Bull. Natl. Mus. Nat. Sci., Ser. D, **36** pp. 13–26, December 22, 2010

Difference in Geographical Variation Patterns of Cranial Measurements between the Jomon and Kofun Periods of Japan

Yuji Mizoguchi

Department of Anthropology, National Museum of Nature and Science
3–23–1 Hyakunincho, Shinjuku-ku, Tokyo 169–0073, Japan
E-mail: mzgch@kahaku.go.jp

Abstract Geographical variation patterns in cranial measurements were compared between the prehistoric Jomon and protohistoric Kofun periods in order to examine human migration routes or differential microevolutionary tendencies between local regions in the Japanese archipelago. Mantel's matrix permutation test showed no significant association between the two periods, suggesting that the geographical distribution of the Kofun people was not a direct succession from that of the Jomon people. Further Mantel's tests showed that, while the Jomon geographical variation pattern in cranial measurements is associated with latitude and the present-day average annual temperature difference pattern at around 10% significance level, the Kofun geographical variation pattern in cranial measurements is associated with the variation pattern in the present-day mean relative annual humidity at the 5% level. Although it is difficult at present to solve the problem of whether the former implies a trace of migration of the Jomon people or their adaptation to temperature, the latter suggests a close connection of the Kofun people with rice cultivation. This is also suggested by Q-mode path analysis, where part of the geographical variation in cranial measurements of the Kofun people was found to be significantly associated with the geographical variation in the present-day annual rainfall. Further, it was also shown by Q-mode path analysis that the geographical variation pattern of the Kofun local populations is explainable by taking account of the Aeneolithic northern Kyushu Yayoi people, who are considered to have been engaged in rice cultivation.
Key words : Formation process of the Japanese population, Cranial measurements, Environmental factors, Mantel's matrix permutation procedure, Q-mode path analysis

With the increase of accumulated ancient skeletal remains, geographical differences in morphological characters between regions or clines across the Japanese archipelago have been reported more frequently than before. In 1973, Ogata found that, in the Late phase of the prehistoric Jomon period, northeastern inhabitants tended to have higher upper facial height and broader bigonial breadth than southwestern people, at least in males. Later, Yamaguchi (1981), using three Jomon samples from eastern, middle, and western regions of Honshu Island, also showed that there were certain geographical clines in some craniofacial measurements, such as cranial length, minimum frontal breadth, biasterionic breadth, basi-bregmatic height, minimum nasal breadth, naso-malar angle, etc. Further, Dodo (1982), adding a male sample from the Tohoku district to those examined by Yamaguchi (1981), confirmed that, at least in basi-bregmatic height, there was a clear geographical cline in an east-west direction in the Japanese archipelago in the Jomon period. This was re-confirmed among four regions on Honshu Island by Mizoguchi and Dodo (2001) on the basis of much larger male samples from the Jomon period.

Kaifu (1995), however, using the data of 22 mandibular measurements from five Jomon local populations, stated that, although significant inter-region differences were observed in some measurements such as ramus breadth, the Jomon local populations had common mandibular features in general compared with the Yayoi people from the northern Kyushu and Yamaguchi region; however, later, the peculiarity of the Hokkaido Jomon population in their broader mandibular ramus, originally pointed out by Kaifu (1995), was confirmed to be remarkable by Maeda (2002).

Among recent reports, Takigawa's (2006) findings are very interesting. He estimated D^2 distances between six Jomon local populations for males and females, respectively, using twelve cranial measurements, and found that the degree of geographical variation was much larger in females than in males. As a possible cause of this, Takigawa pointed out the between-sex difference in social environment or behavior in the Jomon period.

On the other hand, there are also various reports regarding the protohistoric Kofun period. Morisawa (1976) showed that cranial length, horizontal circumference, transverse arc, bizygomatic breadth, anterior interorbital breadth, etc. of males were significantly larger in eastern than western Japan. In 1987, Doi and Tanaka, using many male samples of the Kofun period from western Japan plus one eastern Kofun sample, examined the association of the first principal component extracted from nine cranial measurements, which they called the 'general height factor,' with the railway distance from Chikuzen (Hakata station) to each site, and argued the dispersion process of Aeneolithic Yayoi immigrants from northern Kyushu to various areas suitable for rice cultivation. Mizoguchi (2006) suggested that, not only in the Jomon but also in the Kofun period, there was a geographical cline at least in basi-bregmatic height across Honshu Island. Recently, Kawakubo *et al*. (2009) carried out discriminant function analysis based on 18 cranial measurements of males, where a given individual was classified into the eastern Jomon or northern Kyushu Yayoi population. From this analysis, they suggested that, also in the Kofun period, there was a geographical cline between northeastern and southwestern Japan.

At present, however, it is unknown whether the above-mentioned clines imply a trace of migration in Japan or were caused by environmental differences between local regions. Although it has been considered that not a few immigrants came to western Japan from the Asian continent in the Yayoi period (2400 or 2900 BP–1700 BP), the problem of how they dispersed throughout Japan has not been resolved.

In the present preliminary study, therefore, the problem of whether the geographical variation pattern of cranial measurements in the Kofun period (1700 BP–800 BP) is the same as that in the Middle to Final phase of the Jomon period (5000 or 5500 BP–2400 or 2900 BP) is examined, and also, if there is any difference in the cranial variation patterns, those environmental factors which may be associated with such variations are sought in both periods. However, because of the small number of samples, especially from the Yayoi period, comparisons are carried out mainly between the data sets of Jomon and Kofun local populations. Furthermore, the environmental data used here are those of the present time; however, if any significant associations are found in these analyses, they would be very helpful for understanding the formation process of the Japanese population.

Materials and Methods

The data used here are the mean values for seven cranial measurements as follows: cranial length, cranial breadth, basi-bregmatic height, bizygomatic breadth, upper facial height, nasal breadth, and nasal height. These were collected through a literature survey, and those of six Jomon, one Yayoi, and five Kofun male samples are shown in Appendix 1. All the Jomon samples except for Ota from the Sanyo district, some of which may be derived from the Early phase, are from the Middle, Late, or Final phase. The geographical variation patterns in cranial measurements from the Jomon and Kofun periods are expressed using Mahalanobis' D^2 distances (Rao, 1952; Okuno *et al*., 1976) between local populations in each period. For the variances/covariances necessary for calculating D^2 distances, however, those calculated from 28 or 30 modern Japanese males (Miyamoto, 1924) were used as substitutes under the assumption that all variance/covariance matrices for comparative populations are the same as that of modern Japanese.

Environmental variables examined are latitude, longitude, average annual temperature, mean relative annual humidity, and annual rainfall; however, these data (Appendix 2) are not from the Jomon or Kofun period but from the present time.

To test the significance of similarity between the geographical variation patterns in cranial measurements of the two periods or between those in cranial measurements and environmental factors, Mantel's matrix permutation procedure (Mantel, 1967; Kempthorne, 1969; Dietz, 1983; Dow and Cheverud, 1985; Dow *et al.*, 1987; Mizoguchi, 1993) was used.

In addition to the comparison of matrices, the contributions of ancestral populations to descendant populations were estimated using Q-mode path analysis (Mizoguchi, 1986), which is a Q-mode version of the path analysis method (Wright, 1934; Li, 1956, 1975; Kempthorne, 1969; Yasuda, 1969). The residual variable obtained in this method is very useful because it can point to the existence of unknown factors. In this analysis, however, it should be noted that a Q-mode correlation coefficient is estimated under the assumption that variables which are standardized in R-mode are normally distributed in Q-mode (Sneath and Sokal, 1973). Further, Q-mode correlations can be considerably affected by duplicated information between characteristics, i.e., inter-character correlations (Mizoguchi, 1993). In the present study, therefore, standardized principal component (PC) scores for the mean values of cranial measurements in each sample were estimated in advance because PCs are independent of one another (Lawley and Maxwell, 1963; Okuno *et al.*, 1971, 1976; Takeuchi and Yanai, 1972). For estimating the PC scores in practice, the variance/covariance matrix from the same modern Japanese male sample as the above (Miyamoto, 1924) was used.

The significance of factor loadings on PCs 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 factor loading, 1000 bootstrap replications, including the observed sample, were used. The bootstrap standard deviation was estimated by directly counting the cumulative frequency of the standard deviation in the bootstrap distribution.

In order to examine whether the residual variable from Q-mode path analysis is associated with any environmental factors, the among-group associations between them were estimated using Kendall's rank correlation coefficient (Siegel, 1956).

Statistical calculations were executed using programs written by the author in FORTRAN: BSFMD for calculating variances/covariances, MNTMPP for Mantel's matrix permutation procedure, PCAFPP for the coefficient matrix of simultaneous linear equations for the prediction of principal components from the variables observed, PCSCOR for estimating principal component scores for arbitrary individuals, BTPCA for significance tests of factor loadings and Q-mode correlation coefficients, PATHAN for Q-mode path analysis, and RKCNCT for rank correlation coefficients.

The FORTRAN 77 compiler used is FTN77 for personal computers, provided by Salford Software Ltd. To increase efficiency during programming and calculation, a GUI for programming, CPad, provided by "kito," was used.

Results

In order to know the degree of difference in the geographical variation patterns of cranial measurements between the Jomon and Kofun periods, the D^2 distance matrices for the two periods were compared. The D^2 distances for each period were calculated between five samples from the same regions across the Japanese archipelago: Hokkaido, Tohoku, Kanto, Sanyo, and Northern Kyushu. Mantel's matrix permutation test for this comparison showed that the correlation of 0.07 between the two matrices is not significant at the 5% level (the first row in Table 1). Further, an attempt to eliminate the influence of environmental factors on the D^2 distance matrices of cranial measurements was made using the method of partial correlation. As a result, Mantel's matrix permutation tests again revealed no significant partial correlations between the D^2 distance matrices for the Jomon and Kofun periods (Table 1).

The associations of individual environmental factor difference matrices with the D^2 distance matrices on cranial measurements are shown in Table 2. It was found here that, while the Jomon D^2 distance matrix is relatively highly correlated with the matrices for latitude and average annual temperature, the Kofun D^2 distance matrix is significantly correlated with the matrix for mean relative annual humidity at the 5% level.

In addition to the above direct comparison of distance/difference matrices, an attempt to estimate the degree of contribution of some type, such as genetic, of Jomon local populations to their supposedly descendant Kofun populations was made by Q-mode path analysis. In this analysis, PC scores were used instead of original variables to avoid the distortion of results due to inter-character correlations. The factor loadings listed in Table 3 show the properties of individual PCs. Table 4 and Fig. 1 show the path coefficients from five Jomon local populations to five Kofun local populations in the same regions. A path coefficient (Table 4) is considered a type of

Table 1. Mantel's matrix permutation tests for the significance of the correlation or patial correlation between the Mahalanobis' D^2 distance matrix for five Jomon samples and that for five Kofun samples.[1]

	Environmental factor difference matrix fixed	Kendall's tau	Probability (one-tailed)
Correlation	–	0.07	0.408
Partial correlation	Squared geographical distance matrix	0.04	0.408
Partial correlation	Difference matrix in latitude	−0.05	0.425
Partial correlation	Difference matrix in longitude	0.08	0.342
Partial correlation	Difference matrix in av. ann. temperature	−0.03	0.475
Partial correlation	Difference matrix in mean rel. ann. humidity	0.05	0.408
Partial correlation	Difference matrix in annual rainfall	0.05	0.425

[1] D^2 distances between five samples from Hokkaido, Tohoku, Kanto, Sanyo, and Northern Kyushu in each period were calculated using seven cranial measurements. No. of permutations including the one observed in Mantel's test is 120.

Table 2. Mantel's matrix permutation tests for the significance of the associations between the Mahalanobis' D^2 distance matrix on cranial measurements for five Jomon or Kofun samples and the environmental factor difference matrices for the corresponding regions of the present time.[1]

	D^2 distance matrix for Jomon samples		D^2 distance matrix for Kofun samples	
	Kendall's tau	Probability (one-tailed)	Kendall's tau	Probability (one-tailed)
Squared geographical distance matrix	0.24	0.200	0.11	0.325
Difference matrix in latitude	0.36	0.083	0.31	0.158
Difference matrix in longitude	0.29	0.158	−0.02	0.575
Difference matrix in av. ann. temperature	0.33	0.108	0.29	0.200
Difference matrix in mean rel. ann. humidity	0.05	0.517	0.51	0.033
Difference matrix in annual rainfall	0.07	0.408	0.20	0.208

[1] D^2 distances between five samples from Hokkaido, Tohoku, Kanto, Sanyo, and Northern Kyushu in each period were calculated using seven cranial measurements. No. of permutations including the one observed in Mantel's test is 120.

Table 3. Principal component analysis of the correlation matrix on the seven cranial measurements used to estimate Mahalanobis' D^2 distances and principal component scores for Jomon, Yayoi, and Kofun samples.[1]

Variable[2]	Factor loadings							Total variance (%)
	PC I	II	III	IV	V	VI	VII	
1 Cranial length	0.57*	0.52	0.22	0.37	−0.44	0.12	−0.06	100.00
8 Cranial breadth	0.62*	0.18	0.14	−0.67	0.05	0.33	−0.03	100.00
17 Basi-bregmatic height	0.43	0.59	−0.47	0.28	0.40	0.07	−0.07	100.00
45 Bizygomatic breadth	0.82***	0.24	−0.01	−0.22	−0.02	−0.44	0.17	100.00
48 Upper facial height	0.65**	−0.58	−0.24	0.27	−0.02	0.24	0.24	100.00
54 Nasal breadth	0.40	−0.18	0.80	0.25	0.32	−0.02	−0.03	100.00
55 Nasal height	0.70**	−0.59	−0.24	−0.02	−0.07	−0.13	−0.29	100.00
Total contribution (%)	37.83	20.24	14.82	12.17	6.70	5.63	2.60	100.00
Cumulative proportion (%)	37.83	58.08	72.90	85.07	91.77	97.40	100.00	100.00

[1] The correlation matrix was obtained from data from 28 modern Japanese males.
[2] According to Martin and Saller (1957).
* $P<0.05$; ** $P<0.01$; *** $P<0.001$, by a two-tailed bootstrap test.

Table 4. Path coefficients in the Q-mode path analysis for five Kofun local populations based on a model of five ancestral or Jomon local populations.

Kofun local populations	Path coefficients for ancestral populations				
	Hokkaido Jomon	Tohoku Jomon	Kanto Jomon	Sanyo Jomon	Northern Kyushu Jomon
Hokkaido Epi-Jomon	−1.11	1.02	−0.33	3.36	−2.23
Tohoku Kofun	−0.31	1.81	−2.40	3.50	−1.63
Kanto Kofun	−1.08	3.84	−3.90	4.76	−2.74
Sanyo Kofun	−0.28	2.45	−3.53	4.31	−2.00
Northern Kyushu Kofun	−1.27	0.46	−1.08	3.94	−1.29

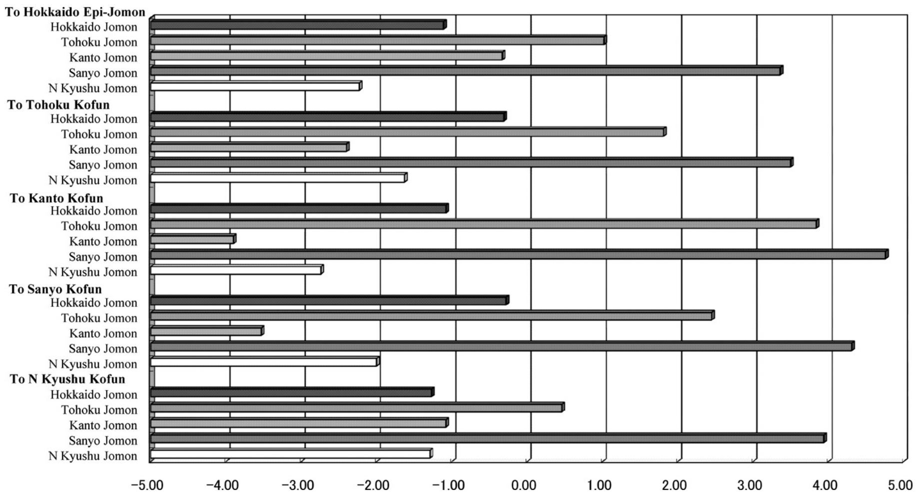

Fig. 1. Path coefficients of five local Jomon populations to each of five Kofun or Epi-Jomon populations.

Table 5. Coefficients of determination in Q-mode path analysis of five Kofun local populations based on a model of five ancestral or Jomon local populations.

Kofun local populations	Direct contributions of ancestral populations					Joint effect of paths	Residual variable
	Hokkaido Jomon	Tohoku Jomon	Kanto Jomon	Sanyo Jomon	Northern Kyushu Jomon		
Hokkaido Epi-Jomon	1.23	1.04	0.11	11.26	4.95	−17.68	0.0976
Tohoku Kofun	0.10	3.26	5.74	12.26	2.64	−23.01	0.0092
Kanto Kofun	1.16	14.76	15.20	22.65	7.51	−60.28	0.0039
Sanyo Kofun	0.08	5.98	12.45	18.56	4.02	−40.13	0.0489
Northern Kyushu Kofun	1.61	0.21	1.17	15.52	1.65	−19.16	0.0029

regression coefficient, and shows how an exogenous variable (ancestral population) contributes to an endogenous variable (descendant population). As a result, the path coefficients from the Sanyo and Tohoku Jomon samples were found to have the highest positive contributions to Kofun people in any of the five local regions. No differences between the observed correlations and those estimated from the obtained path coefficients were found to be significant for any pair of the five endogenous variables, i.e., five Kofun local populations ($P=0.65$ to 0.98).

In Table 5, coefficients of determination of exogenous and residual variables to endogenous variables and the joint effect of paths are shown. In path analysis, the residual variable is very important because it may suggest the existence of some unknown factor other than the exogenous variables used in the analysis. Here, in order to clarify the residual variable, it was preliminarily compared with environmental factors at the present time (Table 6). As a result, it was found that the residual variable had a significant association with annual rainfall.

Although comparative samples from the Yayoi period are very limited at present, further path analysis was carried out after a Yayoi sample from Northern Kyushu and one more Jomon sample from the Tokai district were added to the above data set. The results are shown in Tables 7 and 8 as well as in Fig. 2. In this case, all values of the residual variable were practically zero (Table 8). No differences between the observed correlations and those estimated from the path coefficients were found to be significant for any pair of the five Kofun local populations ($P=0.71$ to 0.92). It is most interesting here that there are four geographical clines in the contributions of supposedly ancestral populations to the Kofun people in the Japanese archipelago, excluding northern Kyushu (Fig. 2): the Tokai Jomon contribution decreases from Sanyo through Kanto and Tohoku to Hokkaido; both Sanyo and Kanto Jomon contributions decrease from Hokkaido through Tohoku and Kanto to Sanyo; and the northern Kyushu Yayoi contribution decreases from Sanyo through Kanto and Tohoku to Hokkaido. It is also interesting that the contributions of all Jomon and Yayoi populations to the northern Kyushu Kofun population are almost the same (Fig. 2).

Table 6. Rank correlations of the squared residual variable in Q-mode path analysis of five Jomon and five Kofun samples with environmental variables.

	Kendall's tau	Probability (one-tailed)
Latitude	0.60	0.142
Longitude	0.60	0.142
Av. ann. temperature	−0.60	0.142
Mean rel. ann. humidity	0.42	0.302
Annual rainfall	−0.80	0.050

[1] D^2 distances between the Jomon samples were calculated using seven cranial measurements. No. of permutations including the one observed in Mantel's test is 120.

Table 7. Path coefficients in Q-mode path analysis of five Kofun local populations based on a model of seven ancestral, or six Jomon and one Yayoi, populations.

Kofun local populations	Path coefficients for ancestral populations						
	Hokkaido Jomon	Tohoku Jomon	Kanto Jomon	Tokai Jomon	Sanyo Jomon	Northern Kyushu Jomon	Northern Kyushu Yayoi
Hokkaido Epi-Jomon	−0.27	0.30	2.69	−4.51	4.66	−1.23	−1.37
Tohoku Kofun	−0.11	1.31	−2.37	3.99	−2.22	−0.94	1.99
Kanto Kofun	−0.38	2.63	−2.68	5.70	−5.40	−1.09	3.19
Sanyo Kofun	−0.01	1.60	−3.90	8.23	−6.75	−0.85	3.98
Northern Kyushu Kofun	−0.93	0.01	−0.16	0.46	1.73	−0.68	0.50

Table 8. Coefficients of determination in Q-mode path analysis of five Kofun local populations based on a model of seven ancestral, or six Jomon and one Yayoi, populations.

Kofun local populations	Direct contributions of ancestral populations							Joint effect of paths	Residual variable[1]
	Hokkaido Jomon	Tohoku Jomon	Kanto Jomon	Tokai Jomon	Sanyo Jomon	Northern Kyushu Jomon	Northern Kyushu Yayoi		
Hokkaido Epi-Jomon	0.07	0.09	7.25	20.33	21.68	1.51	1.87	−51.80	−0.0023
Tohoku Kofun	0.01	1.70	5.60	15.91	4.90	0.89	3.97	−31.99	−0.0011
Kanto Kofun	0.14	6.93	7.17	32.46	29.16	1.18	10.16	−86.18	−0.0039
Sanyo Kofun	0.00	2.55	15.21	67.66	45.53	0.72	15.86	−146.52	−0.0067
Northern Kyushu Kofun	0.86	0.00	0.03	0.21	2.97	0.46	0.25	−3.77	−0.0001

[1]All values seem to be underestimates due to low digit precision. The residual variable must be non-negative.

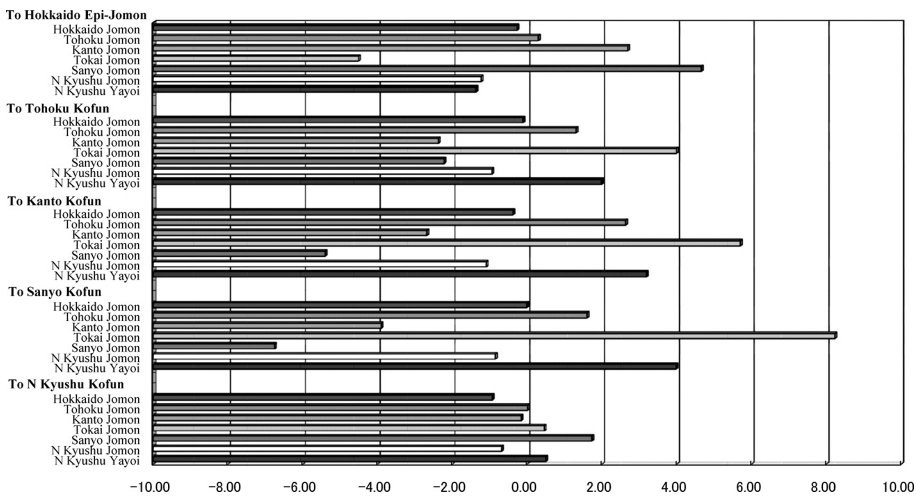

Fig. 2. Path coefficients of six Jomon and one Yayoi populations to each of five Kofun or Epi-Jomon populations.

Discussion

As reported by previous authors (Morisawa, 1976; Yamaguchi, 1981; Dodo, 1982; Mizoguchi and Dodo, 2001; Mizoguchi, 2006; Takigawa, 2006; Kawakubo *et al*., 2009), it is clear that, in both Jomon and Kofun periods, there were geographical clines or among-region differences in some cranial measurements throughout the Japanese archipelago. Up to the present, however, it has not been examined whether such geographical variation patterns in the two periods are similar. In addition, regarding the causes of geographical clines or among-region variations, no quantitative analysis of concrete environmental factors, such as temperature, humidity, etc., has been conducted. The present study may be the first of such attempts.

Mantel's matrix permutation tests

The geographical variation patterns in seven cranial measurements of the pre-Yayoi (i.e., Jomon) and post-Yayoi (i.e., Kofun) periods were found not to be similar to each other (Table 1). This is compatible with previous preliminary Mantel's tests by Mizoguchi (2006), who used eight cranial measurements of males from the Kyushu, Sanyo, Kanto, and Tohoku districts of the Jomon and Kofun periods. These findings suggest that there was a large change in physical characteristics across the Japanese archipelago; however, the causes of the change cannot be inferred from only these analyses.

Candidate causes which are immediately suggested are climatic factors and immigration. Mizoguchi (2008) therefore attempted to compare geographical variation patterns in cranial and postcranial measurements for the Jomon and Kofun periods with those of the same modern environmental variables as those used here; however, directly after Mizoguchi's (2008) report, some of the Kofun data used, i.e., those from Yamoto (Takigawa and Sato, 2008) were reported by Takigawa (2008) to contain some errors. Here, therefore, using corrected Kofun data, the associations between the geographical variation patterns in cranial measurements for the two periods and those in environmental factors were re-estimated. As a result, it was found that the geographical variation pattern in cranial measurements from the Jomon period relatively resembled those of latitude and average annual temperature, although at the about 10% significance level (Table 2), and that the geographical variation pattern in cranial measurements from the Kofun period had a significant association with that of mean relative annual humidity at the 5% level (Table 2).

The above results may be interpreted as follows. The geographical variation pattern in cranial measurements from the Jomon period shows a trace of migration of the Jomon people in the Japanese archipelago or their adaptation to temperature in each local region, and that of the Kofun period suggests a close connection of the Kofun people with rice cultivation because it is considered that the Kofun people were agriculturalists and rice cultivation needs a wet climate. It should be noted here, however, that, although the mean relative annual humidity for Hokkaido is highest among the five regions examined (Appendix 2), the Epi-Jomon people in Hokkaido are not considered to have cultivated rice. Further, in the present preliminary study, the regions where skeletal remains were unearthed are not necessarily correspondent to those for which climatic data were collected. It must be kept in mind, therefore, that these insufficient prerequisites may be source of errors.

Q-mode path analyses

In addition to the above simple comparisons, Q-mode path analyses were carried out using a model in which the Jomon and Yayoi people were considered to be ancestors of the Kofun people. The residual variable obtained in the first Q-mode path analysis based on five Jomon and five Kofun samples (Table 6) suggests that part of the geographical variation in cranial measurements of the Kofun people may have been significantly associated with the geographical variation in annual rainfall. If this is true, it implies, again, that the Kofun people tended to inhabit waterrich regions where they could easily cultivate rice.

The second Q-mode path analysis based on six Jomon, one Yayoi, and five Kofun samples (Tables 7 and 8; Fig. 2) suggests that, in the Japanese archipelago, excluding northern Kyushu, in the Kofun period, there were four geographical clines in the contribution of supposedly ancestral populations to the Kofun people. One was due to the Tokai Jomon contribution, and may be considered a trace of immigration from south to north. Two of the clines are due to the Sanyo and Kanto Jomon contributions, and may be a trace of immigration from north to south. The final one is due to the northern Kyushu Yayoi contribution, and may be considered, again, a trace of immigration from south to north.

In the second Q-mode path analysis, the values of the residual variable for all Kofun samples were estimated as zero in practice (Table 8). Taking account of the results of the first Q-mode path analysis performed without any Yayoi samples, the residual variable of zero in the second analysis may be interpreted as follows: the variation predicted by the residual variable in the first analysis, which is highly associated with annual rainfall (Table 6), corresponds to a certain variation fraction of the cranial measurements of the northern Kyushu Yayoi sample added to the second analysis, who are considered to have been engaged in rice cultivation in wet regions.

It is also interesting that all Jomon and Yayoi local populations had almost the same estimates of path coefficients of around zero to the northern Kyushu Kofun population (Fig. 2). For this, one may consider that northern Kyushu was always a center of amalgamation of immigrants from various regions, in other words, such amalgamation had already progressed further in northern Kyushu prior to the Kofun period than in other regions of the Japanese archipelago.

Finally, it must be noted again that, in this preliminary study, at least one serious assumption was set up: climatic factors are the same in the Jomon and Kofun periods as well as in the present time. Besides, there are some other insufficient prerequisites. For example, Kondo (1994), using several Jomon samples, argued the possibility that the within-region heterogeneity of an arbitrarily pooled sample can be as large as between-region heterogeneity. Whether or not this is an artificial by-product? Furthermore, the definitions of some measurement items with the same name, e.g. upper facial height, may differ from sample to sample. In the future, taking all these problems into account, the associations between craniofacial measurements and climatic factors should be examined in more depth.

Summary and Conclusions

Preliminary Mantel's matrix permutation tests and Q-mode path analyses of seven cranial measurements suggested that the geographical variation patterns of the Jomon and Kofun periods are not significantly associated, and that the geographical variation pattern of cranial measurements of the Kofun people may be associated with a wet climate or rice cultivation.

Acknowledgments

I would like to thank Emeritus Professor Yukio Dodo of Tohoku University School of Medicine, Sendai, for his helpful suggestions and comments. I am also grateful to Salford Software Ltd. and "kito" for kindly providing their very useful software, FTN77 and CPad, respectively, via the Internet. The manuscript was copy edited by Medical English Service, Kyoto.

This work was partly supported by Grants-in-Aid for Scientific Research (S) and (C) from the Japan Society for the Promotion of Science (Project Nos. 17107006 and 22570224).

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Appendix 1. Cranial measurements of six Jomon (Middle to Final phase), one Yayoi, and five Kofun male samples.

Variable[1]	Hokkaido; Jomon[2]	Tohoku; Jomon[3]	Kanto; Jomon[4]	Tokai; Jomon[5]	Sanyo; Jomon[6]	Northern Kyushu; Jomon[7]
	Mean (*n*)	Mean (*n*)	Mean (*n*)	Mean (*n*)	Mean (*n*)	Mean (*n*)
1 Cranial length	190.2 (8)	182.8 (56)	184.1 (74)	182.7 (52)	184.2 (50)	181.2 (22)
8 Cranial breadth	148.9 (9)	143.5 (56)	144.0 (69)	144.7 (53)	144.9 (59)	145.2 (24)
17 Basi-bregmatic height	139.4 (5)	140.9 (32)	139.6 (26)	138.2 (16)	134.9 (42)	135.7 (14)
45 Bizygomatic breadth	145.7 (8)	141.0 (21)	141.2 (26)	139.9 (12)	143.9 (12)	145.5 (6)
48 Upper facial height[14]	65.9 (6)	66.7 (30)	66.7 (38)	65.4 (17)	66.7 (29)	67.0 (10)
54 Nasal breadth	26.9 (7)	27.4 (31)	26.6 (44)	26.7 (23)	26.6 (34)	28.4 (6)
55 Nasal height	49.2 (6)	50.0 (33)	49.2 (46)	48.7 (17)	49.8 (33)	50.3 (7)

Variable[1]	Northern Kyushu; Yayoi[8]	Hokkaido; Epi-Jomon[9]	Tohoku; Kofun[10]	Kanto; Kofun[11]	Sanyo; Kofun[12]	Northern Kyushu; Kofun[13]
	Mean (*n*)	Mean (*n*)	Mean (*n*)	Mean (*n*)	Mean (*n*)	Mean (*n*)
1 Cranial length	183.7 (118)	188.6 (19)	185.5 (19)	182.4 (51)	180.8 (44)	182.5 (60)
8 Cranial breadth	142.4 (117)	142.6 (20)	143.4 (18)	140.1 (53)	141.6 (46)	141.5 (48)
17 Basi-bregmatic height	137.7 (101)	144.0 (16)	137.7 (12)	137.4 (26)	134.0 (35)	135.1 (51)
45 Bizygomatic breadth	140.0 (103)	142.1 (17)	140.1 (10)	139.0 (29)	136.6 (32)	139.5 (22)
48 Upper facial height[14]	74.8 (114)	70.9 (18)	69.1 (13)	66.8 (34)	68.8 (49)	71.5 (69)
54 Nasal breadth	27.1 (117)	26.0 (18)	27.4 (17)	26.9 (37)	26.3 (53)	26.4 (71)
55 Nasal height	52.8 (116)	50.1 (19)	50.5 (15)	51.5 (35)	51.8 (53)	51.0 (81)

[1] According to Martin and Saller (1957).
[2] Southern Hokkaido (Dodo, 1986) and Funadomari (Matsumura *et al*., 2001).
[3] Tohoku (Dodo, 1986), Sanganji (Hanihara and Uchida, 1988), and Ebishima (Mizoguchi and Dodo, 2001).
[4] Horinouchi (Suzuki *et al*., 1957), Kasori (Suzuki *et al*., 1976), Kosaku (Koizumi *et al*., 1985), Kusakari (Hiramoto and Mizoguchi, 1986), Ubayama (Kondo, 1993a, b), and Nakazuma (Matsumura *et al*., 1996).
[5] Yoshiko (Kintaka, 1928), Ikawazu (Suzuki *et al*., 1972; Ehara *et al*., 1988), and Hazawa (Ikeda and Tagaya, 2000).
[6] Tsukumo (Kiyono and Miyamoto, 1926; Kanda, 1977), Ota (Imamichi, 1933), and Taishaku-Yosekura (Suzuki and Fukushima, 1976). Some of the Ota sample are derived from the Early phase.
[7] Ataka (Omori, 1960), Kakiwara (Matsuno *et al*., 1967), Hegi Cave (Naito, 1977), and Northern Kyushu excluding Goryo (Kyushu D.I.K.2K., 1988).
[8] Nakahashi (2003).
[9] Dodo and Kawakubo (2002).
[10] Goshozan Cave (Yamaguchi, 1988), Fukaado B (Ishida and Matsumura, 1991), Kumanodo (Matsumura and Ishida, 1995), Tekiana Cave (Yamaguchi and Ishida, 2000), and Yamoto (Takigawa, 2008).
[11] Southern Kanto (Suzuki, 1969).
[12] Chugoku-Setouchi (Ikeda, 1993).
[13] Northern Kyushu (Kyushu D.I.K.2K., 1988).
[14] The upper facial heights for some samples, e.g. Southern Hokkaido and Tohoku Jomon (Dodo, 1986), were measured according to Howell's (1973) method.

Appendix 2. Environmental factors for the five local areas from which cranial samples were derived.[1]

Environmental factor	Hokkaido; modern[2]	Tohoku; modern[3]	Kanto; modern[4]	Sanyo; modern[5]	Northern Kyushu; modern[6]
Latitude (°N)	43.3	38.1	35.8	34.5	33.2
Longitude (°E)	142.0	140.6	140.2	133.2	130.8
Average Annual temperature (°)	7.0	11.6	14.5	14.7	15.7
Mean relative annual humidity (%)	77.3	75.0	74.3	75.0	75.3
Annual rainfall (mm)	1152.0	1199.3	1560.3	1431.0	1806.5

[1] Tokyo-Temmondai (1980).
[2] Average of Wakkanai, Sapporo, Hakodate, and Kushiro.
[3] Average of Sendai, Yamagata, and Fukushima.
[4] Average of Mito, Choshi, Tokyo, and Yokohama.
[5] Average of Okayama and Hiroshima.
[6] Average of Fukuoka, Saga, Oita, and Kumamoto.