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Taiwan Aboriginals and Peoples of the Pacific-Asia Region: Multivariate Craniometric Comparisons

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Abstract Stepwise discriminant function analysis and Mahalanobis's generalized distance are applied to twenty-nine cranial measurements recorded in 2,531 male crania representing five Taiwan aboriginal cranial series and fifty prehistoric, modern, and near modern human groups. The Taiwan aboriginal cranial series include modern samples of Atayal, Bunun, Pazeh, Babuza, and archaeological human remains from the Shi San Hang site (ca 1800–500 BP). The comparative cranial series represent East Asia, Southeast Asia, Australia, New Guinea, island Melanesia, Polynesia, and Micronesia. The results of two separate analyses, one using five and the other using fifty-five groups, are presented. A relatively close connection between the Babuza, Pazeh, and Shi San Hang aboriginal cranial series is observed while the Atayal and Bunun series remain relatively well differentiated. Connections between Taiwan aboriginal groups and cranial series from Polynesia suggest that Taiwan's aboriginal inhabitants may have been the ancestral source of these inhabitants of Remote Oceania. Similarly, these results suggest that the ultimate source of Taiwan's prehistoric and modern aboriginal groups may be among the early inhabitants of eastern (Northeast or Southeast) Asia. The results of the present craniometric analysis are compared with other lines of evidence which have been used to examine the affinities and origins of Taiwan's aboriginal peoples.

Keywords: multivariate statistics, biodistance studies, craniometry, Taiwan Aboriginals, Shi San Hang

Introduction

Of the nine best known surviving aboriginal tribes of Taiwan (Chai, 1967, 1984; Howells, 1989; Hsu, 1991), eight (Atayal, Saisiat, Bunun, Tsou, Paiwan, Puyuma, Rukai, and Ami) are generally restricted to the more mountainous regions of Taiwan. The ninth group, the Yami, inhabit Lanyu Island (Orchid Island) off the southeastern coast of Taiwan. Taiwan's aboriginal peoples exhibit varying degrees of acculturation with the Han Chinese who began immigrating to Taiwan in the 12th century A.D. (Chai, 1967). Many of the aboriginal groups that lived along Taiwan's western coast

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experienced more acculturation than those living in the mountainous interior and the island's eastern coast. Taiwan aboriginal languages are extremely well differentiated (Li, 1990), several are now extinct (Sung, 1989). Formosan languages are ancient members of the Austronesian language family, speakers of which are found living from Madagascar to Easter Island (Blust, 1995).

In addition to the linguistic and cultural differentiation, the Taiwan aboriginals exhibit considerable biological variation. Taiwan's living aboriginals possess morphological features that are typical of East Asians including darkly pigmented, straight, coarse hair; pale yellow to brown skin color, darkly pigmented eyes, concave nasal bridges, medium thick lips, short stature, and, occasionally, the possession of an epicanthic eye fold (Chai, 1967, 1984). Head form among Taiwan's aboriginal groups is classified as brachycephalic (broad). Other biological traits, including anthropometric traits, dermatoglyphic patterns, and genetic polymorphic traits (e.g., PTC and ABO blood groups) are reported by Chai (1967, 1984). There are biological differences among these aboriginal groups, the Bunun, for example, are typically characterized as being the shortest and most darkly pigmented of the aboriginal groups (Chai, 1967; Ferrell, 1969: 35). According to Lien (1989: 176), tooth ablation was widely practiced among prehistoric and living Taiwan aboriginal groups.

Although southern China and northern Indochina have been suggested as possible source populations (Goddard, 1966), the exact origins of Taiwan's aboriginal groups are not known. Archaeological evidence suggests that Taiwan's aboriginal peoples may have inhabited the island since at least 6000–3000 B.C. (Bellwood, 1997; Chang, 1970; Pearson, 1989). This is more than sufficient time to account for the physical and linguistic diversity observed in the surviving, or recently surviving, aboriginal tribes. While archaeological evidence suggests that Taiwan was inhabited by other people before the arrival of the first aborigines, there is little direct support for the existence of an earlier so-called negrito population in Taiwan prior to their arrival.

There have been very few dental or craniological studies of Taiwan aborigines. The majority of the previous work (e.g., Chang, 1949; Howells, 1983, 1986, 1989; Kanaseki, 1952; Tokitsu, 1960; Turner, 1987; Turner and Lien, 1984) utilized a single cranial series representing the Atayal collected by Takeo Kanaseki following the so-called Wushei incident.

The use of craniometric data for reconstructing biological relatedness between and within populations, past and present, has a long history in studies of physical anthropology (see, e.g., Pietrusewsky, 2000; Van Vark and Howells, 1984). Along with cranial nonmetric traits, this category of variation occupies a prominent position in biodistance studies (Larsen, 1997: 305–306). While subject to environmental and non-genetic influences, craniometric variation is generally viewed as reflecting genetic similarity (Buikstra et al., 1990). The precision and repeatability of measurement techniques, the conservative nature of this category of variation, the direct link with the past, demonstration of a genetic component (e.g., Cheverud et al., 1979; Sjøvold, 1984), improvements in statistical method, and breakthroughs in evolutionary and population biology theories are responsible for this continued interest. Although some studies (e.g., Devor, 1987) has reported relatively low heritability estimates for cranial measurements, this is of little consequence provided environmental variation is random (Larsen, 1997: 304). The demonstration by Relethford (1994) that genetic and craniometric data are in general agreement in assessing the variation in modern humans lends further support for the use of cranial measurements in biodistance studies. Multivariate comparisons provide one of the most objective means now available for comparing human groups and measuring biological relatedness.

In this paper, the biological relationships of Taiwan's aboriginal groups and cranial series from eastern Asia and the Pacific are investigated using multivariate statistical procedures. Stepwise discriminant function analysis and Mahalanobis' generalized distance are applied to measurements recorded in human crania. The approach used is model free, measures of biological distance and discriminant function analysis are used to evaluate patterns of craniometric variation, which, in turn, are used to reconstruct the evolutionary history and possible origins of these groups. Alternative models and the justification for using model free approaches are discussed in Pietrusewsky (2000: 384). The present study expands on earlier work (e.g., Pietrusewsky, 1994, 1995, 1997, 1999, 2000) by including four new Taiwan aboriginal cranial series not included in these earlier comparisons.

Materials

Taiwan Aboriginal Cranial Series

One hundred and twenty-five male crania representing five Taiwan aboriginal groups are used in the present study (Table 1). The Atayal cranial series has been used in previous craniometric investigations by several researchers (e.g., Howells, 1983, 1984, 1989, 1990, 1995; Pietrusewsky, 1994, 1995, 1997, 1999, 2000; Pietrusewsky and Ikehara-Quebral, 2001). The majority of the series is from a single location on the southern edge of Atayal territory, victims who were slain by Japanese-recruited Aboriginal militias in retaliation for an earlier head taking incident, known as the Wushe Incident (Howells, 1989: 109). These specimens have been housed at the National Taiwan University and Academia Sinica, Taipei, since their initial collection. Measurements of the Atayal crania were recorded by Pietrusewsky in 1983 and 1991.

Shi San Hang is a village site located on the northeastern coast of Taiwan, near the modern city of Pa-li, Taipei Prefecture (Fig. 1). The site was occupied between approximately 1800 and 500 years B.P., or just within the prehistoric Taiwan Iron Age (Tsang and Liu, 2001). Many cultural parallels between the prehistoric inhabitants of Shi San Hang and the now extinct plains-dwelling Ketagalan and Kavalan aborig-

Table 1. Fifty-five male cranial series

Sample (abbrev.)	No. of Crania	Location[a] and Number	Remarks
Taiwan Aboriginal			
Atayal (ATY)	36	TPE-28; TKM-7; TKO-1	The Atayal are the second largest surviving Aboriginal tribe in Taiwan. The specimens in Taipei are Atayal slain in the Wushe incident in 1930, collected by T. Kanaseki in 1932 (Howells, 1989:109).
Shi San Hang (SSH)	13	NTU-13	Thirteen of the most complete male skulls excavated at the Shi San Hang site (ca 1800–500 BP) near Taipei. Measurements were recorded by Chang (1993).
Bunun (BUN)	26	NTU-26	The near modern Bunun specimens are curated in the Department of Anatomy, National Taiwan University; measurements recorded by Chang (1993).
Babuza (BAB)	29	NTU-29	The near modern Babuza specimens are curated in the Department of Anatomy, National Taiwan University; measurements recorded by Chang (1993).
Pazeh (PAZ)	21	NTU-21	The near modern Pazeh specimens are curated in the Department of Anatomy, National Taiwan University; measurements recorded by Chang (1993).
East Asia Shanghai (SHA)	50	SHA-50	The specimens are mostly from post-Qing (post-1911) cemeteries in Shanghai.
Hangzhou (HAN)	50	SHA-50	The sample represents near modern crania exhumed in the modern city of Hangzhou, Zhejiang Province, eastern China.
Nanjing (NAN)	49	SHA-49	The sample represents near modern crania exhumed from the modern city of Nanjing, Jiangsu Province, eastern China.
Chengdu (CHE)	53	SHA-10; CHE-43	A majority of these specimens date to the Qing Dynasty (A.D. 1644–1911) and are from Chengdu, Sichuan Province in western China. Ten crania are from Leshan, Lizhong County, Sichuan Province.
Hong Kong (HK)	50	HKU-50	Specimens represent individuals who died in Hong Kong between 1978–1979.
Anyang (ANY)	56	TPE-56	Bronze-age (11th century B.C.) Shang Dynasty sacrificial victims excavated at Anyang in northern Henan Province, northern China (Li, 1977).
Taiwan Chinese (TAI)	47	TPE-47	Modern Chinese living in Taiwan who trace their immediate origins to Fujian and Guangdong Provinces on mainland China.

Table 1 (continued)

Sample (abbrev.)	No. of Crania	Location[a] and Number	Remarks
Hainan Island (HAI)	47	TPE-47	Near modern Chinese immigrants originally from the Canton region of China who began arriving around 200 B.C. (Howells, 1989:108). This material was excavated by T. Kanaseki in Haikou City on Hainan Island.
Manchuria (MAN)	50	TKO-50	Many of the specimens are from northeastern China or the region formerly referred to as "Manchuria," which today includes Heilongjiang and Jilin Provinces and adjacent northern Korea. A great many of these specimens are identified as soldiers, or cavalrymen, who died in battle in the late 19th century A.D.
Korea (KOR)	32	KYO-7; SEN-3, TKM-2; TKO-20	Specific locations in Korea are known for most of these near modern specimens.
Mongolia (MOG)	50	SIM-50	The skulls are identified as coming from Ulaanbaatar (Urga), Mongolia which were purchased by A. Hrdlička in 1912.
Kanto Japanese (KAN)	50	CHB-50	A dissecting room population of modern Japanese from the Kanto District of eastern Honshu Island. The majority of the individuals were born during the Meiji period (1868–1911) and most died well before 1940.
Tohoku Japanese (TOH)	53	SEN-53	Dissecting room specimens of modern Japanese from the Tohoku District in northern Honshu Island.
Kyushu Japanese (KYU)	51	KYU-51	Modern Japanese which derive mostly from Fukuoka Prefecture in Kyushu Island. Other specimens are from Yamaguchi, Saga, Nagasaki and adjoining prefectures.
Edo (EDO)	55	NSM-52	The specimens are from the Joshinji (Tokyo) site which date to the Edo Period, or approximately the 17th to mid-19th centuries.
Kamakura (KAM)	52	NSM-9; TKO-43	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.
Kofun (KOF)	62	KYO-5; KYU-53; NSM-4	The specimens are from sites that date from approximately the third to the sixth century A.D., the traditional dates for the Kofun Period in Japan (Akazawa 1983: 3).

Table 1 (continued)

Sample (abbrev.)	No. of Crania	Location[a] and Number	Remarks
Yayoi (YAY)	62	KYU-62	A combined sample of Yayoi specimens from Doigahama (39), Yoshimohama (14) and Nakanohama (2) sites in Yamaguchi Prefecture. The remaining specimens (7) are from Koura, Shimane Prefecture, in southern Honshu Island. The dates for Yayoi Period in Japan are approximately 300 B.C. to 300 A.D. (Akazawa 1983: 3).
Jomon (JOM)	51	TKO-16; NSM-19 KYO-15; SAP-1	All specimens represent Late to Final (ca 2500 B.C.–300 B.C.) Jomon Period (Akazawa 1983: 3) sites on Honshu Island. The largest series are Ebishima (11) in Iwate Prefecture in Tohoku District, and Tsukumo (12), Okayama Prefecture in the Chugoku District.
Ainu (AIN)	50	SAP-18 TKM-5 TKO-27	Modern to near modern skeletons collected by Koganei in 1888–89 from abandoned Ainu cemeteries in Hokkaido (Koganei 1893–1894).
Ryukyu Islands (RYU)	62	KYU-34; KYO-18 TKO-10	Near modern specimens are from the Sakishima (13), Okinawa (13) and Amami (49) Island groups, respectively. Six more are identified only as Ryukyu Island.
Mainland Southeast Asia			
Vietnam (VTN)	49	HCM-49	Near modern crania are from Hanoi (Van Dien Cemetery) and Ho Chi Minh City.
Bachuc (BAC)	51	BAC-51	Victims of the 1978 Khmer Rouge massacre in Bachuc Village in western Angiang Province, Vietnam.
Cambodia & Laos (CAM)	40	PAR-40	A combined sample of modern and near modern crania from various locations in Cambodia and Laos collected between 1877 and 1920.
Thailand (THI)	50	SIR-50	Most of the crania represent dissecting room specimens from Bangkok.
Island Southeast Asia			
Philippines (PHL)	28	BER-9; DRE-19	Most of the crania represent near modern specimens from Luzon Island.
Lesser Sundas (LSN)	45	BAS-5; BER-6; BLU-2; CHA-1; DRE-17; LEP-1; PAR-6; ZUR-7	These near modern crania are from Bali, Flores, Sumba, Lomblem, Alor, Timor, Wetar, Leti and Barbar Islands.

Table 1 (continued)

Sample (abbrev.)	No. of Crania	Location[a] and Number	Remarks
Borneo (BOR)	34	BER-2; BRE-2; DRE-6; FRE-4; LEP-8; PAR-12	A great many of these near modern specimens are indicated as representing Dayak tribes, some have elaborate decorations.
Sulawesi (SLW)	41	BAS-7; BER-10; DRE-4; FRE-7; LEP-5; PAR-8	These near modern specimens are from several different locations in Sulawesi.
Java (JAV)	50	BER-1; BLU-8; CHA-9; DRE-1; LEP-24; PAR-7	Near modern crania were collected from several different localities in Java.
Sulu (SUL)	38	LEP-1; PAR-37	The specimens in Paris were collected by Montano-Rey circa 1900, they represent mostly near modern crania.
Polynesia			
Easter Island (EAS)	50	BER-5; DRE-9; PAR-36	Most of the crania in Paris were collected by Pinart in 1887 at Vaihu and La Perouse Bay on Easter Island. The exact dates of these specimens are not known.
Hawaii (HAW)	49	BPB-49	Specimens represent prehistoric (pre-1778) Hawaiians from Mokapu, Oahu Island.
Marquesas (MRQ)	63	PAR-49; LEP-1; BLU-1; BPB-12	Crania are from four islands, Fatu Hiva, Tahuata, Nuku Hiva and Hiva Oa. The exact dates for these specimens are not known.
New Zealand (NZ)	50	BRE-3; PAR-21; SAM-1; AIM-13; GOT-1; ZUR-5; DRE-6	A representative sample of Maori from North and South Islands of New Zealand. The exact dates for these specimens are not known.
Tahiti (TAH)	44	PAR-33; BPB-11	Crania are from the island of Tahiti, Society Islands. The exact dates for these specimens are not known.

Table 1 (continued)

Sample (abbrev.)	No. of Crania	Location[a] and Number	Remarks
Micronesia			
Guam (GUA)	46	BPB-42; PAR-4	Most of the specimens in the Bishop Museum were collected by H.G. Hornbostel at Tumon Beach on Guam during WWII. The majority of these specimens represent prehistoric (pre-1521) Chamorro.
Caroline Islands (CAR)	24	TKO-7; DRE-9; PAR-4; GOT-3; AMS-1	Specimens are from Kosrae (1), Pohnpei (6) and Chuuk (Truk) (7). The exact dates for these specimens are not known.
Melanesia			
Admiralty Islands (ADR)	50	DRE-20; GOT-9; CHA-6; TUB-15;	Specimens from Hermit, Kaniet and Manus Islands. The exact dates for these specimens are not known.
Vanuatu (VAN)	47	BAS-47	Most of the specimens were collected by F. Speiser in 1912 from Malo, Pentecost and Espirtu Santo Islands. The exact dates for these specimens are not known.
Fiji (FIJ)	32	BER-1; AMS-3; PAR-8; QMB-1; DRE-4; SAM-3; FRE-3; CHA-1; BPB-8	Crania are from all major islands including the Lau Group in the Fiji Islands. The exact dates for these specimens are not known.
New Britain (NBR)	50	CHA-20; DRE-30	The specimens in Dresden were collected by A. Baessler in 1900, those in Berlin were collected by R. Parkinson in 1911. The exact dates for these specimens are not known.
Sepik R. (SEP)	50	DRE-33; GOT-10; TUB-7	The specimens in Dresden were collected by O. Schlaginhaufen in 1909. The exact dates for these specimens are not known.
Biak Islands (BIK)	48	DRE-48	Most (45) of the specimens were collected by A.B. Meyer in 1873 on Biak Island (Mysore) in Geelvink Bay, Irian Jaya. The exact dates for these specimens are not known.

Table 1 (continued)

Sample (abbrev.)	No. of Crania	Location[a] and Number	Remarks
New Ireland (NIR)	53	AMS-4; BER-2; BLU-6; DRE-18; GOT-15; QMB-1; SAM-6; TUB-1	The crania in Dresden were mostly collected by Pöhl in 1887–1888 from one end of the island; the specimens in Göttingen were collected during the Südsee Expedition in 1908. The exact dates for these specimens are not known.
Australia / Tasmania			
Murray R. (MRB)	50	AIA-39; DAM-11	These near modern crania were collected by G.M. Black, between 1929–1950, along the Murray River (Chowilla to Coobool) in New South Wales.
New South Wales (NSW)	62	AMS-21; DAS-41	These near modern specimens are from coastal locations in New South Wales.
Queensland (QLD)	54	AMS-21; DAS-3; QMB-30	This sample of near modern crania is from the southern and middle-eastern regions of Queensland.
Northern Territory (NT)	50	AIA-4; AMS-3; MMS-1; NMV-38; QMB-1; SAM-3	Near modern crania are from Port Darwin (39) and Arnhemland (36).
Tasmania (TAS)	26	THM-22; CHA-1; SAM-2; NMV-1	The near modern crania represent Tasmanian Aborigines.

[a] AIA = Australian Institute of Anatomy, Canberra, Australia
AIM = Auckland Institute and Museum, Auckland, New Zealand
AMS = The Australian Museum, Sydney, Australia
BAC = Bachuc Village, Angiang Province, Vietnam
BAS = Naturhistorisches Museum, Basel, Switzerland
BER = Museum für Naturkunde, Berlin, Germany
BLU = Anatomisches Institut, Universität Göttingen, Göttingen, Germany
BPB = B. P. Bishop Museum, Honolulu. USA
BRE = Über-see Museum, Bremen, Germany
CHA = Anatomisches Institut der Chairté, Humboldt Universität, Berlin, Germany
CHB = Chiba University School of Medicine, Chiba, Japan
CHE = Dept. of Anatomy, Chengdu College of Traditional Chinese Medicine, Chengdu, China

DAM = Dept. of Anatomy, University of Melbourne, Melbourne, Australia
DAS = Dept. of Anatomy, University of Sydney, Sydney, Australia
DRE = Museum für Völkerkunde, Dresden, Germany
FRE = Institut für Humangenetik u. Anthropologie, Universität Freiburg, Freiburg, Germany
GOT = Institut für Anthropologie, Universität Göttingen, Göttingen, Germany
HCM = Faculty of Medicine, Ho Chi Minh City, Vietnam
HKU = University of Hong Kong, Hong Kong
KYO = Laboratory of Physical Anthropology, Faculty of Science, Kyoto University, Kyoto, Japan
KYU = Dept. of Anatomy, Faculty of Medicine, Kyushu University, Fukuoka, Japan
LEP = Anatomisches Institut, Karl Marx Universität, Leipzig, Germany
MMS = Macleay Museum, University of Sydney, Sydney, Australia
NSM = National Science Museum, Tokyo, Japan
NMV = National Museum of Victoria, Melbourne, Australia
NTU = Dept. of Anatomy, National Taiwan University, Taipei, Taiwan
PAR = Musée de l'Homme, Paris, France
QMB = Queensland Museum, Brisbane, Australia
SAM = South Australian Museum, Adelaide, Australia
SAP = Dept. of Anatomy, Sapporo Medical College, Sapporo, Japan
SEN = Dept. of Anatomy, School of Medicine, Tohoku University, Sendai, Japan
SHA = Institute of Anthropology, College of Life Sciences, Fudan University, Shanghai, China
SIM = National Museum of Natural History, Smithsonian Institution, Washington, D.C., USA
SIR = Dept. of Anatomy, Siriraj Hospital, Bangkok, Thailand
THM = Tasmanian Museum and Art Gallery, Hobart, Tasmania, Australia
TKM = Medical Museum, University Museum, University of Tokyo, Toyko, Japan
TKO = University Museum, University of Tokyo, Tokyo, Japan
TPE = Academia Sinica, Nankang, Taipei, Taiwan
TUB = Institut für Anthropologie u. Humangenetik, Universität Tübingen, Tübingen, Germany
ZUR = Anthropologisches Institut, Universität Zürich, Zürich, Switzerland

inal tribes of northern Taiwan have been noted by previous observers (e.g., Yang, 1961). The human skeletal remains from the Shi San Hang site near Taipei have been examined by Chang (1993) and, more recently by Pietrusewsky (Pietrusewsky and Tsang, 2003). The cranial measurements used in the present study were recorded by the second author in thirteen of the most complete male crania from this site.

The remaining three aboriginal cranial series used in this study are from collections in the Department of Anatomy, National Taiwan University Medical School, Taipei. The cranial measurements representing these three series were recorded by Chang (1993) for her M.A. thesis. Two of these series, Pazeh and Babuza, represent extinct or nearly extinct tribes while the Bunun, the fourth largest group of surviving Taiwan aboriginals, represent one of the better known and least acculturated aboriginal groups. Today, the Bunun are largely confined to the central mountainous interior of Taiwan, generally living at high (4000 to 6000 feet) altitudes.

According to Ferrell (1969), the Pazeh no longer exist as a distinct ethnic group

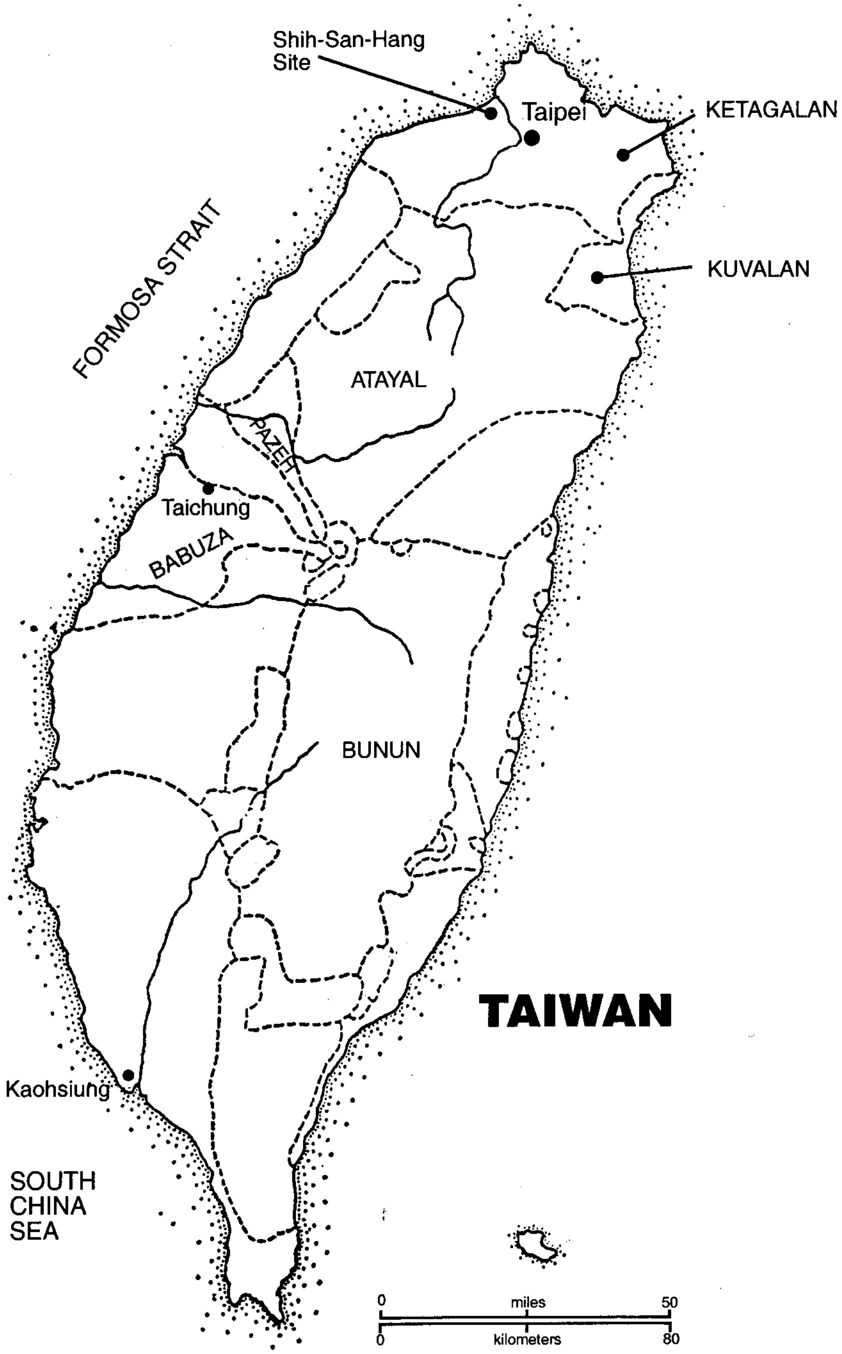

Figure 1. Map of Taiwan showing the location of the Shi San Hang site, some of the major Taiwan aboriginal languages that correspond to the aboriginal cranial series used in the present study, and two other languages, Ketagalan and Kuvalan, mentioned in the text. This map is based on the linguistic atlas of Formosan languages found in Sung (1989:38).

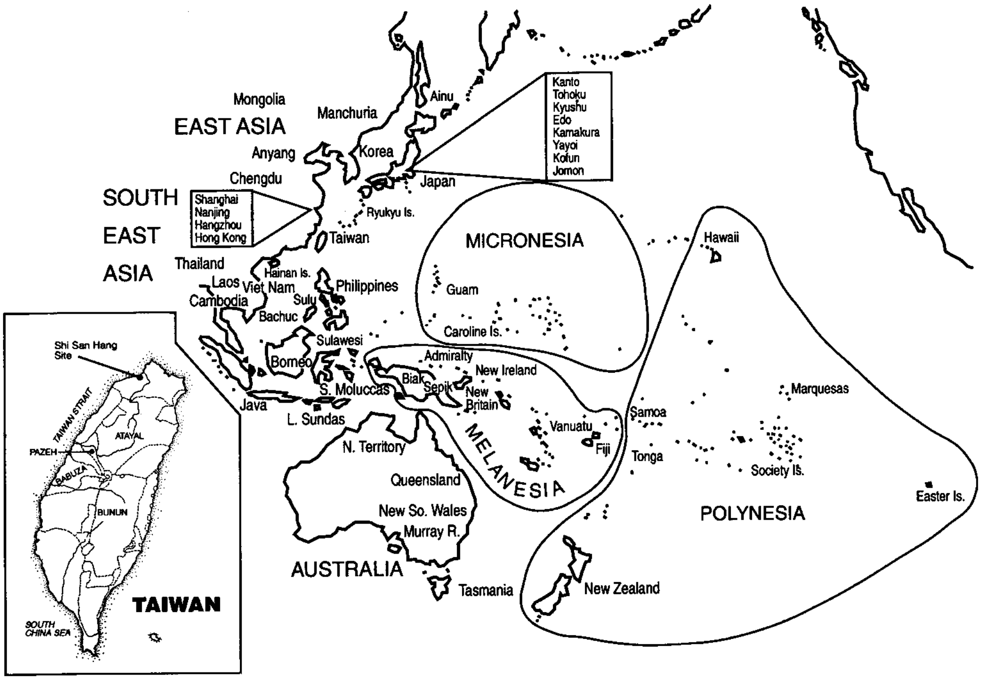

Figure 2. Map showing the approximate location of the Taiwan aboriginal and comparative male cranial series.

but, when documented, this language was spoken by several hundred persons in scattered households and villages in the P‘uil area in west central Taiwan. Former speakers of the Babuza (Favorlang) language (now extinct) were confined to an area on the central western coast of Taiwan surrounding the modern day city of Taichung. The skulls representing these two aboriginal groups were collected from villages where known speakers of these languages lived. The approximate locations of these aboriginal groups, based on a classification of Formosan languages, are indicated on the accompanying map (Fig. 1).

Comparative Cranial Series

In addition to the Taiwan aboriginal cranial series, fifty cranial series representing 2,406 male crania from Polynesia, Micronesia, Melanesia, Australia, Indonesia, Southeast Asia, East Asia and North Asia are used in the present study. The number of crania measured, the location of the specimens, and other information for each series are given in Table 1. The majority of the samples represent museum specimens of near modern, historic, and prehistoric crania. The prehistoric cranial series include Anyang, Jomon, Yayoi, and Kofun. The approximate location of these cranial series is shown in Fig. 2. All comparative data were recorded by Pietrusewsky.

Cranial Measurements

The use of cranial measurements as a source of taxonomic information has along history in physical anthropology (see e.g., Pietrusewsky, 2000). Twenty-nine cranial measurements used in this study, the largest number common to the series being compared, follow the methods of Martin and Saller (1957) and Howells (1973). These measures, which have served as the basic database for multivartiate analysis by Pietrusewsky since 1969, register a relatively broad and representative range of variation in the cranial vault and face. Most of the measurements in this set are linear measures but three chord and one subtense measurement are also represented. The battery of measurements used in this study is typical of multivariate analyses (e.g., Howells, 1989). Additional information on these measurements is given in Table 2. Missing measurements were replaced with regressed values obtained through stepwise regression analysis using the computer program, PAM, of the UCLA Biomedical Computer P-Series (Dixon and Brown, 1979). Because complete or nearly complete specimens were initially selected, very few measurements were actually replaced using this method.

Multivariate Statistics

Two multivariate statistical procedures, stepwise discriminant function analysis and Mahalanobis' generalized distance, are used in this study.

Stepwise Discriminant Function Analysis

The major purpose of discriminant function, or canonical, analysis is to maximize differences between two groups, which is mathematically achieved by producing a new set of variables, referred to as discriminant functions, or canonical variates, from the original measurements (Tatsuoka, 1970). Typically, the first few functions, or canonical variates, account for most of the variation among the groups. In this analysis, the original measurements were selected in a stepwise manner such that, at each step, the measurement that added most to the separation of the groups was the one entered into the discriminant function in advance of the others (Dixon and Brown, 1979). Variables most responsible for the observed differentiation are further identified by this multivariate procedure. Interpretation of discriminant functions and the patterns of group separation is based on an inspection of standardized canonical coefficient values.

At the end of the stepping process, this statistical procedure further reclassifies each individual specimen into one of the original groups based on the several discriminant scores it receives through the calculation of posterior (regular classification) and/or typicality (jackknifed classification) probabilities (Van Vark and Schaafsma, 1992). Jackknifed classification, where cases are classified without using misclassified individuals in computing the classification function, represents a common cross-validation procedure in multiple discriminant analysis. The 'correct' and 'incorrect' classification results provide a general guide for assessing the homogeneity or heterogeneity of the original series. Only jackknifed classification results will be presented. Another useful feature of discriminant function analysis is that it allows group means to be plotted on the first few canonical variates, thus allowing visualization of intergroup relationships. The computer program, BMDP-7M (Dixon and Brown, 1979), was used to perform the stepwise discriminant function analysis. The two-dimensional and three-dimensional plots were made using SYGRAPH found in the SYSTAT programs for personal computer (Systat, 1992).

Mahalanobis' Generalized Distance

Mahalanobis' generalized distance (Mahalanobis, 1936) was applied to the same data analyzed by discriminant function analysis. Generalized distance, or the sum of squared differences, provides a single quantitative measure of dissimilarity (distance) between groups using several variables while removing the correlation between the variables (Mahalanobis, 1936). The significance of the distance was determined using the method of Rao (1952), a method which uses variance ratios (Buranarugsa and Leach, 1993).

Using the SAHN clustering method in the NTSYS-pc computer software program (Rohlf, 1993), the average linkage within group (Unweighted Pair Group Method Algorithm (UPGMA) clustering algorithm (Sneath and Sokal, 1973), was used to construct the diagrams of relationship, or dendrograms, based on Mahalanobis' distances. This algorithm combines clusters so that the average distance between all cases in the resulting cluster is as small as possible and the distance between two clusters is taken to be the average between all possible pairs of cases in the cluster.

Removal of the Size Based Component: Z-Scores and C-Scores

Several researchers (e.g., Brace and Hunt, 1990; Brace and Tracer, 1992; Howells, 1989) have advocated the use of C-scores as a way to compensate, at least partially, for the size differences which may then have an unequal influence on the patterns of variation. Previous work by Pietrusewsky (1994, 1995, 1997) and Green (1990), however, have demonstrated that removal of this size-based component has little or no effect in interpreting patterns of craniometric variation. C-score measures are not used in the present study.

Results

The results of two separate analyses, each using twenty-nine cranial measurements, are reported. In the first analysis, five Taiwan aboriginal series are compared with each other. In the second analysis, five Taiwan aboriginal series are compared with fifty prehistoric and more modern cranial series representing Southeast Asia, East Asia, Australia, and the Pacific.

Analysis I (5 Groups, 29 Measurements)

The means and standard deviations for twenty-nine cranial measurements recorded in the five aboriginal groups are reported, for the first time, in Table 2.

Stepwise Discriminant Function Analysis

A ranking of twenty-nine cranial measurements according to the F-values received at each step of the discriminant function analysis (Table 3) indicates that the highest ranked variables in this analysis are basion-bregma height, maximum cranial breadth, bimaxillary subtense, maximum cranial length, and nasal breadth. Cranial vault height, breadth, and length are the most important discriminating variables in this analysis.

Eigenvalues, the percentage of total dispersion, and the level of significance for the first four discriminant functions are shown in Table 4. The first two variates, or functions, account for 74.1% of the total variation. All eigenvalues in this table are significant at the 1% level.

Canonical coefficients for twenty-nine cranial measurements for the first three canonical variates (Table 5) indicate that the first canonical variate separates most importantly on the basis of cranial vault length, cheek height, and bifrontal breadth. The first function can be described as a vault length, cheek height, and frontal breadth discriminator. Differences in the orbital height, maximum cranial breadth, and bifrontal breadth are responsible for the group separation achieved in the second canonical variate. Discrimination produced in the third canonical variate is based primarily on differences in bimaxillary subtense, cranial vault length, cranial vault height, and bimaxillary breadth.

A summary of the jackknifed classification results from stepwise discriminant function analysis (Table 6) indicates that the total percentage of cases correctly classified for each of the five groups is relatively high indicating that these groups are well differentiated. The Atayal and Shi San Hang series obtain the highest percentage of correct assignments. One each of the Shi San Hang specimens is reclassified as Bunun and Pazeh. The Pazeh series has the highest number of misclassifications. The Bunun series receives the highest number (9) of mis-assignments from other groups represented.

A plot of the group means on the first three canonical variates (Fig. 3) shows the five groups are well differentiated from each other. The means of the Pazeh and Babuza series form a relatively tight cluster. Bunun, Shi San Hang, and Atayal occupy isolated positions in this representation. Bunun is one of the most differentiated of the five aboriginal groups.

Mahalanobis' Generalized Distance

Distances and results of the test of significance, obtained when Mahalanobis' generalized distance is applied to the twenty-nine cranial measurements, are presented in Table 7. Five of the ten distances in this table are significant ($\alpha = 0.01$). The smallest distance, although not significant ($\alpha = 0.01$), is between Pazeh and Babuza, indicating non-differentiation of these two groups. The largest distances obtained are associated with the Atayal and Shi San Hang groups. Small sample sizes are most often associated with the non-significant distances. The grouping shown in the den-

Table 2. Means and standard deviations for 29 cranial measurements for five male Taiwan aboriginal groups

Measurement	Atayal $n = 36$ Mean	S.D.	Bunun $n = 26$ Mean	S.D.	Babuza $n = 29$ Mean	S.D.	Pazeh $n = 21$ Mean	S.D.	Shi San Hang $n = 13$ Mean	S.D.
Maximum cranial length (M-1)[a]	176.4	6.5	184.0	7.0	181.8	6.0	177.3	5.0	187.1	5.8
Nasio-occipital length (M-1d)	173.6	6.2	181.0	6.2	179.6	5.7	175.2	5.1	183.9	6.1
Basion-nasion length (M-5)	97.2	4.2	101.8	3.4	100.7	3.7	100.1	3.8	106.2	5.7
Basion-bregma height (M-17)	132.1	4.3	133.4	3.8	142.3	4.8	138.0	5.7	144.8	4.8
Maximum cranial breadth (M-8)	133.8	4.4	139.8	5.0	144.0	4.4	138.8	4.2	134.8	5.0
Maximum frontal breadth (M-10)	112.4	3.4	114.7	4.1	117.1	4.4	114.4	5.1	113.1	3.8
Minimum frontal breadth (M-9)	92.4	3.5	93.7	3.4	93.8	3.9	92.1	4.7	95.4	3.6
Bistephanic breadth (H-STB)[b]	107.1	4.0	108.3	5.4	112.6	4.5	109.4	5.1	108.1	5.9
Biauricular breadth (M-116)	121.0	5.4	123.3	3.7	127.4	3.8	122.5	4.5	122.8	3.6
Minimum cranial breadth (M-14)	75.7	3.8	76.9	4.3	80.9	4.0	76.7	3.3	74.4	3.1
Biasterionic breadth (M-12)	105.3	5.1	108.2	6.2	108.2	4.8	105.4	4.3	109.6	3.8
Nasal height (H-NLH)	49.6	2.9	50.8	4.1	53.3	2.4	52.0	3.5	52.2	3.0
Nasal breadth (M-54)	24.1	1.9	26.1	1.9	26.2	2.2	27.3	1.7	26.2	2.2
Orbital height, left (M-52)	33.2	1.8	34.6	1.9	34.6	2.0	34.2	1.4	32.5	1.6
Orbital breadth, left (M-51a)	39.6	1.5	41.2	1.6	42.0	1.8	41.0	1.8	42.0	2.1
Bijugal breadth [M-45(1)]	111.4	5.4	113.8	2.6	120.0	4.0	118.0	3.3	119.8	3.5
Alveolar length (M-60)	50.0	2.7	49.8	2.8	51.3	4.4	50.4	3.6	54.1	2.4
Alveolar breadth (M-61)	62.9	4.2	63.2	3.0	66.1	3.5	63.3	3.7	66.6	2.9
Mastoid height (H-MDL)	24.1	2.5	26.2	3.8	28.5	2.5	25.7	2.1	29.8	2.7
Mastoid width (H-MDB)	17.6	2.7	20.3	2.8	19.5	2.8	18.7	2.2	20.9	2.8
Bimaxillary breadth (M-46)	95.8	4.9	97.9	3.1	101.6	5.4	100.8	2.8	102.6	5.3
Bifrontal breadth (M-43)	102.6	3.7	104.1	3.0	104.3	3.4	101.5	5.3	103.5	3.6
Biorbital breadth (H-EKB)	92.9	3.9	96.4	3.2	96.8	5.8	96.2	3.3	97.2	3.3
Malar length, inferior (H-IML)	33.6	3.3	32.1	2.2	34.2	2.6	33.1	2.3	36.3	2.7
Cheek height (H-WMH)	21.1	1.9	22.2	2.6	25.4	2.7	24.1	1.9	24.6	1.4
Nasion-bregma chord (M-29)	109.4	4.6	110.0	3.9	112.8	4.7	111.5	5.9	115.0	3.9
Bregma-lambda chord (M-30)	111.3	6.5	111.3	5.7	115.2	6.6	109.2	6.4	117.7	5.9
Lambda-opisthion chord (M-31)	91.4	4.2	95.4	5.7	99.4	5.8	92.4	5.0	100.7	4.7
Bimaxillary subtense (H-SSS)	19.8	3.4	24.6	2.0	21.9	2.9	22.9	3.0	26.4	3.8

[a]M = Martin and Saller (1957); [b]H = Howells (1973); n = number of crania.

Table 3. Summary ranking of 29 cranial measurements according to *F*-values received in the final step of discriminant function analysis (five male groups)

Step No.	Measurement	*F*-Value	d.f.$_B$/d.f.$_W$[a]	p[b]
1	Basion-bregma	32.590	4/119	*
2	Maximum cranial breadth	18.125	4/118	*
3	Bimaxillary subtense	13.257	4/117	*
4	Maximum cranial length	6.083	4/116	*
5	Nasal breadth	6.252	4/115	*
6	Bijugal breadth	4.804	4/114	*
7	Bifrontal breadth	9.221	4/113	*
8	Alveolar breadth	4.812	4/112	*
9	Nasion-bregma chord	4.468	4/111	*
10	Cheek height	4.161	4/110	*
11	Lambda-opisthion chord	3.330	4/109	*
12	Minimum cranial breadth	3.224	4/108	n.s.[c]
13	Bregma-lambda chord	3.133	4/107	n.s.
14	Biasterionic	2.588	4/106	n.s.
15	Malar length	3.004	4/105	n.s.
16	Bistephanic breadth	2.365	4/104	n.s.
17	Bimaxillary breadth	2.018	4/103	n.s.
18	Biorbital breadth	2.204	4/102	n.s.
19	Nasal height	1.878	4/101	n.s.
20	Nasio-occipital length	1.965	4/100	n.s.
21	Basion-nasion	1.810	4/99	n.s.
22	Mastoid height	1.927	4/98	n.s.
23	Orbital height	1.568	4/97	n.s.
24	Mastoid width	1.608	4/96	n.s.
25	Minimal frontal breadth	1.481	4/95	n.s.
26	Orbital breadth	1.208	4/94	n.s.
27	Alveolar length	1.521	4/93	n.s.
28	Biauricular breadth	1.028	4/92	n.s.
29	Maximum frontal breadth	0.827	4/91	n.s.

[a] d.f.$_B$/d.f.$_W$ = degrees of freedom between/degrees of freedom within.
[b] $p \leq .01$.
[c] n.s. = not significant.

drogram (Fig. 4) is similar to the association seen in the canonical plot in Fig. 3. Babuza and Pazeh form a tight cluster to which Shi San Hang is loosely attracted. The Atayal and Bunun occupy a second cluster in this diagram.

Analysis II (55 Groups, 29 Measurements)

Stepwise Discriminant Function Analysis

A ranking of twenty-nine cranial measurements according to the F-values received at each step of this discriminant function analysis is presented in Table 8. The high-

Table 4. Eigenvalues, percentage of total dispersion, cumulative percentage of dispersion, and level of significance for the first four canonical variates (5 male groups, 29 cranial measurements)

Canonical Variate	Eigenvalue	% Dispersion	Cumulative % Dispersion	d.f.[a]	p[b]
1	5.12231	56.6	56.6	32	*
2	1.57931	17.5	74.1	30	*
3	1.45138	16.1	90.2	28	*
4	0.89081	9.8	100.0	26	*

[a] d.f. = 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: 323)

est ranked variables include maximum cranial breadth, alveolar length, basion-nasion height, minimum cranial breadth, nasal height, orbital breadth, and cranial vault length.

Eigenvalues, the percentage of total dispersion and the level of significance for the first twenty-one discriminant functions (Table 9) indicate that the first three variates, or functions, account for 61.1% of the total variation.

Canonical coefficients for twenty-nine cranial measurements for the first three canonical variates (Table 10) show that the first canonical variate separates most importantly on the basis of orbital breadth, bifrontal breadth, and maximum frontal breadth. The first function can be primarily described as a cranial vault breadth discriminator. Differences in maximum frontal breadth, orbital breadth, mastoid width, and minimum cranial breadth are responsible for the group separation achieved in the second canonical variate. Discrimination produced in the third canonical variate is based primarily on differences in maximum cranial length, cheek height, and naso-occipital length.

The partial jackknifed classification results (Table 11) indicate a substantial number of mis-assigned cases. Groups with some of the poorest classification results (12.5% or fewer of the original cases being re-assigned to their original group) include Shanghai, Hangzhou, Korea, Edo, Sulawesi, and Lesser Sundas Islands. The Taiwan aboriginal groups achieve some of the best classification results. The majority of the misclassifications for the Atayal series are to East Asian cranial series. Three of the five misclassified Shi San Hang cases are assigned to cranial series from Polynesia and Guam. Two of the Bunun specimens are misclassified as New Zealand Maori. Six of the twenty-nine Babuza specimens are reclassified as Pazeh, two are reclassified as Bunun, and one is classified as Shi San Hang. Two of the Pazeh cases are reclassified as Shi San Hang and one each is reclassified as Bunun and Babuza.

Table 5. Canonical coefficients for 29 cranial measurements for the first three canonical variates (5 male groups)

Variable	Canonical Variate 1	Canonical Variate 2	Canonical Variate 3
Maximum cranial length	–0.23295	–0.02606	0.14590
Nasio-occipital length	0.25352	–0.13025	–0.10734
Basion-nasion	0.02249	0.08238	0.14448
Basion-bregma	0.08867	–0.00226	–0.08840
Maximum cranial breadth	0.18101	–0.18812	0.02302
Maximum frontal breadth	–0.00633	0.04809	0.07132
Minimum frontal breadth	0.01358	0.09922	–0.00509
Bistephanic breadth	–0.09302	–0.02460	–0.0705
Biauricular breadth	–0.07813	0.04505	0.00067
Minimum cranial breadth	0.05431	–0.08766	–0.06727
Biasterionic	–0.08917	0.11656	0.02456
Nasal height	–0.12613	0.04979	–0.13697
Nasal breadth	0.08477	–0.01804	0.09431
Orbital height	0.06048	–0.18950	0.11101
Orbital breadth	0.20003	–0.04312	0.03988
Bijugal breadth	0.21324	0.08578	–0.03051
Alveolar length	–0.09830	0.08209	–0.04267
Alveolar breadth	–0.13395	–0.05231	–0.04566
Mastoid height	0.05217	0.07249	0.11365
Mastoid width	–0.11494	0.04379	0.05154
Bimaxillary breadth	–0.02385	–0.01759	–0.14189
Bifrontal breadth	–0.26280	–0.18448	0.02709
Biorbital breadth	0.04563	0.02350	0.04212
Malar length, inferior	–0.02215	0.16927	–0.06395
Cheek height	0.30886	–0.11982	0.03661
Nasion-bregma chord	0.00263	0.12550	–0.04049
Bregma-lambda chord	0.05427	0.03245	–0.0011
Lambda-opisthion chord	0.08397	0.03767	0.0506
Bimaxillary subtense	0.08323	0.08198	0.21841

A plot of the group means on the first two canonical variates (Fig. 5) reveals five relatively distinct clusters. The cranial series from Australia and Melanesia form a major subdivision in this representation. The Polynesian series (and Guam) form a second grouping to which the Shi San Hang sample is attracted. A third constellation includes all the Southeast Asian and the Atayal series. Cranial series from China, Korea, and Mongolia occupy a fourth group. The cranial series from Japan (modern and prehistoric) form a relatively cohesive grouping to which the Bunun, Pazeh, and Babuza series align as peripheral members.

A plot of the group means on the first three canonical variates (Fig. 6) demon-

Table 6. Summary jackknifed classification results from stepwise discriminant function analysis using 29 cranial measurements[a]

Group	SSH	BUN	BAB	PAZ	ATY
Shi San Hang	11		1	1	
Bunun		19	2	2	3
Babuza	2	2	21	3	1
Pazeh	2	4	2	13	
Atayal		3		1	32
Total Cases	13	26	29	21	36
No. Correct. Assign.	11	19	21	13	32
% Correct Assign.	84.6	73.1	72.4	61.9	88.9

[a] The classification results for each group are obtained by scanning the rows across this table rather than down the table.

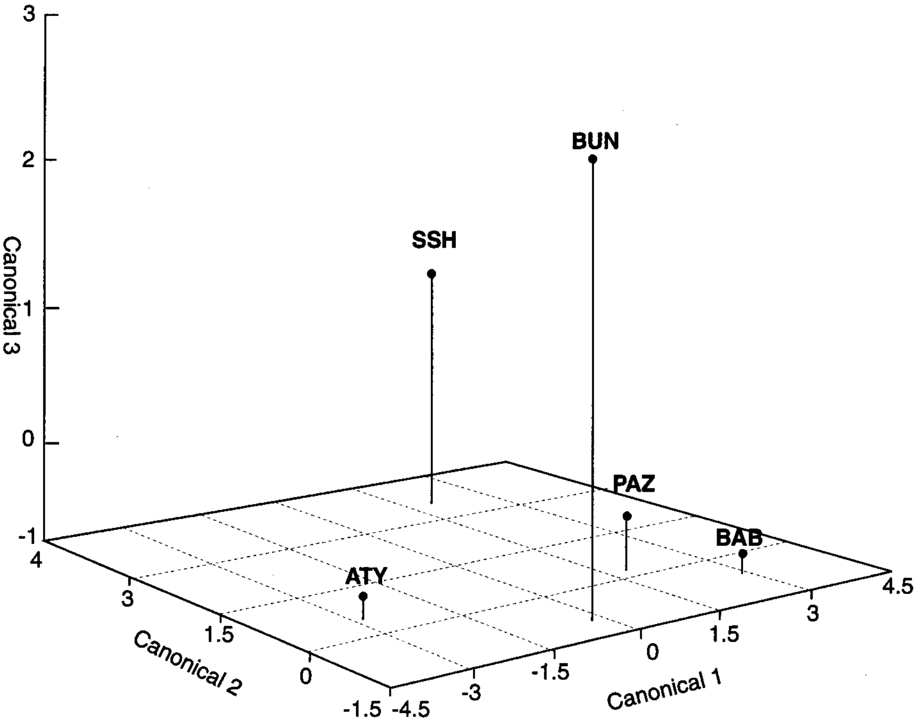

Figure 3. Plot of the five male Taiwan aboriginal group means on the first three canonical variates using 29 cranial measurements. [ATY = Atayal, SSH = Shi San Hang, BUN = Bunun, PAZ = Pazeh, BAB = Babuza.]

strates relationships similar to those seen in Fig. 5. In this representation, the aboriginal groups, Shi San Hang, Babuza, and Pazeh are positioned closest to the Polynesian constellation. The Atayal series, while isolated, is closest to the cluster

Table 7. Mahalanobis' generalized distances for five Taiwan aboriginal groups using 29 cranial measurements; unless otherwise indicated, all variance ratios for these distances are significant at the 1% level

	Atayal	SSH	Bunun	Babuza	Pazeh
Atayal	—	34.456[a]	16.097[a]	33.451[a]	24.682[a]
Shi San Hang			24.764	21.378	18.862
Bunun			—	19.272[a]	15.606
Babuza				—	10.252
Pazeh					—

[a] = Variance ratio not significant at 1% level.

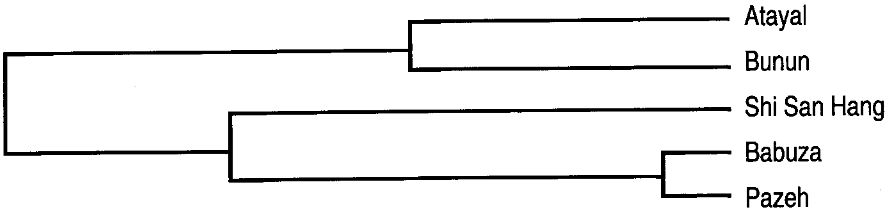

Figure 4. Diagram of relationship based on a cluster analysis (UPGMA) of Mahalanobis' generalized distances using 29 cranial measurements recorded in five male Taiwan aboriginal groups.

containing Southeast Asian series. The Bunun series is closest to the Japanese cranial series. The cranial series representing eastern and northern Asia form the tightest grouping in this representation. The most removed constellation in this diagram is one formed by the cranial series from Australia, Papua New Guinea, and island Melanesia.

Mahalanobis' Generalized Distance

The ten smallest distances for each of the fifty-five groups are presented in Table 12. Two Taiwan aboriginal (Pazeh and Babuza), two Southeast Asian (Borneo and Sulu), and five Pacific Island cranial series (New Zealand, Easter Island, Guam, Fiji, and Marquesas) are the groups associated with the ten smallest distances for the Shi San Hang series. The groups registering the closest (smallest) distances to Pazeh include three Taiwan aboriginal (Babuza, Bunun, and Shi San Hang) and four Southeast Asian (Borneo, Sulawesi, Vietnam, and Sulu) groups. Pazeh, and a number of East Asian cranial series, are closest to Babuza. Nine prehistoric and modern Japanese series (including Ainu, Jomon, and Ryukyu Is.) are among the groups closest to Bunun. Korea, several Japanese series (including Ryukyu Is.), Anyang, Taiwan, and Hainan Island are among the groups closest to the Atayal series.

The dendrogram of distances (Fig. 7) demonstrates, with a few important exceptions, the grouping seen in the plot of the group means on the canonical variates. In

Table 8. Summary ranking of 29 cranial measurements according to *F*-values received in the final step of stepwise discriminant function analysis (55 male groups)

Step No.	Measurement	*F*-Value	d.f.$_B$/d.f.$_W$[a]	p[b]
1	Maximum cranial breadth	36.68	54/2476	*
2	Alveolar length	29.52	54/2475	*
3	Basion-nasion	19.40	54/2474	*
4	Minimum cranial breadth	17.13	54/2473	*
5	Nasal height	14.46	54/2472	*
6	Orbital breadth	14.15	54/2471	*
7	Nasio-occipital length	12.05	54/2470	*
8	Basion-bregma	12.59	54/2469	*
9	Bimaxillary subtense	10.49	54/2468	*
10	Malar length, inferior	10.06	54/2467	*
11	Nasal breadth	9.62	54/2466	*
12	Biauricular breadth	9.55	54/2465	*
13	Maximum cranial length	8.71	54/2464	*
14	Bimaxillary breadth	7.60	54/2463	*
15	Bifrontal breadth	7.68	54/2462	*
16	Bijugal breadth	9.04	54/2461	*
17	Biorbital breadth	7.00	54/2460	*
18	Alveolar breadth	6.85	54/2459	*
19	Nasion-bregma chord	6.43	54/2458	*
20	Cheek height	5.44	54/2457	*
21	Orbital height	5.61	54/2456	*
22	Lambda-opisthion	5.30	54/2455	*
23	Bistephanic breadth	4.87	54/2454	*
24	Maximum frontal breadth	6.15	54/2453	*
25	Mastoid height	4.06	54/2452	*
26	Bregma-lambda chord	3.91	54/2451	*
27	Biasterionic breadth	3.15	54/2450	*
28	Mastoid width	2.95	54/2449	*
29	Minimum frontal breadth	2.91	54/2448	*

[a] d.f.$_B$/d.f.$_W$ = degrees of freedom between/degrees of freedom within

[b] $p \leq .01$

the dendrogram of distances, Atayal loosely clusters with cranial series representing Taiwan, Hainan Island, Korea, and Anyang. The Bunun series, although peripheral, is intermediate between clusters containing the cranial series from Southeast Asia and Polynesia. The Babuza, Pazeh, and Shi San Hang series form a separate cluster that attaches to a greater Asian subdivision immediately after the Bunun and Polynesian series join. The Australian and Melanesian series form a second major subdivision well differentiated from this latter grouping.

Table 9. Eigenvalues, percentage of total dispersion, cumulative percentage of dispersion, and level of significance for the first 21 canonical variates (55 male groups, 29 cranial measurements)

Canonical Variate	Eigenvalue	% Dispersion	Cumulative % Dispersion	d.f.[a]	p[b]
1	3.34771	40.3	40.3	82	*
2	0.93067	11.2	51.5	80	*
3	0.79715	9.6	61.1	78	*
4	0.56224	6.8	67.9	76	*
5	0.46691	5.6	73.5	74	*
6	0.33013	4.0	77.5	72	*
7	0.28386	3.4	80.9	70	*
8	0.23050	2.8	83.7	68	*
9	0.19830	2.4	86.1	66	*
10	0.17071	2.0	88.1	64	*
11	0.14040	1.8	89.9	62	*
12	0.12252	1.4	91.3	60	*
13	0.10593	1.3	92.6	58	*
14	0.09432	1.1	93.7	56	*
15	0.08483	1.0	94.7	54	*
16	0.06647	0.8	95.5	52	*
17	0.05751	0.7	96.2	50	*
18	0.05279	0.6	96.8	48	*
19	0.04920	0.6	97.4	46	*
20	0.04053	0.5	97.9	44	*
21	0.03545	0.4	98.3	42	*

[a] d.f. = degrees of freedom = $(p + q - 2) + (p + q - 4)$

[b] $p < 0.01$ when eigenvalues are tested for significance according to criterion $[N - \frac{1}{2}(p + q)] \log_e (\lambda + 1)$, 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: 323)

Discussion

A previous multivariate craniometric study (Pietrusewsky, 1995) that examined the relationships of Taiwan aboriginal and neighboring groups, utilized a single Taiwan aboriginal cranial series, the Atayal. In the present craniometric analyses, four additional aboriginal cranial series, Bunun, Babuza, Pazeh, and the archaeological series from Shi San Hang, are examined. Of these, only the Bunun and Atayal are represented by Taiwan's extant aboriginal tribes, a factor that limits comparisons with other kinds of data.

Craniometric comparisons of five Taiwan aboriginal series indicate that the closest connection, although not statistically significant, is one between the Pazeh and Babuza cranial series. The canonical plot (Fig. 3) and dendrogram of distances (Fig.

Table 10. Canonical coefficients for 29 cranial measurements for the first three canonical variates (55 male groups)

Variable	Canonical Variate 1 Coefficient	Canonical Variate 2 Coefficient	Canonical Variate 3 Coefficient
Maximum cranial length	0.07039	0.04487	0.22201
Nasio-occipital length	−0.05359	−0.01422	−0.13642
Basion-nasion	−0.00983	−0.07796	−0.09992
Basion-bregma	0.00181	0.02216	0.00322
Maximum cranial breadth	−0.02279	−0.04434	−0.02873
Maximum frontal breadth	0.14395	0.12960	−0.0153
Minimum frontal breadth	−0.00762	−0.09181	0.01733
Bistephanic breadth	−0.0348	−0.03766	0.02873
Biauricular breadth	−0.05064	−0.00875	−0.01649
Minimum cranial breadth	−0.07415	−0.11814	0.02332
Biasterionic	0.08787	−0.06898	−0.0497
Nasal height	0.08551	−0.04755	−0.02357
Nasal breadth	−0.05108	−0.03380	0.03711
Orbital height	−0.09257	0.03954	−0.08981
Orbital breadth	−0.24404	0.12659	0.06140
Bijugal breadth	0.09466	0.00807	0.0166
Alveolar length	−0.03732	−0.11165	0.01871
Alveolar breadth	0.07233	0.09776	−0.00882
Mastoid height	−0.10207	0.00866	−0.01109
Mastoid width	0.05608	0.11875	0.05119
Bimaxillary breadth	−0.04453	0.00987	−0.03206
Bifrontal breadth	−0.1659	0.10615	−0.04458
Biorbital breadth	0.09515	0.03598	−0.03133
Malar length, inferior	−0.0012	−0.11715	0.04025
Cheek height	−0.02663	0.02431	0.21299
Nasion-bregma chord	0.06007	−0.01237	−0.02079
Bregma-lambda chord	0.00217	−0.01769	−0.10135
Lambda-opisthion chord	−0.01026	−0.03761	0.06622
Bimaxillary subtense	0.03225	0.03126	−0.02715

4) dramatically confirm the closeness of these two groups. Speakers of the Pazeh and Babuza, languages which are now either extinct or nearly extinct, occupied neighboring central and inland regions of Taiwan's western coast. In addition to the geographical proximity of the speakers of these two language groups, both languages are members of the same major subgrouping of Formosan languages (Sung, 1989). Thus, while there are no anthropometric or genetic data for these two groups, there is some evidence of concordance between language, geography, and skeletal morphology. Chai (1967) also observed that biological relationships among Taiwan aboriginal tribes closely approximate geography. In the present analysis the Shi San Hang

Table 11. Number of cases reclassified for some of the jackknifed classification results for 55 groups; numbers in parentheses represent the percentage of correct assignments for each group; abbreviation are explained in Table 1.

Bunun	Babuza	Pazeh	Atayal	Shi San Hang	Shanghai	Hong Kong	Chengdu
(65.4)	(48.3)	(57.1)	(58.3)	(61.5)	(10)	(36)	(41.5)
BUN - 17	BAB - 14	PAZ - 12	ATY - 21	SSH - 8	HAN - 16	HK - 18	CHE - 22
TOH - 2	PAZ - 6	HAI - 2	KOR - 2	SUL - 1	SHA - 5	THI - 4	NAN - 8
NZ - 2	BUN - 2	SSH - 2	KYU - 2	EAS - 1	HK - 4	NAN - 3	SHA - 5
ANY - 1	HAN - 1	ADR - 2	PHL - 2	NZ - 1	KAN - 4	SHA - 2	HK - 4
KAN - 1	TAI - 1	KOF - 1	HK - 1	GUA - 1	THI - 4	HAN - 2	MOG - 2
JOM - 1	ANY - 1	BUN - 1	CHE - 1	BAB - 1	NAN - 3	TAI - 2	YAY - 2
SUL - 1	KOR - 1	BAB - 1	TAI - 1		MOG - 2	MAN - 2	PHL - 2
BAB - 1	KAN - 1		KAN - 1		CHE - 1	RYU - 2	HAN - 1
	RYU - 1		EDO - 1		MAN - 1	VTN - 2	ATY - 1
	SSH - 1		KAM - 1		KOF - 1	BUN - 2	MAN - 1
			TOH - 1		YAY - 1	CHE - 1	KOR - 1
Hangzhou	Nanjing	Taiwan Chinese	Hainan Island	Manchuria	Anyang	Mongolia	Korea
(12)	(16.3)	(29.8)	(27.7)	(36)	(39.3)	(80)	(12.5)
SHA - 9	NAN - 8	TAI - 14	HAI - 13	MAN - 18	ANY - 22	MOG - 40	HAI - 4
HAN - 6	SHA - 6	HAI - 7	TAI - 5	CHE - 4	KOR - 3	SHA - 1	KOR - 4
NAN - 6	CHE - 6	ANY - 6	ANY - 3	HK - 3	PHL - 3	CHE - 1	ANY - 3
CHE - 5	HAN - 5	TOH - 4	THI - 3	TAI - 2	SHA - 2	HAN - 1	TAI - 2
HK - 3	MAN - 5	MAN - 2	GUA - 3	HAI - 2	HK - 2	NAN - 1	YAY - 2
ANY - 3	HK - 2	BAC - 2	HK - 2	ATY - 2	NAN - 2	HAI - 1	TOH - 2
MOG - 3	KOR - 2	PHL - 2	KOR - 2	KOR - 2	TAI - 2	KOF - 1	RYU - 2
MAN - 2	VTN - 2	CHE - 1	SLW - 2	KAN - 2	MOG - 2	AIN - 1	THI - 2
BOR - 2	PHL - 2	NAN - 1	PAZ - 2	EDO - 2	KAM - 2	THI - 1	PHL - 2
TAI - 1	BAB - 2	ATY - 1	MAN - 1	THI - 2	TOH - 2	BUN - 1	HAW - 2
HAI - 1	HAI - 1	KAN - 1	KAN - 1	JAV - 2	BAB - 2	BAB - 1	CHE - 1
Kanto Japanese	Edo	Kamakura	Kofun	Yayoi	Tohoku Japanese	Kyushu Japanese	Ainu
(24)	(5.5)	(28.8)	(29)	(24.2)	(24.5)	(23.5)	(48)
KAN - 12	MAN - 5	KAM - 15	KOF - 18	YAY - 15	TOH - 13	KYU - 12	AIN - 24
KYU - 5	KAN - 5	RYU - 6	KAM - 6	KOF - 7	AIN - 6	KAN - 5	JOM - 5
TOH - 3	TOH - 5	KOF - 4	JOM - 6	KAM - 5	RYU - 5	KAM - 5	KAN - 3
BUN - 3	ATY - 4	ANY - 3	CHE - 3	RYU - 4	KAN - 4	RYU - 4	EDO - 2
HK - 2	KYU - 4	EDO - 3	MAN - 3	KAN - 3	ATY - 3	HAI - 3	YAY - 2
NAN - 2	EDO - 3	KYU - 3	TOH - 3	JOM - 3	EDO - 3	KOR - 3	TOH - 2
RYU - 2	BUN - 3	BUN - 3	RYU - 3	THI - 3	KAM - 3	TOH - 3	HK - 1
THI - 2	CHE - 2	KOR - 2	HAN - 2	NAN - 2	KYU - 3	ATY - 2	TAI - 1
HAN - 1	YAY - 2	TOH - 2	TAI - 2	EDO - 2	MAN - 2	EDO - 2	MAN - 1
HAI - 1	AIN - 2	LSN - 2	MOG - 2	BUN - 2	KOF - 2	YAY - 2	ANY - 1
ATY - 1	RYU - 2	HK - 1	KOR - 2	HK - 1	YAY - 2	HK - 1	KAM - 1

Table 11 (continued)

Ryukyu Islands	Jomon	Cambodia & Laos	Thailand	Viet Nam	Bachuc	Sulawesi	Sulu
(21)	(54.9)	(52.5)	(34)	(24.5)	(45.1)	(12.2)	(31.6)
RYU - 13	JOM - 28	CAM - 21	THI - 17	VTN - 12	BAC - 23	CAM - 7	SUL - 12
KAM - 8	KOF - 5	SUL - 3	BAC - 6	PHL - 4	THI - 7	SLW - 5	CAM - 5
JOM - 4	AIN - 5	PHL - 2	VTN - 3	THI - 3	VTN - 4	ATY - 3	BOR - 4
TAI - 3	YAY - 2	LSN - 2	HK - 2	SHA - 2	CAM - 3	BOR - 3	SLW - 3
ANY - 3	KYU - 2	JAV - 2	ATY - 2	HK - 2	BOR - 3	SHA - 2	JAV - 2
KOF - 3	HAI - 1	FIJ - 2	KAN - 2	TAI - 2	HAI - 2	VTN - 2	ADR - 2
YAY - 3	MOG - 1	CHE - 1	KOF - 2	HAI - 2	KYU - 2	BAC - 2	HAN - 1
KYU - 3	KAN - 1	NAN - 1	SLW - 2	ATY - 2	SUL - 2	SUL - 2	AIN - 1
HAI - 2	KAM - 1	JOM - 1	JAV - 2	ANY - 2	HK - 1	PHL - 2	BAC - 1
AIN - 2	TOH - 1	VTN - 1	CAR - 2	KOR - 2	HAN - 1	JAV - 2	PHL - 1
THI - 2	RYU - 1	BAC - 1	SHA - 1	EDO - 2	SLW - 1	NIR - 2	SSH - 1
Philippines	Lesser Sundas	Borneo	Java	Easter Island	Hawaii	Marquesas	New Zealand
(25)	(8.9)	(20.6)	(22)	(72)	(61.2)	(30.2)	(44)
PHL - 7	SLW - 5	BOR - 7	JAV - 11	EAS - 36	HAW - 30	MRQ - 19	NZ - 22
HAN - 2	PHL - 4	VTN - 4	CAM - 5	MRQ - 3	MRQ - 4	TAH - 13	MRQ - 7
MAN - 2	LSN - 4	SLW - 3	SLW - 5	TAH - 3	GUA - 3	NZ - 7	EAS - 3
CAM - 2	BOR - 4	CAM - 2	THI - 4	FIJ - 3	LSN - 2	EAS - 4	TOH - 2
VTN - 2	NBR - 4	SUL - 2	SUL - 3	NIR - 2	EAS - 2	CAR - 3	NIR - 2
BAC - 2	VTN - 3	CAR - 2	PHL - 3	AIN - 1	TAH - 2	KAM - 2	ATY - 1
SLW - 2	HAW - 3	ADR - 2	HAI - 2	SSH - 1	KOR - 1	HAW - 2	KAN - 1
HK - 1	BIK - 3	HAN - 1	BAC - 2	NZ - 1	EDO - 1	FIJ - 2	KAM - 1
ATY - 1	NSW - 3	ANY - 1	LSN - 2	SHA - 0	TOH - 1	BIK - 2	KYU - 1
KOR - 1	CAM - 2	KAM - 1	SEP - 2	HK - 0	CAM - 1	HAI - 1	JOM - 1
YAY - 1	FIJ 2	AIN - 1	HK - 1	CHE - 0	VTN - 1	MAN - 1	BAC - 1
Tahiti	Guam	Caroline Islands	Admiralty Islands	Vanuatu	Fiji	New Britain	Sepik R.
(47.7)	(63)	(25)	(46)	(31.9)	(28.1)	(36)	(44)
TAH - 21	GUA - 29	CAR - 6	ADR - 23	VAN - 15	FIJ - 9	NBR - 18	SEP - 22
HAW - 6	HAW - 6	NBR - 3	SEP - 6	NBR - 6	GUA - 3	VAN - 9	NIR - 6
CAR - 5	CAM - 2	NZ - 2	BIK - 4	BIK - 4	CAR - 3	NT - 6	NBR - 5
MRQ - 4	RYU - 1	TAH - 2	SUL - 2	NIR - 4	NSW - 3	NIR - 4	BIK - 5
EAS - 2	THI - 1	FIJ - 2	LSN - 2	TAS - 4	NBR - 2	FIJ - 2	CAR - 2
TAI - 1	SLW - 1	HK - 1	HAN - 1	SEP - 3	BIK - 2	SEP - 2	ADR - 2
HAI - 1	SUL - 1	VTN - 1	TAI - 1	QLD - 3	NIR - 2	TAS - 2	VAN - 2
ANY - 1	BOR - 1	LSN - 1	VTN - 1	LSN - 2	SUL - 1	BOR - 1	NT - 2
KYU - 1	MRQ - 1	EAS - 1	PHL - 1	NT - 2	BOR - 1	GUA - 1	CAM - 1
NZ - 1	NZ - 1	HAW - 1	BOR - 1	FIJ - 1	EAS - 1	CAR - 1	SUL - 1
FIJ - 1	TAH - 1	VAN - 1	EAS - 1	NSW - 1	HAW - 1	ADR - 1	SSH - 1

Table 11 (continued)

Biak Islands (39.6)	New Ireland (30.2)	New South Wales (37.1)	Queensland (31.5)	Murray R. (48)	Tasmania (65.4)	Northern Territory (46)
BIK - 19	NIR - 16	NSW - 23	QLD - 17	MRB - 24	TAS - 17	NT - 23
FIJ - 5	NBR - 8	QLD - 12	NSW - 12	NT - 10	AIN - 2	QLD - 6
SEP - 5	SEP - 6	NT - 7	NT - 9	NSW - 5	VAN - 2	NSW - 5
NBR - 4	ADR - 5	MRB - 5	MRB - 6	QLD - 4	NSW - 2	MRB - 5
ADR - 3	VAN - 3	NBR - 3	CAR - 2	VAN - 2	BOR - 1	VAN - 3
VAN - 3	FIJ - 3	LSN - 2	NIR - 2	FIJ - 2	SEP - 1	SEP - 3
CAR - 2	LSN - 2	BIK - 2	NAN - 1	NBR - 2	BUN - 1	THI - 1
NIR - 2	CAR - 2	NIR - 2	VTN - 1	TAS - 1		FIJ - 1
KAM - 1	BIK - 2	TAS - 2	SSH - 1			NBR - 1
LSN - 1	HAN - 1	NZ - 1	VAN - 1			BIK - 1
EAS - 1	KAN - 1	VAN - 1	FIJ - 1			NIR - 1

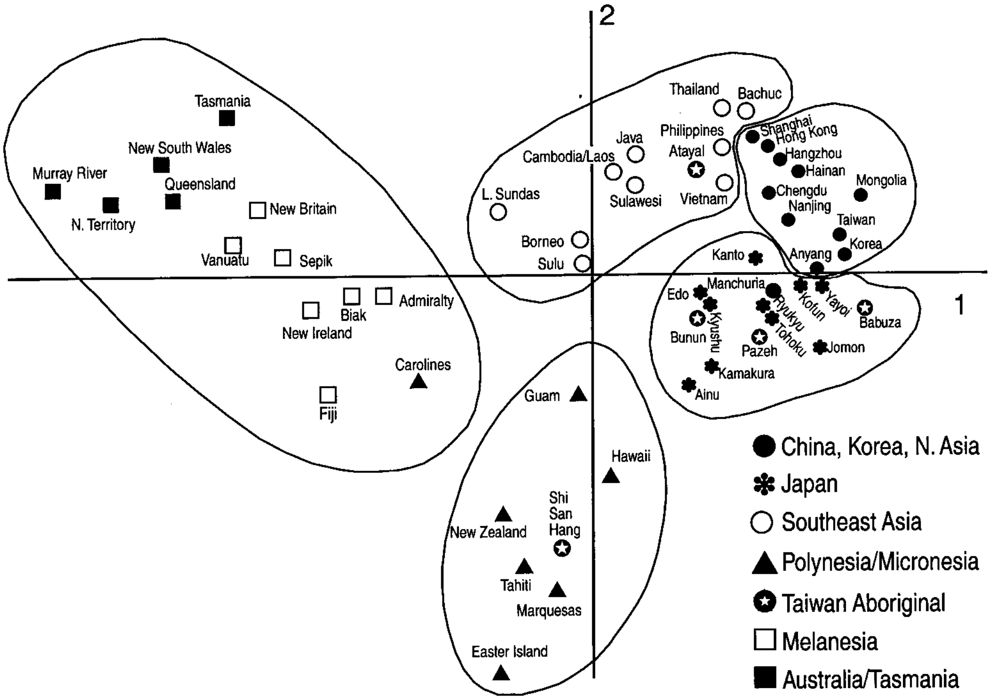

Figure 5. Plot of 55 male groups means on the first two canonical variates using 29 cranial measurements [see Table 1 for explanation of abbreviations].

cranial series is closest to the Pazeh and Babuza groups, all three are located in the western and northern half of the island. Shi San Hang's location in northwestern Taiwan and the cultural parallels between those buried at this site and the now extinct plains-dwelling Ketagalan and Kavalan aboriginal tribes of northern Taiwan (see e.g., Yang, 1961) are consistent with these results.

Although members of separate language subgroups, the Atayal and Bunun cranial series are associated with each other and are well differentiated from the other three remaining aboriginal series investigated in this study. Further support for an Atayal-Bunun connection is provided in a craniometirc study by Howells (1995). Likewise, using anthropometric data, Bowles (1977, 1984) found that the Atayal, Saisiat, Bunun, and Tsou formed a separate cluster, a finding which reiterates earlier anthropometric studies of Taiwan aboriginals by Chai (1967). Using classical genetic polymorphism data, Yuasa et al. (2001) have demonstrated similarities between Bunun and Atayal aboriginal groups. Likewise, although Bunun was one of the most differentiated of the four tribes investigated, Melton et al. (1998) found no significant sequence-specific mtDNA differences among the Ami, Atayal, Bunun, and Paiwan tribes. Overall, these craniometric results indicate similarities as well as differences among Taiwan's aboriginal groups. Geography may explain some of the observed

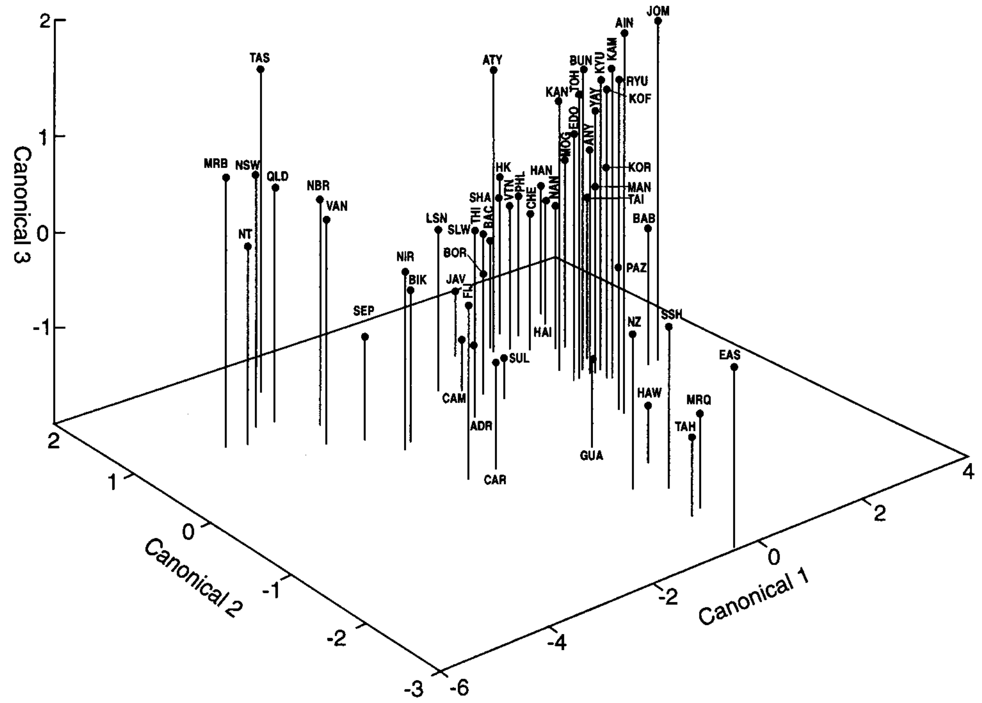

Figure 6. Plot of 55 male groups means on the first three canonical variates using 29 cranial measurements.

similarities while long term isolation, both within and outside Taiwan, may help to explain the observed differences.

The presence of two major divisions representing the inhabitants of eastern Asia and the Pacific, found in this study, reiterates the results of earlier multivariate craniometric analyses (e.g., Pietrusewsky, 1994, 1999, 2000; Pietrusewsky and Ikehara, 2001). All the cranial series from Australia, Tasmania, New Guinea, and geographical (western and eastern island) Melanesia, form one of these divisions. The cranial series from East / North Asia, Southeast Asia, Polynesia, including the Taiwan aboriginal series, represent a second. The sharpness of these divisions suggests separate origins for the human inhabitants of these two major regions. These results further support an earlier colonization of Australia and Near Oceania by a group of people morphologically distinct from those who now occupy East Asia, Southeast Asia, and Remote Oceania, a view supported by anthropometric / craniometric (e.g., Howells, 1970, 1973, 1989, 1995), genetic (e.g., Hill and Serjeantson et al., 1989; Merriwether et al. 1999), archaeological (e.g., Kirch, 1997; Spriggs, 1997), and historical linguistic (Pawley, 1999) evidence. An ancestral homeland in island Southeast Asia for the inhabitants of Remote Oceania is likewise supported by these results, a finding which is consistent with molecular genetic data (e.g., Lum and Cann,

Table 12. The ten smallest distances for 55 groups; except where indicated, all variance ratios calculated for distances are significant at the 1% level.

Bunun		Babuza		Pazeh		Shi San Hang		Atayal		Shanghai		Hong Kong		Chengdu	
TOH -	8.188	PAZ -	7.995*	BAB -	7.995*	NZ -	13.133	KOR -	5.871	HAN -	0.736*	HAN -	4.126	NAN -	2.607*
EDO -	8.254	KOR -	10.919	BUN -	14.233*	PAZ -	14.236*	EDO -	6.826	NAN -	2.434*	SHA -	4.150	HAN -	3.830
KAN -	8.615	YAY -	12.301	SSH -	14.236*	BAB -	14.780*	TOH -	6.974	CHE -	4.120	NAN -	4.320	SHA -	4.120
AIN -	9.345	HAI -	12.492	BOR -	15.863	BOR -	15.396*	HAI -	7.013	HK -	4.150	VTN -	5.141	MAN -	6.273
YAY -	9.762	SHA -	12.557	SLW -	16.536	KAM -	16.254	KYU -	7.053	EDO -	6.076	THI -	5.608	YAY -	7.175
KYU -	10.158	HAN -	12.666	VTN -	16.733	SUL -	16.642*	RYU -	7.549	THI -	6.148	EDO -	6.218	VTN -	7.250
KAM -	10.351	NAN -	12.817	SUL -	17.073	EAS -	16.724	ANY -	7.740	VTN -	6.455	MAN -	6.552	KOR -	7.507
RYU -	10.991	EDO -	13.109	YAY -	17.632	GUA -	17.297	TAI -	7.953	MAN -	6.596	PHL -	6.706	EDO -	7.842
JOM -	11.276	KAN -	13.317	KOR -	17.703	FIJ -	17.601*	KAM -	8.230	KOR -	6.697	HAI -	6.898	HK -	7.888
BOR -	11.494	ANY -	13.321	CAM -	17.912	MRQ -	18.810	PHL -	8.276	YAY -	6.717	KOR -	7.082	KOF -	8.171

Hangzhou		Nanjing		Taiwan Chinese		Hainan Island		Manchuria		Anyang		Mongolia		Korea	
SHA -	0.736*	HAN -	1.670*	HAI -	3.371*	KOR -	2.569*	EDO -	3.554	KOR -	3.358*	YAY -	10.308	HAI -	2.569*
NAN -	1.670*	SHA -	2.434*	ANY -	3.808	TAI -	3.371*	NAN -	3.744	HAI -	3.616	HAN -	10.862	EDO -	2.787*
CHE -	3.830	CHE -	2.607	KOR -	4.002*	ANY -	3.616	KOR -	4.249*	TAI -	3.808	CHE -	11.222	ANY -	3.358*
HK -	4.126	MAN -	3.744	VTN -	6.376	EDO -	4.616	TOH -	5.109	RYU -	4.437	SHA -	12.196	KYU -	3.421*
VTN -	5.708	HK -	4.320	RYU -	6.599	VTN -	4.779	KYU -	5.914	KAM -	5.132	NAN -	12.272	TOH -	3.595*
YAY -	5.823	KOR -	4.797	MAN -	6.678	BAC -	4.805	HAN -	6.008	EDO -	6.046	KOF -	13.418	RYU -	3.822*
KOR -	5.927	EDO -	5.063	EDO -	7.148	RYU -	5.027	HAI -	6.203	KYU -	6.157	SLW -	15.281	TAI -	4.002*
MAN -	6.008	YAY -	5.395	PHL -	7.732	THI -	5.076	YAY -	6.242	NAN -	6.202	MAN -	16.171	KOF -	4.120*
EDO -	6.024	VTN -	6.087	NAN -	7.771	KYU -	5.505	CHE -	6.273	KOF -	6.298	KOR -	16.292	MAN -	4.249*
PHL -	6.462	ANY -	6.202	KYU -	7.859	PHL -	5.777*	RYU -	6.429	MAN -	6.869	RYU -	17.682	KAN -	4.427*

Kanto Japanese		Edo		Kamakura		Kofun		Yayoi		Tohoku Japanese		Kyushu Japanese		Ainu	
EDO -	2.647*	KYU -	1.421*	RYU -	1.447*	YAY -	1.642*	KOF -	1.642*	EDO -	1.766*	EDO -	1.421*	JOM -	4.310
KYU -	2.752*	TOH -	1.766*	KOF -	2.950	RYU -	2.455	RYU -	2.295*	KYU -	2.214*	TOH -	2.214*	KAM -	4.376
TOH -	3.066*	KAN -	2.647*	KYU -	3.093	KAM -	2.950	KAM -	3.238	KAN -	3.066*	KAN -	2.752*	EDO -	4.656
KOR -	4.427*	KOR -	2.787*	YAY -	3.238	KOR -	4.120	EDO -	4.034	KOR -	3.595*	KAM -	3.093	KYU -	4.872
THI -	6.601	RYU -	3.183	EDO -	3.634	EDO -	4.223	TOH -	4.572	KAM -	3.802	KOR -	3.421*	TOH -	5.306
RYU -	6.675	MAN -	3.554	TOH -	3.802	KYU -	4.904	KOR -	4.769	RYU -	4.205	RYU -	3.492	YAY -	5.797
YAY -	6.736	KAM -	3.634	AIN -	4.376	TOH -	5.200	JOM -	5.367	YAY -	4.572	AIN -	4.872	RYU -	6.027
HAI -	6.749	YAY -	4.034	ANY -	5.132	JOM -	5.206	NAN -	5.395	MAN -	5.109	KOF -	4.904	KOF -	6.647
MAN -	6.762	KOF -	4.223	JOM -	5.306	ANY -	6.298	KYU -	5.649	KOF -	5.200	HAI -	5.505	KAN -	6.904
AIN -	6.904	HAI -	4.616	KOR -	5.538	AIN -	6.647	AIN -	5.797	AIN -	5.306	YAY -	5.649	KOR -	9.247

Table 12 (continued)

Ryukyu Islands	Jomon	Cambodia/Laos	Thailand	Viet Nam	Bachuc	Sulawesi	Sulu
KAM - 1.447*	AIN - 4.310	SLW - 2.634*	BAC - 3.264	PHL - 2.816*	THI - 3.264	JAV - 2.477*	CAM - 3.209*
YAY - 2.295*	KOF - 5.206	SUL - 3.209*	VTN - 4.398	THI - 4.398	ATY - 4.805	CAM - 2.634*	SLW - 3.657*
KOF - 2.455	KAM - 5.306	JAV - 3.463*	JAV - 4.560	KOR - 4.653*	VTN - 5.193	LSN - 3.583*	JAV - 4.137
EDO - 3.183	YAY - 5.367	BOR - 5.915	SLW - 4.823	HAI - 4.779	JAV - 5.956	SUL - 3.657*	BOR - 4.511*
KYU - 3.492	RYU - 6.084	THI - 6.009	HAI - 5.076	BOR - 4.944	PHL - 6.279	BOR - 3.842*	LSN - 5.997
KOR - 3.822*	TOH - 7.058	LSN - 6.560	HK - 5.608	EDO - 4.966	SLW - 6.453	PHL - 4.761*	BAC - 6.981
TOH - 4.205	KYU - 7.469	BAC - 6.732	KOR - 5.680	HK - 5.141	CAM - 6.732	THI - 4.823	THI - 7.532
ANY - 4.437	EDO - 7.647	PHL - 6.801*	PHL - 5.827	BAC - 5.193	SUL - 6.981	KOR - 6.043	VTN - 7.991
HAI - 5.027	KAN - 8.503	VTN - 8.199	CAM - 6.009	LSN - 5.241	KAN - 7.167	VTN - 6.117	PHL - 8.053
VTN - 5.509	KOR - 9.937	HAI - 8.305	SHA - 6.148	RYU - 5.509	CHE - 8.217	BAC - 6.453	HAW - 8.557

Philippines	Lesser Sundas	Borneo	Java	Easter Island	Hawaii	Marquesas	New Zealand
VTN - 2.816*	BOR - 3.241*	LSN - 3.241*	SLW - 2.477*	NZ - 7.612	MRQ - 6.885	NZ - 3.896	MRQ - 3.896
SLW - 4.761*	SLW - 3.583*	SLW - 3.842*	CAM - 3.463*	MRQ - 8.716	GUA - 7.531	TAH - 4.444	CAR - 6.601
KOR - 5.527*	JAV - 4.081	SUL - 4.511*	LSN - 4.081	CAR - 10.766	SUL - 8.557	HAW - 6.885	EAS - 7.612
LSN - 5.541*	VTN - 5.241	VTN - 4.944	SUL - 4.137	HAW - 10.965	TAH - 9.188	EAS - 8.716	LSN - 9.053
HAI - 5.777*	EDO - 5.347	JAV - 5.197	THI - 4.560	TAH - 11.113	JAV - 9.813	CAR - 10.307	TAH - 9.102
THI - 5.827	PHL - 5.541*	CAM - 5.915	BOR - 5.197	GUA - 13.994	SLW - 10.037	EDO - 11.564	EDO - 9.296
JAV - 5.869	SUL - 5.997	PHL - 6.718*	PHL - 5.869	FIJ - 14.005	NZ - 10.200	SUL - 11.663	BIK - 9.333
BAC - 6.279	BIK - 6.284	RYU - 6.874	BAC - 5.956	KAM - 14.383	LSN - 10.566	ADR - 12.203	FIJ - 9.477
HAN - 6.462	CAM - 6.560	EDO - 6.934	VTN - 6.182	LSN - 15.639	EAS - 10.965	FIJ - 12.234	ADR - 9.526
NAN - 6.638	RYU - 6.575	THI - 7.352	HAI - 7.134	EDO - 15.954	CAM - 11.526	BOR - 12.523	NIR - 9.634

Tahiti	Guam	Caroline Islands	Admiralty Islands	Vanuatu	Fiji	New Britain	Sepik R.
MRQ - 4.444	HAW - 7.531	NIR - 4.411*	BIK - 8.047	NBR - 2.778*	BIK - 4.212*	VAN - 2.778	NIR - 4.326
NZ - 9.102	LSN - 10.310	FIJ - 5.115*	LSN - 8.112	NIR - 4.661	CAR - 5.115*	NIR - 3.406	BIK - 4.996
HAW - 9.188	BOR - 10.588	BIK - 5.823*	NIR - 8.624	BIK - 5.122	NIR - 5.646	NT - 5.330	CAR - 6.785
CAR - 10.422	SUL - 10.615	NZ - 6.601	SEP - 8.869	QLD - 6.089	VAN - 7.916	BIK - 5.930	NBR - 6.979
EAS - 11.113	NZ - 11.763	SEP - 6.785	SUL - 8.968	NT - 6.247	QLD - 8.441	NSW - 5.957	VAN - 7.404
FIJ - 12.607	CAM - 11.861	LSN - 7.814	CAR - 9.103	NSW - 6.326	LSN - 8.462	QLD - 6.541	LSN - 8.493
MAN - 13.819	NAN - 12.014	ADR - 9.103	BOR - 9.266	SEP - 7.404	NBR - 8.490	SEP - 6.979	ADR - 8.869
EDO - 13.991	SLW - 12.094	NBR - 9.240	NZ - 9.526	MRB - 7.780	SEP - 9.011	LSN - 7.637	FIJ - 9.011
LSN - 14.176	JAV - 12.106	BOR - 9.750	FIJ - 10.886	FIJ - 7.916	NZ - 9.477	MRB - 7.804	NT - 9.134
ADR - 14.735	EDO - 12.948	MRQ - 10.307	VTN - 10.939	TAS - 8.179	NT - 9.477	FIJ - 8.490	NSW - 11.385

Table 12 (continued)

Biak Islands		New Ireland		New South Wales		Queensland		Murray R.		Tasmania		Northern Territory	
FIJ -	4.212*	NBR -	3.406	QLD -	2.260*	NSW -	2.260*	NSW -	2.866	VAN -	8.179	QLD -	3.009*
NIR -	4.640	SEP -	4.326	MRB -	2.866	NT -	3.009*	NT -	3.277	QLD -	8.980	NSW -	3.276
SEP -	4.996	CAR -	4.411*	NT -	3.276	MRB -	3.524	QLD -	3.524	MRB -	10.718	MRB -	3.277
VAN -	5.122	BIK -	4.640	NBR -	5.957	VAN -	6.089	VAN -	7.780	NSW -	10.775	NBR -	5.330
CAR -	5.823*	VAN -	4.661	VAN -	6.326	NBR -	6.541	NBR -	7.804	NBR -	11.263	VAN -	6.247
NBR -	5.930	FIJ -	5.646	FIJ -	9.775	FIJ -	8.441	TAS -	10.718	NT -	13.244	NIR -	8.719
LSN -	6.284	LSN -	6.731	BIK -	9.935	TAS -	8.980	FIJ -	13.747	NIR -	15.496	BIK -	8.785
ADR -	8.047	ADR -	8.624	NIR -	10.048	BIK -	9.305	NIR -	14.351	BIK -	15.781	SEP -	9.134
NT -	8.785	NT -	8.719	TAS -	10.775	NIR -	9.759	BIK -	14.598	LSN -	17.594	FIJ -	9.477
QLD -	9.305	NZ -	9.634	SEP -	11.385	LSN -	11.848	SEP -	17.203	FIJ -	18.543	LSN -	12.706

*Distances not significant at 1% level.

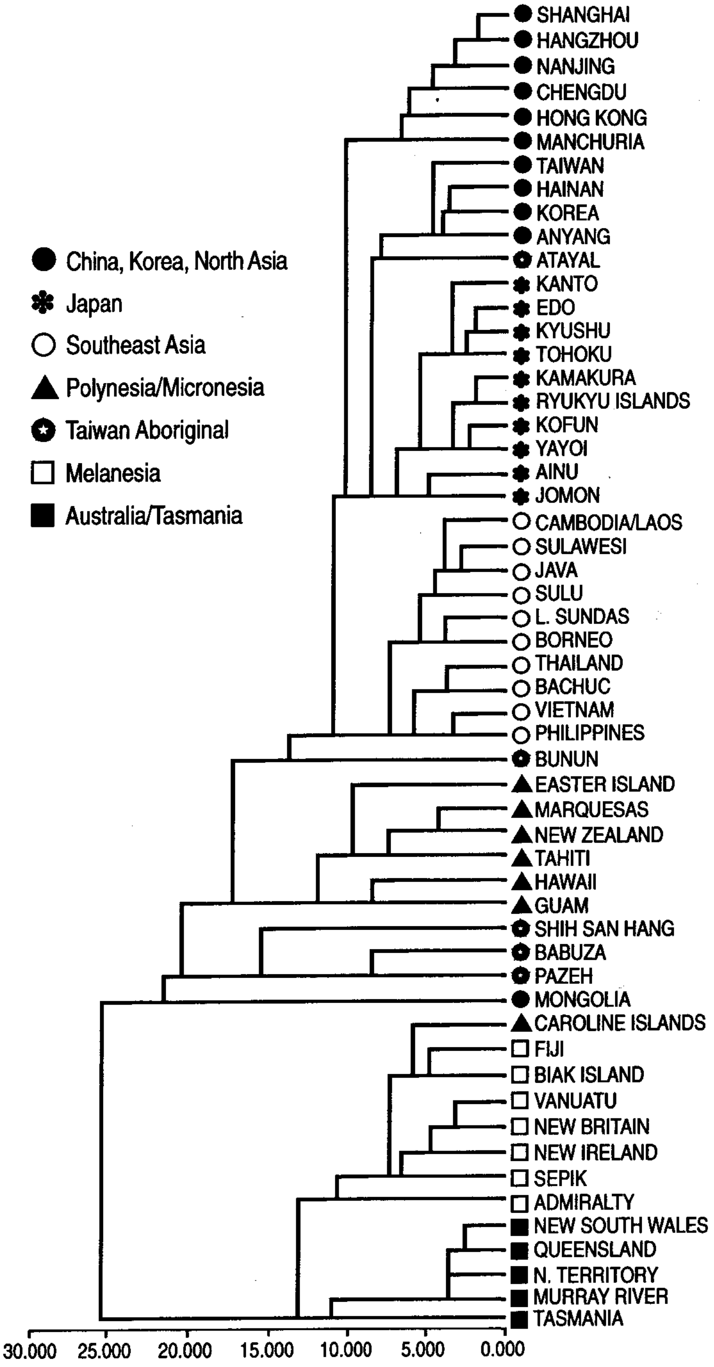

Figure 7. Diagram of relationship based on a cluster analysis (UPGMA) of Mahalanobis' generalized distances using 29 cranial measurements recorded in 55 male groups.

2000; Lum et al., 2002; Oppenheimer and Richards, 2001; Richards et al., 1998).

The relationships between Taiwan aboriginal groups and other cranial series from eastern Asia and the Pacific are more complex. Overall, these results indicate that Taiwan aboriginal groups are relatively well differentiated from mainland Asian series, a view which is supported by traditional biological evidence (see e.g., Chai, 1967) as well as recent studies that utilize molecular data (e.g., Melton et al., 1998). However, there is also evidence for similarities between Taiwan aboriginal groups and groups outside Taiwan in the results of the present analysis. Three of the five aboriginal groups, Babuza, Pazeh, and Shi San Hang, while demonstrating biological closeness to one another, also share similarities with cranial series from Remote Oceania (Polynesia). Shi San Hang's association with Polynesian cranial series in the canonical variate plots in Fig. 5 and 6 is particularly noteworthy. These connections lend some support to linguistic (Bellwood, 1997; Blust, 1995), archaeological (Bellwood, 1997; Diamond, 1988; Kirch, 1997, 2000), and genetic (e.g., Melton et al., 1995; Sykes et al., 1995) evidence that has been interpreted to indicate the spread of proto-Polynesians from Taiwan through island Southeast Asia, an expansion which ultimately led to the initial settlement of Remote Oceania (Polynesia, Micronesia, and eastern Melanesia).

However, as demonstrated in previous analyses (e.g., Howells, 1983, 1984, 1986, 1989, 1995; Pietrusewsky, 1994, 1995), some of the Taiwan aboriginal series show connections with cranial series from northeastern Asia, southern China, and Southeast Asia as well, relationships which may hint at possible ultimate sources for Taiwan's aboriginal groups. These associations are evident in the canonical plots (Fig. 5 and 6), classification results (Table 11), and the table that summarizes the smallest distances (Table 12). Several of the Taiwan Aboriginal specimens are reclassified to Korea, Japan, and China. Likewise, several of the distances closest to the Taiwan aboriginal series include cranial series from Japan, China, Korea, and Southeast Asia. The Ainu, Ryukyu, and Jomon series are among the distances closest to Bunun. These results lend support to mtDNA sequence data (Melton et al., 1998) which demonstrate that Taiwan's extant aboriginal inhabitants derive from a diverse source in central and southern China with possible later intrusions from coastal northeast Asia (e.g., Japan, Ainu, Korea, Ryukyu Is.).

Biological relationships between Atayal, Bunun, and several other Taiwan aboriginal groups and minority groups such as the Rhade of northern Vietnam have been noted in earlier anthropometric studies by Bowles (1977). An Atayal-Southeast Asia (especially Vietnam) connection was reported in an earlier craniometric study (Pietrusewsky,1995). The results of the present study, especially the plot of the group means on the first two canonical variates (Fig. 7), strengthens the association between Atayal, Vietnam, the Philippines, and Southeast Asia. Bowles (1977) noted that the Bunun were most closely related to the Atayal and Saisiat aboriginal groups, a finding which is consistent with the results of the present craniometric analysis. Chai (1967) enumerated some of the distinctive features of the Bunun aboriginals that include short stature, compact bodies, unique facial features, and dark skin color.

Melton et al. (1998), using mtDNA evidence, have reported similarities between some of Taiwan's aboriginal groups and the groups in the Philippines. Similar connections have been reported by others using red cell antigen, serum protein, and red cell enzyme polymorphisms (e.g., Chen et al., 1985; Yuasa et al., 2001). Results based on Y chromosome data (Su et al. 2000) have been used to hypothesize that Southeast Asia was the source of two possible migrations, one toward Taiwan and another toward Remote Oceania by way of island Southeast Asia, results which again can be supported by the results of the present analysis.

Finally, the present craniometric results indicate a clear distinction between the inhabitants of East / North Asia and Southeast Asia (mainland and insular), a distinction that implies long term in-situ evolution for the inhabitants of both regions and further argues against displacement of the earlier inhabitants of Southeast Asia. Similar conclusions have been reached by Turner (1987, 1989, 1990, 1992) using dental morphology and Hanihara (1993) using craniometric data, a view which is at odds with the agricultural colonization model based on archaeological and historical linguistic data (Bayard, 1996; Bellwood, 1993, 1996; Blust, 1996; Glover and Higham, 1996; Higham, 1996).

Conclusions

The results of the present multivariate craniometirc analysis allow some tentative conclusions regarding the biological relationships and possible origins of Taiwan's aboriginal groups.

1. Overall, there are both similarities as well as differences among Taiwan aboriginal groups. While the Babuza, Pazeh, and Shi San Hang cranial series exhibit biological similarities, the Atayal and Bunun series generally remain well differentiated from the other aboriginal groups. The morphological diversity represented by these five series is consistent with a relatively extended period of isolation (externally as well as internally) and the general absence of extensive gene flow among these groups.
2. The observed connections between some of the Taiwan aboriginal groups and Southeast Asia suggest movements of people between these two regions. The aboriginal inhabitants of Taiwan may have served as either the ancestral group of people now living in Southeast Asia or the aboriginal inhabitants of Taiwan may have originated in Southeast Asia.
3. Connections between Taiwan aboriginal cranial series and those from eastern and northeastern Asia may provide evidence for the ultimate source of Taiwan's prehistoric and modern aboriginal groups.

4. The observed similarities between some of the Taiwan aboriginal series and those from Remote Oceania indicate possible ancestral ties between the indigenous inhabitants of Taiwan and Pacific peoples.

5. Separate origins are indicated for the people who occupy Australia and Melanesia and those who inhabit eastern Asia and the Pacific. Taiwan aboriginals are members of the greater Asian / Pacific division.

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