Relationship between masticatory muscle activity and vertical craniofacial morphology

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Moss and Salentijn[1] hypothesized that human facial growth occurred as a response to functional needs and was mediated by the soft tissue. It is generally accepted that the shape of the face is determined by both genetic influences and local environmental factors. Masticatory muscle function has a considerable influence on craniofacial morphology.

Several earlier reports have suggested that biting force and muscle activity are correlated with jaw size and morphology.[2,3] Ringqvist[2] showed that the size and shape of the mandible, including mandibular body length, ramus height, and gonial angle, were correlated with bite force. Møller[4] found a strong correlation between craniofacial morphology and masticatory muscle activity during chewing, swallowing, and maximum clenching. Furthermore, several studies have focused on the relationship between masticatory muscle activity with the mandible at rest and craniofacial morphology.[5-8]

However, in these studies, masticatory muscle activity was recorded only for a short period in the laboratory. Masticatory muscle activity occurs throughout the day. Miyamoto et al.[9] recorded masseter muscle activity over a 24-hour period and demonstrated that a number of low-amplitude bursts were observed at different times. To elucidate the relationship between masticatory muscle activity and facial morphology, it is necessary to analyze muscle activity over time.[9-12]

Abstract

The purpose of this study was to investigate the relationship between masticatory muscle activity during the day and vertical craniofacial morphology. The sample comprised 30 subjects (20 males and 10 females, age range 15 to 28 years, mean 24 ± 3.2 years) who had normal anteroposterior skeletal relationships and complete or nearly complete dentition without serious malocclusion or temporomandibular dysfunction. Using a portable electromyographic recording system, activities of the masseter, temporal, and digastric muscles were recorded for 3 hours during the day, excluding time spent eating, sleeping, and exercising. A lateral cephalogram was taken of each subject with the teeth in occlusion. Activities of the masseter, temporal, and digastric muscles consisted mainly of low-amplitude bursts. The duration of digastric muscle activity was greater than that of either the masseter or temporal muscles. Masseter and digastric muscle activities showed significant negative correlations with vertical craniofacial morphology, whereas temporal muscle activity was positively correlated. The activities of the masseter, temporal, and digastric muscles during the day consist of low-amplitude bursts and may be related to vertical craniofacial morphology.

Key words

Masticatory muscle • Electromyogram • Digastric muscle • Craniofacial morphology

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Figure 1

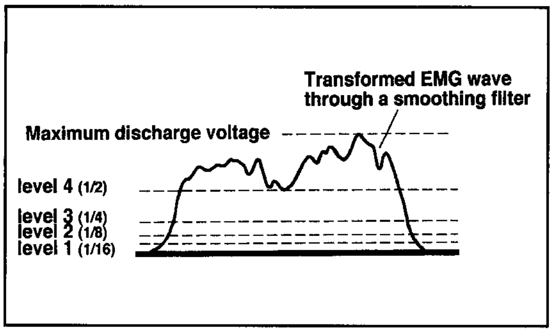

Figure 2

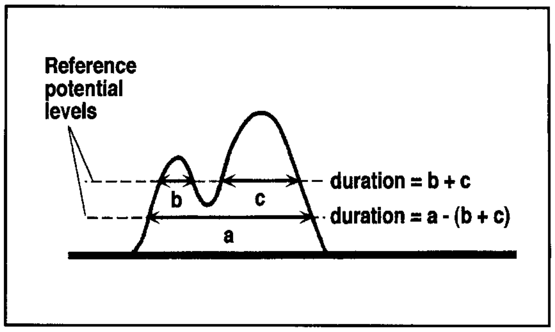

Figure 3

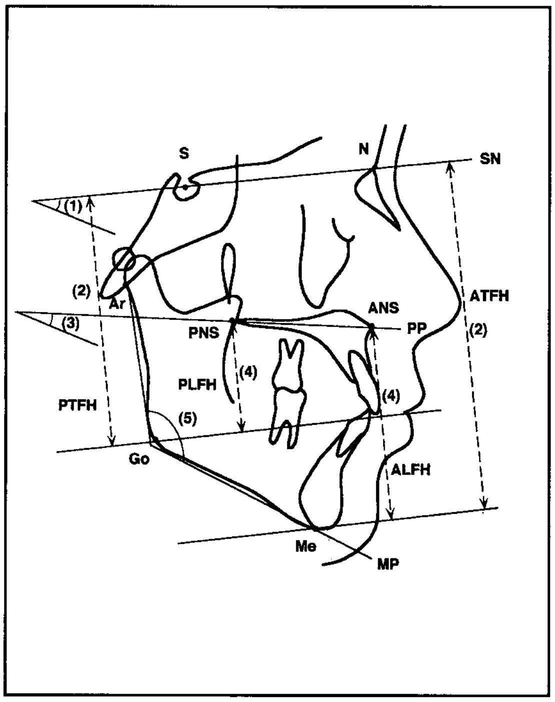

Figure 4

Figure 1
Overall view of portable EMG system. Bipolar surface electrodes and a preamplifier were placed over each masticatory muscle and connected to a portable data recorder.

Figure 2
Reference potential levels defined for the evaluation of muscle activity. Raw EMG data was rectified then transformed through a smoothing filter. Maximum discharge voltage determined by averaging 5 maximum voluntary clenchings or openings at the beginning of recording. Reference potential levels 1, 2, 3, and 4 were defined as 1/16, 1/8, 1/4, and 1/2 of the maximum discharge voltage, respectively

Figure 3
Duration of bursts over each reference potential level.

Figure 4
Landmarks, reference planes, and five measurement items: (1) SN-MP; (2) ATFH/PTFH; (3) PP-MP; (4) ALFH/PLFH; (5) gonial angle; MP = mandibular plane; PP = palatal plane; ATFH = linear distance from Me to SN plane; PTFH = linear distance from Go to SN plane; ALFH = linear distance from ANS to the line that is parallel to SN line through Me; PLFH = linear distance from PNS to the line that is parallel to SN line through Go.

The present study was undertaken to examine the relationship between masticatory muscle activity and vertical craniofacial morphology in adult subjects by means of recording the electromyogram (EMG) for 3 hours during the day.

Materials and methods

Subjects

Twenty male and 10 female subjects [15 to 28 years, mean 24 ± 3.2 (SD) years], who had normal anteroposterior skeletal relationships (ANB angle 0 to 5 degrees) and complete or nearly complete dentition without serious malocclusion or temporomandibular dysfunction, were selected from students enrolled in the School of Dentistry, Hiroshima University. Informed consent was obtained from each subject.

EMG recording

Activities of the right anterior temporal, right masseter, and anterior belly of right digastric muscles were measured using bipolar surface electrodes, which were 10 mm-diameter silver/silver chloride electrodes (45345, NEC Sanei Instruments Ltd, Tokyo, Japan). The electrodes were placed in the direction of the muscle fibers, with an interelectrode distance of 14 mm. Two electrodes were attached to the back of the neck for the ground (Figure 1). Before placement of the electrodes, the skin was scrubbed using an alcohol-soaked gauze pad to reduce impedance between skin and electrodes. Muscle activity was recorded using a 24-hour EMG recording system developed by Yamada et al.[13] The preamplifiers (HDX-82, Oxford, Abingdon, UK) were placed on the skin and connected directly with the electrodes to improve the signal-noise ratio. EMG data were stored in a portable data recorder (HR-30J, TEAC, Tokyo, Japan), which is small and light enough to carry. After recording, EMG data were transformed through a smoothing filter and converted to digital format.

Analysis of EMG data

At the beginning of recording, the maximum discharge voltage of each muscle was measured to define the reference potential levels (1, 2, 3, and 4) for analysis. The subjects were instructed to clench and open with maximum effort five times, with an interval of 10 seconds. The mean maximum discharge voltage for each muscle was derived from these five performances, and the reference potential levels of 1 through 4 were defined as 1/16, 1/8, 1/4, and 1/2 of the mean maximum discharge voltage, respectively (Figure 2). EMG recordings were carried out for 3 hours during the day. The subjects were asked not to eat, fall asleep, or exercise vigorously during the recordings.

The total durations of bursts per hour were analyzed for each subject according to the reference potential levels (Figure 3).

Cephalometric analysis

A lateral cephalogram was taken of each subject with the teeth in occlusion. Landmarks and reference planes used in this study are depicted in Figure 4. Five variables, SN-MP (the angle between cranial base and mandibular plane),

Table 1
The means of vertical cephalometric variables (mean±SD)

	SN-MP (degrees)	ATFH/PTFH	PP-MP (degrees)	ALFH/PLFH	gonial angle (degrees)
20 males	34.2±7.5	1.5±0.1	25.0±6.3	2.1±0.3	121.7±7.8
10 females	37.7±12.0	1.6±0.2	27.9±10.3	2.3±0.4	122.5±11.5
30 subjects	35.4±9.2	1.6±0.1	26.0±7.8	2.2±0.4	122.0±9.0

ATFH/PTFH (the ratio between anterior and posterior total facial heights), PP-MP (the angle between palatal and mandibular planes), ALFH/PLFH (the ratio between anterior and posterior lower facial heights) and gonial angle, were analyzed to evaluate the vertical morphology of the craniofacial skeleton.

Statistics

Mann Whitney *U*-test was performed to examine the difference in the total durations in bursts of three muscles between males and females. After confirming data normality, analysis of variances (ANOVA) and pairwise comparisons (Scheffe) were performed to examine differences in the total durations of bursts among three muscles. To examine the correlation between muscle activity and vertical craniofacial morphology, Pearson's correlation test was employed. Statistical significance was accepted when the probability (p) was less than 0.05.

Results

The means of five cephalometric variables for 20 males and 10 females are shown in Table 1. The mean total durations of bursts per hour for three muscles for 20 males and 10 females are shown in Table 2. Since no significant differences in total duration were found between males and females, the means for 30 subjects were used for the following statistical comparisons.

The total durations of bursts on levels 1, 2, and 3 were significantly larger in the digastric muscle than in masseter and temporal muscles, although there were no significant differences in the total durations of bursts on level 4 among three muscles. The greater part of the activities of all three muscles consisted of low-amplitude bursts. In fact, more than 90% of the bursts were level 3 or below, which was equivalent to 25% of maximum voluntary clenching.

As shown in Tables 3, 4, and 5, statistically significant correlations were found between muscle activity and cephalometric variables. Most of the total durations of bursts on levels 1, 2, 3, and 4 in the masseter muscle were significantly correlated with four cephalometric variables: SN-MP, ATFH/PTFH, PP-MP, ALFH/PLFH (Table 3). However, gonial angle was significantly correlated with only the total duration of bursts on level 2. In contrast, only four significant correlations were found for the temporal muscle between the total durations on levels 1 and 2 and SN-MP, PP-MP, and gonial angle (Table 4). For the digastric muscle, the total durations of bursts on levels 1, 2, and 3 were significantly correlated with cephalometric variables, although no significant correlation was found on level 4 (Table 5). All significant correlations between masseter and digastric muscle activities and cephalometric variables were negative (r = -0.38 ~ -0.71), whereas the correlations with temporal muscle activity were positive (r =0.38 ~ 0.46).

Table 2
The mean total durations of bursts per hour for each muscle (mean±SD)

	Level 1	Level 2	Level 3	Level 4
Masseter				
20 males	2.2±1.2	1.1±0.7	0.2±0.2	0.03±0.03
10 females	1.8±0.8	1.1±0.9	0.4±0.3	0.1±0.2
30 subjects	2.1±1.1	1.1±0.7	0.2±0.2	0.1±0.1
Temporal				
20 males	4.6±2.9	1.3±0.8	0.3±0.2	0.1±0.1
10 females	4.2±2.9	1.5±1.0	0.3±0.4	0.1±0.1
30 subjects	4.5±2.9	1.4±0.8	0.3±0.3	0.1±0.1
Digastric				
20 males	9.3±4.2	4.2±4.2	0.8±0.7	0.1±0.2
10 females	8.6±7.4	3.3±2.6	0.9±1.1	0.2±0.2
30 subjects	9.1±5.3	3.9±3.8	0.8±0.8	0.1±0.2

* significant difference ($p < 0.05$)
(min./hr.)

Discussion

The results of this study demonstrate that the activities of the masseter, temporal, and digastric muscles consist primarily of low-amplitude

Table 3
The correlation coefficients between masseter muscle activity and vertical cephalometric variables

Cephalometric variables	Masseter muscle Level 1	Level 2	Level 3	Level 4
SN-MP	-0.51*	-0.71*	-0.38*	-0.43*
ATFH/PTFH	-0.46*	-0.71*	-0.35	-0.43*
PP-MP	-0.51*	-0.51*	-0.38*	-0.34
ALFH/PLFH	-0.40*	-0.50*	-0.32	-0.38*
Gonial angle	-0.24	-0.48*	-0.27	-0.36

* significant difference ($p < 0.05$)

Table 4
The correlation coefficients between temporal muscle activity and vertical cephalometric variables

Cephalometric variables	Temporal muscle Level 1	Level 2	Level 3	Level 4
SN-MP	0.32	0.38*	0.35	0.13
ATFH/PTFH	0.20	0.27	0.34	0.19
PP-MP	0.41*	0.39*	0.35	0.17
ALFH/PLFH	0.26	0.19	0.27	0.18
Gonial angle	0.30	0.46*	0.30	0.11

* significant difference ($p < 0.05$)

bursts during daytime, excluding periods for meals, sleep, and exertion. The total durations of muscle activity were longer for the digastric muscle than for the masseter and temporal muscles. Activities of the masseter and digastric muscles were correlated closely with vertical craniofacial morphology, although temporal muscle activity presented only a few significant correlations.

Numerous studies have investigated masticatory muscle activity; however, recordings were usually made during mastication or clenching for a limited time in the laboratory.[14-17] Masticatory muscle activity occurs not only during mastication, but also during speaking, breathing, and swallowing. Based on these considerations, a portable EMG system was developed and used for measuring muscle activity over a long period under normal living conditions.[9,12,13] In this study, we focused on the effect of masticatory muscle activity on vertical craniofacial morphology. Few studies have examined the relationship between the activities of the jaw-opening muscles and craniofacial morphology; hence, masseter, temporal, and digastric muscle activity under static conditions in daily life was defined as the target.

No significant differences in masseter, temporal, and digastric muscle activity between males and females were found. Miyamoto et al.[9] also found no significant differences between sexes in 24-hour masseter muscle activity. This may be explained by the reference potential level, which was defined for each subject to standardize muscle activity with maximum voluntary clenching or opening. Meanwhile, differences in total durations of bursts were clearly found among the three muscles in this study. This finding indicates that each muscle has a different role in orofacial function. The masseter muscle may spend most of its time biting or clenching,[18,19] while the temporal and digastric muscles stabilize the mandibular position.[20,21] In addition, the digastric muscle exerts tonic respiratory activity.[4] On the other hand, the maximum discharge voltage, used as a standard, was determined for the digastric muscle during maximum voluntary opening, while maximum voluntary clenching was used for the masseter and temporal muscles. Although both maximum voluntary opening and clenching may involve the strongest activity for the jaw depressor and elevator muscles, differences in performance to obtain the maximum discharge voltage may have influenced the present results.

It was demonstrated that the greater part of the activities of three muscles during daytime consist of low-amplitude bursts. Furthermore, more than 90% of all bursts were level 3 or below. Miyamoto et al.[9] also found that a large percentage of high-amplitude masseter muscle bursts appeared only during meals, whereas a number of low-amplitude bursts were observed during the entire day.

In this study, significant negative correlations were found between masseter muscle activity and vertical measurement items, such as SN-MP, ATFH/PTFH, PP-MP, ALFH/PLFH and gonial angle. These findings are supported by previous studies,[4,22-24] which recorded masseter muscle activity at maximum clenching and demonstrated negative correlations with the mandibular plane and gonial angles. In addition, the cross-sectional area of masseter muscle, measured by ultrasonography, was found to be negatively correlated with vertical facial height.[25,26] Masseter muscle activity is highly related to craniofacial morphology in the vertical direction.

This study showed only a few significant correlations of temporal muscle activity and cephalometric variables. Weijs et al.[27] reported that temporal muscle thickness showed no significant correlations with any measure of skull shape or size. Ahlgren et al.[28] demonstrated that the mandibular plane angle was positively correlated with integrated EMG activity of the temporal muscle at maximum clenching. However, Møller[4] and Ingervall[29] showed negative correlations with temporal muscle activity during maximum clenching and chewing. The differences in recording period and technique may be a possible explanation for the contradiction in these results. As mentioned above, the role of the temporal muscle is different from that of the masseter and digastric muscles.

The present results revealed significant negative correlations between low-amplitude digastric muscle activity and vertical cephalometric variables. Sharkey et al.,[30] measuring the maximum opening force with the extra-oral gnathodynamometer, reported that the maximum opening force was negatively related to the Frankfort mandibular plane angle in females. Spronsen et al.[31] demonstrated that the anterior digastric cross-sectional area was positively correlated with posterior total facial height and negatively with anterior lower facial height. The negative correlations between digastric muscle activity and vertical cephalometric variables may be explained by the higher relationship between digastric and masseter muscle activities, which showed strong positive correlation (data not shown). Since greater jaw-opening force is needed to extend the thicker jaw-closing muscles, even if they are not activated, it may make sense that masseter and digastric muscle activities have the same negative correlations with vertical variables.

In the present study, we found that masticatory muscle activity during daytime consists primarily of low-amplitude bursts and are correlated with vertical craniofacial morphology. Therefore, when the relationship between muscle function and craniofacial morphology is investigated, we should pay attention to low-level muscle activity during the day, as well as to strong activity during mastication.

Table 5
The correlation coefficients between digastric muscle activity and vertical cephalometric variables

Cephalometric variables	Digastric muscle Level 1	Level 2	Level 3	Level 4
SN-MP	-0.49*	-0.44*	-0.53*	-0.36
ATFH/PTFH	-0.52*	-0.44*	-0.45*	-0.30
PP-MP	-0.51*	-0.35	-0.45*	-0.22
ALFH/PLFH	-0.50*	-0.38*	-0.35	-0.10
Gonial angle	-0.38*	-0.48*	-0.51*	-0.32

* significant difference ($p < 0.05$)

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