionally swallowing disorders is accompanied with some disorders, e.g. cerebrovascular diseases, muscular disorders [4].

In many cases patients suffered from swallowing disorders are bedridden and need care for their daily life. Therefore it is very important for clinicians and care persons to evaluate patient's swallowing ability. Evaluation of swallowing ability of patients is said to decrease the risk of aspiration [5]. Therefore many studies related to evaluation of patient's swallowing have been conducted [6-8]. However there still exist some problems in these studies; videofluoroscopic test popular in water injection test is expensive, its equipment is large, it needs long time for evaluation, and it imposes the risk of exposure. About noninvasive tests many sensors and electrodes have to be attached to patient's face, and subjects feel heavy uncomfortable. New measurement method of swallowing for evaluation which is more inexpensive, smaller and easily than existing methods is required in clinical site. In this paper we proposed a new method to evaluate patient's swallowing using the flexible polymer sensor. Their swallowing behaviors can be easily measured by this flexible polymer sensor attached on patient's skin.

As described before swallowing consists of many physiological processes. A lot of muscles are activated during swallowing. Therefore electromyogram (EMG) method has been used to research swallowing [9-10]. There are many muscles from mouth to end of pharynx related to swallowing. However it is difficult to measure EMG of all muscles. Then EMG of a few muscles groups is measured. The two muscles

Yusuke Sakaue is with Graduate School of Science and Engineering, Ritsumeikan University, 1-1-1 Noji-Higashi, Kusatsu, Shiga, 525-8577, Japan(corresponding author to provide phone: +81-77-566-2881; fax:+81-77-561-2665; e-mail:rr003035@ed.ritsumei.ac.jp).

Takahiro Shimizu was with Graduate School of Science and Engineering, Ritsumeikan University, Shiga, Japan. He is now with Kokuyo Co., Ltd.

Motomi Matsushima, Mikiya Matsuura, Katsuei Takahashi and Kazuhiro Asahara are with Kuraray Co., Ltd., 41, Miyukigaoka, Tsukuba, Ibaraki, 305-0841, Japan(provide phone:+81-29-853-1575; fax:+81-29-853-1543; e-mail: Motomi_Matsushima@kuraray.co.jp)

Shima Okada is with Kinki University, Osaka, Japan.

Masaaki Makikawa is with Ritsumeikan University, Shiga, Japan (e-mail: makikawa@se.ritsumei.ac.jp).

groups are mainly used in case of surface electrodes. One group is jaw and perioral muscle and the other is suprahyoid muscles group [11]. The group of suprahyoid muscles consists of mylohyoid muscle, geniohyoid muscle, stylohyoid muscle and digastric muscle. The activity of these muscles works to elevate the hyoid bone. Elevation of larynx is occurred by this activity in the pharyngeal stage of swallowing. This movement is very important to prevent bolus flowing in other oropharyngeal space during swallowing. Suprahyoid muscles group keeps their activities until end of swallowing. Therefore EMG of this muscles group measured by surface electrode has a lot of information about the swallowing. For these reasons, surface EMG of suprahyoid muscles is measured as a reference of swallowing in this study.

II. MEASUREMENT METHOD

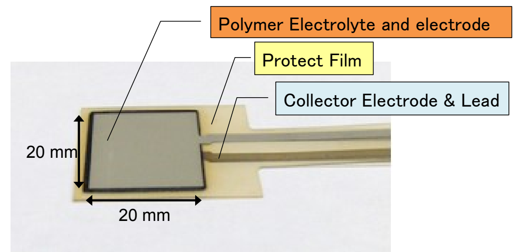
A. *Flexible Polymer Sensor*

A flexible polymer sensor used in this study to measure the swallowing was recently developed by Kuraray Co., Ltd., a Japanese chemical company. A flexible polymer sensor consists of polymer electrolyte, electrode, collector electrode and protect film. This flexible polymer sensor converts its bending curvature to voltage, and is flexible, thin and lightweight because this sensor was made from polymer. Its thickness is approximately 0.5 mm. It can be made into variety shapes, then it can be easily attached anywhere on the skin by double-sided adhesive tape or adhesion bond. The most important feature is that this sensor can keep constant voltage in the same bending curvature comparing piezoelectric sensor. Therefore not only dynamic motion but also static deformation can be measured by this flexible polymer sensor. Moreover this sensor has linearity relationship between output voltage and its bending curvature and it is easily to convert the output voltage to physical deformation. Fig 1 shows an example of a picture and configuration of flexible polymer sensor.

B. *Measurement circuit*

Measurement circuits were developed to measure voltage of a flexible polymer sensor and EMG of suprahyoid muscles. Fig 2 shows the configuration of developed measurement circuits. Developed measurement circuits consists of two differential amplifiers (AD620AN, Analog Devices Co., Ltd.) and two non-inverting amplifiers (TL071CP, STMicroelectronics Co., Ltd.) and RC filter circuits. Total gain of the measurement circuit for a flexible polymer sensor was 60 dB and bandwidth was from DC to 10 Hz. Total gain of the measurement circuit for EMG of suprahyoid muscles was 73 dB and bandwidth was from 20 Hz to 1 kHz. A measurement device was used to measure the output voltage of developed measurement circuits. The measurement device was AD board (AIO-160802AY-USB, CONTEC Co., Ltd.). The sampling frequency was 2 kHz. This AD board was connected to a portable PC. The operating system of this portable PC was windows 7 (32 bits).

a)



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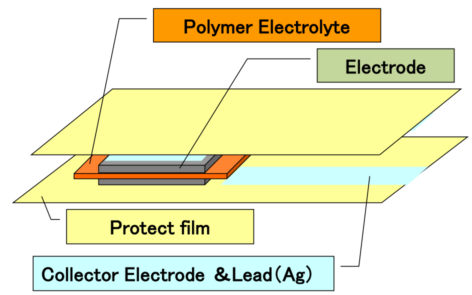

Figure 1. Picture and Configuratoin of flexible polymer sensor; a) is an exmaple of picture and b) is configuration.

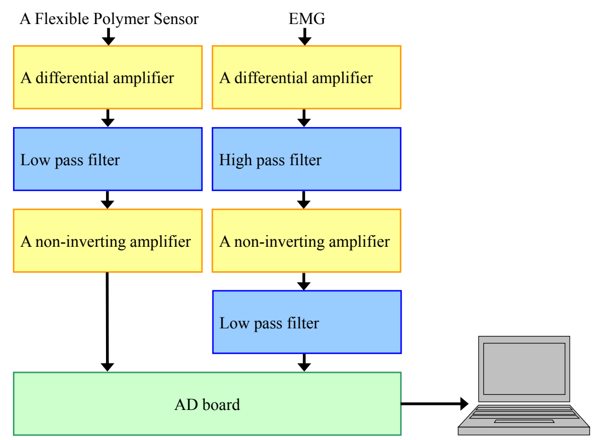

Figure 2. Configuratuin of a developed measurement circuits.

III. EXPERIMENT

A. *Procedures*

We conducted measurement experiments focused on human swallowing. One healthy man was asked to participate as subject. The purpose of this measurement experiments was to confirm swallowing can be measured by a flexible polymer sensor. A flexible polymer sensor was attached on center of prominentia laryngea by double-sided adhesive tape for medical use (MSD-S-1524, 3M Healthcare, Co., Ltd.). The prominentia laryngea moves according to swallowing. Hence a flexible polymer sensor was attached on here. A flexible polymer sensor and its lead wires were fixed by surgical tape on subject's skin. The EMG of suprahyoid muscles was simultaneously measured by bipolar lead as a reference of swallowing. Fig 3 shows the position of a flexible polymer sensor and surface electrodes. Three surface electrodes were attached on subject's skin. A ground electrode was set on left earlap and two measurement electrodes were arranged on about center of anterior belly of digastric in left side. The distance of electrode was approximately 20 mm. This muscle is a part of suprahyoid muscles group. Hence measurement electrodes were attached on here. These surface electrodes were attached using conductive paste after preparation and its lead wires were fixed by surgical tape in the same way as a flexible polymer sensor.

B. Condition

The purpose of this study is to propose new measurement method of human swallowing using flexible polymer sensor and the application for bedridden patients was assumed. Therefore the measurement experiments were conducted in three conditions. The angle between superior and inferior was changed in each condition, and seated positions were defined based on the angle; normal seated position was 90 degree, reclining seated position was 120 degree and supine seated position was 140 degree. These seated positions were assumed as seated posture during the eating. Basically, the normal seated position was assumed as healthy people and the others were assumed as bedridden patients. Fig 4 shows these three different seated positions.

Anatomical mechanism is same in the conscious swallowing and unconscious swallowing. The movement of prominentia laryngea is occurred according to swallowing in both of them. Therefore conscious swallowing was measured in the measurement experiments. A subject was asked to drink a cup of water after in each seated position after about two seconds from beginning of measurement. Amount of water was 10 g. This trial was repeated three times to clarify repeatability.

IV. Result and Discussions

Fig 5 shows an example of output voltage of a flexible polymer sensor and EMG of suprahyoid muscles when the subject drank a cut of water in measurement experiments. In these measurement results, abrupt change is confirmed in EMG of suprahyoid muscles. The time is approximately two seconds. Therefore it is concluded that the change of EMG is elicited by activity of suprahyoid muscles according to subject's swallowing.

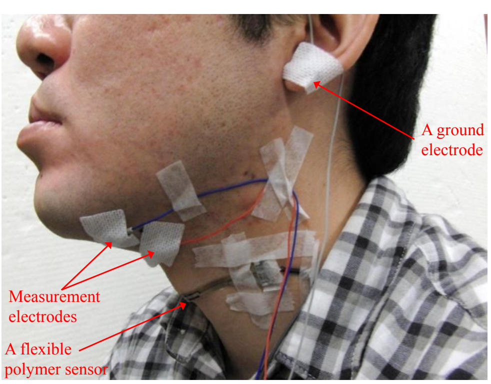

Figure 3. A position of a flexible polymer sensor and surface electrodes for EMG.

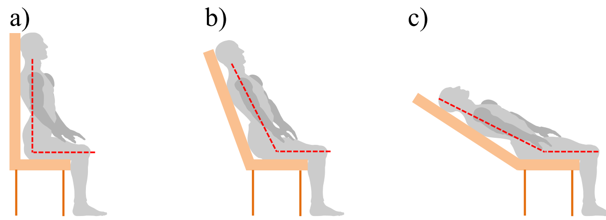

Figure 4. Seated position in the measurement experiments; a) is normal seated position, b) is reclining seated position and c) is supine seated position.

The voltage changes of a flexible polymer sensor are observed at approximately two seconds and synchronized with the voltage changes of EMG of suprahyoid muscles in each result. It is considered that these voltage changes are occurred by the movement of prominentia laryngea according to swallowing. Therefore it is concluded swallowing can be measured by our flexible polymer sensor.

Besides its voltage change of a flexible polymer sensor is different in each seated position: normal position, reclining seated position and supine seated position. It is considered that this different might be occurred by the seated postures because the state of prominentia laryngea would be changed.

V. Conclusion

We proposed a new method to measure human swallowing in this study. A new flexible polymer sensor was adapted in our proposed method. The results of experiments showed that the voltage changes of a flexible polymer sensor synchronized with the EMG of suprahyoid muscles. It was considered that swallowing can be measured by a flexible polymer sensor. Besides the measurement results were different according to sitting postures. This indicates that there was possibility to estimate the subject's postures by a flexible polymer sensor.

A portable PC and AD board were needed to measure swallowing by a flexible polymer sensor in this study. Hence the measurement system was large and heavy and it was difficult to measure for a long time. In near future we will develop a smaller and lighter swallowing measurement device using micro processing unit, will be tested in many subjects. It will become possible to measure for a long time by this device.

Our final goal is to evaluate patient's swallowing to prevent aspiration. The results of this study indicate that swallowing can be measured by more inexpensive, smaller and easier method. In future, the evaluation and diagnosis of swallowing problems could become possible by very simple method using a flexible polymer sensor attached on patient's skin. This method would be practical in clinical cite, the aspiration could be prevented. Moreover decrease of swallowing ability could become gradual by the early diagnosis and treatment of swallowing disorder. This makes it possible to maintain good physical and mental health and improves the patient's QOL.

There is no conflict of interest in this study.

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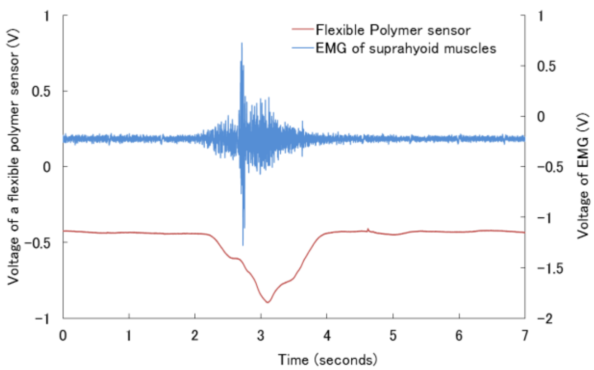

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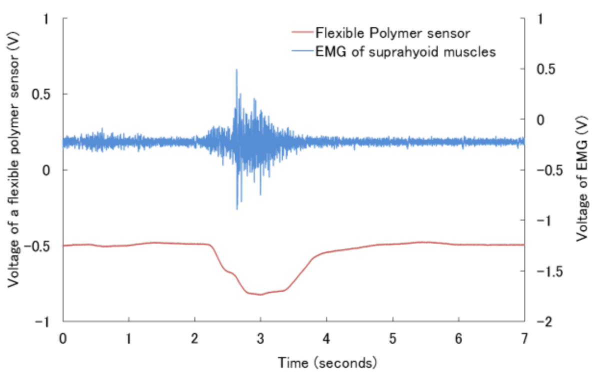

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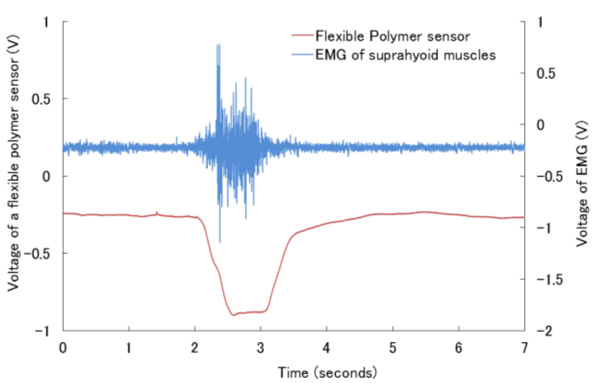

Figure 5. An example of measurment results of a flexible polymer sensor and EMG of suprahyoid muscles in three different postures; a) is normal seated position, b) is reclining seated position and c) is supine seated position. Horizontal axis is measurement time (seconds). Left vertical axis is voltage of a flexible polymer sensor (V) and right vertical axis is voltage of EMG of suprahyoid muscles (V). Curves in red is a flexible polymer sonsor and curves in blue is EMG of suprahyoid muscles.

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