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Covariation of Asymmetries in Metric and Nonmetric Tooth Crown Characters

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Abstract The inter-character covariation of right-left differences in eighteen mesiodistal and buccolingual tooth crown diameters and ten nonmetric tooth crown characters was investigated through the principal component analysis of the tetrachoric correlation coefficients between them. In both males and females, it was found that the right-left differences of the lateral incisor shoveling, the CARABELLI's tubercle of the first molar, the buccolingual crown diameters of maxillary cheek teeth, *etc*. had relatively high correlations with a certain principal component. This suggests a tendency for several dental asymmetries to co-vary to some extent. Such a tendency may be explained, in part, by those common environmental factors which can simultaneously influence the symmetry/asymmetry condition of many dental characters in the same way, *e.g.*, the skewed distribution of nerve fibers or blood vessels within the jaws at early developmental stages, the asymmetrical microstructure of blood vessels, *etc*.

From a series of investigations on dental asymmetry by the present author (MIZOGUCH, 1986, 1987, 1988, 1989) and other previous studies, it is inferred that, in general, there is no directional asymmetry having a biological significance in the metric or nonmetric crown characters of human permanent teeth. And antisymmetry has not been detected for any of the mesiodistal or buccolingual tooth crown diameters, and, for nonmetric tooth crown characters, has not been examined, so far as the present author knows. On the other hand, fluctuating asymmetries have been confirmed to be statistically significant in almost all crown diameters and many nonmetric tooth crown characters. With regard to the nature-nurture problem, it has been suggested, based mainly on twin data, that there is no or little genetic variability for the right-left differences of metric or nonmetric tooth crown characters.

One of the problems that still remain to be elucidated on dental asymmetry is that of correlated asymmetries. Although LUNDSTRÖM (1960), GARN *et al.* (1966, 1967) and TOWNSEND and BROWN (1980) asserted that there were no systematic associations between tooth crown diameters for asymmetry, SOFAER *et al.* (1971), MIZOGUCHI (1986) and HERSHKOVITZ *et al.* (1987) found that the asymmetries of some tooth crown diameters were consistently correlated with one another. In the present study, using the more extensive data of dental characters including both metric and nonmetric ones, this problem was once again examined.

Materials and Methods

The materials used are the same as those analyzed by MIZOGUCHI (1986, 1988), *i. e.*, the dental plaster casts from 161 male and 144 female Japanese who resided in Tokyo. These were collected by Prof. Kazuro HANIHARA of International Research Center for Japanese Studies, Kyoto, and are now kept in the Department of Anthropology and Prehistory, University Museum, the University of Tokyo.

The metric characters dealt with are the mesiodistal tooth crown diameters of the central incisor to the first molar teeth and the buccolingual diameters of the first premolar to the first molar teeth of both jaws. They were measured to an accuracy of 0.05 mm by the present author according to FUJITA's (1949) criteria, and the basic statistics such as mean values of them are presented in MIZOGUCHI (1986). In regard to nonmetric tooth crown characters, twenty-eight characters were first observed, but the item number of 28 was reduced to ten in the following analysis (Tables 1 and 2) because the sample sizes for the right-left differences of the remaining eighteen characters were too small to estimate some inter-character correlation coefficients concerning them. The number of the grades assigned to the degree of development of each nonmetric character is four: absence (0), slightly-developed (1), relatively-well-developed (2) and highly-developed (3) grades or expressivities. The details of the scoring methods are described in MIZOGUCHI (1977), and the frequencies of the four expressivities of each character are presented in MIZOGUCHI (1988). For the assessment of intraobserver errors in measuring and scoring dental traits, MIZOGUCHI (1986, 1988) should be consulted.

Correlation coefficients between the right-left differences of the metric and nonmetric characters were all estimated by the tetrachoric correlation method (PEARSON, 1900; EVERITT, 1910; MIZOGUCHI, 1977). As a right-left difference, a direct arithmetical one was used for metric characters, but, in the case of nonmetric characters, an asymmetry measure with the sign of the difference between the grades of the right and left sides was employed, with the value discontinuously varying from -1 (Right$<$Left) through 0 (R$=$L) to 1 (R$>$L). The estimation of tetrachoric correlation coefficients was restricted to the cases where the absolute frequencies in all the four cells of a fourfold correlation table were equal to or more than unity. To the matrix of the tetrachoric correlation coefficients estimated in this way, the principal component analysis (LAWLEY and MAXWELL, 1963; OKUNO *et al.*, 1971, 1976; TAKEUCHI and YANAI, 1972) was applied in order to elucidate the overall interrelationships of dental asymmetries.

All the calculations were executed with the mainframe, HITAC M680H/M682H (VOS3) System, of the Computer Centre, the University of Tokyo. The programs for calculating tetrachoric correlation coefficients and for the principal component analysis are TETRAC and PCAFPP, respectively, which were written in FORTRAN by the present author.

Results

The factor loadings obtained from the principal component analyses of the signed right-left differences of 10 nonmetric and 18 metric dental characters in males and females are listed in Tables 1 and 2, respectively. These results show that there is no so-called general size factor with a prominently large variance for asymmetries in the dental system. In other words, this means that there is no overall and con-

Table 1. Principal component analysis of the signed right-left differences of metric and nonmetric tooth crown characters in males.[1]

Character	Tooth	Factor loading					Total variance (%)
		PC I	II	III	IV	V	
Shoveling	UI2	.03	−.20	.47*	.49*	.17	53.05
De Terra's tubercle	UP1	−.80*	−.18	.25	−.36*	−.06	86.37
De Terra's tubercle	UP2	−.27	−.38*	.55*	−.12	−.40*	70.07
Carabelli's tubercle	UM1	.26	.18	.35*	.48*	.19	48.40
M. L. A. M. T.[2]	UM1	−.34*	−.42*	−.62*	.45*	.01	87.88
D. B. A. M. T.[3]	UM1	−.19	.44*	−.01	.27	−.01	30.31
D. B. A. M. T.[3]	UM2	−.66*	−.08	.24	.21	.47*	77.07
Protostylid	LM1	.07	−.33*	−.21	.07	.29	25.04
Sixth cusp	LM1	−.42*	.20	−.40*	−.05	−.30	47.20
Lingual accessory cusp	LP2	−.09	−.36*	.04	.33*	−.11	25.65
Mesiodistal diameter	UI1	−.12	.18	−.03	.25	.29	19.30
	UI2	.16	−.36*	−.19	−.25	.22	30.16
	UC	.01	.65*	−.26	.00	−.04	48.90
	UP1	−.58*	.09	.13	−.02	.11	37.88
	UP2	−.43*	.06	−.23	−.40*	.07	40.96
	UM1	−.49*	.44*	−.10	.31*	−.03	54.35
	LI1	−.21	−.33*	−.43*	−.06	−.04	34.61
	LI2	.23	−.65*	.16	−.11	.13	53.81
	LC	.08	−.08	−.15	.34*	.53*	43.21
	LP1	−.18	−.21	−.06	−.36*	.37*	34.63
	LP2	−.05	.04	.47*	−.25	.09	29.31
	LM1	.03	.12	−.05	−.29	.61*	47.46
Buccolingual diameter	UP1	.15	.26	−.14	.14	−.13	14.84
	UP2	−.20	−.30	−.07	.42*	−.48*	54.14
	UM1	−.22	−.40*	−.06	.41*	.01	37.96
	LP1	.24	−.19	−.53*	−.03	.14	39.70
	LP2	−.11	.19	.22	.22	.39*	29.73
	LM1	−.25	.06	−.16	−.10	.25	16.63
Total contribution (%)		9.82	9.60	8.56	8.09	7.46	43.52
Cumulative proportion (%)		9.82	19.42	27.98	36.07	43.52	43.52

1) Based on the tetrachoric correlation coefficients, whose sample sizes range from 34 to 157.
2) Mesiolingual accessory marginal tubercle.
3) Distobuccal accessory marginal tubercle.
* Factor loading greater than 0.30 in absolute value.

Table 2. Principal component analysis of the signed right-left differences of metric and nonmetric tooth crown characters in females.[1]

Character	Tooth	Factor loading PC I	II	III	IV	V	Total variance (%)
Shoveling	UI2	−.50*	.21	.09	.21	−.48*	57.41
DE TERRA's tubercle	UP1	−.13	−.36*	−.25	.30	−.08	30.23
DE TERRA's tubercle	UP2	.26	.06	.47*	−.31*	−.42*	56.59
CARABELLI's tubercle	UM1	−.41*	.32*	.18	−.47*	.11	53.98
M. L. A. M. T.[2]	UM1	−.16	−.25	−.08	−.78*	.27	76.62
D. B. A. M. T.[3]	UM1	.24	−.42*	−.12	.13	−.04	26.62
D. B. A. M. T.[3]	UM2	−.21	−.16	.31*	.18	.64*	60.89
Protostylid	LM1	−.72*	.26	.19	.06	.21	67.35
Sixth cusp	LM1	−.29	.06	−.61*	−.35*	−.07	58.14
Lingual accessory cusp	LP2	.59*	.11	−.32*	−.05	.07	46.15
Mesiodistal diameter	UI1	−.10	.48*	.44*	.02	.02	43.02
	UI2	.14	−.35*	.01	−.23	.16	22.32
	UC	.28	−.56*	−.18	.07	−.22	47.34
	UP1	−.06	.02	−.18	.32*	−.19	17.40
	UP2	.08	−.16	.03	.45*	.11	24.22
	UM1	−.48*	−.39*	−.15	−.39*	.07	55.84
	LI1	.46*	.26	−.08	−.30*	.41*	54.34
	LI2	−.09	.43*	−.59*	.16	−.03	56.30
	LC	−.34*	−.25	−.16	.15	.04	22.44
	LP1	−.16	−.24	.18	.26	.24	24.30
	LP2	.49*	−.25	.37*	−.26	.13	52.78
	LM1	−.00	−.19	.24	.04	−.53*	38.08
Buccolingual diameter	UP1	−.17	−.05	.07	−.39*	−.58*	52.59
	UP2	−.42*	−.16	.09	.16	.23	29.17
	UM1	−.22	−.42*	−.23	−.17	−.34*	41.46
	LP1	.05	−.41*	.54*	.13	−.02	47.76
	LP2	−.08	.03	.57*	−.03	−.20	36.84
	LM1	−.33*	−.59*	.01	−.07	.17	49.20
Total contribution (%)		10.36	9.47	8.95	8.02	7.81	44.62
Cumulative proportion (%)		10.36	19.83	28.79	36.81	44.62	44.62

[1] Based on the tetrachoric correlation coefficients, whose sample sizes range from 41 to 141.
[2] Mesiolingual accessory marginal tubercle.
[3] Distobuccal accessory marginal tubercle.
* Factor loading greater than 0.30 in absolute value.

sistent covariation of the asymmetries of tooth crown characters. Comparing the results in Tables 1 and 2, however, some correspondency between males and females can be recognized in the covariation tendency of dental asymmetries. Such correspondency may be more definitely shown by putting only the factor loadings with higher values from males and females side by side (Table 3).

Table 3. Correspondency between males and females in the two sets of principal components on the right-left differences of metric and nonmetric tooth crown characters.[1]

Character	Tooth	Factor loading			
		Male PC IV[2]	Female PC I	Male PC I	Female PC II
Shoveling	UI2	−.49	−.50	—	.21
De Terra's tubercle	UP1	.36	—	−.80	−.36
De Terra's tubercle	UP2	—	.26	−.27	—
Carabelli's tubercle	UM1	−.48	−.41	.26	.32
M. L. A. M. T.[3]	UM1	−.45	−.16	−.34	−.25
D. B. A. M. T.[4]	UM1	−.27	.24	−.19	−.42
D. B. A. M. T.[4]	UM2	−.21	−.21	−.66	−.16
Protostylid	LM1	—	−.72	—	.26
Sixth cusp	LM1	—	−.29	−.42	—
Lingual accessory cusp	LP2	−.33	.59	—	—
Mesiodistal diameter	UI1	−.25	—	—	.48
	UI2	.25	—	.16	−.35
	UC	—	.28	—	−.56
	UP1	—	—	−.58	—
	UP2	.40	—	−.43	−.16
	UM1	−.31	−.48	−.49	−.39
	LI1	—	.46	−.21	.26
	LI2	—	—	.23	.43
	LC	−.34	−.34	—	−.25
	LP1	.36	−.16	−.18	−.24
	LP2	.25	.49	—	−.25
	LM1	.29	—	—	−.19
Buccolingual diameter	UP1	—	−.17	—	—
	UP2	−.42	−.42	−.20	−.16
	UM1	−.41	−.22	−.22	−.42
	LP1	—	—	.24	−.41
	LP2	−.22	—	—	—
	LM1	—	−.33	−.25	−.59

[1] The only factor loadings of greater than 0.15 in absolute value are shown for making a correspondency between males and females conspicuous in principal components. The value of 0.15 as a dividing point was chosen only for convenience' sake.

[2] The signs of factor loadings are reversed for comparison.

[3] Mesiolingual accessory marginal tubercle.

[4] Distobuccal accessory marginal tubercle.

Discussion

Concerning only tooth crown diameters of permanent teeth, Mizoguchi (1986) demonstrated some correlated asymmetries, especially of the buccolingual diameters of posterior teeth. This was again shown in the present results of the principal component analyses of the expanded data including both metric and nonmetric tooth crown characters (Table 3). Namely, the first principal component (PC) of females and the fourth PC of males have relatively high correlations, in the same direction, not only with the buccolingual diameters of maxillary cheek teeth but also with the mesiodistal diameters of the maxillary first molar and mandibular canine, the lateral incisor shoveling, the CARABELLI's tubercle and mesiolingual accessory marginal tubercle of the maxillary first molar, the distobuccal accessory marginal tubercle of the maxillary second molar, *etc.* both in males and in females. Furthermore, the female second PC and male first PC also indicate other parallel tendencies in the covariation of dental asymmetries (Table 3).

In 1971, SOFAER *et al.*, using an index (right−left)/(right+left), had already presented the results similar to those of the above MIZOGUCHI (1986) and the present study, namely, that there were many significant positive correlations between asymmetries in buccolingual diameters but few between those in mesiodistal diameters. They thought that such positive correlations were due to responses to common local environmental conditions affecting neighboring teeth on the same side of the jaw. Further, TOWNSEND and BROWN's (1980) results also revealed the same tendency for significant positive asymmetry correlations to be a little more prevalent in buccolingual diameters than in mesiodistal ones, though the authors interpreted this as giving no evidence of associations between dental size asymmetries. Recently, moreover, HERSHKOVITZ *et al.* (1987) showed, using the principal component analysis and a rotation method, that asymmetries of several tooth crown diameters, especially of maxillary milk molars and of maxillary and mandibular premolars, separately, tend to systematically co-vary.

On the contrary, however, LUNDSTRÖM (1960), GARN *et al.* (1966, 1967) and TOWNSEND and BROWN (1980), as mentioned above, asserted that no systematic tendency was recognized in asymmetry correlations between tooth crown diameters. Regarding component characters of a tooth crown, CORRUCCINI and POTTER (1981) attempted to estimate correlations between the absolute values of arithmetic right-left differences in the diameters of the protocone, protoconid, hypoconid and hypoconulid of the permanent first molars. In result, they could not find any significant correlations between the cusp size asymmetries except a positive correlation for hypoconid-hypoconulid asymmetry. Although the directions of the asymmetries of the hypoconid and hypoconulid are not clear because of their use of absolute right-left differences, CORRUCCINI and POTTER (1981) interpreted this correlation as the outcome of a disproportionately large hypoconid on one side fostering a relatively small hypoconulid on the same side. Furthermore, using KENDALL's rank correlation coefficient, NOSS *et al.* (1983) found no significant interaction between asymmetries in the tooth crown dimensions and nonmetric morphological traits of upper and lower molars except where nonmetric character development affected crown measurements. From these findings, they considered that environmental or developmental factors affecting mineralization could independently cause right-left differences in dental size and morphology because different parts of the tooth mineralize at different times.

MAYHALL and SAUNDERS (1986), also using KENDALL's rank correlation coefficient, examined interrelationships between asymmetries seen in tooth crown diameters and nonmetric crown characters, and obtained only four significant but very low rank correlation coefficients among twenty-four comparisons. They concluded, again, that there was no apparent association between metric and nonmetric dental asymmetries.

Notwithstanding a considerable number of negative assertions as the above, it has become clearer by using multivariate analyses that there are some covariation tendencies in dental asymmetries. The tendencies found by MIZOGUCHI (1986) and in the present study seem not to be the phenomena due simply to chance because of the reproducibility in the male and female data. Since no or little genetic variation has been found in dental asymmetries (MIZOGUCHI, 1987, 1989), such covariation of dental asymmetries should be ascribed to environmental factors common to some parts of jaws.

According to BOKLAGE (1987), human embryonic body symmetry is determined before the eighth day of gestation; trigeminal neural crest mesenchyme is involved not only with the induction of forebrain development but also with the development of jaws and teeth; and precursors of the trigeminal neural crest at the time of symmetry determination exist between those of the face and the brain. From these reasons, BOKLAGE (1987) considered that events of the symmetry determination period might influence not only asymmetries of the brain but those of face and teeth as well. If BOKLAGE's consideration is acceptable, it should be elucidated, in order to know causes for dental asymmetries, how the condition of symmetry/asymmetry in the distribution of the trigeminal neural crest mesenchyme is determined.

IWAKU (1987) has stated, based mainly on the observation of lower incisors of rats, that the network of blood vessels for an enamel organ and the microstructure of endothelial cells of blood vessels change in the process of amelogenesis, and suggested the correspondency of these morphological changes to the functional changes of ameloblasts during the period of enamel formation. From this, it is easy to suppose that there can be asymmetrical spatial variation and temporal change in the amount of the calcium and other nutrients which are transported to tooth germs. In practice, KURISU (1977) demonstrated that the relative fluctuating asymmetry in the calcium content of the molar teeth of mice firstly increased and then decreased during the calcification period, with the peak of the fluctuating asymmetry being at the beginning of growth spurt of calcification. This means that the state of symmetry or asymmetry which has appeared at an early developmental stage does not necessarily continue to be fixed. Incidentally, although SIEGEL and MOONEY (1987) clearly showed that perinatal artificial noise stress significantly increased the fluctuating asymmetry of relative calcium concentrations in the first lower molars of laboratory rats, it should be noted that this experiment only proves the ability of such environmental factors as noise to increase the fluctuating dental asymmetry but does not necessarily guarantee all the causes of the fluctuating asymmetry in normal condition to be environmental ones.

After all, the correlated asymmetries detected in dental characters seem to be referred to the asymmetries in the distribution of nerve fibers, blood vessels or the like, which are common environment to the dental characters and, in turn, have been randomly determined by some still-to-be-specified factors in the earlier developmental process within the jaws, as was surmised partly by SOFAER *et al.* (1971) and MIZOGUCHI (1986). This supposition should directly be examined through embryological observations in future.

Summary and Conclusions

Correlations between the right-left differences in eighteen tooth crown diameters and ten nonmetric tooth crown characters of human permanent teeth were estimated using the tetrachoric correlation method. The application of the principal component analysis to them showed some tendencies for asymmetries, especially in the metric and nonmetric characters of maxillary cheek teeth, to co-vary in the same direction in both males and females. This was interpreted presumably as the result of the influence of common environmental factors such as the asymmetrical distribution of nerve fibers, blood vessels, *etc.* within the jaws.

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