Bull. Natl. Mus. Nat. Sci., Ser. D, **33**, pp. 39–66, December 21, 2007

Loose Association between Neurocranial Shape and Facial Structure: Toward the Solution of the Brachycephalization Problem

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Abstract Correlations between neurocranial and facial measurements were examined as a step toward elucidating the causes of brachycephalization by principal component analysis and Kaiser's normal varimax rotation methods. The results obtained from 30 male and 20 female modern Japanese show that neither cranial length nor cranial breadth has any consistent associations with facial measurements across sexes, contrary to our expectations. These findings suggest that neurocranial shape and facial structure may be only loosely associated, in accordance with the degree of development of masticatory muscles. It is also noteworthy that, when a certain facial measurement is associated with either cranial length or breadth in males, it is almost always cranial breadth, not cranial length. The difference in the way of connecting with other characters between cranial length and breadth, the former of which has been shown to be associated exclusively with certain postcranial measurements, may be one of the reasons why brachycephalization and dolichocephalization mutually and irregularly occur in a geographic area.
Key words : Brachycephalization, Neurocranium, Face, Principal component analysis, Bootstrap method

In order to clarify the causes of brachycephalization, correlations between cranial and postcranial measurements were examined by the author using principal component analysis and Kaiser's normal varimax rotation methods, and it was found that cranial length is strongly associated with the sagittal and transverse diameters of the vertebral bodies, sacral breadths, costal chords, many humeral measurements, pelvic breadths and heights, femoral lengths and thicknesses, and tibial lengths and thicknesses. On the other hand, cranial breadth was shown to have no consistent association with any measurements of the vertebrae, ribs, sternum, scapula, clavicle, humerus, ulna, radius, pelvis, femur, patella, tibia, fibula or foot bones. The details and interpretation of these results are given in Mizoguchi (1994, 1995, 1996, 1997, 1998a, b, 1999, 2000, 2001, 2002, 2003a, b, 2004, 2005a).

The present study on facial measurements is also one of the above series of analyses. Unlike the correlations between cranial and postcranial measurements, however, inter-character correlations within the skull were repeatedly analyzed for various human samples. These analyses provide the following expectations. First, cranial breadth is strongly associated with facial breadth, especially bizygomatic breadth (Kanda and Kurisu, 1968; Kanda, 1968; Howells, 1972; Brown, 1973; Mizoguchi, 1992a). Second, this association may be caused by the common influence of masticatory muscles upon both facial and neurocranial structures because, for example, Weijs and Hillen (1986) showed that the cross-sectional area of the masseter muscle had significant correlations with head breadth, bigonial width and mandibular length; and Mizoguchi (1992b) found that individuals with a more worn maxillary first molar had significantly smaller inter-parietal-tuber breadth, smaller basi-bregmatic height, and greater bizygomatic breadth. Further, Mizoguchi (2005b) showed that the neurocranium of a person with heavily worn molars tended to be flatter and broader in its anterior-superior part and narrower and higher in its posterior-inferior part. Finally, however, there is also an opposite expectation: neurocranial form may not be so strongly connected to facial structure, because Droessler (1981) has pointed out that the susceptibility to artificial cranial deformation is contrastive between the cranial vault and the facial skeleton, and Mizoguchi (1991) showed that most facial measurements did not consistently suffer from artificial cranial deformation.

In the present study, these expectations were re-examined by comparing three basic neurocranial measurements, cranial length, cranial breadth and basi-bregmatic height, with eighty facial measurements.

Materials and Methods

The data used were the raw measurements of skulls reported by Miyamoto (1924). These are of 30 male and 20 female modern Japanese who lived in the Kinai district. The basic statistics for cranial length, cranial breadth and basi-bregmatic height are presented in Mizoguchi (1994), and those for 90 facial measurements, including the cubic root of mandible weight calculated by the author, are listed in Table 1. This set of facial measurements contains almost all traditional ones.

The measurements of the face were, in practice, divided into ten groups, each of which contained a similar kind of measurements, to carry out the following multivariate analyses. This was necessary because of a statistical restriction on sample size given the number of variables. For the seventh data sets [variable No. 80 to 80(3)/K124 in Table 1] of both sexes, however, the multivariate analyses were not performed because the sample sizes were too small. Further, the angle between id-pg line and alveolar margin [79(1b)] in the tenth data sets [variable No. 79(1) to 79(1a) in Table 1] was excluded from the relevant multivariate analyses, again, because of the small sample sizes.

To examine the overall relations between neurocranial and facial measurements, principal component analysis (Lawley and Maxwell, 1963; Okuno *et al.*, 1971, 1976; Takeuchi and Yanai, 1972) was applied to their correlation matrices. The number of principal components was determined so that the cumulative proportion of the variances of principal components exceeded 80%. The principal components obtained in such a way were then transformed by Kaiser's normal varimax rotation method (Asano, 1971; Okuno *et al.*, 1971) into different factors because these may reveal other associations behind the measurements.

The significance of factor loadings was tested by the bootstrap method (Efron, 1979a, b, 1982; Diaconis and Efron, 1983; Mizoguchi, 1993). In order to estimate the bootstrap standard deviation of a factor loading, 1,000 bootstrap replications, including the observed sample, were used. The bootstrap standard deviation was estimated by directly counting the cumulative frequency for the standard deviation in the bootstrap distribution.

The reality of a common factor such as those represented by a principal component or rotated factor was further tested, although indirectly, by evaluating the similarity between the factors obtained for males and females, i.e. by estimating a Spearman's rank correlation coefficient, rho (Siegel, 1956), between the variation patterns of factor loadings.

Statistical calculations were executed using the programs written by the author in FORTRAN: BSFMD for calculating basic statistics, BTPCA for principal component analysis and Kaiser's normal varimax rotation, and RKCNCT for rank correlation coefficients. The FORTRAN 77 compiler used is FTN77 for personal computers provided by Salford Software Ltd. To increase efficiency in programming and calculation, a GUI for programming, CPad, provided by "kito," was used.

Results

The direct results of principal component

Table 1. Means and standard deviations for facial measurements in Japanese males and females.[1)]

Variable[2)]	Males			Females		
	n	Mean	SD	n	Mean	SD
40 Facial length	29	100.2	4.0	19	94.4	4.7
42 Lower facial length	30	105.6	5.1	20	100.3	4.3
47 Facial height	30	122.2	7.0	19	115.0	4.7
48 Upper facial height	28	72.9	4.3	19	68.7	3.1
45 Bizygomatic breadth	30	133.4	5.3	20	125.9	3.8
43 Upper facial breadth	30	103.9	3.9	20	99.6	3.2
44 Biorbital breadth	30	97.0	7.4	20	94.3	3.2
44(1) Nasomalar breadth	30	104.7	4.3	20	100.4	3.6
46 Bimaxillary breadth	30	100.0	4.0	20	95.8	3.9
K65 Distance between infraorbital foramina	30	53.8	3.2	20	51.4	4.3
50 Interorbital breadth	30	18.2	1.8	20	17.1	1.7
49 Posterior interorbital breadth	30	23.7	2.5	18	22.3	1.6
49(1) Upper ethmoid bone breadth	30	24.5	1.9	20	22.8	2.6
49(2) Lower ethmoid bone breadth	30	36.6	2.4	20	35.9	2.9
51 Orbital breadth	30	43.3	1.9	20	41.6	1.7
K72 Horizontal breadth of orbital inlet	30	38.0	1.6	18	37.1	1.2
52 Orbital height	30	34.3	2.1	20	34.0	1.7
K73 Vertical height of orbital inlet	30	34.4	1.9	19	34.5	1.8
53 Orbital depth	30	48.4	2.1	20	46.9	2.6
53a Orbital axial length	30	48.4	2.3	20	45.5	2.1
54 Nasal breadth	30	26.3	1.8	20	25.0	1.7
55 Nasal height	30	52.5	2.9	20	48.9	2.5
55(1) Height of piriform aperture	30	31.6	2.0	20	29.1	2.5
56 Nasal bone length	30	25.1	3.2	20	23.2	2.5
57(2) Superior nasal bone width	30	10.2	2.7	20	8.6	2.2
57 Minimum nasal bone width	30	7.1	1.9	20	6.9	1.3
57(1) Maximum nasal bone width	30	17.8	2.1	20	17.5	1.6
59(1) Maximum breadth of posterior choanae	30	30.6	2.1	20	30.0	2.0
59 Height of posterior choana	30	26.5	2.9	20	24.6	1.3
K87 Maximum height of zygomatic bone	30	46.2	2.8	20	43.9	2.6
K88 Height of maxillary process	30	25.5	2.0	20	23.2	2.3
K89 Height of temporal process	30	13.4	2.3	20	11.7	1.9
K90 Superior breadth of zygomatic bone	28	44.2	3.1	20	41.9	2.7
K91 Middle breadth of zygomatic bone	28	26.9	2.2	20	24.6	3.7
K92 Inferior breadth of zygomatic bone	30	31.7	3.0	20	28.1	4.5
60 Maxillo-alveolar length	29	54.1	2.9	19	50.9	2.5
61 Maxillo-alveolar breadth	28	65.9	3.2	18	62.3	2.9
61(2) Anterior maxillo-alveolar breadth	25	42.7	2.3	20	41.1	2.7
K96 Orbit-canine height	27	43.6	3.8	17	40.6	2.7
62 Palatal length (ol-sta)	29	46.3	3.0	20	43.9	2.3
62a Palatal length (ol-posterior nasal spine)	29	51.0	2.7	20	48.0	2.8
63 Palatal breadth	24	41.5	2.7	14	38.8	2.8
63(2) Anterior palatal breadth	27	30.0	2.5	19	28.2	1.7
64 Palatal height	24	12.2	2.5	17	12.1	1.9
64a Anterior palatal height	24	8.8	2.5	18	9.8	2.9
68 Mandibular length	30	73.4	3.8	20	69.3	2.8
65 Bicondylar breadth	30	119.3	6.9	20	115.1	5.2
65(1) Bicoronoid breadth	30	97.7	4.5	20	92.5	3.7
66 Bigonial breadth	30	100.3	5.0	20	91.9	3.9
67 Bimental breadth	30	45.9	2.6	20	45.9	1.7
69 Chin height	28	36.6	3.6	20	33.4	2.1
69(1) Mandibular body height	30	33.7	2.8	20	31.5	2.1
69(3) Mandibular body thickness	30	12.8	1.7	20	12.2	1.0
71 Minimum ramus breadth	30	33.7	2.8	20	31.5	2.3
70 Ramus height	30	61.1	5.0	20	55.4	3.4
70(1) Coronoid height	30	64.7	5.1	20	55.7	3.7

Table 1. (Continued)

Variable[2]	Males			Females		
	n	Mean	SD	*n*	Mean	SD
71(1) Mandibular notch width	30	36.9	2.5	20	34.9	3.2
70(3) Mandibular notch height	29	15.0	1.8	20	12.8	1.7
39(1) Weight of mandible	30	93.9	12.5	20	81.5	9.2
Cubic root of mandible weight[3]	30	4.537	0.199	20	4.329	0.160
80 Length of maxillary dental arch	13	54.8	4.9	6	53.8	1.6
80(1)/K118 Dental arch width (maxilla)	14	67.0	3.5	6	52.8	3.0
80a Length of mandibular dental arch	8	50.9	3.4	6	60.2	2.6
80(1)/K120 Dental arch width (mandible)	13	66.2	4.0	6	60.3	4.9
80(2)/K121 Arch length of postcanine teeth (maxilla)	15	42.9	3.4	7	41.1	1.3
80(2)/K122 Arch length of postcanine teeth (mandible)	12	44.5	1.6	8	45.3	2.9
80(3)/K123 Arch length of molar teeth (maxilla)	16	28.8	2.3	6	27.8	0.8
80(3)/K124 Arch length of molar teeth (mandible)	13	31.5	1.2	8	31.3	1.6
72 Facial profile angle	29	83.2	3.0	19	82.5	2.5
73 Nasal profile angle (n-ns-FH)	30	89.2	2.7	20	87.5	2.9
K147 Nasal profile angle (n-ss-FH)	30	85.1	2.7	20	84.2	2.6
74 Alveolar profile angle (ns-pr-FH)	29	66.9	7.3	20	68.5	5.7
K149 Alveolar profile angle (ss-pr-FH)	29	75.8	6.4	20	72.0	4.9
75 Profile angle of nasal dorsum	29	64.2	5.4	20	64.5	5.5
75(1) Angle of nasal dorsum with nasion-prosthion line	28	19.0	5.8	19	18.2	5.2
74(2) Maxillary incisor inclination	29	83.0	11.6	19	79.5	9.9
76(1) Orbit-canine angle	27	77.1	5.0	18	77.7	4.1
77 Transverse profile angle of upper face	29	145.1	5.2	20	147.5	3.8
76 Zygomatic profile angle	29	116.1	4.5	20	116.7	4.4
K155 Angle between zygomatic bones	30	139.8	7.0	20	134.3	5.6
78 Sagittal inclination of orbital inlet	30	92.2	3.3	20	89.4	3.2
78(1) Coronal inclination of orbital inlet	30	15.6	2.6	20	15.6	1.8
78(2) Horizontal inclination of orbital inlet	30	15.4	2.6	20	13.1	2.1
78(3) Angle between orbital axes	30	40.2	3.2	20	41.8	2.8
K160 Inclination of orbital axis plane to Frankfurt Horizontal	30	1.9	2.6	20	2.9	2.8
79(1) Profile angle of mandible	27	78.3	7.0	19	76.2	6.8
79(1b) Angle between id-pg line and alveolar margin	17	94.2	5.7	9	94.4	6.9
K163 Chin angle	27	80.4	5.8	19	81.1	6.7
79 Mandibular angle	30	123.0	6.4	20	128.7	4.7
79(1a) Symphysial angle	29	72.5	5.6	20	72.2	6.6

[1] The estimates of basic statistics listed here were recalculated by the author on the basis of the raw data published by Miyamoto (1924). When measurements are available for both sides, only those on the right side were used.
[2] Bare-numbered variables are measurements according to Martin and Saller (1957), and those with the letter 'K' preceding the number are according to Kiyono (1929).
[3] Cubic roots were calculated by the author.

analyses (PCAs) and the rotated solutions for craniofacial measurements are shown in Tables 2 to 37. The Spearman's rank correlation coefficients between males and females for the variation patterns of factor loadings on the principal components (PCs) and/or rotated factors (Facs) are shown in Tables 38 to 46.

Those PCs or Facs which are significantly correlated both with one or more of the three main neurocranial measurements and with one or more facial measurements are as follows. In the fifth, eighth and tenth data sets, however, no such PCs or Facs were found.

1) PC I from the first data set of males (Table 2)

This PC is significantly correlated both with the three neurocranial measurements and with facial heights and breadths. The female factor most similar to this male PC I (Table 38) is also PC I (Table 4), but female PC I has no significant correlation with any of the three neurocranial measurements.

2) Fac I from the first data set of males (Table 3)

This factor is significantly correlated with both cranial breadth and facial breadths including bizygomatic breadth, but there are no female PCs or Facs which are significantly similar to this male factor (Table 38).

3) PC I from the second data set of males (Table 6)

While this PC is significantly correlated both with the three neurocranial measurements and with many orbital measurements, female Fac III, which is most similar to this male PC I (Table 39), has no significant correlation with any of the measurements analyzed (Table 9).

4) Fac V from the third data set of males (Table 11)

This factor is significantly correlated with both cranial breadth and maximum nasal bone width, but female PC II, which is most similar to this male Fac V (Table 40), has no significant correlation with any of the measurements analyzed (Table 12).

5) Fac IV from the third data set of females (Table 13)

This factor is significantly correlated with cranial length and breadth and also with the maximum breadth of posterior choanae, but male PC III, which is most similar to this female Fac IV (Table 40), has no significant correlation with any of the measurements analyzed (Table 10).

6) PC I from the fourth data set of males (Table 14)

This PC is significantly correlated with cranial length and breadth and with many measurements of the zygomatic bone and maxilla as well, but female PC IV, which is most similar to this male PC I (Table 41), has no significant correlation with any of the measurements analyzed (Table 16).

7) Fac V from the fourth data set of females (Table 17)

This factor is significantly correlated with cranial length and the superior breadth of the zygomatic bone. Although male PC V (Table 14) and Fac II (Table 15) are significantly similar to this female factor (Table 41), they do not have significant correlations with any of the three main neurocranial measurements.

8) PC I from the sixth data set of males (Table 22)

This PC is significantly correlated both with the three main neurocranial measurements and with mandibular ramus measurements, but no female PCs or Facs have significantly similar factor loading variation patterns (Table 43).

9) Fac III from the sixth data set of males (Table 23)

This factor is significantly correlated with basi-bregmatic height and bigonial breadth, but no female PCs or Facs have factor loading variation patterns that are significantly similar to that of this male Fac III (Table 43).

10) Fac VI from the sixth data set of males (Table 23)

This factor is significantly correlated with cranial, bicondylar and bicoronoid breadths. Female PC IV (Table 24) is significantly similar to this male factor (Table 43), but does not have significant correlations with any of the measurements analyzed.

11) Fac III from the sixth data set of females (Table 25)

This factor is significantly correlated with cranial length and bigonial breadth, but no male PCs or Facs have significantly similar factor loading variation patterns (Table 43).

12) Fac III from the ninth data set of males (Table 31)

This factor is positively correlated with cranial breadth and inversely with the inclination of the

Table 2. Principal component analysis of the correlation matrix on the first set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings				Total variance (%)
	PC I	II	III	IV	
1 Cranial length	0.62***	−0.06	−0.20	0.59	77.35
8 Cranial breadth	0.66**	0.04	−0.32	−0.42	71.33
17 Basi-bregmatic height	0.44*	−0.46	0.13	0.51	67.92
40 Facial length	0.49*	0.53	−0.60	0.20	91.24
42 Lower facial length	0.31	0.71	−0.56	0.06	92.06
47 Facial height	0.47*	0.61	0.58	−0.04	93.51
48 Upper facial height	0.52**	0.50	0.64	−0.01	93.30
45 Bizygomatic breadth	0.84***	−0.28	−0.09	−0.15	80.71
43 Upper facial breadth	0.87***	−0.20	0.02	−0.18	83.62
44 Biorbital breadth	0.67*	−0.46	−0.24	−0.20	75.61
44(1) Nasomalar breadth	0.84***	−0.09	0.15	−0.13	75.23
46 Bimaxillary breadth	0.87***	0.04	0.01	−0.05	75.76
K65 Distance between infraorbital foramina	0.80***	−0.07	0.27	0.21	76.58
Total contribution (%)	44.94	15.19	13.40	7.57	81.09
Cumulative proportion (%)	44.94	60.12	73.52	81.09	81.09

[1)] The sample size is 28. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 3. Solution obtained through normal varimax rotation of the first four principal components for the correlation matrix on the first set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings			
	Fac I	II	III	IV
1 Cranial length	0.25	0.37	0.06	0.76
8 Cranial breadth	0.76**	0.34	0.05	−0.12
17 Basi-bregmatic height	0.23	−0.19	−0.01	0.77
40 Facial length	0.20	0.92	0.05	0.15
42 Lower facial length	0.06	0.94*	0.13	−0.09
47 Facial height	0.09	0.14	0.95*	−0.01
48 Upper facial height	0.14	0.04	0.95*	0.07
45 Bizygomatic breadth	0.84***	0.07	0.10	0.29
43 Upper facial breadth	0.84***	0.06	0.24	0.26
44 Biorbital breadth	0.82***	−0.00	−0.17	0.24
44(1) Nasomalar breadth	0.73*	0.04	0.38	0.27
46 Bimaxillary breadth	0.69***	0.24	0.36	0.30
K65 Distance between infraorbital foramina	0.51*	0.03	0.45	0.55

[1)] The sample size is 28. The cumulative proportion of the variances of the four principal components is 81.09%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 4. Principal component analysis of the correlation matrix on the first set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings					Total variance (%)
	PC I	II	III	IV	V	
1 Cranial length	0.05	−0.49	−0.38	0.57	0.43	89.10
8 Cranial breadth	0.29	0.58	0.60	−0.17	−0.20	84.68
17 Basi-bregmatic height	0.36	0.28	0.51	0.60	−0.08	83.15
40 Facial length	0.22	−0.57	0.51	−0.18	0.41	83.20
42 Lower facial length	0.48	−0.62	0.36	0.23	−0.14	82.48
47 Facial height	0.55	0.58	0.08	0.26	0.27	79.16
48 Upper facial height	0.58*	0.60	−0.24	0.34	0.15	89.11
45 Bizygomatic breadth	0.74***	−0.13	0.27	−0.25	0.33	80.20
43 Upper facial breadth	0.85***	−0.14	−0.24	−0.05	−0.21	85.41
44 Biorbital breadth	0.84***	−0.21	−0.37	−0.05	−0.18	92.56
44(1) Nasomalar breadth	0.87***	−0.14	−0.20	−0.02	−0.40*	97.50
46 Bimaxillary breadth	0.72***	−0.26	0.14	−0.16	0.05	63.66
K65 Distance between infraorbital foramina	0.49	0.45	−0.29	−0.45	0.41	89.95
Total contribution (%)	35.71	18.69	12.54	9.73	7.96	84.63
Cumulative proportion (%)	35.71	54.40	66.94	76.67	84.63	84.63

[1)] The sample size is 18. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 5. Solution obtained through normal varimax rotation of the first five principal components for the correlation matrix on the first set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings				
	Fac I	II	III	IV	V
1 Cranial length	0.05	0.10	0.12	0.92*	−0.10
8 Cranial breadth	0.00	0.45	0.12	−0.79*	0.03
17 Basi-bregmatic height	0.05	0.81	0.14	−0.15	−0.37
40 Facial length	−0.03	−0.12	0.90	0.07	−0.09
42 Lower facial length	0.45	0.07	0.57	0.13	−0.52
47 Facial height	0.15	0.80	0.04	−0.09	0.35
48 Upper facial height	0.33	0.76	−0.22	0.06	0.38
45 Bizygomatic breadth	0.41	0.21	0.70	−0.10	0.29
43 Upper facial breadth	0.90**	0.15	0.13	0.02	0.11
44 Biorbital breadth	0.93**	0.08	0.10	0.14	0.16
44(1) Nasomalar breadth	0.97***	0.14	0.06	−0.07	−0.02
46 Bimaxillary breadth	0.58	0.11	0.52*	−0.05	0.09
K65 Distance between infraorbital foramina	0.25	0.18	0.08	−0.12	0.89***

[1)] The sample size is 18. The cumulative proportion of the variances of the five principal components is 84.63%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 6. Principal component analysis of the correlation matrix on the second set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings					Total variance (%)
	PC I	II	III	IV	V	
1 Cranial length	0.59**	−0.07	−0.48	−0.30	−0.19	71.41
8 Cranial breadth	0.55*	0.18	−0.20	0.41	0.45	74.23
17 Basi-bregmatic height	0.47*	0.29	−0.27	−0.46	−0.36	71.76
50 Interorbital breadth	0.64*	−0.44	0.42	0.17	0.03	80.59
49 Posterior interorbital breadth	0.76***	−0.28	0.40	0.00	−0.09	82.53
49(1) Upper ethmoid bone breadth	0.77***	−0.14	0.11	0.18	−0.44	85.47
49(2) Lower ethmoid bone breadth	0.49*	0.11	0.20	0.51	−0.21	59.65
51 Orbital breadth	0.61*	0.62	−0.22	0.16	0.05	83.23
K72 Horizontal breadth of orbital inlet	0.49*	0.58	−0.48	0.20	0.09	86.21
52 Orbital height	0.38	0.59	0.51	−0.34	0.04	87.26
K73 Vertical height of orbital inlet	0.26	0.62	0.49	−0.35	0.28	88.71
53 Orbital depth	0.71*	−0.53	−0.06	−0.18	0.32	91.89
53a Orbital axial length	0.56*	−0.58	−0.26	−0.33	0.25	89.25
Total contribution (%)	33.29	19.28	12.21	9.48	6.68	80.94
Cumulative proportion (%)	33.29	52.57	64.78	74.26	80.94	80.94

1) The sample size is 30. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
2) See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 7. Solution obtained through normal varimax rotation of the first five principal components for the correlation matrix on the second set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings				
	Fac I	II	III	IV	V
1 Cranial length	0.10	0.22	−0.10	−0.70	0.40
8 Cranial breadth	0.18	0.78**	0.03	0.14	0.29
17 Basi-bregmatic height	0.05	0.12	0.23	−0.80*	0.06
50 Interorbital breadth	0.73	−0.04	0.09	0.15	0.50*
49 Posterior interorbital breadth	0.74	−0.02	0.24	−0.10	0.46*
49(1) Upper ethmoid bone breadth	0.82*	0.14	−0.02	−0.37	0.17
49(2) Lower ethmoid bone breadth	0.68*	0.35	0.02	0.03	−0.11
51 Orbital breadth	0.19	0.77	0.30	−0.32	−0.07
K72 Horizontal breadth of orbital inlet	0.01	0.85	0.08	−0.36	−0.07
52 Orbital height	0.17	0.10	0.89	−0.17	−0.08
K73 Vertical height of orbital inlet	−0.02	0.15	0.93	0.00	−0.02
53 Orbital depth	0.29	0.10	−0.01	−0.10	0.90***
53a Orbital axial length	0.08	0.00	−0.15	−0.24	0.90***

1) The sample size is 30. The cumulative proportion of the variances of the five principal components is 80.94%.
2) See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 8. Principal component analysis of the correlation matrix on the second set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings				Total variance (%)
	PC I	II	III	IV	
1 Cranial length	0.23	0.52	−0.63	0.12	73.88
8 Cranial breadth	0.16	−0.30	0.89	−0.07	91.41
17 Basi-bregmatic height	0.39	0.09	0.45	0.76	93.43
50 Interorbital breadth	0.80***	−0.02	−0.21	0.13	69.55
49 Posterior interorbital breadth	0.82***	0.08	−0.17	0.06	71.00
49(1) Upper ethmoid bone breadth	0.84***	−0.29	−0.09	−0.04	79.24
49(2) Lower ethmoid bone breadth	0.83***	−0.26	0.12	−0.25	82.39
51 Orbital breadth	0.76*	0.24	0.26	−0.35	82.84
K72 Horizontal breadth of orbital inlet	0.91***	0.12	−0.01	−0.26	91.13
52 Orbital height	0.56*	−0.64	−0.22	0.20	81.74
K73 Vertical height of orbital inlet	0.46	−0.78	−0.20	0.16	89.21
53 Orbital depth	0.49	0.76	0.03	0.09	82.51
53a Orbital axial length	0.47	0.74	0.25	0.10	84.17
Total contribution (%)	40.89	21.17	13.12	7.32	82.50
Cumulative proportion (%)	40.89	62.06	75.18	82.50	82.50

[1)] The sample size is 18. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 9. Solution obtained through normal varimax rotation of the first four principal components for the correlation matrix on the second set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings			
	Fac I	II	III	IV
1 Cranial length	0.21	0.09	−0.83	0.08
8 Cranial breadth	0.20	−0.00	0.91	0.22
17 Basi-bregmatic height	0.09	−0.14	0.17	0.94
50 Interorbital breadth	0.61	−0.44	−0.26	0.25
49 Posterior interorbital breadth	0.69	−0.32	−0.26	0.24
49(1) Upper ethmoid bone breadth	0.67	−0.58	−0.01	0.09
49(2) Lower ethmoid bone breadth	0.78**	−0.43	0.20	−0.00
51 Orbital breadth	0.89*	0.08	0.12	0.09
K72 Horizontal breadth of orbital inlet	0.93**	−0.19	−0.08	0.07
52 Orbital height	0.22	−0.87	0.01	0.07
K73 Vertical height of orbital inlet	0.12	−0.93	0.11	−0.02
53 Orbital depth	0.57	0.41	−0.38	0.43
53a Orbital axial length	0.57	0.47	−0.17	0.52*

[1)] The sample size is 18. The cumulative proportion of the variances of the four principal components is 82.50%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 10. Principal component analysis of the correlation matrix on the third set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings						Total variance (%)
	PC I	II	III	IV	V	VI	
1 Cranial length	0.36	0.41	−0.46	0.09	−0.41	0.18	71.40
8 Cranial breadth	0.50	0.24	0.03	−0.66	−0.01	0.15	76.22
17 Basi-bregmatic height	0.05	0.79	−0.21	−0.06	−0.18	−0.07	70.86
54 Nasal breadth	0.50	−0.31	−0.46	0.29	−0.34	0.07	76.36
55 Nasal height	0.75*	0.12	0.51	0.27	−0.04	−0.21	96.33
55(1) Height of piriform aperture	0.23	0.10	0.63	0.28	0.22	0.58*	92.35
56 Nasal bone length	0.74**	0.06	0.39	0.18	−0.16	−0.42*	94.88
57(2) Superior nasal bone width	0.67*	−0.38	−0.07	−0.39	0.19	0.14	79.66
57 Minimum nasal bone width	0.53	−0.69	−0.19	−0.23	−0.07	0.12	85.60
57(1) Maximum nasal bone width	0.17	−0.39	−0.51	0.50	0.43	−0.09	87.41
59(1) Maximum breadth of posterior choanae	0.34	0.49	−0.29	−0.20	0.58	−0.28	88.48
59 Height of posterior choana	0.38	0.57	−0.27	0.30	0.19	0.34	78.16
Total contribution (%)	23.40	19.07	14.55	10.77	8.21	7.16	83.14
Cumulative proportion (%)	23.40	42.46	57.01	67.78	75.98	83.14	83.14

[1)] The sample size is 30. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 11. Solution obtained through normal varimax rotation of the first six principal components for the correlation matrix on the third set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings					
	Fac I	II	III	IV	V	VI
1 Cranial length	−0.03	0.83**	0.05	−0.06	−0.05	−0.09
8 Cranial breadth	−0.36	0.19	0.09	−0.50	−0.58*	0.05
17 Basi-bregmatic height	−0.35	0.57	0.04	0.38	−0.32	−0.11
54 Nasal breadth	0.27	0.51	0.20	−0.44	0.42	−0.16
55 Nasal height	−0.07	0.06	0.93*	−0.11	−0.03	0.29
55(1) Height of piriform aperture	0.09	−0.07	0.22	0.01	−0.08	0.93**
56 Nasal bone length	−0.06	0.06	0.96**	−0.15	−0.04	−0.00
57(2) Superior nasal bone width	−0.19	−0.03	0.16	−0.85***	−0.01	0.08
57 Minimum nasal bone width	0.19	−0.03	0.09	−0.88***	0.18	−0.11
57(1) Maximum nasal bone width	−0.16	0.02	−0.05	−0.19	0.90***	−0.04
59(1) Maximum breadth of posterior choanae	−0.92***	0.13	0.10	−0.03	0.04	−0.08
59 Height of posterior choana	−0.41	0.64	0.04	0.08	0.15	0.41

[1)] The sample size is 30. The cumulative proportion of the variances of the six principal components is 83.14%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; ** $P<0.001$, by a two-tailed bootstrap test.

Table 12. Principal component analysis of the correlation matrix on the third set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings					Total variance (%)
	PC I	II	III	IV	V	
1 Cranial length	−0.41	0.62	0.18	0.41	−0.28	82.86
8 Cranial breadth	0.67	−0.32	−0.38	−0.28	−0.05	76.66
17 Basi-bregmatic height	0.49	0.10	−0.43	0.22	−0.56	79.69
54 Nasal breadth	0.13	0.79	0.10	−0.42	−0.17	85.25
55 Nasal height	0.68	0.21	−0.30	0.31	0.46	90.91
55(1) Height of piriform aperture	0.79	−0.09	0.06	0.52	−0.00	89.60
56 Nasal bone length	−0.20	0.44	−0.33	−0.36	0.63	85.93
57(2) Superior nasal bone width	0.59	−0.02	0.65	−0.27	0.02	84.25
57 Minimum nasal bone width	0.51	0.14	0.74	−0.21	−0.07	87.38
57(1) Maximum nasal bone width	0.17	0.72	−0.41	−0.29	−0.34	92.33
59(1) Maximum breadth of posterior choanae	−0.29	0.63	0.25	0.48	0.21	80.76
59 Height of posterior choana	0.72	0.44	−0.01	0.10	0.24	77.25
Total contribution (%)	26.88	20.71	14.62	11.74	10.45	84.41
Cumulative proportion (%)	26.88	47.59	62.21	73.95	84.41	84.41

[1)] The sample size is 20. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.

[2)] See the second footnote to Table 1.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 13. Solution obtained through normal varimax rotation of the first five principal components for the correlation matrix on the third set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings				
	Fac I	II	III	IV	V
1 Cranial length	−0.12	0.28	−0.11	0.84***	−0.16
8 Cranial breadth	0.34	0.13	0.04	−0.78**	−0.16
17 Basi-bregmatic height	0.33	0.42	−0.19	−0.20	−0.66*
54 Nasal breadth	0.00	0.82	0.33	0.20	0.19
55 Nasal height	0.94*	0.04	−0.03	−0.10	0.09
55(1) Height of piriform aperture	0.75	−0.18	0.23	−0.08	−0.48
56 Nasal bone length	0.15	0.29	−0.23	0.02	0.84
57(2) Superior nasal bone width	0.15	−0.01	0.89*	−0.17	−0.04
57 Minimum nasal bone width	0.10	0.08	0.92*	0.02	−0.09
57(1) Maximum nasal bone width	0.11	0.95*	−0.12	0.02	−0.02
59(1) Maximum breadth of posterior choanae	0.19	0.05	−0.02	0.86***	0.17
59 Height of posterior choana	0.76	0.30	0.31	0.00	0.04

[1)] The sample size is 20. The cumulative proportion of the variances of the five principal components is 84.41%.

[2)] See the second footnote to Table 1.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 14. Principal component analysis of the correlation matrix on the fourth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings					Total variance (%)
	PC I	II	III	IV	V	
1 Cranial length	0.58*	0.07	−0.57	0.31	−0.27	84.48
8 Cranial breadth	0.47*	0.30	0.13	0.21	0.47	59.32
17 Basi-bregmatic height	0.17	−0.09	−0.13	0.84*	−0.08	77.03
K87 Maximum height of zygomatic bone	0.66***	0.14	0.65	0.16	−0.20	93.65
K88 Height of maxillary process	0.70***	0.03	0.50	−0.24	−0.33	91.41
K89 Height of temporal process	0.64***	−0.20	0.17	0.51	0.12	75.42
K90 Superior breadth of zygomatic bone	0.22	0.75	−0.40	0.06	−0.35	90.25
K91 Middle breadth of zygomatic bone	0.24	0.79	0.20	0.04	0.30	81.10
K92 Inferior breadth of zygomatic bone	0.55*	0.43	−0.38	−0.34	0.18	78.08
60 Maxillo-alveolar length	0.62**	−0.61	−0.32	−0.16	0.16	90.04
61 Maxillo-alveolar breadth	0.85***	−0.21	−0.02	−0.24	−0.26	88.99
61(2) Anterior maxillo-alveolar breadth	0.70***	−0.25	−0.10	0.03	0.29	65.12
K96 Orbit-canine height	0.75***	−0.03	−0.07	−0.33	0.08	67.73
Total contribution (%)	34.56	15.51	11.74	11.51	6.88	80.20
Cumulative proportion (%)	34.56	50.07	61.81	73.32	80.20	80.20

[1)] The sample size is 23. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 15. Solution obtained through normal varimax rotation of the first five principal components for the correlation matrix on the fourth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings				
	Fac I	II	III	IV	V
1 Cranial length	0.43	0.66	0.04	0.47	−0.07
8 Cranial breadth	0.22	0.01	0.12	0.21	0.70
17 Basi-bregmatic height	−0.04	0.09	−0.04	0.87	0.00
K87 Maximum height of zygomatic bone	0.06	−0.04	0.89***	0.24	0.29
K88 Height of maxillary process	0.26	0.06	0.91***	−0.09	0.07
K89 Height of temporal process	0.38	−0.11	0.35	0.65	0.24
K90 Superior breadth of zygomatic bone	−0.16	0.91*	0.05	0.01	0.21
K91 Middle breadth of zygomatic bone	−0.20	0.29	0.17	−0.09	0.81**
K92 Inferior breadth of zygomatic bone	0.47	0.55	0.02	−0.27	0.42
60 Maxillo-alveolar length	0.92*	−0.09	0.03	0.12	−0.18
61 Maxillo-alveolar breadth	0.69*	0.24	0.59	0.03	−0.10
61(2) Anterior maxillo-alveolar breadth	0.72	−0.03	0.16	0.22	0.23
K96 Orbit-canine height	0.68	0.19	0.36	−0.14	0.20

[1)] The sample size is 23. The cumulative proportion of the variances of the five principal components is 80.20%.
[2)] See the second footnote to Table 1.
* $P<0.05$; * $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 16. Principal component analysis of the correlation matrix on the fourth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings					Total variance (%)
	PC I	II	III	IV	V	
1 Cranial length	−0.15	0.53	0.49	0.13	−0.61	93.28
8 Cranial breadth	0.02	−0.86	−0.03	−0.23	0.12	81.28
17 Basi-bregmatic height	0.01	−0.49	0.40	−0.53	−0.12	69.84
K87 Maximum height of zygomatic bone	0.08	−0.45	0.79	0.21	−0.02	87.22
K88 Height of maxillary process	−0.70	−0.19	0.59	0.11	0.21	92.92
K89 Height of temporal process	0.69	0.14	0.17	−0.00	0.39	67.52
K90 Superior breadth of zygomatic bone	−0.01	0.53	0.74	0.09	0.10	84.62
K91 Middle breadth of zygomatic bone	0.85	0.33	0.12	−0.32	0.00	94.02
K92 Inferior breadth of zygomatic bone	0.77	0.42	0.15	−0.39	−0.04	94.79
60 Maxillo-alveolar length	0.47	−0.43	0.37	0.09	−0.02	55.02
61 Maxillo-alveolar breadth	0.63	−0.26	−0.33	0.50	−0.29	90.62
61(2) Anterior maxillo-alveolar breadth	0.67	−0.17	0.17	0.51	0.21	80.12
K96 Orbit-canine height	0.33	−0.65	0.06	−0.09	−0.40	70.06
Total contribution (%)	26.71	21.48	17.34	9.17	6.94	81.64
Cumulative proportion (%)	26.71	48.19	65.53	74.70	81.64	81.64

[1)] The sample size is 16. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 17. Solution obtained through normal varimax rotation of the first five principal components for the correlation matrix on the fourth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings				
	Fac I	II	III	IV	V
1 Cranial length	0.00	0.05	0.07	−0.09	−0.96***
8 Cranial breadth	−0.21	−0.67	−0.06	0.10	0.56
17 Basi-bregmatic height	0.07	−0.79**	0.23	−0.08	0.05
K87 Maximum height of zygomatic bone	−0.18	−0.55	0.26	0.64*	−0.24
K88 Height of maxillary process	−0.62	−0.17	0.69	0.13	−0.15
K89 Height of temporal process	0.64	0.10	0.07	0.47	0.16
K90 Superior breadth of zygomatic bone	0.21	0.16	0.58	0.29	−0.59*
K91 Middle breadth of zygomatic bone	0.95	−0.05	−0.11	0.15	−0.09
K92 Inferior breadth of zygomatic bone	0.96	−0.04	−0.05	0.05	−0.17
60 Maxillo-alveolar length	0.17	−0.47	−0.10	0.54	0.02
61 Maxillo-alveolar breadth	0.10	0.01	−0.84**	0.43	0.06
61(2) Anterior maxillo-alveolar breadth	0.24	0.05	−0.25	0.82	0.09
K96 Orbit-canine height	−0.01	−0.70	−0.43	0.16	0.06

[1)] The sample size is 16. The cumulative proportion of the variances of the five principal components is 81.64%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 18. Principal component analysis of the correlation matrix on the fifth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings					Total variance (%)
	PC I	II	III	IV	V	
1 Cranial length	0.02	0.29	0.74	−0.40	−0.34	91.72
8 Cranial breadth	0.20	−0.08	0.50	−0.26	0.78*	97.19
17 Basi-bregmatic height	−0.08	0.57	0.54	0.16	0.04	65.06
62 Palatal length (ol-sta)	0.86*	−0.37	0.06	−0.29	−0.15	98.73
62a Palatal length (ol-posterior nasal spine)	0.81	−0.49	−0.02	−0.02	−0.08	90.51
63 Palatal breadth	0.01	−0.51	0.28	0.77	0.10	94.10
63(2) Anterior palatal breadth	−0.15	−0.41	0.74	0.22	−0.25	85.46
64 Palatal height	0.73	0.55	0.06	0.23	0.06	90.58
64a Anterior palatal height	0.49	0.63	−0.08	0.39	−0.06	79.99
Total contribution (%)	24.94	21.42	19.33	13.13	9.32	88.15
Cumulative proportion (%)	24.94	46.36	65.70	78.83	88.15	88.15

[1)] The sample size is 20. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 19. Solution obtained through normal varimax rotation of the first five principal components for the correlation matrix on the fifth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings				
	Fac I	II	III	IV	V
1 Cranial length	0.02	0.02	0.95**	−0.10	0.08
8 Cranial breadth	0.10	−0.02	0.11	0.04	0.97*
17 Basi-bregmatic height	−0.41	0.42	0.51	0.10	0.18
62 Palatal length (ol-sta)	0.98*	0.10	0.09	−0.06	0.09
62a Palatal length (ol-posterior nasal spine)	0.92	0.11	−0.12	0.17	0.06
63 Palatal breadth	0.04	0.01	−0.20	0.95	0.04
63(2) Anterior palatal breadth	0.07	−0.27	0.53	0.70*	0.02
64 Palatal height	0.25	0.91*	0.07	−0.09	0.11
64a Anterior palatal height	0.00	0.88	−0.02	−0.06	−0.13

[1)] The sample size is 20. The cumulative proportion of the variances of the five principal components is 88.15%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 20. Principal component analysis of the correlation matrix on the fifth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings				Total variance (%)
	PC I	II	III	IV	
1 Cranial length	−0.37	−0.19	−0.83	−0.14	88.17
8 Cranial breadth	0.73	0.15	0.58	0.08	90.12
17 Basi-bregmatic height	0.56	0.54	−0.19	−0.30	72.94
62 Palatal length (ol-sta)	0.78	−0.39	−0.30	−0.19	88.79
62a Palatal length (ol-posterior nasal spine)	0.89*	−0.35	−0.10	−0.12	94.50
63 Palatal breadth	−0.22	−0.75	0.36	0.24	80.62
63(2) Anterior palatal breadth	0.56	−0.62	−0.24	0.30	84.88
64 Palatal height	0.40	0.74	−0.15	0.26	79.83
64a Anterior palatal height	0.11	0.20	−0.30	0.88**	91.67
Total contribution (%)	32.59	24.20	16.14	12.79	85.73
Cumulative proportion (%)	32.59	56.79	72.93	85.73	85.73

[1)] The sample size is 14. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 21. Solution obtained through normal varimax rotation of the first four principal components for the correlation matrix on the fifth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings			
	Fac I	II	III	IV
1 Cranial length	0.07	0.02	−0.94	0.01
8 Cranial breadth	0.32	0.20	0.87	0.01
17 Basi-bregmatic height	0.22	0.81	0.15	−0.09
62 Palatal length (ol-sta)	0.93	0.14	0.01	−0.11
62a Palatal length (ol-posterior nasal spine)	0.93	0.14	0.24	−0.08
63 Palatal breadth	0.10	−0.89	0.10	−0.02
63(2) Anterior palatal breadth	0.83	−0.28	−0.01	0.28
64 Palatal height	−0.05	0.74	0.23	0.45
64a Anterior palatal height	0.02	0.06	−0.03	0.95*

[1)] The sample size is 14. The cumulative proportion of the variances of the four principal components is 85.73%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 22. Principal component analysis of the correlation matrix on the sixth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings							Total variance (%)
	PC I	II	III	IV	V	VI	VII	
1 Cranial length	0.59**	−0.32	−0.05	0.29	0.20	−0.24	−0.07	64.03
8 Cranial breadth	0.51*	−0.05	0.28	−0.04	0.20	0.65	−0.27	88.34
17 Basi-bregmatic height	0.49*	0.14	0.40	0.28	0.25	−0.31	−0.05	65.94
68 Mandibular length	0.52	−0.61	−0.32	−0.32	−0.04	−0.18	−0.22	93.44
65 Bicondylar breadth	0.56*	0.01	0.03	0.06	−0.64	0.13	−0.41	90.45
65(1) Bicoronoid breadth	0.65**	0.30	0.40	−0.37	−0.00	0.17	−0.23	89.05
66 Bigonial breadth	0.27	0.26	0.73	0.34	0.06	−0.10	0.19	84.97
67 Bimental breadth	0.35	−0.30	0.23	−0.40	0.50	−0.31	−0.07	78.56
69 Chin height	0.42	0.57	−0.31	0.10	0.37	−0.11	−0.27	81.97
69(1) Mandibular body height	0.43	0.56	−0.53	0.11	0.07	−0.25	−0.07	85.89
69(3) Mandibular body thickness	0.39	0.30	−0.06	−0.63	0.15	0.22	0.43	89.74
71 Minimum ramus breadth	0.60*	−0.62	−0.03	−0.18	−0.15	−0.19	0.14	85.82
70 Ramus height	0.64***	0.13	−0.14	0.52*	−0.09	0.05	0.14	74.44
70(1) Coronoid height	0.84***	0.06	0.07	−0.18	−0.22	0.02	0.33	90.69
71(1) Mandibular notch width	0.19	−0.57	0.15	0.53	0.06	0.17	0.12	71.07
70(3) Mandibular notch height	−0.14	0.27	0.45	−0.23	−0.51	−0.48	−0.06	84.02
Cubic root of mandible weight	0.67**	0.15	−0.36	0.13	−0.22	0.05	0.24	73.54
Total contribution (%)	26.81	13.52	10.89	10.53	7.95	7.04	5.12	81.88
Cumulative proportion (%)	26.81	40.34	51.23	61.76	69.72	76.76	81.88	81.88

[1)] The sample size is 27. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 23. Solution obtained through normal varimax rotation of the first seven principal components for the correlation matrix on the sixth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings						
	Fac I	II	III	IV	V	VI	VII
1 Cranial length	0.16	−0.57	0.35	0.26	−0.27	0.03	−0.18
8 Cranial breadth	−0.05	−0.07	0.15	0.37	−0.06	0.83***	0.14
17 Basi-bregmatic height	0.24	−0.20	0.73**	−0.03	−0.08	0.12	−0.05
68 Mandibular length	0.03	−0.90	−0.28	0.04	−0.14	0.14	−0.01
65 Bicondylar breadth	0.03	−0.19	−0.08	−0.34	−0.58	0.58*	−0.25
65(1) Bicoronoid breadth	0.20	−0.16	0.30	−0.24	−0.09	0.72**	0.38
66 Bigonial breadth	−0.12	0.19	0.86***	−0.12	−0.11	0.14	0.04
67 Bimental breadth	0.09	−0.67**	0.30	0.04	0.40	0.09	0.28
69 Chin height	0.86**	0.03	0.15	0.11	−0.09	0.15	0.07
69(1) Mandibular body height	0.83	−0.01	−0.01	−0.03	−0.39*	−0.10	0.09
69(3) Mandibular body thickness	0.13	−0.06	−0.06	0.00	−0.10	0.16	0.92***
71 Minimum ramus breadth	−0.25	−0.82	0.04	0.02	−0.33	0.05	0.12
70 Ramus height	0.24	−0.06	0.33	0.24	−0.71***	0.08	−0.07
70(1) Coronoid height	0.03	−0.36	0.25	−0.11	−0.62*	0.25	0.50
71(1) Mandibular notch width	−0.42	−0.22	0.27	0.49	−0.24	0.01	−0.34
70(3) Mandibular notch height	−0.12	0.08	0.19	−0.88***	0.06	−0.06	−0.01
Cubic root of mandible weight	0.27	−0.17	0.01	0.09	−0.76***	0.05	0.22

[1)] The sample size is 27. The cumulative proportion of the variances of the seven principal components is 81.88%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 24. Principal component analysis of the correlation matrix on the sixth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings							Total variance (%)
	PC I	II	III	IV	V	VI	VII	
1 Cranial length	−0.03	0.27	0.73	−0.44	0.02	0.22	0.10	85.93
8 Cranial breadth	−0.02	0.14	−0.65	0.47	−0.45	0.15	0.05	89.23
17 Basi-bregmatic height	−0.10	0.63	0.01	0.26	−0.56	−0.08	−0.11	80.69
68 Mandibular length	0.48	0.20	−0.01	0.25	0.45	−0.61	−0.10	91.40
65 Bicondylar breadth	0.44	0.17	0.48	0.36	−0.34	0.11	0.07	71.61
65(1) Bicoronoid breadth	−0.31	0.81	0.11	0.27	−0.00	0.03	−0.06	84.45
66 Bigonial breadth	−0.11	0.62	0.44	−0.27	0.30	0.33	−0.13	88.69
67 Bimental breadth	0.02	0.06	0.72	0.48	0.08	−0.24	−0.26	88.62
69 Chin height	−0.29	0.62	−0.47	−0.22	−0.04	0.01	−0.29	81.81
69(1) Mandibular body height	−0.05	0.54	−0.61	−0.20	0.36	−0.04	0.30	92.24
69(3) Mandibular body thickness	−0.05	−0.37	−0.13	0.43	0.30	0.65	−0.14	87.34
71 Minimum ramus breadth	0.81*	0.17	−0.21	−0.11	0.09	0.13	−0.35	88.75
70 Ramus height	0.72	−0.23	−0.14	−0.34	−0.23	−0.15	−0.14	79.90
70(1) Coronoid height	0.85*	−0.07	0.08	0.18	0.00	0.16	0.14	80.74
71(1) Mandibular notch width	0.72*	0.14	−0.09	−0.38	−0.23	0.14	−0.28	83.70
70(3) Mandibular notch height	0.62	0.39	0.14	−0.01	−0.10	0.04	0.58*	91.97
Cubic root of mandible weight	0.51	0.29	−0.23	0.39	0.48	0.13	0.01	79.32
Total contribution (%)	21.68	16.30	15.74	10.43	8.89	6.75	5.30	85.08
Cumulative proportion (%)	21.68	37.98	53.72	64.15	73.04	79.78	85.08	85.08

[1)] The sample size is 20. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 25. Solution obtained through normal varimax rotation of the first seven principal components for the correlation matrix on the sixth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings						
	Fac I	II	III	IV	V	VI	VII
1 Cranial length	−0.01	−0.00	0.84*	0.18	−0.23	−0.19	0.19
8 Cranial breadth	0.04	0.50	−0.71	−0.19	−0.17	0.23	0.13
17 Basi-bregmatic height	0.01	0.85	−0.09	0.13	−0.08	−0.21	0.12
68 Mandibular length	0.15	−0.04	−0.06	0.05	0.92***	−0.17	0.09
65 Bicondylar breadth	0.18	0.25	0.07	0.57*	0.02	0.04	0.54
65(1) Bicoronoid breadth	−0.29	0.80	0.29	−0.09	0.18	0.03	0.05
66 Bigonial breadth	−0.01	0.33	0.87*	−0.10	0.04	0.12	0.01
67 Bimental breadth	−0.21	0.15	0.25	0.78***	0.39	0.00	−0.00
69 Chin height	0.10	0.61	0.06	−0.55	0.00	−0.08	−0.35
69(1) Mandibular body height	−0.06	0.20	0.01	−0.89***	0.27	−0.02	0.11
69(3) Mandibular body thickness	−0.09	−0.18	−0.13	0.09	−0.09	0.89	−0.09
71 Minimum ramus breadth	0.85	0.04	0.01	−0.08	0.32	0.20	0.14
70 Ramus height	0.78	−0.29	−0.18	0.04	0.02	−0.25	0.13
70(1) Coronoid height	0.52	−0.19	−0.09	0.20	0.23	0.22	0.60*
71(1) Mandibular notch width	0.89	0.04	0.09	−0.04	−0.03	−0.08	0.15
70(3) Mandibular notch height	0.23	0.08	0.13	−0.11	0.13	−0.16	0.89***
Cubic root of mandible weight	0.21	0.10	−0.04	−0.19	0.62*	0.48	0.32

[1)] The sample size is 20. The cumulative proportion of the variances of the seven principal components is 85.08%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 26. Principal component analysis of the correlation matrix on the eighth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings				Total variance (%)
	PC I	II	III	IV	
1 Cranial length	0.03	−0.22	0.71	0.46	76.20
8 Cranial breadth	0.31	−0.48	−0.25	0.25	45.30
17 Basi-bregmatic height	0.24	−0.43	0.48	0.38	61.58
72 Facial profile angle	0.96***	0.06	−0.13	−0.05	94.60
73 Nasal profile angle (n-ns-FH)	0.72*	−0.46	−0.28	0.29	88.92
K147 Nasal profile angle (n-ss-FH)	0.90**	−0.31	−0.17	−0.01	92.69
74 Alveolar profile angle (ns-pr-FH)	0.65*	0.50	0.08	−0.40	83.41
K149 Alveolar profile angle (ss-pr-FH)	0.64*	0.57	0.19	0.00	76.60
75 Profile angle of nasal dorsum	0.25	−0.79	0.17	−0.51	98.66
75(1) Angle of nasal dorsum with nasion-prosthion line	0.26	0.80	−0.23	0.47	97.82
74(2) Maxillary incisor inclination	0.34	0.32	0.74	−0.20	81.54
Total contribution (%)	31.55	24.74	14.42	10.86	81.57
Cumulative proportion (%)	31.55	56.29	70.71	81.57	81.57

[1)] The sample size is 28. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 27. Solution obtained through normal varimax rotation of the first four principal components for the correlation matrix on the eighth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings			
	Fac I	II	III	IV
1 Cranial length	−0.04	0.00	0.87	−0.01
8 Cranial breadth	0.62	−0.23	0.09	−0.09
17 Basi-bregmatic height	0.27	−0.02	0.72	−0.15
72 Facial profile angle	0.72	0.65	−0.07	0.06
73 Nasal profile angle (n-ns-FH)	0.93	0.03	0.12	−0.04
K147 Nasal profile angle (n-ss-FH)	0.87	0.39	0.01	−0.16
74 Alveolar profile angle (ns-pr-FH)	0.11	0.87	−0.25	0.07
K149 Alveolar profile angle (ss-pr-FH)	0.14	0.78	0.05	0.37
75 Profile angle of nasal dorsum	0.33	0.04	0.08	−0.93***
75(1) Angle of nasal dorsum with nasion-prosthion line	0.06	0.30	−0.11	0.93***
74(2) Maxillary incisor inclination	−0.26	0.76	0.41	−0.08

[1)] The sample size is 28. The cumulative proportion of the variances of the four principal components is 81.57%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 28. Principal component analysis of the correlation matrix on the eighth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings				Total variance (%)
	PC I	II	III	IV	
1 Cranial length	0.13	0.13	0.59	0.71	88.58
8 Cranial breadth	−0.44	0.35	−0.70	−0.31	89.87
17 Basi-bregmatic height	−0.27	0.19	−0.51	0.29	45.15
72 Facial profile angle	0.30	0.92*	0.02	−0.11	94.28
73 Nasal profile angle (n-ns-FH)	0.76	0.56	−0.03	−0.19	92.11
K147 Nasal profile angle (n-ss-FH)	0.63	0.59	0.20	−0.25	85.28
74 Alveolar profile angle (ns-pr-FH)	−0.47	0.81	0.19	0.13	91.92
K149 Alveolar profile angle (ss-pr-FH)	−0.47	0.79	0.13	0.08	86.37
75 Profile angle of nasal dorsum	0.84	0.21	−0.38	0.28	97.44
75(1) Angle of nasal dorsum with nasion-prosthion line	−0.77	0.22	0.43	−0.36	96.18
74(2) Maxillary incisor inclination	−0.44	0.32	−0.40	0.52	72.83
Total contribution (%)	29.79	28.55	15.25	11.86	85.46
Cumulative proportion (%)	29.79	58.34	73.59	85.46	85.46

[1)] The sample size is 19. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 29. Solution obtained through normal varimax rotation of the first four principal components for the correlation matrix on the eighth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings			
	Fac I	II	III	IV
1 Cranial length	0.06	0.07	−0.07	0.93*
8 Cranial breadth	0.06	0.22	−0.54	−0.75
17 Basi-bregmatic height	−0.07	−0.04	−0.65	−0.15
72 Facial profile angle	0.92	0.26	−0.18	0.00
73 Nasal profile angle (n-ns-FH)	0.92	−0.23	0.13	−0.02
K147 Nasal profile angle (n-ss-FH)	0.89	−0.00	0.25	0.06
74 Alveolar profile angle (ns-pr-FH)	0.33	0.76	−0.45*	0.15
K149 Alveolar profile angle (ss-pr-FH)	0.32	0.74	−0.45	0.07
75 Profile angle of nasal dorsum	0.61	−0.74	−0.19	0.11
75(1) Angle of nasal dorsum with nasion-prosthion line	−0.23	0.94*	0.11	−0.13
74(2) Maxillary incisor inclination	−0.10	0.14	−0.83*	0.07

[1)] The sample size is 19. The cumulative proportion of the variances of the four principal components is 85.46%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 30. Principal component analysis of the correlation matrix on the ninth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings						Total variance (%)
	PC I	II	III	IV	V	VI	
1 Cranial length	0.02	−0.77	0.39	−0.06	−0.14	−0.25	83.42
8 Cranial breadth	0.16	0.01	0.61	0.45	0.13	0.28	69.62
17 Basi-bregmatic height	0.02	−0.41	0.12	0.09	0.72	−0.49	94.42
76(1) Orbit-canine angle	0.58	0.41	−0.11	0.46	−0.11	−0.29	82.70
77 Transverse profile angle of upper face	−0.69	0.46	−0.12	0.11	0.14	0.05	72.55
76 Zygomatic profile angle	0.33	0.60	0.23	0.29	−0.20	−0.40	80.65
K155 Angle between zygomatic bones	−0.56	−0.29	−0.14	0.68	−0.01	0.01	88.83
78 Sagittal inclination of orbital inlet	−0.32	0.20	0.72	−0.05	−0.00	−0.24	72.50
78(1) Coronal inclination of orbital inlet	0.87	−0.05	0.08	−0.29	0.00	−0.01	85.03
78(2) Horizontal inclination of orbital inlet	0.42	0.17	−0.43	0.15	0.59	0.18	79.40
78(3) Angle between orbital axes	0.44	−0.57	−0.08	0.45	−0.24	0.22	83.60
K160 Inclination of orbital axis plane to FH	−0.15	−0.20	−0.70	0.01	−0.25	−0.44	81.51
Total contribution (%)	21.00	16.93	15.36	10.82	9.12	7.94	81.19
Cumulative proportion (%)	21.00	37.94	53.30	64.12	73.24	81.19	81.19

1) The sample size is 26. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.

2) See the second footnote to Table 1.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 31. Solution obtained through normal varimax rotation of the first six principal components for the correlation matrix on the ninth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings					
	Fac I	II	III	IV	V	VI
1 Cranial length	0.08	−0.26	0.01	0.50	−0.58	−0.41
8 Cranial breadth	−0.12	0.17	0.78***	0.22	−0.05	−0.06
17 Basi-bregmatic height	−0.03	−0.07	0.02	0.02	0.08	−0.97***
76(1) Orbit-canine angle	0.10	0.85*	−0.02	0.18	0.26	0.03
77 Transverse profile angle of upper face	−0.54	−0.04	−0.01	−0.63***	0.07	0.15
76 Zygomatic profile angle	0.11	0.86*	0.13	−0.16	−0.10	0.07
K155 Angle between zygomatic bones	−0.91*	−0.06	−0.03	0.22	−0.04	−0.10
78 Sagittal inclination of orbital inlet	−0.06	0.12	0.41	−0.40	−0.59**	−0.16
78(1) Coronal inclination of orbital inlet	0.82	0.19	0.07	0.33	0.16	−0.05
78(2) Horizontal inclination of orbital inlet	0.13	0.10	0.03	0.02	0.85**	−0.20
78(3) Angle between orbital axes	−0.06	0.02	0.06	0.90***	0.10	0.03
K160 Inclination of orbital axis plane to FH	−0.21	0.06	−0.87***	0.12	0.02	−0.05

1) The sample size is 26. The cumulative proportion of the variances of the six principal components is 81.19%.

2) See the second footnote to Table 1.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 32. Principal component analysis of the correlation matrix on the ninth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings						Total variance (%)
	PC I	II	III	IV	V	VI	
1 Cranial length	−0.57	0.16	0.58	0.45	−0.20	−0.10	93.90
8 Cranial breadth	0.86	0.24	−0.10	0.02	0.28	0.06	89.13
17 Basi-bregmatic height	0.26	0.30	0.47	−0.04	0.68	−0.25	90.37
76(1) Orbit-canine angle	0.16	−0.08	0.51	0.79	−0.04	0.18	95.05
77 Transverse profile angle of upper face	−0.23	0.60	−0.57	0.11	0.01	0.16	76.87
76 Zygomatic profile angle	0.38	−0.02	0.47	−0.36	−0.50	0.04	74.57
K155 Angle between zygomatic bones	−0.71	−0.23	−0.13	0.14	0.42	0.24	82.94
78 Sagittal inclination of orbital inlet	0.50	0.46	0.26	−0.05	−0.02	0.63*	92.58
78(1) Coronal inclination of orbital inlet	0.63	−0.47	−0.27	0.35	0.15	0.00	83.54
78(2) Horizontal inclination of orbital inlet	0.06	−0.56	0.57	−0.32	0.21	−0.01	79.39
78(3) Angle between orbital axes	0.57	−0.49	−0.35	0.32	−0.20	−0.17	85.31
K160 Inclination of orbital axis plane to FH	−0.23	−0.77	−0.07	−0.16	0.08	0.42	86.22
Total contribution (%)	24.05	18.08	16.54	11.17	9.38	6.60	85.82
Cumulative proportion (%)	24.05	42.14	58.67	69.84	79.22	85.82	85.82

[1)] The sample size is 18. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 33. Solution obtained through normal varimax rotation of the first six principal components for the correlation matrix on the ninth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings					
	Fac I	II	III	IV	V	VI
1 Cranial length	−0.02	0.52	0.01	0.78*	−0.03	−0.24
8 Cranial breadth	0.26	−0.54	−0.13	−0.19	0.49	0.49
17 Basi-bregmatic height	−0.02	0.09	0.19	0.06	0.91**	0.14
76(1) Orbit-canine angle	−0.02	−0.24	0.10	0.91	0.08	0.21
77 Transverse profile angle of upper face	−0.22	0.17	−0.80	−0.17	−0.07	0.12
76 Zygomatic profile angle	0.73	0.10	0.37	0.01	−0.13	0.23
K155 Angle between zygomatic bones	−0.84*	0.26	0.06	0.07	−0.14	−0.16
78 Sagittal inclination of orbital inlet	0.25	0.05	−0.08	0.08	0.13	0.91***
78(1) Coronal inclination of orbital inlet	−0.06	−0.90	0.12	0.02	0.03	0.08
78(2) Horizontal inclination of orbital inlet	−0.00	0.04	0.88	−0.00	0.12	−0.02
78(3) Angle between orbital axes	0.18	−0.87*	0.03	0.02	−0.19	−0.15
K160 Inclination of orbital axis plane to FH	−0.48	−0.13	0.58*	−0.15	−0.51	0.04

[1)] The sample size is 18. The cumulative proportion of the variances of the six principal components is 85.82%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 34. Principal component analysis of the correlation matrix on the tenth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings PC I	II	III	IV	Total variance (%)
1 Cranial length	0.58	0.33	0.36	0.54	86.57
8 Cranial breadth	0.59	−0.03	0.54	0.07	65.43
17 Basi-bregmatic height	0.39	0.47	0.49	−0.58	94.72
79(1) Profile angle of mandible	−0.13	0.80	−0.49	−0.01	89.67
K163 Chin angle	0.84*	−0.16	−0.40	−0.12	90.75
79 Mandibular angle	−0.75	−0.36	0.36	−0.07	82.71
79(1a) Symphysial angle	0.73	−0.54	−0.24	−0.11	88.94
Total contribution (%)	37.98	20.31	17.74	9.50	85.54
Cumulative proportion (%)	37.98	58.29	76.04	85.54	85.54

1) The sample size is 26. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
2) See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 35. Solution obtained through normal varimax rotation of the first four principal components for the correlation matrix on the tenth set of craniofacial measurements from Japanese males.[1)]

Variable[2)]	Factor loadings Fac I	II	III	IV
1 Cranial length	0.06	−0.11	0.92*	−0.09
8 Cranial breadth	−0.36	−0.20	0.58	−0.38
17 Basi-bregmatic height	0.07	−0.04	0.16	−0.96
79(1) Profile angle of mandible	0.94***	0.07	−0.04	−0.04
K163 Chin angle	0.03	−0.94***	0.13	−0.08
79 Mandibular angle	−0.46	0.68	−0.38	0.13
79(1a) Symphysial angle	−0.36	−0.87***	0.04	0.03

1) The sample size is 26. The cumulative proportion of the variances of the four principal components is 85.54%.
2) See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 36. Principal component analysis of the correlation matrix on the tenth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings PC I	II	III	Total variance (%)
1 Cranial length	−0.21	−0.45	0.79	86.68
8 Cranial breadth	0.02	0.87	−0.34	86.29
17 Basi-bregmatic height	−0.41	0.62	0.14	57.07
79(1) Profile angle of mandible	−0.58	−0.52	−0.51	86.39
K163 Chin angle	0.96***	0.01	0.08	93.30
79 Mandibular angle	−0.51	0.59	0.48	83.24
79(1a) Symphysial angle	0.96***	0.13	0.10	95.29
Total contribution (%)	37.92	28.16	17.95	84.04
Cumulative proportion (%)	37.92	66.08	84.04	84.04

1) The sample size is 19. The number of principal components shown here was determined so that the cumulative proportion of the variances of the principal components exceeded 80%.
2) See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 37. Solution obtained through normal varimax rotation of the first three principal components for the correlation matrix on the tenth set of craniofacial measurements from Japanese females.[1)]

Variable[2)]	Factor loadings		
	Fac I	II	III
1 Cranial length	−0.02	0.13	0.92
8 Cranial breadth	0.15	0.48	−0.78
17 Basi-bregmatic height	−0.13	0.72	−0.20
79(1) Profile angle of mandible	−0.85	−0.37	−0.02
K163 Chin angle	0.88***	−0.39*	−0.07
79 Mandibular angle	−0.09	0.90	0.10
79(1a) Symphysial angle	0.92***	−0.29	−0.13

[1)] The sample size is 19. The cumulative proportion of the variances of the three principal components is 84.04%.
[2)] See the second footnote to Table 1.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 38. Spearman's rank correlation coefficients between males and females in the variation pattern of factor loadings on the principal components and/or rotated factors obtained from the first sets of craniofacial measurements.[1)]

	Male PC I	II	III	IV	Fac I	II	III	IV
Female PC I	.66*	–	–	.62*	–	–	–	–
II	–	–	.72**	–	–	–	–	–
III	–	–	–	–	–	–	–	–
IV	–	–	–	–	–	–	–	–
V	–	–	–	.67*	–	–	–	–
Fac I	.58*	–	–	–	–	–	–	–
II	–	–	.70**	–	–	–	–	–
III	–	–	.72**	–	–	–	–	–
IV	–	–	–	–	–	–	–	–
V	–	–	.60*	–	–	–	–	–

[1)] Only those rank correlation coefficients significant at the 5% level are listed here. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 2, 3, 4, and 5.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

Table 39. Spearman's rank correlation coefficients between males and females in the variation pattern of factor loadings on the principal components and/or rotated factors obtained from the second sets of craniofacial measurements.[1)]

	Male PC I	II	III	IV	V	Fac I	II	III	IV	V
Female PC I	–	–	–	–	–	–	–	–	–	–
II	–	–	.68*	–	–	–	–	–	–	–
III	–	–	–	–	–	–	–	–	–	–
IV	–	–	–	.81***	–	–	.61*	–	–	–
Fac I	–	–	–	.65*	–	–	–	–	–	–
II	–	–	.73**	–	–	–	–	.58*	–	–
III	.55*	.60*	–	–	–	–	–	–	–	.65*
IV	–	.62*	–	–	–	–	.55*	–	–	.74**

[1)] Only those rank correlation coefficients significant at the 5% level are listed here. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 6, 7, 8, and 9.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

Table 40. Spearman's rank correlation coefficients between males and females in the variation pattern of factor loadings on the principal components and/or rotated factors obtained from the third sets of craniofacial measurements.[1)]

	Male PC I	II	III	IV	V	VI	Fac I	II	III	IV	V	VI
Female PC I	–	–	.62*	–	–	–	–	–	–	–	–	.73**
II	–	–	.77**	.59*	–	–	–	–	–	–	.71**	–
III	–	–	–	–	–	–	–	–	–	–	–	–
IV	–	–	–	–	–	–	–	–	–	.61*	–	–
V	.65*	–	.58*	–	–	–	–	–	.69*	–	–	.64*
Fac I	–	–	.62*	–	–	–	–	–	–	–	–	.73**
II	–	–	.68*	–	–	–	–	–	–	–	–	–
III	–	–	–	–	–	–	–	–	–	–	–	–
IV	–	–	.63*	–	–	–	–	–	–	–	–	–
V	–	–	–	–	–	.62*	–	–	–	–	–	–

1) Only those rank correlation coefficients significant at the 5% level are listed here. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 10, 11, 12, and 13.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

Table 41. Spearman's rank correlation coefficients between males and females in the variation pattern of factor loadings on the principal components and/or rotated factors obtained from the fourth sets of craniofacial measurements.[1)]

	Male PC I	II	III	IV	V	Fac I	II	III	IV	V
Female PC I	–	–	–	–	.68*	–	–	–	–	–
II	–	–	–	–	–	–	–	–	–	–
III	–	–	–	–	.59*	–	–	–	–	–
IV	.66*	–	–	–	–	–	–	–	–	–
V	–	–	–	–	–	–	–	–	–	–
Fac I	–	–	–	–	–	–	–	–	–	–
II	–	–	–	–	–	–	–	–	–	–
III	–	–	–	–	.55*	.57*	–	–	–	–
IV	–	–	–	–	–	–	.59*	–	–	–
V	–	–	–	–	.59*	–	.57*	–	–	–

1) Only those rank correlation coefficients significant at the 5% level are listed here. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 14, 15, 16, and 17.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

Table 42. Spearman's rank correlation coefficients between males and females in the variation pattern of factor loadings on the principal components and/or rotated factors obtained from the fifth sets of craniofacial measurements.[1)]

	Male PC I	II	III	IV	V	Fac I	II	III	IV	V
Female PC I	–	–	–	–	–	.68*	–	–	–	–
II	–	.87**	–	–	–	–	.73*	–	–	–
III	–	–	–	–	.80**	–	–	–	–	–
IV	–	–	–	.68*	–	–	–	–	–	–
Fac I	–	–	–	–	–	–	–	–	–	–
II	–	–	–	–	–	–	–	–	–	.80**
III	–	–	–	–	.70*	–	–	–	–	–
IV	–	–	–	–	–	–	–	–	–	–

1) Only those rank correlation coefficients significant at the 5% level are listed here. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 18, 19, 20, and 21.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

Table 43. Spearman's rank correlation coefficients between males and females in the variation pattern of factor loadings on the principal components and/or rotated factors obtained from the sixth sets of craniofacial measurements.[1)]

	Male PC I	II	III	IV	V	VI	VII	Fac I	II	III	IV	V	VI	VII
Female PC I	–	.60*	–	–	.62**	–	–	–	–	–	–	.49*	–	–
II	–	–	–	–	–	–	–	–	–	–	–	–	–	–
III	–	–	.51*	–	–	–	–	–	–	–	–	–	–	–
IV	–	–	–	.69**	–	–	–	–	–	–	–	–	.52*	.60*
V	–	–	.49*	–	–	–	–	–	–	–	–	–	–	–
VI	–	–	–	–	–	–	–	–	–	–	–	–	–	–
VII	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fac I	–	–	–	–	.60*	–	–	–	–	–	–	.49*	–	–
II	–	–	–	–	–	–	.56*	–	–	–	–	.50*	–	–
III	–	–	–	–	–	–	–	–	–	–	–	–	–	–
IV	–	.50*	–	–	–	–	–	–	.62**	–	–	–	–	–
V	–	–	–	–	–	–	–	–	–	–	–	–	–	–
VI	–	–	–	–	–	.52*	–	–	–	–	–	–	–	.69**
VII	–	–	–	–	.71**	–	–	–	–	–	–	–	–	–

1) Only those rank correlation coefficients significant at the 5% level are listed here. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 22, 23, 24, and 25.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

Table 44. Spearman's rank correlation coefficients between males and females in the variation pattern of factor loadings on the principal components and/or rotated factors obtained from the eighth sets of craniofacial measurements.[1)]

	Male PC I	II	III	IV	Fac I	II	III	IV
Female PC I	–	.80**	–	–	.65*	–	–	.71*
II	.92***	–	–	–	–	.66*	.69*	–
III	–	–	–	–	–	–	–	–
IV	–	–	.90***	–	–	–	–	–
Fac I	.65*	–	–	–	.76**	–	–	–
II	–	.84**	–	–	–	–	.63*	.84**
III	–	–	–	–	–	–	–	–
IV	–	–	–	–	–	–	–	–

1) Only those rank correlation coefficients significant at the 5% level are listed here. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 26, 27, 28, and 29.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

Table 45. Spearman's rank correlation coefficients between males and females in the variation pattern of factor loadings on the principal components and/or rotated factors obtained from the ninth sets of craniofacial measurements.[1)]

	Male PC I	II	III	IV	V	VI	Fac I	II	III	IV	V	VI
Female PC I	–	–	–	–	–	–	–	.59*	.83***	–	–	–
II	–	–	.64*	–	–	–	–	–	–	–	–	–
III	–	–	–	–	–	–	–	–	–	–	–	–
IV	–	–	–	–	–	–	–	–	–	.63*	–	–
V	–	–	–	–	.66*	–	–	–	–	–	–	–
VI	–	–	–	–	–	–	–	–	–	–	–	–
Fac I	–	–	.65*	–	–	–	–	–	.84***	–	–	–
II	.69*	–	–	–	–	–	–	–	–	–	–	–
III	–	–	–	–	–	–	–	–	–	–	–	–
IV	–	–	–	–	–	–	–	–	–	–	–	–
V	–	–	–	–	.77**	–	–	–	–	–	–	–
VI	–	.68*	–	–	–	–	–	.64*	–	–	–	–

1) Only those rank correlation coefficients significant at the 5% level are listed here. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 30, 31, 32, and 33.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

Table 46. Spearman's rank correlation coefficients between males and females in the variation pattern of factor loadings on the principal components and/or rotated factors obtained from the tenth sets of craniofacial measurements.[1)]

	Male PC I	II	III	IV	Fac I	II	III	IV
Female PC I	.96***	–	–	–	–	.96***	–	–
II	–	–	.89**	–	–	–	–	–
III	–	–	–	–	–	–	–	–
Fac I	.86*	.79*	–	–	–	.86*	–	–
II	–	–	.82*	–	–	–	–	–
III	–	–	–	–	–	–	–	–

[1)] Only those rank correlation coefficients significant at the 5% level are listed here. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 34, 35, 36, and 37.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed test.

orbital axis plane to Frankfurt Horizontal. Although female PC I (Table 32) and Fac I (Table 33) are highly significantly similar to this male Fac III (Table 45), these female factors do not have significant correlations with any of the three main neurocranial measurements.

Discussion

In the present study, those principal components or rotated factors which were significantly correlated with both one or more neurocranial measurements and one or more facial measurements were explored in two samples, male and female, because the repeatability of results in both sexes is considered to confirm the reality of an identified common factor. As described above, however, such factors were not found simultaneously both in males and females. Most of the factors correlated with both the neurocranium and the face are found only in males. This may be considered due to the small sample size for females, but the same samples as used here have shown the repeatability of results in many analyses on male and female postcranial measurements (Mizoguchi, 1994, 1995, 1996, 1997, 1998a, b, 1999, 2000, 2001, 2002, 2003a, b, 2004, 2005a). The present discrepant results between sexes, therefore, may be explained in another way.

Unfortunately, many previous analyses of the correlations between craniofacial measurements have been carried out on the basis of male data alone. For example, Kanda and Kurisu (1968), Kanda (1968), Howells (1972), Brown (1973), and Mizoguchi (1992a) showed that cranial breadth was strongly associated with facial breadth, but these authors all used only male data. Weijs and Hillen (1986) showed significant correlations of the cross-sectional area of the masseter muscle with head breadth, bigonial width, and mandibular length, but their results were also obtained only from males. Mizoguchi (1992b, 2005b) found some associations of the degree of wear on the maxillary first molar with bizygomatic breadth and neurocranial shape. These are again based only on male materials.

The present analyses of male data support all the above reports. Significant associations between cranial breadth and bizygomatic and other facial breadths (Table 3) as well as between neurocranial and maxillary or mandibular measurements (Tables 14 and 22) can certainly be found in males, but no such strong associations were obtained from female data. If this is not due to the small size of the present female sample, the finding may suggest that some factors relating to sexual dimorphism, such as the difference in the degree of development of masticatory muscles, produced the difference between males and females in the present results. If so, the association between neurocranial shape and facial structure may not be so strong as previously expected. Namely, neurocranial shape and facial structure may be only loosely associated, for example, in accordance with the degree of development of masticatory muscles, and, therefore, while some relatively strong associations are detectable between the neurocranium and the face in males who have relatively strong masticatory muscles, no such associations are found in females whose muscles are weakly developed.

Mizoguchi (1991), using male and female data, found that most facial measurements were not consistently influenced by artificial cranial deformation. Although the effect of external mechanical pressure is different from those of ordinary physiological or biomechanical processes, Mizoguchi's (1991) finding may not be inconsistent with the idea of weak association between facial and neurocranial structures. Nevertheless, it should also be noted that many factors other than masticatory muscles may cause associations between the face and neurocranium because, for example, Ferrario *et al.* (1997) revealed that dolichocephalic children have significantly more anteriorly convex faces than brachycephalic children both in boys and girls. This problem should be examined in more depth using many female samples in the future.

Another interesting fact is the difference between cranial length and cranial breadth in the way of connecting with other characters. When a certain facial measurement is associated with one of the three neurocranial measurements in males, it is almost always cranial breadth, not cranial length. This contrasts with the analyses of postcranial measurements, where many postcranial measurements are associated exclusively with cranial length (Mizoguchi, 1994, 1995, 1996, 1997, 1998a, b, 1999, 2000, 2001, 2002, 2003a, b, 2004, 2005a, 2007). Such a contrast of cranial length and breadth was noticed for the first time in the present study. If population differences are extensions of individual differences, as stated by Howells (1973), this contrast may be one of the reasons why brachycephalization and dolichocephalization mutually and irregularly occur in a geographic area. In Japan, for example, dolichocephalization proceeded about 1,500 years ago, and then, reversely brachycephalization started between 1,000 BP and 500 BP and continued to the present (Suzuki, 1956; Nakahashi, 1987). We do not know the causes for the reversion at present. But, if the diachronic changes in shape of the masticatory apparatus corresponded to those of available food and if the diachronic changes in shape of limb bones corresponded to those of physical activity, and, further, if the diachronic changes of food and physical activity were not parallel with each other, then the reversion in the trend of neurocranial shape change may be explained by the relatively independent connections of cranial breadth with facial measurements and of cranial length with limb bone measurements. Of course, however, further investigation is necessary to solve this problem.

Summary and Conclusions

Principal component analyses and rotation of the results of craniofacial measurements showed that, at least in males, cranial breadth was significantly associated with facial breadth, including bizygomatic breadth, and both cranial length and breadth were significantly associated with many maxillary and mandibular measurements. In females, however, no such associations were found. From this, it was inferred that neurocranial shape may be only loosely connected with facial structure.

It was also found that, when a certain facial measurement was associated with one of the three neurocranial measurements in males, it was almost always cranial breadth, not cranial length. Cranial length has been reported to be associated exclusively with certain postcranial measurements. The difference between cranial length and breadth in the way of connecting with other characters may be one reason for the fluctuation in the diachronic change of neurocranial shape in a geographic area.

Acknowledgments

I am grateful to Salford Software Ltd. and “kito” for kindly providing their very useful software, FTN77 and CPad, respectively, on the Internet. I would also like to thank two reviewers for their helpful suggestions and comments. The manuscript was copy edited by Medical English Service, Kyoto.

This work was partly supported by a Grant-in-Aid for Scientific Research (S) from the Japan Society for the Promotion of Science (Project No. 17107006).

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