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Relationship between maximum bite force and facial skeletal pattern

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The purpose of this study was to measure maximum bite force and to investigate its relationship with anteroposterior, vertical, and transverse facial skeletal measurements.

From among the dental students at the College of Dentistry, forty subjects (26 male and 14 female) were selected. With two sets of strain gauge, maximum bite force at the right and left first molars and anterior teeth was measured in the morning and afternoon. After taking lateral and posteroanterior cephalograms, fifty and nineteen variables were evaluated, respectively. Paired *t*-tests and an independent *t*-test were done and correlation coefficients were obtained.

1. The maximum bite force at the first molars was 68.0 ± 13.9 kg in males and 55.6 ± 10.5 kg in females ($p<0.05$) while the force at the anterior teeth was 8.4 ±4.9 kg and 5.1 ±3.4 kg respectively ($p<0.05$).
2. Some tendency for a greater value of maximum bite force at the preferred side was observed but not statistically significant ($p>0.05$).
3. Significant difference was observed between the strong bite force group and the weak bite force group in some cephalometric and other measurements ($p<0.05$). N-S-Ar, S-Ar-Go, FH-H1, IMPA and MMO showed a significant difference in posterior maximum bite force (*P*). N-S-Ar and FH-H1 also showed a significant difference in anterior maximum bite force (*A*).
4. Several cephalometric variables showed some correlation with maximum bite force ($p<0.05$). N-S-Ar, S-Ar-Go, UGA, FH-H6, FH-H1, body weight and MMO were significantly correlated with posterior maximum bite force (*P*). Go-Me, P-1 and IMPA were significantly correlated with anterior maximum bite force (*A*).

Key words : Maximum bite force, Facial skeletal pattern, Strain gauge

The major function of human teeth embedded in the maxilla and the mandible is to break up food before its movement into the remainder of the alimentary canal. The teeth carry out their function with force generated by the masticatory muscles attached to the mandible. Bite force is defined as the force originating from the tension generated by the contraction of masticatory muscles, which acts between

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the upper and lower teeth or through the medium of the material intervening between them[1].

Clinicians have long been interested in bite force with regard to its potential influence on the development of the masticatory complex. Finn[2] reported that the maximum bite force of the molar region in individuals with normal facial appearance was approximately twice that of dolichofacial subjects, while brachyfacial types had even greater values. Braun et al.[3] asserted that bite force change may be the cause, and not the result, of facial proportion change. But Throckmorton and co-workers[4] demonstrated that bite force reflects the geometry of the jaw lever system. Therefore, whether bite force difference plays a role in determining the ultimate facial morphology or merely reflects the mechanical advantage obtained by muscles in different facial types has been a matter of some controversy.

Orthodontists should be concerned with bite force if it influences not only the tooth position, but also the facial form. When the bite force acts on the teeth, it can be divided into vertical, horizontal and transverse components.

Among them, the vertical component of bite force could counteract the effect of orthodontic treatment with action such as the extrusion of posterior teeth, opening of the mandibular plane, etc. Additionally, the influence of bite force on the vertical stability of any treatment result is important. The new position of the dentition should be compatible with the dynamics of the muscular and occlusal forces in all planes[3].

The purpose of this study was to measure maximum bite force in normal occlusion and to investigate its relationship with anteroposterior, vertical and transeverse facial skeletal measurements.

MATERIALS AND METHODS

1. Materials

From among the dental students at the College of Dentistry of Seoul National University, 40 subjects(26 male and 14 female) were selected. The mean ages were 25±2.5 for males and 24±0.4 for females. They were all Angle Class I without severe facial asymmetry or dentofacial deformity when examined visually. In the upper and lower molar region, there were no prostheses or lost teeth. Subjects showing temporomandibular signs and symptoms were excluded.

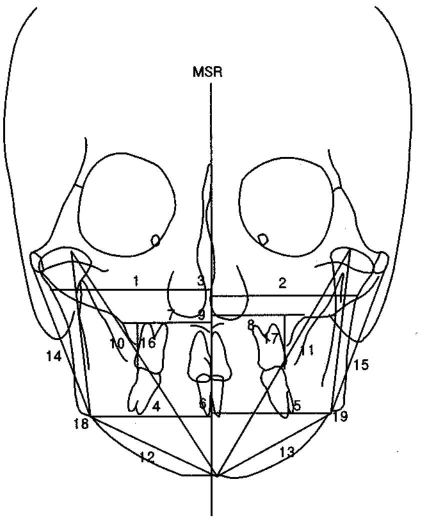

Fig. 1. Posteroanterior Cephalometric Measurements.
1. Ar-MSR (R), 2. Ar-MSR (L), 3. Ar-Ar, 4. Ag-MSR (R), 5. Ag-MSR (L), 6. Ag-Ag, 7. J-MSR (R), 8. J-MSR (L), 9. J-J, 10. Co-Me (R), 11. Co-Me (L), 12. Ag-Me (R), 13. Ag-Me (L), 14. Zy-Ag (R), 15. Zy-Ag (L), 16. J-UM (R), 17. J-UM (L), 18. Co-Ag-Me (R), 19. Co-Ag-Me (L).

2. Methods

(1) Posteroanterior and lateral cephalograms and their measurements

With the cephalometric equipment (Cranex C+, Soredex Orion Corporation, Helsinki, Finland) at Department of Orthodontics, Seoul National University Dental Hospital, posteroanterior and lateral cephalograms were taken. They were traced by a sharp lead pencil on acetate semitranslucent papers.

1) Posteroanterior cephalograms (Figure 1)

On the posteroanterior cephalograms, seven anatomic points were identified and nineteen variables were measured.

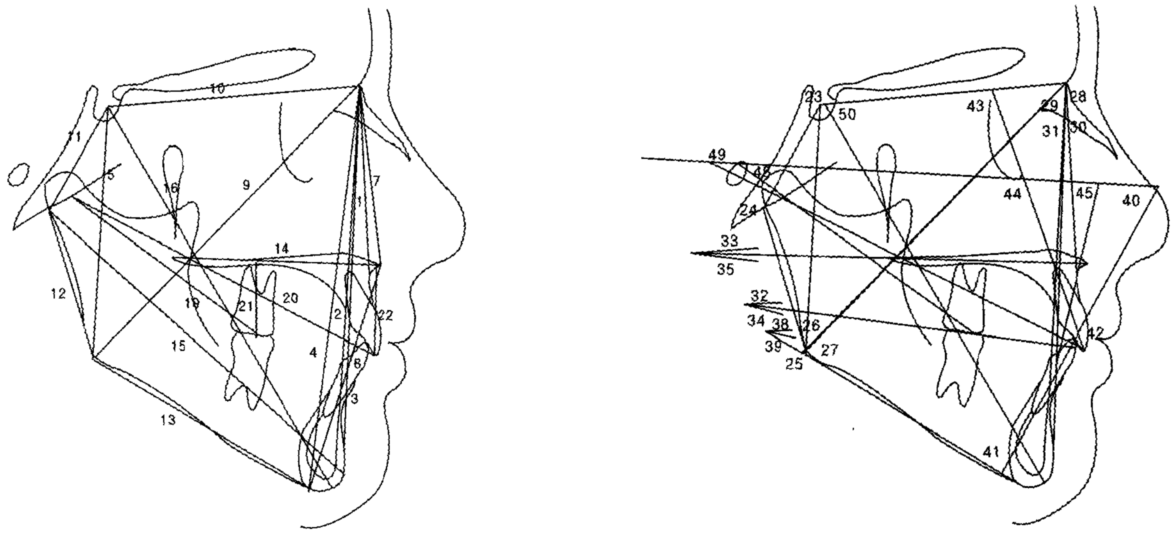

Fig. 2. Lateral Cephalometric Linear Measurements.
1. N-A, 2. N-B, 3. N-Pog, 4. N-Me, 5. S-Go, 6. FHR (Facial height ratio; N-Me / S-Go), 7. N-ANS 8. ANS-Me, 9. N-Go, 10. N-S, 11. S-Ar, 12. Ar-Go, 13. Go-Me, 14. ANS-PNS, 15. Ar-Pog, 16. S-Gn, 17. OB, 18. OJ, 19. H-6, 20. H-1, 21. Palatal plane-UM, 22. Palatal plane-UI, 23. N-S-Ar, 24. S-Ar-Go, 25. Gonial angle, 26. Upper gonial angle, 27. Lower gonial angle, 28. SNA, 29. SNB, 30. ANB, 31. SNPog, 32. SN-occlusal plane, 33. SN-palatal plane, 34. FH-occlusal plane, 35. FH-palatal plane, 36. Palatal-occlusal plane, 37. Occlusal-mandibular plane, 38. SN-mandibular plane, 39. FMA, 40. FMIA, 41. IMPA, 42. IIA (Interincisal angle), 43. U1 to SN, 44. U1 to FH, 45. FABA, 46. ODI, 47. APDI, 48. FH-H6, 49. FH-H1, 50. Y axis angle.

Ar : Articulare, the most lateral point on the inferior part of the condylar neck
Ag : Antegonion, the most superior point of the antegonial notch
J : Jugular Point, the intersection between the zygomatic process of the maxilla and maxillary tuberosity
Co : Condylion, the most superior point on the mandibular condylar head
Me : Menton, the most inferior point of the chin contour
Zy : Zygion, the most lateral point on the zygomatic arch
UM : Upper molar, the mesiobuccal cusp tip of the upper first molar
(MSR : Midsagittal reference line, the reference line passing through the crista galli and anterior nasal spine)

2) Lateral cephalograms (Figure 2)

On the lateral cephalograms, sixteen landmarks were selected and fifty variables were measured.

N : Nasion, the most anterior point of the frontonasal suture
S : Sella, the center of the sella turcica
Po : Porion, the most superior point of the external auditory meatus
Ar : Articulare, the intersection between the external contour of the cranial base and the dorsal contour of the mandibular condyle
Go : Gonion, the intersection between the line from Me to the most inferior-posterior contour of the mandible and the line from Ar to the most posterior-inferior contour of the ramus
Me : Menton, the most lower point of the mandibular symphysis
Gn : Gnathion, the midpoint on the bony contour between Pog and Me
Pog : Pogonion, the most anterior point on the chin contour
A : Subspinale, the most posterior point on the anterior contour of the upper alveolar process

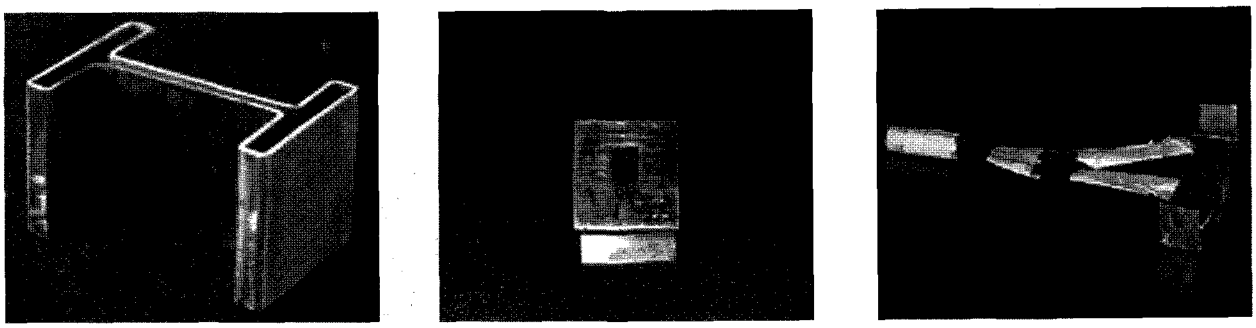
(A) (B) (C)

Fig. 3. Maximum bite force measuring devices.
A : H-type stainless steel device which was 0.5mm thick and welded
B : device attached by strain gauge and termial
C : two devices connected with handle which had hinge type connections

B : Supramentale, the most posterior point on the anterior contour of the lower alveolar process
ANS : Anterior Nasal Spine, the tip of the anterior nasal spine of the palatal bone in the hard palate
PNS : Posterior Nasal Spine, the tip of the posterior nasal spine of the palatal bone in the hard palate
Or : Orbitale, the lowest point on the lower margin of the bony orbit
H : Hinge axis, the midpoint on the intersecting line of the external contour of the cranial base by the mandibular condyle
UM : Upper molar, the mesiobuccal cusp tip of the maxillary first molar
UI : Upper incisor, the incisal tip of the maxillary central incisor

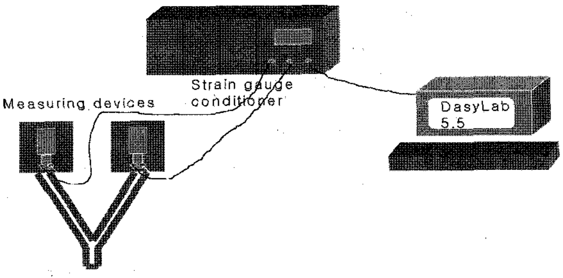

Fig. 4. Schematic drawing of maximum bite force-measuring system.
Measuring devices : two maximum bite force measuring devices connected by handle
Strain gauge conditioner : model 2150 acquiring electric signal from two strain gauges
DasyLad 5.5 : the window program displaying voltage change in various form

(2) Other clinical measurements
① Height : Body height (cm)
② Weight : Body weight (kg)
③ MMO : Maximum mouth opening, the distance between the upper and lower anterior teeth at maximum opening (mm)
④ Masticatory preference : the side on which the subjects prefer to bite daily, right or left

(3) Measurement of maximum bite force

Measuring devices were made of stainless steel in the shape of an H-type hollow (Figure 3A). Strain gauges (EA-06-120LZ-120, Micro-Measurements, Raleigh, North Carolina) were attached on them (Figure 3B). Two H-type devices were connected with stainless steel handle (Figure 3C).

The stainless steel plate was 0.5mm thick and had spring characteristics with hardness to resist heavy biting force. The gap between two plates of the bridge in the H-type device was 5.0mm.Two strain gauges were connected to an IBM PC through the strain gauge conditioner (model 2150, Measurements Group, Raleigh, North

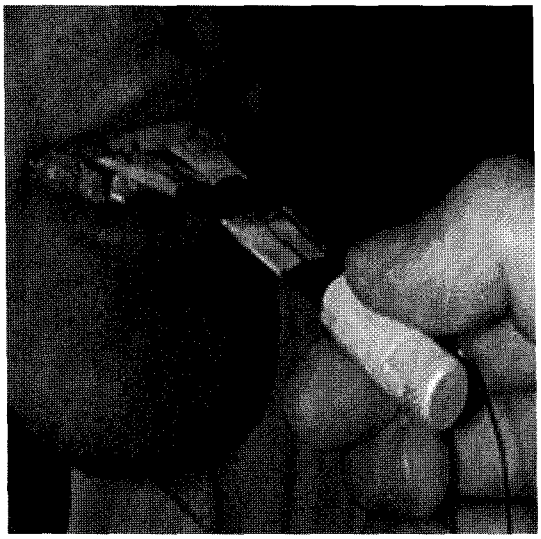

Fig. 5. Picture of measuring maximum bite force .
After the center of each horizontal part of bite force devices being placed on both upper first molars or upper anteriors of subjects, they were told to bite maximally

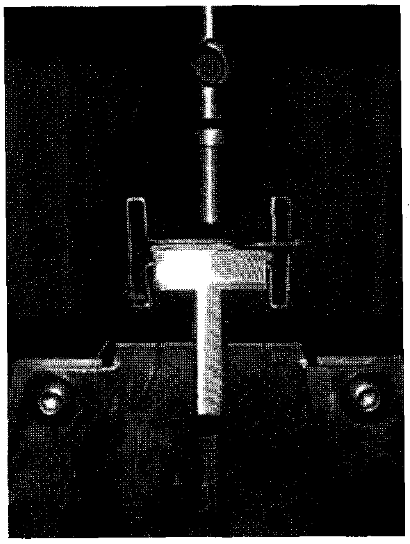

Fig. 6. Calibration of strain gauge by Instron.
1000 kg load cell and 0.2 mm/s head speed were used.

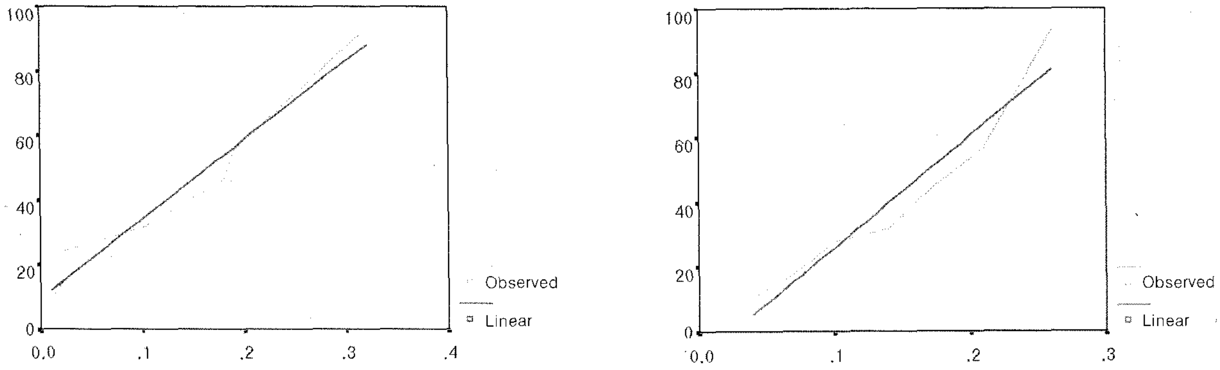

Fig. 7. Left : Calibration graph of left strain gauge (Kg = 183.4 * mV − 1.5)
Right : Calibration graph of right strain gauge (Kg =345.9 * mV − 8.5)

Carolina). DasyLab 5.5 software (National Instruments, Austin, Texas) was used to record and evaluate the changes of milivoltage in analog and digital values (Figure 4).

For calibration, bite force devices were mounted on Instron, and we recorded the changes of load and mV (milivoltage) on the monitor, moving the load cell (1000 kg) in the head speed of 0.2 mm/s (Figure 6). The linear relationship between load (kg) and mV was calculated for each device, respectively (Figure 7).

The subjects sat upright and were relaxed, and kept their head upright comfortably and free of tension.

After placing the center of the bridge part of the bite force device on the upper first molars or upper anterior teeth, maximum biting force were measured (Figure 5).

For each subject, they were measured on three points (the first molars of both sides and anterior teeth), twice at intervals of 5 seconds. The larger value was taken as the maximum bite force of that point. The same procedures were repeated in the morning (9 AM to 10 PM) and in the afternoon (4 PM to 5 PM) of a single day.

The measuring items were as follows :

① PR1 : Maximum bite force on right first molars measured in the morning.
② PL1 : Maximum bite force on left first molars measured in the morning,.
③ A1 : Maximum bite force on anterior teeth measured in the morning.
④ PR2 : Maximum bite force on right first molars measured in the afternoon.
⑤ PL2 : Maximum bite force on left first molars measured in the afternoon.
⑥ A2 : Maximum bite force on anterior teeth measured in the afternoon.
⑦ PR : higher value between PR1 and PR2
⑧ PL : higher value between PL1 and PL2
⑨ P : average of PR and PL
⑩ A : higher value between A1 and A2

(4) Statistical analyses

1) Morning versus afternoon

Paired *t*-test was done to compare the maximum bite force taken in the morning and in the afternoon.

2) Right versus left side

Right and left maximum bite force were also compared by paired *t*-test. These paired *t*-tests were repeated in male, female and total groups.

3) Gender difference

Independent *t*-test was used to evaluate the difference of maximum bite force between males and females.

4) Chewing-side preference

Subjects showing right-side chewing preference (6 males and 3 females) and left-side chewing preference (4 males and 3 females) were compared by independent *t*-tests.

5) Strong versus Weak groups

Ten subjects were selected who showed high means in maximum bite force measurements (Strong Group). Another ten subjects were selected who showed low means in maximum bite force measurements (Weak Group).

a) Independent *t*-tests were done for posteroanterior cephalometric measurements between the two groups.
b) Independent *t*-tests were done for lateral cephalometric measurements between the two groups.
c) Independent *t*-tests were done for age, body height, body weight and maximum mouth opening between the two groups.

6) Correlation of maximum bite force with cephalometric and other clinical measurements

Pearson's correlation coefficients were obtained to search for any factors related with the individual maximum bite force difference

a) Between maximum bite force (PR, PL, P, A, PR-PL) and posteroanterior cephalometric measurements
b) Between maximum bite force (P, A) and lateral cephalometric measurements
c) Between maximum bite force (P, A) and other measurements (age, height, weight and MMO)

RESULTS

1. Cephalometric measurements

(1) Posteroanterior measurements

19 items (17 linear and 2 angular measurements) were measured with 7 cephalometric points. In all 17 linear measurements, males showed greater values than females. Among the linear measurements Co-Me displayed a relatively broad standard deviation. As for one angular measurement (CoAgMe), there showed larger values in females than in males.

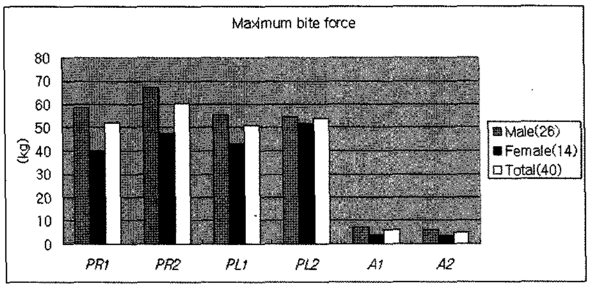

Fig. 8. Maximum bite force measured in the morning and afternoon. The value of male was larger than that of female on all the molar and anterior teeth

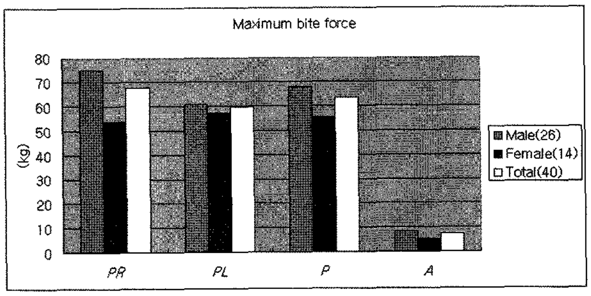

Fig. 9. Mean of maximum bite force calculated from the value in Figure 9

Table 1. The difference of maximum bite force right and left side of subjects

	Male N=26	Female N=14	Total N=40
PR1-PL1	ns	ns	ns
PR2-PL2	*	ns	ns
PR-PL	ns	ns	*

ns : not significant

* : $p<0.05$

(2) Lateral cephalometric measurements

50 items (22 linear and 28 angular measurements) were measured with 15 cephalometric points. In all 22 linear measurements and 12 angular measurements, males produced larger values than females. In the remaining 16 angular measurements, females showed greater values.

2. Clinical measurements

Body height (mm), weight (kg) and maximum mouth opening (mm) were obtained. In all three measurements, males showed greater values than females.

3. Maximum bite force

Fig 8 shows maximum bite force measured in the morning and in the afternoon

4. Statistical analyses

(1) Morning versus afternoon

From the paired t-test, there was no significant difference between measurements taken in the morning and in the afternoon ($p>0.05$).

(2) Right versus left side

In the total group, the measurement on the right side was greater than that on the left side ($p<0.05$), but in each male and female group, the results were in conflict to conclude on which side the measurement was stronger (Table 1).

Table 2. The difference of maximum bite force between male and female (kg)

	Male N=26	Female N=14	Sig.
PR1	58.4	39.9	**
PL1	55.4	43.0	*
A1	7.2	3.9	*
PR2	67.3	47.4	**
PL2	54.9	51.8	ns
A2	5.9	3.4	ns
PR	75.1	53.9	**
PL	60.8	57.3	ns
P	68.0	55.6	**
A	8.4	5.1	*

ns : not significant
* : $p<0.05$; **: $p<0.01$

(3) Male versus female group

There were significant differences between the male and the female group. The male group showed a stronger bite force ($p<0.05$) (Table 2).

(4) Chewing-side preference

Although there were not significant differences between the means of maximum bite force for the two groups, PR of the right preference group was higher than that of the left preference group, while PL of the left preference group was higher than that of the right preference group.

(5) Strong versus Weak groups

a) In the posteroanterior cephalograms, there were no significant variables showing any difference between the two groups, except Zy-Ag (L) ($p<0.05$) in PR .

b) In the lateral cephalograms, N-S-Ar, S-Ar-Go, FH-H1 and IMPA showed significant differences between the two groups in posterior maximum bite force (P) ($p<0.05$). And UGA in the group 'strong' had higher value than in the group 'weak', but there was no statistically significant difference. N-S-Ar and FH-H1 also showed a significant difference in anterior maximum bite force (A) ($p<0.05$).

c) Clinical measurements

Body weight was greater in the Strong group than in the Weak group, but it was not statistically significant. MMO was greater in the Strong group than in the Weak group ($p<0.05$).

(6) Correlation of maximum bite force with cephalometric and other clinical measurements

a) Correlation with posteroanterior cephalometric measurements

As for PR, Zy-Ag(R) and Zy-Ag(L) showed some correlation ($p<0.05$), although the coefficients were not especially high (Table 3).

Between the right-left difference of maximum bite force values (PR minus PL) and that of posteroanterior cephalometric measurements, there was no significant correlation.

b) Correlation with lateral cephalometric measurements

Between the P and lateral cephalometric measurements, the measurement of significant correlations were

Table 3. Correlation coefficients of PR,PL, P and A with posteroanterior cephalometric measurements

	PR N=40	PL N=40	P N=40	A N=40		PR N=40	PL N=40	P N=40	A N=40
Ag-MSR (L)	0.220	−0.047	0.140	0.245	Zy-Ag (R)	0.336*	−0.018	0.245	0.087
Ag-Ag	0.169	−0.076	0.086	0.243	Zy-Ag (L)	0.386*	0.006	0.296	−0.020

* : $p<0.05$

Table 4. Correlation coefficients of P and A for lateral cephalometric measurements

	P N=40	A N=40		P N=40	A N=40
Go-Me	0.013	0.327*	FMIA	−0.151	0.261
ANS-PNS	0.212	0.070	IMPA	0.227	−0.357*
P-6	0.062	0.303	FH-H6	−0.366*	0.161
P-1	0.101	0.344*	FH-H1	−0.357*	−0.183
N-S-Ar	0.399*	0.129	Y axis angle	0.163	−0.004
S-Ar-Go	−0.451**	−0.118	UGA	0.332*	0.054

* : $p<0.05$, ** : $p<0.01$

Table 5. Correlation coefficients of P and A for clinical measurements

	P N=40	A N=40
Weight (kg)	0.380*	0.264
MMO (mm)	0.355*	0.109

* : $p<0.05$

N-S-Ar, S-Ar-Go, UGA, FH-H6, and FH-H1 ($p<0.05$). Especially, S-Ar-Go showed a negative coefficient ($p<0.01$) and FH-H6, FH-H1 also showed a negative correlation ($p<0.05$).

Between the A value and lateral cephalometric measurements, the measurement of significant correlations are Go-Me, P-1 and IMPA ($p<0.05$). IMPA was negatively correlated (Table 4).

c) Correlation with clinical measurements

Weight and MMO (maximum bite opening) were correlated with P (Table 5).

DISCUSSION

There are many ways to evaluate the functional activity of masticatory muscles, which may play a role in producing specific facial skeletal patterns. Measuring maximum bite force has been one of them. In this study the maximum bite force was measured by simple and accurately calibrated devices to find its correlation with facial skeletal morphology. Especially, a variety of variables in the anteroposterior, vertical and transverse views were evaluated by statistical analysis to obtain some predictors of posterior and anterior maximum bite force.

Maximum bite force

In this study the maximum bite force value of the posterior teeth was 68.0±13.9kg in males and 55.6±10.5kg in females, while that of the anterior teeth was 8.4±4.9kg and 5.1±3.4kg respectively. The posterior value was greater than those of previous studies. Proffit[5] reported 31.0kg in male and 20.0kg in female. Dean[15] obtained the value of 50kg and 41kg respectively. In the study of Bakke et al.[16], the value of 53.3kg in males and 45kg in females was produced. In a sample of Korean males, Kim[20] and Lee[21] obtained the value of 53.2kg and 59.61 kg respectively. The first reason why a greater value of posterior maximum bite force was obtained in this study than in previous studies, seemed to be because the spring action of the force measuring device made the subjects less reluctant to bite maximally. Because the shape of the device in this study was a hollow H-type, the whole body acted as a spring by bending itself whenever the subjects bit on the bridge part of the device (Figure 5). Second, the rigidity of stainless steel reduced the loss of maximum bite force during measuring. Because Proffit[5] used Epoxy resin covering to protect the force measuring device, the spongy action of the resin absorbed some amount of maximum bite force.

As for the anterior value, Osborne[19], Kim[20] and Lee[21] reported the values 19.4 kg, 22.9 kg and 17.10 kg in males, respectively. For females, Osborne[19] obtained 5.1kg. The values in this study were smaller than those of others. This is because the vertical part of the device in this study contacted with the incisive papilla, perhaps making some subjects uncomfortable to bite maximally. Braun and his colleagues[3] proposed that a wide range of maximum bite force values was partially due to several mechanical factors : location of the measuring device, the kind of material, and the size, flexibility and dynamic responsiveness of the device.

From that respect, to take accurate measurements and reduce the recording errors and wide ranges, it could be of help to make several devices with step-wise flexibility and spring hardness by changing the thickness and length of the H-type device.

Measuring time

In this study no significant difference was found between maximum bite force in the morning and in the afternoon. In the past, there were few studies which compared the maximum bite force value of the morning with that of the afternoon. Some clinicians have studied the activity change of the masticatory muscles during the whole day. Miyamoto et al.[22] conducted a study to evaluate the biting function during the entire day in 30 young adults by measuring masseter muscle activity with a 24 hour electromyography (EMG) system. In their study, most of the high amplitude bursts of the masseter muscle appeared only during meals and a number of low amplitude bursts were observed during the entire day. However they didn't compare any values from different times – for example in the morning and afternoon perhaps because it was not easy to quantify the EMG data and there were large variations in force.

In this study, to rule out some influence of muscle fatigue, which can be brought on by daily activity, maximum bite force was measured twice – in the morning and in the afternoon. However no difference was shown between the two time periods, so it could be deduced that measuring time may have no influence on the maximum bite force. To investigate the exact reasons for this result more studies are needed.

Preferred side for mastication

There were hardly any previous studies on the difference between right and left posterior maximum bite force. Lee[21] compared maximum bite force on the left and right side of adult males and found no significant difference between them. In this study, no remarkable difference between right and left values could be found. A small difference was observed in males in the afternoon and among total subjects, but the reason for such difference could not be explained easily; possibly there was a large variation in maximum bite force production.

The effects of training and exercise on the strength and endurance of limb muscles has been investigated extensively but the response of the jaw muscles to exercise remains poorly known. Thompson and co-workers[23] measured maximum and submaximum voluntary bite forces and corresponding electromyographic activity in 28 young adults, randomly divided into exercise and non-exercise (control) groups. And he reported that increases in maximum bite force could be easily produced with training, but the actual strengthening of the jaw muscles was more difficult to achieve, which was verified by a recovery to the original level of increased EMG signals.

In this study the preferred side of each subject was decided in the initial history-taking procedure. Only 16 subjects made a definite reply that they had a tendency to masticate food on a preferred side. Although there was no significant difference between the means of maximum bite force of the two groups, among nine subjects of right preference and seven of left preference, PR of the right preference group (72.4kg) was larger than that of the left preference group (68.2kg), and PL of the left preference group (65.9kg) was larger than that of the opposite group (58.5kg). From these results, it seems that there might be a tendency for greater bite force value on the side used more frequently in daily life. If in the next study more subjects are investigated regarding the maximum bite force of the preferred chewing side, some significant results maybe drawn and its relation to facial asymmetry evaluated.

Gender

The gender difference of maximum bite force in this study was significant (Table 2) and coincided with the results of other studies. Osborne and Mao[19], in a small sample, measured incisive bite force and found the average to be 19.4kg in males and 5.1kg in females. In a study of orthognathic surgical patients prior to treatment, Dean and his colleagues[15] found the mean bite force in the molar region to be 50kg in males and 41.0 kg in females. Bakke et al.[16], in a large sample (63 females and 59 males), found the mean bite force in the molar region to be 53.3kg in males and 45.0kg in females. These studies imply that both anterior and posterior bite force are gender-related.

In this study, the mean maximum bite force in the molar region was 68.0kg in males and 55.6kg in females ; the difference between them was statistically significant ($p<0.05$). This was likely to be because the masticatory muscle size of men is usually greater than that of women. Brasel and Gruen[24] found gender differences in total muscle mass, males having slightly higher values than females. Bakke and co-workers[13], Kiliaridis and Kelebo[25], Raadsheer et al.[26] measured masseter muscle size with instruments, for example ultrasonography or anthropological calipers, and found that males had significantly thicker masseters than females ($p<0.01$). Sasaki and his colleagues[11], with MRI and strain gauges, studied the relationship between the size of human jaw muscles and the unilateral first molar bite force in 11 healthy adults, and concluded that the only significant predictors of unilateral molar bite force is the cross-sectional size of the masseter and medial pterygoid muscles. Therefore, it is natural that men with stronger masticatory muscles showed greater bite force than women.

Strong and Weak groups

By comparing the highest ten subjects and lowest ten subjects in respect to maximum bite force, we tried to find if the frontal cephalometric variables differed significantly for PR (maximum bite force of the posterior right molar) and PL (maximum bite force of the posterior left molar). Actually, there were no posteroanterior variables found to be of significant difference between the Strong and Weak groups. Only Zy-Ag (L) in PR showed a significant difference, but with it no general conclusions could be deduced.

But it could be said that the larger the measurement Zy-Ag on the left side was, the greater the right posterior maximum bite force was. As Proffit's study[5] showed, it seemed that the greater the vertical dimension in the left side of frontal view, the smaller the maximum bite force of the left posterior teeth. Perhaps the right vertical dimension was relatively smaller, thus resulting in a greater right posterior bite force. However as no variable for PL showed a significant difference, it was impossible to infer any conclusions. This was likely to be due to the initial selection criteria, in which only those of symmetric facial skeletal pattern were selected. Frontal symmetrical skeletal pattern made nearly no significant cephalometric difference between the two groups.

As for P (posterior maximum bite force), there were some significant differences in the lateral cephalometric measurements between the two groups. In the Strong group, S-Ar-Go (articular angle) was smaller. This is in agreement with Proffit's study[5]. It was concluded that the smaller the anterior facial height, the greater the bite force. As for MMO, its value was greater in the Strong group. So it could be used as a measure to pre-evaluate the masticatory muscular activity and maximum bite force.

Correlation of A (anterior maximum bite force) with cephalometric and clinical measurements

P had a positive correlation coefficient with the saddle angle, upper gonial angle, body weight, and MMO. It had a negative coefficient with S-Ar-Go (articular angle), FH-H1(°), and FH-H6(°). They were all lateral cephalometric measurements and had no correlation with posteroanterior cephalometric measurements. Among them, the articular angle, FH-H1, and FH-H6 represented a vertical dimension, and those values were smaller in the subjects of greater maximum bite force; these findings are in agreement with previous studies[5,6,7]. Finn[6], Proffit et al.[5], and Ringqvist[7] reported that maximum bite force of the molar region was greater in the subjects of smaller anterior vertical dimension.

The saddle angle was related to cranial flexure, and the upper gonial angle to mandibular anteroposterior position. According to van Spronsen and co-workers[27], a negative correlation was found between the flexure of the cranial base and the temporal muscle cross-section. In other words, larger saddle angle(decreased flexure) might be related to greater temporal muscle size. Considering the report, the size increase of temporal muscles - a kind of mandibular levator muscle - may contribute as a causative factor to increase maximum bite force.

Van Spronsen[28] stated that CT and MRI cross-sectional areas of the masseter and medial pterygoid muscle showed highly positive and significant correlations with maximal voluntary bite force. Sasaki[11] reported that the jaw muscle's cross-sectional size alone seems to explain most of the variation in bite force. Raadsheer[29] advocated that bite force magnitude depended on the cross-sectional size of the jaw muscles.

Controversial is the relationship between muscular cross-sectional size and bite force.

According to Hannam's study[30] there was no significant correlation between muscle cross-sectional areas and their respective putative bite forces, and there was no simple relationship between the tension-generating capacity of the muscles and their mechanical efficiency as described by their spatial arrangement. He stated that in modern human population there are many combinations of biomechanically relevant variables.

Larger upper gonial angle usually represented more prognathic mandible and was related to greater bite force in this study. The exact reason could not be inferred. About this topic, more study of mechanical leverage systems in the mandible will be needed.

Generally the weight of the skeletal muscle, including masticatory muscle, is known to be about 40% of whole body weight[1]. Thus, body weight might be indirectly related to masticatory muscular weight or its activity, and possibly determined the posterior maximum bite force together with other factors. MMO representing masticatory muscular length also influenced maximum bite force. These two variables represented muscular contracting ability. The muscular weight and MMO were related, respectively, to the amount and length of mouth-closing muscle fibers. Therefore, body weight and MMO were proportionate to masticatory muscular force or maximum bite force in this study. In future studies, if a body composition analyzer is used to exclude the fat and all physical material other than muscles, a more definite conclusion could be drawn.

Correlation of A (anterior maximum bite force) with cephalometric and clinical measurements

Anterior maximum bite force showed a positive correlation with body length (Go-Me) and P-1 (anterior maxillary dental height). It did have a negative correlation with IMPA.

Considering only these factors, it was not possible to picture the exact facial skeletal pattern.

What was discovered is that for the mandible, a prognathic tendency with lingually inclined lower incisors produced greater anterior bite force, and for the maxilla a larger anterior maxillary dental height had the same effect.

With only this information alone no definite rules can be made. As cited earlier, the maximum bite force measuring device irritated the incisive papilla of the subjects' palate and the resulting force values were smaller than in other previous studies. As for anterior maximum bite force, future studies will be needed after improving the force measuring device.

CONCLUSION

The purpose of this study was to measure the value of maximum bite force and to find if anteroposterior, vertical, and transverse facial skeletal factors in cephalometric measurements correlated with it.

From among the dental students at the dental college of Seoul National University, we selected 26 male and 14 female students for a total of 40 subjects. With a bite force measuring device using strain gauges, we measured maximum bite force of the right and left first molar and the anterior teeth in the morning and afternoon. After taking lateral and posteroanterior cephalograms, we measured 50 and 19 measurements, respectively. The results of our statistical analysis are as follows :

1. The maximum bite force at the first molars was 68.0 ±13.9kg in males and 55.6±10.5kg in females ($p < 0.05$) while those at the anterior teeth were 8.4± 4.9kg and 5.1±3.4kg respectively ($p < 0.05$).
2. There was no significant difference between the force obtained in the morning and that measured in the afternoon.
3. Some tendency for a greater value of maximum bite force on the preferred side was observed but not found to be statistically significant ($p > 0.05$).
4. In each gender group, the right and left first molar maximum bite force was not significantly different. But among the total 40 samples, maximum bite force was greater at the right first molar than at the left first molar ($p < 0.05$).
5. Significant differences were observed between the strong bite force group and the weak bite force group in some cephalometric and other measurements ($p < 0.05$). N-S-Ar, S-Ar-Go, FH-H1, IMPA and MMO showed a significant difference in posterior maximum bite force (P). N-S-Ar and FH-H1 also showed a significant difference in anterior maximum bite force (A).
6. Several cephalometric variables showed some correlation with maximum bite force ($p < 0.05$). N-S-Ar, S-Ar-Go, UGA, FH-H6, FH-H1, body weight and MMO were significantly correlated with posterior maximum bite force (P). Go-Me, P-1 and IMPA were significantly correlated with anterior maximum bite force (A).

There was some tendency for a shorter anterior facial height to result in a greater maximum bite force at the first molars. The maximum bite force at the anterior teeth was greater as the mandibular body length and anterior maxillary dental height were greater, and as the mandibular incisors inclined more lingually.

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국문초록

최대 교합력과 안면 골격 형태에 관한 연구

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본 연구의 목적은 최대 교합력을 측정하여 전후방적,수직적 및 횡적인 안면 골격 요소들과의 관련성을 연구하는 것이다. 연구 대상으로 남녀 대학생들을 각각 26명과 14명씩 총 40명을 선택하였다. 본 연구를 위하여 개발된 strain gauge를 이용한 장치로 좌우 제1대구치와 전치부에서 최대 교합력을 측정하였다. 두부방사선 사진을 촬영하여 여러 계측 항목들을 측정하고, 통계분석을 시행하여 다음의 결과를 얻었다.

1. 제1대구치 최대 교합력은 남자는 68.0±13.9kg, 여자는 55.6±10.5kg 이었고 ($p<0.05$), 전치에서 남자는 8.4±4.9kg, 여자는 5.1±3.4kg이었다($p<0.05$).
2. 저작을 선호하는 쪽의 교합력이 더 크게 나타나는 경향을 보였지만 통계적으로 유의한 차이는 없었다($p>0.05$).
3. 최대교합력이 강한 군과 약한군 간에 여러 항목들에서 유의한 차이를 나타내었는데, 제1대구치 최대 교합력에 대해서는 N-S-Ar, S-Ar-Go, FH-H1, IMPA 그리고 MMO 항목들이 유의한 차이를 보였고, 전치부 최대 교합력에 대해서는 N-S-Ar 과 FH-H1 항목들이 유의한 차이를 보였다($p<0.05$).
4. 최대 교합력과 유의성 있는 상관 관계를 보인 항목들은 제1대구치 최대 교합력에 대해서는 N-S-Ar, S-Ar-Go, UGA, FH-H6, FH-H1, body weight 그리고 MMO, 전치부 최대 교합력에 대해서는 Go-Me, P-1 그리고 IMPA 등이었다($p<0.05$).

이상의 결과들을 종합해 볼 때, 제1대구치의 최대 교합력은 수직 전안면 고경이 짧을수록 증가하였다. 전치의 최대 교합력은 하악체 길이가 길수록, 상악 전방 치조부 고경이 클수록, 그리고 하악 절치들이 설측으로 경사져 있을수록 증가하였다($p<0.05$).

주요 단어 : 최대교합력, 안면 골격 형태, Strain gauge