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Morphological Covariation between the Neurocranium and the Lumbar Vertebrae: Toward the Solution of the Brachycephalization Problem

By

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Abstract Through the principal component analyses based on the data of 30 male and 20 female Japanese, it was found that, while basi-bregmatic height was considerably associated with the vertebral foramen size of the lumbars, cranial length and breadth had no consistently high correlations with any measurements of the lumbar vertebrae. These findings do not support the previous suggestion by the present author that the morphology of the lumbar vertebrae may partially be associated with brachycephalization.

A number of investigations have been carried out to understand the cause of brachycephalization. But, even today, this problem yet remains to be solved. With the ultimate aim of solving it, MIZOGUCHI (1992) also examined the morphological data of male Japanese skeletons from a viewpoint of biomechanical coordination among morphological characters. In result, he showed that cranial length was relatively highly correlated not only with the size of jaws but also with some postcranial measurements such as the body diameters of the third lumbar vertebra or the size of the pelvis. From this and other findings, he inferred that the shape of the cranial vault was determined, in part, through dynamic interaction not only with the masticatory apparatus but with the body build and posture as well.

In the present study, part of the inference by MIZOGUCHI (1992), namely, the inference on the correlations between the neurocranium and a lumbar vertebra is re-examined in more depth by adding the data of all other lumbar vertebrae of males and females.

Materials and Methods

The data used here are the measurements of the neurocranium and the lumbar vertebrae published by MIYAMOTO (1924) and OKAMOTO (1930), respectively. These data are of the same individuals, *i.e.*, 30 male and 20 female Japanese from the Kinai district. The basic statistics for all the measurements are listed in Tables 1 to 3.

In order to examine the overall relationships between the cranial and the lumbar measurements, the principal component analysis (LAWLEY and MAXWELL, 1963; OKUNO

Table 1. Means and standard deviations of main neurocranial measurements in Japanese.[1]

Variable[2]	Male			Female		
	n	Mean	SD	n	Mean	SD
1 Cranial length	30	178.4	5.6	20	169.4	4.9
8 Cranial breadth	30	141.0	4.7	20	137.8	4.1
17 Basi-bregmatic height	30	139.8	5.8	20	132.1	3.8

[1] The estimates of basic statistics listed here were recalculated by the present author on the basis of the raw data published by MIYAMOTO (1924).

[2] Variable number according to MARTIN and SALLER (1957).

et al., 1971, 1976; TAKEUCHI and YANAI, 1972) was applied to the correlation matrices on the measurements. And the solutions of the principal component analyses were further transformed by KAISER's normal varimax rotation method (ASANO, 1971; OKUNO *et al.*, 1971) to get some insight into other aspects of the same complex system of cranial and vertebral characters.

All the statistical calculations were executed with the mainframe, HITAC M880(C) System, of the Computer Centre, the University of Tokyo. The programs used are BSFMD for calculating basic statistics and PCAFPP for the principal component analysis, which had been written in FORTRAN by the present author.

Results

The direct solutions of the principal component analyses (PCAs) for males are shown in Tables 4 to 8, and those for females are in Tables 9 to 13. These tables show the factor loadings on principal components (PCs) of the three main cranial measurements and the thirteen measurements for each of the five lumbar vertebrae.

Throughout all the direct solutions of the PCAs, the first PCs are found to be relatively highly correlated with most of the measurements analyzed, and, therefore, may be regarded as general size factors. In particular, the factor loadings of basi-bregmatic height as well as of all the sagittal and transverse diameters of the vertebral body are greater than 0.30 in absolute value in all the PCAs of both sexes (Fig. 1).

In most of the PCAs, the second PCs are not so strongly correlated with the cranial measurements but mainly with the heights of the vertebral body.

The third PCs from all the PCAs (only for the female second lumber vertebra, the fourth PC) have relatively high correlations (of greater than 0.30 in absolute value) with basi-bregmatic height, and most of them, at the same time, have relatively high correlations with the sagittal and transverse diameters of the vertebral foramen (Fig. 2).

No consistent tendency is discernible in the variation patterns of the factor loadings on the PCs which are most highly correlated with cranial length or breadth.

In the rotated solutions (Table 14), it was found that there were no factors which were consistently highly correlated both with cranial length or breadth and with lumbar

Table 2. Means and standard deviations of lumbar measurements in Japanese males.[1]

Variable[2]		Lumbar I			Lumbar II			Lumbar III			Lumbar IV			Lumbar V		
		n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
1	Ventral height of vertebral body	30	23.7	2.5	30	24.8	2.0	30	26.1	1.7	30	25.8	1.8	30	24.2	2.0
3	Central height of vertebral body	30	22.6	2.3	28	22.8	1.8	30	22.0	1.9	30	21.1	2.0	28	20.8	1.8
2	Dorsal height of vertebral body	30	27.2	1.9	29	27.1	2.1	30	26.1	1.8	30	24.1	2.0	29	21.8	1.7
4	Superior sagittal diam. of vert. body	30	30.1	1.7	29	31.5	2.0	30	33.1	2.0	30	33.3	2.3	30	33.9	2.2
6	Middle sagittal diam. of vert. body	29	28.2	1.6	29	29.5	1.9	29	31.1	2.2	30	31.5	2.0	29	31.3	2.1
5	Inferior sagittal diam. of vert. body	30	31.1	1.6	30	32.7	1.7	30	32.9	1.9	30	33.8	2.3	29	32.6	2.3
7	Sup. transverse diam. of vert. body	30	42.4	2.7	30	45.1	2.9	30	47.2	3.3	30	49.8	3.3	30	50.9	3.2
9	Mid. transverse diam. of vert. body	29	37.5	2.6	30	39.3	2.8	30	41.2	3.2	30	43.5	2.6	30	47.3	3.0
8	Inf. transverse diam. of vert. body	30	45.8	3.1	30	48.3	3.6	30	50.8	3.5	30	52.4	3.4	30	51.0	3.9
10	Sagit. diam. of vertebral foramen	30	15.8	1.2	29	14.7	1.3	30	14.1	1.3	30	14.4	1.9	28	16.0	2.7
11	Trans. diam. of vertebral foramen	30	21.1	1.4	30	21.0	1.9	30	21.8	1.4	30	22.4	2.2	30	26.5	2.2
K12	Max. width between trans. processes	30	62.5	7.1	30	75.9	6.0	30	86.2	7.5	30	83.3	9.1	30	88.7	5.0
K13	Max. wid. between sup. articular proc.	30	38.1	3.2	30	41.4	3.3	30	43.4	3.7	30	46.8	4.6	30	52.9	4.4

[1] The estimates of basic statistics listed here were recalculated by the present author on the basis of the raw data published by OKAMOTO (1930).

[2] Variable number according to MARTIN and SALLER (1957) except for K12 and K13, which are Nos. 12 and 13, respectively, of KIYONO's (1929) measurement system.

Table 3. Means and standard deviations of lumbar measurements in Japanese females.[1)]

Variable[2)]		Lumbar I			Lumbar II			Lumbar III			Lumbar IV			Lumbar V		
		n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
1	Ventral height of vertebral body	19	23.2	1.2	19	24.2	1.4	20	25.1	1.6	20	25.3	1.9	20	22.9	1.7
3	Central height of vertebral body	20	20.9	1.3	20	21.0	1.3	20	20.9	1.6	20	20.1	2.4	20	20.0	1.7
2	Dorsal height of vertebral body	19	25.0	1.0	19	25.2	1.1	19	24.7	1.2	19	22.7	1.3	20	20.5	1.8
4	Superior sagittal diam. of vert. body	19	26.4	1.9	19	27.8	2.2	19	29.4	2.4	19	30.2	2.3	20	30.6	2.0
6	Middle sagittal diam. of vert. body	20	24.9	1.9	20	26.1	2.8	20	27.4	2.0	20	28.1	2.0	20	28.5	2.3
5	Inferior sagittal diam. of vert. body	19	27.3	2.2	19	28.9	2.4	20	29.4	2.2	20	30.5	2.1	20	29.8	2.2
7	Sup. transverse diam. of vert. body	19	37.7	2.4	19	39.9	2.5	19	42.4	2.8	20	44.5	3.5	20	46.5	3.6
9	Mid. transverse diam. of vert. body	20	32.9	2.0	20	34.6	2.5	20	36.3	3.4	20	39.3	3.6	20	44.0	3.8
8	Inf. transverse diam. of vert. body	19	40.8	2.5	19	43.0	3.0	20	45.6	2.8	20	47.7	3.5	20	47.3	3.6
10	Sagit. diam. of vertebral foramen	20	15.4	1.2	20	14.6	1.2	20	14.2	1.3	20	14.8	1.7	20	16.5	2.2
11	Trans. diam. of vertebral foramen	20	19.5	1.5	20	19.8	1.3	20	20.8	1.6	20	22.3	2.0	20	25.1	2.8
K12	Max. width between trans. processes	20	61.0	4.8	20	69.5	6.2	20	77.9	7.6	19	74.8	6.3	19	80.5	5.7
K13	Max. wid. between sup. articular proc.	20	37.2	3.0	20	39.3	2.9	20	41.1	3.9	20	45.2	4.6	20	49.7	4.1

[1)] and [2)] See the footnotes to Table 2.

Table 4. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the first lumbar vertebra of Japanese males.[1)]

Variable[2)]		Factor loadings PC I	II	III	IV	V	VI	Total variance (%)
1	Cranial length	.46*	−.08	.13	−.41*	.39*	.56*	86.07
8	Cranial breadth	.42*	.03	.39*	.50*	.36*	−.05	71.76
17	Basi-bregmatic height	.43*	−.20	.53*	−.29	.09	.28	67.64
1	Vent. height of v. body	.46*	.62*	.39*	.02	−.20	.02	79.03
3	Cent. height of v. body	.24	.87*	.25	.12	−.19	−.03	92.24
2	Dors. height of v. body	.33*	.87*	.20	.04	−.08	.09	92.17
4	Sup. sag. d. of v. body	.77*	−.08	−.09	−.43*	.26	−.27	92.22
6	Mid. sag. d. of v. body	.72*	.13	−.32*	−.02	.23	−.10	70.89
5	Inf. sag. d. of v. body	.84*	.21	−.17	−.12	.29	−.25	93.16
7	Sup. trans. d. of v. b.	.80*	−.26	−.31*	.09	−.37*	.06	94.85
9	Mid. trans. d. of v. b.	.80*	−.31*	−.18	.08	−.40*	.07	94.58
8	Inf. trans. d. of v. b.	.84*	−.22	−.22	.13	−.28	−.00	89.67
10	Sagit. d. of v. foramen	.05	−.20	.66*	−.40*	−.34*	−.16	77.76
11	Trans. d. of v. foramen	.10	−.51*	.62*	−.14	−.13	−.20	73.01
K12	Max. wid. trans. proc.	.28	−.31*	.22	.60*	.05	.51*	84.08
K13	Max. wid. s. art. proc.	.25	−.34*	.37*	.48*	.23	−.45*	80.31
Total contribution (%)		30.65	17.08	12.72	9.46	7.09	6.71	83.71
Cumulative proportion (%)		30.65	47.73	60.45	69.91	77.00	83.71	83.71

[1)] The sample size is 28. The number of the principal components shown here was so determined that the cumulative proportion of the variances of the principal components exceeded 80%. The BARTLETT's approximate significance test (LAWLEY and MAXWELL, 1963)rejects the null hypothesis that all the variances for the rest of the principal components here are equal to one another ($\chi^2=134.2$, d.f.$=54$, $P<0.001$).

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

* Greater than 0.30 in absolute value.

measurements. However, taking account of the rotated factors from all the PCAs, the half of those factors which are relatively highly correlated with basi-bregmatic height also have relatively high correlations with the maximum width between transverse processes. But the variation patterns of the factor loadings on these rotated factors are considerably different from one another.

Discussion

MIZOGUCHI (1992) found, in the direct solution of the PCA for 16 craniofacial and 12 postcranial measurements of males, that the PC having the highest correlation with the cranial length had relatively high correlations not only with facial length, nasal breadth, maxillo-alveolar length and breadth and mandibular length but also with the superior transverse diameter of the vertebral body of the third lumbar. In addition to this, he also discovered in the rotated solution of the PCA that the factor

Table 5. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the second lumbar vertebra of Japanese males.[1)]

Variable[2)]	Factor loadings PC I	II	III	IV	V	VI	Total variance (%)
1 Cranial length	.49*	−.08	.31*	.49*	−.23	−.36*	75.66
8 Cranial breadth	.37*	−.06	−.04	.14	.73*	−.24	75.89
17 Basi-bregmatic height	.34*	.25	.47*	.49*	.14	−.26	73.40
1 Vent. height of v. body	.02	.86*	.22	−.07	−.08	.18	83.69
3 Cent. height of v. body	−.45*	.46*	.05	−.35*	.48*	−.21	81.28
2 Dors. height of v. body	−.05	.94*	.03	−.19	−.04	−.08	92.44
4 Sup. sag. d. of v. body	.68*	.51*	−.21	.09	−.18	.02	80.95
6 Mid. sag. d. of v. body	.77*	.12	−.28	.24	.03	−.17	77.83
5 Inf. sag. d. of v. body	.81*	.19	−.34*	.11	.10	−.06	83.18
7 Sup. trans. d. of v. b.	.89*	−.12	.05	−.30*	−.11	−.03	91.94
9 Mid. trans. d. of v. b.	.82*	−.19	.10	−.35*	−.15	−.12	87.76
8 Inf. trans. d. of v. b.	.82*	−.11	.04	−.46*	−.10	−.01	90.39
10 Sagit. d. of v. foramen	−.04	.05	.84*	.17	−.17	.21	81.20
11 Trans. d. of v. foramen	.23	−.29	.61*	−.33*	.33*	−.07	72.63
K12 Max. wid. trans. proc.	.67*	.12	.23	−.16	.17	.44*	75.82
K13 Max. wid. s. art. proc.	.43*	−.07	−.13	.38*	.33*	.69*	92.40
Total contribution (%)	32.70	14.94	11.01	9.24	7.55	6.84	82.28
Cumulative proportion (%)	32.70	47.65	58.66	67.90	75.44	82.28	82.28

[1)] The sample size is 28. For the way of determination of the principal component number, see the first footnote to Table 4. The result of the BARTLETT's approximate significance test is as follows: $\chi^2=123.9$, d.f.$=54$, $P<0.001$ (for details, also see the first footnote to Table 4).
[2)] See the second footnote to Table 2.
* Greater than 0.30 in absolute value.

Table 6. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the third lumbar vertebra of Japanese males.[1)]

Variable[2)]	Factor loadings PC I	II	III	IV	V	VI	Total variance (%)
1 Cranial length	.41*	.06	.00	.57*	−.31*	.39*	74.04
8 Cranial breadth	.35*	.09	.14	−.04	−.69*	.03	61.82
17 Basi-bregmatic height	.42*	.12	.50*	.44*	.09	.40*	80.07
1 Vent. height of v. body	.21	.66*	.33*	−.01	.20	.09	62.78
3 Cent. height of v. body	.04	.79*	−.12	.09	.18	−.37*	81.35
2 Dors. height of v. body	.06	.92*	.06	.13	.04	−.05	88.14
4 Sup. sag. d. of v. body	.84*	.16	−.17	−.32*	−.14	−.03	88.13
6 Mid. sag. d. of v. body	.83*	.23	−.20	−.31*	−.19	−.01	90.55
5 Inf. sag. d. of v. body	.86*	.11	−.18	−.21	−.18	−.06	86.33
7 Sup. trans. d. of v. b.	.74*	−.34*	−.32*	.03	.31*	.16	89.87
9 Mid. trans. d. of v. b.	.71*	−.31*	−.27	.37*	.13	−.17	84.81
8 Inf. trans. d. of v. b.	.82*	−.22	−.22	.19	.26	−.22	92.40
10 Sagit. d. of v. foramen	.20	−.37*	.70*	.09	.06	−.40*	82.86
11 Trans. d. of v. foramen	.35*	−.15	.71*	.16	−.26	−.38*	87.58
K12 Max. wid. trans. proc.	.56*	.14	.44*	−.13	.41*	.14	73.40
K13 Max. wid. s. art. proc.	.23	−.19	.53*	−.62*	.11	.28	84.31
Total contribution (%)	30.56	15.59	13.60	8.70	7.31	6.02	81.78
Cumulative proportion (%)	30.56	46.14	59.75	68.45	75.76	81.78	81.78

[1)] The sample size is 29. For the way of determination of the principal component number, see the first footnote to Table 4. The result of the BARTLETT's approximate significance test is as follows: $\chi^2=115.9$, d.f.$=54$, $P<0.001$ (for details, also see the first footnote to Table 4).
[2)] See the second footnote to Table 2.
* Greater than 0.30 in absolute value.

Table 7. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the fourth lumbar vertebra of Japanese males.[1)]

Variable[2)]	Factor loadings						Total variance (%)
	PC I	II	III	IV	V	VI	
1 Cranial length	.44*	−.06	.18	.63*	.10	−.29	71.39
8 Cranial breadth	.21	.05	.10	.50*	−.66*	.45*	94.08
17 Basi-bregmatic height	.40*	−.08	.37*	.34*	−.15	−.58*	77.72
1 Vent. height of v. body	.08	.73*	.54*	.10	.06	.15	86.98
3 Cent. height of v. body	.10	.83*	.26	−.04	.05	.27	84.60
2 Dors. height of v. body	.16	.77*	.02	−.12	.21	−.18	71.09
4 Sup. sag. d. of v. body	.88*	.14	−.18	−.14	−.18	−.06	87.75
6 Mid. sag. d. of v. body	.84*	.24	−.11	−.20	−.21	−.18	89.29
5 Inf. sag. d. of v. body	.86*	.22	−.23	−.18	−.20	−.02	91.90
7 Sup. trans. d. of v. b.	.83*	−.24	−.22	.04	.22	.12	86.48
9 Mid. trans. d. of v. b.	.84*	−.21	−.14	.15	.16	.21	86.68
8 Inf. trans. d. of v. b.	.89*	−.18	−.20	−.08	.14	.13	90.70
10 Sagit. d. of v. foramen	.13	−.30	.78*	−.19	−.03	.01	73.99
11 Trans. d. of v. foramen	.34*	−.36*	.40*	.19	.43*	.31*	71.51
K12 Max. wid. trans. proc.	.68*	.06	.45*	−.18	.10	−.03	71.27
K13 Max. wid. s. art. proc.	.14	−.53*	.51*	−.49*	−.28	.02	87.04
Total contribution (%)	34.13	16.24	12.27	7.77	6.31	5.95	82.65
Cumulative proportion (%)	34.13	50.36	62.63	70.40	76.71	82.65	82.65

[1)] The sample size is 30. For the way of determination of the principal component number, see the first footnote to Table 4. The result of the BARTLETT's approximate significance test is as follows: $\chi^2=132.0$, d.f.$=54$, $P<0.001$ (for details, also see the first footnote to Table 4).
[2)] See the second footnote to Table 2.
* Greater than 0.30 in absolute value.

Table 8. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the fifth lumbar vertebra of Japanese males.[1)]

Variable[2)]	Factor loadings						Total variance (%)
	PC I	II	III	IV	V	VI	
1 Cranial length	.47*	.33*	.35*	.59*	−.02	−.07	80.15
8 Cranial breadth	.20	.54*	.21	.21	−.27	.40*	65.57
17 Basi-bregmatic height	.52*	.09	.30*	.36*	.44*	.07	69.33
1 Vent. height of v. body	−.12	.86*	.06	.05	.20	−.04	79.34
3 Cent. height of v. body	.28	.62*	−.18	−.26	−.24	−.54*	91.12
2 Dors. height of v. body	.05	.47*	−.31*	−.57*	.43*	.13	84.47
4 Sup. sag. d. of v. body	.78*	.17	−.09	−.23	−.10	.32*	81.52
6 Mid. sag. d. of v. body	.94*	.06	−.10	−.06	.07	.21	95.50
5 Inf. sag. d. of v. body	.86*	−.02	−.10	−.18	−.08	.20	82.80
7 Sup. trans. d. of v. b.	.81*	−.17	−.38*	.08	−.00	−.11	84.61
9 Mid. trans. d. of v. b.	.82*	−.16	−.23	.23	.10	−.15	83.55
8 Inf. trans. d. of v. b.	.77*	−.27	−.28	.09	.32*	−.14	87.49
10 Sagit. d. of v. foramen	.00	−.04	.70*	−.21	.51*	−.16	82.04
11 Trans. d. of v. foramen	.62*	.11	.54*	−.16	−.27	−.17	82.27
K12 Max. wid. trans. proc.	.78*	−.06	.18	−.11	−.17	−.21	73.23
K13 Max. wid. s. art. proc.	.33*	−.38*	.62*	−.43*	−.11	.10	84.15
Total contribution (%)	36.80	12.86	11.87	8.34	6.64	5.18	81.70
Cumulative proportion (%)	36.80	49.66	61.53	69.87	76.51	81.70	81.70

[1)] The sample size is 25. For the way of determination of the principal component number, see the first footnote to Table 4. The result of the BARTLETT's approximate significance test is as follows: $\chi^2=118.7$, d.f.$=54$, $P<0.001$ (for details, also see the first footnote to Table 4).
[2)] See the second footnote to Table 2.
* Greater than 0.30 in absolute value.

Table 9. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the first lumbar vertebra of Japanese females.[1)]

Variable[2)]	Factor loadings					Total variance (%)
	PC I	II	III	IV	V	
1 Cranial length	.37*	−.14	−.42*	.71*	−.22	88.17
8 Cranial breadth	−.12	.18	.87*	−.14	−.04	81.98
17 Basi-bregmatic height	.46*	.12	.56*	.11	−.61*	93.24
1 Vent. height of v. body	.28	.52*	−.50*	.05	−.33*	71.53
3 Cent. height of v. body	.47*	.65*	−.32*	−.31*	−.08	84.16
2 Dors. height of v. body	.64*	.51*	−.15	−.44*	.14	89.84
4 Sup. sag. d. of v. bady	.77*	−.54*	.01	.07	−.05	88.82
6 Mid. sag. d. of v. body	.75*	−.57*	.10	−.02	.09	90.94
5 Inf. sag. d. of v. body	.70*	−.61*	.18	−.09	.08	91.30
7 Sup. trans. d. of v. b.	.87*	−.10	−.26	−.14	.02	85.79
9 Mid. trans. d. of v. b.	.87*	−.19	−.06	−.21	−.08	85.27
8 Inf. trans. d. of v. b.	.88*	−.21	−.18	−.20	−.04	89.68
10 Sagit. d. of v. foramen	.46*	.68*	.18	.26	.15	80.27
11 Trans. d. of v. foramen	.70*	.27	.34*	.12	.03	68.89
K12 Max. wid. trans. proc.	.77*	.37*	.34*	.13	.07	86.70
K13 Max. wid. s. art. proc.	.58*	.27	.05	.47*	.45*	83.14
Total contribution (%)	41.55	17.84	12.66	7.85	5.08	84.98
Cumulative proportion (%)	41.55	59.39	72.05	79.90	84.98	84.98

[1)] The sample size is 19. For the way of determination of the principal component number, see the first footnote to Table 4. The result of the BARTLETT's approximate significance test is as follows: $\chi^2=199.3$, d.f.$=65$, $P<0.001$ (for details, also see the first footnote to Table 4).
[2)] See the second footnote to Table 2.
* Greater than 0.30 in absolute value.

Table 10. Principal component analysis of the correlation matrix on the measurements of the neurocraium and the second lumbar vertebra of Japanese females.[1)]

Variable[2)]	Factor loadings					Total variance (%)
	PC I	II	III	IV	V	
1 Cranial length	.29	−.02	−.78*	−.07	.43*	89.37
8 Cranial breadth	−.27	−.40*	.57*	.57*	.11	89.02
17 Basi-bregmatic height	.30*	−.43*	.18	.52*	.39*	73.12
1 Vent. height of v. body	.49*	.70*	.39*	−.04	−.15	90.27
3 Cent. height of v. body	.43*	.72*	.26	−.05	.01	76.81
2 Dors. height of v. body	.66*	.43*	.34*	.03	.36*	86.36
4 Sup. sag. d. of v. body	.70*	−.63*	.09	−.10	−.18	93.90
6 Mid. sag. d. of v. body	.61*	−.65*	.07	−.14	−.28	90.18
5 Inf. sag. d. of v. body	.63*	−.68*	.03	−.10	−.18	90.43
7 Sup. trans. d. of v. b.	.83*	−.10	.13	−.34*	.26	90.46
9 Mid. trans. d. of v. b.	.89*	−.07	.15	−.20	.24	92.13
8 Inf. trans. d. of v. b.	.88*	−.07	.01	−.11	.26	86.81
10 Sagit. d. of v. foramen	.63*	.39*	−.26	.40*	−.17	80.55
11 Trans. d. of v. foramen	.68*	.15	−.38*	.50*	−.02	87.79
K12 Max. wid. trans. proc.	.75*	.30	−.04	−.03	−.43*	84.15
K13 Max. wid. s. art. proc.	.71*	.00	−.16	.36*	−.27	73.76
Total contribution (%)	41.09	19.44	9.93	8.48	7.00	85.94
Cumulative proportion (%)	41.09	60.53	70.46	78.94	85.94	85.94

[1)] The sample size is 19. For the way of determination of the principal component number, see the first footnote to Table 4. The result of the BARTLETT's approximate significance test is as follows: $\chi^2=166.2$, d.f.$=65$, $P<0.001$ (for details, also see the first footnote to Table 4).
[2)] See the second footnote to Table 2.
* Greater than 0.30 in absolute value.

Table 11. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the third lumbar vertebra of Japanese females.[1)]

Variable[2)]		Factor loadings					Total variance (%)
		PC I	II	III	IV	V	
1	Cranial length	.36*	−.03	−.43*	.61*	−.06	69.88
8	Cranial breadth	−.26	−.27	.75*	−.27	.02	77.92
17	Basi-bregmatic height	.37*	−.22	.65*	.16	.36*	76.20
1	Vent. height of v. body	.55*	.31*	.03	−.53*	.31*	77.95
3	Cent. height of v. body	.37*	.78*	−.02	−.24	−.06	80.81
2	Dors. height of v. body	.52*	.58*	−.21	−.40*	−.21	84.13
4	Sup. sag. d. of v. body	.72*	−.63*	−.01	−.13	−.13	94.28
6	Mid. sag. d. of v. body	.67*	−.67*	.00	−.06	−.16	93.74
5	Inf. sag. d. of v. body	.51*	−.81*	−.03	−.09	−.09	93.08
7	Sup. trans. d. of v. b.	.76*	.06	−.30	−.08	.12	68.69
9	Mid. trans. d. of v. b.	.69*	−.14	−.23	−.03	.53*	82.84
8	Inf. trans. d. of v. b.	.86*	.02	−.05	.10	.07	75.69
10	Sagit. d. of v. foramen	.41*	.55*	.37*	.41*	.23	82.59
11	Trans. d. of v. foramen	.61*	.30	.49*	.09	−.45*	90.61
K12	Max. wid. trans. proc.	.91*	−.02	.06	−.08	−.18	87.25
K13	Max. wid. s. art. proc.	.70*	.32*	.22	.37*	−.11	78.84
Total contribution (%)		36.96	19.93	11.12	8.33	5.81	82.16
Cumulative proportion (%)		36.96	56.90	68.02	76.35	82.16	82.16

1) The sample size is 19. For the way of determination of the principal component number, see the first footnote to Table 4. The result of the BARTLETT's approximate significance test is as follows: $\chi^2=188.0$, d.f.$=65$, $P<0.001$ (for details, also see the first footnote to Table 4).
2) See the second footnote to Table 2.
* Greater than 0.30 in absolute value.

Table 12. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the fourth lumbar vertebra of Japanese females.[1)]

Variable[2)]		Factor loadings					Total variance (%)
		PC I	II	III	IV	V	
1	Cranial length	.47*	.34*	.39*	−.31*	−.11	59.20
8	Cranial breadth	−.31*	.11	−.16	.89*	−.13	93.85
17	Basi-bregmatic height	.37*	.24	−.42*	.41*	.03	53.67
1	Vent. height of v. body	.31*	−.03	−.19	.02	.86*	88.05
3	Cent. height of v. body	.46*	−.68*	.11	.08	.27	75.63
2	Dors. height of v. body	.23	−.38*	.79*	.25	.20	92.51
4	Sup. sag. d. of v. body	.69*	.60*	−.11	.01	.21	89.59
6	Mid. sag. d. of v. body	.64*	.65*	−.06	.03	.18	86.35
5	Inf. sag. d. of v. body	.69*	.64*	−.03	−.10	.03	89.75
7	Sup. trans. d. of v. b.	.86*	.02	.11	.09	−.28	83.89
9	Mid. trans. d. of v. b.	.93*	−.06	.05	.11	−.26	95.52
8	Inf. trans. d. of v. b.	.94*	.10	.06	.01	−.19	92.71
10	Sagit. d. of v. foramen	.26	−.58*	−.63*	−.32*	−.12	92.69
11	Trans. d. of v. foramen	.67*	−.52*	.03	.24	.09	77.76
K12	Max. wid. trans. proc.	.69*	−.47*	−.17	.08	−.18	76.18
K13	Max. wid. s. art. proc.	.58*	−.54*	−.09	−.16	.07	66.51
Total contribution (%)		37.37	19.48	9.40	8.34	7.53	82.12
Cumulative proportion (%)		37.37	56.85	66.25	74.58	82.12	82.12

1) The sample size is 18. For the way of determination of the principal component number, see the first footnote to Table 4. The result of the BARTLETT's approximate significance test is as follows: $\chi^2=225.9$, d.f.$=65$, $P<0.001$ (for details, also see the first footnote to Table 4).
2) See the second footnote to Table 2.
* Greater than 0.30 in absolute value.

Table 13. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the fifth lumbar vertebra of Japanese females.[1)]

Variable[2)]		Factor loadings PC I	II	III	IV	V	Total variance (%)
1	Cranial length	.61*	.09	−.27	−.46*	.34*	77.76
8	Cranial breadth	−.35*	.41*	.68*	.25	−.24	87.46
17	Basi-bregmatic height	.41*	.28	.53*	.30	.35*	73.53
1	Vent. height of v. body	−.05	−.72*	−.31*	.32*	−.02	73.02
3	Cent. height of v. body	.18	−.65*	−.05	.42*	.26	69.81
2	Dors. height of v. body	−.07	−.66*	−.00	.18	−.47*	68.86
4	Sup. sag. d. of v. body	.75*	.40*	−.28	.26	−.20	90.55
6	Mid. sag. d. of v. body	.80*	.39*	−.29	.13	−.19	92.71
5	Inf. sag. d. of v. body	.69*	.45*	−.31*	.41*	−.01	95.03
7	Sup. trans. d. of v. b.	.89*	−.04	.08	.12	−.06	82.50
9	Mid. trans. d. of v. b.	.91*	.05	.24	−.12	−.11	92.35
8	Inf. trans. d. of v. b.	.90*	.04	.23	−.00	.03	86.01
10	Sagit. d. of v. foramen	.17	−.60*	.29	.12	.13	50.71
11	Trans. d. of v. foramen	.66*	−.30*	.27	−.36*	−.30	81.58
K12	Max. wid. trans. proc.	.77*	−.42*	.10	.01	.33*	88.43
K13	Max. wid. s. art. proc.	.69*	−.48*	.04	−.25	−.22	81.13
Total contribution (%)		39.66	18.79	9.09	7.35	5.82	80.72
Cumulative proportion (%)		39.66	58.45	67.54	74.89	80.72	80.72

[1)] The sample size is 19. For the way of determination of the principal component number, see the first footnote to Table 4. The result of the BARTLETT's approximate significance test is as follows: $\chi^2=222.6$, d.f.$=65$, $P<0.001$ (for details, also see the first footnote to Table 4).
[2)] See the second footnote to Table 2.
* Greater than 0.30 in absolute value.

having the highest correlation with cranial breadth was relatively highly correlated not only with facial length, bizygomatic breadth, orbital breadth and maximum ramus height but with the superior sagittal diameter of the vertebral body of the third lumbar as well.

In the present study, the fourth PC from the PCA for the male third lumbar was found to have relatively high correlations with cranial length, basi-bregmatic height and the middle transverse diameter of the vertebral body (Table 6). But, except this and general size factors, there are no PCs which are simultaneously correlated with the sagittal and/or transverse diameters of the vertebral body and with cranial length and/or breadth. Further, the rotated solutions also showed that there were no factors consistently associated with the measurements of both cranium and vertebral body (Table 14). Moreover, also in respect of the relations with the other vertebral measurements, no factors were found to have high correlations both with them and with cranial length or breadth throughout the direct and rotated solutions of the PCAs. It seems, therefore, that the above-mentioned MIZOGUCHI's (1992) findings were accidental, and it is most likely that cranial length and breadth have no consistent morphological

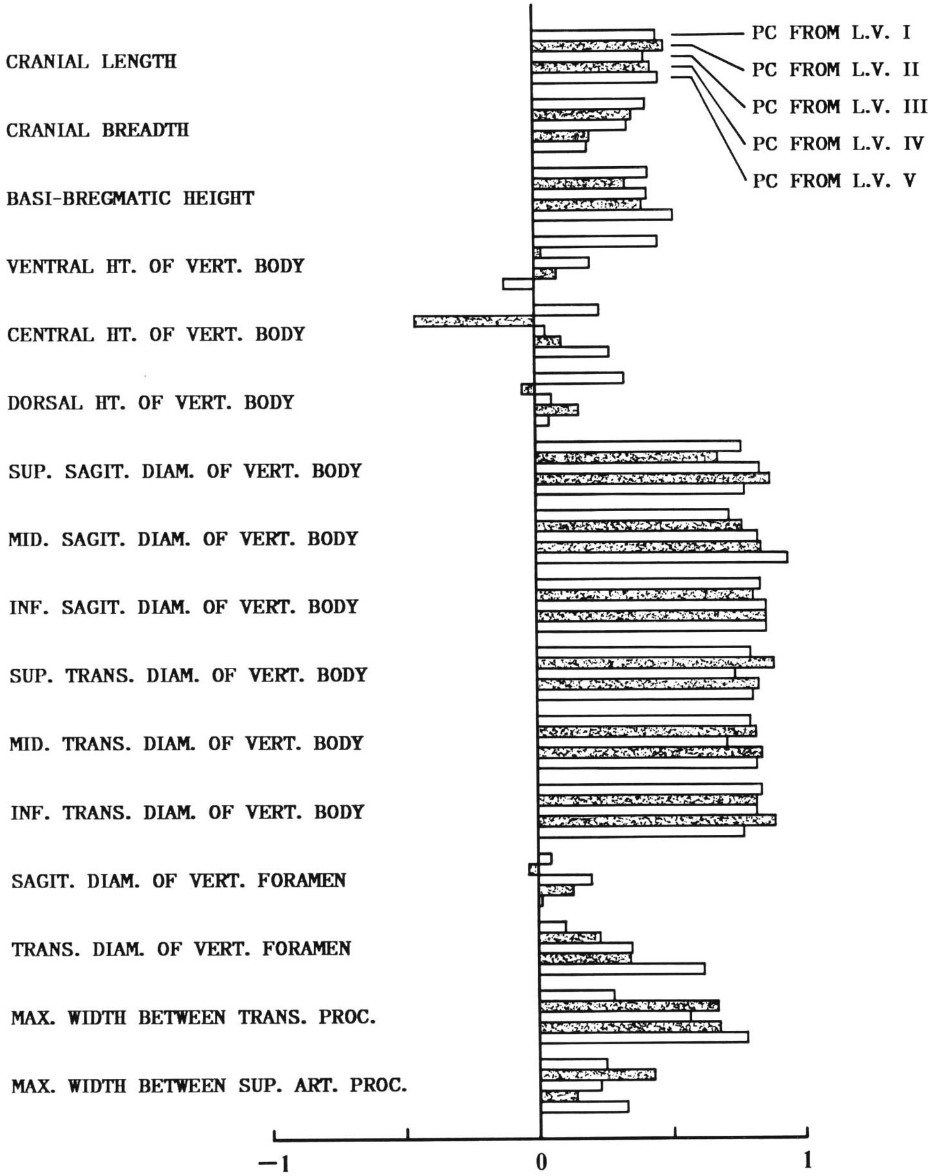

Fig. 1. Loadings of the cranial and lumbar measurements on the first principal components extracted from the data of Japanese males. These components may be regarded as so-called general size factors.

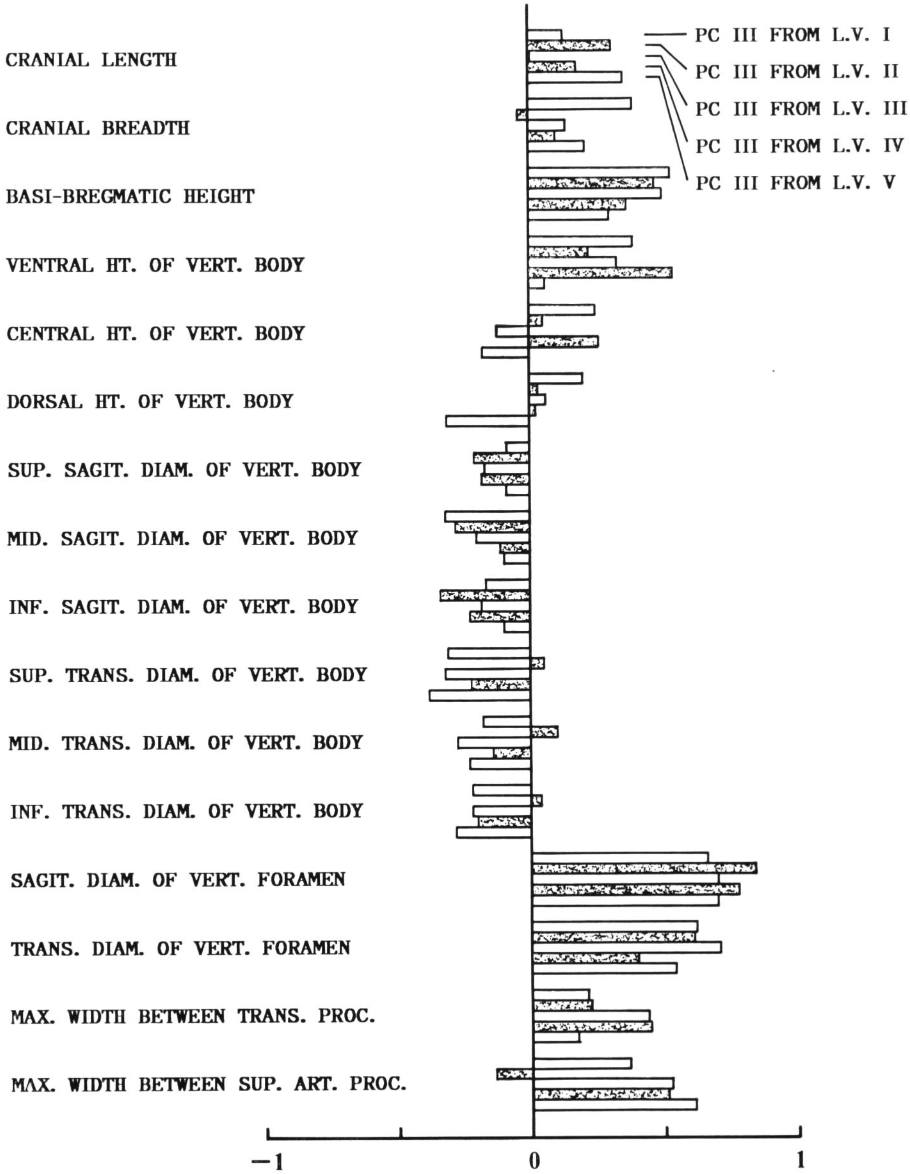

Fig. 2. Loadings of the cranial and lumbar measurements on the third principal components extracted from the data of Japanese males. These principal components are relatively highly correlated both with basi-bregmatic height and with the sagittal and transverse diameters of the vertebral foramen.

Table 14. Rotated factors relatively highly correlated with both cranial and lumbar measurements.[1]

Rotated factors	Cranial measurements[2]	Vertebral measurements[3]
Male lumbar 1:		
Factor 3	17	10, 11
Factor 4	8	K12, K13
Factor 6	1, 17	K12
Male lumbar 2:		
Factor 4	1, 17	4, 6, 10
Factor 5	8	3, 11
Male lumbar 3:		
Factor 4	17	1, K12, K13
Factor 5	8	4, 6, 5
Male lumbar 4:		
Factor 4	1	7, 9, 8, 11
Male lumbar 5:		
Factor 1	17	4, 6, 5, 7, 9, 8, 11, K12
Factor 4	1, 8	1, 4
Factor 5	1, 17	1, 10
Female lumbar 1:		
Factor 3	1	1
Factor 5	8, 17	11, K12
Female lumbar 2:		
Factor 5	1	7, 8, 11
Female lumbar 3:		
Factor 1	17	3, 8, 10, 11, K12, K13
Factor 3	1	7
Factor 5	17	1, 7, 9, 8
Female lumbar 4:		
Factor 1	1, 17	4, 6, 5, 7, 9, 8
Female lumbar 5:		
Factor 3	1, 8 (reverse sign)	2 (reverse sign), K12
Factor 4	1	6, 7, 9, 8, 10, 11, K12, K13
Factor 5	8, 17	8, K12

[1] Only the measurement items whose factor loadings are greater than 0.30 in absolute value are listed here.

[2] See the second footnote to Table 1.

[3] See the second footnote to Table 2.

association with any measurements of the lumbar vertebrae.

Although its relation with brachycephalization is unknown, the most interesting finding in the present study is a tight connection between basi-bregmatic height and the sagittal and transverse diameters of the vertebral foramen. This connection is, however, slightly weaker in females than in males. In females, instead, it is suggested by some PCs that cranial length and breadth also have relatively high correlations with the sagittal and/or transverse diameters of the vertebral foramen (Tables 9, 10, 11 and 13). In any case, the vertebral foramen size of the lumbars is without doubt considerably associated with the neurocranial size, especially the height, suggesting that the vertebral foramen is an extension of the braincase or cranial cavity.

Until now, there have been only a few investigations on the interrelations between cranial and postcranial measurements. Particularly, regarding the relations with the vertebrae, we have few data. Although SOLOW and TALLGREN (1976) and SOLOW *et al.* (1982) examined the correlations between craniofacial morphology and the posture of the head and cervical column, they did not deal with the morphological structure of the vertebrae. HUGGARE (1992), using the data of females from the north and the south of Finland, showed that the inhabitants of the northern area had the raised head posture, the longer atlas and the smaller dorsal and the larger ventral arch heights, and interpreted these findings as evidence of morphogenetic reactions to the changes in function related to climatic conditions. But, in this case, the morphology of the head was not examined. To understand the cause and mechanism of brachycephalization, further comprehensive investigations should be done from the viewpoints not only of population history and environmental changes but also of inter-character correlations, biomechanical stresses, *etc.*

Conclusions

The principal component analyses for cranial and lumbar measurements showed that cranial length and breadth had no consistently high correlations with any measurements of the lumbar vertebrae except for the correlations caused by a general size factor, and that basi-bregmatic height was relatively strongly associated with the sagittal and transverse diameters of the vertebral foramina. Form these, it may be said that the morphology of the lumbar vertebrae is not associated with brachycephalization, and that the vertebral foramen is an extension of the cranial cavity.

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Literature cited

ASANO, C., 1971. Inshi-Bunsekiho-Tsuron (Outlines of Factor Analysis Methods). Tokyo, Kyoritsu-Shuppan. (In Japanese.)

HUGGARE, J., 1992. Population differences in the morphology of the first cervical vertebra. *Am. J. Phys. Anthrop.*, **88**: 197–201.

KIYONO, K., 1929. Jinkotsu sokutei-hyou (Measurement methods for human bones). *In*: Kokogaku Koza I. Tokyo, Yuzankaku. (In Japanese.)

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

MARTIN, R., and K. SALLER, 1957. Lehrbuch der Anthropologie, dritte Aufl., Bd. I. Stuttgart, Gustav Fischer Verlag.

MIYAMOTO, H., 1924. Gendai nihonjin jinkotsu no jinruigaku-teki kenkyu, Dai-1-bu: Togaikotsu no kenkyu (An anthropological study on the skeletons of modern Japanese, Part 1: A study of skulls). *J. Anthrop. Soc. Nippon*, **39**: 307–451; Data 1–48. (In Japanese.)

MIZOGUCHI, Y., 1992. An interpretation of brachycephalization based on the analysis of correlations between cranial and postcranial measurements. *In*: Craniofacial Variation in Pacific Populations, ed. T. BROWN and S. MOLNAR. Adelaide; Anthropology and Genetics Laboratory, Department of Dentistry, the University of Adelaide. pp. 1–19.

OKAMOTO, T., 1930. Gendai Kinai nihonjin jinkotsu no jinruigaku-teki kenkyu, Dai-6-bu: Sekitsuikotsu ni tsuite (An anthropological study on the skeletons of modern Kinai Japanese, Part 6: On the vertebrae). *J. Anthrop. Soc. Nippon*, **45** (Suppl. 2): 9–149. (In Japanese.)

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

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

SOLOW, B., and A. TALLGREN, 1976. Head posture and craniofacial morphology. *Am. J. Phys. Anthrop.*, **44**: 417–435.

SOLOW, B., M. J. BARRETT and T. BROWN, 1982. Craniocervical morphology and posture in Australian aboriginals. *Am. J. Phys. Anthrop,*. **59**: 33–45.

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