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Multivariate comparisons of female cranial series from the Ryukyu Islands and Japan

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Abstract Stepwise discriminant function and Mahalanobis' generalized distance analyses were applied to 29 cranial measurements in six female cranial series from the Ryukyu Islands and ten female cranial series representing modern and prehistoric Japanese and the Ainu. Two separate comparisons were made: the first compares Ryukyu Island cranial series and the second compares 16 cranial series from Japan. The results of this analysis have been used to investigate the biological relationships of the modern and near-modern indigenous inhabitants of the Ryukyu Islands and the modern and prehistoric inhabitants of Japan's main islands. These new multivariate craniometric results are similar to those reported in a previous study that utilized male craniometric data. Overall, the Ryukyu cranial series are generally closest to a cluster consisting of Yayoi, Kofun, and medieval Kamakura cranial series, suggesting these populations were influenced by immigrants from the north. Modern Japanese, Jomon, and Ainu cranial series are well differentiated from each other and from the Ryukyu series. The Jomon are closest to the Ainu, and together these two are the most differentiated groups compared. As in the male results, the female results do not support a connection between Ainu, Jomon, and Ryukyu Island series.

Key words: Ryukyus, Japan, craniometry, biodistance studies

Introduction

A recent multivariate analysis of measurements recorded in male crania (Pietrusewsky, 1999) reached a number of conclusions regarding the historical-biological relationships of the recent and earlier inhabitants of the Japanese archipelago, including the Ryukyu Islands. Among those conclusions was the demonstration of a connection among the Ryukyu Island cranial series and those representing the Yayoi, Kofun, and Kamakura periods of Japan—groups that, in turn, were well differentiated from modern Japanese, Ainu, and Jomon cranial series. The results also reiterated a relatively close connection between the Jomon and Ainu cranial series, a connection that has been demonstrated in numerous studies (e.g. Howells, 1966; Turner, 1976; K. Hanihara, 1985, 1998; Mizoguchi, 1986; Brace et al., 1989; Ossenberg, 1992; Yamaguchi, 1992; Ishida, 1996; Omoto et al., 1996; Matsumura, 2001; Dodo and Kawakubo, 2002). The absence of evidence for a close affinity between any of the Ryukyu Island cranial series and the prehistoric Jomon and modern Ainu cranial series has been supported by other work in physical anthropology (Pietrusewsky, 1996; Doi et al., 1997; Omoto and Saitou, 1997; Dodo et al. 1998).

In this new analysis, multivariate statistical procedures were applied to female crania representing virtually the identical groups from the Ryukyu Islands and the main islands of Japan investigated in Pietrusewsky (1999). The results of this female analysis are compared with the results of the earlier male analysis as well as with other studies that have examined biological relationships of the earlier and later inhabitants of the Japanese Archipelago. The approach used is model free, and measures of biological distance are used to investigate patterns of craniometric variation for assessing biological relationships and population history regardless of exact causes (Pietrusewsky, 2000).

Materials and Methods

Cranial Series from the Ryukyu Islands

Sixteen cranial series, totaling 428 female adult specimens, representing the Ryukyu Islands and the main islands of Japan, are included in this study (Table 1, Figure 1). The Ryukyu Islands cranial series includes Tokunoshima and Yoro Islands in the Amami Group; Okinawa, Gyokusendo Cave, and Kume Island in the Okinawa Group; and Sakishima Islands in the southern Ryukyus. The specimens represent modern or near-modern inhabitants of the Ryukyu Islands, and were collected at least a half century ago from traditional mortuary contexts (caves and/or rockshelters). All data were recorded by the author on two separate occasions in 1990 and 1997, respectively. Drs Hiroto Takamiya, Naomi Doi, and Mark Hudson assisted with the data collec-

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Table 1. Female cranial series

Sample (ABBREV)	No. of crania	Location[a] and number	Remarks
Ryukyu Islands			
Tokunoshima Is. (TOK)	19	KYO-19	Specimens are from Tokunoshima Island of the Amami Islands located north of the Okinawa Group in the central Ryukyu Islands.
Yoro Island (YOR)	9	KYU-9	Crania are from Yoro Island, a small island off the southern tip of Amami-Oshima Island, of the Amami Group in the central Ryukyu Islands.
Okinawa Is. (OKI)	10	KYO-10	All specimens are from the main island of Okinawa in the central Ryukyu Islands.
Gyokusendo (GYO)	17	GYO-17	All specimens were examined at the shrine at the Gyokusendo Cave, located in southeastern Okinawa. The associated pottery and other evidence suggest these remains date to the 18th century.
Kume Is. (KUM)	18	KAN-18	The specimens are from two different locations on Kume Island, an island located west of Okinawa Island: Yattchi (15) and Hiyajo (3).
Sakishima Group (SAK)	9	RYU-4; TKO-5	The specimens are from five separate islands in the Sakishima Group of the southern Ryukyu Islands: Hateruma Is. (1); Iriomote Is. (3); and Yonaguni Is. (5).
Japan-Main Islands			
Kanto Japanese (KAN)	54	CHB-23 TKO-31	A dissecting room sample of modern Japanese from the Kanto District of eastern Honshu Island. The majority of the individuals were born during the Meiji Period (1868 to 1911) and most died well before 1940. Thirty-one of the female specimens died during the Meiji Period at Yoikuin Hospital in Tokyo and were collected by Koganei.
Tohoku Japanese (TOH)	19	SEN-19	Dissecting room specimens of modern Japanese from Miyagi (16) and Fukushima (3) Prefectures, Tohoku District, northern Honshu Island. The date of death of these individuals ranges from 1901 to 1933 AD.
Edo (EDO)	55	NSM-22 TKO-33	The specimens are from the Joshinji (Tokyo) site and date to the Edo Period or approximately the 17th to mid-19th centuries.
Kamakura (KAM)	27	NSM-9 TKO-18	Specimens are from the Medieval mass burial sites of Zaimokuza and Gokurakuji in the city of Kamakura, victims of a war which occurred in 1333 AD.
Medieval Marunouchi (MAR)	15	NSM-15	Medieval Period (1338 to 1603 AD) crania from 16 temples in Marunouchi, Chiyoda-ku, Tokyo, excavated and originally described by Professor H. Suzuki.
Medieval Yamaguchi (YAM)	21	KYU-21	Medieval specimens are from the Yoshimohama site, Yamaguchi Prefecture, in southwestern Honshu Island
Kofun (KOF)	12	KYO-6 KYU-5; NSM-1	The Kofun Period follows the Yayoi Period. The traditional dates for the Kofun Period are the 4th to 6th century AD The specimens are from isolated sites on Kyushu and Honshu Islands.
Yayoi (YAY)	49	KYU-48 TKO-1	A combined sample of Yayoi specimens from Doigahama (18), Yoshimohama (2), Nakanohama (3), and Kanenokuma (14) sites in Yamaguchi Prefecture. Others are from Koura (7), Shimane Prefecture, in southern Honshu Island, and from sites in Fukuoka (3), Kaogoshima (1), and Kamagawa (1) Prefectures in Kyushu Island. The dates for the Yayoi Period are approximately 300 BC to 300 AD
Jomon (JOM)	40	TKO-15; NSM-8 KYO-10; SAP-6 KYU-1	Although Early to Late Jomon Period specimens are represented, the majority of these specimens represent Late to Latest [*ca* 3500 BP to 2000 BP]. Jomon sites located in Hokkaido (6), Tohoku (4), Kanto (3), Chubu (11), Kinki (3), Chugoku (12), and Kyushu (1) Districts are represented. The largest series is from the Tsugumo site (10) in Okayama Prefecture, Chugoku District, Honshu Island.
Ainu (AIN)	54	SAP-15; TKM-2 TKO-34; KYO-3	Skeletons collected by Koganei in 1888-89 from abandoned Ainu cemeteries in Hokkaido (Koganei 1893, 1894).

[a] CHB, Chiba University School of Medicine, Chiba; GYO, Gyokusendo Cave, Okinawa Is.; KAN, Kanegusuku Storage Room, Board of Education Cultural Division, Kanegusuku, Okinawa; KYO, Lab of Physical Anthropology, Faculty of Science, Kyoto University, Kyoto; KYU, Dept. of Anatomy, Faculty of Medicine, Kyushu University, Fukuoka; NSM, National Science Museum, Tokyo; RYU, University of the Ryukyus, Naha, Okinawa Is.; SAP, Dept. of Anatomy, Sapporo Medical College, Sapporo; SEN, Dept. of Anatomy, School of Medicine, Tohoku University, Sendai; TKM, Medical Museum, The University of Tokyo, Tokyo; TKO, The University Museum, The University of Tokyo, Tokyo.

tion on Okinawa Island in 1997. In addition to the cranial series from the Ryukyu Islands, female crania representing prehistoric, historic, and more modern Japanese (and Ainu) are included in these analyses. The sex and age of each specimen were determined by the author using standard criteria (e.g. Krogman and İşcan, 1986; Buikstra and Ubelaker, 1994).

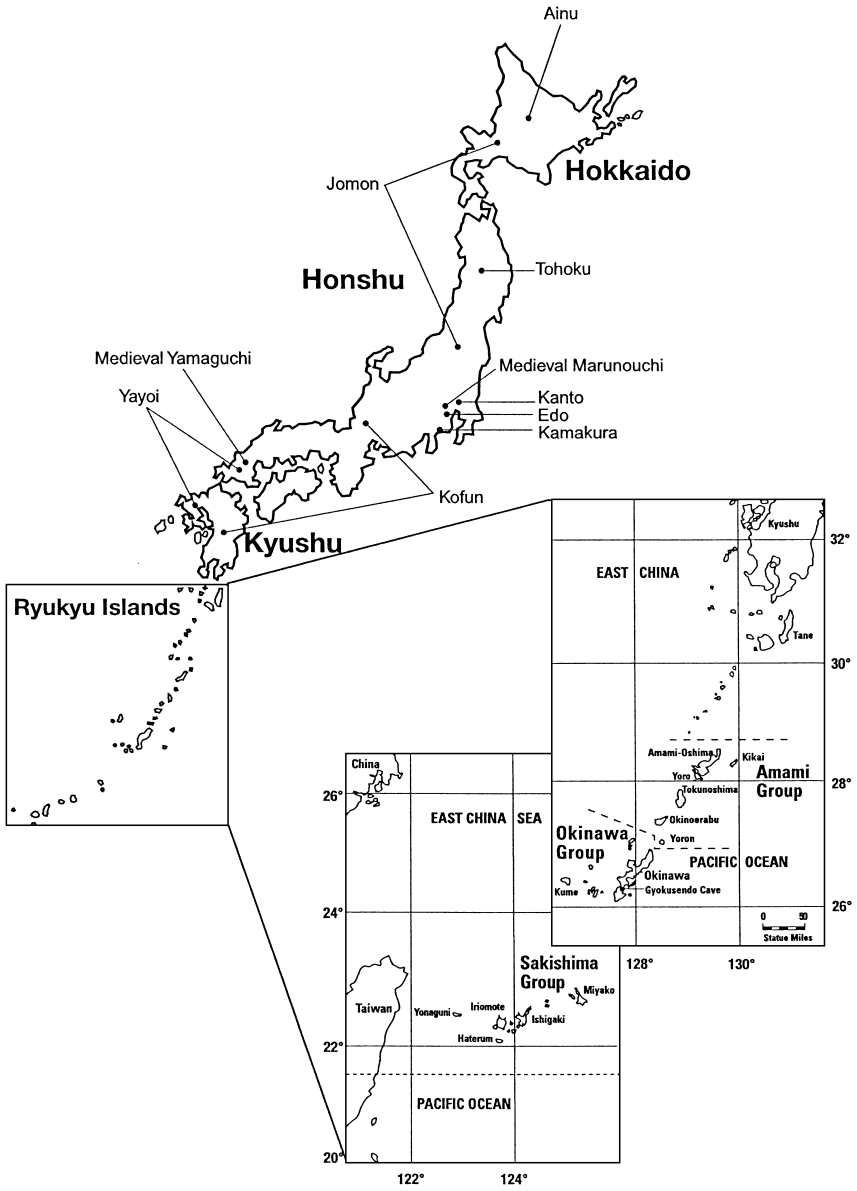

Figure 1. Map of Japan showing the geographical locations of the six Ryukyu and ten female Japanese cranial series used in this analysis.

Cranial measurements

The data consist of 29 standard craniometric landmark measurements, the largest number of variables common to all series compared. The measurements, described in Table 3 and Table 4, include linear dimensions of the cranial vault and face. Because the multivariate statistical procedures used in the present study require complete sets of data, missing measurements were replaced through stepwise regression analysis using the computer program PAM (Dixon and Brown, 1979). Since complete or nearly complete specimens were initially selected, this procedure was used sparingly.

Multivariate statistical procedures

Two multivariate statistical procedures, multiple stepwise discriminant function analysis (canonical analysis) and Mahalanobis' generalized distance (D^2), were applied to 29 cranial measurements.

The computer program BMDP-7M (Dixon and Brown, 1979) was used to perform the multiple stepwise discriminant function analysis. This program selects the original measurements to compute the linear classification functions in a stepwise manner such that, at each step, the measurement that adds the most to the separation of the groups is entered into the discriminant function in advance of the others. The first few canonical variates account for the majority of the variation among groups. In this analysis, the group means are plotted on the first three canonical variates, or functions, for interpreting intergroup relationships.

Mahalanobis' generalized distance (Mahalanobis, 1936; Mahalanobis et al., 1949) was applied to the same data analyzed by discriminant function analysis. Generalized distance analysis provides a single quantitative measure of

dissimilarity (distance) between individual groups using many variables while accounting for intercorrelations between the variables.

The significance of the distances was determined using the methods described in Rao (1952, p. 245) and Burana-rugsa and Leach (1993, p. 17). Non-significance of D^2 generally indicates that the differences are too small for detection of group differences and/or that the sample sizes are too small. The SAHN clustering method in the NTSYS-pc computer software program (Rohlf, 1993), which uses the average linkage within-group clustering algorithm (Sneath and Sokal, 1973), was used to construct the dendrograms using Mahalanobis' distances. This algorithm combines clusters such that the average distance among all cases in the resulting cluster is as small as possible. The distance between two clusters is taken to be the average distance among all possible pairs of cases between the two clusters.

Results

Two separate applications of multivariate statistical procedures to 29 cranial measurements are reported. The first analysis compares six female Ryukyu cranial series and the second analysis compares 16 female Ryukyu and Japanese cranial series. The means and standard deviations for the 29 cranial measurements recorded in 16 female Ryukyu and Japanese cranial series are presented in Table 2.

Analysis I (six Ryukyu female cranial series, 29 measurements)

Stepwise discriminant function analysis

A summary of the 29 measurements, ranked according to the *F*-values received in the final step of discriminant function analysis, is given in Table 3. Among the measurements contributing most to the discrimination are cheek height, minimum cranial breadth, orbital breadth, biauricular breadth, and bimaxillary breadth.

Eigenvalues, the percentage of total dispersion, cumulative percentage of dispersion, and level of significance for the first five canonical variates are presented in Table 4. The first three canonical variates account for 80.9% of the total variation produced. Only the first eigenvalue is significant at the 1% level.

Canonical coefficients for 29 measurements for the first three canonical variates (Table 5) indicate that the most important variables in producing group separation in the first canonical variate are orbital breadth, nasio-occipital length, maximum cranial length, and maximum frontal breadth. Orbital breadth, bifrontal breadth, bijugal breadth, and biorbital breadth are primarily responsible for the discrimination produced in the second canonical variate. Cheek height, orbital breadth, alveolar length, and maximum frontal

Table 2. Means and standard deviations (S.D.) for 29 measurements recorded in 16 female cranial series

Measurements[a]	Tokunosima (*N* = 19)		Yoro Is. (*N* = 9)		Okinawa (*N* = 10)		Gyokusendo (*N* = 17)		Kume Is. (*N* = 18)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Maximum cranial length (M-1)	172.4	4.3	173.8	4.8	173.9	5.7	173.5	7.6	171.9	4.2
Nasio-occipital length (M-1d)	171.0	4.1	172.7	4.8	172.6	5.6	171.2	6.7	170.5	4.2
Basion–nasion length (M-5)	96.5	3.5	95.8	3.7	95.9	2.4	94.4	3.7	95.2	3.5
Basion–bregma height (M-17)	131.1	3.5	128.1	5.2	128.6	3.1	130.7	4.7	130.2	4.5
Maximum cranial breadth (M-8)	133.7	4.3	135.2	4.0	134.5	3.8	137.6	5.5	136.6	5.1
Maximum frontal breadth(M-10)	112.5	4.9	114.0	3.1	111.7	4.2	114.4	4.3	115.8	3.2
Minimum frontal breadth (M-9)	91.3	4.4	91.4	2.2	88.5	3.7	91.1	3.7	90.8	3.3
Bistephanic breadth (H-STB)	108.5	4.9	109.7	3.4	106.2	5.5	109.8	5.2	110.4	3.5
Biauricular breadth (M-11b)	117.1	4.7	119.2	3.4	116.4	2.8	120.6	3.2	119.6	3.3
Minimum cranial breadth (M-14)	70.8	3.4	72.3	3.1	68.7	2.9	72.4	3.7	72.9	2.7
Biasterionic breadth (M-12)	103.5	4.2	105.4	5.2	104.1	3.3	106.6	3.1	105.4	4.6
Nasal height (H-NLH)	47.2	2.9	47.4	2.2	46.5	1.6	46.1	2.9	48.8	2.6
Nasal breadth (M-54)	24.7	1.8	24.8	1.3	23.7	1.8	23.2	2.4	24.3	1.9
Orbital height, left (M-52)	31.5	2.1	30.3	1.7	30.6	3.6	31.9	2.1	32.6	2.0
Orbital breadth, left (M-51a)	39.2	1.5	38.2	1.3	39.0	1.2	38.3	1.3	38.4	1.3
Bijugal breadth [M-45(1)]	108.3	4.2	110.0	3.6	106.2	2.6	108.4	4.0	108.6	3.9
Alveolar length (M-60)	49.2	2.6	52.3	2.3	48.1	3.2	48.3	2.2	49.6	2.3
Alveolar breadth (M-61)	60.2	3.2	61.7	4.3	59.3	2.3	59.2	1.5	59.6	3.9
Mastoid height (H-MDL)	23.1	2.2	22.9	2.5	22.5	2.1	23.6	3.0	21.8	2.4
Mastoid width (H-MDB)	17.6	1.8	17.7	2.4	18.2	2.4	17.4	2.8	16.7	2.5
Bimaxillary breadth (M-46)	95.7	4.7	98.2	3.0	93.9	2.8	95.2	4.0	94.3	3.8
Bifrontal breadth (M-43)	101.4	3.7	100.8	2.6	99.9	3.2	100.6	3.6	101.0	3.6
Biorbital breadth (H-EKB)	91.7	3.8	91.4	2.6	90.4	3.2	89.5	3.6	89.9	3.4
Malar length, inferior (H-IML)	32.2	2.4	32.4	1.9	33.0	2.4	30.4	2.5	31.6	3.7
Cheek height [H-WMH]	22.5	1.5	24.7	2.7	22.4	1.4	20.6	2.6	22.2	2.1
Nasion–bregma chord (M-29)	105.2	3.2	105.4	5.0	105.1	3.5	107.5	3.1	105.8	4.1
Bregma–lambda chord (M-30)	111.3	3.6	111.4	4.2	108.0	4.6	109.9	6.2	111.3	3.9
Lambda–opisthion chord (M-31)	95.1	4.1	96.7	4.4	93.9	3.3	95.8	5.7	94.5	4.8
Bimaxillary subtense (H-SSS)	19.8	2.5	20.8	1.9	19.4	1.6	20.6	3.1	19.4	2.5

[a] M-, Martin and Saller (1957); H-, Howells (1973).

Table 2. (continued)

Measurements[a]	Sakishima ($N = 9$)		Kanto ($N = 54$)		Tohoku ($N = 19$)		Marunouchi ($N = 15$)		Yamaguchi ($N = 21$)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Maximum cranial length (M-1)	175.9	4.0	173.1	5.9	173.8	6.0	173.9	7.7	177.9	4.7
Nasio-occipital length (M-1d)	174.1	3.8	171.9	5.8	172.0	6.2	172.4	7.1	176.0	5.0
Basion–nasion length (M-5)	95.9	3.5	95.5	3.3	96.8	4.6	97.6	2.8	98.0	4.6
Basion–bregma height (M-17)	131.9	3.8	130.2	4.6	131.1	5.1	129.9	3.7	134.1	4.9
Maximum cranial breadth (M-8)	135.2	4.8	134.6	4.7	132.7	5.2	134.0	3.0	132.3	4.8
Maximum frontal breadth (M-10)	113.9	3.9	112.8	4.9	112.4	3.5	113.6	4.3	112.9	4.3
Minimum frontal breadth (M-9)	91.9	3.4	92.0	5.2	90.9	4.2	92.4	3.0	92.8	3.0
Bistephanic breadth (H-STB)	109.2	5.1	107.9	5.3	108.1	4.9	107.9	4.7	108.4	5.5
Biauricular breadth (M-11b)	119.8	2.7	117.9	3.8	117.6	4.2	121.3	4.8	117.9	4.8
Minimum cranial breadth (M-14)	73.4	3.7	73.9	3.6	73.5	3.5	75.5	4.1	72.2	3.0
Biasterionic breadth (M-12)	107.1	4.4	104.3	3.5	104.6	2.6	104.9	3.4	105.0	3.8
Nasal height (H-NLH)	47.4	2.5	48.3	2.4	49.4	3.8	47.3	2.5	48.0	3.2
Nasal breadth (M-54)	23.9	1.9	23.7	2.0	23.8	1.8	23.4	2.1	24.0	2.0
Orbital height, left (M-52)	31.8	1.9	33.4	2.3	34.1	1.7	32.4	2.0	33.2	1.9
Orbital breadth, left (M-51a)	39.7	1.8	39.1	1.7	39.1	1.8	40.0	1.6	40.0	1.6
Bijugal breadth [M-45(1)]	108.1	4.7	107.5	4.2	107.2	4.1	109.9	3.7	109.1	4.5
Alveolar length (M-60)	49.8	2.4	49.4	3.2	49.7	2.7	50.0	3.5	51.0	3.1
Alveolar breadth (M-61)	60.4	4.8	60.2	4.3	61.1	3.7	60.3	4.1	60.8	3.9
Mastoid height (H-MDL)	23.1	2.9	23.4	3.0	22.1	2.7	21.3	2.4	23.6	2.6
Mastoid width (H-MDB)	17.1	1.8	16.8	2.1	16.7	2.7	16.9	2.4	16.9	2.0
Bimaxillary breadth (M-46)	93.0	6.7	93.2	3.8	91.8	4.9	93.7	4.2	95.4	4.8
Bifrontal breadth (M-43)	101.3	2.6	101.0	3.3	100.8	3.3	101.4	3.5	101.7	3.6
Biorbital breadth (H-EKB)	90.8	3.9	91.6	3.4	92.3	3.5	91.8	3.1	92.8	3.4
Malar length, inferior (H-IML)	31.3	3.4	30.1	4.1	30.5	3.7	34.6	2.0	33.0	3.5
Cheek height [H-WMH]	23.2	1.4	21.3	1.5	20.1	2.6	21.8	2.3	21.3	2.6
Nasion–bregma chord (M-29)	108.2	3.5	106.1	4.7	106.8	5.7	106.7	4.2	109.3	4.5
Bregma–lambda chord (M-30)	112.2	7.4	109.8	6.5	107.7	7.3	108.3	6.7	114.0	2.8
Lambda–opisthion chord (M-31)	94.7	4.4	95.5	4.6	96.6	4.8	92.6	4.1	97.4	4.4
Bimaxillary subtense (H-SSS)	19.0	3.0	21.1	2.5	21.7	2.2	17.9	2.5	20.4	2.9

[a] M-, Martin and Saller (1957); H-, Howells (1973).

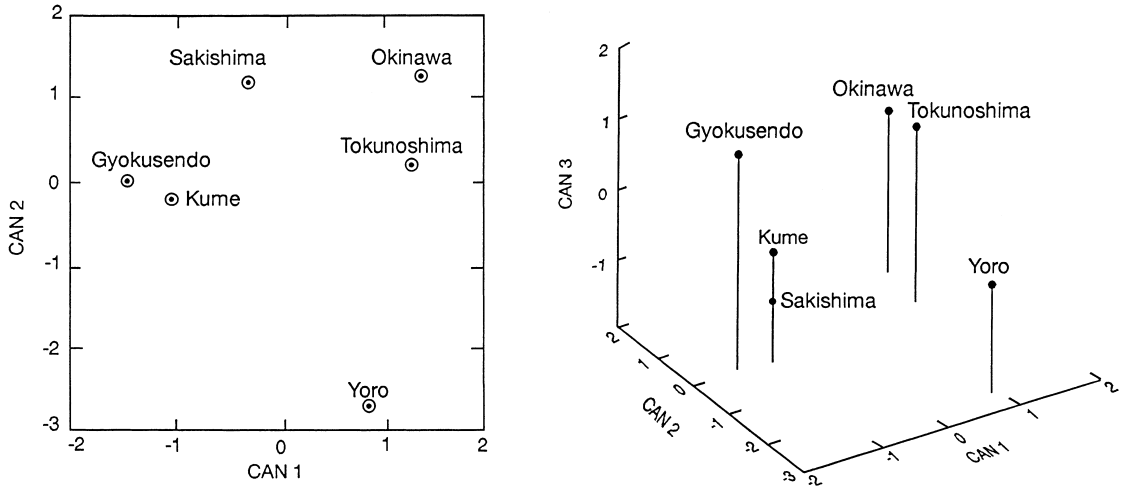

Figure 2. Plot of six female Ryukyu group means on the first two canonical variates (left) and on the first three canonical variates (right), which result from discriminant function analysis.

breadth are primarily responsible for group separation produced in the third canonical variate.

A summary of the group classification results, based on posterior probabilities (Table 6), indicates that Yoro, Gyokusendo, Kume, and Sakishima achieve the best classification results, with over 80% of the cases in these cranial series being correctly classified to their original groups. The poorest classification results are those for the Okinawa and Tokunoshima cranial series.

The jackknifed classification results (Table 7) are uniformly poor for all cranial series. Yoro, Gyokusendo, and Sakishima have the best classification results. Tokunoshima

Table 2. (continued)

Measurements[a]	Edo (*N* = 55)		Kamakura (*N* = 43)		Kofun (*N* = 12)		Yayoi (*N* = 49)		Jomon (*N* = 40)		Ainu (*N* = 54)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Maximum cranial length (M-1)	170.9	7.0	175.4	6.2	177.3	6.4	175.6	5.9	175.0	5.8	178.7	5.6
Nasio-occipital length (M-1d)	169.5	6.8	173.7	6.0	175.3	7.0	174.1	6.1	173.5	5.4	177.4	5.3
Basion–nasion length (M-5)	94.9	4.7	97.4	3.5	96.4	4.3	96.6	3.9	98.1	5.0	100.5	3.5
Basion–bregma height (M-17)	129.8	5.3	130.0	4.0	129.8	6.0	130.4	5.1	131.5	5.4	132.7	4.3
Maximum cranial breadth (M-8)	133.6	4.7	133.3	3.5	136.6	5.8	137.9	5.2	137.9	4.2	135.6	3.7
Maximum frontal breadth (M-10)	113.1	5.1	111.9	4.0	113.0	3.7	116.2	4.5	116.5	3.8	114.4	4.3
Minimum frontal breadth (M-9)	90.8	3.8	92.5	3.9	92.8	3.5	94.5	3.6	94.7	4.5	93.7	4.2
Bistephanic breadth (H-STB)	108.5	5.7	107.8	4.0	109.5	5.1	111.0	5.4	113.1	4.8	109.5	5.8
Biauricular breadth (M-11b)	117.6	4.2	118.5	5.2	121.7	5.9	123.3	4.2	120.4	3.7	118.2	4.3
Minimum cranial breadth (M-14)	73.1	3.4	72.3	4.7	75.0	3.4	74.9	3.3	73.5	4.5	74.3	3.1
Biasterionic breadth (M-12)	103.1	4.3	104.1	3.7	106.3	3.2	107.2	4.5	106.9	4.2	105.5	4.6
Nasal height (H-NLH)	47.8	2.7	47.2	2.3	48.8	2.7	49.0	2.8	46.2	2.8	47.0	2.3
Nasal breadth (M-54)	23.4	1.7	23.3	2.0	24.6	2.1	25.0	1.9	23.8	1.5	23.9	1.8
Orbital height, left (M-52)	33.8	2.1	32.1	1.8	32.7	1.2	33.2	1.6	32.5	2.2	33.2	1.6
Orbital breadth, left (M-51a)	38.7	1.7	39.1	1.9	39.7	1.7	40.3	1.8	40.6	2.2	41.0	1.9
Bijugal breadth [M-45(1)]	106.7	4.4	109.6	4.2	111.3	2.2	112.7	4.4	113.1	4.5	110.1	4.7
Alveolar length (M-60)	49.0	2.8	50.3	3.0	50.3	3.5	50.6	2.8	49.8	2.6	52.5	3.2
Alveolar breadth (M-61)	61.0	3.3	61.2	3.3	61.0	2.4	62.1	3.5	60.1	2.9	60.5	3.8
Mastoid height (H-MDL)	22.3	2.6	21.5	2.4	23.1	3.5	23.1	2.7	22.7	2.7	23.2	2.9
Mastoid width (H-MDB)	16.6	2.6	16.7	2.2	17.3	2.4	17.6	2.5	17.4	2.4	17.6	3.2
Bimaxillary breadth (M-46)	91.7	4.7	94.8	4.7	96.0	3.2	97.8	4.4	95.0	4.4	94.6	4.4
Bifrontal breadth (M-43)	99.6	3.6	100.8	3.6	102.5	3.5	104.4	3.5	103.7	3.8	102.2	3.7
Biorbital breadth (H-EKB)	90.6	3.3	91.4	3.5	94.0	3.8	95.0	3.5	95.0	3.4	93.7	3.4
Malar length, inferior (H-IML)	31.3	3.5	32.8	3.1	33.1	3.2	32.4	3.2	29.9	3.4	31.8	3.2
Cheek height (H-WMH)	21.4	1.9	22.5	2.2	23.5	2.7	23.5	2.3	21.3	1.9	21.2	2.3
Nasion–bregma chord (M-29)	105.1	4.7	106.0	3.8	106.8	5.3	108.3	4.4	106.2	4.3	108.0	4.3
Bregma–lambda chord (M-30)	108.2	5.2	190.4	5.5	110.8	5.9	109.5	5.0	111.8	4.9	109.8	5.0
Lambda–opisthion chord (M-31)	93.3	4.6	93.6	5.0	95.7	8.1	94.9	4.4	96.4	4.3	97.0	4.2
Bimaxillary subtense (H-SSS)	20.6	2.8	19.1	2.6	19.3	2.5	19.4	2.7	19.8	2.6	21.2	2.7

[a] M-, Martin and Saller (1957); H-, Howells (1973).

achieves the poorest classification results, with only 2/19 (10.5%) of its cases being correctly classified. These results reiterate the relative cranial morphological homogeneity of the female Ryukyu Island cranial series.

A plot of the group means on the first two canonical variates (Figure 2) reveals two major clusters, one which includes Tokunoshima and Okinawa, and the other which contains Gyokusendo, Kume, and Sakishima. Yoro occupies an isolated position in this diagram. A plot of the means for these same cranial series on the first three canonical variates (Figure 2), emphasizes these associations.

Mahalanobis' generalized distance

Mahalanobis' distances and tests of significance using 29 measurements and six female Ryukyu cranial series (Table 8) indicate that none of the distances are significant at the 5% level. The smallest distances are those between Tokunoshima and Okinawa (3.907), Kume and Gyokusendo (5.697), and Kume and Tokunoshima (7.600), respectively. The largest distances involve the Yoro series. The dendrogram (Figure 3) created when the UPGMA clustering algorithm is applied to these distances reveals that Okinawa and Tokunoshima occupy a single cluster as do Gyokusendo and Kume. Sakishima and Yoro occupy isolated positions in this diagram.

Analysis II (16 female cranial series, 29 measurements)

In this next analysis, stepwise discriminant function analysis and Mahalanobis' generalized distance are applied to 29 measurements recorded in 16 female Ryukyu and Japanese cranial series.

Stepwise discriminant function analysis

A summary of the 29 measurements, ranked according to the *F*-values received in the final step of discriminant function analysis (Table 9) indicates that the first 17 measurements contribute most to the discrimination produced. In this analysis, bijugal breadth, cheek height, basion-nasion length, nasal height, and biauricular breadth are ranked the highest in overall ability to discriminate.

Eigenvalues for the first 15 canonical variates (Table 10), in this analysis, indicate that the first three canonical variates

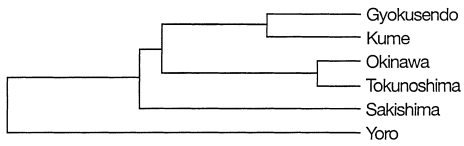

Figure 3. Diagram of relationship based on a cluster analysis (UPGMA) of Mahalanobis' generalized distances for six female Ryukyu cranial series.

Table 3. Summary ranking of cranial measurements according to *F*-values received in the final step of discriminant function analysis (six female Ryukyu cranial series, 29 measurements)

Step number	Measurement[a]	*F*-value	df_B/df_W[b]	*P*[c]
1	Cheek height [H-WMH]	5.188	5/76	*
2	Minimum cranial breadth (M-14)	3.151	5/75	n.s.
3	Orbital breadth, left (M-51a)	3.320	5/74	n.s.
4	Biauricular breadth (M-11b)	3.103	5/73	n.s.
5	Bimaxillary breadth (M-46)	3.364	5/72	*
6	Alveolar length (M-60)	2.366	5/71	n.s.
7	Nasal height (H-NLH)	1.743	5/70	n.s.
8	Nasio-occipital length (M-1d)	1.917	5/69	n.s.
9	Bregma–lambda chord (M-30)	1.401	5/68	n.s.
10	Malar length, inferior (H-IML)	1.331	5/67	n.s.
11	Basion–bregma height (M-17)	1.222	5/66	n.s.
12	Bimaxillary subtense (H-SSS)	1.219	5/65	n.s.
13	Minimum frontal breadth (M-9)	0.916	5/64	n.s.
14	Bijugal breadth [M-45(1)]	1.326	5/63	n.s.
15	Lambda–opisthion chord (M-31)	0.983	5/62	n.s.
16	Maximum cranial breadth (M-8)	1.056	5/61	n.s.
17	Bifrontal breadth (M-43)	1.065	5/60	n.s.
18	Biorbital breadth (H-EKB)	1.193	5/59	n.s.
19	Maximum frontal breadth (M-10)	0.768	5/58	n.s.
20	Bistephanic breadth (H-STB)	0.727	5/57	n.s.
21	Orbital height, left (M-52)	1.234	5/56	n.s.
22	Nasal breadth (M-54)	0.764	5/55	n.s.
23	Maximum cranial length (M-1)	0.738	5/54	n.s.
24	Alveolar breadth (M-61)	0.553	5/53	n.s.
25	Nasion–bregma chord (M-29)	0.465	5/52	n.s.
26	Mastoid width (H-MDB)	0.426	5/51	n.s.
27	Mastoid height (H-MDL)	0.426	5/50	n.s.
28	Biasterionic breadth (M-12)	0.347	5/49	n.s.
29	Basion–nasion length (M-5)	0.214	5/48	n.s.

[a] M-, Martin (1957); H-, Howells (1973).
[b] df_B/df_W = degrees of freedom between/degrees of freedom within.
[c] * $P \leq 0.01$; n.s, not significant.

Table 4. Eigenvalues, percentage of total dispersion, cumulative percentage of dispersion, and level of significance for the first five canonical variates (six female Ryukyu cranial series, 29 measurements)

Canonical variate	Eigenvalue	% dispersion	Cumulative % dispersion	*df*[a]	*P*[b]
1	1.44635	33.6	33.6	33	*
2	1.22677	28.4	62.0	31	n.s.
3	0.81526	18.9	80.9	29	n.s.
4	0.55373	12.9	93.8	27	n.s.
5	0.26809	6.2	100.0	25	n.s.

[a] *df*, degrees of freedom = $(p + q - 2) + (p + q - 4)$.
[b] $P < 0.01$ when eigenvalues are tested for significance according to criterion $[(N - 1)/2(p + q)]\log_e(\lambda + 1)$, where N = total number of crania, p = number of variables, q = number of groups, λ = eigenvalue, all of which are distributed approximately as chi-square (Rao, 1952, pp. 323); n.s., not significant.

account for 56.2% of the total variation. All eigenvalues in this table are significant at the 1% level.

Canonical coefficients for 29 measurements for the first three canonical variates are given in Table 11. Orbital breadth, bifrontal breadth, bijugal breadth, nasal height, and

Table 5. Canonical coefficients of 29 cranial measurements for the first three canonical variates (six female Ryukyu cranial series, 29 measurements)

Measurement[a]	Canonical variate 1	Canonical variate 2	Canonical variate 3
Maximum cranial length (M-1)	–0.24359	0.09890	–0.03323
Nasio-occipital length (M-1d)	0.26198	0.03448	–0.01677
Basion–nasion length (M-5)	0.09384	0.02458	0.01863
Basion–bregma height (M-17)	–0.03081	0.12060	0.04206
Maximum cranial breadth (M-8)	–0.01887	0.10805	0.10704
Maximum frontal breadth (M-10)	–0.23209	0.18585	–0.19262
Minimum frontal breadth (M-9)	0.07551	0.00422	–0.09135
Bistephanic breadth (H-STB)	0.17138	–0.19478	0.11539
Biauricular breadth (M-11b)	–0.09952	–0.23788	–0.02467
Minimum cranial breadth (M-14)	–0.18437	0.00975	–0.11349
Biasterionic breadth (M-12)	–0.04818	0.01621	–0.04428
Nasal height (H-NLH)	0.01921	–0.14591	–0.08776
Nasal breadth (M-54)	0.18468	–0.06842	0.15315
Orbital height, left (M-52)	–0.21518	0.25515	–0.03740
Orbital breadth, left (M-51a)	0.27407	0.61827	–0.33294
Bijugal breadth [M-45(1)]	–0.13600	–0.28870	0.17846
Alveolar length (M-60)	–0.00489	–0.08170	–0.27227
Alveolar breadth (M-61)	–0.01179	0.02661	–0.12988
Mastoid height (H-MDL)	0.01556	0.10495	0.03016
Mastoid width (H-MDB)	0.00745	–0.08974	0.03240
Bimaxillary breadth (M-46)	0.11256	0.00931	0.16493
Bifrontal breadth (M-43)	–0.06821	0.49839	–0.11568
Biorbital breadth (H-EKB)	0.11997	–0.26988	0.14679
Malar length, inferior (H-IML)	0.12035	–0.04201	0.08233
Cheek height [H-WMH]	0.06269	–0.02361	–0.36638
Nasion–bregma chord (M-29)	0.02631	–0.01667	–0.00389
Bregma–lambda chord (M-30)	0.01646	–0.10275	0.05344
Lambda–opisthion chord (M-31)	0.04198	–0.17575	0.04055
Bimaxillary subtense (H-SSS)	–0.10174	–0.20907	0.16588

[a] M-, Martin and Saller (1957); H-, Howells (1973).

Table 6. Summary of classification results from discriminant function analysis (six Ryukyu female cranial series, 29 measurements)

Group	OKI	TOK	YOR	GYO	KUM	SAK
Okinawa	6	3				1
Tokunoshima	3	10	1		2	3
Yoro Is.			8	1		
Gyokusendo				14	3	
Kume Is.	1	1			15	1
Sakishima	1					8
Total number of cases originally assigned	10	19	9	17	18	9
Number of cases correctly assigned	6	10	8	14	15	8
% correct assignments	60.0	52.6	88.9	82.4	83.3	88.9

Number of cases correctly classified into cranial series.

naso-occipital length (those variables with the highest coefficients regardless of sign) are the most important variables in producing group separation in the first canonical variate. Orbital height, cheek height, bijugal breadth, and minimum cranial breadth are most responsible for group separation produced in the second canonical variate. Bimaxillary breadth, malar length, biorbital breadth, and orbital height are primarily responsible for the discrimination produced in the third canonical variate.

A summary of the group classification results, based on posterior probabilities (Table 12), indicate that Yoro,

Table 7. Summary of jackknifed classification results from discriminant function analysis (six Ryukyu female cranial series, 29 measurements)

Group	OKI	TOK	YOR	GYO	KUM	SAK
Okinawa	2	5				3
Tokunoshima	6	2	3	2	3	3
Yoro Is.		1	4	2	1	1
Gyokusendo			2	7	6	2
Kume Is.	1	3	2	6	3	3
Sakishima	3	1	1	1		3
Total cases originally assigned	10	19	9	17	18	9
Number correctly assigned	2	2	4	7	3	3
% correct assignment	20.0	10.5	44.4	41.2	16.7	33.3

Number of cases correctly classified into cranial series.

Table 8. Mahalanobis' generalized distances and level of significance[a] for six female Ryukyu cranial series using 29 measurements

Group	YOR	TOK	OKI	SAK	GYO	KUM
Yoro Is.	0.000					
Tokunoshima	11.085	0.000				
Okinawa	16.796	3.907	0.000			
Sakishima	18.694	10.600	10.130	0.000		
Gyokusendo	15.092	8.888	11.256	11.314	0.000	
Kume Is.	12.598	7.600	10.229	8.783	5.697	0.000

None of the distances are significant at the 5% level when variance ratios are tested according to Rao (1952, pp. 245).

[a] Where the quantity $(n_i n_j/n_i + n_j)\ D^2_{ij}$ is distributed as chi-square with p degrees of freedom (n_i = sample size of group i; n_j = sample size of group j); D^2_{ij} = square of the generalized distance between groups i and j, and p = number of variables employed.

Table 9. Summary ranking of cranial measurements according to F-values received in the final step of discriminant function analysis (16 female Japanese cranial series, 29 measurements)

Step number	Measurement[a]	F-value	df_B/df_W[b]	P[c]
1	Bijugal breadth [M-45(1)]	7.473	15/412	*
2	Cheek height [H-WMH]	6.252	15/411	*
3	Basion-nasion length (M-5)	4.800	15/410	*
4	Nasal height (H-NLH)	5.698	15/409	*
5	Biauricular breadth (M-11b)	4.332	15/408	*
6	Minimum cranial breadth (M-14)	3.978	15/407	*
7	Malar length, inferior (H-IML)	3.493	15/406	*
8	Bimaxillary breadth (M-46)	4.594	15/405	*
9	Orbital breadth, left (M-51a)	3.506	15/404	*
10	Maximum cranial breadth (M-8)	2.897	15/403	*
11	Orbital height, left (M-52)	2.602	15/402	*
12	Alveolar length (M-60)	2.451	15/401	*
13	Biorbital breadth (H-EKB)	2.284	15/400	*
14	Bifrontal breadth (M-43)	2.463	15/399	*
15	Bregma-lambda chord (M-30)	2.160	15/398	*
16	Maximum cranial length (M-1)	2.492	15/397	*
17	Lambda-opisthion chord (M-31)	2.196	15/396	*
18	Bimaxillary subtense (H-SSS)	1.993	15/395	n.s.
19	Nasal breadth (M-54)	1.708	15/394	n.s.
20	Basion-bregma height (M-17)	1.553	15/393	n.s.
21	Maximum frontal breadth (M-10)	1.463	15/392	n.s.
22	Bistephanic breadth (H-STB)	1.763	15/391	n.s.
23	Minimum frontal breadth (M-9)	1.451	15/390	n.s.
24	Alveolar breadth (M-61)	1.410	15/389	n.s.
25	Mastoid height (H-MDL)	1.244	15/388	n.s.
26	Nasio-occipital length (M-1d)	1.164	15/387	n.s.
27	Nasion-bregma chord (M-29)	0.941	15/386	n.s.
28	Biasterionic breadth (M-12)	0.771	15/385	n.s.
29	Mastoid width (H-MDB)	0.610	15/384	n.s.

[a] M-, Martin (1957); H-, Howells (1973).
[b] df_B/df_W = degrees of freedom between/degrees of freedom within.
[c] * $P \leq 0.01$; n.s., not significant

Table 10. Eigenvalues, percentage of total dispersion, cumulative percentage of dispersion, and level of significance for the first 15 canonical variates (16 female Japanese cranial series, 29 measurements)

Canonical variate	Eigenvalue	% dispersion	Cumulative % dispersion	df[a]	P[b]
1	0.90665	27.0	27.0	43	*
2	0.57112	17.0	44.0	41	*
3	0.40853	12.2	56.2	39	*
4	0.35884	10.6	66.8	37	*
5	0.24423	7.3	74.1	35	*
6	0.19610	5.9	80.0	33	*
7	0.15484	4.6	84.6	31	*
8	0.12526	3.7	88.3	29	*
9	0.11102	3.3	91.6	27	*
10	0.08276	2.5	94.1	25	*
11	0.06343	1.9	96.0	23	*
12	0.05266	1.5	97.5	21	*
13	0.03767	1.1	98.6	19	*
14	0.02812	0.9	99.5	17	*
15	0.01768	0.5	100.0	15	*

[a] df, degrees of freedom = $(p + q - 2) + (p + q - 4)$.
[b] * $P < 0.01$ when eigenvalues are tested for significance according to criterion $[(N - 1)/2(p + q)]\log_e(\lambda + 1)$, where N = total number of crania, p = number of variables, q = number of groups, λ = eigenvalue, all of which are distributed approximately as chi-square (Rao 1952, pp. 323).

Gyokusendo, Okinawa, and Jomon achieve the best classification results, with over 70% of the cases being correctly classified to their own groups. The poorest classification results are those for Kanto, Tohoku, Yayoi, and Edo, with less than 40% of these cases being classified to their original group. Two of the Kume cases are reclassified as Kofun and two of the Sakishima specimens are classified as Yayoi.

Jackknifed classification results (Table 13) reveal a much higher percentage of misclassifications. Kofun, Kanto, Gyokusendo, Sakishima, and Okinawa register some of the poorest classification results, while Ainu and Jomon achieve the best classification results. Several of the cases originally assigned to Okinawa, Yoro, and Sakishima are reclassified as Yayoi, Kamakura, and Kofun.

A plot of the group means on the first two canonical variates (Figure 4) reveals three distinct groupings. Two medieval (Yamaguchi and Marunouchi) and three near modern Japanese series (Kanto, Tohoku, and Edo) form one of these clusters. Kofun, Yayoi, and Kamakura and six Ryukyu series form another grouping. The most isolated cluster is the one occupied by Jomon and Ainu. The plot of the means for these same groups on the first three canonical variates (Figure 4) positions the six Ryukyu series between the near modern Japanese series and a group consisting of Yayoi, Kofun,

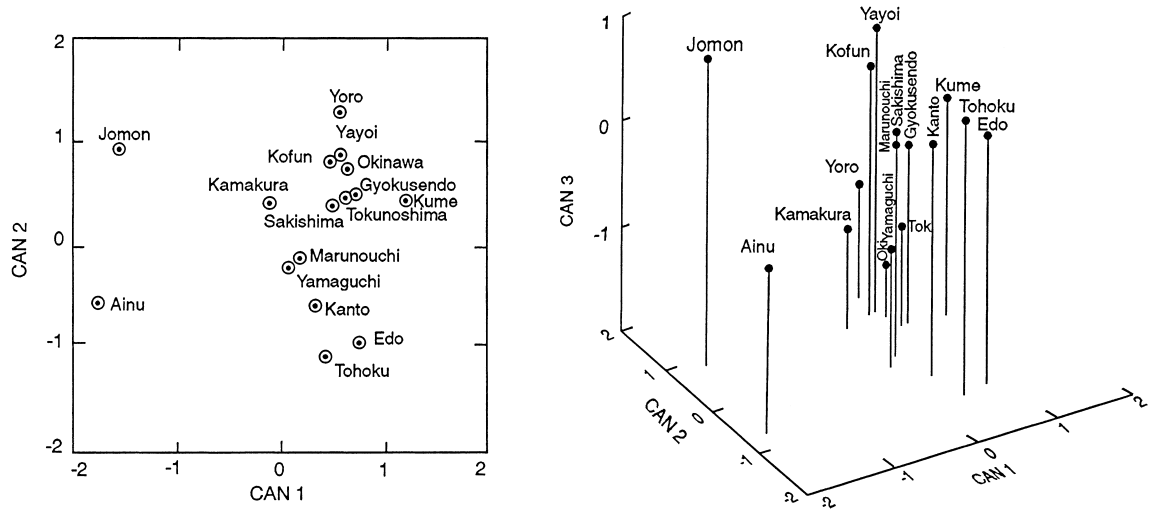

Figure 4. Plot of 16 female Japanese group means on the first two canonical variates (left) and on the first three canonical variates (right) which result from discriminant function analysis

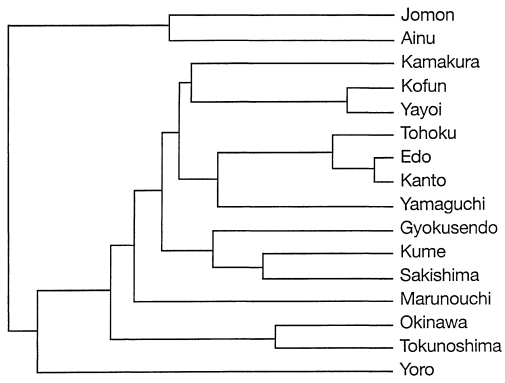

Figure 5. Diagram of relationship based on a cluster analysis (UPGMA) of Mahalanobis' generalized distances for 16 female Japanese cranial series.

and Kamakura. Kamakura is closest, in this representation, to Yoro, one of the Ryukyu series. The Jomon and Ainu cranial series again are relegated to isolated positions in the plot.

Mahalanobis' generalized distance

Mahalanobis' distances and tests of significance using 29 measurements for 16 female Ryukyu and Japanese cranial series are presented in Table 14. Applying the UPGMA clustering algorithm to the distances in Table 14 results in the dendrogram presented Figure 5 Three modern and near-modern Japanese series (Tohoku, Edo, and Kanto) and the medieval series from Yamaguchi prefecture form a separate cluster in this diagram, which then attracts a cluster that includes Kamakura, Kofun, and Yayoi. The Ryukyu Island series and the Marunouchi medieval series are grouped with these latter. The Jomon–Ainu cluster is the last to join this association.

Table 11. Canonical coefficients of 29 cranial measurements for the first three canonical variates (16 female Japanese cranial series)

Measurement[a]	Canonical variate 1	Canonical variate 2	Canonical variate 3
Maximum cranial length (M-1)	0.11541	0.03652	–0.04690
Nasio-occipital length (M-1d)	–0.15450	–0.05858	–0.00095
Basion–nasion length (M-5)	–0.14219	0.01194	–0.02334
Basion–bregma height (M-17)	0.02728	–0.08605	–0.02837
Maximum cranial breadth (M-8)	–0.06294	0.04961	–0.00848
Maximum frontal breadth (M-10)	0.01763	–0.02848	0.00177
Minimum frontal breadth (M-9)	–0.07572	–0.03831	–0.01996
Bistephanic breadth (H-STB)	–0.01552	0.02892	0.02413
Biauricular breadth (M-11b)	0.11312	0.03308	0.12175
Minimum cranial breadth (M-14)	–0.02342	–0.11488	0.06775
Biasterionic breadth (M-12)	0.02184	0.04427	0.04000
Nasal height (H-NLH)	0.16305	0.04098	0.06067
Nasal breadth (M-54)	0.13637	–0.04477	0.03172
Orbital height, left (M-52)	0.05556	–0.19565	0.014530
Orbital breadth, left (M-51a)	–0.22674	–0.05732	–0.07098
Bijugal breadth [M-45(1)]	–0.18229	0.11713	0.14234
Alveolar length (M-60)	–0.10483	–0.06170	–0.03327
Alveolar breadth (M-61)	0.04098	–0.08200	0.02939
Mastoid height (H-MDL)	0.01255	–0.02680	–0.02944
Mastoid width (H-MDB)	–0.06152	0.05207	0.01065
Bimaxillary breadth (M-46)	0.08602	0.05337	–0.18481
Bifrontal breadth (M-43)	0.19736	–0.00071	–0.11126
Biorbital breadth (H-EKB)	–0.08089	0.06347	0.15188
Malar length, inferior (H-IML)	0.11796	–0.03417	–0.15399
Cheek height [H-WMH]	0.06967	0.13501	0.00933
Nasion–bregma chord (M-29)	0.00119	0.04610	0.01050
Bregma–lambda chord (M-30)	0.01108	0.05583	–0.00323
Lambda–opisthion chord (M-31)	–0.03540	0.03465	0.00633
Bimaxillary subtense (H-SSS)	0.01405	–0.09829	–0.02946

[a] M-, Martin and Saller (1957); H-, Howells (1973).

Discussion

Comparisons of six female Ryukyu cranial series in the present analysis demonstrate close similarities with the rela-

Table 12. Summary of classification results from discriminant function analysis for 16 female Japanese cranial series, 29 measurements

Group	YAY	KAM	KOF	AIN	JOM	YAM	TOH	TOK	EDO	KAN	GYO	KUM	OKI	YOR	SAK	MAR
Yayoi	18	2	7	1	5			2	2	1	2	3		2	3	1
Kamakura	1	13	2	2	1	1		3	2						2	
Kofun	1	1	6				1		1		2					
Ainu	2	2	1	35	3	2	1		2				2	1	2	1
Jomon	1		1	4	28		1		1	2		2				
Yamaguchi		2				12		2		2				1	1	1
Tohoku		1		1			12			1	1	2			1	
Tokunoshima	1	2				2		6		2	1	1	4			
Edo	2	2	1	2	2	2	5	4	22	5	1	3	1		1	2
Kanto	2	3	2	3	1	5	7	2	7	10	4	2	2		4	
Gyokusendo					1		1			1	12					2
Kume Is.	1		2			1		1				11			2	
Okinawa								2				1	7			
Yoro Is.	1		1											7		
Sakishima	2					1			1						5	
Marunouchi						2			2		1				1	9
Total cases orig. assign.	49	27	12	54	40	21	19	20	56	52	19	16	11	8	9	15
No. correct assign.	18	13	6	35	28	12	12	6	22	10	12	11	7	7	5	9
% correct assign.	36.7	48.1	50.0	64.8	70.0	57.1	63.2	31.6	40.0	18.5	70.6	61.1	70.0	77.8	55.6	60.0

Number of cases correctly classified into cranial series.

Table 13. Summary of jackknifed classification results from discriminant function analysis for 16 female Japanese cranial series, 29 measurements

Group	YAY	KAM	KOF	AIN	JOM	YAM	TOH	TOK	EDO	KAN	GYO	KUM	OKI	YOR	SAK	MAR
Yayoi	9	2	13	1	5			3	2	1	3	4		2	3	1
Kamakura	1	10	3	3	1	1		4	2						2	
Kofun	6	2					1		1		2					
Ainu	3	2	1	28	5	1	2	1	3				3	2	2	1
Jomon	2		1	5	22		1		1	3	1	2	1		1	
Yamaguchi		2			1	7	1	2		3	1			2	1	1
Tohoku		1		2			3		4	4	1	2		1	1	
Tokunoshima	1	2				3		2		2	1	1	6	1		
Edo	3	2	1	2	2	2	8	4	17	5	1	4	1		1	2
Kanto	2	4	2	3	1	5	7	2	7	6	5	2	2	1	4	1
Gyokusendo					2	1	1	1		3	2	3		1	1	2
Kume Is.	2		2			1		1		1	4	4			3	
Okinawa	1	2						4				1	1			1
Yoro Is.	1	1	2					1	1					3		
Sakishima	2					1			1	1	2				1	1
Marunouchi	1			1		2	1		1		1	2			1	5
Total cases orig. assign.	49	27	12	54	40	23	19	21	55	54	17	18	10	9	9	15
No. correct assign.	9	10		28	22	7	3	2	17	6	2	4	1	3	1	5
% correct assign.	18.4	37.0	0.0	51.9	55.0	33.3	15.8	10.5	30.9	11.1	11.8	22.2	10.0	33.3	11.1	33.3

Number of cases correctly classified into cranial series.

tionships reported in an analysis based on male craniometric data (Pietrusewsky, 1999). As was the case in the male analysis, overall, there is a general lack of marked differentiation among the female Ryukyu cranial series, which suggests relative craniometric homogeneity for this region. A similar conclusion was reached by Dodo et al. (1998) using cranial nonmetric traits recorded in Ryukyu crania. The patterning that is found generally reflects geography and other isolating mechanisms such as genetic drift.

As was found in the analysis of male craniometric data (Pietrusewsky, 1999), the female cranial series from Gyokusendo Cave on Okinawa Island and Kume Island, an island in the Okinawa group, are closely related. Likewise, cranial series representing Okinawa and Tokunoshima (an island in the Amami group north of Okinawa), demonstrate a morphological closeness using both male and female data, and the cranial series representing the southernmost Ryukyu Islands (Sakishima) was found to be related to the cranial series from the Okinawa and Amami groups. Finally, the most isolated cranial series in both the female and male analyses is the one representing Yoro Island, a small island located off the southern tip of Amami-Oshima Island in the Amami group. The geographical isolation of this island may help to explain this result.

Turning to the results of the second analysis presented in this study, again there is broad agreement between the female results and those based on male data (Pietrusewsky, 1999). In both studies, the near-modern Japanese cranial

Table 14. Mahalanobis' generalized distances and level of significance[a] for 16 female Japanese cranial series using 29 measurements

Group	JOM	KAM	MAR	KOF	TOH	YAM	YAY	EDO	KAN	AIN	GYO	KUM	OKI	TAK	YOR	SAK
Jomon	0.000															
Kamakura	8.120*	0.000														
Marunouchi	11.459**	8.087	0.000													
Kofun	8.552	5.346	6.994	0.000												
Tohoku	9.957**	7.826	8.955	6.939	0.000											
Yamaguchi	9.904*	6.053	8.102	6.805	5.904	0.000										
Yayoi	8.052*	6.774*	5.646	2.512	7.30**	6.965**	0.000									
Edo	10.121*	6.169*	5.675	6.167	2.812	6.034**	5.206*	0.000								
Kanto	7.487*	5.638*	6.937	5.107	2.794	4.284	4.539*	1.854	0.000							
Ainu	6.428*	7.591*	7.835**	10.008**	8.870*	6.931*	9.148*	8.045*	6.124*	0.000						
Gyokusendo	9.950**	8.131	9.501	8.492	8.506	7.103	7.296	7.201**	5.184	11.758*	0.000					
Kume Is.	10.815**	8.008	6.949	6.752	7.243	7.056	4.614	4.864	4.079	11.953*	4.618	0.000				
Okinawa	14.465	7.717	10.822	9.611	13.015	10.113	8.871	9.541	9.044	12.197**	8.374	8.724	0.000			
Takunoshima	9.594**	5.273	9.244	6.536	8.048	4.072	6.024	5.583	4.152	9.433*	5.823	4.474	4.026	0.000		
Yoro Is.	12.778	7.677	12.830	7.751	13.344	9.033	7.995	10.967	9.168	13.483**	10.678	7.105	10.514	6.143	0.000	
Sakishima	9.664	7.107	5.616	5.948	8.728	6.352	4.574	5.750	4.390	8.965	6.269	4.423	8.660	5.561	9.877	0.000

[a] Where the quantity $(n_i n_j / n_i + n_j)\, D^2_{ij}$ is distributed as chi-square with p degrees of freedom (n_i = sample size of group i; n_j = sample size of group j); D^2_{ij} = square of the generalized distance between groups i and j, and p = number of variables employed.
* distances significant at 1% level, ** distances significant at 5% level.

series, Tohoku, Edo, and Kanto, are closely related. Likewise, the Kamakura, Kofun, and Yayoi cranial series form a close association that is isolated from the more modern cranial series. The marked separation of the modern Japanese cranial series since Yayoi times and the Jomon–Ainu series agrees with the general consensus among biological anthropologists that a major influx of new people arrived in the Japanese archipelago (via the Korean peninsula) beginning with the Yayoi (ca. 400 BC to 300 AD) and Kofun (4th to 7th century AD) periods. This view has been popularized as the 'dual structure model' by Kazuro Hanihara (1991).

As was demonstrated in the male analyses (Pietrusewsky, 1999), the female Ryukyu Island cranial series are also more closely related to the Kamakura, Kofun, and Yayoi cranial series than they are to the modern Japanese series. The medieval Marunouchi and Yamaguchi cranial series, while dispersed, have a tendency to associate with Ryukyu Island samples (see especially Figure 4). The separation of modern Japanese from the modern inhabitants of the Ryukyu Islands and their presumed ancestors (Yayoi, Kofun, and medieval series) may reflect changes attributable to the effects of modernization in skull form in the modern Japanese since the Yayoi period (Pietrusewsky, 1999). Likewise, the modern inhabitants of the Ryukyu Islands may have differentially retained features of skull form traceable to the Yayoi immigrants.

The Jomon and Ainu cranial series form a cluster well removed from all remaining series in both the male and female analyses. The results based on female data further indicate a close connection between Ainu and Jomon, a finding that reiterates a great many previous studies (e.g. Howells, 1966, 1986; Turner, 1976, 1990; Yamaguchi, 1982, 1992; K. Hanihara, 1985; Dodo, 1986; Mizoguchi, 1986; Brace et al., 1989; Matsumura, 1989, 2001; Kozintsev, 1990; Ossenberg, 1992; K. Hanihara et al., 1993; T. Hanihara, 1993; Ishida, 1996; Omoto et al., 1996; Pietrusewsky, 1996, 2000; Ishida and Kondo, 1999; Dodo and Kawakubo, 2002).

Neither the male or female results support an especially close affinity between the Ryukyu Island and the Ainu/Jomon cranial series, a conclusion supported by other work (e.g. Mouri, 1988; Pietrusewsky, 1994, 1996, 1997; Horai et al., 1996; Doi et al., 1997; Dodo et al., 1998). This conclusion stands in marked contrast to other studies that have suggested a Ryukyu–Ainu–Jomon connection (e.g. Baelz, 1911; Newman and Eng, 1947; K. Hanihara et al., 1974, 1986, 1991; Yamaguchi, 1982, 1992; T. Hanihara, 1989, 1991, 1992; Omoto, 1992; Matsumura, 1995; Omoto and Saitou, 1997).

Finally, the present results do not support the results reported by Brace and co-workers (e.g. Brace et al., 1989; Brace and Tracer, 1992), who claim that the Kamakura series may represent Ainu.

Conclusions

The results of this new multivariate craniometric study, based on female data, allow a number of tentative conclusions regarding the biological relationships of Ryukyu Islanders and their relationship to prehistoric and modern Japanese.

1. As was found in previous work that used male cranial series, the female Ryukyu cranial series are relatively homogeneous. The cranial series from Yoro Island, a small island in the Amami group, is the most differentiated of the Ryukyu Island series.
2. The majority of the Ryukyu cranial series are closest to the Yayoi, Kofun, and Kamakura cranial series, and are well differentiated from modern Japanese, Jomon, and Ainu cranial series. A similar finding using male data suggests that the immigrants from the north commencing during the Yayoi period, or from approximately 400 BC, influenced the inhabitants of the Ryukyu Islands.
3. Comparisons using cranial series from the Japanese archipelago, including the Ryukyu Islands, indicate that the Jomon and Ainu groups are the most differentiated groups, suggesting a separate origin for the Jomon and their presumed descendants, the Ainu.
4. There is no evidence for a close connection between

Ryukyu and the Jomon/Ainu cranial series.

A biological similarity between the Ryukyu series and those representing Yayoi, Kofun, and the medieval series from Kamakura, demonstrated by both male and female craniometric data, warrants further investigation.

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