Original Article

Effect of teeth clenching on isometric and isokinetic strength of ankle plantar flexion

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To investigate the effect of voluntary teeth clenching on the isometric and isokinetic exercises of the lower limbs, the association of muscle strength (peak torque, PT) and muscle activities (integrated electromyographic activity per unit of time, iEMG/s) of the three muscles of the triceps surae with teeth clenching during isometric and isokinetic plantar flexion were simultaneously measured for 12 healthy male volunteers using a Cybex 6000 Extremity Testing and Rehabilitation System and a surface EMG analyzing system. The statistical analysis demonstrated that for the isometric exercise, PT and each iEMG/s significantly increased in association with teeth clenching, and a positive correlation existed between the biting force and each variable. In contrast, no association was found with teeth clenching for the isokinetic exercise. In this study, therefore, it was found that the effect of teeth clenching differed between the isometric and isokinetic exercises.

Key words: Teeth clenching, Plantar flexion, Muscle strength, Muscle activity

Introduction

Since the late 1970s there has been a controversy in dentistry regarding the possible correlation of the stomatognathic function with athletic performance. Some studies found that orthopedic appliances, also referred to as occlusal splints, MORA (Mandibular Orthopedic Repositioning Appliance), and so on, had significant effects on the improvement of performance and muscle strength in the extremities.1–6 Other studies, however, reported no such improvement.7–15 Such a discrepancy resulted partly from the different testing designs due to the application of various kinds of orthopedic appliances, and partly from the failure to make a clear distinction between isometric and isokinetic exercises.16

In recent years, studies have been performed under conditions not involving orthopedic appliances. In the physiological field, Miyahara17 studied the modulation of the human soleus H reflex during teeth clenching; Hagiya18 investigated the modulation of the spinal monosynaptic reflexes during the rhythmical jaw movements in rabbits; and they both proposed that oral motor activity can exert strong influences on the motor activity of the other parts of the body. On the other hand, Ueno19 found a positive correlation between teeth clenching and the isometric muscle strength and muscle activities of the upper limbs. To explain the relationship between the stomatognathic function and general isometric contraction, it seems necessary to investigate whether a relationship exists with the lower limbs. Moreover, in the case of rabbits, Tanaka20 found
a depression of the reciprocal Ia inhibition of the crural motoneurons during rhythmic jaw movement and suggested that the oral motor function could have an advantage for isometric exercises and could restrict isokinetic exercises. However, there is no practical verification for this opinion.

In the present study with human subjects, we investigated how voluntary teeth clenching affects muscle strength and muscle activities during isometric and isokinetic exercises of the lower limbs. We chose plantar flexion as the test performance and compared the two exercises using the same subjects and the same experimental protocol.

Materials and Methods

I. Subjects

Experiments were performed with 12 healthy male volunteers ranging from 20 to 31 years of age (mean age: 23.8), who had all given informed consent to the study. None of them had major malocclusion or histories of musculo-skeletal disorders.

II. Muscle strength and activity

The isometric and isokinetic muscle strength during plantar flexion were measured using a Cybex 6000 Testing and Rehabilitation System (Cybex 6000; Lumex, Inc.). The tested leg was determined as the leg supporting the body when kicking a ball.

The Cybex 6000 User’s Guide provides two positions for the subject to test plantar flexion. One is the prone position with the knee extended, and the other is the supine position with the knee flexed 90°. In this study, we chose the latter position because the subject’s head was fixed and he could comfortably watch the oscilloscope used for the visual feedback method. Moreover, it was stated that flexing the knee prevents hip and knee muscles from contributing to plantar flexion and allows a full range of motion at the ankle.21

The subject was supine on the Upper Body Exercise Table (UBXT) with the knee of the tested leg in a 90° flexed position (Fig. 1). The isometric muscle strength was measured with the footplate locked in the neutral position. The subject was asked to exert his maximum strength in the plantar flexed direction, and the initial 3 seconds of this performance was used for analysis. The isokinetic muscle strength was measured at 180°/s with the foot starting from the maximum dorsiflexed position to the maximum plantar flexed position, and the subject was also asked to exert his maximum strength. The torque signal obtained was processed with a sampling rate of 100 Hz, and peak torque (PT) was calculated on a Cybex 6000 computer. In addition, the signal from the Cybex 6000 was amplified with a DC Amplifier (AD-610J, Nihon Kohden Corporation, time constant: 0.3 s; high-cut: 1 kHz) and transferred to the electromyographic (EMG) record as a trigger (Fig. 2).

Surface EMG activities during exercises were recorded simultaneously from the soleus (Sol) and the lateral and medial heads of the gastrocnemius (GL and GM, respectively) on the tested leg, and from the bilateral masseters and anterior parts of the temporals. The EMG signals were introduced with bipolar surface electrodes of Ag-AgCl (10 mm in diameter) (NE-121J, Nihon Kohden Corporation), which were placed 20 mm apart longitudinally on the muscles. The long axis of the electrodes was consistently parallel to the direction of the fibers and on compatible locations with regard to the muscle belly. The EMG signals were passed through an Input Box (JB-640J, Nihon Kohden Corporation) and were amplified with a High Gain Amplifier (AB-610J, Nihon Kohden Corporation, time constant: 0.03 s; high-cut: 10 kHz). In addition to being recorded in a Thermal Array Recorder (RTA-3200, Nihon Kohden Corporation), the EMG signals were entered into a personal computer with a sampling rate of 2083 Hz through a Multifunction Analog, Digital I/O Timing Board (NB-MIO-16X, National Instruments) and a 32bit Direct Memory Access Control Board (NB-DMA 2800, National Instruments), where they were stored and processed (Fig. 2).

III. Bite conditions

Each subject’s muscle strength and activities were
Peak torque was calculated on a Cybex 6000 computer. The signal from the Cybex 6000 was amplified with a DC Amplifier and transferred to the electromyographic (EMG) record as a trigger. The EMG signals were passed through an Input Box, and were amplified with a High Gain Amplifier. In addition to being recorded in a Thermal Array Recorder, the EMG signals were entered into a personal computer through a Multifunction Analog, Digital I/O Timing Board and a 32bit Direct Memory Access Control Board, where they were stored and processed. The masseter EMG used for the visual feedback method passed through an integration unit and was monitored on the oscilloscope.

measured under the following six bite conditions. 1: Relaxed mandibular position in the supine position (RMP), 2: 0% of maximum voluntary contraction in the intercuspal position (ICP) (0%MVC), 3: 20%MVC, 4: 50%MVC, 5: 70%MVC, 6: 100%MVC.

The subject was instructed that in RMP his upper and lower lips should be in light contact without teeth contacts, and in 0%MVC his teeth should be lightly occluded. The other conditions were controlled using the visual feedback method with the masseter EMG, through an integration unit (EI-601G, Nihon Kohden Corporation), being monitored on the oscilloscope (CS-4025, KENWOOD Corporation) 1.5 m in front of the subject. The masseter used for the visual feedback method was determined as the side of the larger amplitude in EMG records in 100%MVC. On the occasions of RMP and 0%MVC, the subject was also asked to watch the oscilloscope and to keep the line from swaying.

IV. Testing procedure

Each subject was tested during two separate periods, one for the isometric exercise and the other for the isokinetic exercise, using the same testing protocol, at an interval of more than one month.

After the electrodes were set in position, the subject was placed in the supine position on the UBXT with the knee flexed 90° and the hip approximately flexed 45°. He was held with straps positioned just proximal to the knee and hip joints. The foot was strapped to the footplate of the apparatus, and great care was taken to align the axis of the talocrural joint with that of the apparatus. The subject was asked to fold his hands and to watch the oscilloscope. After the visual feedback line was set and the subject was asked to warm up, the test was started.

Before each testing trial, one warm-up trial was given for the purpose of familiarizing the subject with the device and each bite condition. Between testing trials, there was a 3-minute rest period.

One testing period consisted of 4 days at intervals of more than 2 weeks. The first day was for practicing trials to become familiar with controlling the biting force and exerting maximum muscle strength; the latter 3 days were for testing. On each day, the testing trial was performed 4 times per each bite condition (24 testing trials in total for one day). The bite conditions were set in the order of RMP, 0%MVC, 20%MVC, 50%MVC, 70%MVC and 100%MVC, and it was decided that the starting condition would be arbitrarily selected for each testing day. Each subject was tested as close as possible to the same time of the day.
All measurements were carried out in the exclusive laboratory, where the temperature was controlled at approximately 22°C. To relax the subjects, all straps were loosened during as many rest periods as possible. Consistent instructions were given to each subject by the same examiner with no verbal encouragement given during the performance.

V. Analysis of data

PT was analyzed as muscle strength. Figure 3 shows the raw records of EMGs and torque signals. In EMG analysis, the EMG signals were rectified, and the integration was carried out for the duration of each performance from the starting point to the ending point (Fig. 3). The integrated EMG per unit of time (iEMG/s) was calculated by dividing a raw integrated value by its duration, which was analyzed as muscle activity. PT and iEMG/s of Sol, GL and GM were normalized by dividing each value on the testing day by the mean value of the performance in RMP on the same testing day (n-PT and n-iEMG/s of Sol, GL and GM, respectively).

To analyze significant differences among the group

<table>
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<td>GM</td>
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Torque Signal

EMG: 0.5mV
1sec

Fig 3. Raw records of EMG and torque signals.

These are simultaneous records of surface electromyograms of orofacial and appendage muscles under RMP during the isometric exercise on the left and under 100%MVC during the isokinetic exercise on the right. RM: the right masseter, LM: the left masseter, RTa: the anterior part of the right temporalis, LTa: the anterior part of the left temporalis, Sol: the soleus, GL: the lateral head of the gastrocnemius, GM: the medial head of the gastrocnemius, Torque Signal: the trigger. The upward arrow indicates the starting point of EMG integration and the downward arrow indicates the ending point.
Results

Data are given in mean ± standard deviation.

Concerning the muscle strength (Fig. 4), the group values of n-PT under the six bite conditions during the isometric exercise were RMP: 1.000 ± 0.000, 0% MVC: 0.990 ± 0.018, 20% MVC: 0.999 ± 0.028, 50% MVC: 1.017 ± 0.028, 70% MVC: 1.042 ± 0.024 and 100% MVC: 1.076 ± 0.023. Those during the isokinetic exercise were RMP: 1.000 ± 0.000, 0% MVC: 0.978 ± 0.031, 20% MVC: 0.983 ± 0.037, 50% MVC: 1.002 ± 0.045, 70% MVC: 1.014 ± 0.058 and 100% MVC: 1.054 ± 0.070. According to the statistical analysis, during the isometric exercise significant differences existed between 100% MVC and each of the other bite conditions, and between 70% MVC and each RMP, 0% MVC and 20% MVC, whereas during the isokinetic exercise there were no significant differences among the conditions. As shown in Table 1, a significant positive correlation existed between the biting force in ICP and n-PT of each exercise, but the correlation coefficient of the isometric exercise was considerably larger than that of the isokinetic exercise.

Concerning the muscle activity, the group results regarding n-iEMG/s of Sol, GL and GM are shown in Figures 5, 6 and 7, respectively.

The mean n-iEMG/s of Sol for each bite condition during the isometric exercise were RMP: 1.000 ± 0.000, 0% MVC: 0.980 ± 0.047, 20% MVC: 0.982 ± 0.059, 50% MVC: 1.006 ± 0.053, 70% MVC: 1.048 ± 0.045 and 100% MVC: 1.099 ± 0.048, and those during the isokinetic

Table 1. Correlation coefficients between the biting force in the intercuspal position and each variable. (n=60)

<table>
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<th>muscle activity</th>
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<td></td>
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<td>isokinetic</td>
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Fig 4. Muscle strength for each bite condition (mean ± standard deviation).

*: p<0.05 relative to 100% MVC, **: p<0.05 relative to 70% and 100% MVC. Significant differences existed during the isometric exercise, but did not exist during the isokinetic exercise.

Fig 5. Muscle activity of the soleus for each bite condition (mean ± standard deviation).

*: p<0.05 relative to 100% MVC, **: p<0.05 relative to 70% and 100% MVC. Significant differences existed during the isometric exercise, but did not exist during the isokinetic exercise.

Fig 6. Muscle activity of the lateral head of the gastrocnemius for each bite condition (mean ± standard deviation).

*: p<0.05 relative to 100% MVC, **: p<0.05 relative to 70% and 100% MVC. Significant differences existed during the isometric exercise, but did not exist during the isokinetic exercise.
Fig 7. Muscle activity of the medial head of the gastrocnemius for each bite condition (mean±standard deviation).

\[**p<0.05 \text{ relative to } 100\% \text{ MVC}, \quad ***p<0.05 \text{ relative to } 70\% \text{ and } 100\% \text{ MVC}, \quad \] 

\[***p<0.05 \text{ relative to } 50\%, 70\% \text{ and } 100\% \text{ MVC}.\]

Significant differences existed during the isometric exercise, but did not exist during the isokinetic exercise.

Exercise were RMP: 1.000±0.000, 0% MVC: 0.987±0.038, 20% MVC: 1.009±0.047, 50% MVC: 1.023±0.058, 70% MVC: 1.015±0.064 and 100% MVC: 1.086±0.081. During the isometric exercise, the value for 100% MVC was significantly greater than each value for the other bite conditions, and the value for 70% MVC was significantly greater than each value for 0% MVC, 20% MVC and 50% MVC, whereas during the isokinetic exercise no significant differences existed among the bite conditions.

The mean n-EMG/s of GL in the bite conditions during the isometric exercise were RMP: 1.000±0.000, 0% MVC: 1.006±0.055, 20% MVC: 1.008±0.062, 50% MVC: 1.028±0.061, 70% MVC: 1.074±0.051 and 100% MVC: 1.116±0.086, and those during the isokinetic exercise were RMP: 1.000±0.000, 0% MVC: 0.993±0.034, 20% MVC: 1.002±0.055, 50% MVC: 1.021±0.056, 70% MVC: 1.014±0.085 and 100% MVC: 1.092±0.090. Significant differences were found during the isometric exercise between 100% MVC and each RMP, 0% MVC and 20% MVC, and between 70% MVC and RMP, whereas no significant differences were found during the isokinetic exercise.

The mean n-EMG/s of GM during the isometric exercise were RMP: 1.000±0.000, 0% MVC: 0.987±0.046, 20% MVC: 1.005±0.064, 50% MVC: 1.045±0.072, 70% MVC: 1.086±0.055 and 100% MVC: 1.129±0.061, and those during the isokinetic exercise were RMP: 1.000±0.000, 0% MVC: 1.007±0.057, 20% MVC: 1.013±0.073, 50% MVC: 1.039±0.044, 70% MVC: 1.046±0.081 and 100% MVC: 1.100±0.106. During the isometric exercise, significant differences existed between 100% MVC and each RMP, 0% MVC, 20% MVC and 50% MVC, between 70% MVC and each RMP, 0% MVC and 20% MVC and between 50% MVC and 0% MVC, whereas during the isokinetic exercise no significant differences existed.

As described in Table 1, a significant positive correlation was found between the biting force in ICP and each n-EMG/s of each exercise; however, each correlation coefficient of the isometric exercise was larger than that of the isokinetic exercise.

**Discussion**

1. Factors involved in the experiment

We chose plantar flexion because the prime movers of the exercise Sol, GM and GL are unequivocal, it is easy to position electrodes over them, and the number of joints related to the performance is small.

During the isometric exercise, a neutral position of the ankle was selected because it is easy to set up and reproduce. The 180°/s velocity of the isokinetic movement is classified as a high speed for isokinetic plantar flexion in the kinesiological field.\textsuperscript{23–26} and is recommended as the high speed torque test velocity in the Cybex 6000 User's Guide. We selected this velocity for the purpose of clarifying the difference between the isokinetic exercise and the isometric exercise. Besides, to prevent artifacts from appearing in the EMG record, we paid attention to the placement of the electrodes and the fixation of the subject.

The duration of the isometric exercise can be set, whereas that of the isokinetic exercise is not fixed because the acceleration time, which is the time required to catch the dynamometer speed, is different among the trials. Therefore, we normalized all muscle activities by calculating integrated EMG per unit of time.

We used the integrated EMG of the unilateral masseter for the visual feedback method. It can be used as an index of the biting force, because it was reported that there is a positive correlation between the integrated EMG of the unilateral masseter and the biting force.\textsuperscript{27} The group mean values ± standard deviation of the masseter n-EMG/s used for the visual feedback method under the six bite conditions in this study had the following values during the isometric exercise RMP: 1.6±1.4, 0% MVC: 2.8±1.7, 20% MVC:
23.0±3.3, 50%MVC: 51.1±6.0, 70%MVC: 70.5±6.4, and 100%MVC: 100.0±5.5, and during the isokinetic exercise RMP: 2.4±2.1, 50%MVC: 2.9±2.4, 20%MVC: 23.5±7.7, 50%MVC: 51.9±7.7, 70%MVC: 68.5±8.4, and 100%MVC: 100.0±11.0. We compared each n-iEMG/s for the six bite conditions during the isometric exercise with those during the isokinetic exercise. The statistical analysis showed that no significant differences existed between them for all six bite conditions, which meant that there was no difference between controlling the biting force during the isometric exercise and that during the isokinetic exercise. The standard deviations of both exercise types were, on the whole, smaller than those reported by Ueno,19 probably because of the difference of the EMG wave for the visual feedback. In this study the integrated wave was used for the visual feedback, and in Ueno’s study the raw wave was used.

The other conditions and protocol in this study were essentially similar to those in Ueno’s study.19

II. Effect of teeth clenching on plantar flexion strength

With regard to the isometric exercise in this study, there was almost the same relationship between teeth clenching and lower limbs exercise as with upper limbs exercise.19 With regard to the isokinetic exercise in this study, however, no effects of teeth clenching were found.

It is interesting to focus on the individual results. Figure 8 illustrates changes of n-PT given teeth clenching in ICP. During the isometric exercise, all subjects showed almost the same trend that, as the biting force in ICP increased, n-PT increased, whereas during the isokinetic exercise they did not. By analyzing these results through Ueno’s method,19 one would find that during the isometric exercise the correlation coefficients ranged from 0.507 to 0.680 and a significant positive correlation existed in 11 of the 12 subjects. In contrast, during the isokinetic exercise, the correlation coefficients ranged from −0.274 to 0.722, and a significant positive correlation existed in 5 of the subjects. As compared with n-PT in RMP, all n-PT in 100%MVC during the isometric exercise increased, and a significant difference existed in 8 of all subjects, whereas during the isokinetic exercise a significant increase existed in 4 of the subjects.

Because of large individual differences, it seems to be necessary to investigate the effect of teeth clenching on the isokinetic exercise under conditions involving other parts of the body or other velocities of motion.

In Ueno’s report on the upper limbs,19 when the values for 100%MVC were compared with those for the rest position that corresponds to RMP in this study,

![Fig 8. Change of muscle strength of each subject in association with teeth clenching in the intercuspal position during the isometric exercise (a) and the isokinetic exercise (b).](image)

Results obtained from 12 subjects are represented by different symbols connected with lines. The solid line represents a statistically significant correlation between the biting force and the muscle strength, and the dotted line represents a nonsignificant correlation. The horizontal line from the value 1.0 on the abscissa shows the normalized value in RMP.
the increasing rates of n-PT and of n-iEMG for the pectoralis major, the latissimus dorsi, and the teres major, which are major movers of shoulder abduction, were 3.8%, 7.2%, 8.4% and 13.0%, respectively; the latter two values were statistically significant but the former two values were not. In this study we found a similar relationship with isometric plantar flexion. But, although the increasing rates of the muscle activities of the lower limbs were almost the same as those of the upper limbs, the increasing rate of n-PT for the lower limbs was statistically significant and larger than that for the upper limbs. We could explain that it may result from leverage differences or from differences in the number of joints related to the performance.

In this study, we used the visual feedback method to control the biting force, which is the same method used in Ueno’s study, and the subjects were required to execute two tasks which were to produce a maximal muscle strength and to control the biting force. Thus it is supposed that controlling the biting force may become a psychological burden on the subject and may reduce the muscle strength and activities. Therefore, it is necessary in the future to study using a method whereby the biting force is not controlled.

III. Factors involved in the relationship between teeth clenching and performance

The correlation of the oral motor function with the somatic motor function in other parts of the body has gradually been proven in the physiological field. In 1991, Miyahara found that the soleus H reflex is facilitated in association with teeth clenching and that the increase in amplitude of the soleus H-wave shows a positive correlation with the strength of teeth clenching, so that the correlation of the oral motor function with somatic motor function becomes evident. After that, Hagiya studied the modulation of the spinal monosynaptic reflex of the crural extensors and flexors, which are antagonistic to each other, in anesthetized rabbits during rhythmic jaw movements, and reported that the excitability of motoneurons of both extensors and flexors increased. Moreover, Tanaka, who observed the reciprocal inhibition necessary for smooth movements at joints, concluded that the reciprocal Ia inhibition of the crural motoneurons is reduced during the rhythmic jaw movements in anesthetized rabbits.

Considering these facts together with the results of Ueno’s and this study, it is suggested that teeth clenching during exercises may increase the isometric muscle strength and muscle activity, and that its mechanism may involve a non-reciprocal increase in the excitability of motoneurons and a depression of the spinal inhibitory system.

With regard to the isokinetic exercise, we found large differences in the individual results and no general effect of teeth clenching for all subjects. Therefore, we suppose that a much more complicated neuromuscular mechanism may be involved in the relationship between teeth clenching and isokinetic exercises than in the case of isometric exercises. We hope that more developed studies in the physiological field can further identify the existence and role of such a mechanism.

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References


