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Description	

New method of recording the functional activity pattern of the buccinator from the mucosal surface

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Abstract

Objectives: The buccinator (BUC) is an important muscle for oral function. Since it lies deep in the facial skin, recording its activity is difficult; thus, studies on its function are limited. We developed a method to access the deep facial muscles from the mucosal side. The aim of this study was to test the reliability of the new recording method for the BUC and to investigate the BUC behavior in typical facial functions.

Methods: To evaluate the new method, BUC activities were recorded simultaneously with a gel-type electrode on the skin and the newly developed surface electrode on the buccal mucosa. Electromyographic (EMG) activities in function, such as chewing and swallowing, along with the activities of the lower orbicularis oris (OO), zygomaticus major, masseter, and digastric muscles, were compared using the two recording methods. EMG activities among various tasks were compared using normalized values based on those obtained during maximum lip closure (MaxLC).

Results： The new surface electrode was made of gold plates on a thin plastic fixed to a stainless-steel wire frame and weighed less than 1 g. The BUC activity recorded from the mucosa was the highest during a corner-pulling task and was low during clenching. The BUC was active during MaxLC, similar to the OO, and the BUC activity pattern among tasks recorded from the mucosa was identical to that reported by previous studies using intramuscular electrodes. The new electrode evaluated the BUC activities quantitatively, and the recordings by the new electrode were free from contamination.

Conclusions: The findings of this study confirmed the reliability of the new BUC recording method. It could be easily placed correctly within seconds, without the need for cleansing or sterilizing the skin. The BUC and OO were active during a MaxLC task, indicating that the BUC assists lip closure by pulling the corners of the mouth. The basic facial functions evaluated, including chewing, were similar to those studied by intramuscular electrodes.

Keywords: new electrode, buccinator muscle, electromyography, facial functions, lip functions

1 Introduction

Lips perform important functions in daily life, such as articulation, food intake, mastication, and facial expression, by opening and closing the rima oris. Mastication includes the intake and crushing of food and bolus formation, in which the lips open for food intake and may be closed by the perioral muscles. The orbicularis oris (OO), which surrounds the rima oris, squeezes and closes the rima oris, while the buccinator (BUC) assists lip closure by pulling the corners of the mouth backward.

1.1 About the BUC

Orthodontic treatment affects the perioral musculature, including the BUC, and the teeth position. Stavridi and Ahlgren [1] electromyographically examined the response of the masseter (MAS), BUC, and mentalis muscles to the oral-screen activator, which was a conventional activator constructed with buccal shields and lip pads. Their results showed that the lip pads increased mentalis activity during lip closure but reduced it during swallowing; BUC activity was insignificant. Thus, they concluded that buccal shields did not change BUC activity. Gamboa et al. [2] evaluated the activity of the mentalis, BUC, and suprahyoid (SH) muscles among participants with different lip competence. They reported that the activities of the BUC and SH muscles at rest, during swallowing, speaking, reciprocal compression of the lips, and chewing did not show significant differences among the participants.

The BUC is an important muscle, and its role in oral functions should be clarified. It is a relatively large muscle around the lips that runs horizontally from the pterygomandibular raphe toward the occlusal surface of the teeth and stops at the corner of the mouth. Its functions include pulling the corner of the mouth backward, supporting the cheek wall during mastication, and keeping the dental arch [3]. It is also activated upon blowing strong air (such as in wind instruments). Thus, the BUC is called the “trumpeter muscle” and is one of the first muscles in an infant to get activated during sucking [4]. However, most of these functions are considered based on morphological studies because the BUC is relatively large, but it is located deep in the facial skin [3,5,6]. Therefore, when its activity is recorded with surface electrodes placed on the face, contamination by the activity of muscles near the BUC, such as the MAS and zygomaticus major (ZM), is anticipated [7,8].

1.2 EMG studies on BUC function

To avoid contamination by the surrounding muscles, a needle or fine-wire electrode is favorable for recording the muscle activities around the mouth during function [9]. Vitti et al. [10] studied the relationships among the OO, BUC, and genioglossal (GG) muscles using fine-wire electrodes, with the hope of uncovering some factors associated with malocclusion. These muscles showed slight activity during normal oral function; however, during thumb-sucking, the OO and GG muscles showed marked activity, while the BUC showed only slight activity. They concluded that these findings might help explain the classic malocclusion seen in tongue-thrusters and thumb-suckers [10].

Perkins et al. [11] recorded electromyographic (EMG) activities in the upper and lower OO (L-OO), BUC, MAS, and superior pharyngeal constrictor (SP) muscles during function, which included swallowing, smiling, blowing, sucking, pronouncing vowels, chewing, and coughing. The authors aimed to study the “buccinator mechanism,” in which the OO, BUC, and SP muscles form a continuous sphincter-like muscle band and work together. They reported that a marked OO and BUC activity occurred while pronouncing the vowels “o” and “u,” and that simultaneous activity occurred in all five muscles when blowing into and sucking on a closed straw [11]. These studies used fine-wire electrodes, but the EMG activity was expressed in five grades; thus, the analysis was qualitative. A reliable method of recording BUC activities that can cover a wide area simultaneously and is noninvasive is desired [9].

1.3 BUC function during chewing

Since the BUC muscle forms the lateral wall of the oral cavity and is presumed to aid mastication by maintaining the bolus position, Dutra et al. [12] hypothesized that such a function would involve thickening of the cheek. Using minipigs, they studied the BUC functions during mastication and found thickening of the entire cheek. In humans, the BUC burst during mastication is between jaw-closer bursts. In pigs, this timing corresponds with the initiation of jaw closure; therefore, Dutra et al. [12] suggested that the BUC controlled the placement of the bolus on the occlusal table as the jaw closed.

To determine the functional role of the human facial muscles in mastication, Schieppati et al. [7] recorded the activity of the BUC, upper and lower OO, quadratus, and triangularis during mastication using surface and needle electrodes. The activities were compared with those of the masticatory muscles and vertical jaw movements. The needle electrode recorded one BUC burst in a chewing cycle, which began at the end of the MAS burst and ended at the next MAS burst. Meanwhile, the surface electrode over the BUC not only recorded the burst but also the second burst of low-amplitude electrical activity, which was presumed to have been generated in the MAS muscle. Schieppati et al. [7] stressed that there was a large recording interference between the BUC and the MAS with surface electrodes and that it was not easy to record the activity of a single facial muscle, even with concentric needle electrodes.

Avoiding the shortcomings of concentric needle electrodes, Hanawa et al. [8] analyzed the temporal and quantitative relationships between the upper and lower OO and BUC recorded by wire electrodes while chewing gum and peanuts. Their study focused on the masticatory process; thus, the MAS and digastric (DIG) muscles were also recorded using surface electrodes. EMGs of the OO and BUC showed rhythmic single-peaked bursts corresponding to the jaw-opening phase of the chewing cycles. The onset, peak, and offset of the OO and BUC based on the MAS offset did not change, regardless of the bolus size. It was concluded that the changes in OO and BUC activities may be derived from chewing-generated sensory inputs in accordance with the physical properties of food in part, which would relate to the function of these muscles during mastication. They also stressed that the burden on the participant during functional exercises such as mastication is large even with wire electrodes [8]. Thus, if possible, recording the BUC with a surface electrode, which is free from contamination by the surrounding muscles, is desired.

1.4 Aim of the study

Recently, our research group developed a new electrode that can record OO activity with a high signal-to-noise ratio by simply holding the upper and lower lips [13]. Conventional surface electrodes record the activity of the target muscle over the skin covered with a keratinized layer. The new electrodes can record OO activities from the reverse side, that is, from the mucosa, where the electrode makes a contact with the muscle through thin mucosa. Based on the previous study, we developed a new method of recording the EMG of the BUC using surface electrodes placed over the mucosa. The BUC muscle is categorized as a deep muscle when viewed from the skin; however, it is located in the shallow layer when viewed from the mucosal surface. In this study, we tested the reliability of this recording method and investigated the basic characteristics of BUC activity during function.

2 Methods

The study was performed in accordance with the Helsinki Declaration II after approval by the Ethics Committee of Tokyo Dental College. All participants received verbal and written information about the study and gave written consent to participate.

2.1 Participants

Twelve healthy volunteers (7 men and 5 women; mean age: 37 ± 9.7 years) were recruited from the staff and students. The inclusion criteria were good health, full dentition (except for the third molars), and no history of motor abnormalities. Participants with difficulty in closing their lips, deleterious oral habits, or morphological abnormalities of the mandible were excluded. During the experiment, the participants were seated in a relaxed upright position, without head support, with their knees bent at a right angle and their feet touching the floor.

2.2 Electrode and sensor settings

The EMG activities of the L-OO, ZM, MAS, BUC, and DIG muscles were recorded (Figure 1A). BUC activity was simultaneously recorded by electrodes placed on the skin (BUC-out) and on the mucosa of the reverse side (BUC-in). Electrodes, except the BUC-in, were the commercially available gel-type (NCS electrode NM-31; Nihon Kohden

Kogyo Co. Ltd., Tokyo, Japan). Since some of the target muscles were small, each electrode was trimmed to 10 × 20 mm each, and two of them were fixed in parallel, 10 mm apart, with a soft photo-polymerizing resin.

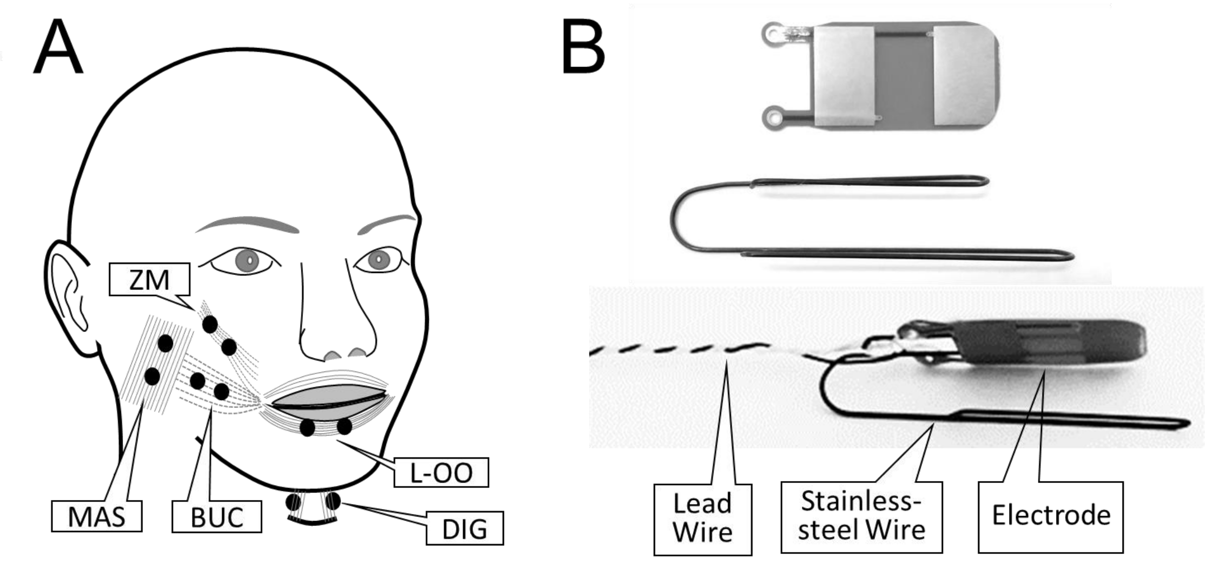

Figure 1: *(A) Target muscles and the electrodes for electromyographic recording*. *(B) New electrode for BUC recording*. The upper two are the bipolar surface electrode and the frame, respectively. The lower part shows an assembled electrode together with lead wire. BUC, buccinator; DIG, digastric; L-OO, lower orbicularis oris; MAS, masseter; ZM, zygomaticus major.

Electrodes for the MAS were placed linearly, parallel to the muscle fibers in the middle. Electrodes for the DIG were placed 1 cm apart horizontally from the midline, 2 cm under the chin. For the ZM, one electrode was placed midway along an imaginary line joining the corner of the mouth and the pre-auricular depression (the bony dimple above the posterior edge of the zygomatic arch), and the second electrode was placed 1 cm inferomedial to the first electrode, along the same imaginary line. Electrodes for the L-OO were placed symmetrically at the center of the lower lip.

For the BUC recordings, we applied a new electrode. The BUC lies deep in the face and difficulties have been reported in recording its activity using surface electrodes placed on the facial skin. Thus, we developed a recording method in which the EMG activity was recorded intraorally, wherein the BUC is shallow for the electrode. The bipolar surface electrode was composed of gold plates (size 6 x 10 mm, with a 6-mm distance between the two electrodes) arranged on a thin plastic (0.1 mm thick). This was fixed to a stainless-steel wire frame, with which it was held on the mucosa. The total weight, including that of the lead wires, was less than 1 g (Figure 1B).

A 170-mm-long, 0.5-mm-diameter stainless-steel wire was bent into U-shapes (width 4 mm), the ends of which were 27 and 35 mm long. Near the center (~5 mm toward the shorter part), the wire was bent again so that the two U-shapes were face-to-face parallel at a 6-mm distance. The gold plate bipolar electrode sheet was then fixed to the shorter arm of the U-shape with glue. To set the electrode at a desired location, the shorter part was inserted horizontally from the corner of the mouth. Accordingly, the thin bipolar electrode was placed parallel to the muscle fibers on the inner surface of the cheek horizontally, 14–36 mm from the corner of the mouth (where the BUC exists). The longer part was fixed to the skin of the cheek with surgical tape to keep the surface electrode stable. The electrode position and frame size were confirmed with a cadaver. BUC-out was placed on the skin under the outer U-part of the frame so that the electrode was at a site homologous to the BUC-in.

A ground electrode was fixed at the frontal head, where the skin was cleansed with alcohol using a larger gel-type electrode. It should be noted that for the conventional surface electrode, the skin has to be cleaned with alcohol before setting; the new surface electrode did not need cleansing of the mucosa.

The lip closing force (LCF) was recorded using a force-sensing resistor (FSR402; Interlink Electronics Inc., Camarillo, CA, USA), which was placed between the lips at the center of the mouth. Baropressure (BP) was recorded in the oral cavity using a small sensor (MPL115A; NXP Semiconductors, Eindhoven, the Netherlands) during the blowing and sucking tasks. EMG signals were amplified (×1,000) and bandpass-filtered (60–200 Hz) by custom-made amplifiers. They were then sampled at 1 kHz using 10-bit A/D converters of a micro-CPU (H8/3694; Renesas Electronics Corporation, Tokyo, Japan). The digitalized signals (EMGs, LCF, and BP) were then fed into a personal computer, monitored on a screen, and logged on a mass storage device in comma separated value format. The stored data samples were digitally filtered (60- to 200-Hz bandpass filter for EMGs and 60-Hz low-pass filter for BP and LCF) and analyzed using Spike 2 (Cambridge Electronics Design Ltd., Cambridge, UK). Details of the recording system have been described previously [13,14].

2.3 Recording protocol and data analysis

EMGs were recorded in seven tasks, all of which were preceded by 5 sec of jaw rest. Each task was recorded for 5 sec except chewing task. The target muscles were the BUC (recorded from the skin-side and the mucosal-side), MAS, ZM, and L-OO muscles, except in the chewing task, where the DIG was recorded instead of the ZM. After normalization based on the values obtained during the maximum lip closure (MaxLC) task, the EMG activity was expressed in arbitrary units (AU). To study the activities of the BUC, the following facial tasks were designed after referring to previous studies [10,11,15,16].

2.3.1 MaxLC task

A force-sensing resistor was placed between the upper and lower lips at the center, and the participants were asked to close the lips against the sensor, as strongly as possible, for 5 sec. EMGs and LCFs were recorded simultaneously.

Since raw EMG data cannot be compared among muscles or tasks, muscle activities were compared based on their normalized values. In this study, the MaxLC task was used as the reference because it may be the most stable task for the target muscles (except for the MAS). The EMG signal was full-rectified, and 3 sec of the signals were then selected and averaged for each muscle to obtain the ∫EMG. These values were used as the base values for the normalization of the following tasks except the chewing task.

2.3.2 Clenching task

The participants were asked to open the mouth slightly, close the mouth gently, and to clench the jaw as strongly as possible for 5 sec each.

2.3.3 Corner-pulling task

The participants were asked to pull the corners of the mouth horizontally, as strongly as possible, for 5 sec.

2.3.4 Sucking task

The participants were asked to suck on a closed straw and keep the oral cavity in negative pressure, as strongly as possible, for 5 sec. BP was recorded along with the EMG activities.

2.3.5 Blowing task

The participants were asked to blow as strongly as possible into a closed straw, with the cheeks held taut. BP was recorded along with the EMG activities for 5 sec.

2.3.6 Trumpet-blowing task

The task imitated the action of trumpeters. Participants were asked to blow into the same straw as used for the blowing task, as strongly as possible. During the task, they were asked to pull the corners of the mouth to avoid puffing out their cheeks. BP was recorded along with EMG activities for 5 sec.

2.3.7 Chewing task

The participants were asked to chew two peanuts on the same side as that of the BUC recording. The recording was completed when the participant swallowed the peanuts. The target muscles were the BUC (outside and mucosal side), MAS, L-OO, and DIG. For the analysis, EMGs of 10 chewing cycles from the fourth cycle were fully rectified and signal-averaged at the MAS onset time. The onset time was identified using the analysis software with the same method as that used by Hanawa et al. [8], that is, an EMG burst corresponding to each chewing cycle was identified when the ∫EMG exceeded the value of the mean +2 standard deviations (SDs) during the rest period for 1 sec.

The burst timings (onset time and cessation time) of L-OO, DIG and BUC-in were identified when the averaged EMG exceeded the value of the mean +2 SD during the rest period for 1sec. During mastication, the activity of BUC-out was not interrupted by a rest period, thus the threshold (+2 SD) could not be obtained as did for the other muscles. Therefore, for BUC-out the threshold was obtained from 0.5 sec of the BUC-out activity at the time when the activity was minimum between the first and second peaks.

Since the cycle time differed among participants, the burst timing of the muscles was expressed in an averaged one chewing cycle between the peak times of the MAS burst. Therefore, the total cycle length and time parameters (onset time, peak time, cessation time, and burst durations of the target muscles during ipsilateral chewing) were calculated based on the onset time of the MAS burst and expressed as an AU (i.e., relative time to one chewing cycle).

2.4 Statistical analysis

Data in the tasks were first analyzed using conventional descriptive statistics (mean and SD). The differences between the muscles among the tasks were analyzed using a repeated-measures one-way analysis of variance test, followed by Bonferroni’s multiple-comparisons test. Differences in amplitude between the recordings by the BUC-in and BUC-out were analyzed using the Wilcoxon matched-pairs signed rank test. A p-value <0.05 was considered statistically significant. Statistical tests were performed using GraphPad Prism 6.0 h (GraphPad Software, San Diego, CA, USA).

3 Results

3.1 MaxLC task

A typical recording of five muscles and LCF during a MaxLC task is shown in Figure 2. When the lips were closed maximally, the BUC activity recorded by BUC-in was larger than that of L-OO. The activities of the BUC recorded by BUC-out and of the ZM were medium. There was also a little activity in the MAS. The mean LCF was 128 ± 33 mN. As described in the previous section, the mean 3-sec ∫EMG during the task was obtained for each muscle as the base value to normalize raw EMG activities in the following tasks.

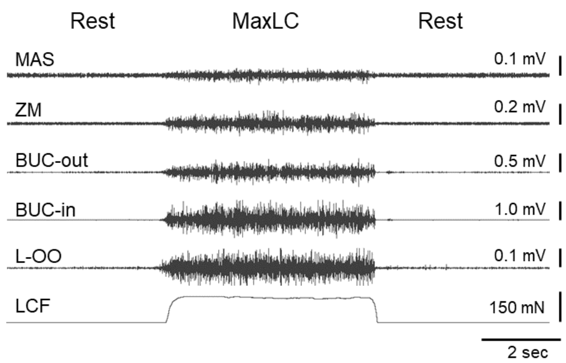

Figure 2: *Example of the recordings of the MaxLC task*. Five muscle activities and LCF were simultaneously recorded when a participant closed the lips as strongly as possible. A force-sensing resistor was placed between the lips. BUC-in, buccinator activity measured on the mucosa; BUC-out, buccinator activity measured on the skin; LCF, lip closing force; L-OO, lower orbicularis oris; MAS, masseter; MaxLC, maximum lip closure; ZM, zygomaticus major.

3.2 Face function tasks

In Figure 3A, the averages of normalized activity of five muscles among the tasks are illustrated with standard deviations. When the face and jaw were relaxed, all the muscles recorded were silent. When the jaw opened slightly, small activities were observed only in the L-OO. When the jaw closed gently, no activity was recorded in any of the observed muscles.

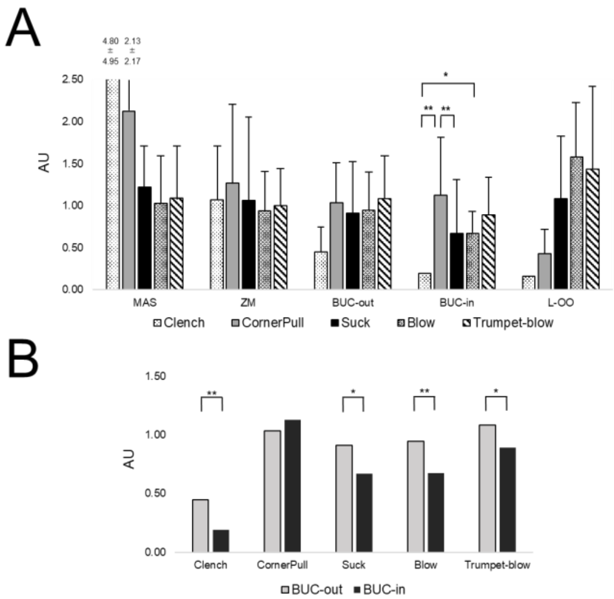

Figure 3: *(A) Averages and standard deviations of the normalized activity of five muscles among the tasks*. The differences in the activity recorded from BUC-in between tasks were analyzed using repeated-measure one-way analysis of variance followed by Bonferroni's multiple-comparison test: *p < 0.05, **p < 0.01. *(B) Comparison of the activities recorded by BUC-in and BUC-out for each task*. Differences in amplitude between the recordings by the BUC-in and BUC-out were analyzed using the Wilcoxon matched-pairs signed rank test: *p < 0.05, **p < 0.01. AU, arbitrary unit; BUC-in, buccinator activity measured on the mucosa; BUC-out, buccinator activity measured on the skin; L-OO, lower orbicularis oris; MAS, masseter; ZM, zygomaticus major.

3.2.1 Clenching and mouth corner-pulling tasks

During clenching, a large activity was observed in the MAS (4.8 ± 4.9), and medium and small activities were obtained in the ZM and BUC recorded by BUC-out, respectively. Activities recorded by BUC-in and L-OO were negligible.

During a corner-pulling task, the activity at BUC-in was the largest among all tasks, being about six times higher (1.13 ± 0.73) than that during clenching. The activity in the ZM (1.23 ± 0.94) was the largest among all tasks, whereas that at the BUC-out was medium. The L-OO showed smaller activities than the other muscles.

3.2.2 Sucking, blowing, and trumpet-blowing tasks

During sucking, the activity recorded by BUC-in was relatively small (0.67 ± 0.69). During blowing, the L-OO showed the largest activity (1.58 ± 0.67) among the tasks. The activity recorded by BUC-out and the activity in the ZM were near the base value, and the activity recorded by BUC-in was relatively small (0.67 ± 0.28).

During trumpet blowing, the activity pattern in the muscles was the same as that of the blowing task. However, all muscles, except the L-OO, were more active during this task than during the blowing task.

3.2.3Difference between BUC-in and BUC-out

In Figure 3B, recordings between BUC-in and BUC-out were compared during face function tasks. There were significant differences in the clenching ($p < 0.01$), sucking ($p < 0.05$), blowing ($p < 0.01$), and trumpet-blowing tasks ($p < 0.05$). However, there was no significant differences between them in the corner-pulling task ($p > 0.37$).

3.2.4 Chewing task

Figure 4 shows a typical pattern of chewing the peanuts until they are swallowed. During chewing, the bursts recorded by BUC-in preceded the MAS bursts, and the bursts in the two muscles alternated. The L-OO showed continuous activities with weak rhythmicity, and the burst was synchronized with that recorded by BUC-in.

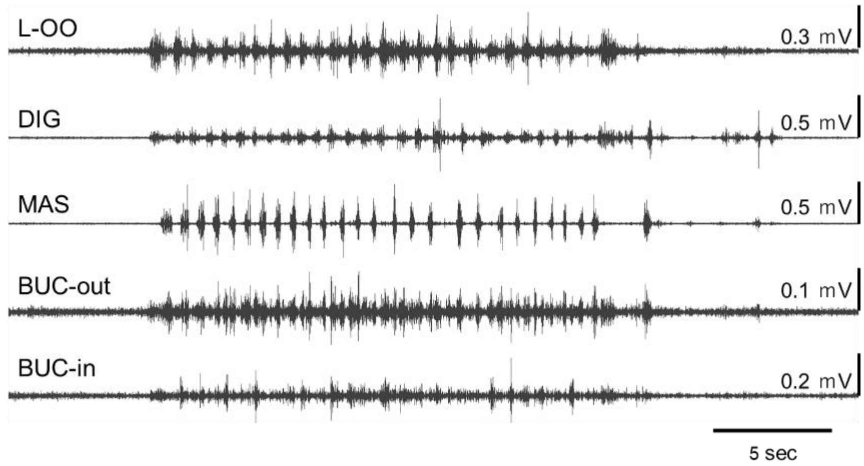

Figure 4: *An example of the recording while chewing peanuts and swallowing*. During chewing, rhythmic bursts were recorded in the muscles.

The burst timings while chewing peanuts were analyzed for each muscle in five participants. For this purpose, the rectified EMGs of 10 chewing cycles were signal-averaged before and after the time when the MAS activity exceeded +2 SDs (Figure 5A). The SD was obtained from one sec of resting activity preceding the chewing task. The vertical dotted line indicates the time when the MAS activity exceeded +2 SDs of resting activity. In Figure 5B, the average timings of onset, peak, and cessation of each muscle are illustrated. In the results described hereinafter, the timings are expressed relative to one chewing cycle between MAS peaks, that is, a chewing cycle begins at one MAS (MAS0) peak (0.0) and ends at the next MAS (MAS1) peak (1.0).

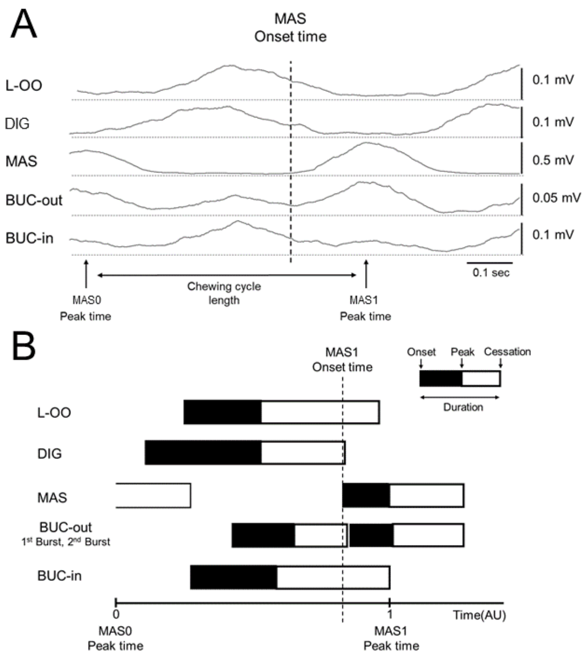

Figure 5: *Activity pattern of five muscles during chewing peanuts*. (A) An example of signal averaging of five muscles for 10 chewing cycles. Muscle activities were full rectified and averaged after aligned at the onset time of the MAS burst. (B) Graphical representation of activity pattern. The onset, peak, and cessation times are shown in the arbitrary time scale. BUC-in, buccinator activity measured on the mucosa; BUC-out, buccinator activity measured on the skin; DIG, digastric; L-OO, lower orbicularis oris; MAS, masseter.

Activities recorded by BUC-in consisted of one burst and those by BUC-out consisted of two bursts. The three muscles (L-OO, BUC at the BUC-in, and the first burst at BUC-out) were active during the opening phase as with DIG; and the second burst at BUC-out was active during the closing phase as with MAS1. The onset times of activities of the DIG, L-OO and BUC (at the BUC-in) were 0.11 ± 0.04, 0.23 ± 0.03, and 0.27 ± 0.05, respectively, and the cessation times were 0.82 ± 0.08, 0.96 ± 0.24 and 1.00 ± 0.16, respectively. The first burst at the BUC-out began the activity shortly after those of the three muscles (0.39 ± 0.05) and ended before those of the muscles (0.83 ± 0.06). Meanwhile, the second burst at the BUC-out started and ended as with MAS1. The DIG burst (began at 0.11 ± 0.04) overlapped with the MAS0 burst (ended at 0.27 ± 0.02), and the BUC burst recorded by BUC-in (ended at 1.00 ± 0.16) overlapped with the MAS1 burst (began at 0.81 ± 0.05).

The peak time of activity recorded by BUC-in (0.57 ± 0.07) was not different from that of the DIG (0.51 ± 0.10), L-OO (0.51 ± 0.05), and the first burst recorded by BUC-out (0.64 ± 0.09). The peak time of the MAS1 (1.00) was not different from that of the second peak of BUC-out (1.04 ± 0.05). The normalized peak value in BUC (recorded by BUC-in) was 0.72 ± 0.32.

4 Discussion

The aim of this study was to test the reliability of a new method of recording BUC activity. The reliability could be cleared by less contamination, coincidence in activity pattern with the task, and usability (i.e., easy setting). The additional aim was to investigate the BUC activities during basic facial functions including chewing.

4.1 Comparison of activities recorded by BUC-in and BUC-out

To determine the reliability of the new recording method, the activity recorded from the mucosa (i.e., BUC-in) was compared with that from a conventional electrode from the skin (i.e., BUC-out). Activity recorded by BUC-in was highest during the corner-pulling task and lowest during the clenching task. The activity pattern of tasks recorded by

BUC-in was identical to that reported by previous studies using needle and wire electrodes (Table 1). Conversely, a recording by BUC-out during clenching showed some activity, although Hanawa et al. [8] reported that the BUC activity was negligible. Changes in the activity recorded by BUC-out among tasks were similar to those in the ZM. The BUC lies deep in the skin, and the anterior border of the MAS and facial muscles stopping at the corners of the mouth are superficial to the BUC. Therefore, BUC-out might pick up other muscle activities, such as those of the MAS and ZM, whereas BUC-in picks up BUC activity solely because it is placed right on the BUC muscle.

Reference \ Task	Lip closure	Clench	Corner-Pull	Suck	Blow	Trumpet Cheeks taut	Chew	Aim / Electrode
Blanton et al [15]	NA	Negligible - moderate	Marked – very marked	Marked	Slight – moderate	marked – very marked	Marked – very marked	Oral function / Wire
Isley & Basmajian [16]	Moderate	NA	Moderate -marked	NA	Slight	depends on player	NA	Oral function / Wire
Vitti et al [10]	NA	NA	Moderate	Slight -moderate	NA	NA	Slight	Malocclusion / Wire
Perkins et al [11] (Percentage of patients showing activity)	NA	NA	8.3% with smile	69.2%	85.7%	NA	85.7%	Buccinator mechanism / Wire
Schieppati et al [7]	NS	NA	NA	NA	NA	NA	Opening phase 140%	Chewing / needle & surface
Hanawa et al [8]	NA	Negligible	Marked	NA	NA	NA	0.32 of corner pull (Opening phase)	Chewing / Wire
This study (arbitrary unit)	1.0 Maximum closure (base value)	0.19 ± 0.20	1.13 ± 0.73	0.67 ± 0.69	0.67 ± 0.28	0.89 ± 0.43	0.72 ± 0.36 (Opening phase)	Oral function / Surface

Table 1: *Comparisons of BUC activity during functioning reported in previous studies*

BUC activities for eight tasks were picked up from the reports and arraigned as with the aim and electrode used. BUC activities were mostly expressed by the Basmajian's grade (five grades of "nil" to "very marked"), and those in this study were expressed as relative values. Ovals indicate that results are in an agreement, and thick double-headed arrows indicate that results are conflicting.

Further evidence that BUC-in recorded BUC activities free from contamination by other muscles was obtained during a chewing task. A burst recorded by BUC-in during peanut chewing was seen in the opening phase identified with the MAS and DIG bursts. This finding corresponds with those reported by previous studies using fine-wire electrodes and needle electrodes [7,8]. However, an activity recorded by BUC-out comprised two bursts in one chewing cycle. The first burst recorded by BUC-out may come from the BUC itself and the second burst was the contamination by MAS activity. Thus, it was concluded that the new electrode on the buccal mucosa (i.e., BUC-in) successfully recorded the BUC activity free from contamination by the surrounding muscles.

4.2 Advantages of the new electrode

Besomi et al. [9] reported a method to select the best electrode for EMG recording. Generally, surface electrodes have the advantages of being non-invasive, causing minimal discomfort, and permitting free movement of the participants. They are also simple to apply, and the detection/recording area is the largest of all electrode types tested [9]. In this respect, our new surface electrode may be the best to record BUC activity. It is small and light (less than 1 g), can be set within seconds, is inserted into the oral cavity easily, and no skill is required for using it. When the electrode is inserted into the mouth, the outer element of the electrode, which may be fixed to the skin with surgical tape so that the electrode is stable even during chewing, indicates the intra-oral location of the electrode. None of the participants complained of discomfort during chewing. Additionally, cleansing or sterilization of the skin is not necessary, as with conventional surface electrodes or intramuscular electrodes. Conversely, Hanawa et al. [8] reported difficulties in determining the recording position for the BUC wire electrodes. If the wire is placed near other muscles, even the wire electrode could not be free from contamination by other muscles [8]. Besomi et al. [9] also stated that surface electrodes are mainly appropriate for superficial muscles, but the recording may be contaminated by muscles that are located adjacent or deep to the intended muscle [9]. In this respect, the new electrode placed on the mucosa directly faces the BUC, and the contamination may be minimal.

4.3 Basic characteristics of BUC activity

The basic characteristics of BUC activity have been reported previously [10,11,15,16]. In Table 1, studies conducted with wire or needle electrodes, which evaluated the BUC activity with six grades, i.e., “nil” to “very marked” with Basmajian’s analysis, are summarized and compared with the results of this study, wherein the recordings were expressed in the analog quantity. Therefore, statistical evaluations could be applied. Lip closure is accomplished through the cooperative action of the OO and BUC, and the BUC plays an important role. Only Isley and Basmajian [16] recorded BUC activity during lip closure and reported that the activity was “moderate.” EMG activities during the MaxLC task were the base values for our study; thus, their evaluation as “moderate” may be reasonable. Additionally, the BUC was active during MaxLC, as was the OO, indicating that the BUC assists lip closure by pulling the corners of the mouth.

During clenching, a large SD was obtained in the MAS. Since the base value for normalization was obtained during MaxLC task, which is almost no load for the MAS, it is imaginable and may not affect any on the study. BUC activity during clenching was evaluated as “negligible” in two studies [8,15], indicating that it was the smallest among the tasks. Our result was 0.19, which was also the smallest among all tasks. In addition, activity during the corner-pulling task was graded as “moderate–marked” by four studies [8,10,15,16], and the evaluation was the highest among tasks. In this study, the BUC activity during the corner-pulling task was 1.13, which was the largest among the tasks. The BUC has been considered a protagonist for the corner-pulling task. The present results support this hypothesis physiologically.

Meanwhile, in the sucking task, Vitti et al. [10] and Blanton et al. [15] reported conflicting results (i.e., “marked” vs “slight–moderate”). This contradiction may be due to the disadvantage of the wire electrode, as pointed out by Besomi et al. [9]; recording conditions may be influenced by the site and size of the electrode tip. However, large SDs were obtained in the ZM and by BUC-in. This can also be interpreted as follows: the negative oral pressure is generated by many muscles, and individuals may use them differently.

Although the BUC is called the “blower muscle” due to its function of puffing out cheeks, our study showed its relatively small action in sucking (0.67) and blowing tasks (0.67). The BUC activity during the blowing and sucking tasks may also differ in individual and performance situations.

In conclusion, the results of this study with surface electrodes coincided with those of studies with intramuscular electrodes.

4.4 Chewing task

Schieppati et al. [7] and Hanawa et al. [8] studied BUC activities during chewing. Their results on the burst timing of the DIG and BUC coincided with those of this study. The onset of the DIG overlapped with MAS cessation, and the BUC lasted until the MAS peak time, i.e., the DIG began its activity before a BUC burst onset and ended before a BUC burst cessation. The BUC started activity shortly after MAS cessation and continued until the following MAS peak time. The BUC burst timing may maintain the required tension in the cheeks, thereby preventing injury of the buccal mucosa. In addition, the role of the BUC may be to position the food bolus between the dental arches just prior to clenching [7]. In this study, the L-OO increased its activity in the opening phase simultaneously with the BUC. Hanawa et al. [8] suggested that the activities of the OO and BUC muscles would be regulated quantitatively and temporally in accordance with the physical properties of the food.

The amplitudes of BUC activity during chewing are discussed below. Previous studies reported conflicting results. Hanawa et al. [8] reported that BUC activity during the ipsilateral mastication of two peanuts was 0.32, after normalizing to the value during pulling the corners of the mouth. Meanwhile, it was reported by Perkins et al. [11] as 140% after normalization to the maximal amplitude obtained during voluntary tonic contraction. The difference in the relative BUC activities seems to be too large to be explained by the difference in base values. In this study, the normalized peak BUC activity was determined to be 0.72. It was 0.64 after compensation with the same base value (i.e., that of the corner-pulling task), close to that reported by Hanawa et al. [8]. Thus, the peak BUC activity during chewing is less than that obtained during the MaxLC task and is equivalent to that during blowing and sucking tasks.

5 Conclusions

We introduced a new surface electrode that is placed on the buccal mucosa and can record BUC activity free of contamination by the surrounding musculature. The electrode is easily set in the right place within seconds and does not require mucosal cleansing or sterilization; thus, it would be useful for clinical use. Among the functional tasks, the BUC showed the largest activity in the corner-pulling task and has been considered a protagonist for it; the present results support the idea physiologically. The BUC was as active during a MaxLC as the OO, indicating that it assists forceful lip closure by pulling the corners of the mouth. During chewing, the BUC was active during the opening phases, similar to the DIG and OO, and the peak value of the BUC bursts was similar to that during blowing and sucking.

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