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Original Article

Evaluation of the myoelectric potential of the infrahyoid muscles as a means of detecting muscle activity of the suprahyoid muscles

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ABSTRACT

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Objective: To investigate the use of the myoelectric potential of the infrahyoid muscles as a synchronizing signal for the contraction of the suprahyoid muscles during swallowing.

Methods: The myoelectric potentials of the anterior belly of the digastric muscle and the sternohyoid muscle of 10 healthy adults during swallowing were measured, and the activity of each muscle was analyzed. Additionally, the real-time process of muscle activity detection was simulated using the measured waveform of the myoelectric potentials.

Results: The ratio of the "elapsed time from the activity of the anterior belly of the digastric muscle to the activity of the sternohyoid muscle" to the "time of activity of the anterior belly of the digastric muscle" was 22.5 ± 19.6%. The sternohyoid muscle activity started in the early period of activity of the digastric muscle. In the simulation, differential processing enabled detection of the activity of the sternohyoid muscle in 49 of 50 trials within the activation time of the anterior belly of the digastric muscle.

Conclusion: The myoelectric potential of the sternohyoid muscle can be used as a synchronization signal for the contraction of the anterior belly of the digastric muscle during swallowing.

Key words: dysphagia, magnetic stimulation, anterior belly of digastric muscle, sternohyoid muscle, myoelectric potential

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Introduction

Japan has become a super-aged society ahead of the rest of the world. As the population ages, the incidence of cerebrovascular disorders, and the number of patients with dysphagia due to sequelae of cerebrovascular disorders, is increasing year by year [1]. If food enters the trachea due to abnormal swallowing, aspiration pneumonia or suffocation may result [1−3]. More than 70% of cases of pneumonia in older adults are associated with aspiration [4], and therefore more effective rehabilitation methods for dysphagia need to be developed.

Our research group is studying a new method of rehabilitation for dysphagia that uses magnetic stimulation for dysphagia training. Magnetic stimulation generates a varying magnetic flux from a magnetic stimulation coil, excites the motor nerve by the change in the magnetic flux, and induces contraction of the target muscle. Magnetic stimulation is minimally invasive, less painful than other stimulation methods,

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Figure 1. Stimulation coil for the suprahyoid muscles.
An eddy current is induced in the submental region by a magnetic pulse to contract the suprahyoid muscles.

and does not require the attachment of electrodes [5]. Our previous studies have shown that applying magnetic stimulation to the suprahyoid muscles results in a substantial elevation of the hyoid bone without pain [6]. Figure 1 shows the coil for stimulating the suprahyoid muscles and its arrangement during stimulation.

Recent research has shown that in physical therapy using electrical stimulation, more effective rehabilitation can be provided by using the myoelectric potential of the target muscle as a trigger than by simply inducing muscle contraction [7]. Similarly, in training using magnetic stimulation, magnetic stimulation of the suprahyoid muscles triggered by the myoelectric potentials of the swallowing-related muscles is expected to provide more effective rehabilitation.

However, when magnetic stimulation is performed from above the electrode attached to the suprahyoid muscles, there is a problem that the metal inside the electrode changes the distribution of the magnetic pulse. Additionally, the unnecessary potential generated on the electrodes due to magnetic induction is greatly amplified by the high-gain amplifier inside the electromyography (EMG) machine, and the internal circuit of the EMG machine may be destroyed. For males, the surface of the lower jaw where the electrode is attached may be covered with a beard, causing poor contact of the electrode. Therefore, it is difficult to use the myoelectric potential of the suprahyoid muscles as a trigger for the magnetic stimulation of the suprahyoid muscles.

During the swallowing reflex, the infrahyoid muscles contract after the suprahyoid muscles. The muscle activity of the infrahyoid muscles starts during the contraction of the suprahyoid muscles [8, 9]. Therefore, it is possible that stimulation synchronized with contraction of the suprahyoid muscles can be performed by using the myoelectric potential of the infrahyoid muscles as a trigger. When the electrode is attached to the infrahyoid muscles and magnetic stimulation is applied to the suprahyoid muscles, the magnetic flux density near the electrodes is small. Therefore, the electrodes do not change the magnetic field distribution of the magnetic stimulation and, in addition, the risk of malfunction of the EMG machine is small.

The purpose of this study was to evaluate the possibility of using the myoelectric potential of the infrahyoid muscles, rather than the suprahyoid muscles, as a trigger signal synchronized with the contraction of the suprahyoid muscles. The myoelectric potentials of the suprahyoid and infrahyoid muscles were measured, and the time series of the activity of these muscles was examined. Additionally, a simulation using the measured myoelectric potential was performed to estimate the timing of the detection of the myoelectric potential of the infrahyoid muscles including the delay due to detection processing in real-time. Using these results, we evaluated the validity of substituting the myoelectric potential of the infrahyoid muscles as a trigger signal synchronized with the contraction of the suprahyoid muscles.

Methods

This study was approved by the Ethics Committee of Tohoku University School of Medicine (accession number: 2019-1-252).

1. Measurement of myoelectric potential

Measurements of myoelectric potential were performed on 10 healthy adults (8 males, 2 females, age 21−67 years, average age 41.7 ± 18.1 years). Written consent for the measurements was obtained from all subjects. The myoelectric potential was measured using an active electrode (Biometrics Ltd., SX230) with a distance of 20 mm between the electrodes. The gain of this active electrode was 60 dB, and the bandwidth was 20−460 Hz. In this study, the amplified signal output from the electrode was treated as a signal of myoelectric potential. The subject's lower jaw and neck were wiped with an alcohol swab, and electrodes were applied to the epidermis along the direction of the muscle fibers corresponding to the anterior belly of the digastric muscle to detect the action potential of the suprahyoid muscles. Similarly, an electrode was attached to the epidermis corresponding to the sternohyoid muscle on the right side of the neck to detect the action potential of the infrahyoid muscle. Figure 2 shows the electrode attachment position and the electrode mounting state. A band with electrodes was attached as a reference electrode so that it touched the head of the subject's right elbow. The subject was seated in a chair in a shielded room in a state of rest with the electrodes attached, and was instructed to perform saliva swallowing five times. The start of swallowing, the

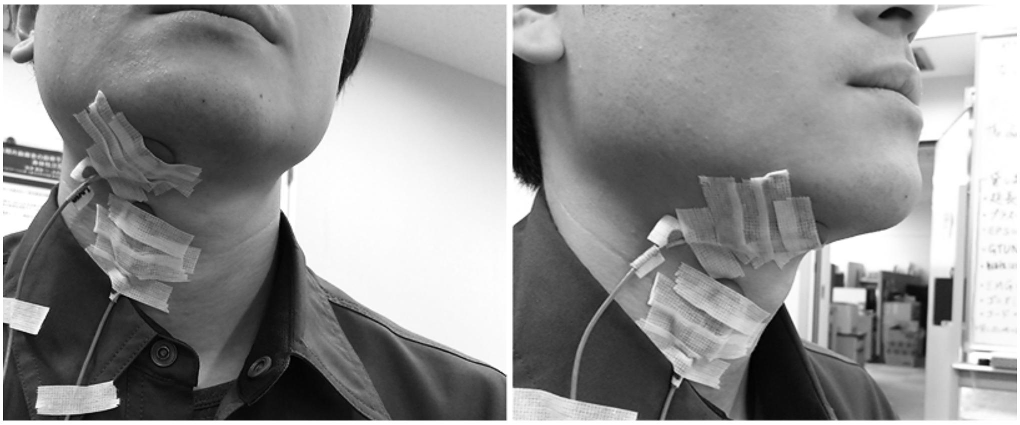

Figure 2. Position of the electromyography electrode.
Electrodes are placed on the epidermis above the anterior belly of the digastric muscle and the sternohyoid muscle.

completion of swallowing, and the timing of the swallowing instruction were recorded. No specific instructions were given about the speed of swallowing or the amount of saliva swallowed. The measurements were recorded with an AD converter (ADInstruments, PowerLab) and recording software (ADInstruments, LabChart 7). Recording was performed at a sampling rate of 1 kHz. The recorded myoelectric potential waveforms of each subject were cut out for each swallowing instruction, with the myoelectric potential waveforms at rest included for at least 2 s before and after the swallow, and saved in such a way that the order of the trials could be identified.

2. Activity time analysis of each muscle

In analyzing the activity time, band-stop filter processing of 48−52 Hz to remove hum noise and time differential processing were performed in advance on each myoelectric waveform by digital signal processing using a personal computer. Digital signal processing was performed with analysis software (National Instrument, Labview). All digital signal processing and analyses in this study were performed in Labview. Figure 3 shows an example of the myoelectric waveforms before digital processing of the anterior belly of the digastric muscle and the sternohyoid muscle during swallowing and the result of a fast Fourier transform (FFT) with a width of 0.2 s for these waveforms. Figure 4 shows the waveforms after filtering and differentiation processing and its FFT waveform. In the waveforms after digital processing, the period below 3 SD of the baseline

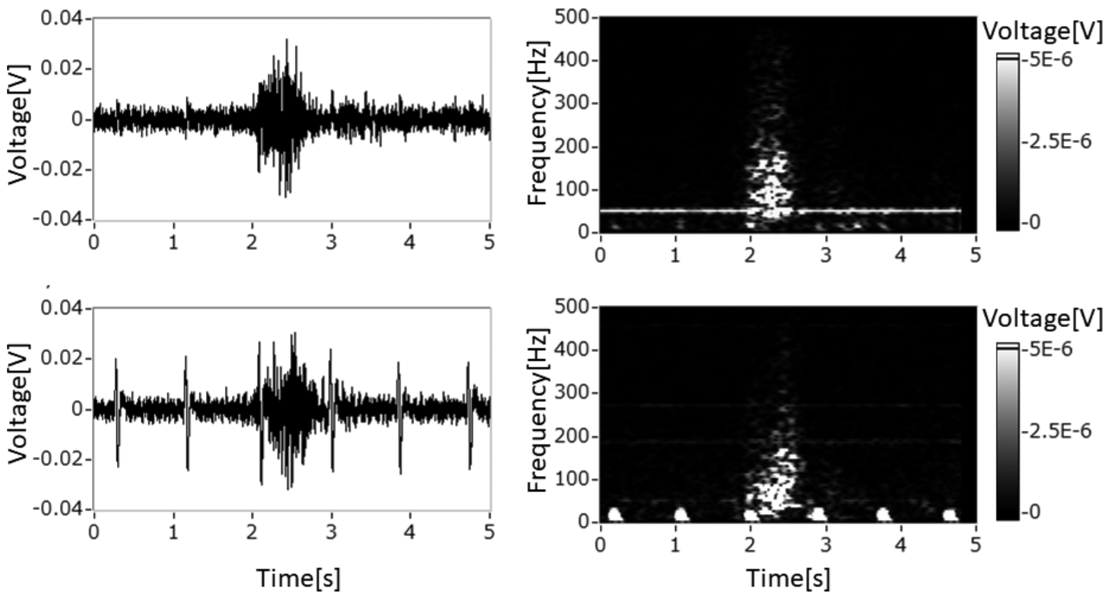

Figure 3. Example of a measured myoelectric waveform (left) and its frequency characteristic analysis result (right).
The upper graph shows measurements for the anterior belly of the digastric muscle, and the lower graph shows measurements for the sternohyoid muscle.

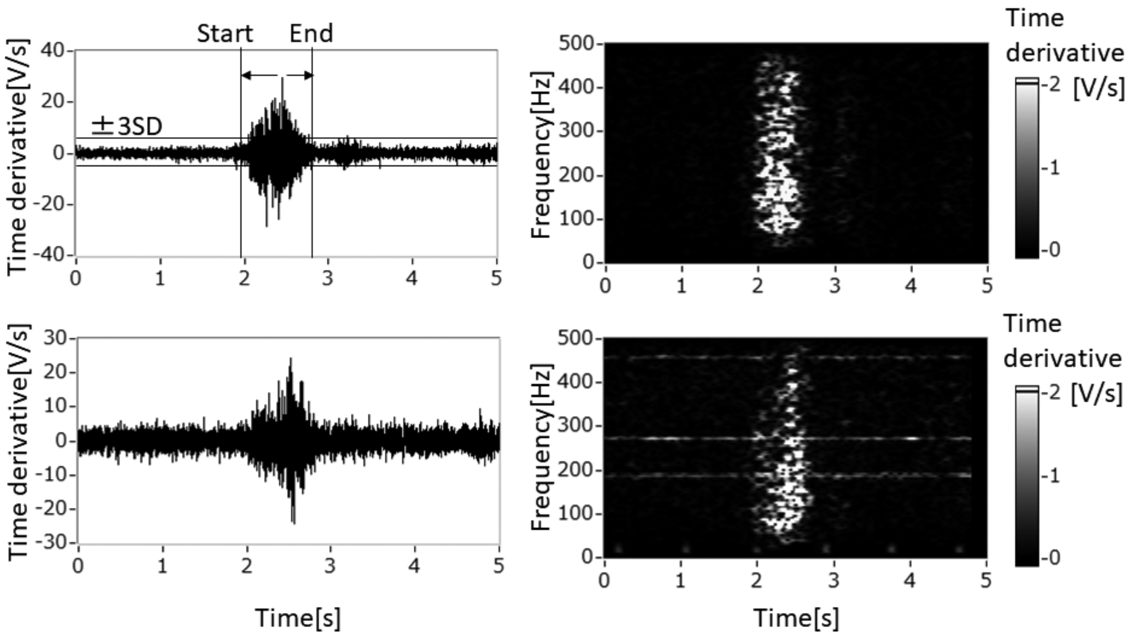

Figure 4. Myoelectric waveform after hum noise filter processing and differentiation processing (left) and its frequency characteristic analysis (right).
The upper graph shows measurements for the anterior belly of the digastric muscle, and the lower graph shows measurements for the sternohyoid muscle. The start and end times of muscle activity can be determined from the period that the myoelectric waveform was less than ± 3 SD of the baseline activity before and after the signal peak.

activity for 0.1 s or more was detected in a negative direction on the time axis from the signal peak, and the end of that period was defined as the muscle activity start time. Similarly, the period below 3 SD of the baseline activity for 0.1 s or more was detected in a positive direction on the time axis from the signal peak, and the beginning of that period was defined as the muscle activity end time. In this analysis, the resting myoelectric waveform for 1 s before swallowing is defined as the baseline activity. This analysis was performed on myoelectric waveforms from a total of 50 trials (five trials on 10 subjects each). Mean, standard deviation, and maximum and minimum values for the muscle activity time of the anterior belly of the digastric muscle (A), the muscle activity time of the sternohyoid muscle (B), the elapsed time from the start of activity of the anterior belly of the digastric muscle to the start of activity of the sternohyoid muscle (C), and the ratio of C to A (C/A) were recorded. Figure 5 shows the definitions of the evaluated time parameters. The value of C/A is a parameter that indicated when the sternohyoid muscle activity started during the entire muscle activity of the anterior belly of the digastric muscle. Because it was confirmed that single-shot muscle activity occurred about once every 0.08 s in the myoelectric waveform of the anterior belly of the digastric muscle of one subject, the muscle activity time for this one subject was determined by detecting the period below 3 SD of the baseline activity for 0.05 s or more.

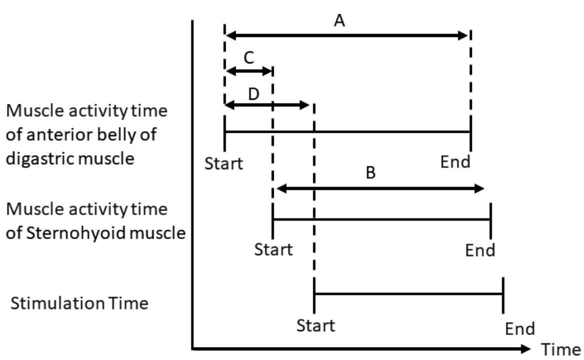

Figure 5. Definitions of the evaluated time parameters.

3. Simulation of real-time processing for detection of the start of muscle activity

Before digital processing, bandstop filter processing of 48−52 Hz was applied to the myoelectric waveform of the sternohyoid muscle of all subjects. Additionally, a differentiated waveform and a non-differentiated waveform were prepared, and root mean square (RMS) processing with a width of 10 ms was performed on each waveform. In the following description, the RMS processed waveform without differential processing is called the RMS waveform, and the RMS processed waveform after differential processing is called the differentiated root mean square (DRMS) waveform. Figure 6 shows an example of the RMS and DRMS waveforms. The waveforms in Figure 6 are the RMS and DRMS waveforms of the myoelectric potential of the sternohyoid muscle shown

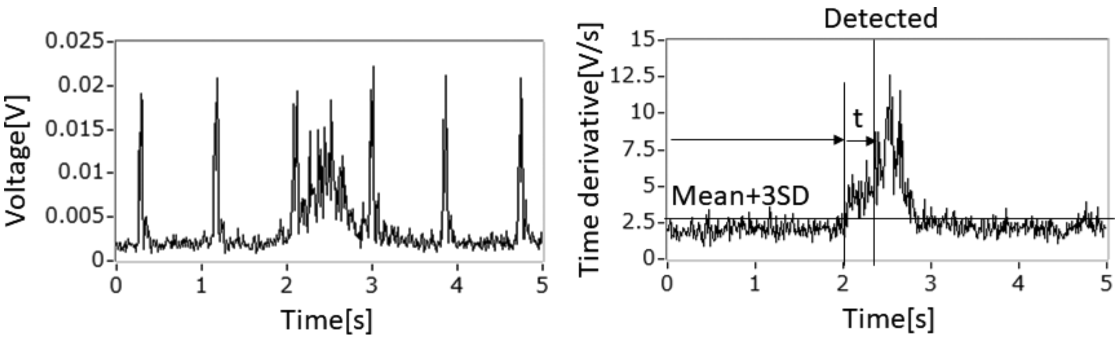

Figure 6. Root mean square (RMS) waveform (left) and differentiated root mean square (DRMS) waveform (right).
The rising of the myoelectric waveform is detected when the waveform exceeds the mean + 3 SD of the baseline activity for a specified time *t*.

in Figure 3. Next, for each of the obtained RMS waveforms and DRMS waveforms, the period that the waveform exceeded mean + 3 SD of the baseline activity for a specified time *t* was detected from the start of the waveform data toward the positive side. The end of the period was defined as the detection time of the start of muscle activity of the sternohyoid muscle. This series of signal processing is possible in real time using an analog circuit. Here, the signal processing by the analog circuit was simulated by a personal computer.

The simulation of the above-mentioned muscle activity detection was performed for a total of 50 trials (five trials on 10 subjects each) while changing the value of *t* from 20 ms to 100 ms. If sternohyoid muscle activity was detected between the start and end of activity of the anterior belly of the digastric muscle, the detection was regarded as successful. If the activity was outside this range, or if muscle activity was not detected, the detection was regarded as failed. In the simulation of the myoelectric waveform for the five trials for each subject, the smallest value of *t* with the highest number of successful detections was determined. Then, from the detection time of the start of muscle activity with the optimal *t* for each subject, the elapsed time from the start of muscle activity of the anterior belly of the digastric muscle to the detection time of the start of muscle activity of the sternohyoid muscle (D) was calculated. Mean, standard deviation, and maximum and minimum values for the ratio (D/A) of (D) to the muscle activity time of the anterior abdominal muscle (A) were calculated. Figure 5 shows the definitions of these time parameters. The value of D/A is a parameter that indicated when the activity of the sternohyoid muscle was detected during the entire muscle activity of the anterior belly of the digastric muscle. The number of successful detections (rate) when the optimal *t* was set for each subject was also calculated.

Results

Table 1 shows the results of the activity time analysis for each muscle. The average muscle activity time of the anterior belly of the digastric muscle (A) and the sternohyoid muscle (B) were both about 1 s long, and the elapsed time from the start of muscle activity of the anterior belly of the digastric muscle to the start of muscle activity of the sternohyoid muscle (C) was 0.31 ± 0.29 s. The elapsed time ranged from −0.07 to 1.16 s, and there were cases in which the myoelectric potential of the sternohyoid muscle occurred slightly earlier than in the anterior belly of the digastric muscle in six trials. The timing of the start of sternohyoid muscle activity (C/A) was 22.5 ± 19.6%, and sternohyoid muscle activity mainly began in the early period of activity of the anterior belly of the digastric muscle. In the 50 trials in this study, the maximum value of the timing of the start of muscle activity of the sternohyoid muscle (C/A) was 66.7%, and the activity of the sternohyoid muscle never started after the end of the activity of the anterior belly of the digastric muscle.

Table 2 shows the simulation results of the real-time detection process for the start of muscle activity. The success rate of detection of the start of muscle activity using the RMS waveform was 41/50, and the success rate of detection using the DRMS waveform was

Table 1. Muscle activity time of the anterior belly of the digastric muscle (A), muscle activity time of the sternohyoid muscle (B), and elapsed time from the start of activity of the anterior belly of the digastric muscle to the start of activity of the sternohyoid muscle (C).

	Mean±SD	Maximum	Minimum
A[s]	1.43±0.64	3.40	0.45
B[s]	1.26±0.58	2.63	0.26
C[s]	0.31±0.29	1.16	−0.07
C/A[%]	22.5±19.6	66.7	−6.5

Table 2. Detection rate of muscle activity and timing of detection (D/A) of the sternohyoid muscle estimated by simulation of real-time analysis.

	Detection rate	D/A [%] Mean±SD	D/A [%] Maximum	D/A [%] Minimum
RMS	41/50	44.9±22.8	92.7	3.4
DRMS	49/50	41.5±21.7	92.2	4.7

49/50. These results suggest that the onset of muscle activity is easier to detect using DRMS waveforms. Additionally, the timing (D/A) of the detection of the start of muscle activity of the sternohyoid muscle was about 40%, regardless of the waveform used. This finding suggests that actual magnetic stimulation triggered by the myoelectric potential of the sternohyoid muscle is applied at a timing slightly earlier than the entire muscle activity of the anterior belly of the digastric muscle.

Discussion

As shown in the waveform in Figure 3, pulsation synchronized with the heartbeat was often mixed in the myoelectric waveform of the sternohyoid muscle, and there were some subjects in whom this pulsation could not be eliminated even when the electrode position was adjusted. This pulsation was difficult to remove by averaging or RMS processing because of the wideness of the pulse. Observation of the FFT waveform of the signal containing this pulsation revealed that the frequency component of the pulsation was at a very low level of about a few Hz, and the frequency component of the myoelectric potential of the anterior belly of the digastric muscle and the sternohyoid muscle during swallowing existed in the frequency band higher than 50 Hz. This was a feature common to the whole myoelectric waveform of all subjects in this study. Additionally, peaks around 50 Hz were observed in FFT waveforms from the baseline activity in many myoelectric waveforms. Therefore, in the analysis to determine the activity time of the muscle, a band-stop filter near 50 Hz and differentiation processing were performed as pre-processing. Differentiation processing was considered to be the best pre-processing for the myoelectric waveform in this study because the low-frequency component is weakened and the high-frequency component is emphasized. As shown in Figures 3 and 4, after pre-processing, the pulsation disappeared, and the high-frequency components and the range of muscle activity due to swallowing that had been buried in the noise were emphasized. It is considered that pre-processing contributed to improving the accuracy of the measurements in this study.

As a feature common to myoelectric waveforms measured in this study, the waveform of some subjects tended to include random, high-amplitude, narrow-pulse noise in the background. If a search is performed in the direction from the signal peak, the influence of the pulse noise on the detection accuracy of the muscle activity is limited, but such processing is not possible with real-time signal processing. Therefore, it is considered that the pulse width trigger, which is a detection condition in which the threshold value is exceeded during a certain time width, is effective for real-time detection of the start of muscle activity. A small noise can be ignored by the pulse width trigger. As a result, in the simulation of muscle activity detection using DRMS waveforms, the start of muscle activity was detected in almost all trials. We consider that the method using the DRMS waveform and the pulse width trigger is effective as a means for detecting the actual start of muscle activity.

In this study, the myoelectric potential of the sternohyoid muscle was measured using a surface electrode, and there was a possibility of cross-talk contamination. However, measurement with the implanted EMG using a hook-type wire electrode also recorded the contraction of the suprahyoid muscle following the contraction of the sternohyoid muscle [9], suggesting that the contraction of the sternohyoid muscle was actually captured by the measurements in this study. Additionally, the relative position between the surface electrode and the muscle was expected to shift due to muscle contraction. However, the conduction velocity of the myoelectric potential was 3−5 m/s [10], and the typical error due to muscle contraction in the analysis was expected to be about 1/100 s. Therefore, it is assumed that the influence of the change of the relative position on the result of the waveform processing was minor.

In conclusion, our findings confirmed that the myoelectric potential of the sternohyoid muscle rises in the early phase of the muscle activity of the anterior belly of the digastric muscle. Additionally, even taking into account the delay caused in real-time processing, it is highly probable that the activity of the sternohyoid muscle can be detected in the first half of the activity of the anterior belly of the digastric muscle. Therefore, it is considered that the myoelectric potential of the sternohyoid muscle can be used as a synchronizing signal for the contraction of the anterior belly of the digastric muscle during swallowing.

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