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Tooth Crown Characters on the Lingual Surfaces of the Maxillary Anterior Teeth: Analysis of the Correlations by the Method of Path Coefficients

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Any morphological characters are attributable to either of two categories in a viewpoint of "parts and the whole." Namely, one is elementary or primitive characters and the other, the total compound characters consisting of the elementary ones. Of course, the former may further be partitioned into several more fundamental characters in the other viewpoint. Among these characters, in general, there are some interrelations. This is probably because they are partly controlled by the common genes and/or the common environment through their developmental processes. By analyzing these interrelationships, the degree of influences of individual elementary characters and of their interactions on the total compound characters may be determined.

HRDLIČKA (1921) said, with regard to dental characters, "The ridges and depression on the crowns and also on the cusps of the teeth are fixed, not incidental characteristics. They vary in detail, but recur typically and in the same locations.... And they appear not only on the incisors, but also on the canines, premolars and molars." His statement seems to be true also at the present time. Their fundamental shapes are already determined at the stage before their calcification in the developmental process (KRAUS and JORDAN, 1965; OOË, 1968). Then their shapes are modified through the calcification stages to the complete condition as seen in the oral cavity. As regards the shovelling, one of the dental characters produced through such a developmental process, SAKAI *et al.* (1965, 1967) and SUZUKI and SAKAI (1966) emphasized that the shovelling of the anterior teeth was not an independent character but a final phenotype caused by relative or absolute degree of the developmental or morphological variations of many characters in the lingual surfaces. The mesiodistal dimensions of tooth crowns are also similarly compound characters in such a vewpoint.

In this article, there are two purposes. One is to systematically show the distributions of the small tooth crown components on the lingual surfaces of the maxillary anterior teeth in Japanese. Another is to determine the degree of influences of the small crown components such as the lingual ridges, on the mesiodistal dimension and on the shovelling in each maxillary anterior tooth. For carrying out the second purpose, the path analysis is utilized in the present study. Since 1918, WRIGHT has developed the method of path coefficients as a flexible means of relating the correlation coefficients between variables in a multiple system to the functional relations among them (WRIGHT, 1934). This method is generally applied to a causal system. However, relations between the morphological elementary characters and the total compound ones are those of "parts and the whole" rather than those of "cause and effect." Both kinds of the characters studied here are the final results of the development. In the path analysis, all of the paths from exogenous variables to endogenous variables must be assumed as a one way process, but the path coefficients are, in fact, standard partial regression coefficients (LI, 1956; KEMPTHORNE, 1969; YASUDA, 1969). Therefore, whether there are what are called causal relations among them or not, the path analysis can be applied to a system of the small component and the total compound characters, if any contribution of the parts to the whole is regarded as that in one direction. It is not easy, however, to know whether the relationship between each small tooth crown component and the mesiodistal dimension or the shovelling is due to a one way action or due to their interaction. Although the method of path coefficients is applied to the system of tooth crown characters in this paper, it should be kept in mind that the anaylsis is effective only under the above assumption of the one way action of the exogenous variables on the endogenous ones.

Materials

Materials are the dental plaster casts derived from 179 males and 168 females in Tokyo and its surrounding areas. These are part of the collections obtained in 1950's by the project team for general twin studies aided by Science Foundation, the Ministry of Education of Japan, and now stored in the Department of Anatomy, the University of Tokyo. Only one member of each twin pair was used for this study.

Another sample of 61 individuals from Okinawa was used in order to check the observational error. This is part of the collections of dental plaster casts obtained by Prof. K. HANIHARA of the Department of Anthropology, the University of Tokyo.

Observations were carried out by the present writer on the right maxillary incisors and canines.

Methods

Methods of observation

The mesiodistal dimensions of tooth crowns were measured according to FUJITA's (1949) criteria with a sliding caliper with an accuracy of 0.05 mm.

The morphological characters in tooth crowns were classified into four categories on the basis of the extent of development in their continuous expression. Those non-metrical characters studied here are the shovelling, five lingual ridges, and three spines derived from the lingual tubercle in each maxillary anterior tooth (Fig. 1).

The shovelling was observed according to HRDLIČKA's (1920) criteria. All of the five lingual ridges, *i.e.* the central ridge, the mesial and distal accessory ridges, and

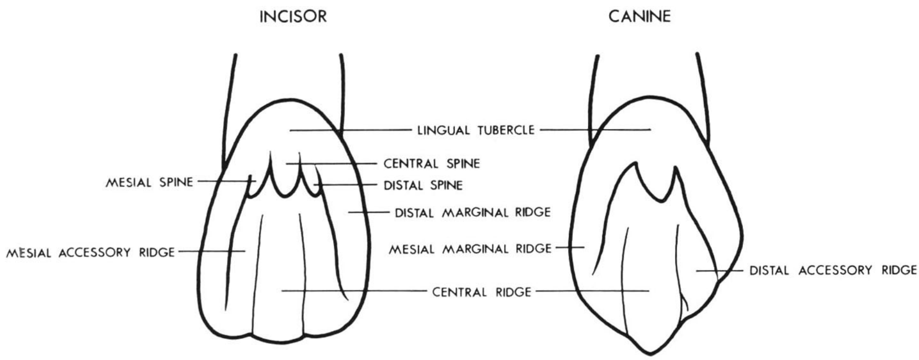

Fig. 1. Schematic diagram of the lingual surfaces of the upper right anterior teeth (Modified from FUJITA, 1973)

the mesial and distal marginal ridges, were classified according to HANIHARA's (1955) criteria as follows:

0: none at all,
1: traceable or weak ridge,
2: swollen ridge with relatively distinct contour,
3: highly-developed and pronounced ridge.

All of the three spines from the lingual tubercle were classified on the basis of HRDLIČKA's (1921) description on the lingual tubercles or basal tuberosity as follows:

0: none at all,
1: elevated ridge from the heel or basal tuberosity, prolonged to and tapering out on the lingual surface,
2: bud or point, the lingual accessory cuspule projecting from the heel instead of ridges,
3: lingual cusp reaching near or to the cutting edge of the tooth.

Assessment of observational error

For the mesiodistal dimensions, the mean measurement error variances have already been calculated (MIZOGUCHI, 1977a) by the double determination method (LUNDSTRÖM, 1948; OSBORNE *et al.*, 1958). Based on these, it was assessed whether the intra-observer error was negligible compared with the total variance of each tooth dimension.

In the case of non-metrical tooth crown characters, the frequencies of within-pair discordances of double observations on the same sample of 61 individuals were calculated. The interval between two observations was about eight months.

Path analysis

Path analysis was suggested by WRIGHT in 1918 (WRIGHT, 1934) and has been developed for clarifying the causal systems among organic phenomena. In general,

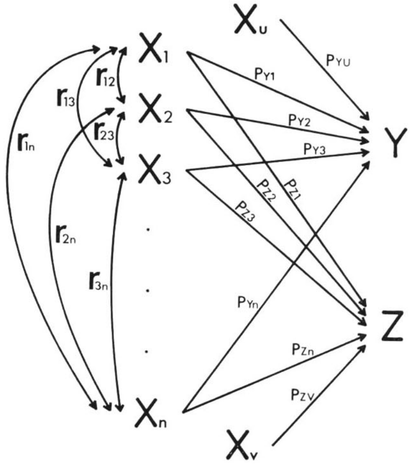

Fig. 2. Path diagram for the case of two endogenous and n exogenous variables

the variables dealt with in the path analysis must be quantitative variables and be written in the form of a regression equation. Although most of the characters observed in this study are non-metrical ones, the correlation coefficients between them were estimated by the tetrachoric correlation method (PEARSON, 1900; EVERITT, 1910; MIZOGUCHI, 1977b) on the assumption that such non-metrical characters were essentially continous or quantitative variables showing the normal distribution, at least, in the underlying conditions. The path analysis can be applied to a set of such tetrachoric correlation coefficients between those characters observed here.

A model of the causal diagram adopted for the tooth crown characters has two endogenous and several exogenous variables as shown in Fig. 2, where correlations between the variables are indicated by two-headed arrows connecting them, and one way processes in the causal system are expressed by one-headed arrows. According to WRIGHT (1934), LI (1956), YASUDA (1969) and KEMPTHORNE (1969), the following regression equations can be set up for this model.

$$Y=p_{Y1}X_1+p_{Y2}X_2+\ldots+p_{Yn}X_n+p_{Yu}X_u,$$
$$Z=p_{Z1}X_1+p_{Z2}X_2+\ldots+p_{Zn}X_n+p_{Zv}X_v, \quad (1)$$

where Y and Z are endogenous or dependent variables; $X_1, X_2, \ldots, X_n$ are exogenous or independent variables; X_u and X_v are the residual variables uncorrelated with each other and with n exogenous variables but acting on the endogenous variables, Y and Z, respectively; and $p_{Y1}, p_{Y2}, \ldots, p_{Yn}, p_{Yu}$, and $p_{Z1}, p_{Z2}, \ldots, p_{Zn}, p_{Zv}$ are path coefficients from X_i ($i=1, 2, \ldots, n, u$ or v) to Y and Z, respectively, in the causal system. The X's, Y and Z are all standardized variables by the respective standard deviations. By taking the expected values of those right-hand and left-hand sides of the equations (1) multiplied by X_q, the following formulae can be obtained (YASUDA, 1969):

$$r_{Yq}=\sum_{i=1}^{n} p_{Yi}r_{iq} \ (q=1, 2, \ldots, n),$$
$$r_{Zq}=\sum_{i=1}^{n} p_{Zi}r_{iq} \ (q=1, 2, \ldots, n),$$

where r_{Yq} or r_{Zq} is a correlation coefficient between an endogenous variable, Y or Z, and an exogenous variable, X_q, and r_{iq} is a correlation coefficient between two exogenous variables, X_i and X_q. In the same way, regarding Y or Z as X_q,

$$r_{YY}=1=\sum_{i=1}^{n} p_{Yi}r_{Yi}+p^2_{Yu},$$
$$r_{ZZ}=1=\sum_{i=1}^{n} p_{Zi}r_{Zi}+p^2_{Zv},$$

where r_{YY} and r_{ZZ} are the respective standardized variances of Y and Z, and r_{Yi} or r_{Zi} is a correlation coefficient between Y or Z and X_i. From these equations, the path coefficients can be obtained. Further, the complete determination of an endogenous variable by exogenous variables and a residual variable can be expressed as follows (KEMPTHORNE, 1969):

$$\begin{aligned} 1&=p^2_{Y1}+p^2_{Y2}+\ldots+p^2_{Yn}+\sum_{i\neq j} p_{Yi}p_{Yj}r_{ij}+p^2_{Yu}, \\ 1&=p^2_{Z1}+p^2_{Z2}+\ldots+p^2_{Zn}+\sum_{i\neq j} p_{Zi}p_{Zj}r_{ij}+p^2_{Zv}. \end{aligned} \tag{2}$$

The quantities p^2_{Yi} or p^2_{Zi} are called coefficients of determination which measure the proportion of the variance of Y or Z attributable to X_i (WRIGHT, 1934; KEMPTHORNE, 1969). The remaining terms except the squared path coefficients in the above formulae (2) measure the change in variance (positive or negative) due to correlated occurrence of the contributions of the exogenous variables (WRIGHT, 1934).

The correlation between the two endogenous variables, Y and Z, is considered, in the path analysis, to be caused by only the common part of the network of causation behind them. It can be analyzed into some compound path coefficients as expressed below (WRIGHT, 1934; LI, 1956; YASUDA, 1969; KEMPTHORNE, 1969):

$$r_{YZ}=\sum_{i} p_{Yi}p_{Zi}+\sum_{i\neq j} p_{Yi}r_{ij}p_{Zj},$$

where r_{YZ} is a coefficient of correlation between the two endogenous variables, Y and Z. The correlation coefficients estimated by the above formula are comparable with the directly observed correlation coefficients between the endogenous variables.

Methods of calculation

All the calculations involved in this paper were done using the programs CLASS, TETRAC and PATHAN written in FORTRAN with the computer, HITAC 8800/8700 (OS–7), of the Tokyo University Computer Centre, the University of Tokyo. All the programs were coded by the present writer. CLASS tests the homogeneity of two series of samples in a two-by-two contingency table by FISHER's exact method. TETRAC, utilizing a subroutine subprogram NORMAL which is contained in the PLAS[1)] program library and for the calculation of cumulative probabilities of the

1) Program Library for Anthropological Statistics (ed. K. HANIHARA, 1974).

normal distribution, computes tetrachoric correlation coefficients between non-metrical characters. The program PATHAN is for the path analysis of a model with one or two endogenous variables.

Results

Basic statistics on tooth crown characters

The frequencies of four expressivities in each of the non-metrical tooth crown characters of the maxillary anterior teeth in Japanese males and females are shown in Tables 1, 2 and 3. Table 4 indicates the percent discordances between the double observations on the same sample by the writer himself. The percent discordance on each character was calculated after the four expressivities were grouped into two categories. The best position of a dividing plane was selected of the three possible positions between four expressivities in favor of estimating the best tetrachoric correlation coefficient in each case (MIZOGUCHI, 1977b). From Table 4, it is found that the intra-observer discordances range from 0.0% to 23.7%.

Between-sex differences in frequency were tested by FISHER's exact method dividing the sample into two groups for the same reason as the above. The results are shown in Table 5. Of the characters observed here, the shovelling of the canine, the mesial and distal accessory ridges of the lateral incisor, the distal marginal and distal

Table 1. Frequencies of tooth crown characters on the lingual surfaces of the maxillary central incisors in Japanese

Character	Sex	No.	Expressivity (%)			
			0	1	2	3
Central ridge	M	158	36.08	58.23	5.70	0.00
	F	151	43.71	53.64	2.65	0.00
Mesial accessory ridge	M	160	73.75	25.63	0.63	0.00
	F	155	67.74	31.61	0.65	0.00
Distal accessory ridge	M	159	62.89	35.85	1.26	0.00
	F	151	56.29	43.05	0.66	0.00
Mesial marginal ridge	M	165	0.00	13.33	76.97	9.70
	F	159	0.63	10.06	79.25	10.06
Distal marginal ridge	M	169	0.00	7.10	80.47	12.43
	F	157	0.00	5.10	83.44	11.46
Central spine of the lingual tubercle	M	144	86.11	13.89	0.00	0.00
	F	141	80.85	19.15	0.00	0.00
Mesial spine of the lingual tubercle	M	153	77.78	22.22	0.00	0.00
	F	147	78.91	21.09	0.00	0.00
Distal spine of the lingual tubercle	M	151	64.90	34.44	0.66	0.00
	F	147	62.59	37.41	0.00	0.00
Shovelling	M	88	1.14	18.14	44.32	36.36
	F	87	2.30	14.94	44.83	37.93

Table 2. Frequencies of tooth crown characters on the lingual surfaces of the maxillary lateral incisors in Japanese

Character	Sex	No.	Expressivity (%) 0	1	2	3
Central ridge	M	157	74.52	23.57	1.91	0.00
	F	154	73.38	26.62	0.00	0.00
Mesial accessory ridge	M	158	85.44	14.56	0.00	0.00
	F	150	73.33	26.67	0.00	0.00
Distal accessory ridge	M	161	83.85	16.15	0.00	0.00
	F	152	71.71	28.29	0.00	0.00
Mesial marginal ridge	M	166	0.60	10.84	82.53	6.02
	F	156	0.00	10.90	86.54	2.56
Distal marginal ridge	M	168	0.00	7.14	86.90	5.95
	F	155	0.00	7.10	90.32	2.58
Central spine of the lingual tubercle	M	124	91.94	4.03	4.03	0.00
	F	116	94.83	2.59	2.59	0.00
Mesial spine of the lingual tubercle	M	140	93.57	5.00	1.43	0.00
	F	129	91.47	8.53	0.00	0.00
Distal spine of the lingual tubercle	M	145	83.45	14.48	2.07	0.00
	F	129	82.95	15.50	1.55	0.00
Shovelling	M	89	1.12	23.60	42.70	32.58
	F	87	8.05	18.39	42.53	31.03

Table 3. Frequencies of tooth crown characters on the lingual surfaces of the maxillary canines in Japanese

Character	Sex	No.	Expressivity (%) 0	1	2	3
Central ridge	M	132	2.27	78.79	15.91	3.03
	F	139	3.60	76.26	20.14	0.00
Mesial accessory ridge	M	120	57.50	40.83	1.67	0.00
	F	133	57.89	37.59	4.51	0.00
Distal accessory ridge	M	122	6.56	28.69	64.75	0.00
	F	136	9.56	38.97	51.47	0.00
Mesial marginal ridge	M	123	0.00	8.13	91.06	0.81
	F	135	0.00	5.19	94.81	0.00
Distal marginal ridge	M	110	0.91	27.27	71.82	0.00
	F	132	0.00	15.15	84.85	0.00
Central spine of the lingual tubercle	M	104	54.81	34.62	10.58	0.00
	F	125	66.40	29.60	4.00	0.00
Mesial spine of the lingual tubercle	M	113	97.35	2.65	0.00	0.00
	F	131	87.79	11.45	0.76	0.00
Distal spine of the lingual tubercle	M	106	83.96	16.04	0.00	0.00
	F	122	82.79	17.21	0.00	0.00
Shovelling	M	128	85.16	12.50	2.34	0.00
	F	139	71.94	20.86	5.04	2.16

Table 4. Percent discordances between double observations on the tooth crown characters of the maxillary anterior teeth

Character	Expressivities grouped together	No.	Discordance (%)
Central incisor:			
Central ridge	1, 2, 3	59	23.73
Mesial accessory ridge	1, 2, 3	57	21.05
Distal accessory ridge	1, 2, 3	59	22.03
Mesial marginal ridge	2, 3	54	5.56
Distal marginal ridge	3	59	10.17
Central spine	1, 2, 3	47	8.51
Mesial spine	1, 2, 3	49	8.16
Distal spine	1, 2, 3	50	6.00
Shovelling	3	56	10.71
Lateral incisor:			
Central ridge	1, 2, 3	58	17.24
Mesial accessory ridge	1, 2, 3	58	15.52
Distal accessory ridge	1, 2, 3	58	10.34
Mesial marginal ridge	2, 3	57	0.00
Distal marginal ridge	2, 3	59	1.69
Central spine	1, 2, 3	35	8.57
Mesial spine	1, 2, 3	46	8.70
Distal spine	1, 2, 3	44	11.36
Shovelling	3	57	12.28
Canine:			
Central ridge	2, 3	58	17.24
Mesial accessory ridge	1, 2, 3	56	12.50
Distal accessory ridge	2, 3	57	14.04
Mesial marginal ridge	2, 3	57	1.75
Distal marginal ridge	2, 3	51	13.73
Central spine	1, 2, 3	52	9.62
Mesial spine	1, 2, 3	51	1.96
Distal spine	1, 2, 3	49	12.24
Shovelling	1, 2, 3	57	3.51

accessory ridges of the canine, and the central and mesial spines from the lingual tubercle of the canine showed the significant sex difference at the 5% level.

In Table 6, the mesiodistal dimensions of the maxillary anterior teeth are shown. The sex differences in the mesiodistal dimensions were ascertained by the *t*-test to be significant at the 5% level for all of the three anterior teeth. Coefficients of variation indicate that, of the three teeth, the lateral incisor is most variable in both males and females and that the teeth of females are generally more variable than those of males. Table 7 shows that the intra-observer measurement error variances are negligible for all of the three teeth.

Table 5. Between-sex differences in incidence of the tooth crown characters in the maxillary anterior teeth

Character	No. Male	No. Female	Expressivities grouped together	Probability[1)]
Central incisor:				
Central ridge	158	151	1, 2, 3	0.1043
Mesial accessory ridge	160	155	1, 2, 3	0.1469
Distal accessory ridge	159	151	1, 2, 3	0.1418
Mesial marginal ridge	165	159	2, 3	0.2883
Distal marginal ridge	169	157	3	0.4623
Central spine	144	141	1, 2, 3	0.1498
Mesial spine	153	147	1, 2, 3	0.4608
Distal spine	151	147	1, 2 3	0.3823
Shovelling	88	87	3	0.4796
Lateral incisor:				
Central ridge	157	154	1, 2, 3	0.4592
Mesial accessory ridge	158	150	1, 2, 3	0.0062*
Distal accessory ridge	161	152	1, 2, 3	0.0070*
Mesial marginal ridge	166	156	2, 3	0.5088
Distal marginal ridge	168	155	2, 3	0.5798
Central spine	124	116	1, 2, 3	0.2627
Mesial spine	140	129	1, 2, 3	0.3358
Distal spine	145	129	1, 2, 3	0.6077
Shovelling	89	87	3	0.4788
Canine:				
Central ridge	132	139	2, 3	0.4614
Mesial accessory ridge	120	133	1, 2, 3	0.5741
Distal accessory ridge	122	136	2, 3	0.0209*
Mesial marginal ridge	123	135	2, 3	0.2415
Distal marginal ridge	110	132	2, 3	0.0103*
Central spine	104	125	1, 2, 3	0.0490*
Mesial spine	113	131	1, 2, 3	0.0043*
Distal spine	106	122	1, 2, 3	0.4772
Shovelling	128	139	1, 2, 3	0.0065*

1) Probability by FISHER's exact test in a two-by-two contingency table.
* Significant at the level of 5% or less.

Table 6. Means, standard deviations and coefficients of variation of the mesiodistal dimensions (in millimeter) of the maxillary anterior teeth

	Male				Female			
	No.	Mean	S.D.	Coef. var.	No.	Mean	S.D.	Coef. var.
Central incisor	92	8.62	0.46	5.28	89	8.38	0.52	6.23
Lateral incisor	91	7.27	0.57	7.86	86	7.10	0.57	8.03
Canine	67	7.99	0.44	5.51	77	7.64	0.43	5.68

Table 7. Comparisons of the mean measurement error variances with the total variances in the mesiodistal dimensions of the maxillary anterior teeth

	Variance (d.f.)		
	Error[1)]	Total	F-ratio
Male:			
Central incisor	0.0054 (58)	0.2073 (91)	38.39*
Lateral incisor	0.0088 (59)	0.3262 (90)	37.07*
Canine	0.0078 (58)	0.1937 (66)	24.83*
Female:			
Central incisor	0.0054 (58)	0.2725 (88)	50.46*
Lateral incisor	0.0088 (59)	0.3254 (85)	36.98*
Canine	0.0078 (58)	0.1882 (76)	24.13*

1) Mean measurement error variance by the double determination method (MIZOGUCHI, 1977a).
* $P < 0.005$, by one-tailed F-test.

Table 8. Correlation matrices on the tooth crown characters in the maxillary

	1. Central ridge	2. Mesial accessory ridge	3. Distal accessory ridge	4. Mesial marginal ridge	5. Distal marginal ridge
1		.49±12(155)	.34±.12(154)	.35±.14(155)	−.25±.16(158)
2	.58±.10(149)		.54±.11(155)	−.02±.17(159)	−.50±.17(159)*
3	.46±.11(147)	.66±.09(147)		.08±.16(156)	−.20±.16(159)
4	.09±.17(151)	.12±.18(155)*	−.10±.17(150)		.88±.02(163)*
5	−.32±.16(148)	−.30±.17(151)*	−.41±.16(149)*	.83±.02(155)*	
6	.16±.16(131)	.18±.15(135)	.12±.16(131)	−.01±.20(138)*	−.12±.21(135)*
7	−.11±.15(137)	.23±.15(141)	.05±.15(137)	—	.06±.19(142)*
8	−.24±.13(136)	−.04±.14(140)	−.26±.13(136)	−.09±.17(144)	.40±.15(142)
9	−.10±.13(151)	.11±.13(153)	.05±.13(151)	.53±.15(157)*	.64±.13(155)*
10	−.15±.13(149)	−.14±.13(152)	−.26±.13(149)	.55±.16(156)*	.82±.09(154)*

* Based on the fourfold correlation table in which one or more absolute frequencies were less than 5.

Table 9. Correlation matrices on the tooth crown characters in the maxillary

	1. Central ridge	2. Mesial accessory ridge	3. Distal accessory ridge	4. Mesial marginal ridge	5. Distal marginal ridge
1		.24±.16(154)	.11±.16(157)	.09±.18(156)*	.15±.21(156)*
2	−.15±.15(150)		.55±.13(156)	.10±.21(157)*	−.05±.22(157)*
3	−.07±.15(151)	.59±.11(148)		−.11±.19(160)*	−.01±.22(160)*
4	.30±.18(154)*	−.08±.18(150)	.06±.18(152)*		.79±.10(165)*
5	.33±.22(153)*	.11±.22(150)*	−.17±.20(152)*	.90±.06(155)*	
6	.16±.26(114)*	.04±.25(112)*	−.16±.27(114)*	−.04±.29(116)*	−.17±.30(116)*
7	.31±.19(127)	.46±.17(125)*	−.01±.22(126)*	.08±.27(129)*	−.11±.29(129)*
8	.04±.18(127)	−.01±.18(125)	−.12±.18(126)	−.26±.19(129)	−.34±.20(129)*
9	−.00±.14(154)	−.07±.14(150)	−.14±.13(152)	.36±.15(156)	.11±.19(155)
10	−.30±.14(153)	−.26±.14(150)	−.22±.14(152)	—	—

* Based on the fourfold correlation table in which one or more absolute frequencies were less than 5.

Inter-character correlations

As the sex differences were recognized for some of the characters studied here, the correlation coefficients were calculated for males and females, separately. The results on each maxillary anterior tooth are shown in Tables 8 to 10. Several tetrachoric correlation coefficients could not be obtained because one or more frequencies in the fourfold correlation table were equal to zero. Some other coefficients of tetrachoric correlation, marked with an asterisk in these tables, are not completely reliable because one or more frequencies in the fourfold correlation table were too low to obtain the best estimate of tetrachoric correlation coefficients.

Path coefficients

Path coefficients were estimated for each of the path diagrams assumed on maxillary anterior teeth of males and females (Tables 11, 12). Table 11 shows the

central incisors of males (upper right) and of females (lower left)

6. Central spine	7. Mesial spine	8. Distal spine	9. Mesiodistal dimension	10. Shovelling
.23±.17(138)*	−.02±.15(143)	.22±.14(139)	−.15±.13(156)	−.20±.13(156)
−.13±.28(138)*	−.09±.15(144)	.02±.14(140)	.23±.13(158)	−.12±.14(159)
.05±.17(137)	−.13±.15(142)	.13±.14(141)	−.01±.13(157)	−.12±.13(157)
.10±.21(138)*	−.11±.18(145)	−.05±.17(143)	.14±.15(162)	.64±.13(162)*
.27±.19(142)*	.12±.18(148)	.01±.17(146)	.48±.13(166)	.64±.11(163)*
	.33±.16(140)	.14±.17(136)	.12±.17(140)	−.11±.17(139)
.01±.17(137)		.71±.09(144)	.08±.14(146)	.04±.15(144)
−.18±.16(137)	.57±.11(139)		.10±.13(144)	.09±.14(142)
.04±.15(137)	.37±.13(143)	.15±.13(143)		.20±.12(162)
.01±.16(135)	.10±.15(141)	.32±.13(141)	.36±.12(155)	

lateral incisors of males (upper right) and of females (lower left)

6. Central spine	7. Mesial spine	8. Distal spine	9. Mesiodistal dimension	10. Shovelling
.33±.21(117)*	.01±.24(133)*	.07±.17(135)	.09±.14(156)	−.16±.14(156)
.18±.25(117)*	.14±.24(134)*	.05±.19(136)*	−.05±.15(157)	−.20±.16(157)
−.08±.27(120)*	−.83±.03(136)*	.15±.18(139)	.03±.15(160)	−.03±.16(160)
.07±.27(122)*	—	−.06±.20(142)*	.33±.15(164)	.44±.16(163)*
—	−.13±.29(140)*	.83±.03(144)*	.53±.15(165)*	—
	.15± 30(118)*	.54±.17(118)	.51±.19(123)*	.27±.20(122)*
.25±.31(110)*		.14±.24(130)*	−.13±.21(138)*	−.16±.22(137)*
.46±.25(109)*	.84±.09(120)*		−.07±.16(142)	−.11±.16(140)
.00±.24(116)*	.27±.19(129)*	.49±.14(129)*		.41±.11(163)
.29±.23(116)*	−.19±.21(129)*	−.22±.17(129)*	.35±.12(158)	

Table 10. Correlation matrices on the tooth crown characters in the

	1. Central ridge	2. Mesial accessory ridge	3. Distal accessory ridge	4. Mesial marginal ridge	5. Distal marginal ridge
1		−.31±.16(119)	.11±.17(120)	.91±.01(122)*	.04±.18(108)
2	.01±.16(132)		−.11±.15(116)	.05±.21(117)*	.30±.15(105)
3	.34±.14(134)	.17±.14(130)		.35±.20(116)*	−.10±.17(108)
4	.83±.03(133)*	.18±.23(131)*	.89±.02(132)*		.46±.19(106)*
5	.10±.20(129)*	−.03±.17(125)	.26±.16(131)	.25±.25(129)*	
6	.10±.16(123)	−.14±.15(120)	.05±.15(124)	−.11±.23(123)*	.25±.17(122)*
7	−.05±.20(128)*	.10±.18(126)	.17±.17(129)	—	.29±.23(127)*
8	−.14±.20(118)*	.27±.16(116)	−.00±.17(120)	.07±.28(119)*	.18±.21(119)*
9	−.12±.15(134)	.15±.14(130)	.18±.13(134)	.31±.21(132)*	−.03±.17(131)
10	−.51±.15(137)*	.04±.15(131)	−.33±.13(135)	−.51±.19(134)*	.41±.17(131)*

* Based on the fourfold correlation table in which one or more absolute frequencies were less than 5.

Table 11. Path coefficients of the mesiodistal dimension on the small crown components in eacn maxillary anterior tooth

	Path coefficient*								
	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_u
I1 (Male, 8 exog. var.)	−1.31	0.85	−0.44	1.11	−0.62	0.67	−0.49	0.75	0.79
I1 (Male, 7 exog. var.)	−1.18	0.73	−0.30	1.13	−0.65	0.51		0.39	0.84
I1 (Female, 7 exog. var.)	−0.34	−0.47	0.42	1.59	−1.04	0.16		0.76	0.83
I2 (Male, 6 exog. var.)	−0.12	0.22	−0.50			0.73	−0.64	−0.31	0.75
I2 (Female, 6 exog. var.)	−0.41	−0.75	0.24			0.03	1.02	−0.34	0.93
C (Male, 7 exog. var.)	−0.19	0.06	0.82	−0.07	0.36	−0.05		−0.17	0.66
C (Female, 7 exog. var.)	0.76	0.04	1.27	−1.47	−0.15	−0.06		0.49	1.09

* See text on the explanation of the subscripts on the p's.

Table 12. Path coefficients of the shovelling on the small crown components in each maxillary anterior tooth

	Path coefficient*								
	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_v
I1 (Male, 8 exog. var.)	−0.22	0.44	−0.20	0.07	0.78	−0.18	−0.20	0.33	0.63
I1 (Male, 7 exog. var.)	−0.16	0.39	−0.14	0.08	0.76	−0.25		0.18	0.64
I1 (Female, 7 exog. var.)	−0.14	−0.75	0.21	1.74	−1.18	0.20		0.99	0.79
I2 (Male, 6 exog. var.)	−0.29	0.03	−0.33			0.56	−0.48	−0.28	0.83
I2 (Female, 6 exog. var.)	0.36	1.12	−0.72			−0.05	−1.92	1.32	1.09
C (Male, 7 exog. var.)	−0.16	0.47	−0.01	0.20	0.25	−0.60		−0.18	0.63
C (Female, 7 exog. var.)	−0.26	0.20	−0.10	−0.37	0.58	0.04		−0.16	0.62

* See text on the explanation of the subscripts on the p's.

maxillary canines of males (upper right) and of females (lower left)

6. Central spine	7. Mesial spine	8. Distal spine	9. Mesiodistal dimension	10. Shovelling
.17±.17(104)	—	.13±.21(106)*	−.20±.16(125)	−.24±.20(127)*
.14±.16(100)	—	.15±.18(103)	.10±.15(116)	.50±.14(120)
.10±.16(100)	.83±.04(108)*	.60±.16(103)*	.62±.11(119)	−.20±.17(121)
.22±.23(102)*	—	.84±.03(106)*	.06±.21(118)	−.09±.24(122)*
.27±.16(96)	.83±.04(101)*	.21±.20(98)*	.21±.16(105)	.27±.19(109)*
	—	.12±.18(100)	.07±.16(100)	−.48±.16(104)*
−.38±.18(124)*		.59±.24(104)*	−.21±.30(108)*	.25±.32(112)*
−.15±.18(118)	.45±.17(119)		.31±.17(102)	.02±.22(106)*
.14±.14(125)	.14±.18(129)	.27±.16(120)		−.13±.17(123)
.19±.15(125)	.05±.19(130)	.00±.18(120)	.02±.14(134)	

Table 13. Coefficients of determination of the mesiodistal dimension on the small crown components in each maxillary anterior tooth

	Coefficient of determination*									
	p_1^2	p_2^2	p_3^2	p_4^2	p_5^2	p_6^2	p_7^2	p_8^2	$\sum p_i p_j r_{ij}$	p_u^2
I1 (Male, 8 exog. var.)	1.72	0.72	0.19	1.23	0.38	0.45	0.24	0.56	−5.13	0.62
I1 (Male, 7 exog. var.)	1.39	0.53	0.09	1.28	0.42	0.26		0.15	−3.83	0.71
I1 (Female, 7 exog. var.)	0.12	0.22	0.18	2.53	1.08	0.03		0.58	−4.42	0.69
I2 (Male, 6 exog. var.)	0.01	0.05	0.25			0.53	0.41	0.10	−0.92	0.56
I2 (Female, 6 exog. var.)	0.17	0.56	0.06			0.00	1.04	0.12	−1.81	0.86
C (Male, 7 exog. var.)	0.04	0.00	0.67	0.00	0.13	0.00		0.03	−0.31	0.44
C (Female, 7 exog. var.)	0.58	0.00	1.61	2.16	0.02	0.00		0.24	−4.80	1.19

* See text on the explanation of the subscripts on the p's.

Table 14. Coefficients of determination of the shovelling on the small crown components in each maxillary anterior tooth

	Coefficient of determination*									
	p_1^2	p_2^2	p_3^2	p_4^2	p_5^2	p_6^2	p_7^2	p_8^2	$\sum p_i p_j r_{ij}$	p_v^2
I1 (Male, 8 exog. var.)	0.05	0.19	0.04	0.00	0.61	0.03	0.04	0.11	−0.47	0.40
I1 (Male, 7 exog. var.)	0.03	0.15	0.02	0.01	0.58	0.06		0.03	−0.29	0.41
I1 (Female, 7 exog. var.)	0.02	0.56	0.04	3.03	1.39	0.04		0.98	−5.69	0.62
I2 (Male, 6 exog. var.)	0.08	0.00	0.11			0.31	0.23	0.08	−0.51	0.69
I2 (Female, 6 exog. var.)	0.13	1.25	0.52			0.00	3.69	1.74	−7.51	1.19
C (Male, 7 exog. var.)	0.03	0.22	0.00	0.04	0.06	0.36		0.03	−0.14	0.40
C (Female, 7 exog. var.)	0.07	0.04	0.01	0.14	0.34	0.00		0.03	−0.01	0.38

* See text on the explanation of the subscripts on the p's.

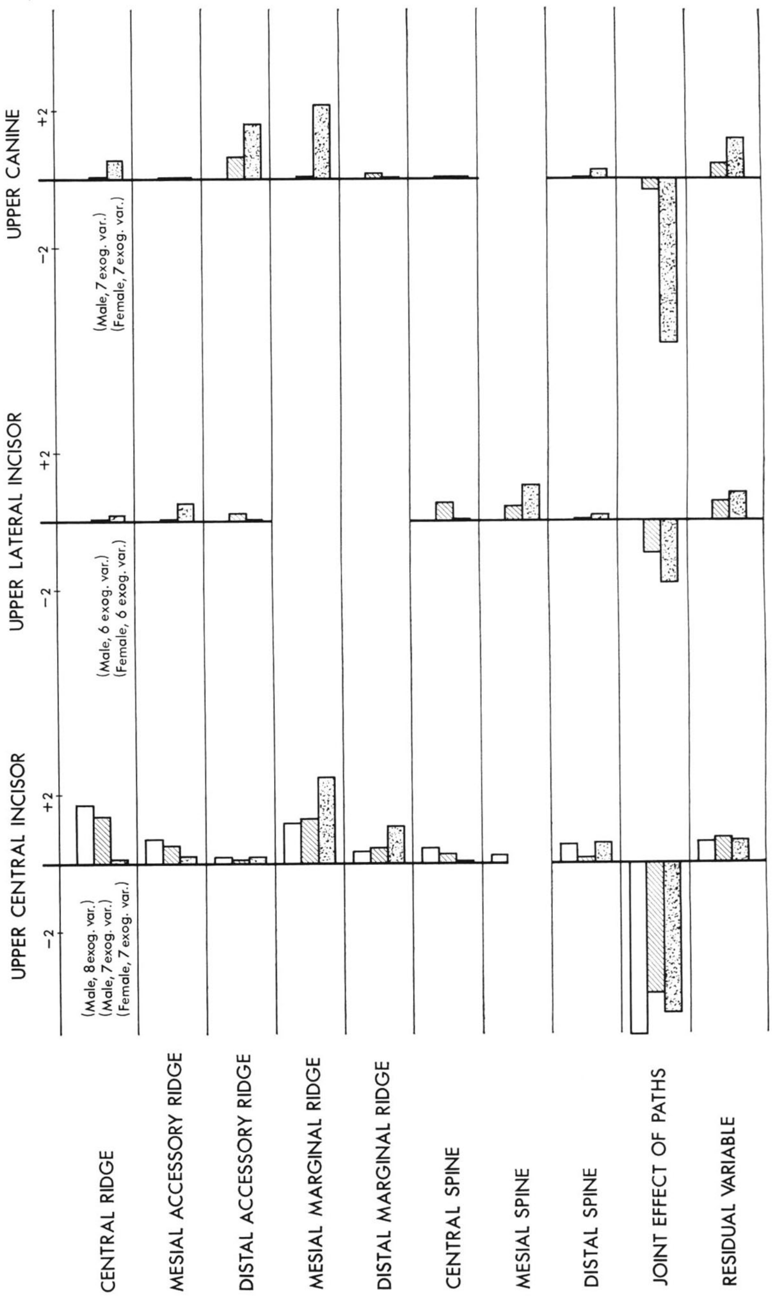

Fig. 3. Degree of determination of each path leading to the mesiodistal diameter

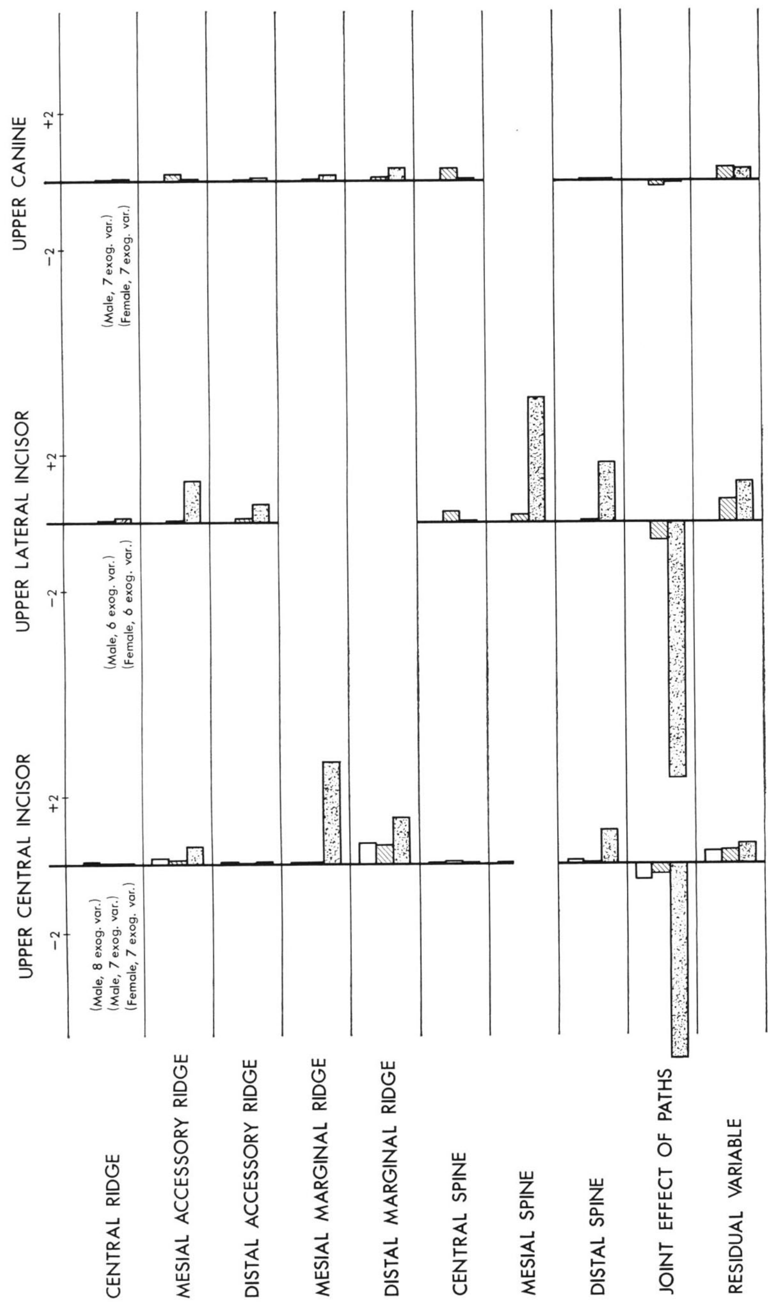

Fig. 4. Degree of determination of each path leading to the shovelling

path coefficients, the p's, from six, seven or eight small crown components to the mesiodistal dimension, and Table 12, to the shovelling. In these tables, p_1 is the path coefficient of the mesiodistal dimension or the shovelling on the central ridge, p_2 and p_3 on the mesial and distal accessory ridges, p_4 and p_5 on the mesial and distal marginal ridges, p_6, p_7 and p_8 on the central, mesial and distal spines, respectively. Additionally, p_u or p_v is on the residual variable.

A complete correlation matrix on all of the eight component characters could be used to carry out the path analysis for only the central incisors of males. In the other cases, a few correlation coefficients on some variables could not be obtained. The path analyses, in such cases, were carried out on the basis of the path diagrams with seven or six exogenous variables. As seen in Tables 11 and 12, the path diagrams for the central incisors of females and for the canines of males and females have no information on the mesial spines. In the models for the lateral incisors of males and females, the information on the mesial and distal marginal ridges is lacking. Another model of the male central incisors with the reduced number of the exogenous variables was set up in order to compare with the model of the female central incisors.

Table 13 shows the coefficients of determination measuring the proportions of the variability of the mesiodistal dimension attributable to the small crown components, and Table 14 similarly shows the coefficients with regard to the shovelling. In Figs. 3 and 4, the coefficients of determination in Tables 13 and 14, respectively, are diagrammatically illustrated, where the "joint effect of paths" indicates the value of the term, $\sum_{i \neq j} p_{Yi} p_{Yj} r_{ij}$ or $\sum_{i \neq j} p_{Zi} p_{Zj} r_{ij}$, in the formulae (2) stated previously.

Table 15 shows the comparisons of the correlation coefficients estimated from the compound path coefficients with those observed directly between the two endogenous variables, *i.e.* the mesiodistal dimension and the shovelling.

Table 15. Comparisons of the observed correlation coefficients between the mesiodistal dimension and the shovelling in each maxillary anterior tooth with those estimated from the compound path coefficients

	Cor. coef. estimated	Cor. coef. observed	Normal deviate*	Prob.
I1 (Male, 8 exog. var.)	0.5123	0.2028±0.1224	2.5294	0.01
I1 (Male, 7 exog. var.)	0.4790	0.2028±0.1224	2.2565	0.02
I1 (Female, 7 exog. var.)	0.2723	0.3593±0.1175	0.7404	0.46
I2 (Male, 6 exog. var.)	0.3252	0.4071±0.1130	0.7257	0.47
I2 (Female, 6 exog. var.)	0.1502	0.3506±0.1204	1.6645	0.10
C (Male, 7 exog. var.)	0.0376	−0.1341±0.1721	0.9977	0.32
C (Female, 7 exog. var.)	−0.1267	0.0222±0.1449	1.0276	0.30

* Normal deviates were obtained from the observed tetrachoric correlation coefficients using their standard errors under the assumption that an estimate obtained from the sum of compound path coefficients was the correlation coefficient in the population.

Discussion

The shovelling has been studied and discussed in detail by a great number of authors. But there seem to be only a few reports on the small crown components of the lingual surfaces of the anterior teeth. At an earlier stage of such studies, HRDLIČKA (1921) discussed the ridges and depressions on the crown surfaces, especially, of the maxillary anterior teeth in the white and the colored peoples. HANIHARA (1954, 1955) described the morphology of the deciduous incisors and canines in Japanese and the Japanese-American hybrids. SAKAI *et al.* (1965, 1967) observed the morphology on the enamel-dentin borders of the maxillary incisors and canines. BERRY (1976) provided some information on the lingual cusps of the anterior teeth in six European samples. Recently, SCOTT (1977) described, in detail, the distal accessory ridges on the lingual surfaces of the maxillary canines in Southwest U.S. Indians, American whites and Asiatic Indians. However, there are few reports on a set of the small component characters covering the whole of a given tooth, especially in terms of the incidence. This is probably because most of the component characters are proportionally small and inconspicuous, and, particularly, have been regarded as those which are not so useful in classification of populations as prominent characters, *e.g.* the shovelling, the CARABELLI's tubercles, *etc.* But they are equally of importance in the studies on crown structure. Therefore, the basic statistical description of all the small crown components on the lingual side was, first, systematically performed for each maxillary anterior tooth.

Before discussing the individual small components, some comments will briefly be given on the error accompanied with the non-metrical method of observation.

Observational error on tooth crown characters

Although HRDLIČKA (1921) said, "the fundamental lingual ridge pattern of the human teeth is that of a median, two lateral and marginal ridges—hence five ridges in all with three intervening depressions," yet some of the lingual ridges are, in fact, considerably variable and, in some cases, not recognized at all. Sometimes, a certain character may not be distinguishable from the other because of its inconspicuous appearance. In the present study, therefore, the discordances between double observations on the same sample were calculated in order to assess the intra-observer error for each non-metrical character. As a result, the most indistinguishable characters were the central, the mesial and distal accessory ridges of the maxillary central incisors. The discordances for these three characters were 23.7%, 21.1% and 22.0%, respectively. The average of the discordances for all the small component characters studied here was 10.9%. For the shovelling, the discordances between double observations were 10.7% in the central incisor, 12.3% in the lateral incisor (MIZOGUCHI, 1977b) and 3.5% in the canine.

Though the relatively high discordances were found out on some characters, they are negligible in most cases of comparing one sample with the other unless there is a certain tendency of the misjudgement in observation, as suggested by SCOTT (1977). In estimating correlation coefficients between the characters, however, the high discordances may cause serious problems. Care should be taken for such a point in interpreting the results.

Shovelling and the small crown components on the lingual surface

Frequencies of several grades in expression of the minor variants are, in general, subjectively determined by the non-metrical means of classification. Strictly speaking, therefore, the frequencies reported by different observers should not simply be compared with one another, even if the observational methods adopted by them were the same. Only for the purpose of roughly ascertaining the tendencies in incidence, comparisons with the previous reports would be allowed. However, homogeneity tests of the popularions were not performed for the above reasons even when the previous results were cited.

Part of many previous reports on the shovelling of the maxillary incisors are shown in Tables 16 and 17. From these, the incidence of all the affected is found to be higher in the so-called Mongoloid populations including the present sample than in the others. According to KRAUS and JORDAN (1965), this trend is already present in fetal stages before commencement of the calcification at the tips of the deciduous incisor crowns. They reported that the frequency of the shovel or semi-shovel shaped incisors in Japanese fetuses was 66%, in American Indians 90%, and in American whites 23%. On the maxillary central deciduous incisors erupted, HANIHARA (1955) reported that the frequency of the semi-shovel shaped incisors was 32.4% in Japanese, 5.6% in the hybrids of Japanese with American whites, and 13.8% in the hybrids of Japanese with American Negroes. These data on the deciduous incisors

Table 16. Frequencies of the shovelling of the maxillary central incisors in various populations

Population	Sex	No.	Expressivity (%)				Source
			no	tr	ss	s	
White	M	1000	66.5	24.5	7.6	1.4	HRDLIČKA
	F	1000	70.4	21.8	5.2	2.6	(1920)
American Negro	M	618	54.5	33.0	7.6	4.9	HRDLIČKA
	F	1000	56.0	32.6	8.0	3.6	(1920)
Pima Indian	M	101	0.0	4.0	0.0	96.0	DAHLBERG
	F	125	0.0	1.0	0.0	99.0	(1949)
Queckchi Indian	M	239	47.7	18.4	0.8	33.1	ESCOBAR *et al.*
	F	194	57.2	8.3	0.0	34.5	(1977)
Chinese	M	1094	7.8	1.3	23.4	66.2	HRDLIČKA
	F	208	3.8	1.0	12.5	82.7	(1920)
Japanese	M	240	10.0	22.9	26.7	40.4	SUZUKI and SAKAI
	F	223	11.2	25.1	31.4	32.3	(1966)
Japanese	M	88	1.1	18.1	44.3	36.4	MIZOGUCHI
	F	87	2.3	14.9	44.8	37.9	(1977b)

Table 17. Frequencies of the shovelling of the maxillary lateral incisors in various populations

Population	Sex	No.	Expressivity (%)				Source
			no	tr	ss	s	
White	M	1000	50.0	36.4	8.8	1.4	HRDLIČKA
	F	1000	59.6	29.9	7.4	1.0	(1920)
American Negro	M	618	42.1	38.0	12.8	4.5	HRDLIČKA
	F	1000	47.5	35.4	11.1	3.8	(1920)
Pima Indian	M	93	1.0	13.0	0.0	81.0	DAHLBERG
	F	119	0.0	7.0	0.0	81.0	(1949)
Queckchi Indian	M	215	50.7	13.0	0.5	35.8	ESCOBAR *et al.*
	F	182	59.3	6.0	0.6	34.1	(1977)
Chinese	M	1094	9.5	1.5	24.0	56.9	HRDLIČKA
	F	208	3.4	1.0	13.5	68.8	(1920)
Japanese	M	252	9.1	23.8	31.4	35.7	SUZUKI and SAKAI
	F	222	10.4	19.4	39.6	30.6	(1966)
Japanese	M	89	1.1	23.6	42.7	32.6	MIZOGUCHI
	F	87	8.1	18.4	42.5	31.0	(1977b)

also support the differential incidences of the shovelling of the permanent incisors among various populations. In most populations, there are no significant sex differences in incidence of the shovelling of the maxillary incisors, though ESCOBAR *et al.* (1977) reported that both central and lateral incisors exhibited significant sex differences in the Queckchi Indians, a subgroup of the now extinct Mayas.

The reports on the shovelling of the canines are very few. In Table 18, the present results are compared with those of SUZUKI and SAKAI (1966). From this, it is realized that the incidence of the shovelling of the canines is extremely low in Japanese populations compared with that of the incisors. Such low frequencies are also recognized in the maxillary deciduous canines as reported by HANIHARA (1955). According to him, the frequency of the semi-shovel shaped canines is 5.0% in Japanese, 1.8% in the hybrids of Japanese with American whites, and 0.0% in the hybrids of Japanese with American Negroes. Another difference of the canines from the incisors is presence of the significant sex difference on the shovelling of the canines. The shovelling of the canines tends to occur more frequently in females than in males.

Table 18. Frequencies of the shovelling of the maxillary canines in Japanese

Population	Sex.	No.	Expressivity (%)				Source
			no	tr	ss	s	
Japanese	M	232	92.7	6.0	1.3	0.0	SUZUKI and SAKAI
	F	214	82.2	14.0	3.3	0.5	(1966)
Japanese	M	128	85.2	12.5	2.3	0.0	Present work
	F	139	71.9	20.9	5.0	2.2	

Incidentally, the maxillary canine has larger number of the characters showing the significant sex differences than the incisors do. Of the seven non-metrical characters with sex difference studied here, five characters belong to the canine (Table 5). Such sexual dimorphisms are probably related to those on the whole size of the canines.

The frequencies of the three lingual ridges, *i.e.* the central ridge, the mesial and distal accessory ridges of the maxillary central incisors are 60.2%, 29.2% and 40.3%, respectively. These values were obtained after combining the data of males and females, regardless the intensity of development in expression. This frequency pattern in which the central ridges are the most frequent and the mesial accessory ridges are the least is consistent with that reported by HANIHARA (1954) on the maxillary central deciduous incisors of Japanese children. However, SAKAI *et al.* (1965) said that the frequencies of these three lingual ridges were almost the same on the enamel-dentin borders of Japanese permanent dentition: 60.9% for the central ridge, 59.1% for the mesial accessory ridge and 60.6% for the distal accessory ridge. Of course, these values are not necessarily comparable to those on the enamel surfaces. But it is difficult to determine whether the difference between the results of SAKAI *et al.* (1965) and those of this study has arisen from the difference between enamel surfaces and enamel-dentin borders, or from the difference between the populations studied, or from the difference of the criteria in observation, or from all of them.

In the maxillary lateral incisors, there were significant sex differences in the incidence of all the affected of the mesial and distal accessory ridges. For the central ridge, however, such a difference was not recognized. The frequency of all the affected of the central ridge is 26.0% in the combined data for sexes, that of the mesial accessory ridge is 14.6% in males and 26.7% in females, and that of the distal accessory ridge is 16.2% in males and 28.3% in females. From these values, it is found out that the frequencies of the three lingual ridges are nearly the same in females, but, in males, the frequencies of the two accessory ridges are lower than that of the central ridge. According to HANIHARA (1954), the central ridge of the deciduous lateral incisor is most common in Japanese children, but the mesial and distal accessory ridges are very few. His results on the deciduous dentition seem to be consistent with those on the male permanent lateral incisor studied here, though the extent of incidence is different from each other.

In the maxillary canines, no significant differences between both sexes were recognized for the central ridge nor for the mesial accessory ridge. For the distal accessory ridge, however, the sex difference in the incidence of the relatively well developed expressivities (2 and 3) was significant at the 5% level. This seems to be compatible with the results reported by SCOTT (1977) that the between-sex differences of the distal accessory ridges in both maxillary and mandibular canines were significant in seven samples of Southwest U.S. Indians and in two American white samples.

The frequency of the relatively well developed expressivities (2 and 3) of the central ridge in the maxillary canine was 19.6% on the basis of the pooled sample of males and females. In the deciduous canines, the corresponding frequency was reported by HANIHARA (1955) to be 39.3% in Japanese, 84.7% in the hybrids of Japanese with American whites, and 78.1% in the hybrids of Japanese with American Negroes. As the criteria of classification used here are the same as those of HANIHARA (1955), the central ridges of the Japanese canines may be said to be more developed in the deciduous dentition than in the permanent if the inter-observer error and the difference between the populations are negligible. This seems to be compatible with the generally accepted view that the deciduous dentition shows the more generalized or primitive form than the permanent. On the enamel-dentin borders of the permanent maxillary canines, SAKAI *et al.* (1967) reported the frequency of 61.0% of the well developed central ridges based on the Japanese data. Although this frequency appears to be higher than that of the present study, they may not be inconsistent with each other because the degrees of development in expression of the central ridge and of the mesial marginal ridge are almost parallel as shown in Table 10 and the marginal ridges are more marked on the enamel-dentin borders than on the enamel surfaces (SAKAI *et al.*, 1967).

HRDLIČKA (1921) said, "The median ridge occurs occasionally on the median upper incisors; more frequently on the lateral upper incisors; ...; generally on the canines...." However, the present study does not completely support his statement. In this work, the frequency on the canines was the highest, but the frequency on the lateral incisors was lower than that on the centrals.

In Table 19, the present results are compared with those of SAKAI *et al.* (1967) on the mesial accessory ridges of the maxillary canines. If only the well developed expressivities (2 and 3) are considered, the frequencies in both results are nearly the same, around 3.5%. The corresponding value on the enamel-dentin border is, again according to SAKAI *et al.* (1967), 1.7%. From these, it may be said that the well developed expressions of the accessory ridges on the enamel surfaces become slightly inconspicuous on the enamel-dentin borders in contrast with the central or marginal ridges. On the Japanese deciduous canines, HANIHARA (1955) reported the value of 15.7% for the corresponding expressivities of this ridge. The difference in frequency of the mesial accessory ridges between the deciduous and the permanent dentitions may suggest that the mesial accessory ridge of the maxillary canine played an important role in the earlier time of the human evolution, if the deciduous dentition indicates the more primitive form than the permanent.

Table 19. Frequencies of the mesial accessory ridges in the maxillary canines on the basis of the data combined for sexes

Population	No.	Expressivity (%)				Source
		0	1	2	3	
Japanese	54	81.5	14.8	3.7	0.0	SAKAI *et al.* (1967)
Japanese	253	57.7	39.1	3.2	0.0	Present work

Table 20. Frequencies of the distal accessory ridges of the maxillary canines in various populations

Population	Sex	No.	Expressivity (%)				Source
			0	1	2	3	
American white	M	69	10.1	24.6	24.6	40.6*	SCOTT (1977)
	F	72	15.3	23.6	43.1	18.1*	
Papago	M	73	2.7	13.7	27.4	56.2*	SCOTT (1977)
	F	69	13.0	24.6	36.2	26.0*	
Navajo (Tuba City)	M	52	7.7	3.8	23.1	65.3*	SCOTT (1977)
	F	37	18.9	13.5	32.4	35.1*	
Hopi (Oraibi)	M	35	5.7	22.9	40.0	31.4*	SCOTT (1977)
	F	43	16.3	20.9	37.2	25.6*	
Yuma	M	19	26.3	15.8	21.1	36.9*	SCOTT (1977)
	F	21	38.1	19.0	23.8	19.1*	
Japanese	unknown	54	14.8	31.5	35.2	18.5	SAKAI *et al.* (1967)
Japanese	M	122	6.6	28.7	64.8	0.0	Present work
	F	136	9.6	39.0	51.5	0.0	

* Combined frequency of the classes 3, 4 and 5 in the classification system used by SCOTT (1977).

Comparisons of some previous reports on the distal accessory ridge of the maxillary canine are shown in Table 20. According to his photographs of several expressions of this character, SCOTT's (1977) classification system seems to be comparable to those system used here if his classes "3, 4" and "5" are grouped into one class and named "3." Therefore, part of SCOTT's (1977) data were recalculated by the present writer and are listed in Table 20. The frequency of the relatively well developed expressivities (2 and 3) was 64.8% in Japanese males of the present sample. This is close to that of American whites, 65.2%, but rather far from those of the Indians, *i.e.* 83.6% in Papago, 88.4% in Navajo, 71.4% in Hopi and 58.0% in Yuma. In females, the corresponding frequencies are 61.2% in American whites, 62.2% in Papago, 67.5% in Navajo, 62.8% in Hopi, 42.9% in Yuma, and 51.5% in the present sample of Japanese. Simply combining the male and female samples of this study, a value of 57.8 is obtained for the percent frequency of the relatively well developed distal accessory ridges. This is a close value to that of the Japanese sample studied by SAKAI *et al.* (1967), 53.7%. In the case of the deciduous canines, HANIHARA (1955) reported a low value of 11.1% for the corresponding expressivities of the distal accessory ridges in Japanese children. This is considerably low compared with those mentioned above of the distal accessory ridge of the permanent canine. If the principle stated above that the deciduous teeth show more primitive form than the permanent is applied to this fact, then it may be said that the developed distal accessory ridge of the maxillary canine is a new specialized character gained recently in the human evolutionary process. However, this point should furthermore be assessed from various viewpoints. Anyway, it is likely that the distal accessory ridges of the maxillary canines are generally more prominent in males than in females, and less frequent in Japanese than in the others, especially than in Southwest U.S. Indians. Of course, repeatedly speaking, this is the case only under the assumption that the differences between the observational methods and the inter-observer error are negligible.

Homogeneity tests showed no significant between-sex differences in the mesial marginal ridges nor in the distal marginal ridges of the maxillary central incisors. Combining the male and female data, the frequencies of the relatively developed expressivities (2 and 3) are obtained as 88.0% for the mesial marginal ridge and 93.9% for the distal one. That is to say, the distal marginal ridge of the central incisor is more frequent than the mesial one, though both of them appear at considerably high percentage. This phenomenon has already been stated by HANIHARA (1954). He demonstrated that it was true of the marginal ridges of the Japanese deciduous incisors. SAKAI *et al.* (1965) reported, however, that the distal marginal ridges were slightly less developed than the mesial one on the enamel-dentin borders, though both ridges were similarly common.

In the lateral incisors, no significant sex differences in incidence of either marginal ridge, mesial or distal, were recognized. The frequencies of the relatively well developed expressivities (2 and 3) based on the combined data for sexes are 88.8% on the mesial marginal ridge and 92.9% on the distal one. This is approximately the same condition as in the case of the central incisor.

The frequencies of the margianl ridges in the maxillary canines are again listed and compared with those of SAKAI *et al.* (1967) in Tables 21 and 22. From these tables, the two populations studied seem to be very different from each other. But common to both the samples is that the frequencies of the relatively well developed mesial marginal ridges are slightly higher than those of distal ones in contrast with the present results on the maxillary incisors. In the deciduous maxillary canines, however,

Table 21. Frequencies of the mesial marginal ridges in the maxillary canines on the basis of the data combined for sexes

Population	No.	Expressivity (%) 0	1	2	3	Source
Japanese	54	14.8	64.8	20.4	0.0	SAKAI *et al.* (1967)
Japanese	258	0.0	6.6	93.0	0.4	Present work

Table 22. Frequencies of the distal marginal ridges of the maxillary canines in Japanese

Population	Sex	No.	Expressivity (%) 0	1	2	3	Source
Japanese	unknown	54	16.7	64.8	18.5	0.0	SAKAI *et al.* (1967)
Japanese	M	110	0.9	27.3	71.8	0.0	present work
	F	132	0.0	15.2	84.9	0.0	

the distal marginal ridges are more frequent than the mesial ones (HANIHARA, 1955). These facts may be related to the distal accessory ridges being less developed in the deciduous canines. A negative correlation coefficient was in fact obtained between the distal accessory and marginal ridges of the male canines in the present study, though not significant. But this problem should further be considered carefully. In the present study, the distal marginal ridges of the maxillary canines showed a significant sex difference in incidence. In this point, the maxillary canine is again different from the maxillary incisors.

As regards the lingual tubercles, HRDLIČKA (1921) reported the frequencies of what were called the lingual "cusps" in the maxillary incisors. They are 5.6% of 2000 maxillary central and lateral incisors on both sides in the white males, 4.05% of 2000 incisors in the white females, 5.8% of 1228 incisors in the colored males, and 5.3% of 2000 incisors in the colored females. Based on these results, he stated that the frequencies of the incisors with the lingual cusps were about 5% in most cases, and that they seemed to appear more frequently in males than in females and more in the colored than in the white. In the present study, however, the sex differences in incidence of the cusp-like formations (expressivities 2 and 3) were not significant in any of the lingual spines, *i.e.* the central, mesial and distal spines, of each maxillary incisor. HRDLIČKA's (1921) data further show that the frequencies of the lingual cusps are higher in the lateral incisors than in the centrals of both the white and the colored. This was ascertained in the present sample as well. The frequencies of the cusp-like formations in the central incisors were 0.0% for the central and mesial spines and 0.7% for the distal spine, and those frequencies in the laterals were 3.3% for the central spine, 0.7% for the mesial spine and 1.8% for the distal spine. Taking account of all the affected, the frequencies in the central incisors were 16.5% for the central spine, 21.7% for the mesial spine and 35.9% for the distal spine. The corresponding frequencies in the laterals were 6.7%, 7.4% and 16.9%, respectively. In both maxillary incisors, the distal spines seem to be the most frequent and the central spines the least frequent. The proportion of the incidence of all the grades for the lingual spines in the central incisors to that in the laterals is reversed compared with the case of considering only the cusp-like formations. In other words, the frequency of all the affected is higher in the centrals than in the laterals. This is consistent with the description by HANIHARA (1954) on the degree of development of the lingual tubercles in the deciduous incisors.

In the maxillary canines, there were significant sex differences in the incidence of all the affected expressivities for both central and mesial spines, but no difference was found in the distal spines. The frequencies were 45.2% for the central spines in males and 33.6% for those in females. Similarly the frequencies for the mesial spines were 2.7% in males and 12.2% in females. For the distal spines, the combined data of males and females showed a frequency of 16.7%. Namely, the distal spines are more frequent than the mesial ones. This is not different from the case of the incisors, but the central spines of the maxillary canines appear most frequently among the three kinds of the lingual spines in contrast with the case of the incisors. If only the cusp-like central spines are counted, the frequencies on the canines is 10.6% in males and 4.0% in females. The corresponding frequency in the central incisors is 0.0% and that in the laterals is 3.3%, both of which are based on the pooled samples for sexes, as was stated previously. For the mesial and distal spines, such frequencies are not so much different from one another among the three anterior teeth. These results seem to be almost consistent with HRDLIČKA's (1921) statement, "The lingual cusps occur most frequently and as a rule singly on the canines; singly and less frequently, rarely doubly, on the lateral upper incisors; . . . ; and doubly, singly, or in several points on the upper median incisors."

Finally, it is generally accepted that the sexual dimorphism is inconspicuous in most dental minor variants but very distinct in the size of most permanent tooth crowns (GARN *et al.*, 1966; MOSS and MOSS-SALENTIJN, 1977; MIZOGUCHI, 1977b). As seen in the present results, however, many of the minor variants in the canines and a few in the other teeth presented clear between-sex differences in incidence. It is noted here that the whole size of a crown commonly shows the sexual dimorphism on the one hand and most of the components do not show such a dimorphism on the other hand in the maxillary incisors (Table 5). This probably suggests that the mechanism harmonizing many component characters with one another in the developmental process of a given tooth crown is controlled by some genes on the sex chromosomes. One of such mechanisms may be prolongation of the period for the amelogenesis in males, as was stated by MOSS and MOSS-SALENTIJN (1977). These problems concerning sex dimorphism should further be considered on the basis of the more detailed studies.

Summarizing the above, the following can be stated. In Japanese, the shovelling of both maxillary central and lateral incisors is most common but that of the maxillary canine is very rare. As regards the central ridge on the lingual side, the frequency is the highest in the canine and the lowest in the lateral incisor among the three anterior teeth. The distal accessory ridges are always more developed than the mesial accessory ridges in all of the three anterior teeth. Similarly, the distal marginal ridges are more developed than the mesial ones in the two maxillary incisors. In the canines, however, the mesial marginal ridges are more developed than the distal ones. This may be related to the well developed distal accessory ridges of the canines in contrast with those of the incisors. Of the three spines derived from the lingual tubercle, the distal spine is most developed and the central spine is least in both of the maxillary incisors. In the canine, the central spine appears most frequently. Among the three anterior teeth, the canine has the largest number of the characters which show the significant sex differences in incidence.

Inter-character correlations

In his paper of 1949, DAHLBERG presented the argumentation by ADLOFF and WEIDENREICH on the shovelling of the incisors. According to DAHLBERG, ADLOFF "disclaimed the shovel-shaped character of the incisors of *Sinanthropus* because of the presence of a strongly developed lingual tubercle or cingulum," but "WEIDENREICH felt that the significant point was the elevation of the lateral borders on the surface, and discounted ADOLOFF's objections." Although this argumentation was caused by the difference between the viewpoints on the shovelling of the two authors, both the lingual tubercle and the elevation of the lateral borders or the marginal ridges, in fact, more or less contribute morphologically to the shovelling (Tables 8, 9, 10).

As shown in Table 8, the correlation coefficients between the shovelling and the marginal ridges are positive and considerably high, ranging from 0.55 to 0.82, in the maxillary central incisor having the typical shovelling. A correlation coefficient between the mesial marginal ridge and the shovelling in the lateral incisor of male also shows a relatively high value of 0.44 (Table 9). In the canines, correlation coefficients between the mesial marginal ridge and the shovelling as well as between the distal marginal ridge and the shovelling seem to be insignificant in males, but, in females, they show relatively high values of −0.51 and 0.41 (Table 10). Although it seems difficult to interpret the negative value as shown here, this may have a certain meaning in the network of the relationships among the characters because the corresponding value for males is also negative. If the mesial marginal ridges have a high positive correlation with the central ridges, then the superficial correlation between the shovelling and the mesial marginal ridge may become negative because the central ridges decrease the extent of the shovelling. In fact, as demonstrated in Table 10, the central ridges and the mesial marginal ridges of the canines have extremely high positive correlation coefficients of 0.91 and 0.83 in males and females, respectively. It is a caution not to simply interpret a single correlation coefficient. Hence the path analysis, which was called by LI (1956) "the analysis of correlation," may be required in order to view the whole relationships among characters. Before discussing the results of the path analysis, however, some words must be added on the single correlation coefficients.

The correlation coefficients of 0.549 and 0.597 were reported by SAKAI *et al.* (1965) as those between the shovelling and the mesial and distal marginal ridges, respectively, on the enamel-dentin borders of the maxillary central incisors. Since these two values are probably based on the method of fourfold point correlation, they are not necessarily the best estimates of the correlation coefficients of the population. However, the present results based on the tetrachoric correlation method approximately support their results. As regards the maxillary canines, SUZUKI and SAKAI (1966) stated, using a χ^2-test, that there were significant positive associations between the shovelling and the marginal ridges at the 0.1% level. SAKAI *et al.* (1967) also obtained the significant positive correlation coefficients of 0.582 and 0.322, which are again probably fourfold point correlation coefficients, between the shovelling and the mesial marginal ridge as well as between the shovelling and the distal marginal ridge, respectively, on the enamel-dentin borders of the canines. Part of their results is compatible with the present results, though it may be too bold to compare the characters on the enamel surfaces directly with the corresponding characters on the enamel-dentin borders.

The spines of the lingual tubercles in question do not seem to significantly correlate to the shovelling in all cases except for the distal spine of the female central incisor and for the central spine of the male canine. SUZUKI and SAKAI (1966) reported that there was a significant positive correlation between the shovelling and the lingual tubercle of the maxillary central incisor in Japanese, and that in the maxillary canine such a correlation was not significant. BERRY (1976) showed by using a contingency χ^2 method that there were significant positive associations between the shovelling and the grooved cingulum or, in the present terminology, the spines of the lingual tubercle of the maxillary central incisor in two English samples. Although these results are not completely consistent with those of the present study, some of the lingual spines of the central incisors are most likely correlated to the shovelling.

As regards the relations of the central ridge to the shovelling, negative correlations were found in all the cases, of which only the correlation coefficients on the female lateral incisor and canine were significant. These results are nearly consistent with those of SAKAI *et al.* (1965) who reported a similar correlation on the enamel-dentin border of the maxillary central incisor, and with those of SUZUKI and SAKAI (1966) and SAKAI *et al.* (1967) of whom the former reported the results on the enamel surface of the canine using a χ^2-test and the latter obtained the correlation coefficient on the enamel-dentin border of the canine, probably, by the fourfold point correlation method.

The mesial accessory ridges were found to correlate negatively but not significantly to the shovelling in the maxillary incisors. SAKAI *et al.* (1965) also reported the negative correlation between the mesial accessory ridge and the shovelling on the enamel-dentin borders of the maxillary central incisors. On the contrary, such correlations were positive in the canines of both sexes, especially as high as 0.50 in males. It is difficult to interpret these positive correlations on the canines. They should be considered from a comprehensive viewpoint of the interrelationships among many component characters.

The correlations between the shovelling and the distal accessory ridge were negative in all the cases, of which only the correlation coefficients on the female anterior teeth were significant. SAKAI *et al.* (1965, 1967) also obtained similar results on the enamel-dentin borders of the maxillary central incisors and canines.

Between both marginal ridges, the correlation coefficients were considerably high, ranging from 0.79 to 0.90, in the maxillary incisors. For the canine, however, they were not so high, *i.e.* 0.46 in males and 0.25 in females. Instead, the correlation coefficient between the distal accessory ridge and the mesial marginal ridge was as high as 0.89 in the female canine. In the incisors with the less developed distal accessory ridges, the corresponding correlation coefficients were not significant at all. These results may suggest that the well developed distal accessory ridges of the canines partly substitute the relatively less developed distal marginal ridges compared with those of the incisors. According to SAKAI *et al.* (1965, 1967), the correlation between both marginal ridges on the enamel-dentin border of the central incisor is relatively high and that of the canine is somewhat low, both of which being positive. These results are almost compatible with those of the present study. However, again according to SAKAI *et al.*, the correlation between the distal accessory ridge and the mesial marginal ridge on the enamel-dentin border was not significant in the canine, but, in the central incisor, negatively significant. This is not necessarily consistent with the present results.

Finally, the correlations between the shovelling and the mesiodistal dimension were found out to be not so high in most cases. Of these correlation coefficients, the significant ones were recognized in the maxillary lateral incisors of both sexes and in the central incisors of females, ranging between 0.35 and 0.40. SUZUKI and SAKAI (1966) said that the differences between the mesiodistal dimensions of the tooth crowns with the well developed shovelling and those with the less developed shovelling were significant in both maxillary incisors but not in the canine. LOMBARDI (1975) also compared the tooth dimensions between those with and without the shovelling, by the use of STUDENT's *t*-test, and found no significant differences in either maxillary central or lateral incisor in both sexes. As a whole, it is likely that there are positive but low correlations between the shovelling and the mesiodistal dimension in the maxillary incisors and that, in the maxillary canines, such correlations are not significant.

The above is discussion on individual correlations. These correlations should now be considered from the more comprehensive viewpoint that all the characters interact one another.

Analysis of correlations by the method of path coefficients

There are some reservations in interpreting the results of the path analysis in the present study. Not all the correlation coefficients are based on the same sample. Some of the correlation coefficients may be biased because the sample size is too small to estimate the more exact tetrachoric correlation coefficients. Furthermore, some other tetrachoric correlation coefficients could not be obtained because there were no concordant or discordant pairs in one or more cells of the fourfold correlation table. In such a case, a series of the correlation coefficients on the character in question were excluded from the correlation matrix on which the path analysis was based.

In the path analysis, some one-way processes in the chain of causation must be assumed. However, the relations between the shovelling or the mesiodistal dimension and the small component crown characters seem to be those of "part and the whole" rather than those of "cause and effect." In this work, therefore, the morphological contribution of the small components to the whole was assumed to be in one direction. Each squared path coefficient, or coefficient of determination, completely measures the portion of the variance of the endogenous variable for which an exogenous variable is directly responsible, if there are no correlations between the exogenous variables (WRIGHT, 1934). Each path coefficient also measures the influence, positive or negative, of the direct path from each exogenous variable to the endogenous variable when the other exogenous variables are held constant (Li, 1956). In fact, there are some joint effects of the exogenous variables on the endogenous variable, as discussed previously with regard to the single correlations between the shovelling and the marginal ridges. But it is easy to assess such joint effects because the sum of the coefficients of determination is expressed as unity (see formulae (2)). Therefore, the following discussion will mainly be done on the basis of the coefficients of determination.

As shown in Fig. 3 and Table 13, the mesiodistal dimensions of the maxillary central incisors appear to be influenced intensively by the central ridges and the mesial marginal ridges in males, and by the mesial and distal marginal ridges in females. These results quantitatively corroborate the impression in observing the maxillary central incisors. The joint effect of the compound paths seems to play a role of extremely diminishing the variance of the mesiodistal dimension. Both the marginal and the accessory ridges on the mesial side seem to contribute to the mesiodistal dimension much more than those on the distal side in both males and females. This is quite the reverse of the observation that the distal ridges were more developed than the mesial ones in the maxillary incisors. A similar condition is again recognized in the case of the lingual accessory ridges of the lateral incisors in females. This problem should be studied in more detail.

The results of two path analyses on the male central incisors were nearly the same, whether the correlation matrices included the mesial spines or not. This suggests that the mesial spine of the male central incisor contributes very little to the mesiodistal dimension.

As regards the relations of the small components to the mesiodistal dimensions in the lateral incisors, the path analyses were not so successful, probably because the marginal ridges, which were suspected to play an important role in the network of compound paths, were excluded from the analyses (Fig. 3, Table 13).

It is very interesting that there is much contribution of the distal accessory ridges to the mesiodistal dimensions in the canines compared with the incisors (Fig. 3, Table 13). Although the results are not so clear in males, yet the mesial marginal ridge, the distal accessory ridge and the central ridge of the female canine influence the mesiodistal dimension intensively, in decreasing order of the extent. The distal marginal ridges of the canines have little or no contribution to the dimension. It seems as if the distal accessory ridge substituted the distal marginal ridge in the canine. The role of the distal accessory ridge is of great importance in determining the mesiodistal dimension of the canine.

In all of the above cases, there were some contributions of the residual variables to the mesiodistal dimensions. If the path coefficients of the mesiodistal dimensions on the residual variables are not equal to zero, they indicate, at least, the presence of something directly contributing to the mesiodistal dimensions other than the small components studied.

In the path analyses of the shovelling and the small crown components, it was found out that the mesial and distal marginal ridges mainly influenced the shovelling of the central incisors (Fig. 4, Table 14).

In the female central incisor, the distal spines of the lingual tubercle also contribute to the shovelling. It is more conspicuous in the lateral incisors of females (Fig. 4, Table 14), where both mesial and distal spines intensively contribute to the shovelling. The mesial and distal spines frequently join to the marginal ridges and make an appearance of the shovelling more clear, especially in the maxillary lateral incisors.

In the canines, small crown components make little or no contribution to the shovelling in either of males and females (Fig. 4, Table 14). It should be noted here that the relatively high correlation coefficients between the shovelling and the other characters (Table 10) were analyzed into the negligibly low path coefficients.

Finally, the correlation coefficients observed between the shovelling and the mesiodistal dimensions are compared with those estimated from the compound path coefficients based on a model of two endogenous variables in Table 15. Of the directly observed correlation coefficients, only those on the female central incisor and on the lateral incisors of both sexes are significant, though relatively low in values. To each of these coefficients, the corresponding correlation coefficient was estimated from the compound path coefficients on the assumptions that there was no path directly connecting the shovelling with the mesiodistal dimension and that the superficial correlation between them, if any, arose only from the common parts of the background. Differences between the observed and estimated correlation coefficients were not significant except for the male maxillary central incisors. The estimated correlation coefficients from the compound path coefficients of the male central incisors were significantly higher than those observed. This may indicate that the shovelling and the mesiodistal dimension are, in practice, not independent of each other at least in the male central incisors. For most maxillary anterior teeth, however, it may be said that the two total compound characters, the shovelling and the mesiodistal dimension, are not directly connected to each other by any path but have lower correlations caused by their common background.

In summary, the path analyses of the crown characters in the maxillary anterior teeth suggest that the central ridge, the mesial and distal marginal ridges mainly influence the mesiodistal dimension in the central incisors, especially of males, and that, in the female canines, the central ridge, the mesial marginal ridge and the distal accessory ridge intensively contribute to the mesiodistal dimension. On the shovelling of the central incisors, the mesial and distal marginal ridges have much influence, as was expected. In addition to this, the mesial and distal spines of the lingual tubercles contribute to the shovelling of the incisors, especially to a great extent in the female lateral incisors. In the canines, small components seem to make little or no contribution to the shovelling. The correlations observed directly between the shovelling and the mesiodistal dimensions are consistent with those correlation coefficients estimated on the basis of the compund path coefficients in all the anterior teeth except for the male central incisors.

Summary and conclusions

One of the purposes of this paper was to describe systematically the tooth crown characters on the lingual surfaces of the maxillary anterior teeth in Japanese, and the other was to quantitatively estimate the degree of influence of the small component crown characters on the shovelling and on the mesiodistal dimension in each tooth. The materials used here were dental plaster casts of 179 males and 168 females. The small component characters observed in each maxillary tooth were the central ridge, the mesial and distal accessory ridges, the mesial and distal marginal ridges, and the central, mesial and distal spines of the lingual tubercle. The frequencies of four expressivities in each of these characters were counted.

The number of characters with the significant between-sex difference in incidence was found out to be the largest in the canine among the three maxillary anterior teeth. The distal accessory ridges tended to be more developed than the mesial ones in all kinds of the teeth studied. The distal marginal ridges were also more developed than the mesial ones in the central and lateral incisors, but, in the canines, the condition was reversed. Instead, the canines carried the well developed distal accessory ridges in contrast with the incisors. Of the three spines from the lingual tubercles of the two incisors, the distal spines were more deveoped than the mesial ones, and the central spines were the least developed. On the contrary, in the canines, the central spines occurred most frequently.

Degree of influence of the small crown components on the mesiodistal dimensions and on the shovelling was estimated by the path analysis. As a result, it was found out that the mesiodistal dimensions of the central incisors were mainly influenced by the central ridges, the mesial and distal marginal ridges. In the female canines, however, the central ridges, the mesial marginal ridges and the distal accessory ridges intensively influenced the mesiodistal dimensions. On the shovelling of the central incisors, as was expected, the mesial and distal marginal ridges had much influences. Besides, the mesial and distal spines of the lingual tubercles contributed to the shovelling of the incisors, especially of the female lateral incisors. On the shovelling of the canines, little or no influence of the small crown characters was recognized. The correlations between the shovelling and the mesiodistal dimensions were observed to be positive but relatively low or insignificant in the maxillary anterior teeth. They were consistent with those correlation coefficients estimated from the compound path coefficients in all the anterior teeth except the male central incisor. This may suggest that the shovelling and the mesiodistal dimension are not directly connected to each other by any path in most maxillary anterior teeth.

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