広大歯誌 34, 60-71, 2002.

Correlation between Maximum Bite Force and Craniofacial Morphology of Young Adults in Indonesia

Sondang Pintauli

(Received for publication, January 24, 2002)

INTRODUCTION

The potential influence of bite force on the development of the masticatory complex has been reported[1-4]. Many researchers focused on bite force with regard to the magnitude and distribution on the dental arch[5-11]. Previous studies provided variable results on maximum bite force, and the variability may be due to a lack in the control of such variables to affect bite force measurements as age[2,12-14], sex[1,13-15], physical characteristics including body height and weight[1,15,16], the number of teeth present[7,14], diverse population and different measuring instruments and techniques[3,17,18].

A number of appliances for bite force measurement have been reported including strain gauge transducer[1,8,13,15,19-23], and biting fork[2,12,16] or bite force dynamometer[3,17]. Recently, an occlusal diagnostic system called the Dental Prescale System® (Fuji Film Co., Japan) was developed. As compared to the appliances described above, the Dental Prescale is more flexible, permits natural occlusion and prevents mandibular displacement during clenching[9]. The reproducibility of this system has been confirmed for the use in complete dentitions[10,11] and complete denture patients[9] as well as in implant supported fixed cantilever prostheses[24] and hemi-maxillectomy patients[25].

Many studies reported on the relationship between bite force and the craniofacial morphology. Nanda *et al.*[26] made an investigation on the influence of masseter muscle function on the shape and structure of bone. They reported that the bone structures depend on the muscle activity. Ringqvist[3] studied the bite force and its relation to dimensions of craniofacial skeleton in 29 healthy females aged 19–23 years and reported that the maximum bite force was associated with large maxilla and mandible, and small gonial angle. Ingervall and Helkimo[4] found a straighter cranial base, a deeper upper face and a more curved mandible in the strong bite force group. Ingervall and Thilander[27] showed that persons with great bite force have a facial profile described as rectangular. Proffit *et al.*[21] reported that long face individuals exhibited significantly less bite force during maximum clenching than individuals with standard vertical facial dimensions. These studies described above, however, were carried out in racial groups of Caucasians. Studies on Asians are few[28-30], and so far, no studies have been undertaken for Indonesians.

The distribution of occlusal load has been studied in various aspects. Harmonious balance of the occlusal load was reported to be important not only for satisfactory artificial dentition but also for maintaining healthy oral function[31]. Maness *et al.*[32] and Boening and Walter[33] evaluated the balance of occlusal load between right and left sides of the dental arch. Olivieri *et al.*[34] described a measuring method for the occlusal load center (OLC) in complete denture patients by T-scan system and Shinogaya *et al.*[5] measured the position of the OLC in complete dentition by the Dental Prescale System. They suggested that the analysis of the OLC might be meaningful for evaluating the occlusal function since the position of the OLC was not affected by race, gender and age.

The purpose of this study was to evaluate:

1. The relationship between bite force and craniofacial morphology.

Department of Prosthetic Dentistry, Division of Cervico-Gnathostomatology, Graduate School of Biomedical Sciences, Hiroshima University (Chief: Prof. Taizo Hamada). A part of this report was presented at the International Association for Dental Research, IADR 79th General Session (June 2001, Chiba, Japan).

2. The relationship between the OLC and craniofacial morphology.

MATERIALS AND METHODS

Subjects

Sixty-four female dental students at North Sumatera University in Medan, Indonesia, with the average age of 21.9 years were selected as subjects. The subjects were selected on the basis of the following criteria: 1) no large caries cavities; 2) no missing teeth; 3) no occlusal contacts at the third molar; 4) no signs or symptoms of the craniomandibular disorder; and 5) no severe periodontal diseases.

All the subjects participated in this study after providing informed consents approved by the Ethics Committee in the Faculty of Dentistry, University of North Sumatera, Medan. The examination was comprised of bite force measurements, measurements of craniofacial morphology and physical characteristics (body height and weight).

Bite force measurements

Maximum bite force was measured by a Dental Prescale System® (Fuji Film Co., Japan), consisting of pressure sensitive sheets (Dental Prescale) and an analyzing computer (Occluzer) (Figure 1). Before recording, each subject was seated at the upright position, in parallel with the Campher's plane and instructed to bite properly to exert and produce the maximum clenching. Dental Prescale sheet (50H, type R) was placed between the upper and lower dentitions and the subjects were instructed to bite at the intercuspal position for 2–3 seconds. On occlusion, the midline of the Dental Prescale was matched with that of the subject's dental arch.

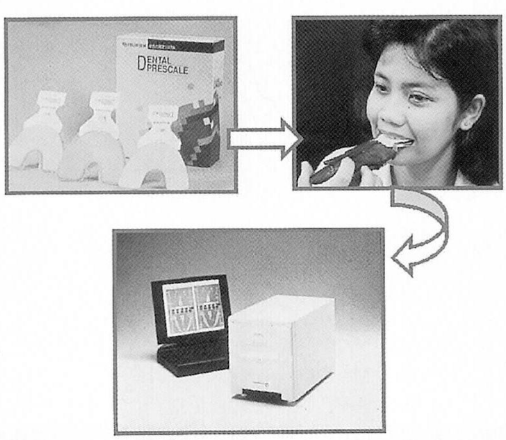

Figure 1 Schematic drawing of bite force measurements.

Occlusal load center measurement

Position of the OLC was measured as described by Shinogaya and Matsumoto[5]. A picture of the occlusal view of maxillary cast obtained from each subject was taken by a digital camera (Casio QV-2400VX) in the perpendicular direction to the occlusal plane. The result of 'balance data mode', one of the data display function of Occluzer, was superimposed on a digitized image of the maxillary dental cast (Figure 2). The relative location of the OLC was then calculated from the size of the dental arches antero-posteriorly and right-left (Figure 3).

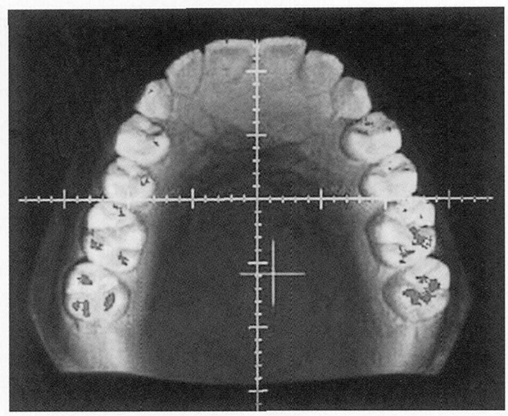

Figure 2 The image file of the scanned data superimposed to the image file of the maxillary dental arch.

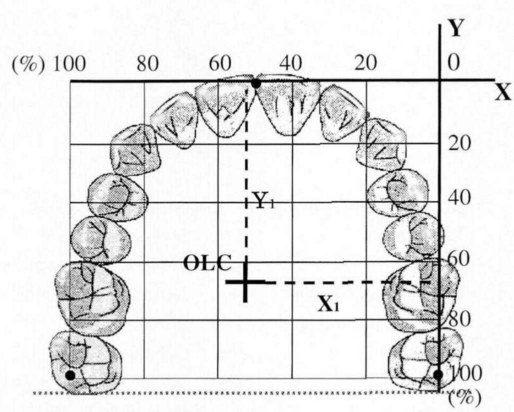

Figure 3 Schematic illustration of the OLC measurement.

Morphometric analysis with cephalograms for the craniofacial skeleton

Craniofacial morphology measurement was obtained from conventional lateral cephalogram. Each lateral cephalogram was traced on acetate paper and 16 landmarks were defined in a X-Y coordinate system (Figure 4). The X and Y coordinates were digitized and the following 25 measurement items were executed by a personal computer (Macintosh Quadra 800, Apple Computer Inc., Cupertino, USA) (Figures 5 and 6). The twenty-five cephalometric variables (11 angular and 14 linear items) used were listed in Tables 1 and 2, respectively.

Data analysis and statistical treatments

The mean and standard deviation were calculated for each of the variables measured. The relationship between the twenty-five cephalometric items and bite force was analyzed by means of a simple correlation analysis at the 95% confidence level.

For multivariable analysis, all the measurement items were first categorized into ten subgroups by

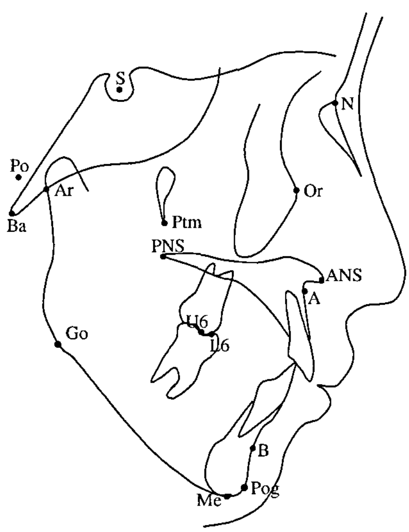

Figure 4 Landmarks for cephalometric analysis.

S	: Sella turcica	Ptm	: Pterygomaxillare
N	: Nasion	PNS	: Posterior nasal spine
A	: Point A (subspinale)	ANS	: Anterior nasal spine
B	: Point B (supramentale)	Po	: Porion
Pog	: Pogonion	Or	: Orbitale
Me	: Menton	U6	: Mesiobuccal of upper first molar
Go	: Gonion	L6	: Mesiobuccal of lower first molar
Ba	: Basion		
Ar	: Articulare		

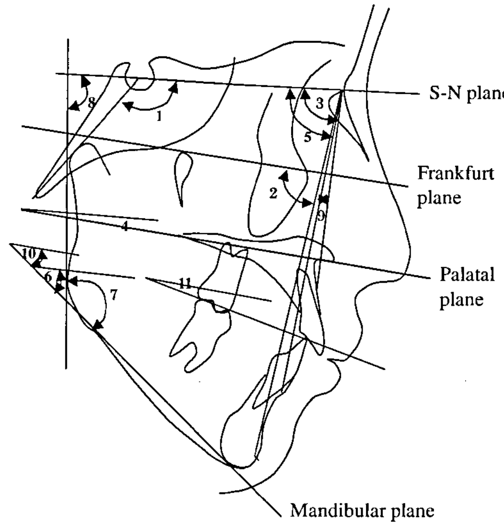

Figure 5 Angular measurement items.

1. NSBa	7. Go A
2. Facial A	8. Rp-SN
3. SNA	9. ANB
4. PP-SN	10. PP-Mp
5. SNB	11. Occ.pl
6. Mp-SN	

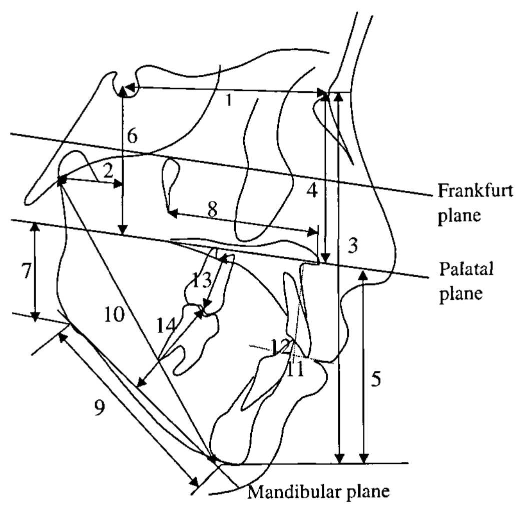

Figure 6 Linear measurement items.

1. S-N	8. Ptm-ANS/PP
2. S-Ar/FH	9. Go-Me
3. N-Me	10. Ar-Me
4. N/PP	11. OJ (PP)
5. Me/PP	12. OB (PP)
6. S/PP	13. U6/PP
7. Go/PP	14. L6/Mp

Table 1 Angular measurement items

NSBa	shape of cranial base
Facial A	antero-posterior position of the mandible evaluated by N-Pog plane relative to FH plane
SNA	antero-posterior position of the maxilla relative to the anterior cranial base
PP-SN	palatal plane angle
SNB	antero-posterior position of the mandible relative to the anterior cranial base
Mp-SN	mandibular plane angle
Go A	angle between the mandibular and ramus planes
Rp-SN	ramus plane angle
ANB	antero-posterior relation between maxilla and mandible
PP-Mp	relative inclination of maxilla and mandible
Occ.pl	bisected occlusal plane related to SN plane

Table 2 Linear measurement items

S-N	antero-posterior length of the anterior cranial base
S-Ar/FH	antero-posterior length of the posterior cranial base
N-Me	total anterior facial height
N/PP	upper anterior facial height
Me/PP	lower anterior facial height
S/PP	upper posterior facial height
Go/PP	lower posterior facial height
Ptm-ANS/PP	antero-posterior size of the maxilla
Go-Me	length of mandibular corpus
Ar-Me	effective length of the mandible
OJ(PP)	horizontal distance between incisal edge registered on the palatal plane
OB(PP)	vertical distance between incisal edge registered on the palatal plane
U6/PP	distance from upper molar to palatal plane
L6/Mp	distance from lower molar to mandibular plane

means of a cluster analysis and the representative measurement items were selected in each subgroup (Figure 7). Secondly, a stepwise multiple regression analysis was performed to calculate the influence of ten items on the occlusal bite force and to determine whether a higher explanatory value could be obtained with ten items selected. The coefficient of determination (r^2) which indicates the explanatory values of the regression model was calculated.

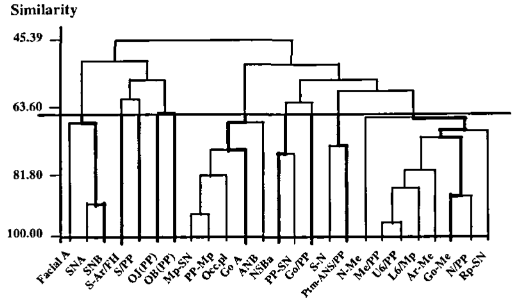

Figure 7 Dendogram showing the amalgamation step.

To evaluate the relation between the position of occlusal load center and craniofacial morphology, simple correlation analysis was performed.

For all the statistical analyses, a software package of SPSS (SPSS Inc., 1999) was used.

RESULTS

The maximum bite force was obtained. The mean was 806.23 N with standard deviation of 324.83 N. Table 3 shows the means and standard deviations of the twenty-five cephalometric measurement items and the physical characteristics. Both body height and weight showed lower correlation coefficients, however the height exhibited a significant correlation with the maximum bite force (Figure 8).

Relationship between bite force and craniofacial morphology

Out of the twenty-five cephalometric measurement items, nine variables showed significant correlations (Table 4). Bite force exhibited significant positive correlations with variables representing the length of posterior cranial base (var. 13), and the vertical and horizontal sizes of the maxilla (var. 19, 24) and mandible (var. 18, 20, 21) (Figure 9). Furthermore, the significant negative correlations were found with variables representing mandibular plane angle (var. 6), gonial angle (var. 7) and palatal plane/mandibular plane (var. 10) (Figure 10).

A stepwise regression analysis was applied to consider the entire set of variables correlated with the maximum bite force. The resultant r^2 value was 0.55 with the correlation coefficient of 0.72. This shows that the maximum bite force can be described by

Table 3 Mean values and standard deviations for the variables recorded

Variables	Mean	SD
Force	806.20	324.84
Height	158.00	5.12
Weight	48.85	5.20
NSBa	131.40	4.73
Facial A	87.56	3.11
SNA	83.74	3.48
PP-SN	7.60	2.84
SNB	80.73	3.24
Mp-SN	30.93	5.43
Go A	118.04	6.24
Rp-SN	92.91	5.25
ANB	3.01	2.16
PP-Mp	23.35	5.21
Occ.pl	15.35	4.46
S-N	68.25	3.04
S-Ar/FH	17.42	3.12
N-Me	121.43	6.58
N/PP	54.30	2.88
Me/PP	66.42	4.81
S/PP	45.29	3.27
Go/PP	34.55	4.37
Ptm-ANS/PP	52.34	2.55
Go-Me	73.26	4.36
Ar-Me	108.42	4.93
OJ (PP)	2.87	0.92
OB (PP)	2.56	1.12
U6/PP	23.93	2.47
L6/Mp	32.26	2.27

(For abbreviations, see Fig. 4 and footnotes to Tables 1 and 2.)

Table 4 Relationship between cephalometric items and bite force magnitude by means of simple correlation analysis

No	Variable	r	Significance
1.	NSBa	+ 0.11	n.s.
2.	Facial A	− 0.01	n.s.
3.	SNA	+ 0.02	n.s.
4.	PP-SN	+ 0.20	n.s.
5.	SNB	+ 0.04	n.s.
6.	Mp-SN	− 0.29	*
7.	Go A	− 0.45	**
8.	Rp-SN	+ 0.22	n.s.
9.	ANB	− 0.03	n.s.
10.	PP-Mp	− 0.41	**
11.	Occ.pl	− 0.18	n.s.
12.	SN	+ 0.03	n.s.
13.	S-Ar/FH	+ 0.33	**
14.	N-Me	+ 0.10	n.s.
15.	N/PP	+ 0.14	n.s.
16.	Me/PP	+ 0.09	n.s.
17.	S/PP	− 0.08	n.s.
18.	Go/PP	+ 0.44	**
19.	Ptm-ANS/PP	+ 0.31	**
20.	Go-Me	+ 0.38	**
21.	Ar-Me	+ 0.31	**
22.	OJ (PP)	+ 0.23	n.s.
23.	OB(PP)	− 0.04	n.s.
24.	U6/PP	+ 0.28	*
25.	L6/Mp	+ 0.18	n.s.

$*p < 0.05$ $**p < 0.01$ n.s.: not significant
+ positive relation − negative relation

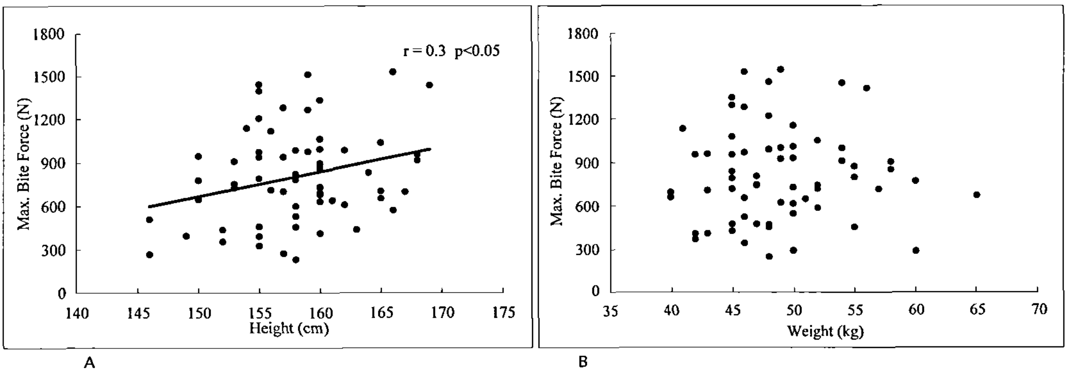

Figure 8 Scatter diagram showing relationship between maximum bite force and physical characteristics. A. Height B. Weight

craniofacial morphology as much as 55% by use of four variables; lower posterior facial height (Go/PP), antero-posterior size of the maxilla (Ptm-ANS/PP), gonial angle (Go A), and antero-posterior length of the posterior cranial base (S-Ar/FH) (Figure 11). Beta-weights indicate that the gonial angle was the main contributor

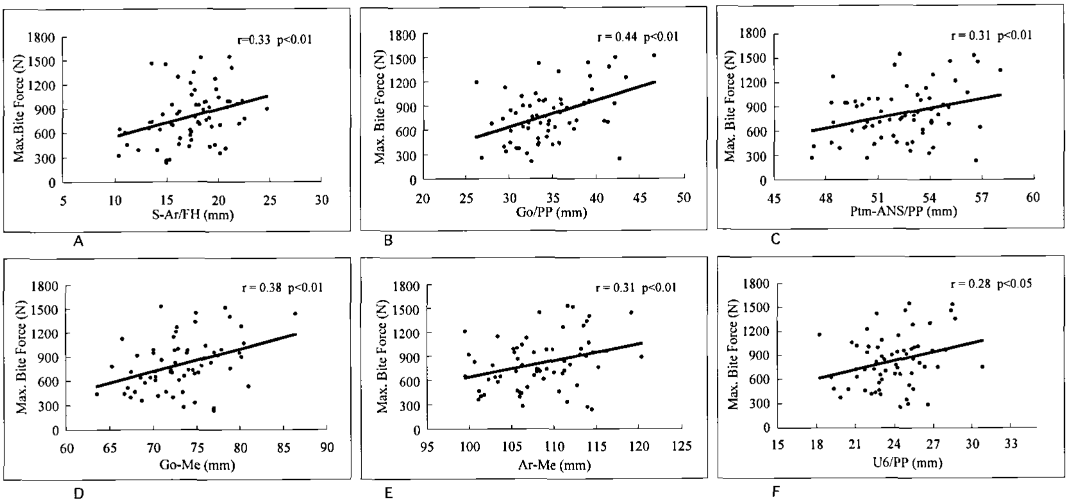

Figure 9 Scatter diagram showing positive correlation between maximum bite force and cephalometric variables.

A. S-Ar/FH D. Go-Me
B. Go/PP E. Ar-Me
C. Ptm-ANS/PP F. U6/PP

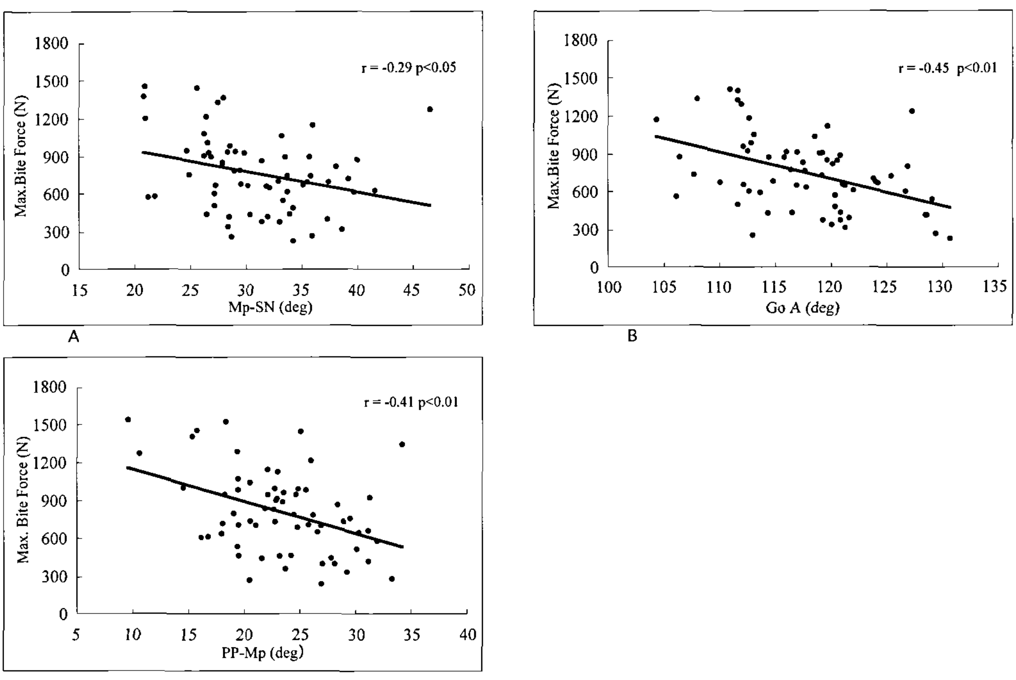

Figure 10 Scatter diagram showing negative correlation between maximum bite force and cephalometric variables.

A. Mp-SN
B. Go A
C. PP-Mp

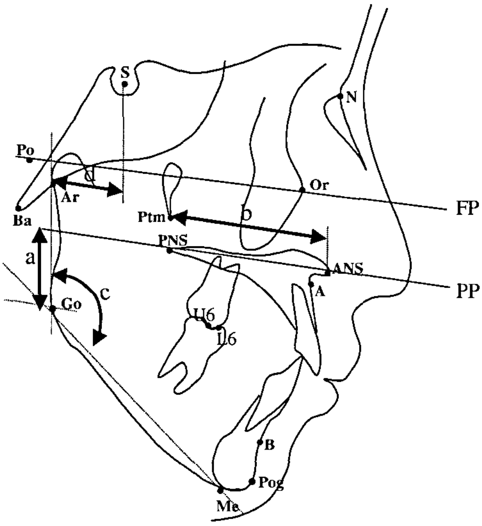

Figure 11 Four cephalometric variables closely related to the maximum bite force.
a. lower posterior facial height
b. antero-posterior size of the maxilla
c. gonial angle
d. antero-posterior length of the posterior cranial base.

Table 5 Values obtained by means of stepwise multiple regression analysis between the ten cephalometric variables and maximum bite force

Variable	Beta (β)	p
Go/PP	+ 0.21	< 0.05
Ptm-ANS/PP	+ 0.43	< 0.001
Go A	− 0.47	< 0.001
S-Ar/FH	+ 0.36	< 0.001

(Table 5) followed by antero-posterior size of the maxilla, antero-posterior length of the posterior cranial base and lower posterior facial height. The gonial angle has a negative relation, i.e, larger bite force coincided with smaller gonial angle. Other three variables; lower posterior facial height, antero-posterior size of the maxilla and antero-posterior length of the posterior cranial base have positive relations, i.e, larger bite force coincided with longer posterior facial height, larger maxilla and longer posterior cranial base.

To explain these relationship, the following predicted equation was obtained:

Maximum Bite Force (MBF) =

$$-379.77 + 15.62\,X_1 + 55.11\,X_2 - 24.44\,X_3 + 37.14\,X_4$$

where: X_1: Go/pp (mm) X_3: Go A (degree)
X_2: Ptm-ANA/PP (mm) X_4: S-Ar/FH (mm)

Relationship between the OLC and craniofacial morphology

The relative positions of the OLC are shown in Table 6. The OLC was located at 73.8 ± 7.0% (antero-posteriorly) and 50.4% ± 3.6% (right-left). It corresponded to the center of upper first molar (antero-posterior) and midline of the dental arch (right-left). For the relation to the twenty-five cephalometric items, the antero-posterior position exhibited a significant negative correlation with gonial angle. It implies that the occlusal load center was located more posteriorly as the gonial angle became smaller. The scattergram to show the linear relationship is presented in Figure 12.

Table 6 Measurement of the relative position of the occlusal load center in the antero-posterior and right-left directions

Position	Mean (%)	SD	Median
Antero-posterior	73.8	7.0	75.5
Right-left	50.4	3.6	50.1

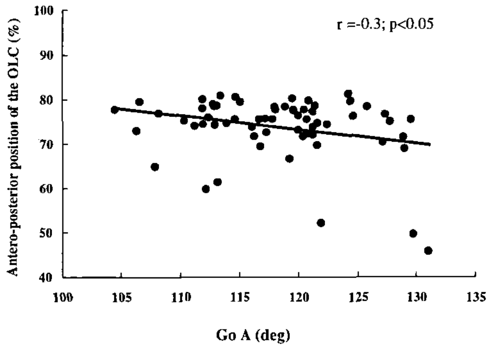

Figure 12 Scatter diagram showing linear relationship between the antero-posterior position of the OLC and gonial angle.

DISCUSSION

In previous studies, maximum bite force was measured using a metal material such as transducer, biting fork or bite force dynamometer with various sizes and thicknesses. The thickness (4–16mm) was one of the reasons for the unstable position. Moreover, subjects might be reluctant to bite maximally because of fear to tooth damage or pain. In this study, maximum bite force was measured using the Dental Prescale System, which consists of pressure sensitive sheet (Dental Prescale) and a computer for analysis (Occluzer). Suzuki *et al.*[9] reported that Dental Prescale System has some advantages as follows: (1) the thin material induces only a small change in the occlusal vertical dimension, and makes it available to measure at a position near the intercuspal position; (2) it is not necessary to prepare special measurement equipment; (3) many patients may be examined for a short time; (4) recording storage, even for an extended period, is simplified; and (5) it is easy to explain the treatment to patients by using dental images. In addition, the clinical usefulness of this system was documented in terms of quantitative evaluation for occlusal load distribution[9,25].

In the present study, the mean value of maximum bite force was greater than that obtained by previous studies. Bakke *et al.*[35] examining a large sample (63 females and 59 males), found a mean bite force of 522 N in males and 441 N in females. Dean *et al.*[36] found the mean values at the molar region to be 490 N in males and 402 N in females. Braun *et al.*[1] reported a mean value of 814 N for males and 615 N for females. This variability might be due to the differences of measuring point and appliances used.

Several authors found positive correlation between bite force and growth variables such as age and body height and weight. It is assumed that persons with larger body build, size and/or weight may exhibit a greater bite force. Kiliriadis *et al.*[16] noticed a correlation between body height and the mean amplitude of the maximum bite force. Ringqvist[3] found significant correlation between body height and maximum molar bite force in female, whereas Braun *et al.*[1] and Linderholm and Wennström[17] did not. The present study agrees with an earlier study by Ringqvist that bite force significantly positively correlated to height. It is probably because Ringqvist and our study were made on the similar type of subjects, a group of young adult females.

Relationship between bite force and craniofacial morphology

Since the activity of masticatory muscle occurs throughout the day[37,38], previous study suggested that the jaw muscle activity at rest was correlated with craniofacial morphology[38]. On the other hand, Nasedkin[39] reported that muscle activity in nocturnal clenching was sometimes six times greater than that in voluntary maximum clenching. The present study focused on the relation between maximum clenching and craniofacial morphology.

Among the twenty-five cephalometric measurements evaluated by means of simple correlation analysis, nine cephalometric items were statistically significant to maximum bite force; Mp-SN, Go A, PP-Mp, S-Ar/FH, Go/PP, Ptm-ANS/PP, Go-Me, Ar-Me, and U6/PP. The potential correlation of maximum bite force to various cephalometric measurements has been reported by many researchers. Most of these studies, however were conducted among Caucasians[3,15,19,20,22,36,40,41] and some studies in Mongoloid[28–30]. Based on racial classifications by Molnar[42] there were three kinds of races, Caucasoid, Mongoloid and Negroid. Indonesian, a variety of the Malay-Indonesian ethnic, belongs to the Mongoloid group with characteristics of short and slender stature, black hair and relatively dark skin pigmentation[43].

A highly significant negative correlation was found between gonial angle and maximum bite force (r = 0.45). All Indonesians are called Orientals[44] and Enlow[45], reported that the facial feature of Oriental tends to be brachycephalic or square jaw. This facial feature was characterized by relatively smaller gonial angle[21].

The size of mandible, denoted by Go-Me and Ar-Me, showed significant correlation with maximum bite force with a positive correlation. This finding supports the findings of the study by Ringqvist[3] and Throckmorton *et al.*[23] who found that size and inclination of mandible were strongly correlated to maximum bite force.

Braun *et al.*[1] and Ringqvist[3] reported that mandibular plane angle and mandibular/palatal plane angle correlated significantly to maximum bite force with negative correlation. This finding supports the widely accepted concept that long face subjects have diminished force[15,21]. In the present study, similar findings were observed.

Ingervall and Helkimo[4] found that shape of the cranial base, denoted by NSBa and S-Ba (the distance between sella and basion) were significantly larger in the group with strong bite force. In this study, the antero-posterior length of the posterior cranial base, denoted by S-Ar/FH positively correlated with maximum bite force. This finding suggests that shape and size of the cranial base were correlated with maximum bite force.

Lower posterior facial height, denoted by Go/PP correlated to maximum bite force with a positively significant correlation. This finding supported the study of Weijs and Hillen[46] who reported that during maximal bite, the cross sectional areas of the lateral pterygoid muscles was positively correlated with lower facial height. It is widely accepted there was interaction among maximum bite force, jaw muscle size and craniofacial morphology[22,38].

In this study, the positive linear relationship was found between the antero-posterior size of the maxilla denoted by Ptm-ANS/PP and maximum bite force. This finding supported the findings by Ringqvist[3] and Ingervall and Helkimo[4] who reported that higher bite force was associated with a broader maxilla.

The correlation of maximum bite force and the posterior dentoalveolar heights, denoted by U6/PP was found in this study. Though Braun *et al.*[19] found a similar finding however, they reported this as unexpected results. Throckmorton *et al.*[23] have shown a positive correlation between maximum bite force and dentoalveolar heights as one of the nine contributing variables representing the size of mandible.

By means of stepwise multiple regression analysis, the outcome indicated that 55% of maximum bite force could be explained by four cephalometric items, lower posterior facial height (Go/PP), antero-posterior size of the maxilla (Ptm-ANS/PP), gonial angle (Go A) and antero-posterior length of the posterior cranial base (S-Ar/FH). The effect of intercorrelation among those variances could explain this condition. A larger bite force implies with greater posterior facial height, smaller gonial angle, larger maxilla and straighter posterior length of the cranial base. In white population, it was accepted that subjects exhibiting a short face or square jaw or brachycephalic tends to bite with greater force[3,4,21]. The outcome of our study indicated that this findings generally supports those found in racial groups of Caucasians.

Relationship between the OLC and craniofacial morphology

Equilibrium of occlusal load distribution is one of the most important factors for the stability of the dentitions and healthy stomatognathic function[7,31,34]. To this end, it is necessary to consider the location of the OLC, a balancing center of the occlusal load distributed over the maxillary dentition[31]. Olivieri *et al.*[34] reported the position of center of force target was approximately 31 mm distal to the incisal plane. In the present study, the relative antero-posterior position of OLC was 73.8 ± 7.0% and the relative right-left position of the OLC was 50.4 ± 3.6%. This finding proposed the relative position of the OLC for Indonesians in accordance with the previous study by Shinogaya *et al.*[31] who studied the relative locations of the OLC in Japanese and Danish. They reported the location of the OLC is approximately the same in different racial groups and concluded that location of the OLC might not be affected by racial differences, gender and age. For these reasons, analysis of the OLC was considered as an important method for making comprehensive evaluation of occlusal function.

With regard to the relation between craniofacial morphology and the position of the OLC, the OLC was located more posteriorly as the gonial angle became smaller. Throckmorton *et al.*[47] evaluated the biomechanical advantage of the masticating muscles including masseter muscle and temporalis muscle and reported that there was a close relationship between the direction of the muscle forces and gonial angle. These findings suggest that occlusal force distribution was correlated with craniofacial morphology.

CONCLUSIONS

The present study was conducted to evaluate the relationship between maximum bite force and craniofacial morphology. Sixty-four Indonesian female dental students aged 19–27 years with normal occlusion were served as the subjects. The Dental Prescale System was used to measure the maximum bite force using a pressure sensitive sheets while craniofacial morphology measurements were determined from conventional lateral radiogram. The antero-posterior and right-left position of the occlusal load center, the OLC were measured also. Stepwise multiple regression analysis was performed to evaluate the relationship between bite force and craniofacial morphology while correlation analysis was used to evaluate the antero-posterior position of the OLC related to craniofacial morphology.

As a conclusion, this study suggests that among

Indonesians, maximum bite force could be explained by craniofacial morphology as it was found in Caucasians. In addition, we have proposed a clinical standard of the OLC for the comprehensive evaluation of occlusion.

ACKNOWLEDGEMENT

I would like to express my most sincere gratitude and appreciation to Prof. Taizo HAMADA, Chairman and Head of the Department of Prosthetic Dentistry for his kind support, wise advice and encouragement during my study at Hiroshima University. Sincere gratitude is also extended to Prof. Kazuo TANNE, Chairman of the Department of Orthodontics and Dean of Faculty of Dentistry, Hiroshima University, for his many valuable suggestions and criticism in developing my manuscript. I extended my gratitude also to Prof. Katsuyuki KOZAI for many kind of suggestions to my manuscript. I am grateful to Dr. Eiji TANAKA, Associate Prof. of the Department of Orthodontics for his sincere support and kind cooperation.

My special thanks and heartiest gratitude is due to Dr. Hiroshi KUMAGAI for his encouragement and special care throughout the period of my PhD course. Sincere appreciations are extended to him for his extraordinary guidance to complete this manuscript. Thanks are also due to all members of Department of Prosthetic Dentistry for their friendly attitude and kind cooperation at different aspects of this research work.

REFERENCES

1) Braun, S., Bantleon, H.P., Hnat, W.P., Freudenthaler, J.W., Marcotte, M.R. and Johnson, B.E.: A study of bite force, part 1. Relationship to various physical characteristics. *Angle Orthod.* **65**, 367–372, 1995.
2) Helkimo, E., Carlsson, G.E. and Helkimo, M.: Bite force and state dentition. *Acta Odontol. Scand.* **35**, 297–303, 1977.
3) Ringqvist, M.: Isometric bite force and its relation to dimensions of the facial skeleton. *Acta Odontol. Scand.* **31**, 35–42, 1973.
4) Ingervall, B. and Helkimo, E.: Masticatory muscle force and facial morphology in man. *Arch. Oral Biol.* **23**, 203–206, 1978.
5) Shinogaya, T. and Matsumoto, M.: Evaluation of prosthodontic treatment by occlusal force distribution: a methodological study. *Eur. J. Prosthodont. Res. Dent.* **6**, 121–125, 1998.
6) Shinogaya, T., Sodeyama, A. and Matsumoto, M.: Bite force and occlusal load distribution in normal complete dentitions of young adults. *Eur. J. Prosthodont. Res. Dent.* **7**, 65–70, 1999.
7) Hidaka, O., Iwasaki, M., Saito, M. and Morimoto, T.: Influence of clenching intensity on bite force balance, occlusal contact area, and average bite pressure. *J. Dent. Res.* **78**, 1336–1344, 1999.
8) Kikuchi, M., Korioth, T.W.P. and Hannam, A.G.: The association among occlusal contacts, clenching effort, and bite force distribution in man. *J. Dent. Res.* **76**, 1316–1325, 1997.
9) Suzuki, T., Kumagai, H., Watanabe, T., Uchida, T. and Nagao, M.: Evaluation of complete denture occlusal contacts using pressure-sensitive sheets. *Int. J. Prosthodont.* **10**, 386–391, 1997.
10) Kumagai, H., Suzuki, T., Hamada, T., Sondang, P., Fujitani, M. and Nikawa, H.: Occlusal force distribution on the dental arch during various levels of clenching. *J. Oral Rehabil.* **26**, 932–935, 1999.
11) Watanabe, M., Hattori, Y. and Satoh, C.: Bite force distribution on the dental arch in normal dentitions. (Morimoto, T., Matsuya, T and Takada, K., Eds.). In Brain and oral functions. Elsevier Science. Tokyo, pp. 399–403, 1995.
12) Fogle, L.L. and Glaros, A.G.: Contribution of facial morphology, age and gender to EMG activity under biting and resting condition. A canonical correlation analysis. *J. Dent. Res.* **74**, 1496–1500, 1995.
13) Garner, L.D. and Kotwal, N.S.: Correlation study of incisive biting forces with age, sex and anterior occlusion. *J. Dent. Res.* **52**, 698–702, 1973.
14) Miyaura, K., Matsuka, Y., Morita, M., Yamashita, A. and Watanabe, T.: Comparison of biting forces in different age and sex groups: a study of biting efficiency with mobile and non-mobile teeth. *J. Oral Rehabil.* **26**, 223–227, 1999.
15) Fields, H.W., Proffit, W.R., Case, J.C. and Vig, K.W.L.: Variables affecting measurements of vertical force. *J. Dent. Res.* **65**, 135–138, 1986.
16) Kiliaridis, S., Kjellberg, H., Wenneberg, B. and Engström, C.: The relationship between maximal bite force, bite force endurance and facial morphology during growth. A cross sectional study. *Acta Odontol. Scand.* **51**, 323–331, 1993.
17) Linderholm, H. and Wennström, A.: Isometric bite force and its relation to general muscle force and body build. *Acta Odontol. Scand.* **28**, 679–689, 1970.
18) Tortopidis, D., Lyons M.F., Baxendale, R.H. and Gilmour, W.H.: The variability of bite force measurement between sessions, in different positions within the dental arch. *J. Oral Rehabil.* **25**, 681–686, 1998.

19) Braun, S., Bantleon, H.P., Hnat, W.P., Freudenthaler, J.W., Marcotte, M.R. and Johnson, B.E.: A study of bite force, part 2: Relationship to various cephalometric measurements. *Angle Orthod.* **65**, 373–377, 1995.
20) Waltimo, A., Nyström, M. and Könönen, M.: Bite force and dentofacial morphology in men with severe dental attrition. *Scand. J. Dent. Res.* **102**, 92–96, 1994.
21) Proffit, W.R., Fields, H.W. and Nixon, W.L.: Occlusal forces in normal and long-face adults. *J. Dent. Res.* **62**, 566–571, 1983.
22) Raadsheer, M.C., van Eijden, T.M.G.J., van Ginkel, F.C. and Prahl-Andersen, B.: Contribution of jaw muscle size and craniofacial morphology to human bite force magnitude. *J. Dent. Res.* **78**, 31–42, 1999.
23) Throckmorton, G.S., Ellis, E. and Buschang, P.H.: Morphologic and biomechanical correlates with maximum bite forces in orthognathic surgery patients. *J. Oral Maxillofac. Surg.* **58**, 515–524, 2000.
24) Suzuki, T., Kumagai, H., Yoshitomi, N. and McGlumphy, E.A.: Occlusal contacts of edentulous patients with mandibular hybrid dentures opposing maxillary complete dentures. *Int. J. Maxillofac. Impl.* **14**, 504–509, 1999.
25) Matsui, Y., Ohno, K., Michi, K., Suzuki, Y. and Yamagata, K.: A computerized method for evaluating balance of occlusal load. *J. Oral Rehabil.* **23**, 530–535, 1996.
26) Nanda, S.K., Merow, W.M. and Sassouni, V.: Repositioning of the masseter muscle and its effect on skeletal form and structure. *Angle Orthod.* **37**, 304–308, 1967.
27) Ingervall, B. and Thilander, B.: Relation between facial morphology and activity of the masticatory muscles. *J. Oral Rehabil.* **1**, 131–147, 1974.
28) Fujita, K.: The correlation between the jaw closing force and the orofacial skeleton. *J. Kyushu Dent. Soc.* **32**, 477–485, 1978 (in Japanese with English abstract).
29) Gionhaku, N., Iinuma, T., Izumi, K., Shimizu, M., Kawamura, Y., Mamiya, K. and Moriya, Y.: Correlation between jaw muscle activity and bite force under the known different craniofacial form. *J. Jpn. Prosthodont. Soc.* **32**, 1378–1381, 1988 (in Japanese with English abstract).
30) Iwasaki, H., Fujita, S., Yoshida, H., Inaba, R. and Iwata, H.: Relationship between biting force and the morphology of the maxilloface. *Jpn. J. Hyg.* **50**, 683–692, 1995 (in Japanese with English abstract).
31) Shinogaya, T., Bakke, M., Thomsen, C.E., Vilmann, A., Sodeyama, A. and Matsumoto, M.: Effects of ethnicity, gender and age on clenching force and load distribution. *Clin. Oral Invest.* **5**, 63–68, 2001.
32) Maness, W.L. and Podoloff, R.: Distribution of occlusal contacts in maximum intercuspation. *J. Prosthet. Dent.* **62**, 238–242, 1989.
33) Boening, K.W. and Walter, M.H.: Computer-aided evaluation of occlusal load in complete dentures. *J. Prosthet. Dent* **67**, 339–344, 1992.
34) Olivieri, F., Kang, K., Hirayama, H. and Maness, W.L.: New method for analyzing complete denture occlusion using the center of force concept: a clinical report. *J. Prosthet. Dent.* **80**, 519–523, 1998.
35) Bakke, M., Holm, B., Jensen, L., Michler, L. and Moller, E.: Unilateral, isometric bite force in eight 68-year-old women and men related to occlusal factors. *Scand. J. Dent. Res.* **98**, 149–158, 1990.
36) Dean, J.S., Throckmorton, G.S., Ellis, E.E. and Sinn, D.P.: A preliminary study of maximum voluntary bite force and jaw muscle efficiency in pre-orthognathic surgery patients. *J. Oral Maxillofac. Surg.* **50**, 1284–1288, 1992.
37) Miyamoto, K., Ishizuka, Y., Ueda, M., Saifuddin, M., Shikata, N. and Tanne, K.: Masseter muscle activity during the whole day in children and young adults. *J. Oral Rehabil.* **26**, 858–864, 1999.
38) Ueda, H.M., Ishizuka, Y., Miyamoto, K., Morimoto, N. and Tanne, K.: Relationship between masticatory muscle activity and vertical craniofacial morphology. *Angle Orthod.* **68**, 233–237, 1998.
39) Nasedkin, J.N.: Occlusal dysfunction. *Gen. Dent.* **26**, 52–57, 1978.
40) Raadsheer, M.C., Kiliaridis, S., van Eijden, T.M.G.J., van Ginkel, F.C. and Prahl-Andersen, B.: Masseter muscle thickness in growing individuals and its relation to facial morphology. *Arch. Oral Biol.* **41**, 323–332, 1996.
41) Tallgren, A. and Tryde, G.: Relationship between facial morphology and activity of orofacial muscles in patients with a complete upper and a partial lower denture. *J. Oral Rehabil.* **22**, 643–651, 1995.
42) Molnar, S.: Human variation. Races, types, and ethnic groups. 3rd ed. Prentice Hall. Englewood Cliffs, pp. 1–11, 1992.
43) Johnson, J.S., Soetamat, A. and Winoto, N.S.: A comparison of some features of the Indonesian occlusion with those of two other ethnic groups. *Br. J. Orthod.* **5**, 183–188, 1978.
44) Munandar, S. and Snow, M.D.: Cephalometric analysis of Deutero-Malay Indonesians. *Aust. Dent. J.* **40**, 381–388, 1995.
45) Enlow, D.H.: Facial growth. 3rd ed. WB

Saunders. Philadelphia, pp. 222–228, 1990.

46) Weijs, W.A. and Hillen, B.: Correlations between the cross-sectional area of the jaw muscles and craniofacial size and shape. *Am. J. Physic. Anthropol.* **70**, 423–431, 1986.

47) Throckmorton, G.S., Finn, R.A. and Bell, W.H.: Biomechanics of differences in lower facial height. *Am. J. Orthod.* **77**, 410–420, 1980.