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Metrical Studies of the Crown Components of the Japanese Mandibular Molars

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Abstract We performed metrical studies of the mandibular crown components of molar teeth in Japanese. Materials used were 140 dental plaster casts (75 males and 65 females). The mandibular first and second molars (M1 and M2) were measured using sliding calipers. Sex differences were greater in the talonid dimensions than in the trigonid dimensions, and were greater in M2 than in M1. Those of the molar reduction were also noted in the talonid dimensions. Although the trigonid mesiodistal diameter was significantly larger in M2 than in M1 ($P < 0.01$), the talonid dimensions were significantly larger in M1 than in M2 ($P < 0.01$). The variability of the crown dimensions was higher in M2 than in M1, especially in the talonid dimensions. This result related to the fact that the talonid developed later than the trigonid in both ontogeny and phylogeny. Allometric relationships between the trigonid or talonid component to total crown size showed that males had negative allometry in the trigonid and positive allometry in the talonid, while females showed isometry in both crown components. These results indicated that the talonid was more variable under the influence of the total size variation, and related to sex difference in tooth size.

Keywords: trigonid, talonid, sex difference, molar reduction, allometry

Introduction

The crown of a mammalian mandibular molar is composed of two components; the trigonid component (the mesial half) and the talonid component (the distal half). Butler (1939) was first to apply the concept of biological fields to dentitions in an attempt to explain the close similarities of adjacent teeth. He suggested that there was an observable mesiodistal gradation of form along the dental arch. Since the mesiodistal gradation of form is quantitative rather than qualitative, the gradation in a molar tooth series thought to occur as the result of the quantitative change of the trigonid and talonid components (Kondo et al., 1999a,b).

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There are a few publications on the metrical variability of these components. Yamada (1992a,b) has reported the metrical variability of the mesiodistal diameters for these components in a Japanese population, and showed that the mesiodistal crown diameter and the talonid mesiodistal diameter were larger on the average in the 5-cusped molars than those in the 4-cusped, but there were no clear differences in these measurements according to the groove patterns. Meanwhile the metrical variability of the buccolingual diameters was not mentioned. The metrical relationships of these crown components between first and second molars were not clear yet, either.

Kondo et al. (1999a) reported the sizes of crown components of the mandibular molars in the southern group of Cook Islanders. They showed that the variability in the crown components related to their developmental timing.

The aim of this study was to investigate the sexual dimorphism and the differences between first and second molars in these crown components of the mandibular molars in a Japanese population using an odontometrical approach.

Materials and Methods

We examined 140 dental plaster casts taken from 75 males and 65 females who were students of Showa University School of Dentistry (Tokyo, Japan). These subjects were from 19 to 25 years old.

Mandibular first and second molars (M1 and M2) were measured to the nearest 0.05 mm using sliding calipers. Measurements taken of the tooth crown (Fig. 1) were the following: the mesiodistal and buccolingual crown diameters (MD and BL) (Fujita, 1949), mesiodistal diameters of the trigonid (TRMD) and the talonid (TLMD) (Yamada, 1992a), and buccolingual diameters of the trigonid (TRBL) and the talonid (TLBL) (Kondo et al., 1998). These measurements were taken irrespective of the cusp number and groove pattern. As a rule, the measurements were taken on the teeth of the right side. When a tooth on the right side could not be measured because of absence, abnormality, heavy wear, or other reasons, the corresponding tooth on the left side of the arch was measured.

In the present study the measurement errors were analyzed by a procedure in which double determination measurements were made on separate occasions for 20 subjects selected at random. Differences between first and second determinations were analyzed by computing the standard deviation of a single determination using method of Dahlberg (1940). The measurement errors ranged from 0.04 mm to 0.11 mm (Table 1). These values were extremely small in magnitude compared with the mean values and comparable with the errors of 0.11 mm and 0.13 mm reported by Yamada (1992a). Thus the errors thought to give no effect for the statistical analysis.

The following crown areas and indices were calculated from the raw measurement values:

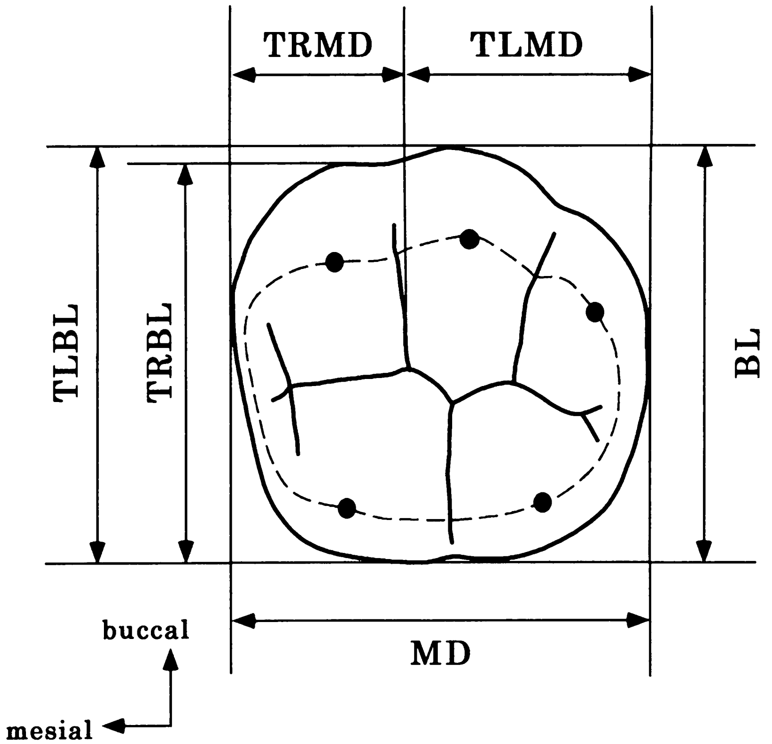

Figure 1. Measurements of the crown diameter of mandibular molars. The measurements of the tooth crown include mesiodistal and buccolingual diameters (MD and BL), and mesiodistal diameters of the trigonid (TRMD) and the talonid (TLMD), and buccolingual diameters of the trigonid (TRBL) and the talonid (TLBL).

Table 1. Measurement errors of the crown dimensions in the mandibular molars (mm)

	N	M1	M2
MD	20	0.05	0.07
BL	20	0.07	0.06
TRMD	20	0.06	0.11
TLMD	20	0.04	0.09
TRBL	20	0.05	0.07
TLBL	20	0.06	0.06

Error estimated as standard deviation of a single determination according to Dahlberg (1940):

$$\text{Error} = \sqrt{\frac{\Sigma d^2}{2N}}$$

where d = difference between 2 determinations

N = number of double determinations

Trigonid area (TRA) = TRMD × TRBL
Talonid area (TLA) = TLMD × TLBL
Total crown area (Area) = TRA + TLA

Crown index (CrI) = BL/MD × 100

Talonid area percentage (TLA%) = TLA/Area × 100

Individual relationships within the molar series were analyzed according to the reduction index described as M2/M1 × 100 by Fujita (1950). This index represents the size of the more reduced tooth (M2) relative to the stable tooth (M1) as a percentage.

Sex differences were compared by the percentage of sexual dimorphism (Garn et al., 1967), defined as [(M-F)/F] × 100. M and F are the mean values of males and females. In the cases of crown indices, talonid area percentages and reduction indices, a percentage of sex difference was simply defined as (M-F).

Allometric trends were assumed by examining the slope of the regression line of the logarithmic trigonid or talonid areas to the logarithmic total crown area. When a slope is nearly 1.0, a crown component area shows isometry. If it is larger or smaller than 1.0, it has positive or negative allometry, respectively.

Statistical analysis was performed with JMP statistical software (SAS Institute, Ver. 3.2.6 for Windows) on a personal computer. Differences between the mean values were analyzed using the two-tailed Student's t-test assuming as a normally distributed data.

Results

Sex difference

Tables 2 and 3 show basic statistics of the crown dimensions, crown areas and indices in the mandibular molars. The crown diameters and crown areas in males were significantly larger than those in female in both M1 and M2 ($P < 0.01$), with the exception of TRMD in M2. The TRMD in M2 was larger in males than in females as the other crown diameters, but the difference was not significant. Percentage sexual dimorphism was greater in M2 than in M1, and was greater in the talonid dimensions than in the trigonid dimensions. The crown indices were slightly larger in females than in males, but the differences were not significant. The talonid area percentage of M2 was significantly larger in males than in females ($P < 0.05$).

Difference between M1 and M2

With the exception of the TRMD and the TRBL of males, crown diameters of both sexes were significantly larger in M1 than in M2 ($P < 0.01$). The TRMD was, however, significantly larger in M2 than in M1 ($P < 0.01$), and the TRBL in males was slightly larger in M1 than in M2, but the difference was not significant. The TRA was larger in M2 than in M1 ($P < 0.01$), while the TLA was larger in M1 than in M2 ($P < 0.01$). The crown index was larger in M2 than in M1 ($P < 0.01$). The talonid area percentage was larger in M1 than in M2 ($P < 0.01$).

Table 2. Basic statistics of the crown dimensions and crown indices in the mandibular first molar

	Male				Female				Sex diff.	
	N	mean	SD	CV	*N*	mean	SD	CV	% diff	*t*-test
Crown diameters (mm)										
MD	73	11.71	0.44	3.73	63	11.36	0.37	3.28	3.04	**
BL	73	11.06	0.45	4.06	63	10.80	0.39	3.66	2.37	**
TRMD	73	5.15	0.25	4.76	63	5.01	0.27	5.30	2.81	**
TLMD	73	6.56	0.41	6.23	63	6.35	0.27	4.20	3.22	**
TRBL	73	10.78	0.43	4.00	63	10.50	0.40	3.76	2.71	**
TLBL	73	11.03	0.47	4.23	63	10.78	0.40	3.66	2.29	**
Crown areas (mm^2)										
TRA	73	55.57	3.63	6.54	63	52.66	4.00	7.61	5.54	**
TLA	73	72.45	6.84	9.44	63	68.53	4.11	6.00	5.73	**
Area	73	128.03	8.72	6.81	63	121.18	6.86	5.66	5.65	**
Crown indices (%)										
CrI	73	94.48	3.36		63	95.12	3.67		– 0.63	NS
TLA%	73	56.52	2.33		63	56.57	1.81		– 0.05	NS

**: $P < 0.01$, *: $P < 0.05$, NS: not significant

Table 3. Basic statistics of the crown dimensions and crown indices in the mandibular second molar

	Male				Female				Sex diff.	
	N	mean	SD	CV	*N*	mean	SD	CV	% diff	*t*-test
Crown diameters (mm)										
MD	71	11.13‡	0.67	6.00	61	10.60‡	0.46	4.31	5.04	**
BL	71	10.72‡	0.56	5.25	61	10.28‡	0.46	4.44	4.23	**
TRMD	71	5.52‡	0.42	7.64	61	5.39‡	0.41	7.62	2.32	NS
TLMD	71	5.62‡	0.65	11.61	61	5.21‡	0.45	8.70	7.86	**
TRBL	71	10.64^{NS}	0.53	4.98	61	10.22‡	0.48	4.68	4.14	**
TLBL	71	10.52‡	0.61	5.76	61	10.01‡	0.46	4.64	5.04	**
Crown areas (mm^2)										
TRA	71	58.81‡	6.41	10.91	61	55.20‡	5.93	10.74	6.54	**
TLA	71	59.25‡	9.20	15.52	61	52.20‡	5.86	11.22	13.52	**
Area	71	118.07‡	12.09	10.24	61	107.40‡	8.36	7.78	9.93	**
Crown indices (%)										
CrI	71	96.39‡	4.58		61	97.05‡	3.58		– 0.66	NS
TLA%	71	50.05‡	4.24		61	48.60‡	3.85		1.45	*

Sex diff. **: $P < 0.01$, *: $P < 0.05$, NS: not significant
difference between M1 and M2 ‡: $P < 0.01$, NS: not significant

Reduction index

Table 4 shows the reduction indices of the crown components. In general, the

Table 4. Basic statistics of reduction indices (%)

	Male			Female			Sex diff.	
	N	mean	SD	*N*	mean	SD	% diff	*t*-test
MD	62	94.87	4.89	48	93.60	3.70	1.26	NS
BL	62	96.79	4.27	48	95.45	3.52	1.33	NS
TRMD	62	107.21	9.12	48	108.18	7.76	- 0.97	NS
TLMD	62	85.41	9.49	48	82.06	6.06	3.36	*
TRBL	62	98.70	4.04	48	97.78	3.67	0.92	NS
TLBL	62	95.13	4.57	48	92.98	3.80	2.15	**
TRA	62	105.91	10.98	48	105.82	9.06	0.09	NS
TLA	62	81.44	11.33	48	76.36	7.12	5.08	**
Area	62	91.91	7.60	48	89.18	5.32	2.73	*

**: $P < 0.01$, *: $P < 0.05$, NS: not significant

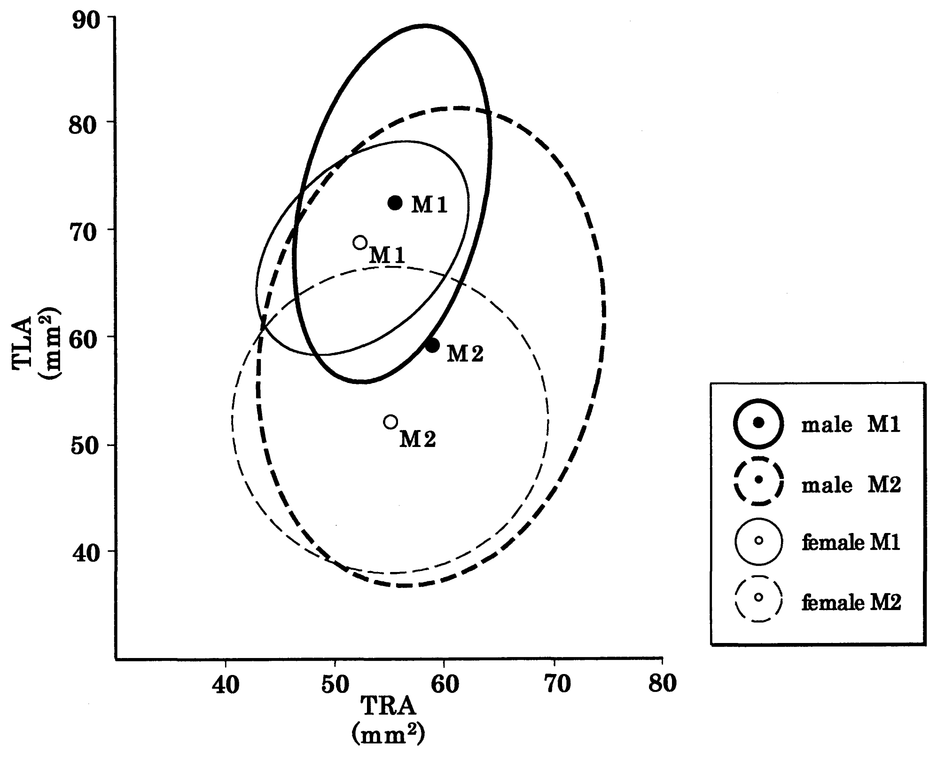

Figure 2. Plots of mean value of the trigonid area (TRA) versus the talonid area (TLA). The ellipse shows the 95% confidence range for bivariate means.

crown reduction was greater in the talonid than in the trigonid and was greater in the MD diameter than in the BL diameter. The TRMD and TRA were not reduced in M2 compared with those of M1, because the reduction indices were larger than 100. Sex differences in the reduction indices were significant in the talonid dimensions and total crown area.

Coefficient of variation

The crown dimensions tended to be more variable in M2 than in M1 (Tables 2 and 3). Particularly, the talonid dimensions showed fairly larger coefficients of variation (11.61% in TLMD of males). Coefficients of variation showed that males varied more than females in size and area dimensions.

Fig. 2 shows the mean values and the 95% confidence ranges of the crown component areas. This figure summarizes the size variability of the two crown components. Sex differences were greater in the talonid than in the trigonid, and were noted in M2. Males varied more than females; the 95% confidence region for the bivariate means in males almost included those in females. The differences between M1 and M2 were also evident in the talonid.

Allometry of crown area

Table 5 shows correlation coefficients and slopes for the linear fitting of the logarithmically transformed areas in which 95% confidence intervals for the slope were obtained. Correlation coefficients ranged from 0.673 to 0.922 ($P < 0.01$). They seemed to be higher in M1 than in M2. Males showed negative allometry in the TRA, but positive allometry in the TLA ($P < 0.05$), while females showed isometry in both the

Table 5. Correlation coefficients and regression slopes of log crown component areas versus log total crown area

			Correlation coefficient	Regression slope	95% confidence interval of slope		Allometry ($P < 0.05$)
					lower 95%	upper 95%	
M1	TRA	male	0.673	0.647	0.478	0.815	–
		female	0.847	1.140	0.956	1.323	0
	TLA	male	0.922	1.267	1.141	1.393	+
		female	0.852	0.893	0.753	1.034	0
M2	TRA	male	0.676	0.734	0.542	0.926	–
		female	0.727	1.019	0.768	1.270	0
	TLA	male	0.845	1.250	1.060	1.440	+
		female	0.697	0.977	0.715	1.240	0

–: negative allometry, 0: isometry, +: positive allometry

TRA and TLA. These results indicated that the talonid was more variable under the influence of the total size variation.

Discussion

Although previous studies showed that M1 had significantly larger MD and BL than M2, the crown component is not always larger in M1 than in M2 (Yamada, 1992a,b; Kondo et al., 1998, 1999a,b). Yamada (1992a) reported that the TRMD was significantly larger in M2 than in M1, while the TLMD was significantly larger in M1 than in M2 in Japanese samples. These results were consistent with this study. In mandibular molar series, studies of the Cook Islanders and Australian Aborigines showed that the trigonid was slightly larger in M2 than in M1, but the difference was not significant. And they showed that the talonid was significantly larger in M1 than in M2. (Kondo et al., 1999a,b).

Comparison between coefficients of variation showed that M2 was more varied than M1 in size, especially in the talonid dimensions. This result seems to relate to the schedule of tooth development; M1 develops earlier than M2, and the trigonid is the first part of the crown to differentiate in both ontogeny (Kraus and Jordan, 1965) and phylogeny (Osborn, 1907). Gingerich (1974) noted an association between early crown formation and low morphological variability in M1. Corruccini (1979) reported cusp-size variability in hominoid primates and concluded that the progression of increasing variability corresponded closely to the order of calcification of the cusps. The ontogenetic hypothesis could be also applied to the variability of the crown components. Kondo et al. (1999a,b) also showed that the later-formed talonid was more varied than the early-formed talonid. Thus, the results of the present study could be explained by the ontogenetic hypothesis.

This study revealed that males had positive allometry in the talonid, but negative allometry in the trigonid. These two contrasting allometric trends in trigonid and talonid components were found in the study of Kanazawa et al. (1985), which analyzed allometrical variation of the cuspal area in M1. They found that Japanese males had positive allometry in hypoconulid but negative allometry in protoconid and metaconid, and this trend was also found in both sexes of Australian Aborigines. On the other hand, we found that females had isometry in both talonid and trigonid components. Kanazawa et al. (1985) described that Japanese females had positive allometry only in hypoconulid, and the other cusps showed isometry. Although their results partially coincided with ours, they showed that hypoconulid had positive allometry as males. They concluded that the allometric variation of M1 was more distinctive in the population that had large teeth. They analyzed each cuspal area, while we analyzed crown components. Although there was a difference in the method between two surveys, similar results were found. There is a discrepancy in the allometric relationships of crown components between sexes, and this finding may relate to sexual dimorphism in tooth size.

Table 6. Percentage of sexual dimorphism of the permanent teeth in Japanese (%)

		MD		BL	
		Gonda (1959)	Kogiso (1982)	Gonda (1959)	Kogiso (1982)
Maxilla					
	I1	1.4	1.8	1.0	0.7
	I2	1.1	2.9	1.7	4.6
	C	3.0	3.7	4.8	3.0
	P1	0.1	1.1	1.7	2.2
	P2	1.2	0.3	2.0	3.0
	M1	2.0	1.5	3.1	3.6
	M2	1.7	2.2	4.8	5.3
Mandible					
	I1	0.2	0.4	1.9	2.6
	I2	1.5	1.3	2.1	3.5
	C	5.8	4.4	8.5	5.2
	P1	1.7	3.1	3.7	3.9
	P2	1.8	1.5	3.3	1.9
	M1	3.5	3.0	3.2	2.3
	M2	3.8	4.6	3.2	3.1

Table 7. Percentage of sexual dimorphism of the mandibular molars in Japanese and Cook Islanders (%)

	M1			M2		
	JPN		Cook	JPN		Cook
	Present study	Yamada (1992b)	Kondo et al. (1999a)	Present study	Yamada (1992b)	Kondo et al. (1999a)
Crown diameters						
MD	3.0	3.5	3.4	5.0	4.7	3.6
BL	2.4	2.1	5.3	4.2	2.8	5.3
TRMD	2.8	2.3	1.2	2.3	1.3	0.8
TLMD	3.2	5.7	5.1	7.9	7.7	6.1
TRBL	2.7		5.5	4.1		5.7
TLBL	2.3		5.6	5.0		4.6
Crown areas						
TRA	5.5		6.8	6.5		6.5
TLA	5.7		10.8	13.5		10.8
Area	5.6	5.9	9.1	9.9	7.4	8.8

JPN: Japanese, Cook: Southern group of Cook Islanders

We calculated the percentage of sexual dimorphism from the average of previous studies in Japanese (Gonda, 1959; Kogiso, 1982) (Table 6). The mandibular canine showed the largest sexual dimorphism, ranging from 4.4% to 8.5%, and these percentages were included the rage from 3% to 9% in many ethnic groups (Keiser, 1990). As for the mandibular molars, the percentage of sexual dimorphism ranged from 2.3% to 4.6%. The percentage of sexual dimorphism of the TLMD in M2 was 7.9% (Table 3), which was comparable to that of the mandibular canine. This finding was consistent with the previous studies (Yamada, 1992b; Kondo et al., 1999a).

Table 7 shows the percentage of sexual dimorphism for the crown dimensions in Japanese (this study and Yamada, 1992b) and Cook Islanders (Kondo et al., 1999a). With the exception of the TLMD of M1, two different studies of the Japanese population showed similar percentages. In buccolingual diameters (BL, TRBL and TLBL), Cook Islanders showed a larger percentage than the Japanese. It was common characteristics in the two populations that the sex differences of the mandibular molars were greater in talonid dimensions than in trigonid dimensions, especially in M2.

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