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Sternocleidomastoid and Posterior Cervical Muscle Coordination in Response to Symmetrical and Asymmetrical Jaw Functions in Normal Adults

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Purpose: The aim of this study was to elucidate the coordination patterns of the sternocleidomastoid and posterior cervical muscles in response to symmetrical and asymmetrical jaw functions in normal adults.

Methods: Twenty-seven healthy volunteers (8 females, 19 males; mean age, 30.4±2.5 years) participated in this study. Surface electromyography (EMG) was used to record activities in the masseter, suprahyoid, sternocleidomastoid, and posterior cervical muscles at rest and during maximum tooth clenching, biting of a cotton roll with the anterior teeth, unilateral biting of a cotton roll with the posterior teeth, bilateral biting of cotton rolls with the posterior teeth, and jaw opening while seated. Normalized amplitude, activity indices, and asymmetry indices were compared between the muscles and the jaw tasks.

Results: During symmetrical jaw functions (e.g., tooth clenching, biting with the anterior teeth, bilateral biting with the posterior teeth, jaw opening), the sternocleidomastoid and posterior cervical muscles showed elevated EMG amplitudes compared with the resting condition. The co-activation pattern of the sternocleidomastoid muscle was more pronounced than those of the posterior cervical muscles during these tasks. During asymmetrical jaw functions (e.g., unilateral biting with the posterior teeth), the ipsilateral sternocleidomastoid and masseter muscles showed higher contraction activity than did the contralateral muscles, but the contralateral posterior cervical muscles were more active than the ipsilateral muscles.

Conclusions: The sternocleidomastoid and posterior cervical muscles were shown to be co-activated and coordinated anteroposteriorly or bilaterally according to symmetrical or asymmetrical jaw function. These results suggest an integrated neural control mechanism for the jaw and neck muscles, and provide further evidence supporting the intimate functional coupling between the trigeminal and cervical neuromuscular systems.

Key Words: Co-activation; Coordination; Electromyography; Masticatory muscles; Neck muscles

INTRODUCTION

Numerous studies have noted the close association between the craniofacial and cervical regions, and the relationship is thought to reflect anatomical, developmental, neurophysiological, and functional connections between these regions.1) Pain in the cervical musculoskeletal tissues may be referred to craniofacial structures, including the jaw muscles.2-4) Postural positions and functional movements of the jaw, head, and neck are elaborately and finely coordinated by neuromuscular controls, such as reciprocal innervation.5) Jaw-closing muscles, such as the temporalis, masseter, and medial pterygoid, are antagonized by jaw-opening muscles in the anterior neck, including the suprahyoid (SH) and infrahyoid muscles. During voluntary jaw opening and closing activities, mandibular and head/neck movements occur concomitantly.[6-9] Neck muscles are co-activated during jaw functions, including clenching,[10-16] biting,[14,17,18] and chewing.[19] They can also be co-inhibited by stimuli that inhibit the masticatory muscles.[20]

More than 20 pairs of neck muscles are involved in the stabilization and movement of the head and neck.[21] They can be categorized as anterior and posterior neck muscles. The SH and infrahyoid groups, sternocleidomastoid (SM), and scalene muscles are anterior neck muscles, whereas the splenius capitis, semispinalis capitis, rectus capitis and obliquus capitis groups, upper trapezius, and levator scapulae are posterior neck muscles. Some of these muscles are directly accessible with surface electrodes and their roles in neck movement and stabilization have been explored using surface electromyography (EMG).[22] Research has shown that the SM muscle is responsible for head flexion, rotation, and lateral bending; the splenius capitis is active during neck extension, ipsilateral rotation, and lateral bending; and the semispinalis capitis contributes to neck extension and posterolateral bending.[23-25] The SM and upper trapezius muscles have often been chosen to examine functional coupling between the trigeminal and cervical motor systems.[10-14,16,19,26] Co-contraction of deep cervical muscles has also been demonstrated in studies using needle EMG,[15,18] and even the activity of trunk muscles has been shown to be related to jaw function.[12]

Most studies in humans have reported the responses of neck muscles to bilaterally balanced or symmetrical jaw tasks. Few studies have compared neck muscle activities between the right and left sides to investigate asymmetrical co-activation patterns in response to asymmetrical jaw functions. Thus, this study aimed to examine the EMG responses of the SM and posterior cervical (PC) muscles to asymmetrical jaw functions as well as symmetrical to elucidate coordination patterns related to jaw activities in normal adults.

MATERIALS AND METHODS

1. Participants

A sample of 27 subjects (8 females, 19 males) was selected from a group of student volunteers (mean age, 30.4±2.5 years; mean height, 170.8±6.0 cm; mean weight, 66.2±11.5 kg) of School of Dentistry, Chonnam National University from January 2012 to September 2012. All participants had 28 permanent teeth except third molars. Subjects with current orthodontic treatment, known histories of head and neck trauma or surgery, jaw and neck pain, or neuromuscular disorders were excluded. Each volunteer was informed about the study procedure and risks involved, and written informed consent was obtained before participation in the study. Ethical approval was obtained from the Chonnam National University Hospital's Institutional Review Board (CNUH-2011-212).

2. Instrumentation

One independent researcher assessed bilateral jaw and neck muscle EMG activities. The skin was carefully cleaned with 83 volume/volume percent (v/v %) ethanol prior to electrode placement. Self-adhesive pre-gelled disposable bipolar Ag/AgCl surface electrodes (Duotrode; Myotronics-Noromed Inc., Seattle, WA, USA) were placed parallel to the longitudinal axes of the muscles and secured using surgical tape. The conducting surface diameter of each bipolar circular electrode was 14 mm and the center-to-center distance between electrode pairs was 20 mm. Electrodes were placed along the fibers of the superficial masseter (MS) muscle, 1 cm from the anterior margin of the muscle, and the lower unipolar electrode was placed 2 cm superior to the inferior mandibular border. Electrodes were placed over the anterior digastric belly along the fibers of the SH muscles, about halfway between the mental and hyoid attachments. On the SM muscle, electrodes were placed over the muscle belly halfway between the mastoid process and sternal notch. Electrodes were placed on the PC muscles at the approximate level of the fourth cervical vertebra, 2 cm lateral of the midline and parallel to the cervical spine. The reference electrode was placed over the spinous process of the seventh cervical vertebra.

EMG signals from each electrode arrangement were amplified using an eight-channel single differential amplifier (K7 EMG PRE-AMP; Myotronics-Noromed Inc.). Input impedance was >20 MΩ, the common mode rejection ratio was >110 dB, the instrument noise voltage was <0.2 μV, and the maximum output voltage was 2.048 mV. The signals were band-passed at 15 to 400 Hz and band-stop filtered at 60 Hz. The raw signals were digitized by a 12-bit analog-to-digital converter at a sampling rate of 690 Hz, amplified, and stored in a personal computer. The EMG signals were analyzed using K7 software (Myotronics-Noromed Inc.). The average rectified value (in microvolts) served as the amplitude variable for the resting condition (15-second duration). The integral average value (in microvolts) was calculated from the 1.42-second time window with the highest amplitude during a 3-second muscle contraction period for each task.

3. Experimental Protocol

The subjects were carefully instructed in the experimental protocol. Each subject was seated upright in a dental chair with the head unsupported and the Frankfurt horizontal plane parallel to the floor. Resting muscle activity was recorded for 15 seconds. The maximum voluntary contraction (MVC) activities of the jaw and neck muscles were then recorded during the following nine tasks: (1) MVC of the MS muscle (ICP): the subject was instructed to clench the jaw as strongly as possible in the intercuspal position without a cotton roll and to maintain the same level of contraction; (2) MVC of the SH muscles (Open): the subject was instructed to open the mouth as widely as possible and to maintain the maximum level of opening activity; (3) MVC of the SM muscle: while the experimenter held the subject's head with the hands to resist rotation, the subject was instructed to rotate his/her head right and left, respectively, as strongly as possible; (4) MVC of the PC muscles: while the experimenter held the subject's head with the hands to resist dorsiflexion, the subject was instructed to flex his/her head backward as strongly as possible; (5) MVC during bilateral posterior biting (PostBite): the subject was instructed to bite down as strongly as possible on two 10-mm-thick cotton rolls positioned bilaterally in the premolar and molar regions; (6) MVC during anterior biting (AntBite): the subject was instructed to bite down as strongly as possible on one 10-mm-thick cotton roll positioned between the anterior teeth; (7) MVC during right unilateral posterior biting (RtBite): the subject was instructed to bite down as strongly as possible on one 10-mm-thick cotton roll positioned in the right premolar and molar region; and (8) MVC during left unilateral posterior biting (LtBite): the subject was instructed to bite down as strongly as possible on one 10-mm-thick cotton roll positioned in the left premolar and molar region.

The subjects performed two or three test trials for training before EMG measurements were recorded. During each contraction task, four MVC trials were performed, with 30-second rest periods between trials. To avoid fatigue, tasks were separated by 1-minute rest periods.

4. EMG Data Processing

Data obtained during the first four contraction tasks were used to calculate mean global MVC values for the MS, SH, SM, and PC muscles; after exclusion of the lowest value, the average of the remaining three values was used. Notably, MVC amplitudes for the PC muscles were higher during lateral head rotation than during dorsiflexion in most subjects. Thus, a higher amplitude value was adopted for the MVC of the PC muscles for each subject. According to a guide for electrode placement,[27)] behavioral tests for midcervical (C4) paraspinal placement include lateral bending and cervical rotation, as well as cervical extension. The amplitudes of the other tasks were divided by the global MVC values for each subject and expressed as normalized amplitudes (%).

The activity index was used to compare the quantitative contributions (EMG activities) of the SM and PC muscles to contraction efforts.[28)] The activity index of the SM+PC muscle pair was calculated for each side using data obtained from the four symmetrical contraction tasks (ICP, PostBite, AntBite, and Open).

The activity index of the SM+PC muscle pair was defined as:

$$\text{Activity index}_{SM/PC}=(A_{SM}-A_{PC})/(A_{SM}+A_{PC})\times 100,$$

where amplitude (A) is the EMG amplitude of the SM or PC muscles for a specific task. The index ranges from −100% to +100%, with +100% denoting exclusive SM activity. Thus, a higher activity index indicates a greater contribution from the SM muscle than from the PC muscles.

The asymmetry index of the jaw and neck muscles were used to quantify asymmetry in EMG activities between the left and right muscles using data from the two asymmetrical contraction tasks (RtBite and LtBite).

The asymmetry index[28)] was defined as:

$$\text{Asymmetry index}=(A_{right}-A_{left})/(A_{right}+A_{left})\times 100,$$

where A is the EMG amplitude of the right or left muscles for a specific task.

The index ranges from −100% to +100%, with a positive index indicating right-side dominance and a negative index reflecting left-side dominance.

5. Statistical Analyses

The Kolmogorov-Smirnov test showed that not all data were normally distributed; thus, medians and interquartile ranges were used as central tendency and dispersion statistics and non-parametric statistical tests were chosen for all subsequent statistical analyses. Friedman's test and the post hoc Wilcoxon signed rank test with Bonferroni correction were used to examine pairwise median differences between experimental conditions. Friedman's test was used to identify significant differences in normalized amplitude values among jaw contraction tasks. A p-value <0.05 was considered to indicate statistical significance. When significant interaction existed between jaw activities, the Wilcoxon signed rank test with Bonferroni correction was used as post hoc analysis. All analyses were performed using the IBM SPSS Statistics software version 20 (IBM Co., Armonk, NY, USA).

RESULTS

1. Co-activation of Neck Muscles in Response to Symmetrical Jaw Functions

The raw amplitude values of the jaw and neck muscles under the resting condition were generally ~1.0 μV and did not exceed 2.0 μV. The median of normalized amplitude values for the SM were <1.0% MVC during rest and ~5% MVC during the ICP and AntBite tasks. The median of normalized amplitude values were higher during the PostBite task than during the ICP task (right side, 6% MVC; left side, 8% MVC). The median value obtained during the Open task exceeded 20% MVC and was about fivefold higher than the value obtained during the ICP task (Fig. 1). The normalized amplitude values for the SM muscle differed significantly among the resting state and the four contraction tasks for the right and left sides (p<0.001). Pairwise comparison demonstrated significant differences between all paired conditions for both sides (p<0.001), except the ICP-AntBite pair (right side, p=0.058; left side, p=0.086).

The median of normalized amplitude values for the PC muscles were ~1.0% MVC during rest, ~3.0% MVC during the ICP task, and ~4% MVC during the PostBite task. The

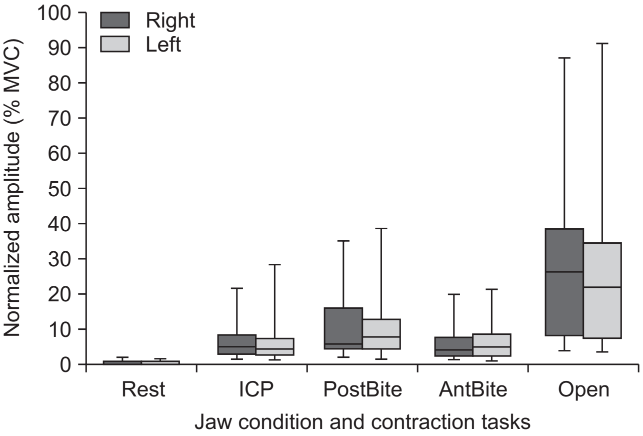

Fig. 1. Normalized amplitude values for sternocleidomastoid muscle activity differed significantly among the resting condition and the four symmetrical jaw contraction tasks on the right and left sides (p<0.001). Pairwise comparison showed significant differences between all paired conditions for both sides (p<0.001), except the ICP-AntBite pair (right side, p=0.058; left side, p=0.086). MVC, maximum voluntary contraction; Rest, resting condition; ICP, maximum jaw clenching; PostBite, maximum bilateral biting of two cotton rolls with the posterior teeth; AntBite, maximum biting of a cotton roll with the anterior teeth; Open, maximum jaw opening.

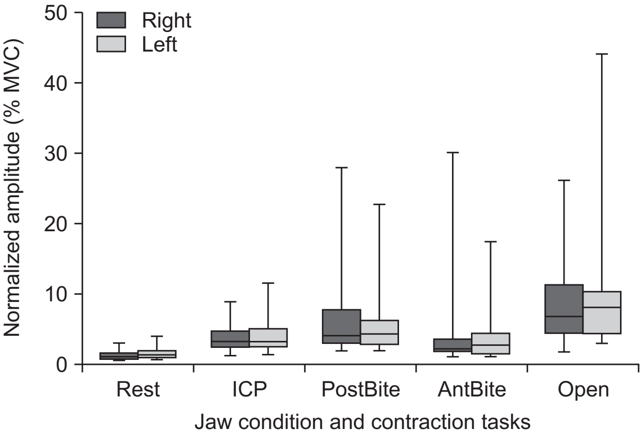

Fig. 2. Normalized amplitude values for posterior cervical muscle activity differed significantly among the resting condition and the four symmetrical jaw contraction tasks on the right and left sides (p<0.001). Pairwise comparison revealed significant differences between all paired conditions for both sides (p≤0.001), except the ICP-AntBite (right side, p=0.155; left side, p=0.130) and PostBite-Open (right side, p=0.014; left side, p=0.020) pairs. MVC, maximum voluntary contraction; Rest, resting condition; ICP, maximum jaw clenching; PostBite, maximum bilateral biting of two cotton rolls with the posterior teeth; AntBite, maximum biting of a cotton roll with the anterior teeth; Open, maximum jaw opening.

value obtained during the Open task was more than twofold that during the ICP task, but was not >10% MVC (Fig. 2). The normalized amplitude values for the PC muscles differed significantly different among the resting state and the four contraction tasks for the right and left sides (p<0.001). Pairwise comparison demonstrated significant differences between all paired conditions for both sides (p≤0.001), except the ICP-AntBite (right side, p=0.155; left side, p=0.130) and PostBite-Open (right side, p=0.014; left side, p=0.020) pairs.

2. Anteroposterior Coordination of Neck Muscle Activities in Response to Symmetrical Jaw Functions

Fig. 3 depicts activity indices for the SM and PC muscles during the four symmetrical contraction tasks (ICP, PostBite, AntBite, and Open). Median activity indices exceeded 40% during all contraction tasks. The highest median values were observed during the Open task (right side, 64.9%, p=0.022; left side, 57.2%, p=0.004). Pairwise comparison showed significant differences in the Open-ICP (p=0.007), Open-PostBite (p=0.009), and Open-AntBite (p=0.005) pairs for the right side; and the Open-ICP (p=0.001) and the Open-AntBite (p=0.004) pairs for the left side.

3. Bilateral Coordination of Jaw and Neck Muscle Activities in Response to Asymmetrical Jaw Functions

Fig. 4 and Table 1 show asymmetry indices for the jaw and neck muscles (MS, SH, SM, and PC) during the two asymmetrical contraction tasks (RtBite and LtBite). There were significant differences of the asymmetry indices of MS, SH, SM, and PC between the two tasks (RtBite and LtBite) (Table 1). Median asymmetry indices for RtBite were positive for the MS, SH, and SM muscles and negative for the PC muscles (Fig. 4A). The median value was largest for the SM muscle, followed by the SH and MS muscles (p=0.039). Pairwise comparison revealed a significant

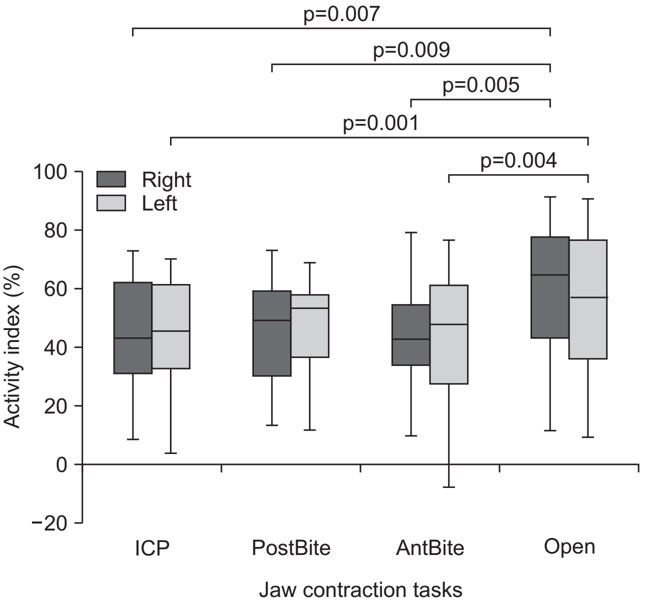

Fig. 3. Activity indices for the sternocleidomastoid+posterior cervical muscle pair during four symmetrical jaw contraction tasks. ICP, maximum jaw clenching; PostBite, maximum bilateral biting of two cotton rolls with the posterior teeth; AntBite, maximum biting of a cotton roll with the anterior teeth; Open, maximum jaw opening.

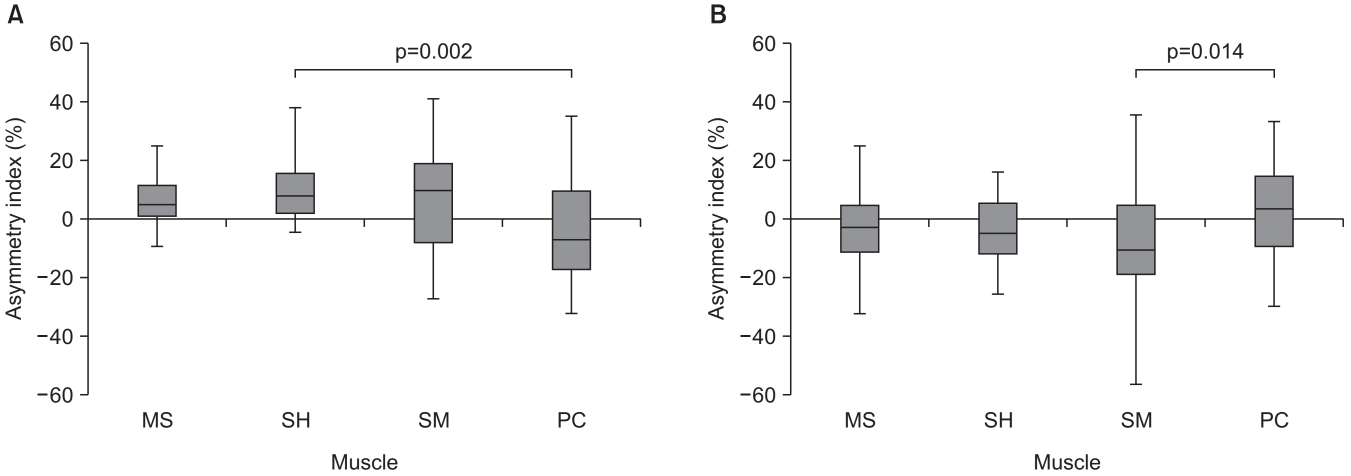

Fig. 4. Asymmetry indices for the jaw and neck muscles during unilateral biting tasks. (A) Biting down on a cotton roll with the right posterior teeth (RtBite); (B) biting down on a cotton roll with the left posterior teeth (LtBite). MS, superficial masseter; SH, suprahyoid; SM, sternocleidomastoid; PC, posterior cervical.

Table 1. Asymmetry indices for the jaw and neck muscles during unilateral biting tasks

Biting task	Muscle				p-value[a]
	MS	SH	SM	PC	
RtBite	5.16 (1.14 to 11.89)	8.31 (2.40 to 15.86)	10.06 (−7.51 to 19.16)	−6.78 (−17.01 to 9.73)	0.039
LtBite	−2.93 (−11.42 to 4.81)	−4.9 (−11.82 to 5.61)	−10.49 (−18.66 to 4.80)	3.33 (−9.12 to 15.08)	0.041
p-value[b]	<0.001	<0.001	<0.001	0.001	

RtBite, biting down on a cotton roll with the right posterior teeth; LtBite, biting down on a cotton roll with the left posterior teeth; MS, superficial masseter, SH: suprahyoid; SM, sternocleidomastoid; PC, posterior cervical.
Values are presented as median (interquartile range).
There were significant differences of the asymmetry indices of MS, SH, SM, and PC between the two tasks.
[a]Friedman test. [b]Related samples Wilcoxon signed rank test.

difference only for the PC-SH pair (p=0.002). Median asymmetry indices for LtBite were negative for the MS, SH, and SM muscles and positive for the PC muscles (Fig. 4B). The median values was smallest for the SM muscle (p=0.041). Pairwise comparison revealed a significant difference only for the PC-SM pair (p=0.014).

DISCUSSION

In this study, the coordination patterns of the SM and PC muscles during several symmetrical and asymmetrical jaw functions were investigated in healthy adults. Symmetrical jaw function was evaluated using four contraction tasks (ICP, AntBite, PostBite, and Open). The SM and PC muscles showed elevated EMG amplitudes during all four of these tasks compared with the resting condition. The co-activation pattern of the SM muscle was more pronounced than that of the PC muscles during these tasks. During the ICP task, the median amplitudes of the SM and PC muscles were ~5% MVC and slightly greater than 3% MVC, respectively. These values are lower than those reported in previous studies.

Clark et al.[11] showed that the SM co-contraction level was ~14% MVC, and Ferrario et al.[13] reported values of 14% to 24% MVC. Sforza et al.[16] found that the average co-contraction levels of the upper trapezius were 10% to 12% MVC. Forrester et al.[14] reported co-contraction activities of 11% MVC for the anterior digastric muscle, 17% MVC for the SM muscle, and 7% MVC for the trapezius muscle. Hellmann et al.[18] found significant co-activation of the SM, SH, infrahyoid, and semispinalis capitis muscles (7% to 19% MVC). In a similar study, Giannakopoulos et al.[15] reported co-activation levels of 15% to 25% MVC for the SM, trapezius, splenius capitis, and levator scapulae muscles. The comparatively low amplitude values obtained in this study may be due to several reasons. First, median EMG amplitude values were used instead of mean values, which are generally higher than median values. Second, the subjects might have performed MVC tasks very efficiently as a consequence of vigorous training. Third, for the MVC of the PC muscles, the higher amplitude value between the values during lateral head rotation and dorsiflexion was adopted.

In the present study, co-activation of the SM and PC muscles was more pronounced during the PostBite task than during the ICP and AntBite tasks. Although not shown in the results, the median amplitude value for the MS muscle was higher during the PostBite task than during the ICP task, in agreement with the findings of another study.[14] Wang et al.[29] explained that surface EMG values for the jaw muscles are higher and more stable, with more contact points, when subjects bite on a soft surface compared with a hard surface. Thus, our subjects' neck muscles might have been co-activated to a greater degree as the jaw-closing muscles were activated further when the occlusal relationship became more stable with the bilateral insertion of cotton rolls between the posterior teeth, compared with maximum clenching in the intercuspal position.

In this study, the EMG amplitude of the neck muscles was higher during the Open task than during the other three jaw contraction tasks. For the SM muscle, this value (>20% MVC) was about fivefold that during the ICP task. For the PC muscles, it was more than twofold that obtained during the ICP task, but did not exceed 10% MVC. Several factors could contribute to such pronounced co-activation of the neck muscles during maximum jaw opening. First, the Open task used in this study involved a maximal, forceful opening action, which requires much greater contraction of the involved muscles than do ordinary functional opening movements, such as talking and yawning. Second, the jaw opening movement accompanies slight head extension[5-7,9)] due to increased posterior neck muscle activity. Therefore, the SM muscle exerts additional co-activation to antagonize the PC muscles and stabilize the skull. Eriksson et al.[7)] demonstrated the consistent activation of the SM and upper trapezius muscles along with the SH muscles during jaw opening. Finally, the infrahyoid muscles are also active during jaw opening, and crosstalk from these neighboring muscles to the SM electrode site might have affected the EMG amplitude of the SM muscle to some extent.

In the present study, the activity index was used to describe the coordination patterns of the anterior and posterior neck muscles in response to symmetrical jaw muscle contraction tasks. Activity indices for the SM-PC muscle pair were >40% during the four symmetrical jaw tasks (ICP, PostBite, AntBite, and Open). The highest activity index was observed during the Open task on the right and left sides. This result is consistent with previous reports,[10,12,14,18,26)] in that the co-activation pattern of the SM muscle was more prominent than that of the PC muscles during symmetrical jaw functions.

In the present study, asymmetrical jaw function was evaluated using the RtBite and LtBite tasks. Muscle activity was quantified for each side separately using the asymmetry index. Contraction activity was higher in the ipsilateral MS, SH, and SM muscles than in the contralateral muscles during asymmetrical jaw function, and this asymmetry was most pronounced in the SM muscle. In contrast, the contralateral PC muscles were more active. These findings indicate that the ipsilateral SM muscle is co-activated along with the masticatory muscles during unilateral biting, and that the contralateral PC muscles are also co-activated to counterbalance SM muscle activity across the cervical spine.

Several studies have analyzed asymmetrical EMG activity of the jaw muscles during unilateral posterior biting. For example, Wang et al.[17)] reported that EMG amplitudes of the masseter during maximal voluntary biting with cotton roll loading in the molar areas were 209 μV on the working side and 182 μV on the balancing side, and that those of the temporalis anterior were 194 μV and 153 μV, respectively. In another study, Wang et al.[29)] confirmed that EMG activity in the MS and anterior temporalis muscles was greater on the working side than on the balancing side during unilateral clenching with molar support. In contrast, relatively little research has explored asymmetrical co-activation of the neck muscles during asymmetrical jaw functions. Ferrario et al.[30)] showed that the symmetrical pattern of SM muscle contraction became asymmetrical, even when clenching unilaterally on a very thin material, such as a monolateral 200-μm-thick occlusal film.

In this study, when jaw activity was directed unilaterally, it affected the ipsilateral and contralateral neck muscles. Our findings suggest that the ipsilateral SM and contralateral PC muscles are co-activated to counterbalance each other across the cervical spine during asymmetrical jaw functions, which implies a mechanism of integrated neural control of the jaw and neck muscles on both sides for head stabilization. Anatomically, both the MS and SH muscles are supplied by motor nerves from the trigeminal mandibular branch, and the SM and upper trapezius muscles are innervated by the spinal accessory nerve, which arises from levels C2 to C4. Neurophysiologically, trigeminal afferents seem to influence motor neurons of the neck region via widespread connections.[7)] Trigeminal descending fibers are found throughout the spinal cord bilaterally in the ventral and dorsal horns.[31,32)] Proprioceptive feedback from the orofacial region projects directly to the cervical spinal cord.[33)] There are strong reflex connections from MS muscle afferents to fusimotor neurons at the C3 to C4 level.[34)] Trigeminal sensory inputs not only modulate jaw movements but also produce head movements or modify the neck muscle tone during mastication.[35,36)] Zeredo et al.[35)] showed that unilateral stimulation of periodontal mechanoreceptors could elicit tonic discharge in the splenius muscles bilaterally, which was consistent with a tendency to head extension. Zafar et al.[6)] proposed that jaw and neck muscle actions are elicited and synchronized by pre-programmed neural commands common to both the jaw and the neck motor systems.

Electrode placement sites can be graded as general, quasi-specific, or specific.[37)] The specific placement strategy is applied to detect the myoelectric activity of a specific muscle, which is usually close to the surface and easily accessible with surface electrodes. In this study, electrode placement on the MS and SM muscles followed this placement strategy. The quasi-specific placement strategy also attempts to record signals from specific muscles. However, such signals are not clearly isolated from other signal sources due to the proximity of neighboring muscles or the depth of the muscle from the surface. In this study, electrode placement on the SH and PC muscles followed this strategy. Although the electrodes on the SH muscle were aligned along the fibers of the digastric anterior belly, they were expected to record general activity from the muscles that open the mouth and move the tongue. Electrodes on the PC muscles were placed paraspinally in the midcervical region (C4 level) and were assumed to record activity from the fibers of the upper trapezius, semispinalis capitis, and splenius muscles. This situation is due to the arrangement of the PC muscles in at least four layers38): the upper trapezius is outermost and partially covers the splenius and semispinalis capitis, and the splenius is located over the semispinalis. Previous EMG studies have tended to use the term "trapezius" to describe these muscles, but differences in specified locations render comparison of the results of these studies difficult. In addition, bioelectric signals did not likely originate from the trapezius muscle alone, according to the locations described in these studies. In this study, the term "posterior cervical", rather than "trapezius", was used to better represent the signal features.

Several methodological and technical limitations of this study should be addressed. First, all jaw functions were static tasks performed while the subjects were seated upright. Thus, the findings of the present study cannot be generalized to other clinical conditions, including different postures or various dynamic tasks. Second, the co-activation and coordination patterns of the neck muscles were monitored only under maximal contraction of the jaw muscles. The co-activation response of the neck muscles to submaximal contraction of the jaw muscles might imitate more natural phenomena than did maximal contraction. In contrast, testing of the maximal contraction of a muscle is a fundamental step that maximizes the detectability of any response. In addition, EMG amplitudes collected during MVC are known to have the best repeatability for the head and neck muscles.14,39,40) Third, integral averages instead of root-mean-square (RMS) values were used to measure the amplitudes of myoelectric signals because the software attached to the EMG equipment did not support RMS calculation. RMS values are considered to be less susceptible to distortion during signal processing and are preferred to integral average values in most applications.37) Nonetheless, the conclusions are not influenced by this shortcoming because all data were normalized before analysis. Finally, the order of contraction tasks was not randomized. The measurements could have been affected by systematic error related to the subjects' adaptation to the fixed order of task performance.

In conclusion, this study revealed that the SM and PC muscles are co-activated during various jaw functions, and they are coordinated anteroposteriorly and bilaterally according to functional symmetry or asymmetry. Our results suggest the existence of an integrated neural control mechanism for the jaw and neck muscles, and provide further evidence of functional coupling between the trigeminal and cervical neuromuscular systems.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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