Bull. Natn. Sci. Mus., Tokyo, Ser. D, **12**, December 22, 1986

Correlated Asymmetries Detected in the Tooth Crown Diameters of Human Permanent Teeth

By

Yuji MIZOGUCHI

Department of Anthropology, National Science Museum, Tokyo

Abstract Right-left asymmetry was examined for the crown diameters of all the permanent teeth except the third molars of both jaws on the basis of a sample consisting of 161 male and 144 female Japanese. The fluctuating asymmetry was confirmed to be statistically significant in almost all the teeth, as was expected. Directional asymmetry was found in some particular teeth consistently in both sexes and it was considered to be due possibly to systematic measurement errors. Antisymmetry was inferred not to be present in any of the tooth crown diameters. Positive correlations were detected between the signed antimeric differences of the buccolingual crown diameters, especially of maxillary cheek teeth. These correlations in a complex of the crown diameters were suspected to be referable to some asymmetry of the jaws forming in the early developmental processes.

In one of the earliest studies on the asymmetry in the human body, v. VERSCHUER (1930) classified many kinds of asymmetry of organs and behavior into two types. One is normal asymmetry, such as the position of the heart, the left-handedness referable to the functional asymmetry of the cerebral cortex, *etc.*, which can be recognized in an ordinary way. The other is an exception of the symmetry which is expected in ideal condition. For instance, distortion of the median plane of the face, left-right differences in the lengths and circumferences of limbs, asymmetric distribution of pigment or hair on the body, *etc.* were included in this type. Based on the twin data of some asymmetric characters, v. VERSCHUER (1930) considered that in a character which is completed to its final phenotype at an earlier developmental stage, a difference in the degree of its asymmetry between monozygotic twins is less than those for other characters which are much later determined. Namely, the asymmetry of the latter was thought to be influenced much more by accidental environmental factors, resulting in the increase of the difference of the asymmetry between monozygotic twins.

While the above classification of asymmetry by v. VERSCHUER (1930) is used when asymmetry is examined at the level of individuals, VAN VALEN (1962) classified the asymmetry into three types from another viewpoint, that is, on the basis of the way of existence or distribution of the asymmetry within a population. The first type of asymmetry of VAN VALEN is "directional asymmetry." When a greater development of a character on one side is found systematically in most of the members of a certain population, the directional asymmetry of the character can be expressed as a mean value of the differences between the two sides. The second type is "antisymmetry." This is the situation in which asymmetry is normally present in the members of a population, but the side with a character showing a greater development varies from individual to individual. An example of this type presented by VAN VALEN (1962) is lateral hand dominance seen in human populations. The third type of asymmetry is "fluctuating asymmetry." This term is assigned to the asymmetry which may derive from the inability of organisms to develop in precisely determined paths, that is, referable to random deviations from the perfect symmetry to be produced through the canalization or buffering of the genotype (WADDINGTON, 1942). As a measure of the fluctuating asymmetry, the mean intrapair variance or the simple variance of the differences between the two sides has widely been employed. VAN VALEN (1962) noted that any two or all of the above three asymmetry types can exist simultaneously in the same character.

As regards dimensional asymmetry in the human dentition, many investigators have frequently observed evidence for it. Among others, BALLARD (1944) is possibly the first student who suggested that the difference in mesiodistal tooth crown diameters between the left and right sides was the greatest in the maxillary lateral incisor of the permanent teeth from the central incisors to the first molars of both jaws. Since then, the greater left-right variability, *i.e.*, fluctuating asymmetry of the maxillary lateral incisor or of the distal tooth within each morphological tooth class has been repeatedly demonstrated (LUNDSTRÖM, 1948, 1960, 1977; MOORREES and REED, 1964; GARN *et al.*, 1966, 1967, 1970; BAILIT *et al.*, 1970; SUARES, 1974; PERZIGIAN, 1977; BARDEN, 1980; HARRIS and NWEEIA, 1980; TAVERNE, 1980; TOWNSEND and BROWN, 1980; NASS, 1982; MAYHALL and SAUNDERS, 1986). As factors increasing fluctuating dental asymmetry, inbreeding (NISWANDER and CHUNG, 1965), congenital malformation like an oral cleft (ADAMS and NISWANDER, 1967), genetic disease like DOWN syndrome (GARN *et al.*, 1970; BARDEN, 1980), the poor condition of health and nutrition (BAILIT *et al.*, 1970; PERZIGIAN, 1977; HARRIS and NWEEIA, 1980; CORRUCCINI *et al.*, 1982), *etc.* have been suggested. Many authors have considered these and other random environmental factors to influence the buffering or canalization processes of organisms, resulting in the fluctuating asymmetry of teeth. However, DIBENNARDO and BAILIT (1978) asserted that dental asymmetry did not relate to prenatal stress affecting birth weight, gestational age, *etc.* in a Japanese sample. Incidentally, SIEGEL and SMOOKLER (1973) experimentally demonstrated that intermittent high intensity sound increased the degree of fluctuating asymmetry in the lower first molars of laboratory rats.

With respect to directional asymmetry, most investigators have not been able to find any significant antimeric differences for either mesiodistal or buccolingual tooth crown diameters of human teeth (ASANO, 1965; GARN *et al.*, 1966, 1967; ADAMS and NISWANDER, 1967; DOYLE and JOHNSTON, 1977; PERZIGIAN, 1977; TOWNSEND and BROWN, 1979, 1980; HARRIS and NWEEIA, 1980; TAVERNE, 1980) although LUNDSTRÖM

(1948) and CORRUCCINI *et al.* (1982) found significant directional asymmetry for a few teeth. Regarding antisymmetry, few investigators have attempted to detect it in the tooth crown diameters of human teeth. Of them, GREENE (1984) reported, testing the kurtosis of the distribution of antimeric differences, that there was no significant antisymmetry for the mesiodistal and buccolingual tooth crown diameters of the maxillary and mandibular first molars.

As was briefly reviewed above, the previous findings seem to indicate that individual human teeth are led to perfect symmetry by canalization when ideal conditions are provided. That is, most of the asymmetries practically found in the dental size seem to be fluctuating asymmetries.

As regards interrelationships between dental asymmetries, a few authors (GARN *et al.*, 1966, 1967; TOWNSEND and BROWN, 1980) have reported no systematic associations between tooth crown diameters for asymmetry. To the present author, however, it seems that there is some dental size asymmetry which is associated with the sidedness of jaws because we sometimes realize our preferential chewing on one or the other side, and, in fact, the asymmetrical patterns of tooth wear have been reported in man and other primates (MOLNAR and WARD, 1977). In this paper, evidence for such associations between the preferential chewing and dental size asymmetry will be sought, though indirectly, after the presence or absence of fluctuating and directional asymmetries and of antisymmetry has been confirmed.

Materials and Methods

The dental plaster casts from 161 male and 144 female Japanese living in Tokyo were used to assess dental asymmetry. Mean measurement error variances for tooth crown diameters were estimated based on another sample consisting of 61 Japanese individuals. These samples were collected by Prof. K. HANIHARA of the Department of Anthropology, the University of Tokyo. First, the mesiodistal tooth crown diameters of the teeth from the central incisors to the second molars and the buccolingual diameters from the first premolars to the second molars of both jaws were recorded to an accuracy of 0.05 mm by the present author after FUJITA (1949) on the plaster casts. Then only intact antimeric pairs of the dental measurements were selected in the above two samples. The selected data were processed through the following statistical analyses.

Fluctuating asymmetry in each tooth crown diameter and intraobserver measurement errors were assessed by using the mean intrapair variance from the one-way analysis of variance (KEMPTHORNE, 1969). Data for measurement errors were obtained by the double determination method (DAHLBERG, 1926; LUNDSTRÖM, 1948) from the left and right teeth of the above latter sample. Homogeneity throughout all the teeth for bilateral symmetry/asymmetry in the frequency that a right tooth was larger, equal to, or smaller than the corresponding left tooth was examined by chi-square test (SIEGEL, 1956) separately in males and females.

Table 1. Fluctuating asymmetry, *i.e.*, mean intrapair variances from the one-way analyses of variance for the mesiodistal (MD) and buccolingual (BL) tooth crown diameters of permanent teeth.

	Measurement error variance		Right-left variance					
			Male			Female		
	Var.	d.f.	Var.	d.f.	F-ratio[1)]	Var.	d.f.	F-ratio[1)]
MD of UI1	.0049	108	.0258	158	5.31***	.0198	142	4.07***
UI2	.0074	120	.0450	157	6.06***	.0482	142	6.50***
UC	.0061	114	.0205	153	3.33***	.0205	137	3.35***
UP1	.0048	116	.0179	155	3.75***	.0161	142	3.36***
UP2	.0063	102	.0247	150	3.93***	.0217	120	3.46***
UM1	.0110	114	.0371	154	3.38***	.0273	137	2.49***
UM2	.0268	30	.0694	87	2.59***	.0761	89	2.84***
LI1	.0042	112	.0164	144	3.95***	.0114	122	2.73***
LI2	.0079	108	.0171	145	2.17***	.0131	127	1.66***
LC	.0140	114	.0175	157	1.25	.0189	141	1.35*
LP1	.0066	106	.0189	159	2.88***	.0234	141	3.57***
LP2	.0107	92	.0316	147	2.97***	.0298	121	2.80***
LM1	.0112	102	.0306	148	2.73***	.0332	135	2.96***
LM2	.0149	38	.0403	55	2.71***	.0493	61	3.32***
BL of UP1	.0098	120	.0302	153	3.07***	.0330	141	3.36***
UP2	.0099	108	.0536	145	5.41***	.0408	119	4.12***
UM1	.0328	114	.0714	153	2.18***	.0513	130	1.56**
UM2	.0125	42	.0686	50	5.49***	.0546	51	4.37***
LP1	.0189	104	.0409	157	2.16***	.0303	141	1.60**
LP2	.0144	94	.0260	148	1.80***	.0315	123	2.19***
LM1	.0132	102	.0316	150	2.39***	.0229	135	1.73***
LM2	.0142	36	.0343	64	2.42***	.0386	65	2.73***

[1)] One-sided F-test for the significance of a right-left variance in comparison with its corresponding measurement error variance.
* $P<0.05$; ** $P<0.01$; *** $P<0.005$.

For the significance of directional asymmetry, a signed antimeric difference mean (difference=right−left) was tested by using STUDENT's t-test under the null hypothesis that a population mean is zero. Furthermore, for detecting directional asymmetry in a dental multivariate system at a time, a correlation matrix for the tooth crown diameters of the right and left teeth was decomposed into covariance matrices by a method using dummy variables (TAKEUCHI and YANAI, 1972). One of the two matrices is related to the symmetrical part of the dental system and the other to the asymmetrical part. The principal component analysis (LAWLEY and MAXWELL, 1963; OKUNO *et al.*, 1971, 1976; TAKEUCHI and YANAI, 1972) of the asymmetry covariance matrix concisely shows the relative degree of asymmetry for each diameter in the dental system as a whole.

Antisymmetry can be indicated generally by the platykurtosis and sometimes

Table 2. Homogeneity tests for the bilateral symmetry/asymmetry of tooth crown diameters in the permanent dentition.

	Male				Female			
	No. of pairs	Frequency (%)			No. of pairs	Frequency (%)		
		R>L	R=L	R<L		R>L	R=L	R<L
MD of UI1	158	42.4	19.0	38.6	142	43.7	23.2	33.1
UI2	157	54.1	16.6	29.3	142	53.5	18.3	28.2
UC	153	32.7	21.6	45.7	137	34.3	21.9	43.8
UP1	155	38.7	17.4	43.9	142	37.3	22.5	40.1
UP2	150	44.7	16.7	38.7	120	40.8	17.5	41.7
UM1	154	47.4	16.9	35.7	137	54.7	16.8	28.5
UM2	87	62.1	13.8	24.1	89	59.6	11.2	29.2
LI1	144	21.5	26.4	52.1	122	24.6	36.9	38.5
LI2	145	31.7	26.2	42.1	127	27.6	31.5	40.9
LC	157	42.7	19.7	37.6	141	55.3	17.7	27.0
LP1	159	48.4	18.9	32.7	141	44.7	19.9	35.5
LP2	147	29.2	14.3	56.5	121	38.0	20.7	41.3
LM1	148	46.6	23.7	29.7	135	47.4	17.8	34.8
LM2	55	41.8	18.2	40.0	61	47.5	21.3	31.2
BL of UP1	153	39.9	15.0	45.1	141	44.0	16.3	39.7
UP2	145	40.0	13.1	46.9	119	42.0	14.3	43.7
UM1	153	31.4	13.1	55.6	130	39.2	10.0	50.8
UM2	50	34.0	20.0	46.0	51	41.2	9.8	49.0
LP1	157	42.0	19.1	38.9	141	55.3	10.6	34.0
LP2	148	52.7	18.2	29.1	123	43.1	14.6	42.3
LM1	150	54.0	18.7	27.3	135	46.7	16.3	37.0
LM2	64	40.6	17.2	42.2	65	29.2	18.5	52.3
	$\chi^2=1908.07$ (d.f.=42) Probability=0.11				$\chi^2=1607.22$ (d.f.=42) Probability=0.11			

by the leptokurtosis of the distribution of right-left differences (Van Valen, 1962). However, it should be cautioned that superficial leptokurtosis is frequently caused also by sampling errors.

If any common factors control the asymmetry of a complex of characters, the interrelation between the asymmetries of arbitrary two characters in the same complex may be detected by calculating a correlation coefficient between the asymmetries, *i.e.*, signed side differences of the two characters. For example, if, at an earlier developmental stage, an artery of one side of a jaw is formed thicker by chance or other certain factors than that of the other side in an individual, then they will carry blood and nutrients differentially to the two sides of the jaw, resulting in the greater size of teeth on the side with the thicker artery as a whole. In this case, the asymmetry of a complex of the artery, teeth, and others can be regarded as fluctuating asymmetry if the factors are random ones. In the meanwhile, if the factors are not random but those which necessarily cause a bimodal distribution of side differences, the asymmetry

Table 3. Significance tests for the directional asymmetry, *i.e.*, right-left differences in size of tooth crowns in a male sample.

	Sample size	Right		Left		Difference (R−L)		
		Mean	S.D.	Mean	S.D.	Mean	S.D.	*t*-value
MD of UI1	158	8.74	.52	8.71	.49	.03	.23	1.56
UI2	157	7.19	.59	7.11	.65	.08	.29	3.23**
UC	153	8.17	.40	8.18	.39	−.01	.20	−0.73
UP1	155	7.52	.40	7.53	.41	−.01	.19	−0.39
UP2	150	6.96	.40	6.94	.43	.02	.22	0.94
UM1	154	10.66	.52	10.63	.53	.03	.27	1.46
UM2	87	9.81	.55	9.65	.57	.16	.34	4.28***
LI1	144	5.52	.36	5.58	.35	−.06	.17	−4.43***
LI2	145	6.20	.36	6.24	.38	−.04	.18	−2.52*
LC	157	7.21	.38	7.20	.40	.01	.19	0.73
LP1	159	7.41	.41	7.37	.41	.05	.19	2.99**
LP2	147	7.29	.45	7.35	.43	−.06	.24	−3.13**
LM1	148	11.65	.51	11.60	.51	.04	.24	2.19*
LM2	55	10.76	.56	10.73	.56	.02	.29	0.62
BL of UP1	153	9.73	.56	9.73	.59	.01	.25	0.25
UP2	145	9.54	.57	9.55	.59	−.01	.33	−0.29
UM1	153	11.92	.57	11.98	.57	−.05	.38	−1.78
UM2	50	11.56	.65	11.62	.72	−.06	.37	−1.23
LP1	157	8.17	.53	8.18	.52	−.00	.29	−0.17
LP2	148	8.71	.55	8.65	.54	.07	.22	3.73***
LM1	150	11.17	.51	11.12	.53	.05	.25	2.63**
LM2	64	10.56	.49	10.55	.56	.01	.26	0.33

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by the two-sided t-test for the null hypothesis that a population mean is zero.

is regarded as antisymmetry. And, if the above artery was inevitably thickened in only one side by some reasons, directional asymmetry would be found in both the artery and dental size.

Here, two kinds of methods were employed to assess the interrelations of tooth crown asymmetries. First, the tooth crown diameter of a tooth on the side where the mesiodistal or buccolingual tooth crown diameter of the maxillary first molar was larger than that of its antimere was preliminarily compared with that of the corresponding tooth on the other side. From this analysis, the individuals who had the equal-sized maxillary first molars were excluded. A mean value of the signed side differences, which are obtained by subtracting the diameter of a tooth on the side with the smaller maxillary first molar from that on the other side, is still expected to be zero except for the maxillary first molar if the asymmetry of the tooth crown diameter is due to completely random factors and independent of the asymmetry of the maxillary first molar. Namely, a signed difference mean value which is significantly different from zero implies the presence of the correlation between the asymmetries

Table 4. Significance tests for the directional asymmetry, *i.e.*, right-left differences in size of tooth crowns in a female sample.

	Sample size	Right Mean	Right S.D.	Left Mean	Left S.D.	Difference (R−L) Mean	Difference (R−L) S.D.	Difference (R−L) *t*-value
MD of UI1	142	8.45	.49	8.44	.48	.02	.20	1.08
UI2	142	6.94	.61	6.86	.59	.08	.30	3.29**
UC	137	7.71	.45	7.73	.43	−.02	.20	−1.33
UP1	142	7.36	.45	7.35	.41	.01	.18	0.40
UP2	120	6.86	.39	6.85	.40	.02	.21	0.89
UM1	137	10.31	.47	10.27	.49	.04	.23	2.13*
UM2	89	9.62	.47	9.52	.47	.10	.38	2.43*
LI1	122	5.37	.34	5.41	.35	−.04	.15	−2.79**
LI2	127	5.99	.39	6.01	.38	−.02	.16	−1.40
LC	141	6.71	.38	6.68	.39	.03	.19	2.04*
LP1	141	7.19	.43	7.16	.45	.03	.22	1.55
LP2	121	7.17	.45	7.20	.43	−.03	.24	−1.26
LM1	135	11.26	.53	11.23	.53	.03	.26	1.45
LM2	61	10.43	.53	10.41	.58	.02	.32	0.49
BL of UP1	141	9.33	.60	9.32	.58	.01	.26	0.60
UP2	119	9.10	.55	9.11	.57	−.01	.29	−0.27
UM1	130	11.33	.50	11.39	.54	−.06	.32	−2.02*
UM2	51	11.03	.64	10.99	.63	.04	.33	0.88
LP1	141	7.84	.56	7.81	.55	.04	.25	1.70
LP2	123	8.34	.49	8.32	.49	.02	.25	0.93
LM1	135	10.72	.58	10.70	.56	.02	.21	0.92
LM2	65	10.04	.55	10.09	.55	−.05	.28	−1.52

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by the two-sided *t*-test for the null hypothesis that a population mean is zero.

of the maxillary first molar and the relevant tooth. The second method is the principal component analysis of a correlation matrix for ordinarily signed differences between the right and left sides. This clearly indicates the presence of correlated asymmetries in a complex of tooth crown diameters in the form of the covariance with the common factors extracted (the effect of directional asymmetry, if any, is automatically eliminated when the correlation coefficients are estimated, and fluctuating asymmetry inherent to each diameter is expressed as the residual variance in the diameter).

All the calculations for statistical analysis were executed with the HITAC M680H/M682H System of the Computer Centre, the University of Tokyo. Basic statistics such as means and standard deviations were calculated by the use of the BSFMD program. STUDENT's *t*-test, the chi-square test, the analysis of variance and the principal component analysis were performed by using the programs STSTBT, X2TST, MIVCRL and PCAFPP, respectively. All the programs used here were written in FORTRAN by the present author.

Table 5. Covariances between the principal components extracted from the standardized variance-covariance matrices of two kinds, which are related to the symmetrical and asymmetrical parts of tooth crown diameters, and the original variables in a male sample.[1)]

	PCA of symmetrical part					PCA of asymmetrical part		
	PC			Contribution of 3 PC (%)	Total variance	PC	Contribution of PC I (%)	Total variance
	I	II	III			I		
MD of UI1	.70*	.30*	−.21	62.3	.9993	−.03	100.0	.0007
UI2	.40*	.41*	−.34*	44.6	.9950	−.07*	100.0	.0050
UC	.66*	.22	−.33*	59.0	1.0000	.01	100.0	.0000
UP1	.80*	−.11	−.22	70.8	.9996	.02	100.0	.0004
UP2	.73*	−.10	.00	54.1	.9991	−.03	100.0	.0009
UM1	.70*	.29	.48*	80.4	.9979	−.05	100.0	.0021
LI1	.71*	.47*	−.14	74.0	.9912	.09*	100.0	.0088
LI2	.61*	.43*	−.18	59.5	.9967	.06*	100.0	.0033
LC	.71*	.25	−.23	62.2	.9991	−.03	100.0	.0009
LP1	.76*	−.15	−.08	60.3	.9985	−.04	100.0	.0015
LP2	.75*	−.05	.22	60.8	.9958	.07*	100.0	.0042
LM1	.61*	.33*	.53*	75.1	.9997	−.02	100.0	.0003
BL of UP1	.69*	−.46*	−.21	72.7	.9997	−.02	100.0	.0003
UP2	.75*	−.42*	.01	72.9	.9996	−.02	100.0	.0004
UM1	.76*	.02	.37*	72.4	.9996	.02	100.0	.0004
LP1	.61*	−.55*	−.16	69.8	1.0000	.00	100.0	.0000
LP2	.73*	−.45*	.01	73.9	.9948	−.07*	100.0	.0052
LM1	.71*	−.14	.33*	62.6	.9972	−.05*	100.0	.0028
Total variance	8.6361	1.9218	1.2975	66.0	17.9628	.0372	100.0	.0372
Total contribution (%)	48.1	10.7	7.2	66.0	100.0	100.0	100.0	100.0
Cumulative proportion (%)	48.1	58.8	66.0	66.0	100.0	100.0	100.0	100.0

[1)] The sample consists of 90 individuals with a set of intact teeth for all the measurements.

* Covariance greater than 0.30 for the symmetrical part or 0.05 for the asymmetrical part in absolute value.

Results

The significance of the fluctuating asymmetry, *i.e.*, mean intrapair variances between the two sides in the tooth crown diameters is tested on the basis of the mean measurement error variances calculated from the double determination data of both right and left teeth (Table 1). These tests demonstrated the presence of significant fluctuating asymmetry in all the tooth crown diameters examined but the mesiodistal diameter of the male mandibular canine. In passing, a mean intrapair variance, as listed in Table 1, is equal to half of the variance of the difference between the two

Table 6. Covariances between the principal components extracted from the standardized variance-covariance matrices of two kinds, which are related to the symmetrical and asymmetrical parts of tooth crown diameters, and the original variables in a female sample.[1)]

	PCA of symmetrical part					PCA of asymmetrical part		
	PC			Contribution of 3 PC	Total variance	PC	Contribution of PC I	Total variance
	I	II	III	(%)		I	(%)	
MD of UI1	.73*	.43*	−.07	71.9	.9995	−.02	100.0	.0005
UI2	.66*	.39*	.00	58.5	.9972	−.05*	100.0	.0028
UC	.70*	.38*	−.08	63.5	.9992	.03	100.0	.0008
UP1	.86*	.03	−.18	77.4	.9989	−.03	100.0	.0011
UP2	.84*	−.06	−.01	71.0	.9991	−.03	100.0	.0009
UM1	.74*	.05	.52*	82.7	.9999	−.01	100.0	.0001
LI1	.69*	.49*	−.09	73.4	.9907	.10*	100.0	.0093
LI2	.78*	.35*	−.17	75.6	.9998	.01	100.0	.0002
LC	.78*	.26	−.11	68.6	.9997	−.02	100.0	.0003
LP1	.83*	−.02	−.14	71.1	.9973	−.05*	100.0	.0027
LP2	.83*	−.22	.08	74.5	.9972	.05*	100.0	.0028
LM1	.70*	.08	.56*	80.7	.9981	−.04	100.0	.0019
BL of UP1	.73*	−.30	−.37*	76.2	.9997	−.02	100.0	.0003
UP2	.74*	−.43*	−.16	76.1	1.0000	−.00	100.0	.0000
UM1	.65*	−.25	.43*	68.2	.9923	.09*	100.0	.0077
LP1	.69*	−.33*	−.28	66.7	.9974	−.05*	100.0	.0026
LP2	.68*	−.53*	−.13	75.1	.9998	−.01	100.0	.0002
LM1	.72*	−.30*	.30	70.1	.9994	−.02	100.0	.0006
Total variance	9.9784	1.7804	1.2283	72.3	17.9652	.0348	100.0	.0348
Total contribution (%)	55.5	9.9	6.8	72.3	100.0	100.0	100.0	100.0
Cumulative proportion (%)	55.5	65.4	72.3	72.3	100.0	100.0	100.0	100.0

[1)] The sample consists of 69 individuals with a set of intact teeth for all the measurements.

* Covariance greater than 0.30 for the symmetrical part or 0.05 for the asymmetrical part in absolute value.

members of a pair, as in Tables 3 and 4 where it is expressed in the form of standard deviation, if the sample size is sufficiently large and the mean difference is zero. If such a mean intrapair variance, not the variance of difference, is used as a measure of fluctuating asymmetry when there is directional asymmetry, then the mean intrapair variance should be corrected for the directional asymmetry.

Table 2 shows that the proportion of the three frequencies that a right tooth is larger, equal in size, and smaller than the corresponding left tooth is statistically homogeneous through all the tooth crown diameters studied. However, it is discernible that there are tendencies particularly for the mesiodistal diameters of the maxillary lateral incisor and second molar to be greater on the right side in both sexes,

Table 7. Skewness and kurtosis of the distributions of right-left differences in the tooth crown diameters of permanent teeth.

		Male			Female		
		Sample size	Skewness	Kurtosis	Sample size	Skewness	Kurtosis
MD of	UI1	158	0.70***	2.71***	142	−0.05	0.03
	UI2	157	1.32***	8.24***	142	−0.03	1.16**
	UC	153	0.46*	0.49	137	−0.50*	2.10***
	UP1	155	−0.03	1.41***	142	0.33	0.53
	UP2	150	−0.19	−0.08	120	0.25	1.11*
	UM1	154	−0.36	2.88***	137	−0.87***	2.86***
	UM2	87	0.54*	0.90	89	−1.36***	3.26***
	LI1	144	−0.56**	3.43***	122	−0.31	−0.02
	LI2	145	−0.79***	1.58***	127	1.20***	4.70***
	LC	157	−0.02	0.28	141	−0.97***	2.19***
	LP1	159	−0.10	0.74	141	0.05	−0.29
	LP2	147	0.32	0.86*	121	−0.32	0.68
	LM1	148	0.64**	2.33***	135	−0.23	0.30
	LM2	55	−0.01	−0.15	61	−0.13	0.21
BL of	UP1	153	0.26	0.10	141	0.11	1.34***
	UP2	145	1.14***	4.20***	119	0.27	1.30**
	UM1	153	0.28	2.94***	130	0.22	1.14**
	UM2	50	−0.08	1.65*	51	1.27***	2.09**
	LP1	157	−0.02	0.45	141	−0.21	0.24
	LP2	148	0.12	0.08	123	0.15	0.34
	LM1	150	−0.18	1.93***	135	−0.30	0.62
	LM2	64	1.64***	8.42***	65	0.52	1.33*

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by the approximate significance test using a normal deviate (FISHER, 1958).

and for the buccolingual diameter of the maxillary first molar to be greater on the left. These tendencies were confirmed to be statistically significant by a more sensitive test, *i.e.*, the STUDENT's *t*-test for the null hypothesis that a population mean is zero. As shown in Tables 3 and 4, additional significant differences between the right and left sides were detected similarly in males and females. These results suggest directional or systematic asymmetry for some of the tooth crown diameters examined. The principal component analysis of the asymmetry covariance matrix (Tables 5 and 6) definitely indicates the same directional asymmetry tendencies, though the diameters of the second molars were not included in this analysis because of their small sample size. Based on these results, the proportion of the variance due to the directional asymmetry to the total standardized variance (equal to the number of variables) was estimated to be as low as about 0.2% in both males and females.

In Table 7, it is shown that about half of the crown diameters studied have significant leptokurtosis at the 5% level. This may suggest that a small number of extremely large antimeric differences are present for the half of the tooth crown di-

Table 8. Significance tests for the differences in tooth crown size between a tooth on the side where the mesiodistal crown diameter of the maxillary first molar is larger than that of its antimere and the corresponding tooth on the other side.

		Male				Female			
		N	Mean	S.D.	*t*-value	N	Mean	S.D.	*t*-value
MD of	UI1	125	−.01	.23	−0.62	112	−.01	.19	−0.33
	UI2	126	−.02	.29	−0.65	112	.01	.31	0.47
	UC	122	.02	.21	1.20	107	.02	.19	1.13
	UP1	122	.02	.20	1.18	112	−.00	.19	−0.17
	UP2	118	−.02	.22	−1.01	95	.01	.21	0.27
	UM1	128	.24	.18	15.74***	114	.21	.15	15.54***
	UM2	63	−.01	.37	−0.11	71	.08	.36	1.80
	LI	116	−.00	.19	−0.11	98	−.04	.15	−2.33*
	LI2	115	−.03	.19	−1.79	100	−.01	.18	−0.51
	LC	125	.00	.18	0.12	111	.02	.18	1.05
	LP1	126	−.01	.20	−0.79	112	.04	.21	1.77
	LP2	114	−.02	.25	−0.77	93	.01	.26	0.41
	LM1	116	.01	.23	0.47	107	.02	.26	0.81
	LM2	40	−.03	.27	−0.70	49	−.01	.27	−0.21
BL of	UP1	121	.02	.23	0.95	111	.04	.24	1.93
	UP2	112	−.00	.30	−0.14	94	.02	.26	0.67
	UM1	122	.01	.39	0.34	105	.03	.33	0.92
	UM2	35	−.06	.35	−1.07	42	.01	.35	0.19
	LP1	125	.01	.28	0.20	112	.01	.26	0.29
	LP2	115	.02	.23	0.99	96	.01	.26	0.37
	LM1	121	.06	.24	2.53*	108	.05	.20	2.43*
	LM2	46	.05	.29	1.11	50	.01	.28	0.31

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by the two-sided *t*-test for the null hypothesis that a population mean is zero.

ameters. For the other half, neither significant platykurtosis nor leptokurtosis was found.

The results of *t*-tests for detecting those dental asymmetries which are correlated to the asymmetry of the maxillary first molar are shown in Tables 8 and 9. The significant differences which are obtained by subtracting the diameter of a tooth on the side where the mesiodistal (Table 8) or buccolingual (Table 9) diameter of the maxillary first molar is smaller than that of its antimere from the diameter of the corresponding tooth on the opposite side suggest the presence of the asymmetry or unilateral predominance in the relevant tooth crown diameters which is correlated with the asymmetry of the maxillary first molar. In Table 8, the mean difference only for the buccolingual diameter of the mandibular first molar is significant at the 5% level in both sexes except for the mesiodistal diameter of the maxillary first molar used as a key tooth. In Table 9, there is no significant difference in both of males and females. But the buccolingual diameter of one of the maxillary premolars shows a significant

Table 9. Significance tests for the differences in tooth crown size between a tooth on the side where the buccolingual crown diameter of the maxillary first molar is larger than that of its antimere and the corresponding tooth on the other side.

	Male				Female			
	N	Mean	S.D.	*t*-value	N	Mean	S.D.	*t*-value
MD of UI1	131	−.03	.24	−1.20	116	−.02	.21	−1.10
UI2	132	−.02	.32	−0.58	117	−.05	.32	−1.54
UC	126	−.04	.20	−2.04*	110	.02	.20	1.23
UP1	128	.00	.18	0.12	115	−.01	.18	−0.30
UP2	126	−.00	.21	−0.11	96	−.01	.22	−0.23
UM1	129	.00	.27	0.17	115	.05	.23	2.31*
UM2	78	−.07	.38	−1.74	71	−.01	.36	−0.16
LI1	119	.03	.18	2.04*	100	−.01	.15	−0.93
LI2	120	.00	.20	0.17	101	−.01	.17	−0.47
LC	130	−.01	.18	−0.32	115	−.00	.20	−0.16
LP1	131	−.02	.20	−0.87	115	−.04	.21	−1.86
LP2	123	.02	.25	0.84	99	−.02	.24	−0.65
LM1	121	−.02	.24	−0.88	111	.03	.26	1.32
LM2	45	−.03	.29	−0.67	51	−.13	.32	−2.88**
BL of UP1	127	.03	.25	1.11	114	.05	.26	2.27*
UP2	122	.08	.32	2.93**	95	.06	.30	1.86
UM1	133	.31	.26	14.04***	117	.27	.20	14.78***
UM2	45	.10	.37	1.72	42	.08	.33	1.62
LP1	129	.01	.30	0.19	115	−.05	.25	−2.01*
LP2	124	−.02	.23	−0.98	100	−.02	.25	−0.79
LM1	124	−.02	.25	−0.90	110	.03	.20	1.49
LM2	54	−.03	.27	−0.84	56	−.01	.27	−0.33

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by the two-sided *t*-test for the null hypothesis that a population mean is zero.

difference in males and females. This condition is more clearly illustrated in Fig. 1, suggesting the presence of correlated asymmetries in the buccolingual diameters of the maxillary cheek teeth.

In order to seek an overall tendency of such correlated asymmetries in a dental system, the principal component analysis for signed antimeric differences was carried out separately in males (Table 10) and females (Table 11). The tendency which was suggested in Table 9 and Fig. 1 was again detected through the first principal component in males and through the second principal component in females (Tables 10 and 11; Fig. 2). The other tendency of asymmetry correlations for females shown in Table 8 seems to be represented by the first principal component in females (Table 11).

Table 10. Principal component analysis for the signed right-left differences of mesiodistal and buccolingual tooth crown diameters in a male sample.[1)]

	Factor loading			Total variance
	PC I	II	III	(%)
MD of UI1	.11	.48*	.18	27.2
UI2	−.28	−.41*	.07	25.3
UC	.24	.66*	.34*	60.9
UP1	−.22	.22	.53*	37.3
UP2	−.35*	−.24	.35*	30.4
UM1	−.06	.30*	−.07	9.8
LI1	.29	−.45*	.38*	43.4
LI2	−.03	.18	−.32*	13.7
LC	−.19	−.00	.21	8.2
LP1	−.31*	−.54*	.28	46.6
LP2	−.17	−.03	−.32*	13.4
LM1	−.17	.11	.48*	27.4
BL of UP1	.55*	.04	.33*	40.8
UP2	.83*	−.10	−.04	69.3
UM1	.55*	−.14	.08	32.5
LP1	−.37*	.30*	.08	23.7
LP2	−.54*	.19	.04	32.5
LM1	−.17	.04	−.33*	13.8
Total contribution (%)	13.0	9.6	8.3	30.9
Cumulative prop. (%)	13.0	22.6	30.9	30.9

[1)] The sample consists of 90 individuals with a set of intact teeth for measurements.
* Factor loading greater than 0.30 in absolute value.

Discussion

Fluctuating asymmetry

As was stated previously, fluctuating asymmetry has been demonstrated to be present in the tooth crown diameters of human teeth by many authors (LUNDSTRÖM, 1948; GARN *et al.*, 1966, 1967; and others). This was confirmed also in the present study (Table 1). The tendency for a distal tooth to have the increased degree of fluctuating dimensional asymmetry in comparison with a mesial tooth within each morphological tooth class (TOWNSEND and BROWN, 1980; and others) has also been suggested to be consistent with the tendency in the variation of the tooth crown diameters expected from the field theory of BUTLER (1939) and DAHLBERG (1945, 1951). This was again verified to be mostly the case in the present study. Although causes for the fluctuating asymmetry in size of human teeth have not yet been analyzed enough, it is widely accepted for the present that they may be random environmental factors in the developmental processes. It should be noted, however, that part of the "mean intrapair variance" between the two sides may be due to the effect of directional asymmetry, if any, and, further, caused by the factors relating to antisymmetry.

Table 11. Principal component analysis for the signed right-left differences of mesiodistal and buccolingual tooth crown diameters in a female sample.[1)]

	Factor loading			Total variance
	PC I	II	III	(%)
MD of UI1	−.09	−.18	.27	11.0
UI2	.43*	−.43*	−.12	37.8
UC	.23	.16	−.39*	23.3
UP1	.21	−.11	−.21	10.3
UP2	−.04	−.00	.66*	43.7
UM1	.53*	.42*	.07	46.2
LI1	−.47*	−.27	.30*	47.8
LI2	−.09	.50*	−.26	32.6
LC	.16	−.36*	.28	23.3
LP1	.27	−.20	−.16	13.6
LP2	.53*	−.14	−.01	29.8
LM1	.57*	.02	−.31*	42.4
BL of UP1	.48*	.35*	.17	37.8
UP2	.39*	.15	.71*	68.3
UM1	.22	.64*	.27	53.3
LP1	.36*	−.54*	.04	43.0
LP2	.59*	−.27	.10	43.4
LM1	.43*	.04	−.00	18.3
Total contribution (%)	14.4	10.3	9.5	34.2
Cumulative prop. (%)	14.4	24.7	34.2	34.2

1) The sample consists of 69 individuals with a set of intact teeth for measurements.
* Factor loading greater than 0.30 in absolute value.

Incidentally, Bailit *et al.* (1970) and Townsend and Brown (1980) used the "intra-class correlation coefficient (per individual)" to measure the degree of buffering (or fluctuating asymmetry) in an individual. However, this is not the so-called intra-class correlation coefficient but a quantity like the Q-mode correlation coefficient (Sneath and Sokal, 1973; Corruccini, 1973) probably without R-mode standardization. Therefore, this quantity cannot fairly represent the degree of buffering for an individual if there is any correlation between characters under consideration.

Directional asymmetry

Although many authors (Garn *et al.*, 1966, 1967; and others) have reported no directional asymmetry for dental dimensions, it was found in some of the tooth crown diameters in the present study (Tables 3 and 4). Among a few authors who found directional asymmetry in teeth, Lundström (1948) referred it to systematic measurement errors without any experiment. In his findings on the maxillary anterior teeth, the mesiodistal diameters of the central and lateral incisors on the left side were significantly greater than those of their antimeres. In the present study, however, the right maxillary incisors were greater (Tables 3 and 4), though the directional asymmetry

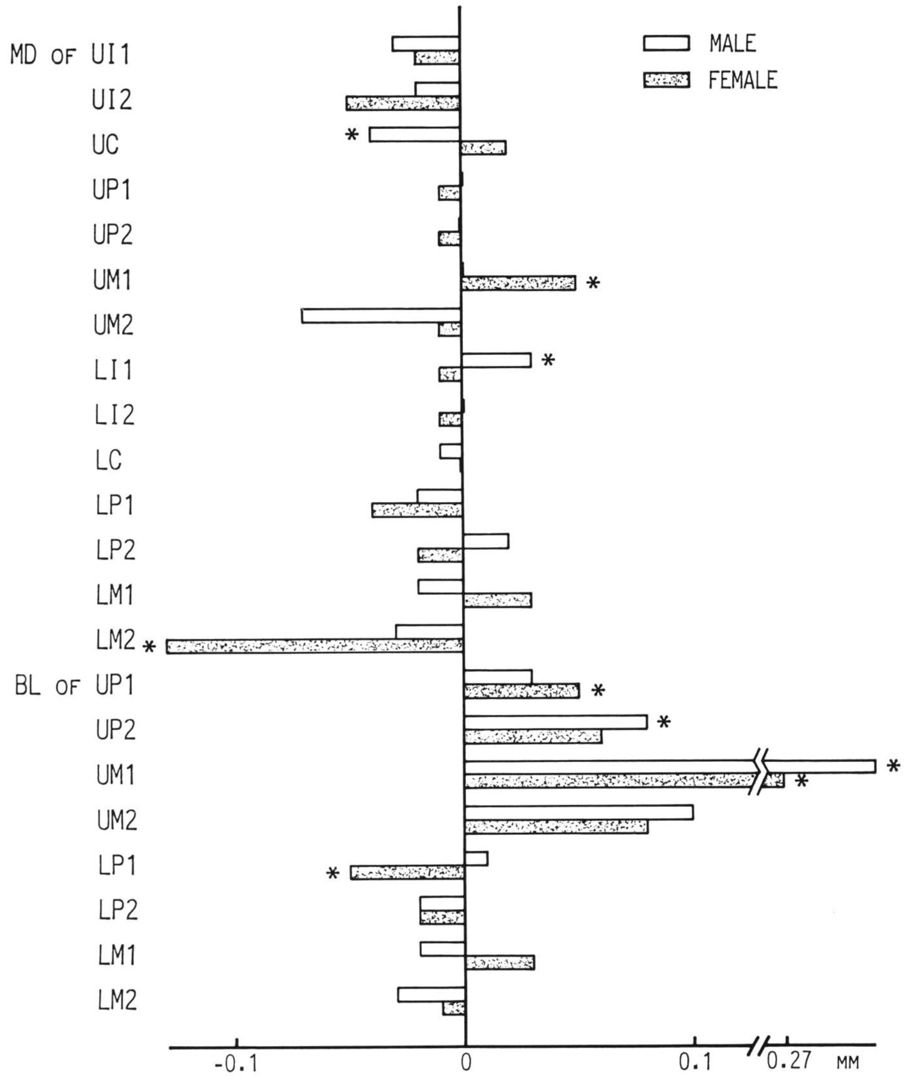

Fig. 1. The mean differences obtained by subtracting the diameter of a tooth on the side where the buccolingual diameter of the maxillary first molar is smaller than that of its antimere from the diameter of the corresponding tooth on the opposite side, suggesting the presence of correlated asymmetries in the buccolingual size of the maxillary cheek teeth. An asterisk denotes a significant mean difference at the 5% level.

for the central was not significant at the 5% level. On the contrary, the directional asymmetry detected by CORRUCCINI *et al.* (1982) is partly consistent with the present results. In their findings on the teeth from the canines to the third molars of both jaws, the mesiodistal diameter of the maxillary second molar as well as the mesiodistal

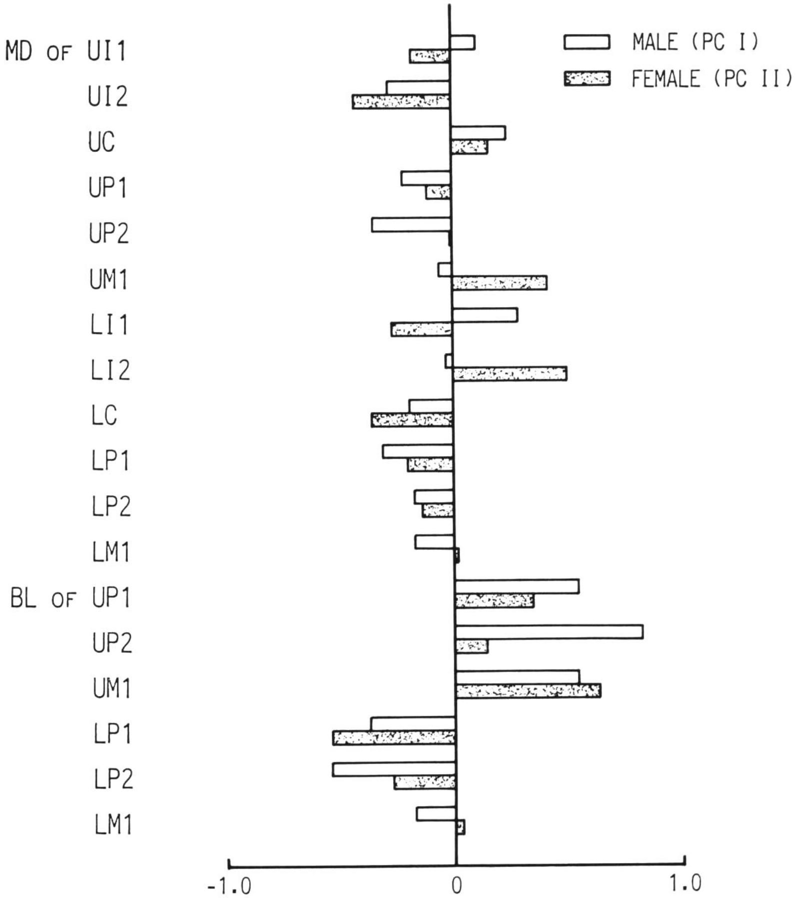

Fig. 2. Factor loadings of the principal component intensively relating to the buccolingual diameters of the cheek teeth, suggesting the presence of correlated asymmetries in the buccolingual size of at least two groups of teeth, *i.e.*, the maxillary cheek tooth group and the mandibular premolar group for the both sexes. The two tooth groups are considered to be independent of each other or to have a negative correlation for asymmetry as a whole.

and buccolingual diameters of the mandibular third molar on the right side were significantly greater than those of the left teeth. The directional asymmetry for the mesiodistal diameter of the maxillary second molar was significant also in the present study. From only these, however, any definite conclusion cannot be drawn.

In the present study, it was further found that the pattern of the appearance of directional asymmetry on tooth rows was very similar in males and females, as shown in Tables 3 and 4. The rank correlation coefficients of two kinds for the directional asymmetry between the male and female dentition were significant at the 1% level

Table 12. Rank correlation coefficients between the patterns of differential directional side asymmetry over the crown diameters of the permanent teeth of the male and female Japanese and Australian Aboriginal samples.[1]

	No. of items	Spearman rank correlation		Kendall rank correlation	
		rho	Prob.	tau	Prob.
Males vs. Females:					
Japanese	22[2]	0.61	<.01	0.49	<.01
Australian	32[3]	0.63	<.001	0.53	<.001
Japanese vs. Australian Ab.:					
Male	22[2]	0.25	>.20	0.17	>.20
Female	22[2]	0.38	<.10	0.27	<.10

[1] The data of antimeric differences in Australian Aborigines were reported by TOWNSEND and BROWN (1980). The sample size varies from 36 to 207 in males and from 41 to 184 in females over measurement items. The rank correlation coefficients were calculated by the present author.

[2] The mesiodistal crown diameters of the permanent teeth from the central incisors to the second molars and the buccolingual crown diameters from the first premolars to the second molars of both jaws.

[3] The mesiodistal and buccolingual crown diameters of all the permanent teeth from the central incisors to the third molars of both jaws.

(Table 12). This tendency is again discernible in the dentition of Australian males and females. The rank correlations based on the data reported by TOWNSEND and BROWN (1980) were also significant at the 0.1% level (Table 12) although TOWNSEND and BROWN could not find any significant directional asymmetry for each crown diameter. However, the rank correlation coefficients between the Japanese and Australian Aboriginal dentition were not significant at the 5% level either in males or in females (Table 12). After all, these findings suggest that some factors specific to each population cause differential directional asymmetry similarly on the tooth rows of males and females. Such factors may or may not be biological. It cannot be denied for the present that they may be associated with systematic measurement errors, as was suspected by LUNDSTRÖM (1948) and NOSS *et al.* (1983).

Antisymmetry

In about half of the tooth crown diameters studied, significant leptokurtosis for the antimeric differences was found (Table 7). This indicates the possibility of the presence of antisymmetry. As mentioned above, however, superficial leptokurtosis is often caused by sampling errors. In fact, the data of males and females did not show the completely same results for all the crown diameters. Therefore, the presence of antisymmetry for these crown diameters should further be examined carefully. For the present, it seems safe to consider that the detected leptokurtosis derives from sampling errors.

Correlated asymmetries

The presence of correlated asymmetries was clearly demonstrated in this study, especially for the buccolingual diameters of posterior teeth (Tables 8 to 11; Figs. 1 and 2). To date, however, there are some investigators who have calculated such intercharacter correlations for the side differences of tooth crown diameters. For example, GARN *et al.* (1966) calculated the intraindividual intertooth asymmetry correlations for mesiodistal diameters, but could not find any consistent tendency between males and females, though a few correlation coefficients were significant. GARN *et al.* (1967) further analyzed buccolingual asymmetry in like manner and, again, could not find any systematic tendency for the asymmetries to be associated within individuals. TOWNSEND and BROWN (1980) stated, separately analyzing the data on mesiodistal and buccolingual crown diameters, that there was no evidence of associations between teeth or tooth classes for asymmetry, although, in fact, they found some significant asymmetry correlations.

Causes for the correlated asymmetries detected in this study are inconspicuous for the present. POTTER and NANCE (1976) examined the mesiodistal and buccolingual diameters of the teeth from the central incisors to the second molars of both jaws in a twin study, and stated that there was no consistent evidence for a genetic basis of asymmetry on tooth crown diameters. If any factors such as the position or direction of a fetus in the uterus, gravity, *etc.* affected the primordium of a jaw at an early developmental stage, the influence of such factors on many tissues or organs like condyles, teeth, *etc.* within the jaw might be kept till later stages. If so, the correlated asymmetries detected here for some tooth crown diameters may be referred to a phenomenon generated at an earlier developmental stage, *e.g.*, to some asymmetry in the jaw primordium. However, the problem as to whether this asymmetry of a complex of the tooth crown diameters may be fluctuating one or antisymmetry is another problem to be resolved in the future. It should further be noted that the bone structure of jaws is more susceptible to environmental factors than teeth at later developmental stages. Therefore, it seems not easy to detect weak interrelationships between jaws and teeth for asymmetry. Recently, COSTA (1986) suggested that there was no tendency for the side with the larger condyle of mandible to be consistent with the side having the greater attrition of cheek teeth. This seems to predict further difficulties in analyzing interrelations between the functional sidedness of jaws and the morphological asymmetries of jaws and teeth. Nevertheless, it is desired to make it sure whether there is a possibility for the asymmetry in the primordium of jaws to cause the asymmetry of teeth, and furthermore, primary preferential chewing on one side.

Acknowledgments

I am highly indebted to Dr. Hajime SAKURA of the Department of Anthropology, National Science Museum, Tokyo, for his detailed reading and many suggestions on this paper. I would also like to thank Prof. Kazuro HANIHARA of the Department of Anthropology, the University of Tokyo for permitting me to measure the teeth used in the present study. Further, my appreciation is expressed to Miss Akiko NAKATSUKA for drawing the excellent figures.

I utilized the NROFF program developed by the Computer Centre, the University of Tokyo, as a word-processor.

Literature cited

ADAMS, M. S., and J. D. NISWANDER, 1967. Developmental 'noise' and a congenital malformation. *Genet. Res., Camb.*, **10**: 313–317.

ASANO, H., 1965. The genetic study on mesio-distal crown diameters of deciduous teeth in twins. *Jap. J. Hum. Genet.*, **10**: 72–89. (In Japanese with English summary.)

BAILIT, H. L., P. L. WORKMAN, J. D. NISWANDER and C. J. MACLEAN, 1970. Dental asymmetry as an indicator of genetic and environmental conditions in human populations. *Hum. Biol.*, **42**: 626–638.

BALLARD, M. L., 1944. Asymmetry in tooth size: A factor in the etiology, diagnosis and treatment of malocclusion. *Angle Orthod.*, **14**: 67–70.

BARDEN, H. S., 1980. Fluctuating dental asymmetry: A measure of developmental instability in Down syndrome. *Am. J. Phys. Anthrop.*, **52**: 169–173.

BUTLER, P. M., 1939. Studies of the mammalian dentition: Differentiation of the post-canine dentition. *Proc. Zool. Soc. London, Ser. B*, **109**: 1–36.

CORRUCCINI, R. S., 1973. Size and shape in similarity coefficients based on metric characters. *Am. J. Phys. Anthrop.*, **38**: 743–753.

CORRUCCINI, R. S., J. S. HANDLER, R. J. MUTAW and F. W. LANGE, 1982. Osteology of a slave burial population from Barbados, West Indies. *Am. J. Phys. Anthrop.*, **59**: 443–459.

COSTA, R. L., Jr., 1986. Asymmetry of the mandibular condyle in Haida Indians. *Am. J. Phys. Anthrop.*, **70**: 119–123.

DAHLBERG, A. A., 1945. The changing dentition of man. *J. Am. Dent. Asso.*, **32**: 676–690.

DAHLBERG, A. A., 1951. The dentition of the American Indian. *In*: Papers on the Physical Anthropology of the American Indian, ed. W. S. LAUGHLIN. New York, Viking Fund, 138–176.

DAHLBERG, G., 1926. Twin Births and Twins from a Hereditary Point of View. Stockholm, Bokförlags-A. -B. Tidens Tryckeri.

DIBENNARDO, R., and H. L. BAILIT, 1978. Stress and dental asymmetry in a population of Japanese children. *Am. J. Phys. Anthrop.*, **48**: 89–94.

DOYLE, W. J., and O. JOHNSTON, 1977. On the meaning of increased fluctuating dental asymmetry: A cross populational study. *Am. J. Phys. Anthrop.*, **46**: 127–134.

FISHER, R. A., 1958. Statistical Methods for Research Workers, 13th ed. Edinburgh, Oliver and Boyd. (Translated into Japanese by K. ENDO and S. NABEYA, 1970, and entitled "Kenkyusha no Tame no Tokeiteki-Hoho." Tokyo, Morikita Shuppan.)

FUJITA, T., 1949. On the standard of the measurement of teeth. *J. Anthrop. Soc. Nippon*, **61**: 27–32. (In Japanese.)

GARN, S.M., M.M. COHEN and M.A. GECIAUSKAS, 1970. Increased crown-size asymmetry in Trisomy G. *J. Dent. Res.*, **49**: 465.

GARN, S. M., A. B. LEWIS and R. S. KEREWSKY, 1966. The meaning of bilateral asymmetry in the permanent dentition. *Angle Orthod.*, **36**: 55–62.

GARN, S. M., A. B. LEWIS and R. S. KEREWSKY, 1967. Buccolingual size asymmetry and its developmental meaning. *Angle Orthod.*, **37**: 186–193.

GREENE, D. L., 1984. Fluctuating dental asymmetry and measurement error. *Am. J. Phys. Anthrop.*, **65**: 283–289.

HARRIS, E. F., and M. T. NWEEIA, 1980. Dental asymmetry as a measure of environmental stress in the Ticuna Indians of Colombia. *Am. J. Phys. Anthrop.*, **53**: 133–142.

KEMPTHORNE, O., 1969. An Introduction to Genetic Statistics. Ames, Iowa State University Press.

LAWLEY, D. N., and A. E. MAXWELL, 1963. Factor Analysis as a Statistical Method. London, Butterworth. (Translated into Japanese by M. OKAMOTO, 1970, and entitled "Inshi-Bunsekiho." Tokyo, Nikkagiren.)

LUNDSTRÖM, A., 1948. Tooth Size and Occlusion in Twins. Basle, S. Karger.

LUNDSTRÖM, A., 1960. Asymmetries in the number and size of the teeth and their aetiological significance. *Trans. Europ. Orthod. Soc.*, **36**: 167–185.

LUNDSTRÖM, A., 1977. Dental genetics. *In*: Orofacial Growth and Development, ed. A. A. DAHLBERG and T. M. GRABER. The Hague, Mouton, 91–107.

MAYHALL, J. T., and S. R. SAUNDERS, 1986. Dimensional and discrete dental trait asymmetry relationships. *Am. J. Phys. Anthrop.*, **69**: 403–411.

MOLNAR, S., and S. C. WARD, 1977. On the hominid masticatory complex: Biomechanical and evolutionary perspectives. *J. Hum. Evol.*, **6**: 557–568.

MOORREES, C. F. A., and R. B. REED, 1964. Correlations among crown diameters of human teeth. *Arch. Oral Biol.*, **9**: 685–697.

NASS, G. G., 1982. Dental asymmetry as an indicator of developmental stress in a free-ranging troop of *Macaca fuscata*. *In*: Teeth: Form, Function, and Evolution, ed. B. KURTÉN. New York, Columbia University Press, 207–227.

NISWANDER, J. D., and C. S. CHUNG, 1965. The effects of inbreeding on tooth size in Japanese children. *Am. J. Hum. Genet.*, **17**: 390–398.

NOSS, J. F., G. R. SCOTT, R. H. Y. POTTER and A. A. DAHLBERG, 1983. Fluctuating asymmetry in molar dimensions and discrete morphological traits in Pima Indians. *Am. J. Phys. Anthrop.*, **61**: 437–445.

OKUNO, T., T. HAGA, K. YAJIMA, C. OKUNO, S. HASHIMOTO and Y. FURUKAWA, 1976, Zoku-Tahenryo-Kaisekiho (Multivariate Analysis Methods, Part 2). Tokyo, Nikkagiren. (In Japanese.)

OKUNO, T., H. KUME, T. HAGA and T. YOSHIZAWA, 1971. Tahenryo-Kaisekiho (Multivariate Analysis Methods). Tokyo, Nikkagiren. (In Japanese.)

PERZIGIAN, A. J., 1977. Fluctuating dental asymmetry: Vairation among skeletal populations. *Am. J. Phys. Anthrop.*, **47**: 81–88.

POTTER, R. H., and W. E. NANCE, 1976. A twin study of dental dimension: I. Discordance, asymmetry, and mirror imagery. *Am. J. Phys. Anthrop.*, **44**: 391–395.

SIEGEL, M. I., and H. H. SMOOKLER, 1973. Fluctuating dental asymmetry and audiogenic stress. *Growth*, **37**: 35–39.

SIEGEL, S., 1956. Nonparametric Statistics for the Behavioral Sciences. Tokyo, McGraw-Hill Kogakusha.

SNEATH, P. H. A., and R. R. SOKAL, 1973. Numerical Taxonomy. San Francisco, W. H. Freeman and Company.

SUARES, B. K., 1974. Neandertal dental asymmetry and the probable mutation effect. *Am. J. Phys. Anthrop.*, **41**: 411–416.

TAKEUCHI, K., and H. YANAI, 1972. Tahenryo-Kaiseki no Kiso (A Basis of Multivariate Analysis). Tokyo, Toyokeizai-Shinposha. (In Japanese.)

TAVERNE, P. P., 1980. Een Fysisch-anthropologisch Onderzoek van de Gebitten van Vier Surinaamse Bevolkingsgroepen. Thesis, Rijksuniversiteit te Groningen.

TOWNSEND, G. C., and T. BROWN, 1979. Tooth size characteristics of Australian Aborigines. *In*: Occasional Papers in Human Biology, No. 1. Canberra, Australian Institute of Aboriginal Studies, 17–38.

Townsend, G. C., and T. Brown, 1980. Dental asymmetry in Australian Aboriginals. *Hum. Biol.*, **52**: 661–673.
Van Valen, L., 1962. A study of fluctuating asymmetry. *Evolution*, **16**: 125–142.
v. Verschuer, O., 1930. Zur Frage der Asymmetrie des menschlichen Körpers. *Z. Morph. Anthrop.*, **27**: 171–178.
Waddington, C. H., 1942. Canalization of development and the inheritance of acquired characters. *Nature*, **150**: 563–565.