Original Article

Effects of Experimental Nasal Obstruction on Human Masseter and Suprahyoid Muscle Activities During Sleep

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Abstract: The effect of nasal obstruction on nocturnal masseter and suprahyoid muscle activities using a newly developed portable electromygram (EMG)–recording unit was examined. Ten healthy Japanese males participated in this study. EMG activities of both the right masseter and bilateral suprahyoid muscles were recorded with a portable EMG-recording unit. At midnight, the subject was asked to lie on a bed after complete preparation with surface electrodes. After maximal clenching and jaw-opening effort (100% maximum voluntary contribution), the subject was allowed to fall asleep. In the first half of the night, EMG activities were recorded for about three hours of sleep without nasal obstruction. In the second half of the night, EMG activities were recorded for about three hours of sleep with nasal obstruction. In both muscles, there were no significant changes in either the maximal EMG activities or the number of events beyond 40% MVC with nasal obstruction. But in an evaluation based on the distribution of muscle activities, the EMG activity of the masseter muscle tended to decrease ($P = .07$) and that of the suprahyoid muscles increased significantly ($P = .02$) with nasal obstruction. These results suggest that nasal obstruction could modulate the activities of the masseter and suprahyoid muscles during sleep. (*Angle Orthod* 2003;73:151–157.)

Key Words: Masseter muscle; Suprahyoid muscles; Nasal obstruction; Sleep; Electromyogram

INTRODUCTION

Oral respiration strongly affects craniofacial growth and leads to a particular facial pattern, ie, adenoidal facies.[1,2] This change in craniofacial growth may induce a simultaneous occlusal change, and many researchers have found a close relationship between oral respiration and the development of malocclusion,[3–6] although some have argued to the contrary.[1] In addition, experimental nasal obstruction induces a change in head posture.[7] Further, Solow et al[8] reported that a change in head posture, which was related to an increase in upper-airway resistance, may affect the craniofacial morphology.

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On the other hand, regarding the relationship between masticatory muscle function and the craniofacial morphology, Tabe[9] reported that masseter muscle activity was significantly and positively correlated with the posterior facial height, and significantly and negatively correlated with the mandibular plane angle. Ingervall and Helkimo[10] reported that men with strong bite force had a smaller anterior and a greater posterior facial height, and a smaller gonial angle compared with men with weak bite force. Lowe[11] also showed a significant correlation between masseter muscle activity and overbite. To elucidate the cause-and-effect relationship between masticatory muscle function and craniofacial structures, experiments involving the removal of masticatory muscles[12,13] or lesion of the trigeminal motor nucleus[14,15] have been conducted. Consequently, changes in muscular function can actually induce remarkable changes in the facial skeleton.

On the basis of the above findings, it is reasonable to speculate that a change in the respiratory mode may affect craniofacial structures through alterations in masticatory muscle function. Many previous animal and human studies have sought to clarify this hypothesis. Using rhesus monkeys that had been adapted to nasal obstruction for two years, Miller et al[16] demonstrated that nasal obstruction markedly increased both the tonic and phasic activities of tongue muscles. They also reported that nasal obstruction increased the phasic activities of the geniohyoid and digastric muscles, whereas no significant changes were found in the activities of the masseter, medial pterygoid, and anterior temporalis muscles.[16] Yamada et al[17] reported that experimental nasal obstruction remarkably reduced the activity of the masseter muscle in *Macaca fuscata*. Ono et al[18] also showed a decrease in the activity of the masseter muscle caused by nasal obstruction in cats. In humans, Hellsing et al[19] reported that obstruction of the nasal airway decreased postural activities of the postcervical and anterior temporalis muscles, and increased those of the suprahyoid muscles. But no significant changes were recorded in the infrahyoid, masseter, and sternocleidomastoid muscles.[19] Ishizuka et al[20] recorded the 24-hour electromyographic (EMG) activity of the masseter muscle in four adult females and demonstrated that the EMG activity of this muscle significantly decreased with nasal obstruction during wakefulness, whereas no significant changes were detected during sleep. Recently, Otani-Saito et al[21] demonstrated a significant reduction in the amplitude of the stretch reflex in the masseter muscle during experimental oral respiration in humans. Thus, there have been many studies on the relationship between the respiratory mode and activities of masticatory muscles; however, the experimental design in these previous studies has been inadequate. In many human experiments, muscle activities recorded before and immediately after nasal obstruction were usually compared, and few of these studies were based on long-term EMG recording. When we record EMG activities of masticatory muscles for a long period during wakefulness, the EMG activities fluctuate depending on the diurnal behavior of the subject. Therefore, nocturnal muscle activities to examine the effect of nasal obstruction on muscle activities independent of the subject's consciousness must be recorded. To our knowledge, only one previous study has considered this matter.[20] Unfortunately, since Ishizuka et al[20] recorded EMG activities with or without nasal obstruction on different nights, it is difficult to accurately distinguish the effect of nasal obstruction on muscle activities from day-to-day variations in nocturnal EMG activities of jaw-closing muscles, which has recently been reported.[22]

The effect of nasal obstruction on nocturnal masseter and suprahyoid muscle activities using a newly developed portable EMG-recording unit was examined.[23] To eliminate the influence of day-to-day variation, EMG activities both with and without nasal obstruction were recorded on the same night. This is the first split-night study that examined the effect of nasal obstruction on nocturnal EMG activities of human masseter and suprahyoid muscles using such a sophisticated method.

MATERIALS AND METHODS

Subjects

Ten healthy Japanese males (mean age 26.3 years) participated in this study. All the participants had an acceptable incisal relationship and complete dentition except for their third molars. On the basis of a careful clinical examination using simple questionnaires, they were confirmed to have no medical history of nasal obstruction or sleep-disordered breathing, such as snoring or apnea. Among the subjects, three were aware of nocturnal bruxism. Before the study, all the subjects gave their informed consent to participate after receiving a full explanation of the aim and design of the study.

Experimental procedures

EMG activities of both the right masseter and bilateral suprahyoid muscles were recorded with a portable EMG-recording unit (Muscle Tester ME3000 Professional: Mega Electronics, Kuopio, Finland).[23] Amplified signals were filtered with a frequency band of 15–500 Hz. The sampling frequency was one kHz. A bipolar surface electrode was set on the masseter muscle to be parallel to the muscle fibers, whereas a bipolar surface electrode for recording of suprahyoid muscle activities was positioned bilaterally in the submental region. Ground electrodes for the masseter and suprahyoid muscles were attached to the forehead and ipsilateral ear lobe, respectively (Figure 1).

The overnight experiment was conducted in a room at a lodging managed by the Dental Alumni of Tokyo Medical and Dental University. At midnight, the subject was asked to lie on a bed after complete preparation with surface electrodes. The subject was instructed to perform three-second maximal clenching three times in the intercuspal position and maximal jaw opening three times. The mean EMG activities recorded during maximal clenching and jaw opening were used as a basis (100% MVC) for the following analysis of masseter and suprahyoid EMG activities, respectively. After the maximal clenching and jaw-opening effort, the subject was allowed to fall asleep. In this study, complete oral respiration was experimentally induced by obstructing the nasal airway with a nose clip used for synchronized swimming. The experimental session was divided into two parts. In the first half of the night, EMG activities were recorded for about three hours of sleep without nasal obstruction. After the first recording session, the subject was awakened to fit the nose clip, and then asked to sleep again. In the second half of the night, EMG activities were recorded for about three hours of sleep with nasal obstruction. After the second recording session was completed, all electrodes and the nose clip were removed.

Data analysis

Integrated EMG activities were transferred to a personal computer (FMV-BIBLO NR IX 30L: FUJITSU, Tokyo, Japan) using an SRAM card (MELCARD: MITSUBISHI, Tokyo, Japan), and data analysis was performed with accessory software (Muscle Tester ME3000P Software v.1.4-program: Mega Electronics, Kuopio, Finland). First, the total

FIGURE 1. Surface electrodes to record EMG activities of the masseter and suprahyoid muscles.

recording time with and without nasal obstruction was calculated. Second, the periods between 30 minutes after the beginning of the first and second halves of the experiment and five minutes before the end of each half of the experiment were used for further analysis (Figure 2). The following variables were calculated.[23]

Maximal EMG activity. Maximal EMG activities of each muscle recorded during sleep with and without nasal obstruction were calculated as percentages of 100% MVC for each muscle.

Number of events beyond 40% MVC per hour. EMG activities beyond 40% MVC in the masseter muscle were regarded as bruxing events during sleep.[24] The total number of these events was counted for recordings with and without nasal obstruction and divided by the hours in the recording period to give the number of events per hour. Similarly, EMG activities beyond 40% MVC in the suprahyoid muscles were regarded as significant events, and the number of events per hour was calculated in the same manner. Two or more consecutive events separated by less than one second were regarded as a single event.

Distribution of muscle activities. The duration of recording for each level of muscle activity (0–1% MVC, 1–5% MVC, 5–10% MVC, and more than 10% MVC) with and without nasal obstruction was measured, and ratios to the total recording time were calculated.

The Wilcoxon signed-rank test and Fisher's exact probability test were used for the statistical analysis. A value of $P < .05$ was considered significant.

RESULTS

Changes in the maximal EMG activities of the masseter and suprahyoid muscles with and without nasal obstruction in 10 subjects are shown in Figure 3. In both muscles, there were no significant changes in the maximal EMG activities with nasal obstruction. The mean maximal EMG activities of the masseter and suprahyoid muscles without nasal obstruction were 58.9% MVC and 91.9% MVC, respectively. Those recorded during nasal obstruction were on average 66.0% MVC and 87.7% MVC, respectively. The maximal EMG activity of the masseter muscle exceeded 100% MVC in only one subject, whereas that of the suprahyoid muscles exceeded 100% MVC in four subjects, and was thus beyond the EMG activity during maximal clenching and jaw opening in the awake state.

Changes in the number of events beyond 40% MVC before and after nasal obstruction are shown in Figure 4. No significant changes were found in the number of events in either muscle. The mean number of events in the masseter and suprahyoid muscles was 8.4/hour and 10.4/hour without nasal obstruction and 8.1/hour and 14.4/hour with nasal obstruction, respectively.

Table 1 shows changes in the duration of the lowest (0–1% MVC) and highest (more than 10% MVC) levels of EMG activities of the masseter and suprahyoid muscles by wearing the nose clip. In the masseter muscle, the duration of the lowest level of EMG activity increased in seven subjects, decreased in two subjects, and did not change in one

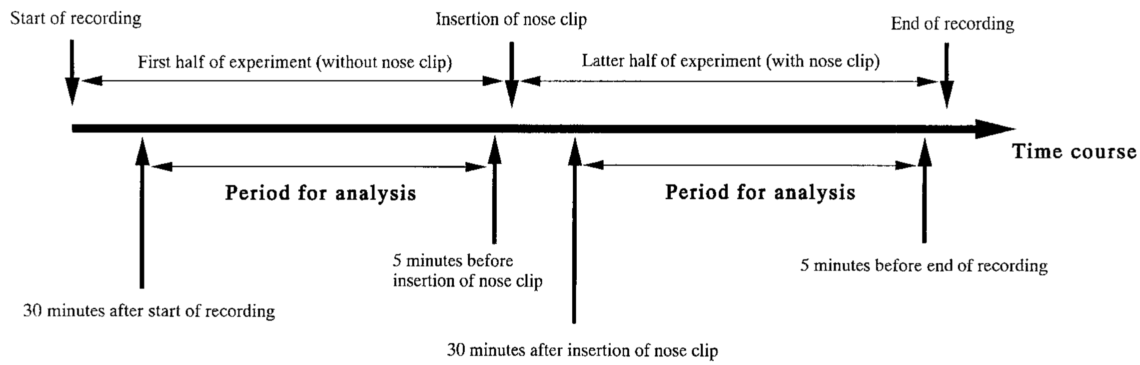

FIGURE 2. Definition of recording periods for analysis.

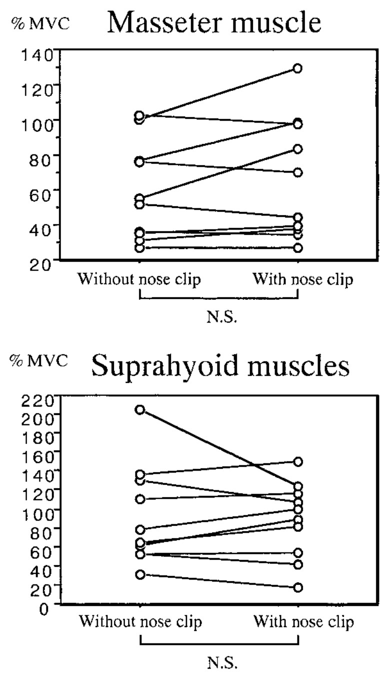

FIGURE 3. Changes in the maximal EMG activities of the masseter and suprahyoid muscles recorded during sleep with and without a nose clip. NS: not significant.

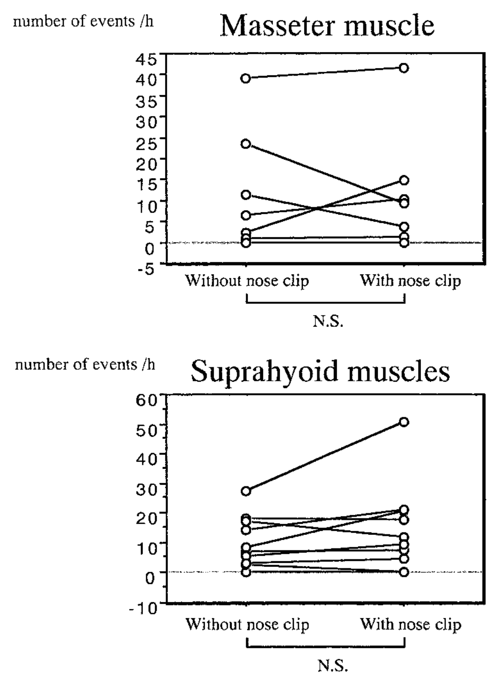

FIGURE 4. Changes in the number of events beyond 40% MVC recorded during sleep with and without a nose clip (per hour). NS: not significant.

subject. On the other hand, the duration of the highest level of EMG activity decreased in seven subjects and increased in three subjects. These findings indicate that the EMG activity of the masseter muscle tended to decrease with nasal obstruction ($P = .07$). In the suprahyoid muscles, the duration of the lowest level of EMG activity increased in three subjects and decreased in seven subjects, whereas the duration of the highest level of EMG activity decreased in only one subject and increased in nine subjects. Therefore, the EMG activity of the suprahyoid muscle increased significantly with nasal obstruction.

DISCUSSION

Methodology

When recording EMG activities of masticatory muscles during sleep, we should be aware of noises derived from unconscious body movements. With the portable EMG-recording unit used in the present study, problems with motion interference that normally occur in field measurements have been solved using state-of-the-art amplification technology, in which the amplifier is connected directly to the ground electrode. This effectively eliminates noises caused by disturbances, such as body movements[25,26] and retains EMG signals.

In all our subjects, EMG activities were recorded with and without nasal obstruction in the first and second halves of the experiment. The electroencephalogram and the electrooculogram (to determine the sleep stage) were not monitored simultaneously during the night in this study. There is a definite sleep cycle in normal sleep and the average period of the nonrapid eye movement (NREM)-REM sleep cycle is approximately 90 minutes throughout the night.[27]

TABLE 1. Changes in the Duration of Muscle Activity by Wearing the Nose Clip[a]

	Increase	Decrease
Masseter muscle		
The lowest level of muscle activity (0–1% MVC)	7 subjects	2 subjects
The highest level of muscle activity (over 10% MVC)	3 subjects	7 subjects
Suprahyoid muscles		
The lowest level of muscle activity (0–1% MVC)	3 subjects	7 subjects
The highest level of muscle activity (over 10% MVC)	9 subjects	1 subjects

[a] In 1 subject, no changes could be detected at the lowest level of masster muscle activity.

In the present study, the recording time in both the first and second halves of the experiment was about three hours (180 minutes), which was twice the period of the normal sleep cycle. Because all the subjects in this study were healthy young adults who were following a conventional sleep-wake schedule and without sleep complaints, the distribution of the sleep stage may have been similar between the first and second halves of the experiment. The distribution of sleep stages did not significantly differ between full-night polysomnography and polysomnographic recording during only the first half of the night, and a split-night study is appropriate for the diagnosis and treatment of sleep-disordered breathing, instead of conventional two-night diagnostic and therapeutic studies.[28,29] Moreover, a sleep latency shorter than 5 or 10 minutes can be related to abnormal sleep such as sleep-disordered breathing, although the precise definition of the onset of sleep has been controversial.[27] To ensure that the EMG activities recorded during sleep can be properly analyzed, 30 minutes after the beginning of the first and second halves of the experiment were defined as the start of data analysis.

In the present study, EMG activity of the masseter muscle exceeding 40% MVC was considered to be significant, according to a previous study,[24] which mentioned that clenching of less than 40% MVC could be intermingled with swallowing, which generally occurred at less than 30% MVC. On the other hand, regarding the suprahyoid muscles, EMG activity beyond 40% MVC was analyzed in the same manner as for the masseter muscle, because no previous studies have provided criteria for evaluating the EMG activity of the suprahyoid muscles.

To evaluate the distribution of EMG activity, four levels (0–1% MVC, 1–5% MVC, 5–10% MVC and over 10% MVC) were established in this study. The lower level of EMG activity was recorded throughout almost the entire night of sleep, which means that the lower level of EMG activity should be subdivided and analyzed in more detail than the higher level. Therefore, we used these levels of EMG activity for analysis.

Change in EMG activity induced by nasal obstruction

There were no significant changes related to nasal obstruction in the nocturnal EMG activities of both muscles in the evaluation based on the maximal EMG activity and the number of events beyond 40% MVC (Figures 3 and 4). Among our 10 subjects, EMG activities exceeding 40% MVC, which were recognized to be muscle activities related to nocturnal bruxism,[24] were recorded in six subjects. This indicates that some subjects who were unaware of nocturnal bruxism performed bruxism during sleep. On the other hand, on the basis of the finding of the distribution of muscle activities (Table 1), the incidence of the higher level of EMG activity of the masseter muscle decreased and that of the lower level increased with nasal obstruction, which suggests that masseter muscle activity tended to decrease after obstructing the nasal airway ($P = .07$). On the contrary, the incidence of the lower level of EMG activity of suprahyoid muscles decreased and that of the higher level increased, which suggested that suprahyoid muscle activities increased significantly with nasal obstruction. Although the muscle response to nasal obstruction can be interpreted differently depending on the method used for evaluation, an evaluation based on the long-term recording of muscle activity (Table 1) seems to provide more important information than an evaluation based simply on instantaneous muscle activities, such as the maximal EMG activity or the number of events beyond 40% MVC. This is because a weak but continuous force that is produced at rest has a greater effect on the tooth position, and on craniofacial morphogenesis, than a strong but instantaneous force.[30] An evaluation based on the prolonged recording of muscle activity (Table 1) is considered to more accurately reflect changes in whole muscle activity during one night of sleep. The present results are consistent with those of a previous study,[20] which reported that the nocturnal EMG activity of the human masseter muscle tended to decrease with nasal obstruction. The change observed in masseter muscle activity might contribute to an increase in the amount of jaw opening to maintain the oral airway, and thus compensate for obstruction of the nasal passage. As a physiological mechanism of the reduction in EMG activity observed for the masseter muscle with nasal obstruction, Ono et al[18] and Otani-Saito et al[21] have suggested a decrease in the activity of the γ-system. The decrease recorded in the nocturnal EMG activity of the masseter muscle with nasal obstruction in the present study might also be related to a change in the activity of the γ-system. Meanwhile, the distribution of the sleep stage is affected by experimental nasal obstruction, in that the duration of stage 1 NREM sleep was increased.[31,32] In a previous study on changes in muscle activities related to changes in the sleep stage, jaw-closing muscle activity decreased as the sleep stage became deeper.[33] Therefore, the decrease in nocturnal EMG activity of the masseter muscle induced by nasal obstruction does not seem to be related to the increase in stage 1 NREM sleep which was previously reported as a consequence of nasal obstruction.

On the other hand, EMG activities of suprahyoid muscles increased significantly with nasal obstruction (Table 1). Although a change in the EMG activities of suprahyoid muscles related to nasal obstruction has been reported in awake human subjects,[19] no previous studies have investigated the change in suprahyoid muscle activities induced by nasal obstruction during sleep. Hellsing et al[19] reported that EMG activities of suprahyoid muscles were increased as a result of nasal obstruction during wakefulness, which was similar to the finding observed during sleep in the present study. This observed increase in the nocturnal EMG activities of suprahyoid muscles could contribute to the increase in the amount of jaw opening to maintain the oral airway in cooperation with a reduction in masseter muscle activity. Moreover, considering that suprahyoid muscles also play a role in dilating the upper airway,[34,35] the increased activities of suprahyoid muscles might play an important role in increasing the upper-airway dimension, which was reduced as a consequence of jaw opening, to maintain the oral passage.

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