Original Article

Maximum Closing Force of Mentolabial Muscles and Type of Malocclusion

Min-Ho Jung[a]; Won-Sik Yang[b]; Dong-Seok Nahm[b]

ABSTRACT

Objective: To measure the closing force of the upper and lower lips and to ascertain the relationship between the maximum closing force of the mentolabial muscles and types of malocclusion.

Materials and Methods: Of those who showed the full eruption of a second molar and no permanent tooth loss, 99 subjects were chosen who showed a positive overbite and ANB and no skeletal asymmetry. By using the Y-meter, which can measure the lip force in the vertical direction using a load cell, the closing forces of the upper and lower lips were measured separately. A one-way analysis of variance (ANOVA) test and the Pearson's correlation test were used to evaluate the interrelationship between lip force and dentofacial morphology.

Results: The lip closing force was greater in male and Class I subjects. Upper lip force was greater than that of the lower lip in all groups. The values of lip closing forces were related to the variables of upper incisor angulation. In Class II subjects, the values of lip closing forces were also related to the vertical skeletal pattern.

Conclusions: The mentolabial muscle force was highly correlated with dentofacial structure and types of malocclusion. (*Angle Orthod* 2010;80:72–79.)

KEY WORDS: Muscle force; Types of malocclusion; Incisor angulation

INTRODUCTION

There are more than 20 muscles in the human face. Particularly in the lip and cheek area, many muscles converge or are intermingled with each other. Their functional harmony and balance is very important in the growth and development of the craniofacial region.

Oral competence is maintained by the orbicularis oris muscle.[1,2] The orbicularis oris is a concentric muscle around the mouth, and its action and muscle composition are analogous to the orbicularis oculi located around the eye.[3] Elevation and protrusion of the central aspects of the lower lip are caused by the paired mentalis muscles.[4] They are often overactive during lip closing in patients with lip incompetence,[5] who must voluntarily close their lips, causing the chin prominence to be heavily dimpled during use of these muscles.

Since the teeth are positioned between the lips and cheeks on one side and the tongue on the other, the opposing forces or pressures from these organs should be major determinants of the dental equilibrium. In some malocclusion patients, such as those with severe bialveolar protrusion or Class II division 1 with a large overjet, there is a functional imbalance of the perioral musculature.[6]

To clinically assess the perioral muscle function, Posen[7,8] described a method for measuring the strength of the lips for clinical use. His pommeter consisted essentially of a mouthpiece connected to a dynamometer, which registered a pull force when the mouthpiece is drawn from the lips. He believed that great lip strength might indicate a high tone in the lips and thus, substantially greater forces acting on the front teeth. He also found that the subjects with Angle Class II division 2 malocclusion had high lip strength and that the subjects with bimaxillary protrusion had low lip strength when measured with his method.[7]

Posen's measuring equipment had some limitations. Patients with lip incompetency usually show upper lip hypotonicity and compensatory mentalis hyperfunction,[5] but Posen's pommeter could not evaluate the upper and lower lips separately. Also, it measured the

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Table 1. Age, Number, and Definition of Each Group

Group	Gender	Angle Classification	Age, y	n
1	Male	Class I	22.86 ± 3.38	41
2	Female	Class I	22.34 ± 3.26	23
3	Male	Class II	21.74 ± 3.38	15
4	Female	Class II	21.74 ± 3.38	19
Total			22.62 ± 3.62	98

resisting force from pulling the device out of the mouth, so the direction of force is different from that created by normal functioning.

Jung et al[9] used a Y-meter, which was devised to measure the vertical closing force of the lip with a load cell to evaluate the influence of lip force on incisor position. They found that upper incisor inclination was related to upper lip closing force in male subjects with Class I molar relationships.

The purposes of this study were to compare the upper and lower maximum lip closing forces and to ascertain whether or not a relationship exists between maximum lip closing forces and dentofacial features in adult Class I and II subjects.

MATERIALS AND METHODS

The subjects were male and female volunteer university students, and were classified into four groups (Table 1). All subjects in groups 1 and 2 showed Class I dental and skeletal relationships ($0^\circ < ANB < 4^\circ$) and appropriate overbite (> 0 mm) and overjet (< 4 mm). Groups 3 and 4 consisted of Class II subjects who showed Class II molar and skeletal ($ANB > 4^\circ$) relationships. To minimize the influence of excessive vertical discrepancies, subjects with open bites were excluded. There were no significant differences in age distributions between the groups.

The inclusion criteria were fully erupted second molars, no permanent tooth loss, no congenital missing or supernumerary teeth, no full jacket crown on incisors, no history of orthognathic surgery or previous orthodontic treatment, no known congenital craniofacial anomaly, and no noticeable occlusal plane canting or asymmetric skeletal pattern found with clinical examination or cephalometric analysis. At the time of this study, an Institutional Review Board (IRB) did not exist at the University Dental Hospital and therefore IRB approval was not present. However, all volunteers gave informed consent before entering the study. Souvenirs were given for participation in the experiment.

Lateral and frontal cephalometric radiographs were taken with the Asahi CX-90SP (Asahi Co, Kawasaki, Japan) cephalostat at 72–74 Kvp and 20 mA/sec. Twenty landmarks were digitized on each lateral cephalometric radiograph, from which 20 variables were calculated (Figures 1 through 3). The landmarks were

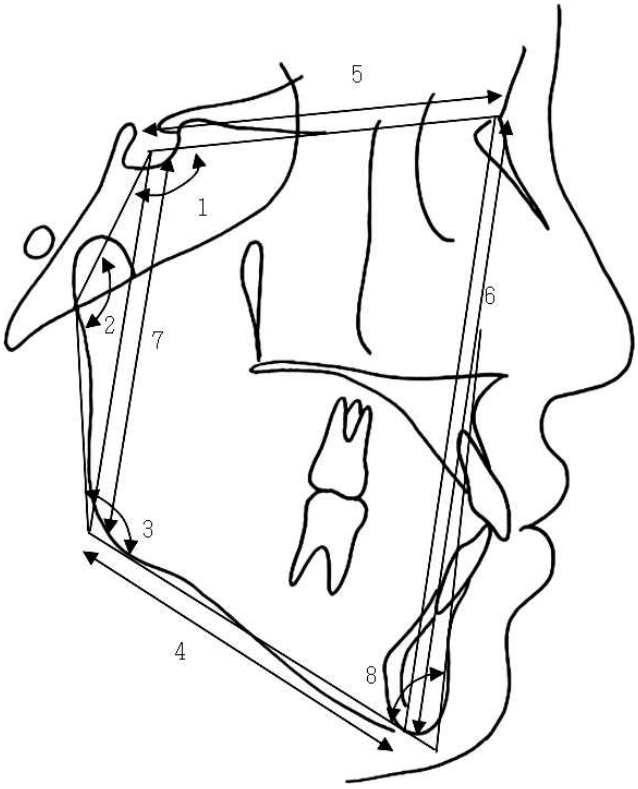

Figure 1. Measurements used in this study: 1, saddle angle (Na-S-Ar); 2, articular angle (S-Ar-Go); 3, gonial angle (Ar-Go-Me); 1+2+3, Björk sum; 4, body length; 5, anterior cranial base length (ACB); 4/5, body to ACB; 6, anterior facial height; 7, posterior facial height; 7/6, facial height ratio (FHR); 8, AB to mandibular plane (MP).

digitized with a graphic tablet (KD4300, Graphtec Co, Yokohama, Japan) interfaced with a desktop computer. All landmarks were identified and digitized by a single investigator. For convenience of analysis, these variables were subdivided into three categories: skeletal patterns, dental patterns, and soft tissue relationships.

To measure the vertical vector of lip closing force, a Y-meter[9] was used. The Slimline Sensor (9131A49, Kistler C, Winterthur, Switzerland), a very small load cell, was located on the upper surface of the horizontal plate of the Y-meter (Figure 4). A base plate part was designed to prevent the influence of lip force from the opposite side, and a bite plate part was designed to hold the Y-meter during measurement. To minimize distortion of the gauge, the plates were made by milling stainless steel. To test reliability, a calibration procedure was done using a Universal testing machine (Instron Inc, Canton, Mass) before the experiment. Measurement was done three times at 0–50 N with 5-N interval and sensitivity 2.77 pC/N. In all measurements, the standard deviation of current intensity measurement was less than 0.5% of average value. During the experiment, the Y-meter was stored in a 37°C dried water bath to minimize temperature-induced error.

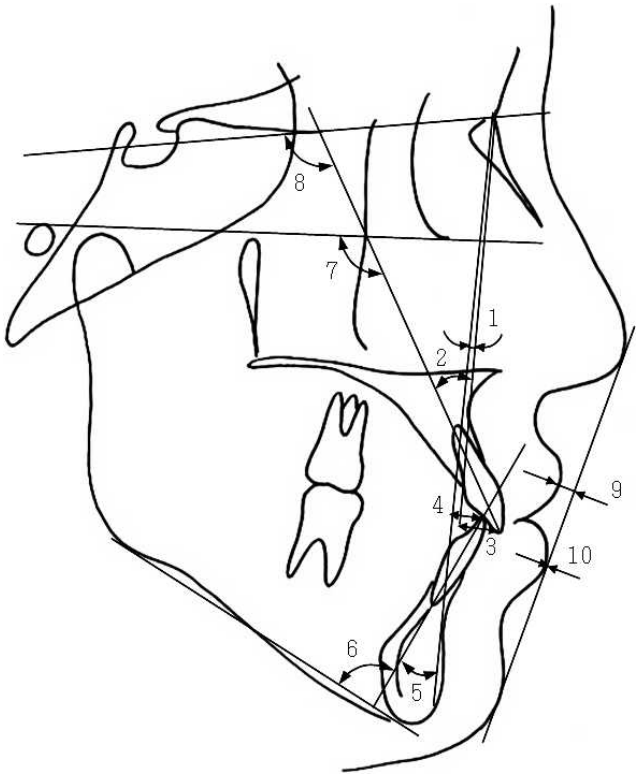

Figure 2. Measurements used in this study (continued): 1, ANB (A-Na-B); 2, upper central incisor (U1) to NA (angle); 3, upper central incisor (U1) to NA (mm); 4, lower central incisor (L1) to NB (mm); 5, lower central incisor (L1) to NB (angle); 6, L1 to mandibular plane (IMPA); 7, U1 to FH; 8, U1 to SN; 9, upper lip position (Ricketts' E-line); 10, lower lip position (Ricketts' E-line).

Each subject was asked to hold the bite plate portion with his/her incisors. Baseplate wax was added on the bite plate portion each time before measuring to help hold the gauge. When the subject was asked to close his lips lightly, the position of the upper lip was checked to determine whether it was placed in the center of the load cell portion. After explanation and a few trials of the exercise, each subject was asked to close the lips with maximum force (Figure 5). The value of the maximum lip closing force was measured for 5 seconds. The maximum value and the average value during the 5 seconds were also measured (Figure 6) using the DASYLab 5.50 (DASYTEC, Amherst, NH) program. Measurements were done twice with a 3-minute interval between them, and the average value of two measurements was used in statistical analysis. When the maximum or average value of the second measurement was different by more than 10% of the first one, a third measurement was done and the two closer values were used for data analysis. After measuring the maximum upper lip closing force, the Y-meter was positioned between the lips on the opposite side to measure the closing force of the lower lip. The second experiment was done with the same procedure.

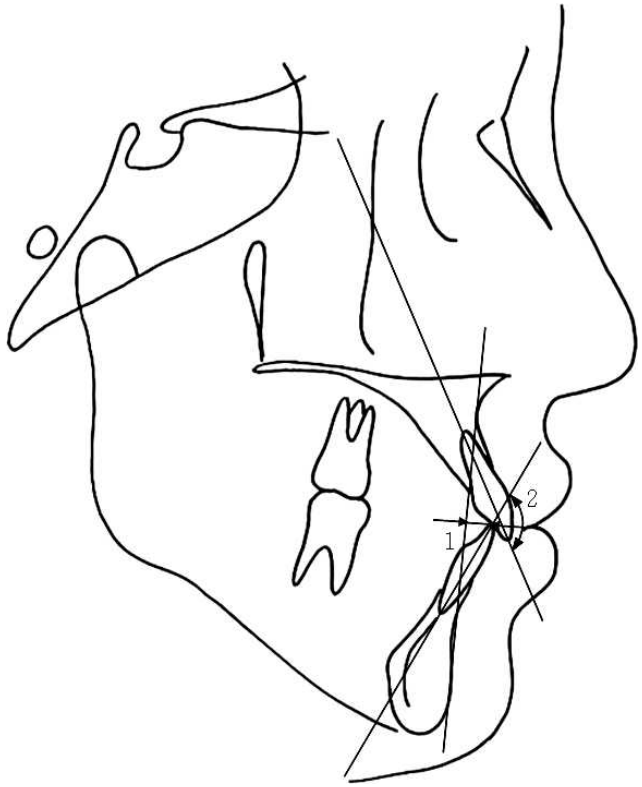

Figure 3. Measurements used in this study (continued): 1, L1 to APog (mm); 2, interincisal angle (IIA).

One-way analysis of variance (ANOVA) and Pearson's correlation test were done to analyze the differences between groups and the relationships of lip force and craniofacial morphology with the use of the SPSSWIN 10.0 program (SPSS Inc, Windows, version 10.0, Chicago, Ill).

To evaluate the magnitude of measurement error involved in this study, the lateral cephalograms of 12 randomly selected subjects were retraced, redigitized, and reanalyzed after a 2-week interval, and the error was calculated by Dahlberg's formula.[10] The error ranged between 0.04 mm and 0.20 mm for the linear measurements and between 0.15° and 1.12° for the angular measurements. All measuring procedures and cephalometric analyses were done by the same researcher.

RESULTS

The means and standard deviations of the cephalometric measurements and lip force measurements of each group are given in Table 2. The results of ANOVA demonstrated that there were significant differences in many variables among the four groups; thus, Scheffe's multiple comparison tests were performed to analyze the differences. The measurements that are frequently used to evaluate skeletal anteroposterior relationships, such as ANB and AB to the

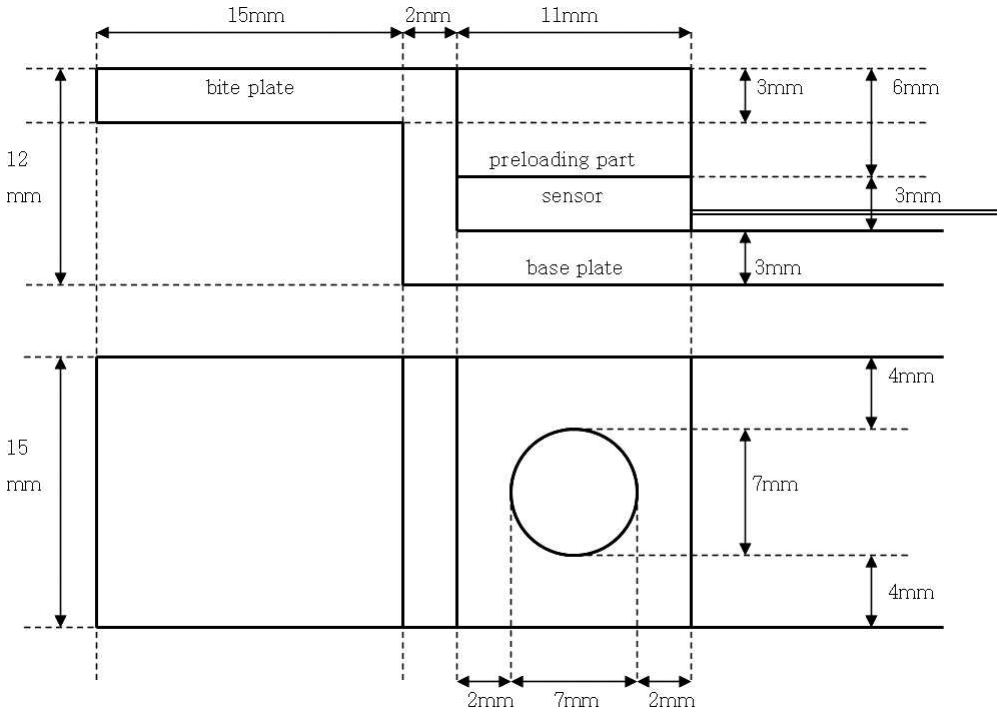

Figure 4. Y-meter: appliance design.

mandibular plane, showed significant differences between Class I (groups 1 and 2) and Class II (groups 3 and 4) samples. Group 4 showed a more vertical skeletal pattern. The measurements of maximum lip closing force showed significant differences between Class I and Class II samples. Sexual dimorphism was also evident in lip force measurements (Table 2).

In correlation analysis, Class I subjects and Class II subjects showed different results. In groups 1 and 2, upper incisor angulation was negatively related with maximum lip closing force, but other variables did not show significant correlation (Tables 3 and 4). In groups 3 and 4, soft tissue lip protrusion was negatively related,and vertical skeletal pattern was also related with maximum lip closing force. Different correlation statuses between the upper lip and lower lip were also shown in Class II subjects (Tables 5 and 6).

DISCUSSION

The opposing forces or pressures from the tongue and lips should be major determinants of the dental equilibrium in the anterior segment of the arch.[11] Proffit[12] described primary and secondary force factors related to tooth position, and he concluded that pressure of the tongue and lips is one of the primary factors, but other factors are also related to equilibrium. If the equilibrium is upset by a change in the pressure of tongue or lips, the position of the teeth can

Figure 5. Lip closing force measurement using Y-meter.

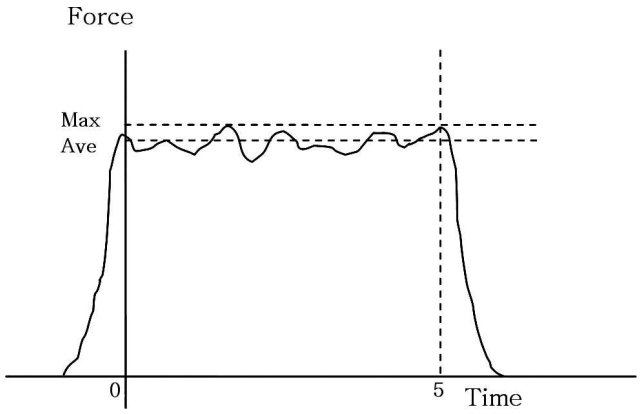

Figure 6. Graph of lip closing force measurement. Max indicates maximum value of lip closing force during 5 seconds; AVE, average value of lip closing force during 5 seconds.

Table 2. Mean, Standard Deviation, and Result of ANOVA of Each Variable*

	Group 1	Group 2	Group 3	Group 4
	Mean SD	Mean SD	Mean SD	Mean SD
Skeletal pattern				
Björk sum	389.32 ± 6.98^{A}	395.9 ± 4.33^{AB}	391.19 ± 10.31^{AB}	396.57 ± 9.07^{B}
Body to ACB	1.13 ± 0.07^{A}	1.13 ± 0.08^{A}	1.08 ± 0.07^{AB}	1.04 ± 0.07^{B}
FHR	70.82 ± 4.76^{A}	64.55 ± 3.24^{AB}	67.76 ± 6.6^{AB}	63.56 ± 6.29^{B}
SNA	84.42 ± 3.61^{A}	81.04 ± 2.80^{B}	85.71 ± 4.27^{AB}	83.02 ± 2.87^{AB}
SNB	82.41 ± 3.47^{AB}	78.86 ± 2.20^{C}	79.88 ± 3.88^{B}	76.11 ± 3.03^{AC}
ANB	2.04 ± 1.21^{A}	2.21 ± 1.26^{A}	5.83 ± 1.13^{B}	6.92 ± 2.4^{B}
AB to MP	71.22 ± 6.13^{A}	68.48 ± 4.11^{A}	77.52 ± 8.59^{B}	77.34 ± 8.78^{B}
Dental pattern				
Overbite	2.12 ± 1.20^{A}	1.37 ± 1.11^{A}	3.33 ± 2.55^{B}	3.38 ± 2.32^{B}
Overjet	1.92 ± 1.12^{AB}	1.27 ± 0.98^{A}	2.22 ± 2.11^{AB}	2.83 ± 1.69^{B}
U1 to NA, degree	29.54 ± 6.26^{A}	25.40 ± 5.06^{A}	25.63 ± 7.87^{A}	26.29 ± 6.89^{A}
U1 to NA, mm	5.62 ± 1.87^{A}	4.42 ± 1.44^{AB}	3.82 ± 2.08^{B}	4.69 ± 1.51^{AB}
L1 to NB, degree	26.14 ± 5.47^{A}	27.05 ± 6.54^{A}	30.27 ± 7.03^{A}	36.24 ± 7.24^{B}
L1 to NB, mm	5.15 ± 1.94^{A}	4.94 ± 1.9^{A}	7.28 ± 2.18^{B}	8.92 ± 3.19^{B}
IMPA	94.4 ± 7.7^{A}	92.31 ± 7.71^{A}	99.2 ± 9.39^{AB}	103.57 ± 11.81^{B}
L1 to APog, mm	3.63 ± 1.93^{A}	3.38 ± 1.84^{A}	3.89 ± 2.30^{A}	5.07 ± 2.59^{A}
U1 to FH	120.38 ± 5.76^{A}	117.89 ± 5.42^{A}	118.22 ± 6.81^{A}	118.12 ± 7.20^{A}
U1 to SN	112.87 ± 6.44^{A}	107.04 ± 6.23^{B}	111.34 ± 6.43^{AB}	109.31 ± 8.70^{AB}
IIA	122.31 ± 10.45^{A}	125.36 ± 9.51^{A}	118.27 ± 11.82^{AB}	110.55 ± 14.19^{B}
Soft tissue relation				
EL to UL	−1.14 ± 2.09^{A}	−1.14 ± 1.38^{A}	0.37 ± 2.67^{AB}	1.37 ± 2.37^{B}
EL to LL	0.83 ± 2.01^{A}	0.87 ± 1.26^{A}	1.65 ± 3.41^{AB}	3.59 ± 2.79^{B}
Lip closing force[a]				
Max UL	8.81 ± 3.08^{A}	4.89 ± 2.13^{BC}	7.31 ± 3.81^{AB}	4.15 ± 2.15^{C}
Ave UL	6.6 ± 2.96^{A}	3.68 ± 1.91^{BC}	5.89 ± 2.97^{AB}	3.09 ± 1.69^{C}
Max LL	3.44 ± 2.03^{A}	1.99 ± 1.00^{BC}	2.94 ± 1.80^{AB}	1.56 ± 1.06^{C}
Ave LL	2.27 ± 1.44^{A}	1.38 ± 0.88^{AB}	1.82 ± 1.36^{AB}	1.01 ± 0.91^{B}

[a] Max UL indicates maximum upper lip closing force; Ave UL, average upper lip closing force; Max LL, maximum lower lip closing force; Ave LL, average lower lip closing force.

* The same letters are not statistically significant at $P = .05$ by Scheffe's multiple comparison.

Table 3. Correlation Coefficients of Each Variable in Group 1 ($P < .05$)[a]

With Max UL	*R*	With Ave UL	*R*	With Max LL	*R*	With Ave LL	*R*
Max LL	0.492	Max UL	0.947	Max UL	0.492	Max UL	0.521
Ave UL	0.947	Max LL	0.429	Ave UL	0.429	Max LL	0.883
Ave LL	0.521	Ave LL	0.470	Ave LL	0.883	Ave UL	0.470
U1 to FH	−0.618	U1 to FH	−0.622	U1 to FH	−0.417	U1 to FH	−0.402
U1 to SN	−0.562	U1 to SN	−0.593	EL to LL	−0.428		
U1 to NA (angle)	−0.414	U1 to NA (angle)	−0.403				

[a] Max UL indicates maximum upper lip closing force; Ave UL, average upper lip closing force; Max LL, maximum lower lip closing force; Ave LL, average lower lip closing force; *R*, correlation coefficient.

Table 4. Correlation Coefficients of Each Variable in Group 2 ($P < .05$)[a]

With Max UL	*R*	With Ave UL	*R*	With Max LL	*R*	With Ave LL	*R*
Max LL	0.577	Max UL	0.978	Max UL	0.577	Max UL	0.622
Ave UL	0.978	Max LL	0.611	Ave UL	0.611	Max LL	0.949
Ave LL	0.622	Ave LL	0.672	Ave LL	0.949	Ave UL	0.672
U1 to FH	−0.617	U1 to FH	−0.593			U1 to SN	−0.433
U1 to SN	−0.547	U1 to SN	−0.504				
U1 to NA (mm)	−0.431						
IIA	0.447						

[a] Max UL indicates maximum upper lip closing force; Ave UL, average upper lip closing force; Max LL, maximum lower lip closing force; Ave LL, average lower lip closing force; *R*, correlation coefficient.

Table 5. Correlation Coefficients of Each Variable in Group 3 ($P < .05$)

With Max UL	*R*	With Ave UL	*R*	With Max LL	*R*	With Ave LL	*R*
Max LL	0.606	Max UL	0.987	Max UL	0.606	Max UL	0.538
Ave UL	0.987	Max LL	0.653	Ave UL	0.653	Max LL	0.943
Ave LL	0.538	Ave LL	0.587	Ave LL	0.943	Ave UL	0.587
U1 to SN	−0.595	sum	−0.555	sum	−0.749	sum	−0.781
U1 to NA (angle)	−0.601	FHR	0.553	FHR	0.697	FHR	0.769
U1 to NA (mm)	−0.632	U1to FH	−0.583	AB to MP	0.695	AB to MP	0.732
L1 to NB (mm)	−0.537	U1 to NA (angle)	−0.597	EL to UL	−0.658	EL to UL	−0.759
IIA	0.633	U1 to NA (mm)	−0.623	EL to LL	−0.823	EL to LL	−0.858
EL to UL	−0.547	IIA	0.616				
EL to LL	−0.670	EL to UL	−0.537				
		EL to LL	−0.668				

[a] Max UL indicates maximum upper lip closing force; Ave UL, average upper lip closing force; Max LL, maximum lower lip closing force; Ave LL, average lower lip closing force; *R*, correlation coefficient.

be changed. A previous study with the Y-meter showed that upper lip closing force has influence on maxillary incisor angulation in Class I male subjects.[8] That influence could also be found in Class II and female subjects in this study.

Thüer and Ingervall[13] studied the relationship between lip strength and lip pressure in children with varying types of malocclusions. As in their study, lip strength was lower in Angle Class II division 1 malocclusions than in Class I malocclusions. The lip pressure on the upper incisors, on the other hand, was higher in Class II division 1 than in Class I malocclusions, and was lowest in children with Class II division 2 malocclusions. They concluded that lip pressure on the teeth was a result of the incisor position, and maximum lip force showed a negative correlation with incisor angulation. Our results also support these findings. There is no consensus about differences in developmental mechanisms of Class II division 1 and 2 malocclusions, but upper lip closing force may be one of the important factors.

It has been postulated that forces operating for a cumulative time of longer than 4 to 6 hours per day can produce tooth movements, even if they act for relatively short durations.[14,15] If lip incompetency occurs in someone, pressure from the lip would be reduced for more than 6 hours per day and anterior tooth position can be altered.

Ingervall and Janson[16] measured the strength of the lips with a dynamometer, and the POM values were not significantly correlated with sex. Posen[7] also found no sexual dimorphism in lip strength. However, Mitchell and Williamson[17] found sexual differences in maximum perioral muscle force in both Class I and Class II groups, and our findings show a similar result. These differences seem to be attributed to the subjects' ages and the varying types of malocclusions included.

In contrast to masticatory muscle studies,[18,19] groups 1 and 2 (Tables 3 and 4) did not show any correlation between the muscle force of the lip and vertical skeletal pattern. This result might be influenced by the relatively small range of variation in vertical measurements in Class I subjects, but it seemed more logical to assume that muscle force of the lip did not have direct correlation with skeletal pattern. However, in groups 3 and 4, vertical measurements showed a negative correlation with lower lip closing force (Tables 5 and 6). Ingervall and Janson[16] also showed the negative correlation between vertical skeletal pattern and lip strength. Because the sample of

Table 6. Correlation Coefficients of Each Variable in Group 4 ($P < .05$)

With Max UL	*R*	With Ave UL	*R*	With Max LL	*R*	With Ave LL	*R*
Ave UL	0.989	Max UL	0.989	Ave LL	0.952	Max LL	0.952
U1 to FH	−0.661	Ave LL	0.481	sum	−0.523	Ave UL	0.481
U1 to SN	−0.581	U1 to FH	−0.673	FHR	0.524	FMA	−0.484
U1 to NA (angle)	−0.610	U1 to SN	−0.589	SNA	0.526	sum	−0.555
U1 to NA (mm)	−0.611	U1 to NA (angle)	−0.625	SNB	0.502	FHR	0.489
L1 to NB (angle)	−0.458	U1 to NA (mm)	−0.635				
L1 to NB (mm)	−0.498	L1 to NB (angle)	−0.469				
IIA	0.584	L1 to NB (mm)	−0.502				
L1 to APog	−0.541	IIA	0.600				
EL to LL	−0.640	L1 to APog	−0.522				
		EL to LL	−0.616				

[a] Max UL indicates maximum upper lip closing force; Ave UL, average upper lip closing force; Max LL, maximum lower lip closing force; Ave LL, average lower lip closing force; *R*, correlation coefficient.

Ingervall and Janson was composed mainly of Class II subjects, their results were very similar to those of our study. If the chin point moves downward and backward, the distance between subnasale and soft tissue pogonion would be increased, and the incidence of lip incompetency could also be increased.

In the case of lymphoid tissue enlargement during growth or allergic rhinitis, partial respiratory obstruction and mouth breathing can be seen. If the lip incompetency occurred due to these or any other reasons, it would be difficult for this to be self-corrected in many cases unless orthodontic or surgical intervention is given, and in this situation, the muscular changes related with muscle disuse are suspected to happen to the muscles related with lip (especially upper lip) closing movement. Those suspected changes are loss of muscle strength,[20] decrease in muscle volume,[21] and decrease in tissue extensibility.[22] If one cannot close the lips because of certain habits or because of mouth breathing for a long period, the frequency and intensity of normal muscle movement or action of the lip (especially upper lip) would be decreased significantly, and such decrease may cause muscular change similar to change associated with immobilization.

Even though horizontal lip force or pressure is an important factor in evaluation of force equilibrium in the anterior part of the dental arch, measuring the "horizontal vector" of lip muscle force or pressure with intraoral force gauges, such as hydraulic pressure gauge[13] or lip bumper with straingauge,[23] has several limitations. Soft tissue's tension change by the volume of the gauge, changes of lip function consciously or unconsciously and difficulties in data interpretation. The results of our study showed the vertical vector of maximum lip closing force has a close correlation with incisor angulation, Although the exact reason for such a relation has not been proven yet, it seems that vertical lip closing force measurements can be one of the diagnostic tools in the evaluation of lip function.

Close correlation between the maximum closing force of upper and lower lips was shown in groups 1, 2, and 3. In spite of a small correlation coefficient in group 4, lower lip force was proportional to upper lip force to a certain degree. It seemed that in most of the subjects without lip incompetency, upper and lower lip forces were closely related.

In Class II samples, correlations between variables were somewhat complex in this study. The measurements related to soft tissue protrusion showed a close relationship with both lip closing forces in group 3 and with upper lip closing forces in group 4. These results seemed to be related with the sample selection. Among the subjects of this experiment, two subjects of group 1 (4.9%), three subjects of group 3 (20%), and six subjects of group 4 (31.6%) showed a moderate to severe degree of lip incompetency, which indicates lip separation at rest by more than 4 mm[5] and tensing of the mentalis muscle (chin dimpling) in lip closure.[24] Because cephalometric films were taken with a closed lip posture, these subjects might influence the entire results. For more precise analysis, subjects with lip incompetency should be analyzed separately.

The malrelationship of teeth is often the result of variations in tissue growth and development and the interplay of forces within the oral environment. One of the goals of orthodontic treatment is to produce or maintain a stable balance of forces. We have only a partial understanding of these forces and how to modify them. Notwithstanding that "lip hypotonicity" was described long ago and considered as an etiology or result of malocclusion, no objective evaluation or measuring method of lip function that can be used in orthodontic clinics has been accepted to date. Most of the measuring methods were too difficult, or there were difficulties in interpreting their results. For clinical usage in daily practice, more simple equipment and measuring methods should be developed and researched.

CONCLUSIONS

- The maximum lip closing force was greater in male and Class I subjects. Upper lip force was greater than lower lip force in all groups.
- In Class I subjects, the values of the maximum lip closing forces were related to the variables of upper incisor angulation.
- In Class II subjects, the values of the maximum lip closing forces were related to the variables of upper incisor angulation, vertical skeletal pattern, and lip protrusion.

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