ORIGINAL ARTICLE

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Change in maximum occlusal force in association with maxillofacial growth

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Structured Abstract

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Objective – To clarify the correlation between variations in maximum occlusal force and the maxillofacial skeletal pattern in subjects with malocclusion using a compact device.

Design – Three hundred and fifty patients (150 males 200 females) with malocclusion were included. The male and female subjects were divided into five groups each based on chronological age. The maximum occlusal force was measured with a simplified occlusal force meter. The maxillofacial skeletal pattern was analyzed with lateral cephalograms. On the basis of these data, we studied the correlation between the maximum occlusal force and the maxillofacial skeletal pattern in each age group.

Results – The maximum occlusal force tended to increase with age, with a tendency to be greater in male than in female subjects. In the male subjects, up to their 20s, the maximum occlusal force continued to increase, while in the female subjects its increase almost terminated in the later teens. In some of the age groups, the maximum occlusal force showed a negative correlation with the mandibular plane angle.

Conclusions – Maximum occlusal force tended to increase with age. There was a gender difference in the maximum occlusal force at all age groups, values being larger in the males. In the males, the maximum occlusal force continued to increase until their 20s, while in the females, this increase almost terminated at the age of 17.

Key words: bite force; cephalometry; maxillofacial growth; orthodontics

Introduction

In orthodontic diagnosis, clinical documentation is indispensable for analysis of malocclusion in patients. The materials required include plaster models, various radiographs, and intraoral and facial photographs (1, 2). These clinical records aid in understanding the static configuration of a patient's dentition and facial skeleton, however, they do not represent the dynamic state of the maxillofacial and intraoral environments, i.e. jaw movements and activities of masticatory muscles (3). The mandibular muscles seem to play an important role in active orthodontic treatment and in maintaining stability after treatment. Accordingly, measurement of occlusal forces, which would be useful for evaluation of malocclusion was

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introduced (3–5), and the clinical usefulness of this method was determined by recording the maximum occlusal force (6, 7).

So far, most studies have measured maximum occlusal force either in adults or children (6, 8). There are very few studies dealing with variations in maximum occlusal force with different age groups (8–10). Previous studies showed that maximum occlusal force was strongly correlated with skeletal factors in adults. Braun reported a gender difference in maximum occlusal force (8). Maximum occlusal force in children was shown to increase along with growth (11). A simplified measuring device for occlusal force, which allowed relatively easy measurements in a large number of samples, was used to determine the maximum occlusal force and the measurements were shown to be reliable (4).

With the aim of clarifying the correlations between variations in the maxillofacial skeletal pattern and changes in maximum occlusal force in different age groups, the following cross-sectional studies were conducted.

Materials and methods

For measurement of maximum occlusal force, a simplified occlusal force meter, was used (Nagano Keiki Seisakusho, Nagano, Japan) (3, 4, 12) (Fig. 1). It is a compact digital device that averages 10 readings and displays the average and also the highest reading in a given series. The top surface of this device is covered with a diaphragm, and the pressure of liquid charged in the housing is measured with a built-in manometer (4). The measured value of maximum occlusal force as measured on the occlusal surface of the maxillary first molar is assumed to denote the jaw-closing force generated by the oral unit as a whole, i.e. maximum jaw-closing force (13).

The study population included 150 males and 200 females, who attended the Department of Orthodontics, Matsumoto Dental University with the chief complaint of malocclusion. Patients who were in good general health and had neither congenital anomalies nor subjective symptoms suggestive of temporomandibular joint disorders were selected. The subjects were divided into two groups based on gender, and each group was then subdivided into five groups on the basis of chronological age (Table 1). Informed consent was obtained from all subjects.

The subjects were seated in a dental chair with their head and upper body in a natural upright position.

Table 1. **Classification of age groups (years)**

	Male		Female	
Group	n	Mean ± SD	n	Mean ± SD (years)
I	30	8.6 ± 0.7	40	8.6 ± 0.7
II	30	10.8 ± 0.6	40	10.9 ± 0.4
III	30	13.0 ± 0.9	40	13.4 ± 0.7
IV	30	17.8 ± 2.0	40	17.5 ± 1.7
V	30	25.4 ± 2.5	40	25.1 ± 2.4

The subjects were selected on the basis of the following criteria: 1) no history of orthodontic treatment, 2) no congenital disease, 3) no signs or symptoms of a craniomandibular disorder and 4) no severe periodontal disease. They were divided by gender and chronological age.
SD, standard deviation.

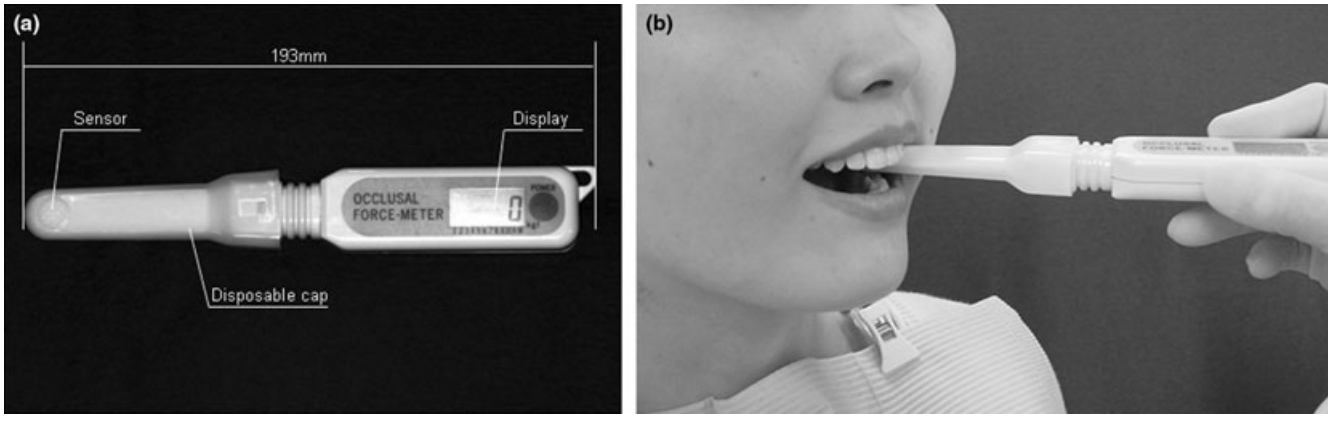

Fig. 1. A device for measuring occlusal force and positioning of subjects and occlusal force meter. Photograph of occlusal force meter. The subject was sitting in natural head position. The mean of five measured values was taken as the maximum occlusal force after the preliminary measurement. The site of measurement was the maxillary first molar.

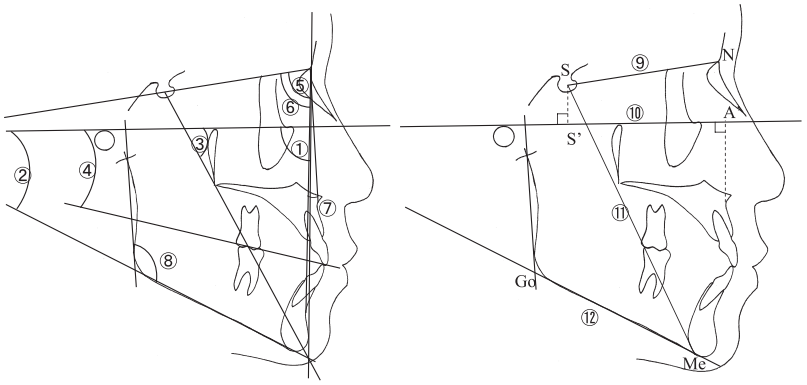

Fig. 2. Evaluation of maxillofacial morphology. 1) Facial plane angle, 2) mandibular plane angle, 3) *Y*-axis, 4) occlusal plane angle, 5) SNA, 6) SNB, 7) ANB, 8) gonial angle 9) distance of S-N, 10) distance of S'-A', 11) distance of S-Me, 12) distance of Go-Me.

Measurement of occlusion started at the position where the sensor of the occlusal force meter touched the maxillary teeth (Fig. 1). On the basis of a pilot study (4), we adopted the maxillary first molar as the site of measurement and it was demonstrated that experimental measurements were performed consecutively for five times after repeating the preliminary measurements 10 times. The mean of these five measured values was taken as the maximum occlusal force. The measurements were performed successively with no intervals between them. They were repeated on the other side after an interval of 1 min. The occlusal bite force was determined as the average of both sides.

For assessment of the maxillofacial skeletal pattern, lateral cephalometric radiograms were taken in a habitual occlusal position. Using the reports by Coben (14) and Kurihara et al. (3) as our reference, we measured the angle and distance of 12 craniofacial dimensions (Fig. 2).

To study the interrelation between the maximum occlusal force and the maxillofacial skeletal pattern, we analyzed the correlation between the measured values of maximum occlusal force and the measured values of craniofacial dimensions. For statistical analysis, we used the statistical software SPSS (vs.14.0 J, WinXP; SPSS Japan Inc., Tokyo, Japan). Three-way ANOVA was used to test whether the difference was significant. Correlation was assessed with Spearman's correlation coefficient.

Results

Results of measurements of maximum occlusal force

The results of measurements of maximum occlusal force in the male and female subjects are shown in Table 2.

Table 2. **Results of maximal occlusal force (kgf)**

	Male	Female
Group	Mean ± SD	Mean ± SD (kgf)
I	26.2 ± 9.1	20.9 ± 10.9
II	35.1 ± 13.2	26.2 ± 13.0
III	37.5 ± 16.3	32.0 ± 12.8
IV	43.2 ± 15.8	40.7 ± 15.5
V	51.6 ± 21.5	40.7 ± 15.0
p-value	**	**

Maximum occlusal force continued to increase until adulthood in the male, but stabilized at 17 years of age (group IV) and thereafter in females. The maximum occlusal force for age groups and gender groups was compared by three-way ANOVA.
SD, standard deviation.
**$p < 0.01$.

The maximum occlusal force increased with age in the male subjects. The standard deviation of maximum occlusal force was smallest in group I and largest in group V. The difference was largest between groups I and II, and smallest between groups II and III. There was a significant difference in maximum occlusal force ($p < 0.05$) between group I and groups IV and V, between group II and groups IV and V, and between group III and group V.

The maximum occlusal force also tended to increase with age in the female subjects. The standard deviation of maximum occlusal force was smallest in group I and largest in group V. The difference was largest between groups I and II, and smallest between groups IV and V. The maximum occlusal force was significantly different ($p < 0.05$) between group I and groups II, III, IV and V, between group II and groups III, IV and V, between group III and groups IV and V, and, between group IV and group V.

Comparison between the male and female subjects revealed that the maximum occlusal force tended to be larger in the male subjects, and that the increase between respective age groups was also larger in the male subjects. The maximum occlusal force showed a tendency to increase until adulthood in the male subjects, while in female subjects it tended to stabilize at 17 years of age in group IV and thereafter.

Results of analysis of lateral cephalometric radiograms

The results of the cephalometric analysis are shown in Tables 3 and 4.

The facial plane angle tended to increase with age in both male and female subjects. No significant changes in the mandibular plane angle, *Y*-axis angle, SNA angle and gonial angle were found in either the male or female subjects. The mean values of the Occlusal plane angle tended to decrease with age in both the male and female subjects. SNB angle, ANB angle, S-N distance, S'-A' distance, S-Me distance and Go-Me distance tended to increase with age in both the male and female subjects.

Correlation between maximum occlusal force and the maxillofacial skeletal pattern

The coefficients of correlation between the mean values of maximum occlusal force and the cephalometric measurements in respective age groups are shown in Tables 5 and 6.

Significant correlations were found between maximum occlusal force and the mandibular plane angle in groups I, II and V, and between the maximum occlusal force and the S-Me distance in group V in male subjects. No significant correlations were found between maximum occlusal force and any of the facial plane angles, Y-axis angle, occlusal plane angle, SNA angle, SNB angle, ANB angle, gonial angle, S-N distance, S'-A' distance and G-Me distance.

In female subjects, the maximum occlusal force showed a significant correlation with the facial plane angle in groups I and II, with the mandibular plane angle in groups I, II, III and IV, with the *Y*-axis angle in group II, with the occlusal plane in groups I and II, with the SNB angle in group I, with the gonial angle in group IV, and with the Go-Me distance in group I. The

Table 3. **Cephalometric measurements in male subjects**

Group	I (n = 30) Mean ± SD	II (n = 30) Mean ± SD	III (n = 30) Mean ± SD	IV (n = 30) Mean ± SD	V(n = 30) Mean ± SD	*p*-value
Angular measurement (°)						
Facial plane	84.6 ± 3.1	83.8 ± 3.5	85.7 ± 3.3	87.3 ± 3.6	87.4 ± 6.4	**
Mandibular plane	29.6 ± 4.1	30.1 ± 5.6	30.5 ± 5.5	28.1 ± 5.8	28.2 ± 8.8	NS
Y-axis	63.3 ± 3.1	64.7 ± 4.4	64.6 ± 3.5	63.4 ± 3.8	64.3 ± 6.6	NS
Occlusal plane	13.6 ± 3.7	13.3 ± 4.2	12.3 ± 3.0	8.1 ± 4.8	9.2 ± 5.4	**
SNA	80.3 ± 3.3	79.4 ± 3.8	80.8 ± 3.6	79.1 ± 4.3	81.2 ± 4.1	NS
SNB	78.2 ± 3.9	76.6 ± 3.2	78.5 ± 5.2	78.8 ± 5.0	80.6 ± 5.8	*
ANB	2.1 ± 3.2	2.8 ± 3.1	2.3 ± 4.8	0.4 ± 3.9	0.5 ± 5.1	NS
Gonial angle	125.4 ± 4.3	125.2 ± 5.7	125.8 ± 7.5	124.4 ± 7.3	124.2 ± 8.5	NS
Linear measurement (mm)						
S-N	66.8 ± 3.3	69.5 ± 3.6	69.7 ± 3.7	72.8 ± 4.7	73.6 ± 2.8	**
S'-A'	63.5 ± 3.8	66.0 ± 4.9	67.3 ± 4.8	69.0 ± 5.4	70.3 ± 5.5	**
S-Me	115.4 ± 6.7	120.8 ± 4.5	131.0 ± 10.5	138.8 ± 9.8	144.3 ± 8.3	**
Go-Me	65.8 ± 4.3	69.4 ± 4.0	74.0 ± 6.1	77.2 ± 6.0	80.8 ± 6.3	**

The maximum occlusal force for age groups and gender groups was compared by three-way ANOVA. The facial plane angle increased with age in both genders. No significant changes in the mandibular plane, *Y*-axis, SNA, ANB and gonial angles were found in the male subjects. The SNB angle, S-N distance, S'-A' distance, S-Me distance and Go-Me distance increased with age.
SD, standard deviation; NS, not significant.
*$p < 0.05$, **$p < 0.01$.

Table 4. **Cephalometric measurements in female subjects**

Group	I (n = 40) Mean ± SD	II (n = 40) Mean ± SD	III (n = 40) Mean ± SD	IV (n = 40) Mean ± SD	V (n = 40) Mean ± SD	*p*-value
Angular measurement (°)						
Facial plane	84.4 ± 2.9	84.3 ± 4.0	86.1 ± 4.0	87.2 ± 3.4	85.9 ± 3.7	**
Mandibular plane	30.2 ± 4.2	31.9 ± 6.0	30.2 ± 5.1	28.7 ± 6.1	30.6 ± 4.9	NS
Y-axis	63.4 ± 3.1	65.3 ± 4.7	64.5 ± 3.6	63.5 ± 3.1	65.1 ± 3.6	NS
Occlusal plane	14.0 ± 2.8	13.4 ± 4.4	11.3 ± 3.8	10.4 ± 4.3	11.7 ± 4.2	**
SNA	80.5 ± 2.8	79.9 ± 3.2	80.8 ± 4.0	81.0 ± 3.2	81.1 ± 2.8	NS
SNB	77.6 ± 3.3	77.2 ± 4.4	78.1 ± 4.0	80.0 ± 3.8	78.4 ± 3.6	*
ANB	2.9 ± 2.4	2.6 ± 3.1	2.7 ± 3.3	0.9 ± 3.4	2.6 ± 3.0	*
Gonial angle	126.3 ± 6.2	127.1 ± 7.7	124.0 ± 7.0	121.0 ± 19.7	124.0 ± 6.7	NS
Linear measurement (mm)						
S-N	65.6 ± 3.5	67.1 ± 3.0	67.8 ± 3.6	68.9 ± 2.7	69.4 ± 3.7	**
S'-A'	63.3 ± 4.1	63.8 ± 3.5	65.1 ± 4.3	66.5 ± 4.0	67.6 ± 4.2	**
S-Me	112.6 ± 5.6	120.8 ± 11.9	125.3 ± 6.5	130.3 ± 8.3	132.7 ± 6.9	**
Go-Me	64.1 ± 4.5	69.7 ± 5.1	72.2 ± 5.5	74.4 ± 4.8	75.6 ± 5.1	**

The maximum occlusal force for age groups and gender groups was compared by three-way ANOVA.
The facial plane angle increased with age in both genders. No significant changes in the mandibular plane, *Y*-axis, SNA and gonial angles were found in female subjects. The SNB angle, S-N distance, S'-A' distance, S-Me distance and Go-Me distance increased with age.
SD, standard deviation; NS, not significant.
*$p < 0.05$, **$p < 0.01$.

Table 5. **Correlation coefficients between maximum occlusal force and cephalometric angular measurements (males)**

Group	I	II	III	IV	V
Angular measurement					
Facial plane	0.02	0.16	0.06	−0.03	0.26
Mandibular plane	−0.41*	−0.46**	−0.22	−0.15	−0.41*
Y-axis	−0.08	−0.26	0.07	−0.30	−0.35
Occlusal plane	−0.26	−0.01	0.05	−0.29	−0.18
SNA	0.16	−0.05	0.16	0.01	0.24
SNB	0.09	−0.16	0.06	−0.01	0.14
ANB	0.06	−0.16	0.06	0.03	0.01
Gonial angle	−0.07	−0.22	−0.24	0.00	−0.34
Linear measurement					
S-N	0.07	0.07	0.13	0.45**	0.15
S'-A'	0.23	0.06	0.19	0.37	0.38
S-Me	0.01	−0.15	0.14	0.03	−0.37*
Go-Me	−0.10	−0.15	0.05	−0.05	−0.05

Associations between maximum occlusal force and the 12 cephalometric items were analyzed by Spearman's correlation coefficient at the 95% confidence interval. A *p*-value of <0.05 was considered significant.
*$p < 0.05$, **$p < 0.01$.

Table 6. **Correlation coefficients between maximum occlusal force and cephalometric angular measurements (females)**

Group	I	II	III	IV	V
Angular measurement					
Facial plane	0.46	0.34**	0.18	0.23	0.05
Mandibular plane	−0.34*	−0.44**	−0.34*	−0.35*	−0.26
Y-axis	−0.31	−0.36*	−0.14	−0.26	−0.10
Occlusal plane	−0.34*	−0.47**	−0.15	−0.09	−0.05
SNA	0.16	0.29	0.30	−0.13	−0.04
SNB	0.37*	0.28	0.31	0.13	−0.09
ANB	0.28	−0.04	0.01	−0.27	−0.08
Gonial angle	−0.22	−0.28	−0.28	−0.44**	−0.17
Linear measurement					
S-N	0.18	−0.11	−0.04	−0.08	0.02
S'-A'	0.17	0.18	0.29	−0.12	−0.10
S-Me	0.31	0.03	0.17	−0.02	−0.15
Go-Me	0.35*	0.20	0.17	0.22	−0.03

Associations between maximum occlusal force and the 12 cephalometric items were analyzed by Spearman's correlation coefficient at the 95% confidence interval. A *p*-value of <0.05 was considered significant.
*$p < 0.05$, **$p < 0.01$.

maximum occlusal force showed no significant correlations with the SNA angle, ANB angle, S-N distance, S'-A' distance and S-Me distance.

Discussion

Method for measurement of maximum occlusal force

Generally, occlusal force is expressed by the magnitude of force exerted on a unitary occlusal contact area. As it was hard to accurately determine the occlusal contact area by the method used in this study, we defined the whole pressure generated by occlusion of the maxillary and mandibular teeth as maximum occlusal force (11). To study the variations in the occlusal force depending on the site of measurement, we measured the maximum occlusal force with respect to each tooth in a pilot study, and observed that occlusal force showed the maximum value at the maxillary first molar (4). In addition, as the occlusal relationship at the molar region is particularly important from the orthodontic viewpoint (15), we selected the maxillary first molar as the site of measurement. Although there is a report that the second molar region shows the maximum occlusal force value when measured with pressure-sensitive sheets (16), the difference could be ascribed to the difference in jaw position at the time of measurement because of the difference in thickness of the sensor part of the occlusal force meter and the pressure-sensitive sheets.

As for the thickness of the sensor part, Morimoto et al. (17) inserted specimens of small polyurethane sheets (2 mm thick) between the maxillary and mandibular molars during cerebro-cortically induced rhythmic jaw movements in rabbits. They reported that the masticatory force and activity of the masseter muscle increased with an increase in hardness of the specimen, and that afferent information from periodontal mechanoreceptors and muscle spindles played an important role in the increase in masticatory force and muscle activity. It is suggested that the hardness and thickness of the masticatory specimen are factors affecting the masticatory force. In view of the report that maximum occlusal force generated in the molar region attained the largest value when the inserted specimen was 4.4–15.5 mm thick (13), the thickness of the sensor part of the occlusal force meter used in this study seemed to be suitable for clinical measurements of maximum occlusal force because the thickness was 8.8 mm when covered with a soft disposable cap.

As for the number of measurements, we studied the variations of maximum occlusal force 100 times consecutively in each subject, and found that the maximum occlusal force tended to decrease and showed unstable values in the middle and later periods compared with the initial period of measurement (4). In functional tests such as in this study, muscle fatigue and psychological factors such as feeling of anxiety in subjects seem to significantly influence the measured values. Hence, the number of measurements in this study, which was determined on the basis of the results of preliminary experiments, seemed to provide high reproducibility and practicability allowing for relaxation of physical fatigue in the device and psychological anxiety, as well as simplification of clinical measuring methods.

Changes in maximum occlusal force

Comparison of maximum occlusal force between male and female subjects revealed that in each age group, the male subjects showed significantly larger values ($p < 0.0001$), as was demonstrated in a previous report (8). This difference in maximum occlusal force could be attributed to gender difference in physical strength, as there is correlation between athletic ability, physical strength and occlusal force (18).

As shown in Table 2, maximum occlusal force of male and female subjects on the average showed an increasing tendency with age. The results were closely similar to previous reports that occlusal force increased with growth (11). Comparing the male and female subjects, in the male subjects the maximum occlusal force tended to continue to increase until the first half of their 20s, while in the female subjects the increase nearly terminated before they reached their 20s. In group V, where the maximum occlusal force was largest in both the male and female subjects, it was significantly larger in the male subjects. This could be due to differences in physical capabilities (8). The standard deviation of maximum occlusal force also tended to increase in association with the increase in maximum occlusal force with age. This might not be explained by variations caused by the difference either in the site or the number of repetition of measurements. However, intra-group differences in age and physical capacities

in respective groups seemed to be deeply involved in the increase in the standard deviation of maximum occlusal force. Individual differences in the physical capacities of adults may exist because of differences in life style, and could be a factor contributing to the increase in the standard deviation of maximum occlusal force.

Relationship between maximum occlusal force and maxillofacial skeletal pattern

The results of this study showed a significant correlation between maximum occlusal force and the mandibular plane angle in most of the age groups. The significant negative correlation between the mandibular plane angle and maximum occlusal force indicates that long-face individuals whose mandibles tend to rotate in a clockwise direction have a small occlusal force. This result is in accordance with similar studies (19–21). The cause for the tendency of opening of the mandibular plane angle in a high angle case can be explained on the basis of the functional substrate theory (22). If muscle growth is interrupted during the growth process and the muscle contraction force remains weak even in adulthood, the countenance results in a long-face configuration (23). Open bite in the patients of progressive muscular dystrophy (24, 25) is also an example of morphological changes induced by muscles. The results of this study were almost entirely consistent with those of a previous similar study (20), but no significant correlations were found between maximum occlusal force and the mandibular plane angle in the male groups III and IV and in the female group V (Tables 5 and 6). However, Iwasaki et al. (26) reported a significant negative correlation between maximum occlusal force and the mandibular plane angle. This discrepancy may have been caused by the fact that the subjects in the present study were patients with malocclusion who were cross-sectionally extracted, resulting in an increase in inter-group variations of the measured values.

Maximum occlusal force would increase progressively with age up to 20s, after termination of the growth of mandible, which follows that of maxilla. From these results, we assumed that the mandible completed growth following the maxilla, and 6–7 years after this completion maximum occlusal force attained the largest value. According to a study using implant pins as markers by Björk and Skieller (27), the maxillary first molar was assumed to continue its eruption around 11–18 year of age, and its eruption was assumed to terminate thereafter. For illustration purposes, age-related variations in S'-A' distance, S-Me distance and maximum occlusal force were summarized in Figs 3 and 4. It was expressed as per cent of the values of the S'-A' distance, S-Me distance and

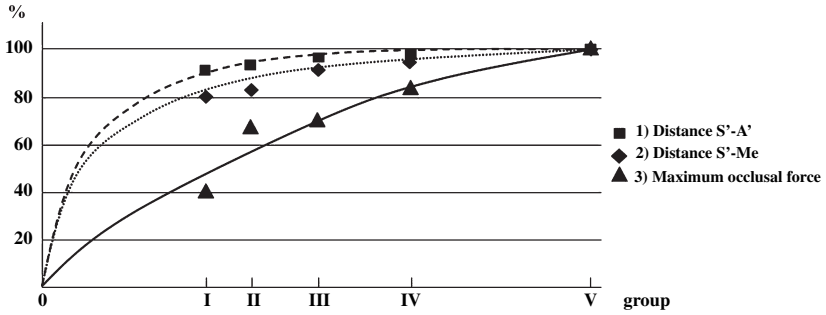

Fig. 3. Illustration of changes in 1) distance of S'-A' and 2) distance of S-Me and 3) maximum occlusal force (male).

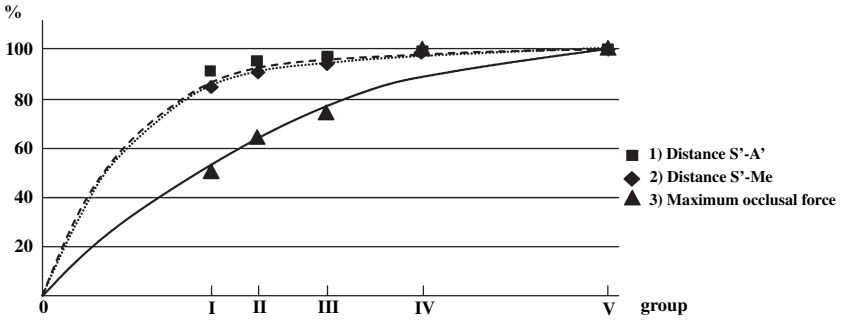

Fig. 4. Illustration of changes in 1) distance of S'-A' and 2) distance of S-Me and 3) maximum occlusal force (female).

maximum occlusal force of respective male and female age groups to those of the males and females in group V, respectively, and compared between respective groups. Taking this report and the results of this study showing that maximum occlusal force continued to increase in groups IV and V into consideration, we were able to infer that the largest value of maximum occlusal force could be attained after teeth eruption was complete. It appears to be reasonable to assume that maximum occlusal force would mature as one of the maxillofacial functions only after termination of eruption of teeth and growth of the mandible following that of the maxilla. The same situation has been reported in training physiology in sports (28). Physical performance exhibited peak development after peak growth velocity with training. It is suggested that improvement of occlusal force can be achieved after peak growth velocity.

As this study demonstrated a correlation between maximum occlusal force and the maxillofacial skeletal pattern, the possibility was suggested that measurements of longitudinal specimens would further clarify the relationship between the changes in maximum occlusal force and the changes in the maxillofacial skeletal pattern in association with growth. The results suggest the clinical usefulness of the simplified device to assess the potential influences of mandibular muscle function on morphologic variation. The routine examination of occlusal force might be useful for orthodontic treatment (29) and stability, including muscular anchorage, extrusive mechanics and retention in each patient.

Conclusions

1. Maximum occlusal force tended to increase from childhood to 20 years of age.
2. There was a gender difference in the maximum occlusal force at all age groups, values being larger in the male.
3. In males, the maximum occlusal force continued to increase until their 20s, while in the females, it almost terminated before they reached the age of 20.
4. A negative correlation exists between maximum occlusal force and mandibular plane angle.
5. The occlusal force meter appears to be clinically useful in assessing masticatory force.

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