Effects of interocclusal distance on bite force and masseter EMG in healthy participants

T. ARIMA*, T. TAKEUCHI*, K. HONDA†, A. TOMONAGA*, T. TANOSOTO*, N. OHATA* & P. SVENSSON‡

*Department of Oral Rehabilitation, Graduate School of Dental Medicine, Hokkaido University, Sapporo, †Clinical Division of Crown and Bridge Prosthodontology, Hokkaido University Hospital, Sapporo, Japan and ‡Section of Clinical Oral Physiology, Aarhus University, Aarhus, Denmark

SUMMARY The aim of this study was to investigate effects of interocclusal distance (IOD) on bite force and masseter electromyographic (EMG) activity during different isometric contraction tasks. Thirty-one healthy participants (14 women and 17 men, 21.2 ± 1.8 years) were recruited. Maximal Voluntary Occlusal Bite Force (MVOBF) between the first molars and masseter EMG activity during all the isometric-biting tasks were measured. The participants were asked to bite at submaximal levels of 20%, 40%, 60% and 80% MVOBF with the use of visual feedback. The thickness of the force transducer was set at 8, 12, 16 and 20 mm (= IOD), and sides were tested in random sequence. MVOBF was significantly higher at 8 mm compared with all other IODs (P < 0.001). Only in women, IOD always had significant influence on the corresponding root-mean-square (RMS) value of EMG (P < 0.011). When biting was performed on the ipsilateral side to the dominant hand, the working side consistently showed higher masseter EMG activity compared with the balancing side (P < 0.020). On the contralateral side, there was no difference between the masseter EMG at any IODs. The results replicated the finding that higher occlusal forces can be generated between the first molars at shorter IODs. The new finding in this study was that an effect of hand dominance could be found on masseter muscle activity during isometric biting. This may suggest that there can be a general dominant side effect on human jaw muscles possibly reflecting differences in motor unit recruitment strategies.

KEYWORDS: electromyography, interocclusal distance, masseter muscle, maximal voluntary occlusal force, trigeminal physiology

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Introduction

It is important to have good knowledge about the basic physiological properties of human masticatory muscles in order to understand the pathophysiology as well as implications for rehabilitation of the stomatognathic system. One such basic question relevant for prosthetic rehabilitation procedures is the influence of the vertical bite height on jaw-muscle function (1). The fact that active single-twitch force and peak tetanic isometric force depend on muscle length has been extensively studied in limb muscles (2–4). The isometric force increases with increasing muscle length, reaches a plateau and then decreases (2, 3). This length–tension relationship in skeletal muscle has been well explained by the cross-bridge theory (5–8) as well as sliding filament theory (9, 10). The sliding filament theory assumes that length changes in sarcomeres, fibres and muscles are accomplished by relative sliding of the essentially inextensible myofilaments, actin and myosin, within a sarcomere. The cross-bridge theory suggests that the relative sliding of actin and myosin is caused by independent force generators (5). These theories have also been applied to the jaw-closing muscles (11–15), and some studies have examined the length–tension relationship of

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jaw-closing muscles (12, 13). A peak force from jaw-closing muscle may exist within the length–tension relationship, and the occlusal bite force increases up to a certain range of jaw opening (around 15–20 mm separation between the canines) and then decreases at wider jaw opening (14, 16, 17).

Force-electromyographic (EMG) characteristics meaning the relationship between muscular performance and EMG activity have also been studied in various human muscles (12, 18). In human limb muscles, when the relationship is described as a force–EMG curve, a linear function has been reported (18–21). On the other hand, other studies reported a non-linear relationship (22–25), especially when a muscle contract to nearly the maximum efforts (26). Also, some studies have investigated the force–EMG relationship in jaw-closing muscles and found linear relationships during isometric contractions (27–30). Interestingly, there seems to be differences between the working and balancing side in terms of the degree of linearity in the force–EMG relationships (31–33). Moreover, non-linear relationships have also been observed in jaw-closing muscles in some studies (31–36).

Thus, there are several reasons to re-examine the relationship between both length–tension and force–EMG especially in jaw-closing muscles. This study examined occlusal bite force and EMG activity of the masseter muscle during isometric contractions at different IODs in a group of healthy participants. We expected to find higher force values in men and at lower IOD with a difference between the working and balancing side. We also explored the potential influence of hand dominance on these relationships. The hand dominance is a natural behavioural phenomenon that has been postulated to arise from an asymmetry in the structural and functional cortical organisation (37). The literature suggests that the primary motor cortex (MI) is larger in the dominant than in the non-dominant hemisphere (38). This may have significant impact on the basic physiological aspect in human masticatory function, for example, concentric contraction, in terms of EMG activity.

Materials and methods

Participants

Thirty-one healthy participants, 10 right-handed men (mean ± s.d.: 21 ± 3 ± 2.7 years old), 11 right-handed women (21 ± 1.6 years old), seven left-handed men (21.5 ± 1.0 years old) and three left-handed women (21.3 ± 0.6 years old), were recruited amongst a university population. Exclusion criteria were painful muscle disorders and temporomandibular joint problems according to the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) (39). None of the participants had missing teeth except for third molars or any history of orthodontic treatment. Informed consent was obtained from each participant and the experimental protocol followed the Helsinki Declaration and had been approved by the local ethics committees.

Study design

The participants sat on a comfortable chair and were first asked to perform a maximal voluntary contraction (MVOBF: maximal voluntary occlusal bite force, Newton). After that, the submaximal forces (20%, 40%, 60% and 80% of MVOBF) were calculated, and then, the participants performed these submaximal isometric contractions with the use of visual feedback. The interocclusal distances (IOD = thickness of bite force transducer) between the upper and lower first molars were adjusted to 8, 12, 16 and 20 mm, and the MVOBF and submaximal bite forces were performed again. The order of the levels of submaximal bite forces, the IODs and the side of bite force meter application were randomised in each participant. Force and the corresponding EMG activity (µV) of the bilateral masseter muscles were simultaneously recorded during the isometric contraction tasks, stored on a PC and later used for off-line analyses.

Maximal voluntary occlusal bite force

A bite force transducer (area of 1 cm in radius, GM10,*) was covered with plastic tubes to protect the teeth. The MVOBFs were measured between the upper and lower first molars on both sides, and participants were instructed to clench their teeth as hard as they could for about 15 s. Verbal encouragement was given to obtain the maximal effort. The peak value MVOBF was stored on a display of the bite force meter. The MVOBF measurement was repeated three

*Nagano Keiki, Tokyo, Japan.
times with intervals of approximately 1 min, and the average MVOBF value was used for subsequent analyses.

Submaximal isometric contractions

After determination of the average MVOBF at each IOD (8, 12, 16 and 20 mm) and side (left and right), the participants were instructed to perform four levels (20%, 40%, 60% and 80% MVOBF) of submaximal bite forces (target levels) in random order. The participants increased the occlusal bite forces up to the specified target level and held the contraction for about 15 s with the use of visual feedback by looking at a display of the force transducer.

Interocclusal distances

The IODs of the bite force transducer (original thickness of transducer with plastic tube: 8 mm) were adjusted by elastic silicon sheets (EVA: ethylene-vinyl acetate copolymer, thickness: 4 mm). The number of sheets directly meant the IODs and EVAs and plastic tube of the bite force transducer were fixed by an adhesive agent (12 mm: one EVA layer, 16 mm: two layers, 20 mm: three layers).

EMG recordings and analysis

The EMG activity during the MVOBFs and submaximal bite forces was simultaneously recorded from bilateral masseter muscles. Bipolar disposable surface electrodes (F-150S,†) were placed with their long axis parallel to the main direction of the muscle fibres in the central part of the left or right masseter muscles. Electrode placement was based on palpation of the muscles during full effort (34). The interelectrode distance was about 30 mm. The EMG signals were amplified (6-4 × 10⁶), 0-53–250 Hz signal filtered by a processor box (5201,†), A/D converted with sample frequency of 500 Hz, and were stored in a PC. A custom-made software program, which can determine the peak EMG amplitude during the maximal and submaximal contractions, calculated the corresponding root-mean-square (RMS) value of the EMG signals in a 5-s window (Fig. 1). Each RMS value was, then, expressed as the percentage of the EMG activity during the maximal voluntary contraction in the centric occlusion without the bite force transducer.

Hand dominance

A set of questionnaire (40) was used to determine which side (left or right) hand was the dominant hand of each participant. The participants were asked and selected the left or right side of their hand dominance for writing, throwing and hitting.

Statistics

Parametric statistics (mean ± s.d.) and multivariate analysis of variance (MANOVA) with repeated measures were used to describe the data. The MVOBF (Newton) and RMS (%) were analysed with IOD (mm) as the repeated factor and comparing gender and side (left-right and ipsilateral-contralateral to the hand dominance). Furthermore, the RMSs were also analysed between the working and balancing side. The levels of significance were adjusted for multiple pairwise comparisons with the Tukey’s honest significant difference (HSD) test (STATISTICA, StatSoft for post-hoc tests). Significance was accepted at $P < 0.050$.

Results

Hand dominance

The questionnaire regarding hand dominance indicated that 10 men and 11 women were predominantly right-handed and seven men and three women were predominantly left-handed. No indication of ambidextrous was shown.

Maximal voluntary occlusal bite force

Figure 2 shows the MVOBFs at each IOD levels (8 mm, 12 mm, 16 mm and 20 mm) with the effects of gender (Fig. 2a), side (Fig. 2b), and hand dominance (Fig. 2c). The MVOBF was significantly dependent on IOD (MANOVA $P < 0.001$, Fig. 2). Men always had significantly higher MVOBF than women at any IODs (MANOVA $P < 0.001$, Fig. 2a). The highest MVOBFs were always observed at 8 mm (left side:

†Nihon Koden, Tokyo, Japan.
‡NF Corporation, Yokohama, Japan.
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Fig. 2. Length–force curve of the data within 100% MVOBF. Figures show near linear relation between interocclusal distance (IOD) and maximum voluntary occlusal bite force (MVOBF) comparing (a) men with women, (b) left with right side, respectively, including both with and without a bite force transducer, (c) ipsilateral with contralateral side to hand dominance.

EMG findings during MVOBF

The length–EMG relationship is shown in Fig. 3. Almost all graphs showed a peak EMG value at 8- or 12-mm IOD. In women, the IOD always had a significant influence on the RMS (MANOVA P < 0.001, Fig. 3e,f), while, in men, the significant influence of IOD was only observed on the balancing side (MANOVA P < 0.024, Fig. 3c2,d2). The MANOVA showed that there were no significant differences between the RMS (%) of the left and right side or the ipsilateral and contralateral side to hand dominance, except between working side in all participants (P = 0.039, Fig. 3b1) and women (P = 0.036, Fig. 3f1).

Submaximal isometric contractions

Figure 4 shows the force–EMG relationship with 8-mm IOD. As expected, the RMS-EMG values increased with increased forces, and the force–EMG curves showed nearly linear relationships ($R^2 > 0.9783$). When RMS-EMG activities were recorded during isometric contractions on the left and right side and the contralateral side to hand dominance, the MANOVA did not show a significant difference in RMS-EMG activity between the working and balancing side (Fig. 4a,b,d). However, the RMS-EMG activity on the working side was significantly higher than that on the balancing side during biting on the ipsilateral side of the dominant hand in both men (8-mm IOD: $P = 0.038$ and 20 mm: MANOVA $P = 0.012$, Fig. 4c1) and women (8 mm: $P = 0.0497$ and 12 mm: MANOVA $P = 0.042$, Fig. 4c2).

Discussion

This systematic and controlled study investigated the effects of interocclusal distance (IOD) on maximal voluntary occlusal bite force (MVOBF) and electromyographic (EMG) masseter muscle activity during different levels of isometric contractions. The results...
showed that within a range of 8–20 mm between first molars, the shorter IOD leads to the higher occlusal bite force; men can produce higher occlusal bite forces than women; only in women, the RMS-EMG from the working-ipsilateral side to the dominant hand is greater than the working-contralateral side, and IOD always had significant influence on RMS-EMG; on the ipsilateral side to the dominant hand, RMS-EMG...
on the working side was higher than on the balancing side.

In the present study, IOD is not a precise distance because the layers of EVA were applied to the bite force transducer. Nevertheless, higher occlusal bite forces between the first molars can be produced at the shortest IOD within a range of 8–20 mm (Fig. 2). This means that there is an optimal distance to achieve the maximum occlusal bite force at around 8-mm IOD or less. It is known that maximum occlusal bite forces produced during jaw movement occur at 15- to 20-mm separation between the distal borders of the canines (17). Although our results cannot be compared simply with that value because, in the present study, the MVOBFs were measured between the upper and lower first molars, our results are in general agreement with that observation (17).

The length–tension curve of the present data showed near linear relationships (Fig. 2). In previous studies on jaw muscles, a variety of length–tension curves have been reported (13–15, 41, 42). The length–tension relationship is thought to be dependent on the lengths of actin and myosin filaments in the sarcomere and the elastic characteristics of the tendons and aponeuroses (43, 44). A muscle may reach its optimum length at the time it maximises active tension (45). During jaw closing, occlusal bite force and masseter muscle activity accelerate, reach maximum and then decelerate (14, 30). Some participants might produce the maximum occlusal bite force at the masseter optimum length (17, 45–47), others at the temporalis optimum length (14). A combination of different optimum ranges of sarcomere lengths in the masseter and temporalis muscles may partly explain the variety of curves in previous studies. Most muscle parts may function in agreement with their respective active length–tension curve (12). For the further studies, we would suggest that EMG activities of temporalis muscle at anterior and posterior parts should be included, and then, the direction of bite force and the contributions of these masseter and temporalis muscle on the bite force could be estimated.

The present force–EMG curves demonstrated nearly perfect linear relationships (Fig. 4). Both linear and non-linear relations have been reported between the EMG activity and force in limb (18, 19, 24) and jaw muscles (27, 30, 31, 33). These observations imply that jaw-closing muscles may be controlled by different mechanisms compared with limb muscles. That may be because at low forces, the majority of masseter motor units are excited only by the contralateral hemisphere, while these motor units are usually excited from both hemispheres at higher forces (48).

Men always had significantly higher MVOBF than women at any IODs (Fig. 2a). Many review papers have dealt with potential sex variations in skeletal muscle function (49–54). Sex-related differences in skeletal muscle might be related to differences in fibre-type composition (55), and compared with male muscles, female muscles contain more type I fibres, which have a slower speed of contraction, consequently a slower rate of energy utilisation and more fatigue resistant than type II fibres (56–58). However, there are few studies on sex variations in EMG masseter muscle activity (58, 59). The present results suggested that masseter muscles in men and women could function differently. Therefore, care must be taken when comparing the value of EMG activity between men and women. Further research is necessary to assess and improve the validity of the present findings and better understand the mechanisms that influence the sex-related differences in muscle activity.

Only in women, the RMS-EMG from the working-ipsilateral side to the dominant hand is greater than the working-contralateral side (Fig. 3f1). In addition, the RMS-EMG activities in women were associated with the levels of IOD (MANOVA P < 0.011, Fig. 3e,f), while the RMS-EMG in men were associated with the levels of IOD only on the balancing side (Fig. 3c2, d2). This indicated that male and female masseter muscles might work in slightly different ways (58). Figure 3 shows that a peak in RMS-EMG activity could be observed between 8 and 12-mm IOD, which is larger than the optimum length for MVOBF. Some studies also reported that peak-integrated EMG precedes maximal occlusal force (36, 60). Thus, EMG and force may accelerate in different ways and reach maximum at different stages of clenching.

Furthermore, the present force–EMG curves had a consistent finding that the RMS-EMG activity from the working side was always greater than that from the balancing side when performed on the ipsilateral side to the dominant hand side, while contractions on the contralateral side showed no difference between the working and balancing side at any IODs (Fig. 4). In addition, this tendency is showed greater in
women than in men. This may suggest that the mas-
setter muscle activation during isometric contractions
is associated with a side dominance of motor unit
recruitment possibly reflecting differences in the hand
motor cortex mechanisms.

This study appears to show that masseter muscle
has a superior side of the activity corresponding to
the ipsilateral side to the dominant hand. This sug-
gests that research findings from the masseter muscle
could be influenced by hand dominance of the
included participants. For instance, if biological
responses are monitored bilaterally on the masseter
muscles without taking the side of hand dominance
into consideration, this may introduce a systematic
bias in the interpretation of the results. Of course, fur-
ther investigations are still needed with larger groups
to verify these preliminary observations.

In conclusion, the present study demonstrated that
higher occlusal forces could be generated between the
first molars at shorter interocclusal distances. The new
finding in this study was that there might be an effect
of hand dominance on masseter muscle activity
during isometric biting. It is suggestive that there can
be a general dominant side effect in human jaw
muscles possibly reflecting differences in motor unit
recruitment strategies. However, a full understanding
of the mechanisms underlying these relationships
between muscle activity and interocclusal distance,
sex and hand dominance require further study.

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and the experimental protocol followed the Helsinki
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Correspondence: Taro Arima, Department of Oral Rehabilitation, Graduate School of Dental Medicine, Hokkaido University, North13 West7, Kita-ku, 060-8586 Sapporo, Japan, E-mail: TAR@den.hokudai.ac.jp