Morphological Characteristics of Vertical Sections of the Mandible Obtained by CT Scanning

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Abstract The external structure of the mandible is not only under the control of genetic factors, but is also influenced by biomechanical factors such as the masticatory muscles. As is well known, one of the characteristics of the morphology of the mandible which represents the influence of these factors is the gonial angle. It varies from a low angle with strong masseter development to a high angle with reduced muscle activity. The aims of this study were to investigate the internal structures of vertical sections of the mandibular body and to evaluate the relationship between these structures and the gonial angle.

A principal component analysis grouped all cortical thicknesses except for the buccal cortical bone thickness together with large loadings on the same factor. Buccal cortical bone thickness was more variable than the other variables and showed a different pattern of variation.

The gonial angle was associated with buccal and lingual cortical bone thickness in the second molar section, and was also related to the height of the symphysis and the height and width of the second molar section. These results confirmed the relationship between the gonial angle and the size of the mandibular body at the second molar region.

This study provided evidence that masticatory function influenced on both the internal structure and the size of mandibular body.

Key Words: mandibular body, CT scanning, internal structure, gonial angle, PCA

INTRODUCTION

The interaction between the masticatory muscles and the craniofacial skeleton has been widely recognized as playing an important role in the control of craniofacial growth. In particular, there are many reports on the relationship between the masseter muscle and the craniofacial morphology (Proctor and De Vincenzo, 1970; Takada *et al.*, 1984; Haskell and Tetz, 1986; Van Spronsen *et al.*, 1992; Kasai *et*

al., 1994; Braun *et al.*, 1995a, 1995b). Recently, the cross-sectional areas of the jaw muscles have been imaged by Computer Tomography (CT) and Magnetic Resonance Imaging (MRI), and the muscles have been shown to be different in shape between groups with different skeletal forms (Weijjs and Hillen, 1984a, 1984b, 1986; Hannam and Wood, 1989; Gionhaku and Lowe, 1989; Van Spronsen *et al.*, 1989, 1991, 1992; Sasaki *et al.*, 1989). The jaw-closing muscle activity is said to be the greatest in subjects with a large posterior facial height, a small anterior facial height, a long mandible, a flat mandibular plane, and a small gonial angle (Moller, 1966; Ingervell and Thilander, 1974; Tabe, 1976). Temporal and masseter cross-sectional areas are larger in subjects with larger facial widths, while masseter and pterygoid muscle cross-sections are greater when the mandibular length is larger (Weijjs and Hillen, 1986). These relationships are independent of the over-all size, and their specificity argues for differences in the tension-generating capacities of muscles according to facial types. The external shape of the mandible is not only under control of genetic factors, but is also influenced by biomechanical factors such as the orientation of the masticatory muscles and the forces which they generate (Kasai *et al.*, 1990).

While many previous studies have focused on the masseter muscle and its influence on the growing craniofacial skeleton (Takada *et al.* 1984; Van Spronsen *et al.*, 1992), there are sound reasons to believe that other aspects of the masseter muscle morphology should vary with changing masticatory function (Kasai *et al.*, 1994). The aims of this study were to investigate the internal structures of vertical sections of the mandibular body and to evaluate the relationship between these structures and the morphology of the gonial angle which has been shown to be associated with the masticatory function (Takada *et al.*, 1984; Tabe, 1976; Moller, 1966; Ingervell and Thilander, 1974).

MATERIALS AND METHODS

The data for this study was obtained from 44 male Asiatic Indian dry skulls at the Department of Anatomy, Nihon University School of Dentistry at Matsudo. The subjects have normal occlusion with minimal dental crowding. All subjects have lower third molars. Five of subjects showed impacted third molars.

For each subject, a lateral radiograph of the skull and four CT scans (GE YOKOGAWA MEDICAL SYSTEM CO. CT VERTEX 3000) of the mandibular body were available. These CT scans (slice thickness, 3 mm; scan time 3 s; 120 kV) were made in the high-precision mode, intersecting the symphysis, second premolar, first molar and second molar as accurately as possible at a right angle to the mandibular plane. The reference points and variables are defined in Table 1 and Figs. 1 and 2. Landmarks were traced from each film, digitized, and scaled to allow for radiographic enlargement.

Table 1. Definitions of cephalometric and radiographic (CT) measurements

gonial angle	Angle between ramus line (the line through posterior border of condyle, tangent to the mandibular posterior at the angle region) and mandibular line (the line through Menton, tangent to the mandibular border at the angle region)
sym buccal cort. bone thick.	Thickness of the buccal cortical bone of symphysis section
sym lingual cort. bone thick.	Thickness of the lingual cortical bone of symphysis section
sym base cort. bone thick.	Thickness of the basal cortical bone of symphysis section
sym height	Height from the lowest median point on the mandible to the point infradentale
sym width	Thickness of mandibular body measured at the symphysis parallel to the vertical axis of the body of mandible
sym area	Area of symphysis section
sym cortical bone area	Area of the cortical bone of symphysis section
premolar buccal cort. bone thick.	Thickness of the buccal cortical bone of second premolar section
premolar lingual cort. bone thick.	Thickness of the lingual cortical bone of second premolar section
premolar base cort. bone thick.	Thickness of the basal cortical bone of second premolar
premolar height	Height from the lowest median point on the mandible to the highest point of alveolar bone at second premolar section
premolar width	Thickness of mandibular body measured at the second premolar parallel to the vertical axis of the body of mandible
premolar area	Area of second premolar section
premolar cortical bone area	Area of the cortical bone of second premolar section
1st molar buccal cort. bone thick.	Thickness of the buccal cortical bone of first molar section
1st molar lingual cort. bone thick.	Thickness of the lingual cortical bone of first molar section
1st molar base cort. bone thick.	Thickness of the basal cortical bone of first molar section
1st molar height	Height from the lowest median point on the mandible to the highest point of alveolar bone at first molar
1st molar width	Thickness of mandibular body measured at the first molar parallel to the vertical axis of the body of mandible
1st molar area	Area of first molar section
1st molar cortical bone area	Area of the cortical bone of first molar section
2nd molar buccal cort. bone thick.	Thickness of the buccal cortical bone of second molar section
2nd molar lingual cort. bone thick.	Thickness of the lingual cortical bone of second molar section
2nd molar base cort. bone thick.	Thickness of the basal cortical bone of second molar section
2nd molar height	Height from the lowest median point on the mandible to the highest point of alveolar bone at second molar
2nd molar width	Thickness of mandibular body measured at the second molar parallel to the vertical axis of the body of mandible
2nd molar area	Area of second molar section
2nd molar cortical bone area	Area of the cortical bone of second molar section

The mean and standard deviation were estimated for each of the variables assessed from the CT scans. A principal component analysis was undertaken to summarize this data. In addition, multiple regression analyses were undertaken to assess the relationship between the gonial angle and each of the variables. All

statistical analyses were performed by SPSS (Levine, 1991) routines.

To assess the significance of the error involved in the radiographic measurement methods, the authors re-assessed a series of 20 subjects two months after the initial measurements were made. The mean difference between the first and second measurements, the standard error of a single measure, and the percentage of the total variance attributable to measurement errors were calculated for each variable. The error variance (V_E) was calculated using the following formula;

$$V_E = \sum(X_1 - X_2)^2 / 2n ,$$

where “ X_1 ” and X_2 ” are the measurements repeated and “ n ” is the sample size. The mean differences were less than 1.0 mm or 1.0 degree. A small number of significant mean differences between the first and second measurements of some variables reflected difficulties in the identification of some reference points, especially the tooth axis. In general, the contributions of errors to the total variance were small, ranging from 1.8 to 6.5%.

RESULTS

Table 2 shows the means and standard deviations for the mandibular body variables. The results of the principal component analysis after the varimax rotation were presented in Table 3. Before performing statistical analyses, all variables were tested for normality by Shapiro-Wilk W test. The first factor showed large positive loadings on the area, cortical bone area and the height of all sections. This factor was interpreted as the size of sections. The second factor showed large positive loadings on the width of each section. The third factor showed the relationship with the lingual cortical bone thickness of each section. The fourth factor showed the association with the base cortical bone thickness. The fifth factor showed buccal cortical bone thickness in the symphysis and premolar sections. The sixth factor reflected the buccal cortical bone thickness in the second molar section. These factors were interpreted as a width factor, a lingual cortical bone, a base cortical bone and buccal cortical bone factors. Furthermore, the buccal cortical bone thickness was showed a different pattern of variation than other variables and showed much greater variation.

Table 4 indicated the result of the regression analysis of the gonial angle and cortical bone thickness of each section. The multiple correlation coefficient (multiple R) was 0.691. There were significant correlations between the gonial angle and the buccal and lingual cortical bone thickness of the second molar section.

Correlations between the gonial angle and the height and width of each section was presented in Table 5. The values indicated that there were statistically significant relationships between the gonial angle and the symphysis height, the second molar height and width. The multiple R was 0.886. The coefficients indicated

Table 2. Means and standard deviations of measurements

variables	(mm or mm ²)	
	mean	s.d.
sym buccal cort. bone thick.	2.32	0.75
sym lingual cort. bone thick.	2.82	0.71
sym base cort. bone thick.	3.61	0.90
sym height	28.98	3.86
sym width	14.38	3.04
sym area	259.89	51.26
sym cortical bone area	157.02	28.12
premolar buccal cort. bone thick.	3.22	0.77
premolar lingual cort. bone thick.	3.35	0.83
premolar base cort. bone thick.	4.47	0.82
premolar height	29.03	3.34
premolar width	16.67	2.07
premolar area	354.23	72.45
premolar cortical bone area	199.25	44.18
1st molar buccal cort. bone thick.	3.47	0.98
1st molar lingual cort. bone thick.	2.97	0.71
1st molar base cort. bone thick.	4.23	0.77
1st molar height	27.37	3.07
1st molar width	17.68	2.06
1st molar area	342.37	70.95
1st molar cortical bone area	184.52	36.82
2nd molar buccal cort. bone thick.	3.47	0.68
2nd molar lingual cort. bone thick.	2.44	0.81
2nd molar base cort. bone thick.	3.92	0.56
2nd molar height	25.10	2.86
2nd molar width	19.60	1.69
2nd molar area	330.73	55.70
2nd molar cortical bone area	174.72	26.63

that second molar height was inversely related to the gonial angle.

The relationship between the gonial angle and section areas are shown in Table 6.

DISCUSSION

Bone masses and bone remodelling activities such as bone deposition and resorption vary not only from bone to bone, but also within a single bone of the skeleton. These variations in bone mass and bone activity are among the factors determined by the function of the bone or part of the bone (Nordin, 1973). The function of the mandible is different in the three regions (incisor, premolar, and molar), and is also different in the alveolar process and the mandibular body because the attachment of muscles differs from region to region. There is, therefore, great variation in shape, course of trajectories, and thickness of cortices within the mandible (Jourde and Vanneuville, 1971a, 1971b; Sagne 1976). Furthermore,

Table 3. The result of PCA after varimax rotation

variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
sym buccal cort. bone thick.	.131	.230	.336	.112	-.740	-.163
sym lingual cort. bone thick.	.078	.281	.813	.162	.091	.228
sym base cort. bone thick.	.414	-.186	.628	.468	-.211	.078
sym height	.711	-.024	.106	-.138	.484	.404
sym width	.406	.820	.227	.207	-.130	-.018
sym area	.747	.513	.187	.030	.143	.066
sym cortical bone area	.784	.152	.420	.271	.002	.163
premolar buccal cort. bone thick.	.235	.438	.379	.094	.561	-.361
premolar lingual cort. bone thick.	.675	-.031	.217	.338	.460	-.225
premolar base cort. bone thick.	.379	.273	.377	.559	.355	.107
premolar height	.910	.157	-.064	.119	-.194	.056
premolar width	.641	.640	.070	.153	.283	-.013
premolar area	.856	.334	-.014	.166	.216	.064
premolar cortical bone area	.810	.163	.313	.315	.277	-.007
1st molar buccal cort. bone thick.	.231	.415	.688	.242	-.140	-.082
1st molar lingual cort. bone thick.	-.091	.476	.777	-.164	-.133	-.028
1st molar base cort. bone thick.	.219	-.104	.106	.922	-.031	-.113
1st molar height	.952	.114	-.012	.122	-.102	-.098
1st molar width	.378	.840	.256	-.118	.001	.060
1st molar area	.889	.369	.053	.034	-.012	-.035
1st molar cortical bone area	.766	.324	.387	.251	.009	-.035
2nd molar buccal cort. bone thick.	.098	.016	.092	.124	.056	.964
2nd molar lingual cort. bone thick.	.035	-.234	.798	.447	.086	-.018
2nd molar base cort. bone thick.	.099	.048	.311	.820	-.076	.348
2nd molar height	.952	.083	.011	.095	-.064	.036
2nd molar width	.293	.885	.041	-.153	-.076	-.004
2nd molar area	.880	.420	-.043	.043	.020	.041
2nd molar cortical bone area	.871	.221	.342	.149	.056	.119
Eigen value	14.11	3.83	3.08	1.69	1.51	1.02
Percentage of variables	50.4	13.7	11.0	6.0	5.4	3.6

the function of the mandible depends on the dentition. Therefore, a variation in bone mass and bone activity in the different regions within the mandible would be expected.

Wowern and Stoltze (1978) found that there was no significant sex or age differences in the bone mass of the buccal and lingual cortices, trabecular coarseness or the bone activity. In the buccal and lingual cortices, a significant age difference was demonstrated, but there was no sex difference in the percent bone mass. The cortical porosity in mandibles clearly increases with age, but seems to be independent of sex.

Kasai *et al.* (1990) studied the relationship between the gonial angle and the outline of vertical sections of the mandibular body. They found that the gonial angle was negatively related to the height and width of the second molar region, but that

Table 4. Multiple regression analysis of gonial angle and cortical bone thickness

variables	B	SE B	Beta	T	Sig. T
sym buccal cort. bone thick.	-2.100	1.795	-0.215	-1.170	0.251
sym lingual cort. bone thick.	-1.115	2.179	-0.108	-0.512	0.612
sym base cort. bone thick.	0.004	1.753	0.004	0.002	0.998
premolar buccal cort. bone thick.	-0.499	2.082	-0.048	-0.240	0.812
premolar lingual cort. bone thick.	-1.855	1.742	-0.210	-1.065	0.295
premolar base cort. bone thick.	-2.899	2.056	-0.323	-1.410	0.168
1st molar buccal cort. bone thick.	-1.544	1.275	-0.234	-1.211	0.235
1st molar lingual cort. bone thick.	0.592	1.940	0.057	0.305	0.762
1st molar base cort. bone thick.	1.358	1.975	0.146	0.687	0.497
2nd molar buccal cort. bone thick.	4.011	1.571	0.399	2.553	0.015*
2nd molar lingual cort. bone thick.	4.341	1.726	0.477	2.516	0.017*
2nd molar base cort. bone thick.	-3.697	2.710	-0.282	-1.364	0.182
constant	138.051	8.991			
Multiple R R square					
0.691 0.478					

B: partial regression coefficient

*: $P<0.05$, **: $P<0.01$

SE B: standard error of partial regression coefficient

Beta: beta coefficient

T: student's t value

Sig. T: significant level of t value

Table 5. Multiple regression analysis of gonial angle and height and width of each section

variables	B	SE B	Beta	T	Sig. T
sym height	1.589	0.632	0.631	2.515	0.029*
sym width	0.547	1.572	0.120	0.348	0.734
premolar height	0.453	1.044	0.188	0.434	0.672
premolar width	-2.023	1.293	-0.590	-1.565	0.146
1st molar height	2.001	1.670	0.811	1.198	0.256
1st molar width	-1.159	1.067	-0.344	-1.087	0.300
2nd molar height	-4.864	1.482	-1.957	-3.282	0.007**
2nd molar width	3.495	1.357	0.687	2.576	0.026*
constant	106.856	19.699			
Multiple R R square					
0.886 0.784					

B: partial regression coefficient

*: $P<0.05$, **: $P<0.01$

SE B: standard error of partial regression coefficient

Beta: beta coefficient

T: student's t value

Sig. T: significant level of t value

there was no relationship between the gonial angle and symphysis variables. They also described how the height and area of the second molar section in the low angle (small gonial angle) group were significantly larger than those in the high angle

Table 6. Multiple regression analysis of gonial angle and area and cortical bone area of each section

variable	B	SE B	Beta	T	Sig. T
sym area	-0.041	0.085	-0.254	-0.481	0.640
sym cortical bone area	-0.130	0.137	-0.443	-0.949	0.363
premolar area	0.061	0.088	0.536	0.691	0.504
premolar cortical bone area	0.001	0.134	0.005	0.007	0.995
1st molar area	0.033	0.075	0.286	0.444	0.665
1st molar cortical bone area	-0.209	0.131	-0.937	-1.597	0.139
2nd molar area	-0.062	0.122	-0.395	-0.512	0.619
2nd molar cortical bone area	0.167	0.131	0.634	1.281	0.226
constant	150.083	12.474			
Multiple R R square					
0.734 0.539					

B: partial regression coefficient

*: $P < 0.05$, **: $P < 0.01$

SE B: standard error of partial regression coefficient

Beta: beta coefficient

T: student's t value

Sig. T: significant level of t value

(larger gonial angle) group. On one hand the symphysis form might relate to vertical factors of the face, the size of the mandible and the types of occlusion, on the other hand, the form of the second molar section which was closer to the attachment of the masseter and the medial pterygoid muscle was related to the ramus size and the gonial angle.

In this study, the gonial angle was associated with the buccal and lingual cortical bone thickness in the second molar section. Furthermore, the gonial angle was related to the heights of both the symphysis and second molar sections. However, when considering the relationship between the gonial angle and the height of each section, the gonial angle was positively related to the symphysis height, but was negatively related to the height in the second molar region. The correlation between the second molar section height and the gonial angle confirms the results of previous studies (Kasai *et al.* 1990).

It has been suggested that in skeletal deep over-bite cases, the masseter muscle is more anteriorly attached to the mandible and also that it assumes a vertical position (Sassouni, 1969; Sassouni and Nanda, 1964). In contrast, more recent studies have suggested that the biomechanical force vector of the masseter muscle is more anteriorly inclined in Class II short-faced subjects than in Class II long-faced subjects (O'Ryan and Epker, 1982) although a detailed study which compared children who had various malocclusions directly from lateral headfilms, indicated a more upright direction of the masseter muscle in short-faced subjects (Takada *et al.*, 1984) confirmed Sassouni's findings.

The suggestion that masseter muscle angulation is constant relative to the occlusal plane is controversial. Some studies have found this to be the case (Proctor and De Vincenzo, 1970), but others suggest that the masseter muscle is more anteriorly inclined relative to the occlusal plane in subjects with short posterior facial height, steep mandibular plane, and large gonial angle. Despite the differences in these studies, most authors agree that there is no constant relationship between the masseter muscle angulation and the orientation of the occlusal plane (Hannam and Wood, 1989; Horaist, 1974; Takada *et al.*, 1984; Iwasaki 1987). The influence of the masticatory function on the buccal bone thickness is still unknown.

From the view of the functional anatomy, the buccal and lingual structures of second molar sections seemed to be influenced by masticatory function. This is not unexpected as the second molar section was closer to the ramus and the area of attachment of masticatory muscles. However, in this study the buccal cortical bone thickness of the symphysis was negatively associated with the buccal cortical bone thickness of the premolar (see loadings for factor five). It appeared that the buccal cortical bone thickness in the symphysis region was influenced by the inclination of incisors. Thus, the dental arch form and the inclination of teeth were affected by the occlusal bite force of masticatory muscles.

Wowern (1977) indicated that bone mass in the lingual cortex of the mandibular body might not vary between regions. However, in the buccal cortex bone mass might vary from region to region, with a fall in bone mass from incisors to molar region. In addition, bone mass in the buccal cortex of mandibular body in the incisor region showed the greatest individual variations. Generally, lingual cortical bone mass levels might be lower in the incisor and premolar regions of the mandibular body, while bone mass elsewhere might not differ between the two cortices (Wowern 1977).

In this study, the results suggested that the height of second molar section was less than that of symphysis, on the contrary the width of second molar section was greater than that of symphysis. In addition, the second molar section was more round in shape than symphysis form.

In the stress transmission system of mandible, the thin but high bony structure of symphysis resists bending moments, on the other hand low but round bony structure of molar section resists torsional moments (Fujino, 1983). The morphological characteristics of symphysis and of the second molar section represent the extremes of a continuum of variation in both form and function between the two regions with masticatory function influencing both the internal structure and the shape of mandibular body.

In summary, the results of this study provided evidence that there is a significant but complex relationship between the internal structure of the mandibular body and the gonial angle. This relationship is most clearly evident in the principal component

analysis which showed the different characteristics of the buccal and lingual cortical bone thickness. More information about the relationship between the cortical bone thickness of the mandible and the masticatory function should be provided by further studies of comparing modern and ancient mandibles.

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