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Relationship between masseter muscle size and maxillary morphology

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SUMMARY The aim of this study was to investigate the relationship between masseter muscle size and craniofacial morphology, focusing on the maxilla. Twenty-four patients (11 males and 13 females; mean age 27.6 ± 5.6 years) underwent cephalometric analyses. Ultrasonography was used to measure the cross-sectional area (CSA) of the masseter muscle and bite force was measured using pressure sensitive film.

The results showed that CSA-relaxed was positively correlated with upper anterior face height (UAFH)/total anterior face height (TAFH) and negatively with lower anterior face height (LAFH)/TAFH and LAFH ($P < 0.05$). CSA-clenched was correlated positively with SN-palatal, FH-palatal, UAFH/TAFH, and lower posterior face height (LPFH)/total posterior face height (TPFH) and negatively with LAFH/TAFH, LAFH, upper posterior face height (UPFH)/TPFH, and UPFH ($P < 0.05$). Bite force was positively correlated with LPFH/TPFH and negatively with UPFH/TPFH ($P < 0.05$). As the masseter became larger, the anterior maxillary region tended to shift downwards relative to the cranial base, whereas the posterior region tended to shift upwards. The decrease in LAFH/TAFH and increase in LPFH/TPFH as the size of the masseter muscle increases may be influenced not only by the inclination of the mandibular plane but also by the clockwise rotation of the maxilla.

Introduction

What influence do the masticatory muscles exert on the maxilla? There is insufficient information detailing the influence of the masseter muscle on the overall craniofacial complex, including the maxilla.

Moss (1962) stated that bone is shaped by the reaction accompanying the development of all soft tissue functions associated with bone structures in the maxillofacial complex. Sassouni (1969) observed a flat mandible with larger masticatory muscles in deep bite skeletal subjects and a steep mandible with thinner muscles in open bite skeletal types. Naeije *et al.* (1989) indicated that temporalis activity tended to dominate during moderate jaw clenching, whereas masseter activity was stronger during forceful clenching.

Several studies have stated that the masseter is correlated with craniofacial morphology (Weijs and Hillen, 1984; Gionhaku and Lowe, 1989; Bakke *et al.*, 1992; Benington *et al.*, 1999; Boom *et al.*, 2008). Some authors have also reported that diverse factors, such as the occlusal plane angle, *y*-axis, mandibular plane angle, and palatal-mandibular plane angle, are negatively correlated with bite force (Kubota, 2001; Kovero *et al.*, 2002; García-Morales *et al.*, 2003; Sondang *et al.*, 2003).

These studies primarily described the relationships between muscle features and lower facial morphology, or comparatively evaluated characteristics of the maxilla and mandible, such as total face height or palatal–mandibular plane angle. The masseter, which is attached to the zygomatic arch and masseteric tuberosity, may affect both the mandible and the maxilla. An understanding of the relationship between the size of the masseter and maxillary morphology can aid in orthodontic diagnosis and treatment. Thus, to understand its influence on the maxilla, the objective of this study was to evaluate the relationship of the maxilla to the cranial base. This study also evaluated bite force, which is positively correlated with cross-sectional area (CSA; Van Spronsen *et al.*, 1992; Hatch *et al.*, 2000; Ueki *et al.*, 2006), to objectively confirm the relationship between the masseter muscle and craniofacial morphology.

Subjects and methods

This research was approved by the Ethics Committee of the School of Dentistry at Nihon University and was sufficiently explained to the subjects based on the committee's regulations. Informed consent was obtained from all subjects before they participated in the study.

Subjects

Twenty-four patients [11 males and 13 females; mean age 27.6 ± 5.6 years (mean ± SD), range 17.8–41.17] who attended the Orthodontic Department of Nihon University Dental Hospital. The subjects met the following criteria: 1. no history of orthodontic treatment; 2. no missing teeth, except for third molars; 3. no prosthesis; 4. no history of diseases involving the neuromuscular mechanisms; and

5. no symptoms or history of temporomandibular disorders, including limitation of jaw opening on interview.

Morphological measurements

A lateral cephalometric radiograph was taken of each subject in centric occlusion for routine diagnostic purposes. Conventional skeletal landmarks were traced by one author (YU), digitized using an image scanner at 72 dpi, and analysed using cephalometric analysis software (Winceph, version 8.0; Rise Corporation, Sendai, Japan). Sixteen standard angles and 10 linear measurements were measured (Figure 1A–1D; Table 1).

To determine the reliability of the method, all radiographs were retraced and remeasured by the same examiners after an interval of approximately 2 weeks. A paired *t*-test was used to compare the two measurements. No significant difference was found between the measurements ($P > 0.05$).

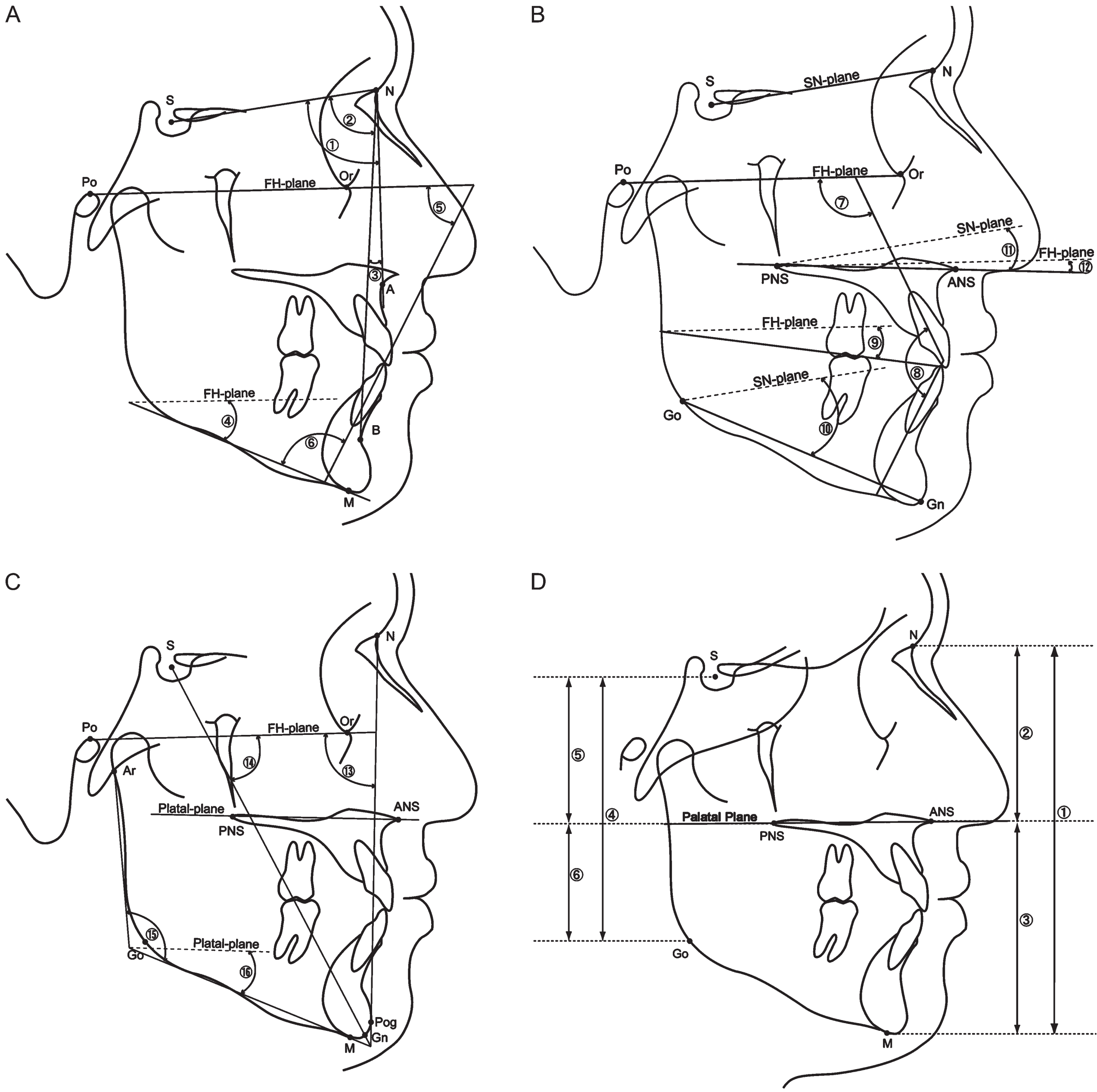

Figure 1 (A-C) Measurements obtained from the lateral cephalogram. Angular 1. SNA, 2. SNB, 3. ANB, 4. FMA, 5. FMIA, 6. IMPA, 7. U1-FH, 8. U1-L1, 9. Occlusal-FH, 10. GoGn-SN, 11. SN-palatal, 12. FH-palatal, 13. facial angle, 14. Y-axis, 15. gonial angle, 16. palatal-mandibular plane angle. (D) Linear 1. N-M: total anterior face height, 2. N-ANS: upper anterior face height, 3. ANS-M: lower anterior face height, 4. S-Go: total posterior face height, 5. S-PNS: upper posterior face height, 6. PNS-Go: lower posterior face height.

Table 1 Measurements made on the lateral cephalometric radiographs.

	Mean	SD	Maximum	Minimum
Angular measurements (°)				
SNA	83.8	3.2	91.4	77.2
SNB	80.0	3.1	88.2	74.4
ANB	3.8	2.4	7.5	−2.1
FMA	27.4	4.4	35.2	19.8
FMIA	57.3	10.0	83.3	42.7
IMPA	95.3	8.6	110.3	74.9
U1–FH	114.7	6.5	124.3	98.9
U1–L1	122.7	12.7	152.8	102.9
Occ–FH	10.6	3.7	18.2	4.5
GoGn–SN	34.9	4.4	41.5	27.2
SN–palatal	9.7	2.9	17.6	5.9
FH–palatal	1.5	2.9	6.9	−4.8
Facial angle	88.1	3.1	95.3	83.0
Y-axis	62.7	2.8	68.8	55.8
Gonial angle	124.0	6.6	139.4	113.6
Palatal–mandibular	25.9	5.2	35.0	13.8
Linear measurements				
N–ANS/N–M (ratio)	44.1	2.3	48.4	38.5
ANS–M/N–M (ratio)	56.0	2.3	61.5	51.6
N–ANS (mm)	58.2	3.1	65.2	53.0
N–M (mm)	132.4	7.4	150.3	116.9
ANS–M (mm)	74.1	6.4	92.4	63.2
S–PNS/S–Go (ratio)	54.1	4.6	61.6	42.8
PNS–Go/S–Go (ratio)	45.9	4.6	57.2	38.4
S–Go (mm)	84.1	7.8	100.0	69.2
S–PNS (mm)	45.3	3.7	52.3	37.3
PNS–Go (mm)	38.8	6.8	54.7	28.9

The magnitude of the method error was calculated using the formula of Dahlberg (1940), $Se = \sqrt{\Sigma d^2/2n}$, where d is the difference between two registrations of a pair and n is the number of double registrations. The method errors and coefficients of reliability (Houston, 1983) for the angular measurements ranged from 0.029 to 0.924 degrees and from 0.959 to 0.999, respectively. Those of the linear measurements ranged from 0.072 to 0.621 mm and from 0.980 to 0.999 mm, respectively.

Ultrasound imaging of the masseter muscle

All images were obtained by one author (YU) using a diagnostic ultrasound system (SSA-250A; Toshiba, Tokyo, Japan) at the same visit when the radiographs were taken. This system has a real-time B-mode scanner with an annular array transducer. The specifications of the system are: piezoelectric material, polymer film P(VDF-TrFE), 7.5 MHz centre frequency, 36 mm diameter aperture, 60 mm radius of curvature, 12 elements, and 45–90 mm effective focal range. To image the masseter, the probe was placed perpendicular to the skin surface and parallel to the occlusal plane. To avoid excess pressure on the skin, the examiner's hand was carefully placed on the occipital region. To locate the probe, the occlusal plane was drawn on the skin surface with a specially designed facebow that was placed on the tips of the upper central incisors and cusps of the upper first molars and held with a gentle bite and the operator's hand to prevent deformation of the soft tissues. The upper and lower lips were then closed with the muscles relaxed, and the lines corresponding to the occlusal plane were drawn bilaterally on the skin surface in accordance with the outer bow. Ultrasound imaging was performed with the subject sitting, both with the muscle relaxed in the intercuspal position (CSA-relaxed) and with maximal clenching in centric occlusion (CSA-clenched). The imaging was repeated three times, during which CSA was measured by bilaterally tracing the muscle outline with the ultrasound system's cursor (Figure 2). To ensure smoothing of the errors by margin tracing, the three measured values were averaged and the mean value was used for analysis (Table 2).

Measurement of bite force

Bite force was measured using 100 µm thick pressure sensitive film (Prescale®: medium, mono-sheet type; Fuji Photo Film, Tokyo, Japan) and a pressure imaging and analysis system (FPD-9210; Fuji Photo Film). This procedure was performed for each subject by one author (YU) during the same visit at which the radiographs were taken. The film was cut, shaped in the form of the dental arch, and wrapped in 30 µm thick polypropylene film to keep it dry. Each subject was directed to bite on the film with the maximum clenching force in centric occlusion for 5 seconds. This procedure was performed three times at 30 second intervals. The films were then read using the pressure imaging and analysis system. The mean value of the three measurements was used as the maximum bite force (Table 2).

Statistical analyses

Statistical analyses were performed using the Statistical Package for Social Sciences for Windows version 8.0.1 (SPSS® Japan, Tokyo, Japan). A paired *t*-test was used to examine the differences between right and left CSA and between CSA-relaxed and CSA-clenched. Pearson's correlation coefficient was used to evaluate the relationships between the cephalometric measurements and CSA and bite force.

Results

The cephalometric measurements are listed in Table 1, and those for the CSA and bite force in Table 2. No statistically significant difference was found between the right and left sides for CSA-relaxed or CSA-clenched. CSA-clenched was significantly greater than CSA-relaxed bilaterally ($P < 0.001$).

The correlation coefficients between CSA and the cephalometric measurements, and those between bite force and the cephalometric measurements, are shown in Table 3. Both CSA-relaxed and CSA-clenched showed a significant negative correlation with FMA, GoGn–SN, gonial angle,

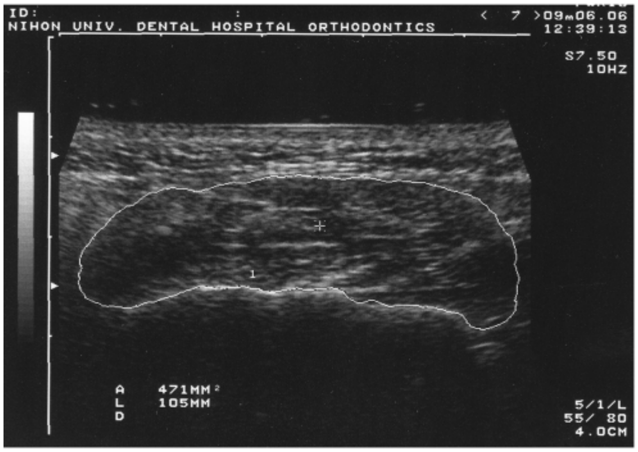

Figure 2 Cross-sectional ultrasound image of the masseter muscle measured using electronic cursors to instantaneously calculate the cross-sectional area.

Table 2 Cross-sectional area (CSA) of the masseter muscle (mm^2) and occlusal bite force (Newton).

	Mean	SD	Maximum	Minimum
CSA-relaxed right	409.2	73.7	593.9	293.6
CSA-relaxed left	420.3	79.5	667.2	316.5
CSA-relaxed right and left mean (1)	414.7	74.3	600.0	311.4
CSA-clenched right	489.4	101.6	705.9	338.3
CSA-clenched left	494.8	97.6	710.3	325.8
CSA-clenched right and left mean (2)	492.1	97.8	680.8	345.2
(2) minus (1)	77.4	38.8	203.0	19.9
Bite force	759.4	314.1	1432.3	214.3
				n = 24

and palatal–mandibular plane angle. The difference between CSA-relaxed and CSA-clenched correlated negatively with FMA, gonial angle, and palatal–mandibular plane angle. Bite force showed a significant negative correlation with FMA, GoGn–SN, and palatal–mandibular plane angle.

The correlation coefficients between masseter muscle CSA and bite force are shown in Table 4. Bite force was significantly correlated with both CSA-relaxed and CSA-clenched ($P < 0.01$).

Characteristic features concerning maxillary location

CSA-relaxed correlated positively with N–ANS/N–M and negatively with ANS–M/N–M and ANS–M ($P < 0.05$). CSA-clenched correlated positively with SN–palatal, FH–palatal, N-ANS/N-M, and PNS–Go/S–Go and negatively with ANS–M/N–M, ANS–M, S–PNS/S-Go, and S–PNS ($P < 0.05$). The difference between CSA-relaxed and CSA-clenched correlated positively with SN–palatal, N–ANS/N–M, and PNS–Go/S–Go and negatively with ANS–M/N–M and S–PNS/S–Go ($P < 0.05$). Bite force correlated positively with PNS–Go/S–Go and negatively with S–PNS/S–Go ($P < 0.05$).

Table 3 Correlation coefficient between masseter muscle cross-sectional area (CSA) and occlusal bite force and lateral cephalometric measurements.

	(1) CSA-relaxed, (right and left mean)	(2) CSA-clenched, (right and left mean)	CSA difference (2)−(1)	Bite force
SNA	0.22	0.21	0.09	–0.11
SNB	0.24	0.16	–0.057	0.19
ANB	–0.011	0.07	0.19	–0.391
FMA	–0.52**	–0.586**	–0.481*	–0.568**
FMIA	0.11	0.13	0.13	0.4
IMPA	0.15	0.15	0.1	–0.17
U1–FH	–0.051	–0.183	–0.365	–0.08
U1–L1	0.11	0.2	0.29	0.35
Occ–FH	–0.37	–0.39	–0.275	–0.195
GoGn–SN	–0.503*	–0.525**	–0.36	–0.532**
SN–palatal	0.32	0.44*	0.49*	0.17
FH–palatal	0.39	0.45*	0.39	0.17
Facial angle	0.17	0.14	0.02	0.26
Y-axis	–0.357	–0.334	–0.157	–0.378
Gonial angle	–0.431*	–0.501*	–0.436*	–0.234
Palatal–mandibular	–0.664**	–0.756**	–0.632**	–0.583**
N–ANS/N–M	0.43*	0.5*	0.43*	0.29
ANS–M/N–M	–0.431*	–0.5*	–0.434*	–0.29
N–ANS	0.13	0.21	0.29	0.13
N–M	–0.3	–0.288	–0.15	–0.16
ANS–M	–0.405*	–0.431*	–0.31	–0.247
S–PNS/S–Go	–0.39	–0.49*	–0.489*	–0.452*
PNS–Go/S–Go	0.39	0.49*	0.49*	0.45*
S–Go	0.05	0.11	0.17	0.29
S–PNS	–0.351	–0.408*	–0.356	–0.153
PNS–Go	0.25	0.35	0.39	0.42*

*$P < 0.05$, **$P < 0.01$.

Discussion

It is clinically important to understand the influence of the masseter on the overall craniofacial complex, including the maxilla, as a background to craniofacial growth and development. To determine this influence, this study focused on the maxilla and investigated the relationship between CSA and craniofacial morphology.

Measurement of the size of the masseter muscle

Representative indices of the size of the masseter are its thickness (Kiliaridis and Kälebo, 1991; Bakke *et al.*, 1992; Raadsheer *et al.*, 1994; Close *et al.*, 1995; Kubota *et al.*, 1998; Fikret *et al.*, 2005; Castelo *et al.*, 2007; Charalampidou *et al.*, 2008), CSA (Hannam and Wood, 1989; Close *et al.*, 1995; Gan *et al.*, 2000; Kitai *et al.*, 2002; Boom *et al.*, 2008), and volume (Gionhaku and Lowe, 1989; Kitai *et al.*, 2002; Boom *et al.*, 2008). Thickness can be measured easily with ultrasound, although measurement error can result from

Table 4 Correlation coefficient between masseter muscle cross-sectional area (CSA) and bite force.

	CSA-relaxed (1), (right and left mean)	CSA-clenched (2), (right and left mean)	CSA difference (2)−(1)
Bite force	0.68**	0.58**	0.15

**$P < 0.01$.

the location of the probe or excess pressure on the skin (Kiliaridis and Kälebo, 1991; Raadsheer *et al.*, 1994). Volume is considered a superior index with few errors (Boom *et al.*, 2008) but requires the use of computed tomography (CT) or magnetic resonance imaging (MRI), which is more time-consuming. All the study subjects were orthodontic patients, and CT and MRI were deemed to be excessive examinations. Thus, CSA was measured using a diagnostic ultrasound system. Because this system is non-invasive and features real-time recording, it has no risks and is quick to perform. During CSA imaging, the probe was positioned parallel to the occlusal plane, based on a report indicating that the direction of the superficial masseter relative to the occlusal plane is independent of the craniofacial skeleton (55.8 ± 6.1 degrees; Murata *et al.*, 2000).

Correlations between CSA and cephalometric measurements

The correlations between CSA and cephalometric measurements indicated that as the masseter became larger, mandibular inclination (i.e. FMA and GoGn–SN) tended to become smaller (Table 3), consistent with previous reports (Sassouni, 1969; Gionhaku and Lowe, 1989; Bakke *et al.*, 1992; Kubota *et al.*, 1998; Benington *et al.*, 1999; Fikret *et al.*, 2005). Gionhaku and Lowe (1989) evaluated the volume of the masseter in adults with a partial or full dentition and found that muscle volume showed significant negative correlations with SN–mandibular, SN–occlusal, and gonial angle. Similar correlations for CSA were observed in the present study, except for the occlusal plane angle. This difference may be due to the indirect effect of the masseter on the teeth, through the intervention of the bone and periodontal membrane, and to the variation in the inclination of the occlusal plane, even in subjects with similar skeletal patterns. Bakke *et al.* (1992) found similar correlations between muscle thickness and maximum clenching. Furthermore, they reported that the difference between the thicknesses with the muscle relaxed and maximally clenched also correlated significantly with total anterior face height, lower anterior face height (LAFH), FMA, and palatal–mandibular plane angle. The present study found similar tendencies not only for CSA-relaxed and CSA-clenched but also in the difference between the two.

Characteristic features concerning maxillary location

CSA-clenched showed significant positive correlations with SN–palatal, FH–palatal, PNS–Go/S–-Go, and N–ANS/N–M and negative correlations with ANS–M/N–M and S–PNS/S–Go ($P < 0.05$; Table 3). These results indicate that as the masseter becomes larger, the anterior region of the maxilla tends to shift downwards, relative to the cranial base, whereas the posterior region tends to shift upwards. Accordingly, as the masseter became larger, the ratios of LAFH and upper posterior face height to the corresponding totals became smaller and the ratios of upper anterior face height (UAFH) and lower posterior face height (LPFH) to the corresponding totals became larger. This suggests that the maxilla tends to rotate clockwise with increasing masseter muscle size, while the mandible rotates counter-clockwise. Additionally, it was found that the difference between CSA-relaxed and CSA-clenched was also correlated with values associated with the maxilla, such as SN–palatal, N–ANS/N–M, and S–PNS/S–Go ($P < 0.05$; Table 3). These results indicate that as the change in masseter muscle size between contraction and relaxation becomes larger, the ratio of UAFH and LPFH to the corresponding totals becomes larger.

Correlations between bite force and cephalometric measurements

Bite force, which has been reported to correlate with CSA (Van Spronsen *et al.*, 1992; Hatch *et al.*, 2000; Goto *et al.*, 2005; Ueki *et al.*, 2006), was evaluated objectively in this study to confirm the relationship between the masseter muscle and craniofacial morphology. Bite force correlated significantly with both CSA-relaxed and CSA-clenched ($P < 0.01$; Table 4). While the strength of the jaw-closing muscle has been thought to affect craniofacial morphology (Kubota, 2001; Kovero *et al.*, 2002; García-Morales *et al.*, 2003; Sondang *et al.*, 2003), bite force in the present study was correlated negatively with S–PNS/S–Go ($P < 0.05$) and positively with PNS–Go/S–Go ($P < 0.05$). No correlation with cephalometric values was observed for the anterior maxillary region, such as anterior face height or palatal plane angle (Table 3). Bite force has been thought to be produced as the reciprocal action of four masticatory muscles, including the masseter, and it has been suggested that these results tend to differ from those of CSA.

Conclusions

1. Bite force did not correlate with the cephalometric values for the anterior maxillary region, such as anterior face height or palatal plane angle. These results tended to differ from those for CSA.
2. The decrease in ANS–M/N–M and increase in PNS–Go/S–Go with an increase in masseter muscle size may be

influenced not only by the inclination of the mandibular plane but also by clockwise rotation of the maxilla.

3. As the masseter became larger, the anterior maxillary region tended to shift downwards relative to the cranial base, whereas the posterior region tended to shift upwards.

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