New method of neck surface electromyography for the evaluation of tongue-lifting activity

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SUMMARY

Elevation of the posterior part of the tongue is important for normal deglutition and speech. The purpose of this study was to develop a new surface electromyography (EMG) method to non-invasively and objectively evaluate activity in the muscles that control lifting movement in the posterior tongue. Neck surface EMG (N-EMG) was recorded using differential surface electrodes placed on the neck, 1 cm posterior to the posterior border of the mylohyoid muscle on a line orthogonal to the lower border of the mandible. Experiment 1: Three healthy volunteers (three men, mean age 37.7 years) participated in an evaluation of detection method of the posterior tongue lifting up movement. EMG recordings from the masseter, temporalis and submental muscles and N-EMG revealed that i) N-EMG was not affected by masseter muscle EMG, and ii) N-EMG activity was not observed during simple jaw opening and tongue protrusion, revealing the functional difference between submental surface EMG and N-EMG. Experiment 2: Seven healthy volunteers (six men and one woman, mean age 27.9 years) participated in a quantitative evaluation of muscle activity. Tongue lifting tasks were performed, exerting a prescribed force of 20, 50, 100 and 150 gf with visual feedback. For all subjects, a significant linear relationship was observed between the tongue lifting force and N-EMG activity ($P < 0.01$). These findings indicate that N-EMG can be used to quantify the force of posterior tongue lifting and could be useful to evaluate the effect of tongue rehabilitation in future studies.

Keywords: tongue lifting, electromyography, tongue pressure, rehabilitation, neck surface, muscle coordination

Background

As our population ages, the number of patients with cerebrovascular accidents or neurologic disorders is increasing (1). Dysphagia and dysarthria are serious problems that affect quality of life in these conditions (2, 3). Tongue function has been studied from several aspects using various modalities. Although age-related changes in tongue movement during mastication and swallowing have been reported in studies involving videofluorography and ultrasound diagnostic systems (4–8), these imaging methods are not suitable for evaluating the strength of functional muscle activity. Pressure-sensitive film has been used to measure tongue pressure during swallowing (1); however, this methodology is not adequate when tongue cannot be in contact with palate. From this point of view, the importance of the posterior part of the tongue in functional movement has also been reported (9). However, considering the importance of functional tongue rehabilitation of tongue dysfunction in dysphagia and dysarthria, tongue movement dynamics should be analyzed through the entire range of motion, and not only when the tongue contacts the palate. To address this clinical requirement, Shirahige et al. (9) established a non-invasive method to evaluate the lifting movement of the posterior tongue. Their method has been used in speech rehabilitation for stroke patients (10), where it showed a significant effect and demonstrated the role of visual feedback in rehabilitation. On the other hand, bipolar fine-wire electrodes have been used to elucidate tongue muscle activity (11, 12). That method is, however, invasive and therefore impractical for repetitive functional evaluation. The use of surface electrodes directly attached to the tongue surface has also been reported, but direct adhesion of the electrodes can be unstable during tongue movement. Although skin surface electromyography (EMG) is one means of objectively and non-invasively evaluating tongue functional activity, no practical methodology has been reported to date. This study aimed to establish a new method to evaluate posterior tongue lifting force, neck surface EMG measurements corresponding to the location of the posterior tongue (abbreviated neck surface EMG: N-EMG).

Materials and Methods

EMG

N-EMG measurements corresponding to the location of the posterior tongue were recorded using differential surface electrodes, according to the method described below.

A high-precision surface EMG recording system was used, as reported by Kawakami et al. (13). The ambulatory EMG recording hardware consisted of an analog signal-processing and differential amplification integrated hybrid circuit (NB-6201HS; Nabtesco Co., Kobe, Japan), which included a high-pass filter (10 Hz) and a low-pass filter (1000 Hz), and a two-channel digital recorder (ICR-PS004M; Sanyo Electric Co., Ltd., Osaka, Japan). Three disposable Ag/AgCl surface electrodes (6615 mm, Vitrode F-150S; Nihon Kohden Corp., Tokyo, Japan) with center-to-center distances of 15 mm were used to record the EMG. Surface electrodes were placed on the skin over the left neck vein, as shown in Figure 1. The three electrodes were placed 1 cm posterior to the posterior border of the mylohyoid muscle, on a line perpendicular to the inferior border of the mandible. The uppermost electrode was located 1 cm below the inferior border of the mandible. The lowest electrode was located just above the sternocleidomastoid muscle. The electrodes and cables were secured to the skin with thin biocompatible adhesive tape (Cathereep FS 1010; Nichiban Co. Ltd., Tokyo, Japan).

In addition to N-EMG, surface electrodes were placed on the left masseter muscle, on the anterior part of the left temporal muscle, on the left sternocleidomastoid muscle, on the left platysma muscle, and in the submental area. On the temporal, sternocleidomastoid and masseter muscles, electrodes were attached to the center of the muscle belly, parallel to the muscle. The electrodes for the submental area were attached 2 cm posterior to the chin (Fig. 1b). The electrodes for the sternocleidomastoid and platysma muscles, and N-EMG were attached not to be in contact with each other.

Preliminary experiment

Three healthy volunteers (three men, mean age 30.6 ± 2.51 years) participated in this experiment. This experiment was performed to clarify the cross contamination of N-EMG from the sternocleidomastoid and platysma muscles. The tasks used to evaluate cross contamination included i) isometric contraction of the sternocleidomastoid muscle without tongue movement, ii) maximum effortful mastication of medium gummy jelly (KajuGumi, Meiji Co., Ltd., Tokyo, Japan) with their head stabilized.

For the task of isometric contraction of the sternocleidomastoid muscle, the subjects were instructed to push the left back of their heads into the weight scale (a 300-mm square) with their greatest force for five 5-sec. In addition, subjects were instructed to keep their mandible in the resting position and not to move their tongue during this task. For maximum effortful mastication of medium gummy jelly, the subject was instructed to perform maximum comminution in the shortest time possible with their head stabilized in head rest of dental chair.

Experiment 1

Three healthy volunteers (three men, mean age 37.7 ± 16.8 years) participated in this experiment. The tasks used to evaluate muscle coordination included i) maximum pressing on the incisive papilla in the anterosuperior direction by the tongue tip, ii) maximal voluntary clenching, iii) relaxed 20mm jaw open-close movement at a rate of five open-close cycles per 4 sec without any occlusal contact, iv) relaxed slow and gentle mastication of medium gummy jelly, and v) maximum effortful mastication of medium gummy jelly. For the task of relaxed slow and gentle mastication, the subject was instructed not to comminute the gummy jelly.

Experiment 2

Seven adult subjects (six men and one woman, mean age 27.9 ± 3.1 years) participated in this experiment. As shown in Figure 2a, tongue pressure was measured with a force-sensing film (Flexi

Force Sensor model A101-1, Tekscan Corp., Boston, USA), which was adhered to a 16×120×7 mm resin rod and covered with a disposal plastic cover. Subjects were instructed to sit upright in a chair with a headrest to keep their Frankfort plane parallel to the floor. A silicone bite block was placed on the molars to keep the interincisal distance at 10 mm during the task, preventing signal contamination by jaw-opening muscle activity (Fig. 2b). The tip of the sensor was located on the center of the tongue. Participants were instructed to push the sensor tip upwards with a specified force, which the participant could see on a force display for visual feedback (Fig. 2c). Tongue elevation forces were set at 20, 50, 100 and 150 gf. Each subject performed each task three times. Pressure data were acquired through an A/D converter on a personal computer. The sampling rate was 100 Hz. EMG signal and pressure data were synchronized with a trigger signal.

Data processing

N-EMG was analyzed for a 5-sec period after pressure stabilization for each experimental task (Fig. 2c). The fluctuation in tongue pressure for the time period used for N-EMG analysis was less than 5%. EMG data were 250 Hz low-pass filtered, full-wave rectified and then down-sampled for 100 Hz. Mean EMG amplitude was calculated for each data sample.

Statistical analysis

The relationship between EMG amplitude and tongue pressure was evaluated using Pearson's correlation coefficient. Data analyses were performed using SPSS (IBM SPSS Statistics ver. 20.0, IBM Corp., Somers, NY, USA). A significance level of 0.05 was used in this study.

Results

Preliminary experiment

An example of muscle cross contamination in one subject (male, 31years) is shown in Figure 3. Figure 3a shows the results for the task of isometric contraction of the sternocleidomastoid muscle. N-EMG, sternocleidomastoid, and platysma muscles showed strong activity during this task.

Figure 3b shows the results for maximum effortful mastication of medium gummy jelly. N-EMG, masseter EMG, and submental surface EMG were prominent during mastication. In contrast, sternocleidomastoid EMG and platysma EMG activity were weak during this task.

Experiment 1

An example of muscle activity coordination in one subject (male, 57years) is shown in Figure 4. Figure 4a shows the results for the task of maximum pressing against the incisive papilla in an anterosuperior direction by the tongue tip. Submental EMG activity was most prominent during this task, compared with activity during the other tasks, suggesting the role of the submental muscles in tongue protrusion. In contrast, N-EMG activity was weak during this task.

Figure 4b shows the results for maximal voluntary clenching. The N-EMG showed high muscle activity during this task. It should be noted that there was a clear delay between the onset of masseter and temporalis muscle activity and the onset of N-EMG, as indicated by Arrow 1 in Figure 4b. The delays between onset of masseter and temporalis EMG and N-EMG in three participants were 0.58 ± 0.12, 0.21 ± 0.05, 0.18 ± 0.06 second, respectively.

Figure 5c shows the results for relaxed 20mm jaw open–close movement without occlusal contact. As indicated by Arrows 2, 3 and 4 in Figure 4c, clear reciprocal activities were observed between the submental and temporalis EMGs. Almost no EMG bursts were observed in the N-EMG or masseter muscle EMG during this task.

Figure 4d shows the results for relaxed slow and gentle mastication of medium gummy jelly. Masticatory and temporal muscles showed nearly synchronous bursts during this task. There was a slight delay between the onset of jaw-closing muscle activity (temporalis and masseter muscles) and the onset of N-EMG activity (Arrow 5, Fig. 4d). The strength of N-EMG activity during this task was moderate. As indicated by Arrow 6 in Figure 4d, the submental EMG burst began slightly before the offset of the jaw-closing muscles.

Figure 4e shows the results for maximum effortful mastication of medium gummy jelly. N-EMG showed strong activity during this task. As indicated by Arrow 7 in Figure 4e, the peak of N-EMG activity occurred slightly after the peak of the jaw-closing muscles and was maintained until slightly after the end of the jaw-closing muscle bursts. As indicated by Arrow 8, submental muscle activity increased from the latter half of the masseter muscle burst. Submental muscles showed peak activity near the end of masseter muscle activity.

Experiment 2

Raw wave examples of N-EMG at each prescribed tongue pressure are shown in Figure 5. The intensity of N-EMG activity increased with increasing lifting pressure of the tongue. The relationship between N-EMG activity and tongue lifting pressure for seven subjects is shown in Figure 6. For all seven subjects, a significant correlation was observed between N-EMG activity and tongue lifting pressure ($P < 0.01$). The correlation coefficients for different participants ranged from 0.789 to 0.959. Although N-EMG activity showed a fairly linear correlation with pressure from 20 gf through 150 gf in Subjects 1, 4, 6 and 7, similar N-EMG activities were observed at 20 gf and 50 gf in Subjects 2, 3 and 5. A linear correlation was observed between N-EMG strength and tongue lifting pressure in all subjects for pressures ranging from 50 gf to 150 gf.

Discussion

Cross contamination of N-EMG from the sternocleidomastoid and platysma muscles

Preliminary experiment was performed to evaluate cross contamination of N-EMG from the sternocleidomastoid and platysma muscles. N-EMG activity was occurred during the task of isometric contraction of the sternocleidomastoid in spite of without tongue movement, suggesting that there was a cross contamination between the sternocleidomastoid muscle and N-EMG during the isometric contraction of the sternocleidomastoid muscle. For maximum effortful mastication of medium gummy jelly, however, sternocleidomastoid and platysma muscle activities were remarkably low compared with N-EMG. Furthermore, the onset and offset of N-EMG were not consistent with those of masseter EMG and submental surface EMG, although these three muscles showed high activity during mastication. This finding indicated that N-EMG was occurred independently from the other muscles. Therefore, subjects were instructed to keep their head stabilized in head rest of dental chair in this study because the cross contamination of N-EMG from sternocleidomastoid and platysma muscles was remarkably low with subject's head stabilized.

Detection method of the posterior tongue lifting up movement

Strong EMG activity was observed in the submental surface EMG recording during incisive papilla pressing. This finding is consistent with submental surface EMG data reported in a previous study (12). In contrast, N-EMG showed only slight activity during this task, suggesting that the muscles whose activities are recorded with N-EMG participate very little in tongue protrusion.

In the task of maximal voluntary clenching, although the masseter muscle is located adjacent to the surface electrodes for N-EMG, a clear difference between the onset of N-EMG activity and masseter muscle bursts. This prevents the possibility of electrical contamination between these EMGs. During maximal voluntary clenching, strong N-EMG activity was observed, although the subject did not receive any instruction on tongue movement. This finding suggests that the posterior tongue exerts lifting force during clenching. The participation of tongue movement during mandibular movement is consistent with the findings of a fine-electrode study of tongue-related musculature reported by Hiyama et al. (14). In contrast, slight activity was observed in the submental EMG during and after clenching. These activities might result from slight forward tongue tonicity and possible jaw opening after clenching. Simultaneous recording of jaw movement in future studies with a greater number of subjects would help clarify muscle activity.

In the task of relaxed jaw opening and closing, the jaw-opening temporal muscle and the jaw-closing submental muscles showed clear reciprocal activity. However, no N-EMG activity was observed during this task. This finding confirms that N-EMG does not participate in simple jaw opening, indicating that N-EMG records the activities of muscles whose role differs from that of the submental muscles.

During slow and gentle mastication of medium gummy jelly, the submental and jaw-closing muscle EMGs showed reciprocal activity. However, submental EMG bursts started before the EMGs of the jaw-closing muscles had completely ceased. Although these data are not sufficient to fully explain the phenomenon, this submental EMG activity could be related to forward movement of the tongue tip to position the gummy jelly. The onset of N-EMG during this task occurred slightly after the onset of jaw-closing muscle activity, followed by weak but continuous activity until jaw-closing muscle activity ceased. Therefore, N-EMG demonstrated different dynamics from the submental muscles during this task as well.

During maximum effortful mastication of medium gummy jelly, peak N-EMG activity occurred slightly after the peak of the jaw-closing muscles and remained high until slightly after the end of the jaw-closing muscle bursts. Submental EMG activity gradually increased beginning near the peak of jaw-closing muscle activity, peaking at the end of the jaw-closing muscle burst. The peak submental EMG intensity during this task was almost equivalent with that during maximum pressing against the incisive papilla. Continuous N-EMG activity was observed during maximum voluntary clenching, and was not observed during relaxed jaw opening and closing in this study. Hori et al. reported that the tongue is usually in contact with the palate in the occlusal phase during mastication, and has no contact with the palate in the opening phase (15). These results suggested that N-EMG activity was occurred when tongue was in contact with the palate during mastication. Furthermore, tongue pressure represents the maximum value at the beginning of the opening phase (15). This finding was consistent with our result which high N-EMG activity was observed during at the end of the jaw-closing muscle burst in terms of the timing tongue works. In the task of maximum effortful mastication, submental EMG activity as well as N-EMG activity was stronger than during slow and gentle mastication. This result indicates that the tongue contributes greatly to the bolus formation and keeping the boluses on the occlusal surface. These muscle coordination patterns likely differ among individuals, and need to be clarified in future studies. However, the clear difference in the timing of the onset of N-EMG and masseter muscle activity shows that N-EMG was not affected by contaminating signals from the masseter muscle.

Quantitative analysis of tongue pressure and N-EMG

The lifting movement of the tongue is important when performing physiological functions such as mastication, deglutition and speech. For all subjects, a significant relationship was observed between N-EMG activity and tongue lifting force in experiment 1. N-EMG activity did not differ much at 20 gf and 50 gf in some of the subjects; however, a linear relationship was observed for tongue pressures ranging from 50 gf to 150 gf. Submental surface EMG has long been used to evaluate muscle activity in the neck region, including the activities of the geniohyoid muscle, mylohyoid muscle, the anterior belly of digastric muscle and the genioglossus muscle. Submental surface EMG has been used to evaluate jaw-opening movement, tongue protrusion and swallowing (12). Therefore, during recording of the N-EMG to evaluate EMG activity and tongue lifting force in the present study, a bite block was used to eliminate the possible effect of submental muscle activity. Mylohyoid muscle, geniohyoid muscle, digastric muscle and muscles of the tongue are existed in the neck region. These muscles are jaw-opening muscles except for muscles of the tongue. The restriction of jaw-opening movement by using a bite block decreases muscle activity of jaw-opening muscles considerably regardless of without an actual inhibition. Therefore, this makes it possible to detect muscle activity with regard to tongue movement from N-EMG. The use of a bite block assured that the recorded N-EMG was not affected by submental muscle activity during unintended jaw opening. However, judging from the differences between N-EMG and submental EMG activities during the various tasks, which showed no identifiable contamination, the bite block would not be necessary in future studies.

This study has several limitations. First of all, only seven participants took part in this study. The number of participants in this study was much fewer than that in similar previous studies. Secondly, tongue EMG was not carried out directly in this study. Strictly speaking, considerations to the validity and reliability of N-EMG recording were required to evaluate tongue activity; however, the tongue EMG was not recorded because the unrestricted tongue movement was the highest priority in this study. Therefore, further research is needed to overcome these limitations.

In conclusion, within the limitation of this study, N-EMG can quantitate the force of posterior tongue lifting and N-EMG could be used to evaluate the effect of tongue rehabilitation in future studies.

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Conflict of interests

The authors declare no conflict of interests.

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Figure Legends

Fig. 1. Schematic diagram of the location of surface electrodes for EMG. Neck surface electrodes were placed on the neck, 1 cm posterior to the posterior border of the mylohyoid muscle, on a line perpendicular to the lower border of the mandible. The uppermost electrode was located 1 cm below the inferior border of the mandible. The lowest electrode was located just above the anterior border of the sternocleidomastoid muscle.

Fig. 2. Tongue lifting pressure measurement. a: Sensor for tongue pressure measurement. b: Silicone bite block in position. The height of the bite block was adjusted to maintain an interincisal distance of 10 mm. c: N-EMG quantification was achieved for a 5-s pressure-stable period.

Fig. 3. Cross contamination of neck surface (N), masseter muscle(M), submental surface(Su), sternocleidomastoid muscle(St) and platysma muscle(P) during two tasks. a: isometric contraction of the sternocleidomastoid muscle without tongue movement, b: maximum effortful mastication of medium gummy jelly

Fig. 4. Coordination of neck surface (N), masseter muscle (M), temporal muscle (T) and submental area (S) EMGs during five tasks. a: Maximum pressing against the incisive papilla in an anterosuperior

direction by the tongue tip; b: maximal voluntary clenching; c: relaxed 20 mm jaw opening and closing at a rate of five open–close cycles per 4 sec without occlusal contact; d: relaxed slow and gentle mastication of medium gummy jelly; e: maximum effortful mastication of medium gummy jelly. Arrow 1: onset of N-EMG burst; Arrow 2: onset of submental EMG burst; Arrow 3: onset of temporal muscle EMG burst; Arrow 4: onset of second submental EMG burst; Arrow 5: onset of masseter and temporal muscle bursts; Arrow 6: offset of masseter and temporal muscle bursts; Arrow 7: peak of N-EMG burst; Arrow 8: peak of submental EMG burst.

Fig. 5. Typical raw N-EMG waves for four tongue lifting pressures.

Fig. 6. Relationship between N-EMG activity and tongue pressure. Note that significant correlations ($P < 0.01$) were observed for all subjects.