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Associations between Cranial Length and Scapular Measurements: Toward the Solution of the Brachycephalization Problem

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Abstract It was examined whether there were any associations between the neurocranium and the shoulder girdle. Principal component analyses based on 30 male and 20 female skeletons showed that cranial length had relatively high correlations with the size of the scapula, especially of the infraspinous fossa, and with the breadth and tilt of the glenoid cavity. On the other hand, cranial breadth was found to have no consistent association with any of scapular or clavicular measurements. These results as well as previous studies suggest that cranial length and cranial breadth tend to have some different kinds of connections with postcranial bones.
Key words: Brachycephalization, Neurocranium, Scapula, Clavicle, Principal component analysis

The multivariate analyses by the present author (Mizoguchi, 1994, 1995, 1996, 1997, 1998a, b, 1999) have shown that, while cranial breadth has no consistent correlation with any of vertebral or costal measurements, cranial length is strongly associated with the sagittal and transverse diameters of the vertebral bodies, sacral breadths, and costal chords. These findings are very suggestive in clarifying the causes and mechanism of brachycephalization. In the present study, as a further step toward solving the brachycephalization problem, it is examined whether there are any associations between the neurocranium and the shoulder girdle.

Materials and Methods

The original measurement data reported by Miyamoto (1924, 1925) were used in the present study. They are those of the neurocranium (Miyamoto, 1924) and of the right scapula and clavicle (Miyamoto, 1925) from the same 30 male and 20 female modern Japanese who lived in the Kinai district. The basic statistics for three main neurocranial measurements, *i.e.*, cranial length, cranial breadth and basi-bregmatic height, are presented in Mizoguchi (1994), and those for scapular and clavicular measurements are listed in Tables 1 and 2, respectively.

For examining the overall relations between the neurocranial and the scapular or clavicular measurements, principal component analysis (Lawley and Maxwell, 1963;

Table 1. Means and standard deviations for the measurements of the right scapula in Japanese males and females.[1)]

	Variable[2)]	Males			Females		
		n	Mean	SD	*n*	Mean	SD
1	Anatomical breadth (height)	30	152.5	8.8	18	134.5	6.8
2	Anatomical length (breadth)	30	98.8	5.5	20	89.9	4.2
2a	Length of scapula	30	105.6	5.9	20	95.5	4.2
3	Length of lateral border	30	125.0	8.4	19	112.0	6.3
4	Length of superior border	30	73.8	8.1	19	68.2	6.3
6a	Anatomical breadth of supraspinous fossa	30	54.1	6.6	19	45.0	5.2
6	Projective br. of suprasp. fossa (height)	30	42.1	5.5	20	35.2	5.6
5a	Anatomical breadth of infraspinous fossa	30	113.7	8.7	19	101.8	7.8
5	Projective br. of infrasp. fossa (height)	30	109.6	8.1	20	99.2	7.8
7	Length of spine	30	133.8	6.8	20	121.2	5.3
8	Length of spinal base	30	83.4	5.4	20	75.5	3.8
9	Maximum breadth of acromion	30	29.8	3.8	20	26.7	2.8
10	Length of acromion	30	40.7	4.7	20	34.1	3.7
11	Maximum length of coracoid process	30	46.0	3.4	20	41.8	1.8
12	Length of glenoid cavity	30	35.1	1.8	20	31.6	2.3
13	Breadth of glenoid cavity	30	24.8	1.6	20	21.1	1.2
14	Depth of glenoid cavity	30	4.4	0.9	20	3.5	0.6
K18	Acromioglenoid breadth after Hasebe	30	17.3	2.0	20	17.0	2.2
15	Breadth-length angle	30	85.8	4.6	20	87.9	4.8
15a	Scapulospinal angle	29	83.7	4.5	20	85.9	4.7
16	Axillospinal angle	30	48.5	4.2	20	49.4	5.2
17	Axilloglenoid angle	30	134.9	4.7	20	135.6	4.7
18	Vertebroglenoid angle	30	172.2	5.8	20	173.8	5.1
19	Spinoinfraspinous angle	30	79.5	4.0	20	78.1	4.1
20	Spinosupraspinous angle	30	51.2	7.4	20	51.9	6.1
22[3)]	Spinoglenoid angle	30	86.5	4.7	20	86.1	4.9

[1)] The estimates of basic statistics listed here were recalculated by the present author on the basis of the raw data published by Miyamoto (1925).

[2)] Variable number according to Martin and Saller (1957) except for those with the letter 'K' preceding the number, which are measurement item nos. in Kiyono's (1929) measurement system.

[3)] The measurement item number of 22 in Martin and Saller (1957) should be read 21.

Okuno *et al.*, 1971, 1976; Takeuchi and Yanai, 1972) was applied to the correlation matrices. In the present study, the number of principal components was so determined that the cumulative proportion of the variances of the 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. These may suggest some other associations hidden behind the measurements dealt with.

Table 2. Means and standard deviations for the measurements of the right clavicle in Japanese males and females.[1]

Variable[2]		Males			Females		
		n	Mean	SD	*n*	Mean	SD
1	Maximum length	30	142.4	7.3	16	127.9	6.3
2	Height of shaft curvature	30	11.0	2.7	20	8.9	2.5
2a	Height of shaft curvature	30	31.8	2.8	20	26.6	2.4
2(1)	Curvature of lateral end	30	31.3	3.6	20	27.7	2.9
3	Chord of shaft curvature	30	100.9	6.9	20	89.7	7.9
5	Sagittal diameter at midshaft	30	12.1	1.2	20	10.7	1.0
4	Vertical diameter at midshaft	30	10.3	1.1	20	8.3	1.1
6	Circumference at midshaft	30	38.0	2.8	20	32.1	2.5
K9	Medial angle	30	142.7	6.9	20	144.4	7.0
K10	Lateral angle	30	144.8	6.5	20	148.7	7.5

[1] The estimates of basic statistics listed here were recalculated by the present author on the basis of the raw data published by Miyamoto (1925).

[2] Variable number according to Martin and Saller (1957) except for those with the letter 'K' preceding the number, which are measurement item nos. in Kiyono's (1929) measurement system.

In the case of the scapula, the measurements were divided into two groups in carrying out the above multivariate analyses because of a statistical restriction on sample size and the number of variables. Namely, the number of individuals was too small in both males and females compared with the total number of variables to obtain the solutions.

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

The statistical calculations were executed with the mainframe, HITACHI MP5800 System, of the Computer Centre, the University of Tokyo. The programs used are BSFMD for calculating basic statistics, BTPCA for principal component analysis and Kaiser's normal varimax rotation, and RKCNCT for rank correlation coefficients. All of these were written in FORTRAN by the present author.

Results

The direct results of the principal component analyses and the rotated solutions for the neurocranium and the scapula are shown in Tables 3 to 10, and those for the neurocranium and the clavicle, in Tables 11 to 14. In Tables 15 to 18, Spearman's rank correlation coefficients are listed to show similarities between males and females in the variation patterns of the factor loadings on principal components (PCs) or rotated factors.

In these results, there is neither PC nor rotated factor which is significantly correlated at the 5% level with one or more of the three main neurocranial measurements and, at the same time, found both in males and in females. But, if a PC or rotated factor with the factor loading of greater than 0.5 in absolute value can be regarded as an important one, there are two pairs of such PCs from the cranial and scapular measurements. They have significantly similar factor loading variation patterns between males and females at the 1% level (Table 15). One is the pair of PC I's seen in Tables 3 and 5. The measurement items having correlations of greater than 0.5 in absolute value with the PC I's both in males and in females are as follows: cranial length, anatomical breadth (of the scapula), anatomical length, length of scapula, length of lateral border, anatomical breadth of infraspinous fossa, projective breadth of infraspinous fossa, and length of spinal base. This suggests that cranial length has a relatively high correlation with the size of the scapula, especially of the infraspinous fossa.

The other pair of important PCs is that of PC II's in Tables 7 and 9. In this case, the measurement items having correlations of greater than 0.5 in absolute value with the PC II's both in males and in females are as follows: cranial length, breadth of glenoid cavity, vertebroglenoid angle, and spinoglenoid angle. This indicates that cranial length is relatively highly correlated also with the breadth and tilt of the glenoid cavity.

In the present analyses, it was not found that cranial breadth or basi-bregmatic height was consistently associated with scapular or clavicular measurements.

Discussion

It was suggested here that cranial length is relatively highly correlated with the size of the scapula and with the breadth and tilt of the glenoid cavity. If this is the case, we have to consider how cranial length is related with the functions of scapular muscles, or to confirm whether or not the genes controlling, directly or indirectly, both the skull and the shoulder girdle, which were structurally connected to each other in our fish ancestors (Kardong, 1995), are still retained in our DNA. For the present, however, we have no biomechanical or genetic data to solve this problem. The accumulation of such data is anticipated in the near future.

Table 3. Principal component analysis of the correlation matrix on the first set of measurements of the neurocranium and the scapula from Japanese males.[1)]

Variable[2)]	Factor loadings					Total variance (%)
	PC I	II	III	IV	V	
1 Cranial length	.61***	.30	.04	.09	−.31	57.44
8 Cranial breadth	.30	.44	.05	−.46	.53	77.92
17 Basi-bregmatic height	.39	.38	.19	.33	−.39	58.96
1 Anat. breadth (height)	.90***	.14	−.29	−.16	.06	93.86
2 Anat. length (breadth)	.90***	−.23	.27	.06	.04	94.59
2a Length of scapula	.93***	−.15	.17	.14	.07	93.53
3 Length of lat. border	.81***	.09	−.03	−.23	−.11	72.22
4 Length of sup. border	.04	−.05	.89	.06	.26	86.34
6a Anat. br. of suprasp. f.	.62*	−.54	−.48	−.14	−.10	93.84
6 Proj. br. of suprasp. f.	.42	−.76	−.32	−.24	.08	91.44
5a Anat. br. of infrasp. f.	.70***	.62	−.18	−.03	−.01	90.50
5 Proj. br. of infrasp. f.	.66***	.71	−.11	−.03	.03	94.33
7 Length of spine	.83***	−.37	.29	.01	.01	91.79
8 Length of spinal base	.81***	−.38	.34	.05	−.06	91.54
9 Maximum br. of acromion	.12	−.26	−.28	.73	.24	75.07
10 Length of acromion	.35	.24	−.31	.52	.37	68.06
Total contribution (%)	41.92	16.85	11.02	8.25	5.18	83.21
Cumulative proportion (%)	41.92	58.77	69.79	78.04	83.21	83.21

[1)] The sample size is 30. The number of the principal components shown here was so determined 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 4. Solution obtained through the normal varimax rotation of the first five principal components for the correlation matrix on the first set of measurements of the neurocranium and the scapula from Japanese males.[1)]

Variable[2)]	Factor loadings				
	Fac I	II	III	IV	V
1 Cranial length	.32	.67	−.08	.00	.09
8 Cranial breadth	.06	.03	.10	−.08	.87
17 Basi-bregmatic height	.14	.73**	.15	.08	−.11
1 Anat. breadth	.57*	.42	−.42	.13	.50**
2 Anat. length (breadth)	.91*	.27	.06	.11	.14
2a Length of scapula	.86**	.33	.01	.23	.17
3 Length of lat. border	.60**	.43	−.24	−.10	.34
4 Length of sup. border	.31	−.10	.86	−.11	.03
6a Anat. br. of suprasp. f.	.65	−.08	−.71	.09	−.02
6 Proj. br. of suprasp. f.	.66	−.42	−.54	.01	−.05
5a Anat. br. of infrasp. f.	.18	.72	−.17	.14	.55**
5 Proj. br. of infrasp. f.	.12	.74	−.08	.13	.60**
7 Length of spine	.94*	.15	.04	.04	.05
8 Length of spinal base	.94*	.18	.08	.02	−.03
9 Maximum br. of acromion	.13	−.07	−.08	.81	−.27
10 Length of acromion	.05	.24	−.07	.75	.24

[1)] The sample size is 30. The cumulative proportion of the variances of the five principal components is 83.21%.

[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. Principal component analysis of the correlation matrix on the first set of measurements of the neurocranium and the scapula from Japanese females.[1)]

Variable[2)]		Factor loadings					Total variance (%)
		PC I	II	III	IV	V	
1	Cranial length	.59	.46	−.24	.03	−.33	72.47
8	Cranial breadth	−.19	−.49	.02	.55	.58	90.70
17	Basi-bregmatic height	.15	−.48	−.36	.67	−.19	87.25
1	Anat. breadth (height)	.62	.29	.58	.13	−.17	85.42
2	Anat. length (breadth)	.81*	−.50	−.09	−.23	.05	95.88
2a	Length of scapula	.89**	−.23	−.07	−.17	.03	88.82
3	Length of lat. border	.65*	−.13	.25	.40	−.24	71.86
4	Length of sup. border	.20	−.52	−.62	−.21	−.21	78.66
6a	Anat. br. of suprasp. f.	.10	−.35	.90	−.16	−.03	96.30
6	Proj. br. of suprasp. f.	−.08	−.61	.71	.02	−.22	94.43
5a	Anat. br. of infrasp. f.	.64	.72	.04	.04	.09	94.90
5	Proj. br. of infrasp. f.	.63	.74	−.06	.10	.02	95.03
7	Length of spine	.47	−.68	−.08	−.24	.18	77.63
8	Length of spinal base	.80*	−.42	−.10	−.29	.18	93.73
9	Maximum br. of acromion	.54	.45	.16	.04	.52	79.52
10	Length of acromion	.71*	−.30	−.09	.39	−.04	74.78
Total contribution (%)		32.31	24.05	14.77	8.63	6.33	86.09
Cumulative proportion (%)		32.31	56.35	71.13	79.76	86.09	86.09

[1)] The sample size is 18. The number of the principal components shown here was so determined 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 6. Solution obtained through the normal varimax rotation of the first five principal components for the correlation matrix on the first set of measurements of the neurocranium and the scapula from Japanese females.[1)]

Variable[2)]		Factor loadings				
		Fac I	II	III	IV	V
1	Cranial length	.14	.48	−.26	.28	−.57
8	Cranial breadth	.01	−.13	.03	.26	.91*
17	Basi-bregmatic height	.13	−.28	−.19	.83	.23
1	Anat. breadth (height)	.08	.65	.53	.25	−.29
2	Anat. length (breadth)	.94	.09	.11	.21	−.07
2a	Length of scapula	.83	.33	.06	.23	−.18
3	Length of lat. border	.27	.32	.34	.64	−.12
4	Length of sup. border	.58	−.49	−.39	.19	−.16
6a	Anat. br. of suprasp. f.	.14	−.01	.96	−.11	.08
6	Proj. br. of suprasp. f.	.08	−.37	.88	.13	.12
5a	Anat. br. of infrasp. f.	.05	.91	−.14	.04	−.32
5	Proj. br. of infrasp. f.	.02	.87	−.22	.13	−.36
7	Length of spine	.83	−.18	.12	.06	.18
8	Length of spinal base	.95*	.18	.06	.08	−.02
9	Maximum br. of acromion	.18	.85	−.03	−.11	.16
10	Length of acromion	.51	.24	.04	.65	.06

[1)] The sample size is 18. The cumulative proportion of the variances of the five principal components is 86.09%.
[2)] See the second footnote to Table 1.
*$P<0.05$; **$P<0.01$; ***$P<0.001$, by a two-tailed bootstrap test.

Table 7. Principal component analysis of the correlation matrix on the second set of measurements of the neurocranium and the scapula from Japanese males.[1)]

Variable[2)]		Factor loadings						Total variance (%)
		PC I	II	III	IV	V	VI	
1	Cranial length	.35	.57	.10	−.11	.06	−.42	64.34
8	Cranial breadth	.35	.25	−.11	.03	.55	.51	76.41
17	Basi-bregmatic height	.34	.57	.24	−.35	.04	.04	62.07
11	Max. len. of cor. proc.	−.15	.46	.27	.21	.23	−.62*	78.37
12	Len. of glenoid cavity	−.07	.73	.41	.12	.19	.25	82.43
13	Br. of glenoid cavity	.14	.85	.22	.21	.07	.09	85.76
14	Depth of glenoid cavity	−.35	.10	.43	.66	−.08	.14	77.68
K18	Acromioglen. br. Hasebe	.37	.29	.10	−.73	.11	.01	78.59
15	Breadth-length angle	.92***	−.13	−.18	.21	.12	−.08	95.88
15a	Scapulospinal angle	.91***	−.16	−.18	.21	.10	−.03	95.37
16	Axillospinal angle	.82**	.26	−.26	.08	−.37	.06	94.75
17	Axilloglenoid angle	.68*	−.27	.53	−.12	−.29	.05	91.88
18	Vertebroglenoid angle	.63*	−.53	.54	.04	.08	.01	97.81
19	Spinoinfraspinous angle	−.85**	−.19	−.01	−.25	.27	.02	89.47
20	Spinosupraspinous angle	.33	−.58	−.04	.10	.66*	−.18	91.79
22[3)]	Spinoglenoid angle	−.09	−.53	.82	−.14	.00	.04	98.60
Total contribution (%)		29.41	21.28	12.19	8.85	7.35	6.00	85.08
Cumulative proportion (%)		29.41	50.69	62.88	71.73	79.08	85.08	85.08

[1)] The sample size is 29. The number of the principal components shown here was so determined that the cumulative proportion of the variances of the principal components exceeded 80%.
[2)] See the second footnote to Table 1.
[3)] See the third footnote to Table 1.
*$P<0.05$; **$P<0.01$; ***$P<0.001$, by a two-tailed bootstrap test.

Table 8. Solution obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the second set of measurements of the neurocranium and the scapula from Japanese males.[1)]

Variable[2)]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.29	.26	−.07	−.35	−.07	−.60
8	Cranial breadth	.20	.58*	−.16	−.18	.49	.30
17	Basi-bregmatic height	.17	.49	.09	−.53	−.15	−.20
11	Max. len. of cor. proc.	−.14	.21	−.07	.10	.02	−.84**
12	Len. of glenoid cavity	−.12	.86	−.01	.01	−.14	−.22
13	Br. of glenoid cavity	.18	.80	−.17	−.01	−.20	−.34
14	Depth of glenoid cavity	−.17	.36	.17	.74	−.16	−.11
K18	Acromioglen. br. Hasebe	.07	.20	.13	−.85	−.02	−.04
15	Breadth-length angle	.87*	−.06	.09	−.10	.42	−.02
15a	Scapulospinal angle	.87*	−.06	.11	−.09	.41	.05
16	Axillospinal angle	.92*	.09	−.09	−.22	−.18	.06
17	Axilloglenoid angle	.50	−.02	.79	−.18	−.08	.07
18	Vertebroglenoid angle	.39	−.09	.83	−.01	.35	.05
19	Spinoinfraspinous angle	−.91*	−.16	−.14	.05	.07	.09
20	Spinosupraspinous angle	.10	−.27	.21	.02	.89*	−.02
22[3)]	Spinoglenoid angle	−.34	−.08	.92	.09	.05	.05

[1)] The sample size is 29. The cumulative proportion of the variances of the six principal components is 85.08%.
[2)] See the second footnote to Table 1.
[3)] See the third footnote to Table 1.
*$P<0.05$; **$P<0.01$; ***$P<0.001$, by a two-tailed bootstrap test.

Table 9. Principal component analysis of the correlation matrix on the second set of measurements of the neurocranium and the scapula from Japanese females.[1]

Variable[2]		Factor loadings						Total variance (%)
		PC I	II	III	IV	V	VI	
1	Cranial length	.19	−.63	.21	−.42	−.24	−.18	73.91
8	Cranial breadth	−.24	.29	.00	.64	.21	.55	89.98
17	Basi-bregmatic height	−.37	−.11	.64	.51	−.11	.07	83.17
11	Max. len. of cor. proc.	−.20	−.26	.64	−.22	.07	.44	76.46
12	Len. of glenoid cavity	.29	−.13	−.30	.38	−.70*	.17	84.18
13	Br. of glenoid cavity	−.07	−.54	.29	−.20	−.45	.19	65.75
14	Depth of glenoid cavity	.19	−.22	−.63	.20	−.45	.15	73.39
K18	Acromioglen. br. Hasebe	−.10	−.75	.22	.02	−.07	.07	62.99
15	Breadth-length angle	.93***	−.07	.26	.21	.07	−.08	98.99
15a	Scapulospinal angle	.93***	−.05	.16	.25	.04	−.08	96.57
16	Axillospinal angle	.89***	−.19	−.06	−.00	.22	.18	91.90
17	Axilloglenoid angle	.61	.54	.01	−.39	−.10	.31	91.43
18	Vertebroglenoid angle	.52	.67	.36	−.21	−.25	.01	96.48
19	Spinoinfraspinous angle	−.94***	.14	−.01	.05	−.12	−.14	93.24
20	Spinosupraspinous angle	.12	.42	.47	.48	−.32	−.43	92.33
22[3]	Spinoglenoid angle	−.35	.73	.11	−.39	−.35	.14	97.19
Total contribution (%)		28.68	18.68	12.12	11.23	8.58	6.21	85.50
Cumulative proportion (%)		28.68	47.36	59.48	70.71	79.29	85.50	85.50

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

Table 10. Solution obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the second set of measurements of the neurocranium and the scapula from Japanese females.[1]

Variable[2]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.17	−.16	.47	−.67*	−.04	.08
8	Cranial breadth	−.08	−.05	−.01	.94***	−.05	−.07
17	Basi-bregmatic height	−.19	−.24	.47	.36	.13	−.61*
11	Max. len. of cor. proc.	−.05	.06	.78**	.13	.36	.04
12	Len. of glenoid cavity	.16	.04	.08	.05	−.88**	−.16
13	Br. of glenoid cavity	−.07	−.07	.72**	−.29	−.22	−.00
14	Depth of glenoid cavity	.06	−.11	−.12	−.02	−.81**	.21
K18	Acromioglen. br. Hasebe	.05	−.50	.58*	−.19	−.05	.04
15	Breadth-length angle	.96***	.08	−.01	−.08	−.03	−.25*
15a	Scapulospinal angle	.94***	.07	−.08	−.06	−.11	−.23*
16	Axillospinal angle	.92***	.04	−.01	−.04	−.08	.25
17	Axilloglenoid angle	.42	.83	−.09	.00	−.02	.20
18	Vertebroglenoid angle	.34	.85	−.08	−.07	.09	−.32
19	Spinoinfraspinous angle	−.93***	−.15	−.01	.11	.10	−.17
20	Spinosupraspinous angle	.08	.18	−.15	.04	−.01	−.93***
22[3]	Spinoglenoid angle	−.56*	.80	−.03	.05	.06	−.08

[1] The sample size is 20. The cumulative proportion of the variances of the six principal components is 85.50%.
[2] See the second footnote to Table 1.
[3] See the third footnote to Table 1.
*$P<0.05$; **$P<0.01$; ***$P<0.001$, by a two-tailed bootstrap test.

Table 11. Principal component analysis of the correlation matrix on the measurements of the neurocranium and the clavicle from Japanese males.[1)]

Variable[2)]		Factor loadings						Total variance (%)
		PC I	II	III	IV	V	VI	
1	Cranial length	.51	.15	−.50	−.15	.27	.09	63.56
8	Cranial breadth	.08	.47	−.14	−.36	−.29	.68	92.89
17	Basi-bregmatic height	.11	.49	−.51	−.31	.18	−.45	84.29
1	Maximum length	.18	.45	.66	−.49	−.06	−.22	95.24
2	Ht. of shaft curvature	−.86	.03	−.12	−.05	−.02	.13	77.08
2a	Ht. of shaft curvature	−.79	.39	.06	−.08	.18	.04	81.30
2(1)	Curv. of lateral end	.48	.62	.00	.03	−.41	−.14	81.04
3	Chord of shaft curv.	−.21	.42	.69	−.42	.14	.01	89.07
5	Sag. diam. at midshaft	.00	.43	.37	.71	−.26	−.07	89.01
4	Vert. diam. at midshaft	.05	.72	−.31	.05	.40	.09	78.74
6	Circumf. at midshaft	−.10	.76	−.04	.59	.14	.07	96.35
K9	Medial angle	.91	−.04	.18	.02	.07	.17	90.66
K10	Lateral angle	.26	−.20	.52	.19	.62	.17	83.41
Total contribution (%)		22.01	21.03	15.32	11.94	8.08	6.44	84.82
Cumulative proportion (%)		22.01	43.04	58.36	70.29	78.38	84.82	84.82

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

Table 12. Solution obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the measurements of the neurocranium and the clavicle from Japanese males.[1)]

Variable[2)]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.40	.60*	−.23	−.16	.03	.20
8	Cranial breadth	−.00	.12	.13	.02	−.17	.93*
17	Basi-bregmatic height	−.02	.82*	.11	−.07	−.38	−.12
1	Maximum length	.17	.03	.96*	.04	−.07	.04
2	Ht. of shaft curvature	−.86	−.10	−.08	−.04	−.06	.09
2a	Ht. of shaft curvature	−.84	.15	.23	.16	.06	.08
2(1)	Curv. of lateral end	.46	.24	.28	.45	−.47	.21
3	Chord of shaft curv.	−.24	−.03	.88	.05	.20	.12
5	Sag. diam. at midshaft	.05	−.21	.09	.91	−.03	−.09
4	Vert. diam. at midshaft	−.11	.76	.04	.35	.11	.24
6	Circumf. at midshaft	−.18	.38	−.02	.87***	.09	.12
K9	Medial angle	.90	.04	.07	.02	.24	.16
K10	Lateral angle	.26	−.09	.16	.05	.84	−.17

[1)] The sample size is 30. The cumulative proportion of the variances of the six principal components is 84.82%.
[2)] See the second footnote to Table 2.
$^{*}P<0.05$; $^{**}P<0.01$; $^{***}P<0.001$, by a two-tailed bootstrap test.

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

Variable[2)]		Factor loadings PC I	II	III	IV	Total variance (%)
1	Cranial length	.13	.67	.49	.21	75.23
8	Cranial breadth	.39	−.60	−.19	.43	74.12
17	Basi-bregmatic height	.49	−.47	.46	.34	78.15
1	Maximum length	−.35	.14	.58	.46	69.33
2	Ht. of shaft curvature	.76	−.21	.33	−.45	93.72
2a	Ht. of shaft curvature	.79	.37	.16	−.32	89.59
2(1)	Curv. of lateral end	.61	.46	.31	.48	90.35
3	Chord of shaft curv.	.27	−.47	.46	−.05	51.23
5	Sag. diam. at midshaft	.44	.03	−.56	.51	76.68
4	Vert. diam. at midshaft	.77	.44	−.08	−.18	81.47
6	Circumf. at midshaft	.68	.42	−.54	.15	95.17
K9	Medial angle	−.90	.14	−.11	.11	85.78
K10	Lateral angle	−.72	.50	.15	−.05	80.32
Total contribution (%)		36.61	17.72	14.79	10.96	80.09
Cumulative proportion (%)		36.61	54.33	69.12	80.09	80.09

[1)] The sample size is 16. The number of the principal components shown here was so determined that the cumulative proportion of the variances of the principal components exceeded 80%.

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

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

Table 14. Solution obtained through the normal varimax rotation of the first four principal components for the correlation matrix on the measurements of the neurocranium and the clavicle from Japanese females.[1)]

Variable[2)]		Factor loadings Fac I	II	III	IV
1	Cranial length	.23	.17	.08	.81*
8	Cranial breadth	−.12	−.67	−.48	−.22
17	Basi-bregmatic height	.07	−.85	−.04	.22
1	Maximum length	−.44	−.10	.24	.65
2	Ht. of shaft curvature	.78	−.51	.21	−.11
2a	Ht. of shaft curvature	.92	−.07	−.06	.20
2(1)	Curv. of lateral end	.38	−.21	−.38	.75*
3	Chord of shaft curv.	.11	−.65	.29	.00
5	Sag. diam. at midshaft	.06	−.09	−.87	−.03
4	Vert. diam. at midshaft	.83	.05	−.31	.17
6	Circumf. at midshaft	.56	.18	−.78	.04
K9	Medial angle	−.73	.53	.21	.01
K10	Lateral angle	−.37	.66	.37	.31

[1)] The sample size is 16. The cumulative proportion of the variances of the four principal components is 80.09%.

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

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

Table 15. Principal components from the measurements of the neurocranium and scapula which show significantly similar loading variation patterns at the 5% level.[1)]

First variable set				Second variable set			
Principal components compared			Spearman's rank corr.	Principal components compared			Spearman's rank corr.
Male		Female		Male		Female	
I	—	I	0.63**	I	—	I	0.72**
II	—	II	0.54*	I	—	V	0.60*
II	—	IV	0.66**	II	—	II	0.82***
III	—	III	0.78***	III	—	V	0.62**
IV	—	III	0.61*	IV	—	I	0.56*
				VI	—	III	0.67**
				VI	—	VI	0.60*

[1)] The similarity in the variation patterns of factor loadings between two PCs, one of which was from males and the other from females, was assessed by Spearman's rank correlation coefficient. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 3, 5, 7 and 9.

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

Table 16. Rotated factors for the measurements of the neurocranium and scapula which show significantly similar loading variation patterns at the 5% level.[1)]

First variable set				Second variable set			
Rotated factors compared			Spearman's rank corr.	Rotated factors compared			Spearman's rank corr.
Male		Female		Male		Female	
I	—	I	0.63**	I	—	I	0.79***
I	—	III	0.58*	II	—	II	0.54*
II	—	II	0.59*	II	—	III	0.59*
II	—	V	0.52*	II	—	V	0.50*
III	—	III	0.55*	III	—	II	0.56*
IV	—	II	0.60*	III	—	III	0.61*
				V	—	VI	0.59*
				VI	—	III	0.56*

[1)] The similarity in the variation patterns of factor loadings between two rotated factors, one of which was from males and the other from females, was assessed by Spearman's rank correlation coefficient. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 4, 6, 8 and 10.

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

Table 17. Principal components from the measurements of the neurocranium and clavicle which show significantly similar loading variation patterns at the 5% level.[1)]

Principal components compared			Spearman's rank correlation
Male		Female	
I	—	I	0.69**
IV	—	III	0.72**
V	—	IV	0.62*

[1)] The similarity in the variation patterns of factor loadings between two PCs, one of which was from males and the other from females, was assessed by Spearman's rank correlation coefficient. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 11 and 13.

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

Table 18. Rotated factors for the measurements of the neurocranium and clavicle which show significantly similar loading variation patterns at the 5% level.[1)]

Rotated factors compared			Spearman's rank correlation
Male		Female	
I	—	I	0.65*
V	—	II	0.72**

[1)] The similarity in the variation patterns of factor loadings between two rotated factors, one of which was from males and the other from females, was assessed by Spearman's rank correlation coefficient. The signs of rank correlation coefficients are removed because the signs of factor loadings are reversible. The original factor loadings are listed in Tables 12 and 14.

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

Regarding the associations with clavicular measurements, Mizoguchi (1992), in his preliminary analysis on cranial and postcranial measurements, showed that a rotated factor had relatively high correlation (−0.69) with cranial length and, at the same time, relatively high inverse correlation (0.60) with the maximum length of the clavicle. This result is based on the same male sample as that used here. PC III from the present analysis on the male data certainly shows a similar tendency (Table 11), but the factor loadings in question are not significant at the 5% level. And, further, this is not confirmed in females (Tables 13 and 14). It seems, therefore, safe for the present to say that there are no consistent associations between neurocranial and clavicular measurements.

Finally, it may be possible from a series of multivariate analyses by Mizoguchi (1994, 1995, 1996, 1997, 1998a, b, 1999) and the present study to point out that cranial length and cranial breadth tend to have some different kinds of associations with postcranial bones. If this is ascertained also in the analyses of correlations with other extremity bones, brachycephalization may be explained, at least in part, by the difference in the intrinsic way of varying between cranial length and breadth.

Summary and Conclusions

The analyses on the neurocranium and the shoulder girdle suggested that cranial length is relatively highly correlated with the size of the scapula, especially of the infraspinous fossa, and with the breadth and tilt of the glenoid cavity. But cranial breadth is not consistently associated with any of scapular or clavicular measurements. From these and previous analyses, it seems that cranial length and cranial breadth tend to have some different kinds of associations with postcranial bones.

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