Human maxillofacial morphology related to masseter thickness, biting force and occlusal contact area

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Abstract : Many investigators have reported that the masticatory function have a great influence on the maxillofacial morphology. This study was performed to investigate the relationship between the maxillofacial morphology and the masticatory function as represented by the thickness of the masseter muscle, biting force and occlusal contact area.

The subjects were consisted of 31 male volunteers, with a mean age of 24 years, 5 months (S. D. ± 1year, 3 months). Maxillofacial morphology was observed using conventional roentgenographic cephalometry. Masseter muscle thickness was determined through ultrasonography. Biting force was obtained by pressure-sensitive film and a strain-gauge, Occlusal contact area was measured by pressure-sensitive film.

The following results were obtained:

1. Masseter muscle thickness was positively correlated with SNA, mandibular ramus inclination, ramus height and cortical bone thickness, and negatively with mandibular plane angle.

2. Biting force and occlusal contact area were positively correlated with mandibular ramus inclination, ramus height and cortical bone thickness, and negatively with mandibular plane angle.

It was indicated that masticatory function appears to affect the maxillofacial morphology, in particular the mandibular bone. Subject with a strong masticatory function had a flat mandibular plane, small gonial angle and enlargement of cortical thickness of mandibular base.

Key words : masseter muscle thickness, biting force, occlusal contact area, maxillofacial morphology

Introduction

A consensus exists that attached muscle activity and manifold functional stress, as acquired factors, are potent determinants in the initial formation of bone morphology and/or internal structure as well as a genetic factor. Experimental studies have shown that normal functional loads are responsible for the skeletal development in

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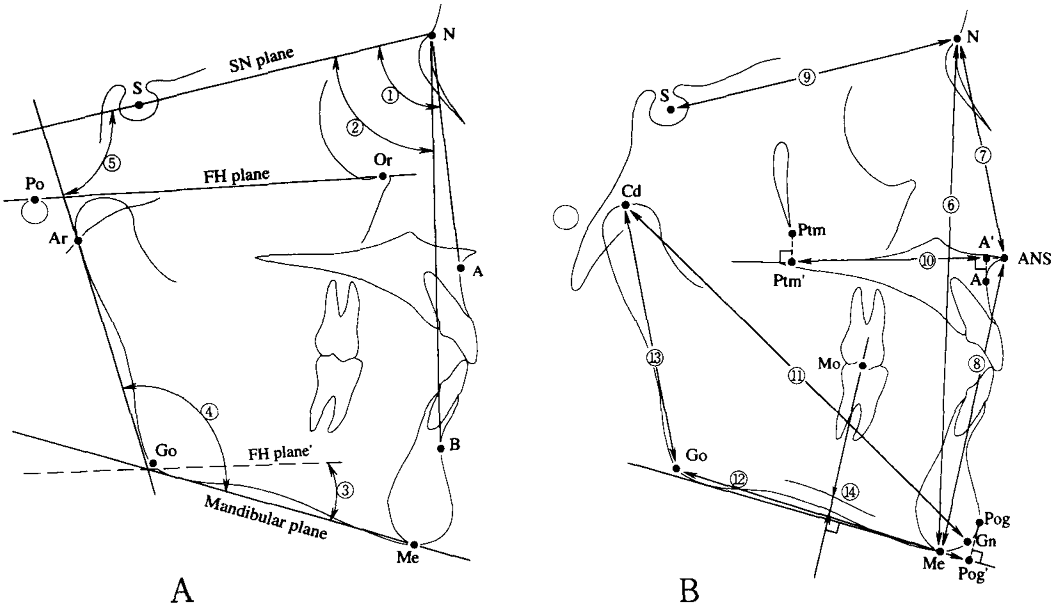

Fig. 1. Measurement variables of rooentgenographic cephalogram
A: Angular measurements
1 : SNA 2 : SNB 3 : Mandibular plane angle 4 : Gonial angle 5 : Ramus inclination
B : Linear measurements
6 : N-Me 7 : N-ANS 8 : ANS-Me 9: S-N 10 : A'-Ptm' (maxillary length) 11 : Gn-Cd (mandibular length) 12 : Pog'-Go (mandibular body length) 13 : Cd-Go (mandibular ramus height) 14 : Cortical bone thickness of mandibular base (Cortical bone thickness of mandibular base was defined as on a line passing the Mo point and crossing the mandibular plane perpendicularly.)

early long bone during ossification and growth[1].

Similar effects were occurred between the function of the masticatory system and the development of the maxillofacial skeleton. In animal experimental studies, poor functional stimuli due to eating behavior causes underdevelopment of the mandible, including the condyle[2,3].

Biting force is functional loading of the greatest magnitude applied to the maxillofacial skeleton, and has been considered a reliable indicator for quantitatively evaluating the potential of the masticatory function. Proffit[4] reported that biting force varies by facial type. Previous studies suggested that the cross-sectional area and/or thickness of masticatory muscles, as a parameter of the functional ability of its muscle, are significantly correlated with biting force, and the properties of facial morphology [5,6].

However, it is not yet known the association of the masticatory function including occlusal contact area to the maxillofacial morphology. Therefore, the purpose of this study was to investigate the relationship between maxillofacial morphology and the masticatory function as represented by the thickness of the masseter muscle, biting force and occlusal contact area.

Subjects and methods

1. Subjects

The subjects of this study were 31 male volunteers born between 1966 to 1973. Their mean age was 24 years, 5 months (S.D.: ± 1 year, 3 months). All the subjects participated after providing informed consent. The selection criteria for enrollment were as follows; no history of orthodontic treatment, no missing teeth in the incisor region, no more than two missing teeth in the molar region apart from the third molars, and no pain in the temporomandibular joint.

2. Measurements of lateral roentgenographic cephalograms

The *maxillofacial morphology* was evaluated with regard to five angular and nine linear measurements acquired from lateral roentgenographic cephalometry. The cortical bone thickness of the mandibular base was defined as shown Fig. 1–A, B.

3. Measurements of biting force using the pressure-sensitive film and a strain-gauge

Biting force and the occlusal contact area were measured by means of the Dental Prescale® system using the pressure-sensitive film. This system, which has been recently developed for clinical applications, consists of pressure sensitive film (Dental Prescale®: regular type, Fuji Photo Film Co., Ltd., Tokyo, Japan) with a thickness of 98μm, and an analyzing computer (Occluzer®: Dental occlusion pressure graph, FPD703, Fuji Photo Film Co., Ltd., Tokyo, Japan). The pressure-sensitive film provides accurate information on the distribution of occlusal contacts on the dental arch almost in the intercuspal position, and enables evaluation of the occlusal contact area, biting force and balance of occlusion. Dental Prescale® 50H, which was used in this study and has a wide measurement range for occlusal pressure (5 MPa to 120 MPa), is applied primarily for measuring biting force. Red coloration occurs on the surface of the film when it is subjected to the pressure. Density of red coloration depends on the magnitude of the applied pressure.

Each subject was asked to bite down on a film with maximum voluntary biting force in the intercuspal position for five seconds approximately. Films were packed in light-resistant material and refrigerated for more than 30 minutes. The occlusal contact area and biting force were calculated using the Occluzer®. Biting force was estimated from the following formula:

Biting force (N) = occlusal contact area (mm^2) × average pressure (MPa)

Uchiyama[7] reported that the reproducibility of the occlusal contact area was affected by the erroneous coloration caused by cusp slidings and/or straining around the colorated area, and its reproducibility was improved by deleting of low-level pressure less than 7 MPa.

In our preliminary study, the lower limit of the pressure value was set in two steps, and the biting force was measured using the following ranges of pressure:

Prescale 5 : pressure range of above 5 MPa.

Prescale 7 : pressure range of above 7 MPa.

The results of the paired t-test indicated no significant difference between the biting force of Prescale 5 and that of Prescale 7.

It has not been reported that significant relationship was found between the measurement value of biting force obtained by Dental Prescale® and that of the

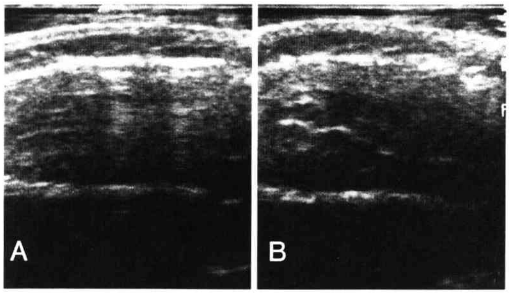

Fig. 2. Ultrasound images of the masseter muscle corresponding to the scanning position.
Ultrasonography provides clear images of superficial structures. Measurable difference can be observed between the muscle thickness in relaxed state (A) and in clenched state (B). Muscle fasciae are depicted by white shadow. A shadow of upper side is outer fascia, and lower side is inner fascia. The masseter muscle lies between both the fasciae.

conventional strain-gauge method. Therefore the measurement values of each step were compared with data on the biting force obtained by a strain-gauge method.

The measurement method using a strain-gauge was developed based on a study of masticatory patterns[8]. The magnitude of the maximum voluntary biting force was measured by recording the force between two metal plates. Each plate was attached to the upper and lower dental arch in parallel to the occlusal plane (18-8 stainless steel, 2 mm in thickness). The biting force transducer contained within a strain-gauge (TJ-300T, Nihon Koden Inc., Tokyo, Japan) was placed at the point corresponding to the center between the bilateral first molars. The upper and lower plates were set 9.5 mm -10.0 mm apart at the first molar regions (10.0 mm - 20.0 mm at the central incisors). The measurement value for each subject was the average of three measurements.

Fig. 2 shows the result of a simple regression analysis. The data on maximum voluntary biting force measured using the strain-gauge is significantly correlated with the biting force of both prescale 5 and that of prescale 7 ($p < 0.0001$). According to the results and as indicated by Uchiyama (1997), the biting force of Prescale 7 was regarded as the measurement value of biting force for each subject.

4. Measurement of the thickness of the masseter muscle

The procedures for scanning and measurement were performed according to Kubota *et al*[9]. Cross-sectional imaging of the masseter muscle was obtained by ultrasonographic scanning (Aloka Co., LTD. SSD-500, Japan).

The scanning plane of the masseter muscle was orientated perpendicular to the ramus of the habitual chewing side. The 7.5 MHz linear scanning probe (Aloka Co., LTD. UST-5512U-7.5, linear type, Japan) was placed with feather-like pressure at a site on the buccal surface where a line connecting the lateral commissure of the lips to the intertragic notch of the ear crosses the masseter muscle. The scanning position was confirmed on the display imaging. Images of the masseter muscle in a relaxed and clenched state were recorded to high-density printing paper (Aloka Co., LTD. ECP-303HD, Japan). All measurements were performed by the same observer to eliminate inter-observer differences.

Ten points an interval of 2 mm were measured on both the inner and outer fasciae of the muscle corresponding to the central area of the muscle. The thickness was measured by a computer analysis

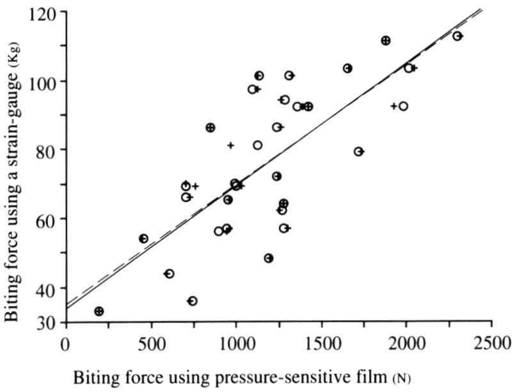

Fig. 3. Relationship between the two biting force values using pressure-sensitive film that the measuring conditions changed of Prescale 5, and Prescale 7 and the biting force value using a strain-gauge.
+ : Prescale 5, ------ : r = 0.745 ($p<0.0001$),
○ : Prescale 7, ——— : r = 0.751 ($p<0.0001$)

system (computer : NEC, PC9801, Japan ; digitizer : Graphtec, KD4030, Japan). The mean value of the 10 points was regarded as the thickness of the masseter muscle for each subject (Fig. 3).

5. Statistical methods

The data on masseter muscle thickness, biting force, occlusal contact area and cephalometric measurements were confirmed to show normal distribution. A simple regression analysis was performed to examine the relationship between the maxillofacial morphology and masseter muscle thickness and/or occlusal condition represented by masseter muscle thickness, biting force and occlusal contact area.

Results

The means and standard deviations of the variables are shown in the table 1 and 2. The mean biting force of the subjects was found to be 1186.9 N with a standard deviation of 469.4 N, and the mean occlusal contact area was found to be 27.9 mm^2 with a standard deviation of 11.7 mm^2. The masseter muscle thickness was 14.5 ± 2.7 mm in the relaxed state, and 16.3 ± 2.3 mm in the clenched state.

The correlation coefficients between the variables of cephalometric measurements and masseter muscle thickness, occlusal contact area and biting force are shown in the table 3.

The biting force and occlusal contact area were positively correlated with masseter muscle thickness in the clenched state ($p<0.05$). The masseter muscle thickness in

Table 1. Means and standard deviations of the variables of lateral roentgenographic cephalogram.

	Mean	S. D.
Angular measurements (degrees)		
SNA	83.3	4.6
SNB	80.2	4.5
Mandibular plane angle	27.3	7.0
Gonial angle	120.2	8.0
Ramus inclination	89.3	6.4
Linear measurements (mm)		
N-Me	134.6	6.6
N-ANS	60.7	3.6
ANS-Me	75.9	5.1
N-S	72.0	3.1
A'-Ptm'	53.4	6.7
Gn-Cd	127.1	5.5
Pog'-Go	82.5	5.2
Cd-Go	66.9	4.7
Thickness of the cortical bone	3.4	0.5

Table 2. Means and standard deviations of masseter muscle thickness, biting force and occlusal contact area.

	Mean	S. D.
Thickness of the masseter muscle (mm)		
Relaxed state	14.5	2.7
Clenched state	16.3	2.3
Biting force (N)	1186.9	469.4
Occlusal contact area (mm^2)	27.9	11.7

Table 3. Correlation coefficients between the cephalometric variables and masseter muscle thickness, biting force and occlusal contact area.

	Masseter muscle thickness			
	Relaxed state	Clenched state	Biting force	Occlusal contact area
SNA	0.464 **	0.421 *	0.318	0.282
SNB	0.316	0.277	0.256	0.243
Mandibular plane angle	−0.377 *	−0.390 *	−0.440 *	−0.399 *
Gonial angle	−0.091	−0.023	−0.269	−0.267
Ramus inclination	0.298	0.446 *	0.477 **	0.448 *
N-Me	−0.283	−0.199	−0.055	−0.012
N-ANS	−0.065	−0.050	−0.051	−0.027
ANS-Me	−0.248	−0.213	−0.027	0.004
N-S	−0.149	0.075	0.326	0.349
A'-Ptm'	0.193	0.256	0.135	0.197
Gn-Cd	−0.017	0.120	0.275	0.286
Pog'-Go	−0.193	−0.127	0.259	0.268
Cd-Go	0.421 *	0.492 **	0.574 **	0.560 **
Thickness of the cortical bone	0.388 *	0.368 *	0.389 *	0.374 *

Statistically significance of the correlation coefficients *: $p<0.05$, **: $p<0.01$

relaxed state was positively correlated with SNA ($p<0.01$), mandibular ramus height and cortical bone thickness ($p<0.05$), and negatively with the mandibular plane angle ($p<0.05$). The masseter thickness in the clenched state positively correlated with the mandibular ramus height ($p<0.01$), SNA, ramus inclination and cortical bone thickness ($p<0.05$), and negatively correlated with the mandibular plane angle ($p<0.01$).

The occlusal contact area showed a positive correlation with mandibular ramus height (Cd-Go) ($p<0.01$), ramus inclination and a cortical bone thickness ($p<0.05$), and a negative correlation with the mandibular plane angle ($p<0.05$). The biting force showed a positive correlation with ramus inclination, mandibular ramus height (Cd-Go) ($p<0.01$) and cortical bone thickness ($p<0.05$), and a negative correlation with the mandibular plane angle ($p<0.05$).

Discussion

1. The measurement method for biting force by means of the Dental Prescale® system

Several clinical studies have attempted to measure biting force altered vertical dimension of jaw separating. Proffit[4] showed that, using a force transducer contained within a strain-gauge, significant differences were observed between occlusal forces at the 2.5 mm and 6.0 mm bite openings when the normal and long-face group were combined. This fact suggests that the measurement values for biting force were altered in accordance with the vertical dimensions of the bite openings.

The Dental Prescale® has several advantages, including the fact that it is capable of measuring biting force almost in the intercuspal position and is not affected by the distance of jaw separation. In this study, the data measured using the Dental

Prescale® showed a significant correlation with the data measured using a strain-gauge ($r=0.751$, $p<0.0001$) although the vertical dimension of the bite openings and measurement regions differed. It was confirmed that the Dental Prescale® system is sufficiently reliable.

2. The measurement method for muscle thickness by ultrasonography

Non-invasive measurement methods for muscle thickness, include computed tomography (CT)[10~13], magnetic resonance imaging (MRI)[5] and ultrasonography[6,14]. In their reports, Spronsen[5] pointed out that the intra-observer error for MRI was 5.2 % of the right side and 4.7 % of the left side. Likewise, the difference between the two subsequent measurements for the masseter muscle using CT has been reported to be 3.5 % ± 3.9 %[10]. Neither CT nor MRI, however, are simple methods : they require complicated equipment and are time-consuming in terms of site selection and imaging time. Investigation of muscle size using CT is particularly inappropriate due to the X-ray exposure involved. On the other hand, ultrasonography is compact and easy to operate in a large group.

The results of our preliminary study showed that the measurement error was 1.03 % when a 7.5 MHz probe was used, and this value indicates high accuracy compared to that of the other modalities. It is considered that, due to the high ultrasonic frequency of the probe, clearer images could be obtained when the measured region was superficial. In this study, measurements of masseter thickness were taken twice on the same recording, enabling an intra-observer error of 3.2 % to 3.6 % to be obtained. Therefore, the ultrasound technique was confirmed to be sufficiently accurate for measuring masseter muscle thickness.

3. Relationships between maxillofacial morphology and the variables of masticatory function

It is widely accepted that, along with genetic factor, various environmental factors affect to the human growth and development positively. Environmental factors, e. g., nutrition and physical exercises including attached muscle function, have a great influence on individual inherent skeletal growth. Experimental evidence shows that the development of the skeletal system is very closely related to the development of muscular system[15].

Mascticatory function is considered a prominent determinant in craniofacial growth and development. Moss[16] put forth the functional matrix hypothesis, which states that the morphology of the maxillofacial complex is affected by the development of the function of the stomatognathic system and its surrounding function, including swallowing and naso-respiratory function, and that the final morphology is strongly dependent on the functional ability of the masticatory muscles.

Various approaches for quantitatively evaluating the activity of the skeletal muscles have been taken with *in-vivo* experimentation. Maughan *et al.*[17] found a positive significant correlation, using CT, between the maximum voluntary force (strength) produced by the knee-extensor muscles and the cross-sectional area of its muscles, and suggested that normal human skeletal muscle thickness and/or their cross-sectional area were a factor in determining muscle strength.

Consequently, the thickness and/or cross-sectional area of the jaw-closing muscles is considered to enable estimation of the intrinsic strength of its muscles, and this concept was confirmed by Sasaki *et al.*[18], Spronsen *et al.*[5] and Bakke *et al.*[6]. In this study, a similar result was obtained, with masseter muscle thickness in the clenched state showing a positive correlation with biting force. However, the measurement methods and instruments differed from those of the above studies.

Cross-sectional images of the masticatory muscles have been studied using CT, MRI and ultrasound techniques, to clarifying the effect of the activities of the masticatory muscles on maxillofacial morphology. The cross-sectional area of the masseter muscle was negatively correlated with both anterior facial height and gonial angle, and positively correlated with both head width and mandibular length[11,12]. The thickness of this muscle showed a negative correlation with the mandibular plane angle and gonial angle, and a positive correlation with the mandibular ramus height[13].

These findings corresponded well with the data on correlational studies describing the positive correlation between incisal and/or molar biting force and maxillofacial morphology. These studies showed that individuals with weak biting force tend to have a relatively large gonial angle[19] and mandibular plane angle[20] and a large anterior facial height[6].

Similar findings were revealed in our study, suggesting that the stimulating influence of the masseter muscle function and/or intensity of biting force are strongly correlated with the external shape of the gonial region, as well as the mandibular ramus height. According to Sanjo[21], the same interaction could be observed in child already that items indicating masseter muscle function showed a positive correlation with gonial angle, mandibular plane angle and ramus length. It was determined that initial formation of the mandible was affected by the function of the masseter muscle and related function during growth, and that its function is a potent determinant of the ultimate bone morphology in the gonial region and the height of the mandibular ramus.

It may be speculated that tooth contact has a great effect on the contraction of the jaw-closing muscles, and that the occlusal contact area is a determining factor in biting force. Therefore, a significant relationship was observed between occlusal contact area and masseter muscle thickness in the clenched state, mandibular plane angle, ramus inclination, mandibular ramus height and cortical bone thickness.

Suzuki *et al.*[22] pointed out the possibility that cortical thickness of mandibular base is a morphological indicator for estimating the density of the mandible. This study produced significant evidence that the cortical bone thickness of the mandibular base was altered in proportion to the changes in masseter muscle thickness, biting force and occlusal contact area. Kiliaridis[23] conducted on experimental investigation in which animals were bred under different physical consistency, and showed that the cortical bone thickness of the mandible in the soft-diet group was less than that of the normal-diet group. This significantly supports the hypothesis with regard to the adaptation of bony structures that make up the maxillofacial complex to the functional demands of mastication.

Other variables related to skeletal structure, such as the densities of the trabeculated architecture and/or strength of the jaw bone, are not taken into account in this study. However, it is obvious that biting force affects the bone mineral content of the mandible[24].

Based on this study, it was concluded that the stimulating influence of masseter muscle function and/or biting force were reflected not only in the external shape of the maxillofacial skeleton, but also in the cortical thickness of the mandible.

Conclusion

1. The values of biting force measured using the Dental Prescale® showed a positive correlation with those obtained using a strain-gauge ($p<0.01$), and were confirmed to be sufficiently accurate for practical use.

2. Masseter muscle thickness was found to be correlated positively with SNA, mandibular ramus inclination, ramus height and cortical bone thickness, and negatively with mandibular plane angle. Biting force and occlusal contact area were observed to be correlated positively with mandibular ramus inclination, ramus height and cortical bone thickness, and negatively with mandibular plane angle.

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ヒト顎顔面形態と咬筋の厚さ，咬合力，咬合接触面積との関連

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抄録：多くの研究者は，咀嚼システムにおける機能が顎顔面の形態に強い影響を及ぼしていると指摘してきた。本研究は，咬筋の厚さや咬合力，咬合接触面積に代表される咀嚼機能と顎顔面形態との関係を調べることを目的とした。

本研究における被験者は，平均年齢24歳5か月（S.D.±1歳3か月）の31名の男子からなる。顎顔面形態は通法の頭部X線規格写真計測法から求め，咬筋の厚さは超音波画像から計測した。また，咬合力の計測には感圧フィルムとストレインゲージを用い，咬合接触面積の計測には感圧フィルムを用いた。

得られた結果は以下の通り：

1．咬筋の厚さは，SNA，下顎枝傾斜角，下顎枝高，皮質骨の厚さと正の相関を示し，下顎下縁平面角と負の相関を示した。

2．咬合力と咬合接触面積は，下顎枝傾斜角，下顎枝高，皮質骨の厚さと正の相関を示し，下顎下縁平面角と負の相関を示した。

以上のことから，咀嚼機能は顎顔面形態，特に下顎骨の形態に影響を及ぼすことが示された。強い咀嚼機能を持つ者は，下顎下縁平面が平坦で，下顎角が小さく，厚い下顎底部の皮質骨を有していた。