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Relationships among facial type, buccolingual molar inclination, and cortical bone thickness of the mandible

Toyohiko Masumoto, Ikumasa Hayashi, Akira Kawamura, Katsuji Tanaka and Kazutaka Kasai
Department of Orthodontics, Nihon University School of Dentistry at Matsudo, Chiba, Japan

SUMMARY The purpose of this study was to evaluate the relationships between different facial types, and both the buccolingual molar inclination and cortical bone thickness of the mandible. The material consisted of 31 dry skulls of modern Japanese males from the Museum of the University of Tokyo. They all demonstrated normal occlusion with minimal dental discrepancy, and without crossbite or facial asymmetry. The buccolingual inclination of the second molar (M2) in the long-faced subjects was significantly smaller than the same dimension in the average- and short-faced subjects. It was found that the teeth of long-faced subjects were more lingually inclined than those of the short-faced subjects. The cortical bone thickness of the first molar (M1) and M2 sections was thicker in short-faced subjects than in average- and long-faced subjects. The results of this study provide evidence that a significant, but complex relationship exists between structures of the mandibular body and facial types. The morphological features that relate to masticatory function and facial types are associated with the cortical bone thickness of the mandibular body, and the buccolingual inclination of the first and second molars.

Introduction

Many factors such as the tongue, buccinator muscle, and mastication (Kanazawa and Kasai, 1998) are involved in the position and inclination of the teeth, which are matters of great importance in orthodontic treatment. Regarding tooth position in the mandibular structure, there have been many reports on the relationship between the lower incisor and symphysis based solely on evaluation of cephalograms (Robinson *et al*., 1972; Jacobson *et al*., 1974; Worms *et al*., 1976; Wehrbein *et al*., 1996). Kanazawa and Kasai (1998) and Kasai *et al*. (1999) investigated the differences in tooth axis between ancient and modern people, and Tsunori *et al*. (1998) reported the characteristics of the mandible in Asiatic Indians using computed tomography. However, the relationship between the bucco-lingual position of the molars and dentofacial morphology has not been fully investigated.

In a previous study (Tsunori *et al*., 1998), Asiatic Indians skulls were used, but the sex and age of these skulls was estimated by linear discriminate analysis (the probability of correct discrimination was approximately 80 per cent). With males being, on average, somewhat larger than females, a generalization that is commonly employed in approaching the determination of gender on the basis of skeletal morphology is that the cortical bone of males will be thicker and, overall, individual bones will be more massive and heavier. Therefore, in this study, modern male Japanese skulls were used as the sex and age of each subject was recorded in the burial records archived at the University of Tokyo. The purpose of this study was to evaluate the relationship between different facial types, molar inclination, and thickness of mandibular cortical bone in Japanese.

Materials and Methods

The materials consisted of 31 dry skulls of modern (born between 1880 and 1920) Japanese

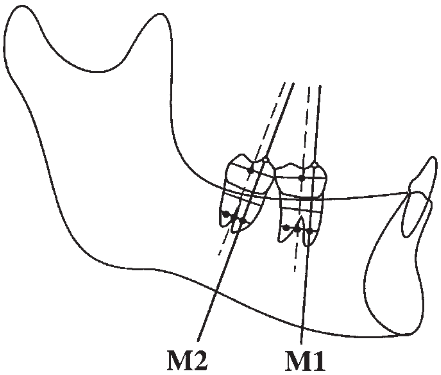

Figure 1 Guidelines of mandibular sections used by computed tomography. On a preliminary view lateral digital localizer image, the central axes (dotted lines) of M1 and M2 were defined as passing through the mid-point of the mesiodistal crown width, and the mid-point between both middle points at one-third of the distance from the root apex of the mesial and the distal roots. The guideline (solid lines) of each molar was placed parallel to the axes through the mesial cusps to obtain radiographs of each mesial root.

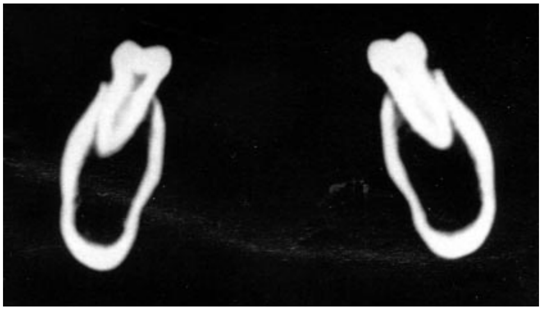

Figure 2 Computed tomogram of M2.

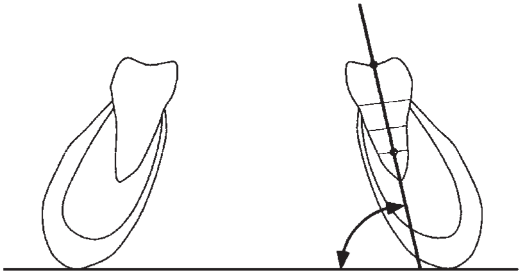

Figure 3 Angular measurement of the tooth inclination (degree). The angle between the basal line (right and left inferior border of the mandibular section) and tooth axis (central fossa and mid-point at one-third of the distance from the root apex).

males (mean age 27 years, range 18–45 years of age) housed in the Department of Anthropology and Prehistory, University Museum of the University of Tokyo. They all demonstrated normal occlusion with minimal dental discrepancy, and without crossbite or facial asymmetry.

Two computed tomograms of the coronal sections at the first molar (M1) and second molar (M2) were obtained. The tomograms were taken with a slice thickness of 1 mm (scan time: 3 seconds, 120 kV, 80 mA; window width: 3000; window level: 300; GE Yokogawa Medical System Co. CT Vertex 3000 Tokyo Japan). The standard plane for positioning consisted of the mid-point of both central incisors and the mesiobuccal cusp of both first molars. The standard plane was positioned perpendicular to the vertical line of the positioning light in the computer tomography machine. The guideline of each molar was made parallel to its axis through the mesial cusp to obtain tomograms of each mesial root. Figure 1 shows the guidelines of the mandibular sections used for the computer tomography. On a preliminary view (lateral digital localizer image) the central axes of M1 and M2 were defined as passing through the mid-point of the mesiodistal crown width, and the mid-point of both middle points at one-third of the root apex of both mesial and distal roots. Figure 2 shows the computed tomogram of the M2. The tooth inclination and cortical bone thickness were measured on the right side. The reference points and variables are defined in Figures 3 and 4. Landmarks were traced from each film and scaled to allow for radiographic enlargement.

The dentofacial morphology was investigated with a lateral cephalogram, which was traced on acetate drafting film, and the selected angles were automatically obtained following landmark digitization. The reference points and variables are defined in Figure 5.

A number of parameters have been used to categorize vertical facial types, including the cant of the mandibular plane, cant of the gonial angle, facial axis, and mandibular arc, as well as the structural morphology of the mandible. The subjects in this study were divided into

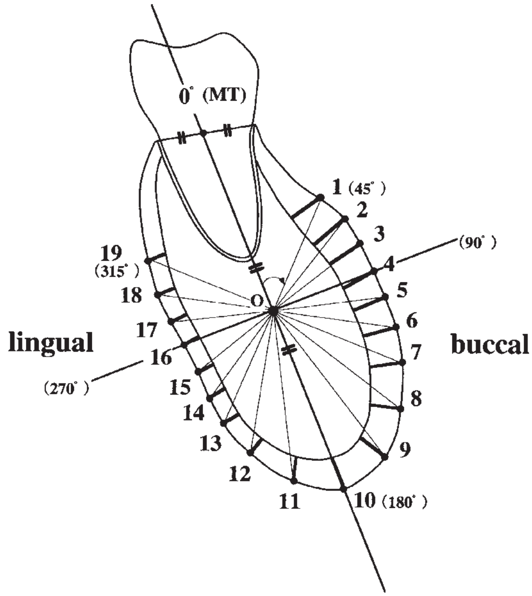

Figure 4 Reference points and measurements of cortical bone thickness (mm). A mid-point was set up from the highest margins of the buccal and lingual alveolar process (the mid-tooth point, MT) and the origin point (O) is the mid-point between MT and the most inferior point on the lower border of the mandible. The MT was then established as 0 degrees and external points on the cortical bony surface were placed every 15 degrees clockwise from point O. The thickness was defined on the 19 points from point 1 (45-degree) to point 19 (315-degree), as the shortest distance from a point on the external cortical bone to the inner cortical bone.

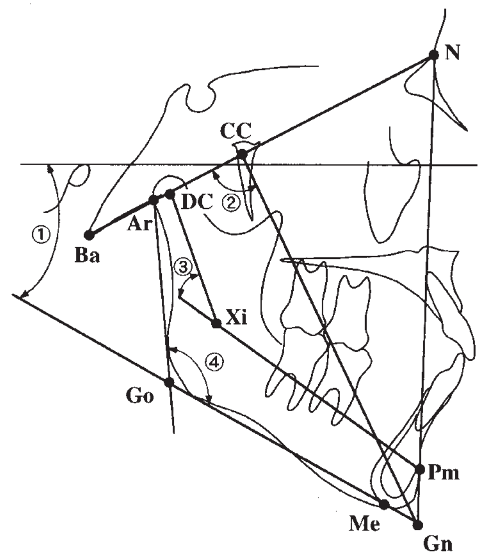

Figure 5 Reference points and angular measurements utilized on the lateral cephalogram. N, nasion; Ar, articulare; Me, menton; Go, gonion; Ba, basion; Gn, gnathion; Pm, protuberane menti; Xi, centroid of the ramus; CC, centre of cranium; DC, condyle centre; ① FMA (Mandibular plane angle); ② Facial axis; ③ mandibular arc (Ricketts *et al*., 1982); ④ gonial angle.

three groups according to facial pattern: short-, average-, and long-faced types. Assignments were based on evaluation of the following facial parameters:

(1) the inclination of the mandibular plane relative to the Frankfort horizontal plane (FMA);
(2) gonial angle (the inclination of the mandibular plane relative to the ramus plane);
(3) facial axis (the inclination of the facial axis relative to the cranial base line);
(4) mandibular arc (the inclination of the corpus axis relative to condyle axis; Ricketts *et al*., 1982).

For each of these four facial parameters, all subjects were rank ordered and divided. Concordance in the ranking was then determined. The 31 subjects were divided into the following facial types: seven short-faced (SF), 17 average-faced (AF), and seven long-faced (LF). Analysis of variance was used to assess differences between the skeletal types for molar angulation and cortical bone thickness.

To assess the significance of the error involved in the computed tomogram, a series of 12 skulls were assessed 2 months after the initial measurements. The mean difference between the first and second measurements, the standard error of a single measurement, and the percentage of the total variance attributable to measurement errors were calculated for each variable. The error variance (*Ve*) was calculated using the following formula;

$$Ve = \Sigma(X_1 - X_2)^2/2n,$$

where X_1 and X_2 are the repeated measurements and n is the sample size. The mean differences were less than 0.2 mm or 1.0 degree. A small

Table 1 Measurement of facial types and tooth inclination.

	SF (n = 7)		AF (n = 17)		LF (n = 7)		ANOVA, significance of F		
	Mean	SD	Mean	SD	Mean	SD	SF–AF	AF–LF	SF–LF
FMA	20.4	4.78	26.7	3.00	32.2	2.53	**	**	**
Facial axis	86.4	3.46	84.3	3.86	83.0	4.00			
Mandibular arc	38.8	5.17	36.7	4.63	33.8	4.14			
Gonial angle	119.2	3.98	122.5	6.69	125.1	5.23			*
Tooth inclination									
M1	79.4	5.35	78.2	4.70	77.7	4.81			
M2	72.3	3.67	72.2	6.40	66.7	3.09		*	**

*Significance of $F < 0.05$; **$F < 0.01$. SF, short-faced; AF, average-faced; LF, long-faced.

Table 2 Cortical bone thickness at the first molar region among facial types (mm).

Degrees	SF (n = 7)		AF (n = 17)		LF (n = 7)		ANOVA, significance of F		
	Mean	SD	Mean	SD	Mean	SD	SF–AF	AF–LF	SF–LF
45	3.17	0.52	2.81	0.75	2.97	0.67			
60	3.67	0.62	3.13	0.70	3.16	0.78			
75	3.82	0.42	3.28	0.58	3.10	0.73	*		*
90	3.51	0.28	3.15	0.65	2.91	0.62			*
105	3.07	0.39	2.84	0.63	2.78	0.57			
120	2.87	0.31	2.69	0.51	2.62	0.39			
135	2.76	0.40	2.63	0.41	2.62	0.50			
150	3.07	0.47	2.87	0.34	2.67	0.48			
165	3.43	0.42	3.05	0.44	2.76	0.60			*
180	3.70	0.72	3.34	0.62	3.15	0.78			
195	3.57	0.72	3.32	0.50	3.25	0.72			
210	3.04	0.44	2.64	0.35	2.53	0.40	*		*
225	2.70	0.29	2.40	0.44	2.33	0.71			
240	2.39	0.33	2.15	0.46	2.27	0.47			
255	2.44	0.48	2.37	0.57	2.52	0.54			
270	2.70	0.31	2.55	0.40	2.60	0.53			
285	2.85	0.16	2.54	0.47	2.57	0.48			
300	2.99	0.16	2.66	0.48	2.47	0.46			**
315	3.11	0.73	2.57	0.49	2.29	0.52	*		*

*Significance of $F < 0.05$; **$F < 0.01$.

number of significant mean differences between the first and second measurements of some variables reflected difficulties in the identification of some reference points, especially tooth axes. In general, the contributions of errors to the total variance were small, ranging from 3.1 to 7.2 per cent. Correlation coefficients were used to summarize these data in order to assess the relationships between tooth inclination, cortical bone thickness, and dentofacial morphology.

Results

The classification of facial types from the cephalograms is given in Table 1, and the differences in tooth inclinations of M1 and

Table 3 Cortical bone thickness at the second molar region among facial types (mm).

Degrees	SF (n = 7)		AF (n = 17)		LF (n = 7)		ANOVA, significance of F		
	Mean	SD	Mean	SD	Mean	SD	SF–AF	AF–LF	SF–LF
45	3.99	0.50	3.69	0.78	3.65	0.70			
60	4.15	0.41	3.92	0.73	3.55	1.14			
75	3.72	0.56	3.60	0.62	3.18	0.92			
90	3.30	0.42	3.35	0.71	2.83	0.77			
105	3.15	0.31	2.98	0.56	2.52	0.67			*
120	2.78	0.32	2.74	0.40	2.29	0.47		*	*
135	2.59	0.55	2.57	0.43	2.29	0.60			
150	2.60	0.40	2.64	0.49	2.13	0.37		*	*
165	3.15	0.51	3.00	0.51	2.72	0.63			
180	3.25	0.42	3.10	0.46	2.99	0.84			
195	3.39	0.28	3.16	0.50	2.96	0.60			
210	2.74	0.46	2.62	0.37	2.44	0.62			*
225	2.50	0.59	2.27	0.51	2.16	0.61			
240	2.26	0.45	1.96	0.43	1.83	0.45			
255	2.32	0.46	2.03	0.39	1.77	0.47			*
270	2.44	0.46	2.14	0.51	1.90	0.41			*
285	2.83	0.47	2.64	0.67	2.20	0.54			*
300	3.06	0.62	2.65	0.59	2.35	0.56			*
315	2.69	0.39	2.45	0.45	2.10	0.48			*

*Significance of $F < 0.05$; **$F < 0.01$.

M2 are shown in Table 2. The inclination of M2 in LF subjects was significantly smaller than in SF and AF subjects. However, this indicated that the molars of LF subjects were positioned more lingually than those of the SF subjects. There was no significant difference in M1 inclination; the mean value for SF subjects was just 1.7 degrees larger than that of LF subjects.

Tables 3 and 4 show the differences in cortical bone thickness among the facial types. The buccal regions (from 45- to 120-degree areas) of SF subjects were thicker than those of AF and LF subjects. The basal regions (from 135- to 225-degree areas) of SF subjects were thicker than those of LF subjects. In addition, the lingual regions (from 240- to 315-degree areas) of SF subjects were thicker than those of AF and LF subjects.

Tables 5 and 6 show the correlation coefficients between cortical bone thickness of each section and facial type parameters. Significant correlation coefficients in M1 sections were found between FMA, and basal and lingual cortical bone thickness (165, 180, 210, 300, and 315 degrees), and between mandibular arc, and buccal and lingual cortical bone thickness (90 and 285 degrees). Significant correlation coefficients in M2 sections were found between FMA, and basal and lingual cortical bone thickness (165, 180, 195, and 315 degrees), between facial axis and cortical bone thickness (135 degrees), and between the gonial angle and lingual cortical bone thickness (315 degrees).

Discussion

In orthodontic research, there have been many reports on the relationship between lower incisor and mandibular symphysis evaluated on lateral cephalograms. The mesiodistal changes of the mandibular molar axis during treatment have also been evaluated by lateral radiographic tomography (Rebellato *et al.*, 1997). However, the buccolingual inclination of molars is not yet fully understood. Computed tomography of the coronal section is necessary when examining the buccolingual inclination. On the measurement accuracy of computed tomography, Kawamura

Table 4 Correlation coefficients between facial measurements and cortical bone thickness at the first molar region.

Degrees	FMA	Facial axis	Mandibular arc	Gonial angle
45	–0.04	–0.16	–0.04	–0.06
60	–0.17	–0.19	0.06	–0.02
75	–0.26	–0.04	0.23	–0.10
90	–0.27	0.02	0.42*	–0.24
105	–0.04	–0.14	0.18	0.11
120	0.03	–0.08	0.25	0.07
135	0.03	–0.21	0.14	0.14
150	–0.29	–0.13	0.28	–0.03
165	–0.50**	0.05	0.26	–0.25
180	–0.41*	–0.05	0.25	–0.36
195	–0.33	–0.03	0.33	–0.31
210	–0.56**	0.11	0.35	–0.26
225	–0.29	–0.01	0.23	–0.07
240	–0.08	0.08	0.26	0.06
255	0.18	–0.27	0.24	0.04
270	0.09	–0.23	0.28	–0.12
285	–0.17	–0.11	0.36*	–0.25
300	–0.36*	–0.06	0.32	–0.28
315	–0.40*	0.19	0.32	–0.32

Significant level of *t*-value of correlation coefficient: *$P < 0.05$; **$P < 0.01$.

Table 5 Correlation coefficients between facial measurements and cortical bone thickness at the second molar region.

Degrees	FMA	Facial axis	Mandibular arc	Gonial angle
45	–0.03	–0.19	0.20	0.04
60	–0.07	–0.27	–0.06	0.15
75	–0.06	–0.25	–0.13	0.00
90	–0.05	–0.24	–0.17	0.00
105	–0.12	–0.22	–0.04	–0.14
120	0.13	–0.18	0.02	–0.18
135	–0.02	–0.43*	–0.08	–0.06
150	–0.29	–0.06	0.23	–0.19
165	–0.37**	0.15	0.00	–0.08
180	–0.38*	0.04	0.09	–0.23
195	–0.39*	–0.06	–0.17	–0.09
210	–0.27	–0.25	0.02	–0.21
225	–0.19	–0.19	–0.03	0.01
240	–0.32	–0.21	–0.03	–0.06
255	–0.32	–0.16	0.09	–0.16
270	–0.21	–0.09	0.04	–0.12
285	–0.11	–0.06	–0.06	0.00
300	–0.17	–0.05	0.14	–0.15
315	–0.39*	–0.21	0.25	–0.46**

Significant level of *t*-value of correlation coefficient: *$P < 0.05$; **$P < 0.01$.

et al. (1998) indicated that the reliability of tooth inclination by computed tomography should be assessed by a paired *t*-test of initial and repeated measurements of the first and second molars. In this study, the means and standard deviations of absolute errors computed for linear and angular measurements remained less than 0.1 mm and 0.13 degrees. There was no significant difference between the initial and repeated measurements. Thus, the method was confirmed to be useful and reliable, and might contribute to the evaluation of tooth inclination and cortical bone thickness. In this study, right-sided data were used for analysis because the guideline of the mandibular section was defined by right side of the mandible on the preliminary view (lateral digital localizer image).

The results of this study provide evidence that buccal cortical bone thickness is associated with facial type. A thicker buccal cortical bone is associated with a smaller gonial angle and mandibular plane angle. On the other hand, with respect to tooth inclination, the subjects with a smaller gonial angle and mandibular plane angle were found to have more vertically positioned molars. Kawamura (1999) reported that the buccolingual inclination of mandibular molars was associated with facial types characterized by ramus height, gonial angle, and mandibular plane angle. The results of this study agree with those findings.

From the perspective of functional anatomy, the characteristics of the gonial and mandibular plane angles have been investigated with regard to the relationship between dentofacial morphology and masticatory function. Muscle activity during maximal clenching has been correlated with mandibular prognathism, anterior inclination of the mandible, and a small gonial angle (Varrela, 1992). Patients with myotonic dystrophy show weak masticatory muscles, and their craniofacial morphology is characterized by a large angle between the mandibular and palatal planes, and a steep mandible (Ringqvist, 1973). Most studies have reported that bite force is associated with a large posterior facial height, a long mandible, a flat mandibular plane, and a small gonial angle (Møller, 1966; Ingervall and Helkimo, 1978; Ingervall and Bitsanis, 1987; Kiliaridis *et al.*, 1989; Ingervall, 1997), which characterize SF types. These relationships are independent of the overall size and their specificity argues for differences in the tension-generating capacities of muscles according to facial type (long, average, and short face).

Ishida and Soma (1993) reported that the direction of force applied to the molars in the occlusal terminal phase showed a buccal direction of the lower molar. Originally, the mandibular molars erupt lingually and then incline towards the buccal. Also, the molars move buccally because of tongue pressure and masticatory function. Finally, the molars reach a balanced position between tongue and buccal pressure, and also are in the position of adaptability of masticatory function. The changes in dental arch width are greater in the mandibular first molar than in the second molar (Moyers *et al.*, 1976). The bite force of the second molar is also greater than that of the first molar as a result of jaw muscle orientation and moment arms (Van Spronsen *et al.*, 1997). Kanazawa and Kasai (1998) reported that the lingual inclination of the mandibular molars of ancient people was less than that of modern people, and the mandibular cortical bone of the ancient people was thicker because of the supporting strong bite force and masticatory function. The standing position of teeth might therefore be changed by masticatory function.

The cortical bone thickness of the molar sections seems to be influenced by masticatory function. The mandibular body of the molar region had a structure resistant to torsional moments. The width of the cortical bone in the buccal-alveolar part of the mandibular molar region was 2.59~4.15 mm. The widths of cortical bone and spongy bone on the buccal side were relatively thicker than on the lingual side. The buccal cortical bone thickness of the mandibular molars was influenced by the masticatory muscle and mandibular movement.

The bite force or masticatory function caused by the masticatory muscles influences not only tooth positions and dental arch forms, but also mandibular shapes and structures (Fogle and Glaros, 1995; Kiliaridis *et al.*, 1995). Investigation of the mandibular structures, including the teeth, is important for understanding occlusal stability and tooth position in orthodontic treatment. The relationship between facial types and structures of the mandibular body would also be interesting from the view of functional anatomy.

The results of this study suggest that the mandibular body of the second molar region has a structure resistant to applied force from the buccal direction. Therefore, the cortical bone becomes thicker to support the second molar. In addition, the results of this investigation might indicate that the buccolingual inclination of the mandibular second molar is related to the masticatory function associated with facial type.

Conclusions

The results of this study provide evidence that facial types are associated with the cortical bone thickness of the mandibular body, and with the buccolingual inclination of first and second molars, and the standing position of mandibular molars, which are affected by masticatory function.

Address for correspondence

Dr Toyohiko Masumoto
Department of Orthodontics
Nihon University School of Dentistry at Matsudo
2–870–1 Sakaecho-nishi
Matsudo
Chiba 271-8587
Japan

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