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Discriminant function analysis of craniometric data for distinguishing Japanese and Filipino crania

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ABSTRACT

Given their similar morphology and gene-flow histories, determining whether an unidentified cranium found in the Philippines is Japanese or Filipino presents a challenge. Two different analyses are undertaken. First, discriminant function (DF) analyses are applied to 295 crania using 22 measurements for distinguishing between: 1) males and females, 2) Japanese and Filipino males, and 3) Japanese and Filipino females, and 4) among four groups (Japanese males, Filipino males, Japanese females, and Filipino females). Second, a DF equation for distinguishing Japanese males and Filipino males using 173 crania and 29 measurements is introduced. In addition to being able to distinguish between Japanese and Filipino crania, this study found that seldom used cranial measurements such as simonic chord (least nasal breadth -WNB), inferior malar length (IML), and maximum malar length (XML) are influential for distinguishing between these two Asian groups. The predicted classification accuracy of DF equations from both analyses ranged from 82.0% to 93.6%. Sixty test crania for the first study and 40 for the second study maintains classification success rates between 82.0% and 93.3%. The DF equations reported in this study can be a useful initial screening tool for identifying Japanese war dead in the Philippines.

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Introduction

The three broad categories for assessing the ancestry of an unknown cranium currently used by forensic anthropologists are Asian, African, and European. After the Industrial Revolution in the late 18th century, this classification scheme became somewhat untenable given the acceleration of gene exchange that resulted from colonization, war, influx of refugees, economic globalization, and improvements in transportation technology. This was especially true in regions of the world such as Latin America and Southeast Asia, where it has become increasingly difficult to classify individuals into one of the three continental groups[1–4].

One Southeast Asian country that has experienced an increased frequency of gene exchange is the Philippines. The Republic of the Philippines has been under the rule of Spain (1565–1898), United States (1898–1946), and occupation by Japan (1942–1945). More than three hundred years before the World War II (WWII), the Japanese had contact

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with the Philippines when the Christian feudal lord, Ukon Takayama, was forced into exile by the first Shogun Ieyasu Tokugawa in 1614[5]. Beginning in the early 20th century, the first groups of Japanese began arriving in the Philippines as labourers in the construction of the Halsema (or Benguet-Mountain Province) Highway in northern Luzon[6–9] and later as workers in the hemp industry in Mindanao[7–10]. Japan also had trade and cultural exchanges with neighbouring North/East Asian countries including North and South Korea, China, Mongolia, and the Russian Far East for more than a few centuries.

In Japan, the first contact with Europeans was in 1543 when the Portuguese trade introduced guns, and in 1549 when Francisco Xavier and other Spanish missionaries attempted to introduce Christianity in Japan. Soon, however, persecution of Christian converts began, followed by the over 214-year isolationist foreign policy of the Japanese Tokugawa shogunate that severely limited trade between Japan and other countries. During this period, nearly all foreigners were barred from entering Japan and most common Japanese people were not allowed to leave the country. With the end of WWII in 1945, Japan was briefly occupied by nearly 1 million American-led Allied soldiers until 1952 although Okinawa was not returned to Japan until 1972. In 1953, the Japanese Ministry of Health, Labour and Welfare (MHLW) dispatched collection teams to recover the remains of war dead from battlefields in the Pacific[11]. Of the 3.2 million Japanese, including civilians, who died during the war, 518,000 Japanese soldiers lost their lives in the Philippines, of which 369,470 have yet to be recovered[12]. At the same time, approximately 1 million Filipino casualties, including civilians and members of the liberation army, were recorded during the war period[13]. Given that a great many Japanese war dead have yet to be discovered in the Philippines, there is a need to develop an accurate way of identifying and separating Japanese skeletal remains from Filipino remains during field recovery operations in the Philippines.

Biodistance studies by physical[14–29] and dental[30–33] anthropologists have demonstrated that North/East (Sinodonty) and Southeast (Sundadonty) Asian groups can be separated by cranial and dental morphology. Other studies have examined differences between Japanese and Koreans[34] and between Japanese and Thai groups[35]. Harrington[34] found that regardless of the intertwined history of gene flow between the Korean peninsula and the Japanese archipelago, the crania of Japanese and Koreans can be distinguished using traditional two-dimensional (2D) craniometric and three-dimensional (3D) geometric morphometric methods. The same author found the Korean crania were more brachycephalic and higher, with larger facial features than Japanese crania. Likewise, Kongkasuriyachai et al.[35] reported that Thai crania were more brachycephalic, with broader facial features than the Japanese crania. In the same study, it was found that the inclusion of mandible measurements resulted in a higher accuracy in distinguishing between Thai and Japanese individuals than if cranial measurements were used alone. Both Harrington and Kongkasuriyachai et al. noted the paucity of craniometric studies involving closely related Asian groups and the lack of discriminant function (DF) analysis of craniometric data focusing on Japanese and Filipinos.

The present study examines how accurately the crania of Japanese and Filipino individuals can be discriminated using traditional 2D morphometrics. Specifically, this study is designed mainly as a screening tool for use in a field setting involving the search and recovery of Japanese war dead in the Philippines. The study is divided into two parts. First, discriminant function equations are produced for distinguishing between: 1) males and females, 2) Japanese males and Filipino males, and 3) Japanese females and Filipino females and 4) a multigroup equation using 22 measurements. Second, as a way of improving classification results, a DF equation for distinguishing Japanese males and Filipino males using 29 measurements is introduced. The second analysis uses measurements not available in the first analysis. Only measurements recorded in male crania were available for the second analysis.

Given that twice as many Filipinos, including civilians, died during the war than Japanese, it is essential that DF equations based on cranial measurements be used as a preliminary screening tool for separating Japanese and Filipino skeletal remains, results which can then be amplified using other methods such as stable isotope anlaysis[36–41] and DNA analysis[42–51].

Materials and methods

A total of 295 Japanese and Filipino crania are used in the first analysis (Table 1) and a total of 173 Japanese and Filipino male crania are used in the second analysis (Table 2). Data recorded in Japanese crania are from Howells[14] and Hanihara[23,24], while the measurements recorded in Filipino crania are those from Howells[14], Hanihara[23,24], Pietrusewsky[25–29], and Go et al.[1 2 3]. The Japanese crania measured by Howells are from two dissecting room collections representing modern individuals from northern (Hokkaido) and southern (Kyushu) Japan. The crania measured by Hanihara represent modern Japanese from Honshu Island. The Filipino crania measured by Howells include convicts who died in prison in Manila, but who likely were from different regions outside Manila. The Philippine series used by Hanihara

Table 1. Japanese and Filipino cranial series used in the first analysis; the numbers within the parentheses represent the number of test crania* used in this study.

				Japanese
	Sex			
Researcher	Male	Female	Total	Provenience/Collection Location
Howells (1989)	86(20)	43(10)	129(30)	North Japan: Hokkaido/Hokkaido University, Sapporo; South Japan: North Kyushu/Department of Anatomy, Kyushu University, Fukuoka
Hanihara, T (2013)	20	-	20	Honshu/The University Museum, The University of Tokyo; National Museum of Natural History, Smithsonian Institution, Washington, D.C.
Total	106(20)	43(10)	149(30)	
				Filipino
Hanihara, T (2000)	64(11)	26(7)	90(18)	Recent native inhabitants of the Philippines: Tagalog and other ethnic groups from Luzon, Mindanao, and Sulu Islands/ Musée de l'Homme, Paris; University of Cambridge (UK); National Museum of Natural History, Smithsonian Institution, Washington, D.C.
Go et al. (2019)	-	16(3)	16(3)	Manila, Luzon/ Archaeological Studies Program, University of the Philippines Diliman, Quezon City
Howells (1989)	40(9)	-	40(9)	Manila and other regions of the Philippines/Medical School, University of the Philippines, Manila
Total	104(20)	42(10)	146(30)	
Grand Total	210(40)	85(20)	295(60)	

*():test samples were NOT included for developing discriminant function equations: considered as unknown individuals.

Table 2. Japanese and Filipino male cranial series; the numbers within the parentheses represent the number of test crania* used in this study.

Researcher		Provenience/Collection Location
		Japanese males
Howells (1989)	86(20)	North Japan: Hokkaido/Hokkaido University, Sapporo; South Japan: North Kyushu/Department of Anatomy, Kyushu University, Fukuoka
		Filipino males
Howells (1989)	40(10)	Manila and other regions of the Philippines/Medical School, University of the Philippines, Manila
Pietrusewsky (2008)	47(10)	Abra, Cagayan, Ilocos Sur, Mountain, Tarlac, Infanta, Lalanga, and Bataan Provinces, Luzon; Sulu Islands/Museum für Naturkunde, Berlin; Museum für Völkerkunde, Dresden; Musée de l'Homme, Paris
Total	173(40)	

*():test samples were NOT included for developing discriminant function equations: considered as unknown individuals.

represent a collection of diverse ethnic/linguistic groups from various geographic locations. The majority of the Filipino crania measured by Pietrusewsky are from the multiple regions of Luzon and the Sulu Islands found in museum collections in Europe. The sample analysed by Go et al.[2] comprises skeletons from exhumed and abandoned tombs at the Manila North Cemetery in Manila representing contemporary Filipinos, most with documented age and sex obtained from tombstone inscriptions. The test samples, randomly selected and not included in the study sample, were used for efficacy tests for each equation.

In order to obtain the best results of multivariate discriminant function analysis only complete sets of data were used. Accordingly, in the first study, 22 cranial measurements, measurements common to Howells, Hanihara, and Go et al. were used (Table 3). Since the least nasal breadth (WNB) was not available in the Filipino data from Go et al., this measurement was recorded by the first author (AH) for these crania. In the second study, twenty-nine cranial measurements were used to generate the discriminant function (DF) equation for distinguishing between Japanese males and Filipino males to see if the precision accuracy would change using 22 variables from first study (Table 3). Both studies further allowed the identification of the measurements that were most important for the accuracy of the DF results.

Before performing the statistical analyses, the underlying assumptions associated with discriminant function analysis (DFA) were examined. Among the most important statistical assumptions associated with DFA are multivariate normality (each variable is normally distributed and all pairs of variables are bivariate normal), homogeneity of variances/covariances (testing the level of variation in each group), outlier individuals, and trait interdependence or correlation. Once the assumptions of the multivariate data were satisfied, a total of 295 individuals for the first study, and 173 individuals for the second study, were used to produce discriminant function equations in this study.

The classification accuracy was compared using the stepwise method, which computes the linear classification functions by selecting those variables that contributed the most to the discrimination by maximizing the separation of the groups[25]. A test sample of 20 each Japanese males and Filipino males, ten each Japanese females and Filipino females for the first study, and 20 each Japanese and Filipino males for second study, were used for the efficacy test to compare the accuracy. Statistical programs IBM SPSS 24, Excel 2016, and Minitab 14 were used for these analyses.

Table 3. Cranial measurements (and abbreviations[17]) used in this study.

	Measurement	Howells, Hanihara, and Go et al.*	Howells and Pietrusewsky**
1	Glabello-occipital length	GOL	GOL
2	Nasio-occipital length	NOL	NOL
3	Basion-nasion length	BNL	BNL
4	Basion-bregma height	BBH	BBH
5	Maximum cranial breadth	XCB	XCB
6	Maximum frontal breadth	XFB	XFB
7	Bizygomatic breadth	ZYB	ZYB
8	Biauricular breadth	AUB	AUB
9	Biasterionic breadth	ASB	ASB
10	Minimum cranial breadth	-	WCB
11	Basion prosthion length	BPL	BPL
12	Nasion-prosthion height	NPH	NPH
13	Nasal height	NLH	NLH
14	Nasal breadth	NLB	NLB
15	Palate breadth	MAB	MAB
16	Mastoid height	MDH	MDH
17	Orbit height	OBH	OBH
18	Orbit breadth	-	OBB
19	Interorbital breadth	DKB	-
20	Bimaxillary breadth	ZMB	ZMB
21	Nasion-bregma chord	FRC	FRC
22	Bregma-lambda chord	PAC	PAC
23	Lambda-opisthion chord	OCC	OCC
24	Simotic chord (least nasal breadth)	WNB	-
25	Bijugal breadth	-	JUB
26	Biorbital breadth	-	EKB
27	Malar length, inferior	-	IML
28	Malar length, maximum	-	XML
29	Cheek height	-	WMH
30	Bistephanic breadth	-	STB
31	Foramen magnum length	-	FOL

*22 cranial measurements are from Howells, Hanihara, and Go et al.; the WNB measurement for Filipino females was recorded by the first author (AH).
** 29 cranial measurements are from Howells and Pietrusewsky.

Results: 22 measurements recorded in 295 crania

In the first study, simple two-way DF equations were generated for distinguishing between male and female, Japanese and Filipino males, Japanese and Filipino females, and one DF equation involving multiple groups. The descriptive statistics (means and confidence intervals) and t-test results for 22 cranial measurements from Howells, Hanihara, and Go et al. used in the first study are given in Tables 4–6. The descriptive statistics for 22 cranial measurements recorded in 40 male and 20 female test individuals are given in Tables 7 and 8, respectively. The results presented in Tables 5–8 indicate that Japanese crania are generally larger than Filipino crania, whereas Filipino male crania have wider nasal aperture (NLB), larger nasal bones (WNB) and wider interorbital breadth (DKB) than Japanese male crania. In addition, NLB and WNB are larger in Filipino female crania than Japanese female crania. The classification results obtained from each stepwise discriminant function analysis, including cross-validation classification, canonical unstandardized and standardized coefficients, centroids, sectioning points, in the first study are given in Tables 9–12. Histograms of the two-way DF analyses are presented in Figures 1–3. Scatter plots and a 3D graph resulting from the DFA are shown in Figures 4, 5, respectively.

Table 4. Descriptive statistics and t-test results for 22 cranial measurements (in mm) recorded in 295 individuals (pooled males and females) by Howells, Hanihara, and Go et al. (CI: confidence interval, L: lower limit, U: upper limit).

		Male n = 210				Female n = 85					
				95%CI				95%CI			
		Mean	SD	L	U	Mean	SD	L	U	*t*	Sig.
1	GOL	180.15	6.31	179.29	181.00	169.67	6.52	168.26	171.08	12.79	0.000
2	NOL	177.55	6.18	176.71	178.39	167.91	6.68	166.47	169.35	11.85	0.000
3	BNL	100.73	4.24	100.15	101.38	94.90	3.33	94.18	95.62	11.33	0.000
4	BBH	136.30	5.10	135.61	137.00	129.66	4.79	128.63	130.70	10.30	0.000
5	XCB	140.02	5.23	139.31	140.74	134.59	4.49	133.62	135.56	8.39	0.000
6	XFB	115.73	4.74	115.09	116.38	111.25	4.52	110.27	112.22	7.46	0.000
7	ZYB	133.69	4.95	133.01	134.36	124.36	4.21	123.45	125.26	15.27	0.000
8	AUB	123.43	4.81	122.78	124.09	117.48	4.26	116.56	118.39	9.94	0.000
9	ASB	108.21	4.28	107.63	108.80	103.26	3.77	102.45	104.08	10.47	0.000
10	BPL	98.60	5.15	97.90	99.30	92.59	4.42	91.64	93.55	9.30	0.000
11	NPH	68.20	4.29	67.61	68.78	64.67	4.18	63.77	65.57	9.45	0.000
12	NLH	51.85	2.75	51.48	52.23	49.01	2.88	48.39	49.63	6.44	0.000
13	NLB	26.69	1.99	26.42	26.96	25.92	1.78	25.53	26.30	7.93	0.002
14	MAB	65.69	3.73	65.18	66.20	61.86	3.88	61.02	62.70	7.89	0.000
15	MDH	29.23	3.41	28.77	29.70	25.17	2.81	24.56	25.78	9.73	0.000
16	OBH	33.85	1.66	33.62	34.08	33.78	1.93	33.36	34.19	0.35	0.727
17	DKB	21.94	2.05	21.66	22.22	20.83	2.12	20.37	21.29	4.18	0.000
18	WNB*	7.58	1.97	7.31	7.85	7.90	1.85	7.50	8.29	−1.27	0.204
19	ZMB	98.20	4.38	97.60	98.79	93.13	4.29	92.20	94.06	9.05	0.000
20	FRC	111.36	4.60	110.73	111.98	105.92	4.62	104.93	106.92	9.19	0.000
21	PAC	112.53	5.93	111.72	113.34	108.03	6.00	106.74	109.32	5.88	0.000
22	OCC	98.72	5.37	97.99	99.45	94.79	4.91	93.73	95.85	5.83	0.000

*The first author (AH) recorded the WNB measurement for Filipino females.

Table 5. Descriptive statistics and t-test results for 22 cranial measurements (in mm) recorded in Japanese and Filipino male (pooled) crania by Howells and Hanihara (CI: confidence interval, L: lower limit, U: upper limit).

		Japanese male n = 106				Filipino male n = 104					
				95%CI				95%CI			
		Mean	SD	L	U	Mean	SD	L	U	*t*	Sig.
1	GOL	181.92	5.68	180.82	183.01	178.34	6.43	177.09	179.59	4.269	0.000
2	NOL	179.37	5.53	178.30	180.43	175.70	6.28	174.48	176.92	4.492	0.000
3	BNL	101.81	4.18	101.01	102.62	99.63	4.04	98.84	100.41	3.855	0.000
4	BBH	137.38	5.11	136.40	138.37	135.21	4.87	134.26	136.15	3.156	0.002
5	XCB	140.31	4.80	139.38	141.23	139.74	5.65	138.64	140.83	0.790	0.430
6	XFB	116.01	4.45	115.15	116.87	115.45	5.02	114.48	116.43	0.852	0.395
7	ZYB	134.61	4.44	133.75	135.46	132.75	5.29	131.72	133.77	2.769	0.006
8	AUB	123.82	4.41	122.97	124.67	123.03	5.18	122.03	124.04	1.187	0.237
9	ASB	109.09	4.51	108.23	109.96	107.32	3.85	106.57	108.07	3.069	0.002
10	BPL	98.83	5.40	97.80	99.87	98.37	4.89	97.42	99.32	0.654	0.514
11	NPH	70.22	3.84	69.48	70.96	66.14	3.72	65.42	66.86	7.808	0.000
12	NLH	52.46	2.88	51.91	53.02	51.24	2.48	50.75	51.72	3.310	0.001
13	NLB	25.91	1.83	25.55	26.26	27.49	1.82	27.14	27.85	−6.283	0.000
14	MAB	66.63	3.89	65.88	67.38	64.73	3.32	64.08	65.38	3.795	0.000
15	MDH	30.16	3.32	29.52	30.80	28.29	3.25	27.66	28.92	4.128	0.000
16	OBH	34.41	1.53	34.12	34.71	33.29	1.61	32.98	33.60	5.177	0.000
17	DKB	21.60	2.26	21.16	22.03	22.29	1.75	21.95	22.63	−2.465	0.015
18	WNB	7.19	1.86	6.83	7.55	7.98	2.00	7.59	8.37	−2.952	0.004
19	ZMB	98.42	4.68	97.52	99.32	97.97	4.05	97.18	98.76	0.739	0.461
20	FRC	111.09	4.70	110.18	112.00	111.63	4.49	110.76	112.51	−0.859	0.392
21	PAC	112.96	5.94	111.82	114.11	112.09	5.91	110.94	113.23	1.071	0.286
22	OCC	100.17	5.18	99.17	101.16	97.24	5.18	96.23	98.25	4.091	0.000

Table 6. Descriptive statistics and t-test results for 22 cranial measurements (in mm) recorded in Japanese and Filipino female (pooled) crania by Howells, Hanihara, and Go et al. (CI: confidence interval, L: lower limit, U: upper limit).

		Japanese female n = 43				Filipino female n = 42					
				95%CI				95%CI			
		Mean	SD	L	U	Mean	SD	L	U	*t*	Sig.
1	GOL	171.56	6.36	169.60	173.52	167.74	6.18	165.81	169.66	2.808	0.006
2	NOL	170.28	6.42	168.30	172.25	165.49	6.11	163.58	167.39	3.524	0.001
3	BNL	95.58	3.31	94.56	96.60	94.20	3.23	93.19	95.21	1.938	0.056
4	BBH	129.56	4.84	128.07	131.05	129.77	4.80	128.28	131.27	−0.206	0.837
5	XCB	133.70	4.11	132.43	134.96	135.51	4.72	134.04	136.98	−1.890	0.062
6	XFB	110.63	4.73	109.17	112.08	111.88	4.26	110.55	113.21	−1.283	0.203
7	ZYB	124.95	4.50	123.57	126.34	123.75	3.85	122.55	124.95	1.324	0.189
8	AUB	117.21	4.63	115.79	118.63	117.75	3.88	116.54	118.96	−0.583	0.561
9	ASB	104.37	3.57	103.27	105.47	102.13	3.66	100.99	103.27	2.858	0.005
10	BPL	93.72	4.12	92.45	94.99	91.44	4.45	90.05	92.83	2.450	0.016
11	NPH	66.16	3.63	65.05	67.28	63.14	4.19	61.84	64.45	3.552	0.001
12	NLH	49.93	2.51	49.16	50.70	48.07	2.96	47.15	49.00	3.122	0.002
13	NLB	25.49	1.68	24.97	26.01	26.36	1.78	25.80	26.91	−2.313	0.023
14	MAB	62.74	3.45	61.68	63.81	60.95	4.12	59.67	62.24	2.174	0.033
15	MDH	25.98	2.76	25.13	26.82	24.35	2.65	23.52	25.17	2.779	0.007
16	OBH	34.19	1.92	33.60	34.78	33.36	1.88	32.77	33.94	2.014	0.047
17	DKB	20.51	2.02	21.13	20.56	21.15	2.19	20.47	21.84	−1.408	0.163
18	WNB*	7.23	1.69	6.72	7.75	8.57	1.77	8.02	9.12	−3.561	0.001
19	ZMB	92.49	4.07	91.23	93.74	93.79	4.46	92.40	95.18	−1.406	0.163
20	FRC	105.53	4.84	104.04	107.03	106.32	4.40	104.95	107.69	−0.783	0.436
21	PAC	108.00	5.35	106.35	109.65	108.06	6.66	105.98	110.13	−0.045	0.964
22	OCC	95.42	4.96	93.89	96.95	94.14	4.82	92.64	95.65	1.202	0.233

*The first author (AH) recorded the WNB measurement for Filipino females.

Equation 1: Sex unknown (Table 9, Figure 1)

The classifications results used to generate Equation 1 for separating males and females, obtained through the application of DFA to 22 cranial measurements, are given in Table 9. Regardless of the differences in ancestry, nine cranial measurements (GOL, NOL, XCB, ZYB, AUB, NLH, MDH, OBH, and WNB) effectively discriminate on the basis of sex. The average accuracy revealed more than 93.0% in both the study and test samples. Figure 1 illustrates the sectioning point (−0.585), centroids (male: 0.795, female: −1.965) in the histogram of discriminant scores calculated by Equation 1.

Equation 2: Japanese males and Filipino males (Table 10, Figure 2)

The classifications results used to generate Equation 2, obtained through DFA indicate that ten of 22 cranial measurements (BNL, BPL, FRC, MDH, NLB, NLH, NOL, NPH, OBH, and WNB) were most responsible for separating Japanese and Filipino males (Table 10). The highest coefficient of canonical standardized function was NPH (1.041), suggesting this is a crucial variable in separating Japanese male and Filipino male crania. The negative coefficient of WNB (−0.467) in the standardized function also contributes relatively good discriminating power. On average, 87% of Japanese males and Filipino males were correctly classified in the study and test samples, while the cross-validation procedure

Table 7. Descriptive statistics for 22 cranial measurements (in mm) recorded in 40 test male individuals by Howells and Hanihara (CI: confidence interval, L: lower limit, U: upper limit).

		Japanese Male: JM n = 20				Filipino Male: PM n = 20			
				95%CI				95%CI	
		Mean	SD	L	U	Mean	SD	L	U
1	GOL	183.30	5.89	180.54	186.06	176.78	6.48	173.74	179.81
2	NOL	180.40	5.57	177.79	183.01	173.85	6.75	170.69	177.01
3	BNL	101.05	3.95	99.20	102.90	98.50	4.12	96.57	100.43
4	BBH	138.50	5.78	135.79	141.21	134.65	4.27	132.65	136.65
5	XCB	139.30	4.18	137.34	141.26	136.34	5.25	141.26	139.00
6	XFB	115.65	3.62	113.96	117.34	113.65	5.02	111.30	116.00
7	ZYB	133.45	4.70	131.25	135.65	131.30	4.64	129.13	133.47
8	AUB	121.90	3.72	120.16	123.64	121.70	5.24	119.25	124.15
9	ASB	107.50	4.01	105.62	109.38	107.85	5.48	105.29	110.41
10	BPL	98.50	3.68	96.78	100.22	98.15	4.09	96.23	100.07
11	NPH	69.65	3.59	67.97	71.33	67.10	3.49	65.47	68.73
12	NLH	51.80	2.73	50.52	53.08	51.48	2.41	50.35	52.60
13	NLB	25.90	1.29	25.29	26.51	27.50	1.28	26.90	28.10
14	MAB	66.15	3.83	64.36	67.94	65.00	3.42	63.40	66.60
15	MDH	31.30	2.56	30.10	32.50	28.90	3.04	27.48	30.32
16	OBH	33.90	1.48	33.21	34.59	33.28	1.71	32.47	34.08
17	DKB	21.35	1.84	20.49	22.21	21.53	1.94	20.62	22.43
18	WNB	7.04	1.57	6.30	7.78	7.78	2.49	6.62	8.94
19	ZMB	96.65	5.49	94.08	99.22	99.75	4.67	97.57	101.94
20	FRC	111.90	3.01	110.49	113.31	110.55	4.06	108.65	112.45
21	PAC	116.25	4.83	113.99	118.51	110.70	5.94	107.92	113.48
22	OCC	100.55	6.83	97.35	103.75	98.20	5.53	65.61	100.79

Table 8. Descriptive statistics for 22 cranial measurements (in mm) recorded in 20 test female individuals by Howells, Hanihara, and Go et al. (CI: confidence interval, L: lower limit, U: upper limit).

		Japanese Female: JF n = 10				Filipino Female: PF n = 10			
				95%CI				95%CI	
		Mean	SD	L	U	Mean	SD	L	U
1	GOL	170.60	5.17	166.90	174.30	168.70	6.34	164.16	173.24
2	NOL	169.10	5.07	165.48	172.72	165.80	6.52	161.13	170.47
3	BNL	96.60	3.78	93.90	99.30	94.55	2.65	92.65	96.45
4	BBH	129.80	6.05	125.47	134.13	129.45	4.78	126.03	132.87
5	XCB	133.70	4.37	130.57	136.83	133.75	5.29	129.97	137.53
6	XFB	109.60	4.58	106.33	112.87	110.90	3.03	108.73	113.07
7	ZYB	127.20	6.37	122.64	131.76	122.65	5.27	118.88	126.42
8	AUB	119.10	6.82	114.22	123.98	117.70	5.17	114.01	121.39
9	ASB	105.10	3.81	102.37	107.83	102.55	2.17	101.00	104.10
10	BPL	93.10	3.48	90.61	95.59	90.35	4.99	86.78	93.92
11	NPH	66.00	4.92	62.48	69.52	63.00	3.40	60.57	65.43
12	NLH	49.60	3.37	47.19	52.01	47.30	3.34	44.91	49.69
13	NLB	25.70	2.16	24.15	27.25	24.55	1.14	23.73	25.37
14	MAB	63.90	3.11	61.68	66.12	59.50	2.68	57.58	61.42
15	MDH	25.90	3.41	23.46	28.34	24.25	2.04	22.79	25.71
16	OBH	35.00	2.11	33.49	36.51	32.70	2.26	31.08	34.32
17	DKB	20.50	2.99	18.36	22.64	21.50	2.80	19.50	23.50
18	WNB*	7.07	1.43	6.05	8.09	8.44	1.90	7.08	9.79
19	ZMB	94.00	5.48	90.08	97.92	92.41	3.11	90.19	94.64
20	FRC	104.10	3.63	101.50	106.70	105.10	3.13	102.86	107.34
21	PAC	107.50	5.80	103.35	111.65	107.65	5.68	103.59	111.71
22	OCC	95.10	4.63	91.79	98.41	95.45	4.95	91.91	98.99

*The first author (AH) recorded the WNB measurement for Filipino females.

Table 9. Discriminant function results: classification of individuals into male and female groups using 22 measurements from Howells, Hanihara, and Go et al.

Study sample							
Cross tabulation				Predicted group n = 295			
		Male	Female		Male/%	Female/%	Total %
Actual Male	n = 210	200	10	Original	200/95.2%	76/89.4%	93.6%
Actual Female	n = 85	9	76	Cross-validated	200/95.2%	74/87.1%	92.9%
Test sample							
Cross tabulation				Predicted group n = 60			
		Male	Female		Male/%	Female/%	Total %
Actual Male	n = 40	37	3	Efficacy test	37/92.5%	19/95.0%	93.3%
Actual Female	n = 20	1	19				

Canonical discriminant coefficients	Unstandardized Function 1 for **Eq. 1**	Standardized Function 1
GOL	0.228	1.450
NOL	−0.168	−1.063
XCB	0.072	0.361
ZYB	0.185	0.879
AUB	−0.123	−0.575
NLH	0.081	0.226
MDH	0.092	0.299
OBH	−0.188	−0.328
WNB	−0.089	−0.172
Constant	−29.744	

Centroid	
Male	Female
0.795	−1.965

Sectioning point
−0.585

Example: test #2170 as unknown sex individual.
(GOL:184, NOL:181, XCB:139, ZYB:134, AUB:123, NLH:54, MDH:33, OBH:33, WNB:6.9) using **Equation 1** to discriminate male and female.
(0.228*GOL)+(−0.168*NOL)+(0.072*XCB)+(0.185*ZYB)+(−0.123*AUB)+(0.081*NLH)+(0.092*MDH)+(−0.188*OBH)+(−0.089*WNB)-29.744 = **2.061**. A value less than −0.585 indicates female and a value greater than −0.585 indicates **male**.

indicated the precision is approximately 3% lower than the original data. Figure 2 illustrates the sectioning point (−0.01) and centroids (Japanese male: 1.059, Filipino male: −1.079) in the histogram of discriminant scores calculated by Equation 2.

Equation 3: Japanese females and Filipino females (Table 11, Figure 3)

A similar precision accuracy rate of 87.1% was obtained (Equation 3) with three measurements of length (FRC, GOL, PAC), two nasal measurements (WNB, NOL), and the mastoid height (MDH) being most responsible for separating Japanese and Filipino females (Table 11). All canonical standardized coefficients were considered as highly effective variables in separating Japanese and Filipino female crania. Figure 3 illustrates the sectioning point (0.015) and centroids (Japanese female: −1.205, Filipino female: 1.234) in the histogram of discriminant scores calculated by Equation 3.

Table 10. Discriminant function results: classification of individuals into Japanese male (JM) and Filipino male (PM) using 22 measurements from Howells and Hanihara.

Study sample							
Cross tabulation				Predicted group n = 210			
		JM	PM		JM/%	PM/%	Total %
Actual JM	n = 106	92	14	Original	92/86.8%	91/87.5%	87.1%
Actual PM	n = 104	13	91	Cross-validated	88/83.0%	89/85.6%	84.3%
Test sample							
Cross tabulation				Predicted group n = 40			
		JM	PM		JM/%	PM/%	Total %
Actual JM	n = 20	18	2	Efficacy test	18/90.0%	17/85.0%	87.5%
Actual PM	n = 20	3	17				

Canonical discriminant coefficients		
	Unstandardized Function 1 for **Eq. 2**	Standardized Function 1
BNL	0.100	0.411
BPL	−0.106	−0.547
FRC	−0.060	−0.276
MDH	0.085	0.278
NLB	−0.202	−0.370
NLH	−0.273	−0.734
NOL	0.085	0.502
NPH	0.275	1.041
OBH	0.151	0.236
WNB	−0.242	−0.467
Constant	−12.933	

Centroid	
Japanese male	Filipino male
1.059	−1.079

Sectioning point
−0.01

Example: test #2170 as unknown JM and PM individual.
(BNL:105, BPL:97, FRC:109, MDH:33, NLB:25, NLH:54, NOL:181, NPH:69, OBH:33, WNB:6.9) using **Equation 2** to discriminate Japanese male and Filipino male.
(0.100*BNL)+(0.106*BPL)+(0.060*FRC)+(0.085*MDH)+(0.202*NLB)+(0.273*NLH)+(0.085*NOL)+(0.275*NPH)+(0.151*OBH)+(−0.242*WNB) −12.933 = **1.431**. A value less than −0.01 indicates Filipino male and a value greater than −0.01 indicates **Japanese male.**

Equations 4a, 4b, 4c: Sex and Group Unknown (Table 12, Figures 4 & 5)

The classification results used to generate Equations 4a, 4b, and 4c for functions 1, 2, and 3, respectively, indicate that 14 of the 22 cranial measurements allowed maximum separation of Japanese males, Japanese females, Filipino males, and Filipino females prior to assessing sex (Table 12). The measurements that show high absolute value of canonical standardized coefficients in the first function include maximum cranial length (GOL), three cranial breadth measurements (ZYB, XCB, and AUB), upper facial height (NPH), mastoid height (MDH), and the least nasal breadth (WNB). Two cranial length measurements (GOL and NOL), upper facial height (NPH), nasal height (NLH) and breadth

Table 11. Discriminant function results: classification of individuals into Japanese female (JF) and Filipino female (PF) using 22 measurements from Howells, Hanihara, and Go et al.

Study sample							
Cross tabulation				Predicted group n = 85			
		JF	PF		JF/%	PF/%	Total %
Actual JF	n = 43	37	6	Original	37/86.0%	37/88.1%	87.1%
Actual PF	n = 42	5	37	Cross-validated	37/86.0%	37/88.1%	87.1%
Test sample							
Cross tabulation				Predicted group n = 20			
		JF	PF		JF/%	PF/%	Total %
Actual JF	n = 10	8	2	Efficacy test	8/80.0%	9/90.0%	85.0%
Actual PF	n = 10	1	9				

Canonical discriminant coefficients		
	Unstandardized Function 1 for **Eq. 3**	Standardized Function 1
FRC	0.201	0.930
GOL	0.569	3.565
MDH	−0.156	−0.422
NOL	−0.789	−4.945
PAC	0.122	0.736
WNB	0.307	0.531
Constant	3.072	

Centroid	
Japanese female	Filipino female
−1.205	1.234

Sectioning point
0.015

Example: test #809,632 as unknown Japanese and Filipino female individual.
(FRC:105, GOL:165, MDH:24, NOL:162, PAC:108, WNB:9.51 using **Equation 3** to discriminate Japanese female and Filipino female.
(0.201*FRC)+(0.569*GOL)+(−0.156*MDH)+(−0.789*NOL)+(0.122*PAC)+ (0.307*WNB)+3.072 = **2.596.**
A value less than 0.015 indicates Japanese female and a value greater than 0.015 indicates **Filipino female**.

(NLB), height of the eye orbit (OBH), base length (BPL), and frontal chord (FRC) are most responsible for separation in the second function. Cranial length (GOL, NOL), cranial base length (BNL, BPL), upper facial height (NPH), and nasal height (NLH) are most responsible for the separation observed in the third function. The three discriminant function equations classified 88 of 106 Japanese males, 87 of 104 Filipino males, 32 of 43 Japanese females, and 35 of 42 Filipino females correctly. The total precision accuracy was 82.0% and the cross-validated classification was 77.3% in the study sample. The efficacy test from the test sample demonstrated an average of 83.8% accuracy.

Figures 4 and 5 provide a visualization of the individual score plots and centroids of the 4 groups in 2D and 3D graphs, respectively. The test sample # 2170 (GOL: 184, NOL: 180, BNL: 105, XCB: 139, ZYB: 134, AUB: 123, BPL: 97, NPH: 69, NLH: 54, NLB: 25, MDH: 33, OBH: 33, WNB: 6.9, FRC: 109) was directly classified into Japanese male without assessing sex of the individual beforehand (Figure 4). After entering the cranial measurements into Equations 4a, 4b, and 4c, the discriminant scores were calculated as Function 1: 2.384,

Table 12. Discriminant function results: classification of individuals into 4 groups (JM: Japanese males, PM: Filipino males, JF: Japanese females, PF: Filipino females): Unknown sex and ancestry: using 22 measurements from Howells, Hanihara, and Go et al.

Study sample											
Cross tabulation						Predicted group n = 295					
		JM	PM	JF	PF		JM/%	PM/%	JF/%	PF/%	Total %
Actual JM	n = 106	88	16	1	1	Original	88/83.0%	87/83.7%	32/74.4%	35/83.3%	82.0%
Actual PM	n = 104	10	87	5	2	Cross-validated	85/80.2%	82/78.8%	28/65.1%	33/78.6%	77.3%
Actual JF	n = 43	3	3	32	5	Specificity	0.932	0.899	0.957	0.969	
Actual PF	n = 42	0	2	5	35	Accuracy	0.895	0.929	0.928	0.953	
Test sample											
Cross tabulation						Predicted group n = 60					
		JM	PM	JF	PF		JM/%	PM/%	JF/%	PF/%	Total %
Actual JM	n = 40	19	1	0	0	Efficacy test	19/95.0%	16/80.0%	8/80.0%	8/80.0%	83.8%
Actual PM	n = 40	3	16	1	0						
Actual JF	n = 20	0	0	8	2						
Actual PF	n = 20	0	0	2	8						

	Canonical unstandardized coefficients			Canonical standardized coefficients		
	Function 1 for **Eq. 4a**	Function 2 for **Eq. 4b**	Function 3 for **Eq. 4c**	Function 1	Function 2	Function 3
GOL	0.125	0.208	0.473	0.766	1.274	2.896
NOL	−0.047	−0.255	−0.532	−0.281	−1.532	−3.203
BNL	0.051	−0.041	0.192	0.199	−0.161	0.747
XCB	0.070	0.033	0.066	0.352	0.168	0.332
ZYB	0.185	0.024	−0.029	0.867	0.113	−0.138
AUB	−0.159	0.029	0.000	−0.743	0.133	0.002
BPL	−0.017	0.088	−0.143	−0.086	0.431	−0.702
NPH	0.095	−0.234	0.183	0.365	−0.894	0.698
NLH	−0.017	0.235	−0.342	−0.047	0.636	−0.925
NLB	−0.089	0.213	0.021	−0.161	0.384	0.037
MDH	0.121	−0.016	0.009	0.378	−0.051	0.030
OBH	−0.073	−0.193	0.070	−0.123	−0.323	0.118
WNB	−0.201	0.149	0.101	−0.377	0.280	0.189
FRC	−0.030	0.079	0.026	−0.140	0.365	0.118
Constant	−31.117	−12.790	−2.856			

Centroid			
	Function 1	Function 2	Function 3
JM	1.537	−0.516	0.186
PM	0.070	1.048	−0.184
JF	−1.395	−1.247	−0.571
PF	−2.624	−0.015	0.573

Example: test #2170 as unknown sex and ancestry individual (see text and Figures 4, 5).

Function 2: −0.461, Function 3: 0.283, respectively (Figure 4). The squared Mahalanobis distance of Japanese males was 0.730. The score coordinates of # 2170 are represented by a bowtie symbol in Figure 4 and a star in Figure 5, both of which are closest to the Japanese male centroid. While the distance from the centroid of Filipino males was 7.850, the distance from the centroid of Japanese females was 15.629, and the distance from the centroid of Filipino females was 25.364. The efficacy test shows that Japanese males had

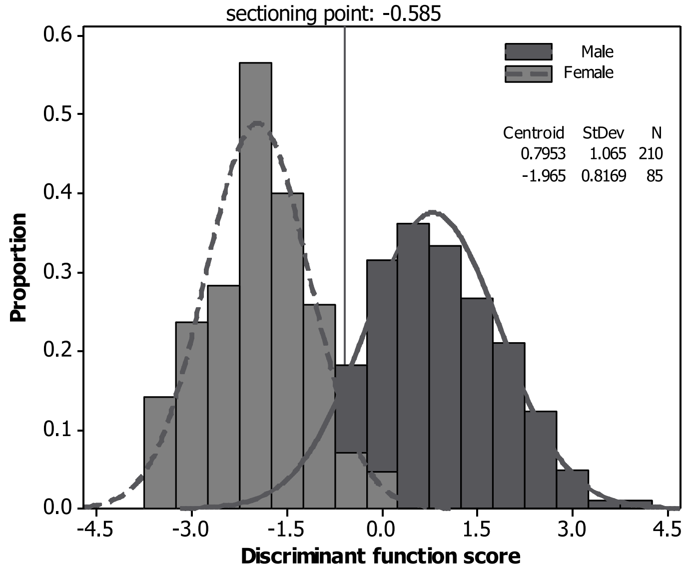

Figure 1. Histogram of two-way discriminant scores for males and females based on Equation 1.

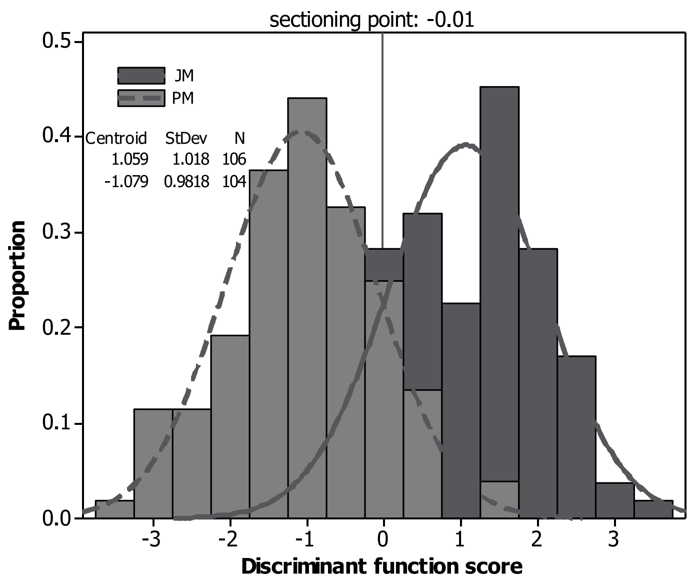

Figure 2. Histogram of two-way discriminant function scores for Japanese males (JM) and Filipino males (PM) based on Equation 2.

a higher precision accuracy of 95.0%, while the other three groups remained at 80.0% (Table 12). The specificity between 0.899 and 0.969 presents very few false positive rates (Type I error) explained with the four group discriminant function equation models.

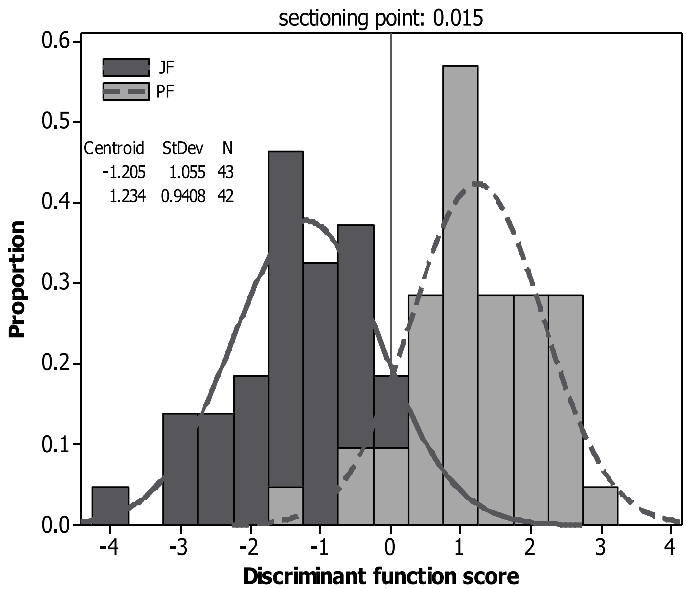

Figure 3. Histogram of two-way discriminant function scores for Japanese females (JF) and Filipino females (PF) based on Equation 3.

Because the calculation of scores and distances is more time-consuming than two-way DF equations, for a quick assessment in the field, Equation 1 should be calculated first to estimate sex, followed by Equation 2 or 3 for evaluating if the cranium is Japanese male or Filipino male, and if the cranium is Japanese female or Filipino female.

Results: 29 measurements recorded in 173 crania (Tables 3, 13, & 14)

In the second study, 29 cranial measurements, measurements common to Howells and Pietrusewsky (Table 3), were used to produce a simple two-way DF equation for distinguishing Japanese males and Filipino males. The descriptive statistics (means and confidence intervals) and t-test results for 29 measurements recorded by Howells and Pietrusewsky in 173 individuals and 40 test individuals are given in Tables 13 and 14, respectively. Filipino male crania have significantly longer inferior malar lengths (IML) and shorter maximum malar lengths (XML) compared to Japanese male crania (Table 13).

Equation HP (H = Howells and P = Pietrusewsky): Japanese male or Filipino male (Table 15, Figure 6)

The classification results used in Equation HP (Table 15) indicate that 11 of 29 cranial measurements (GOL, FOL, NPH, MAB, NLB, OBB, XML, OBH, IML, NLH, and ZMB) were selected to maximize the separation of Japanese males and Filipino males. Two measurements, IML and XML, were not available in the Hanihara and Go et al. data. In addition to these two measurements, maximum length of cranium (GOL), three measurements of the nasal region, (NPH, NLH, NLB), orbital measurements (OBH, OBB), bimaxillary breadth (ZMB) and foreman magnum length (FOL) were selected for Equation HP. Overall,

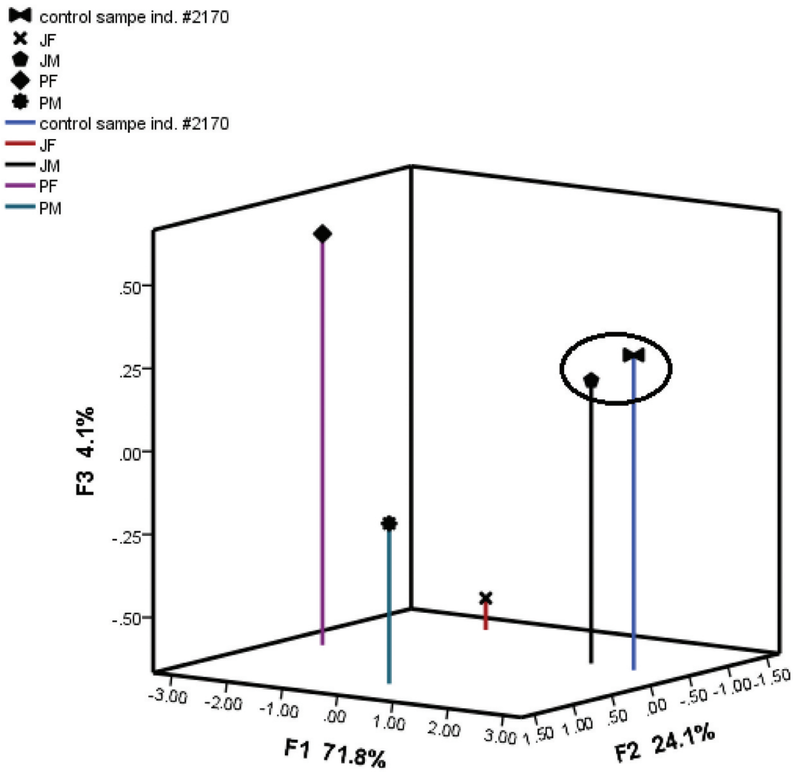

Figure 4. A 3D graph showing the centroids of Japanese male-JM (F1: 1.537, F2: −0.516, F3: 0.186), Filipino male-PM (F1: 0.070, F2: 1.048, F3: −0.184), Japanese female-JF (F1: −1.395, F2: −1.247, F3: −0.571) and Filipino female-PF (F1: −2.624, F2: −0.015, F3: 0.573) and test sample individual #2170 (F1: 2.384, F2: −0.461, F3: 0.283) for the first three discriminant functions based on DFA for sex and group unknown calculated by Equations 4a, 4b, and 4c. The coordinate of #2170 (the bowtie shape symbol) is closest to the centroid of JM.

Equation HP resulted in 89.6% correct classification in both study and test samples. Figure 6 illustrates the sectioning point (0.015) and centroids (Japanese male: 1.259, Filipino male: −1.244) in the histogram of discriminant scores calculated by Equation HP. Compared to Equation 2, precision and accuracy increased 2.5% in the predicted group and 4.7% in the cross-validated classification results. All eleven measurements had high or relatively high loading in the standardized canonical discriminant coefficients on the function; the negative coefficient of IML (–0.815) and positive coefficient XML (0.767) were the most influential variables in separating the Japanese males and Filipino males.

Discussion

Utility of group-specific DF equations for differentiating sex for Japanese and Filipinos

Compared to other groups, there is reduced sexual dimorphism in Asian groups, creating problems for determining the sex of Asian crania[52]. A geometric morphometric analysis of unilateral and midline landmark coordinates by Green and Curnoe[53] detected significant

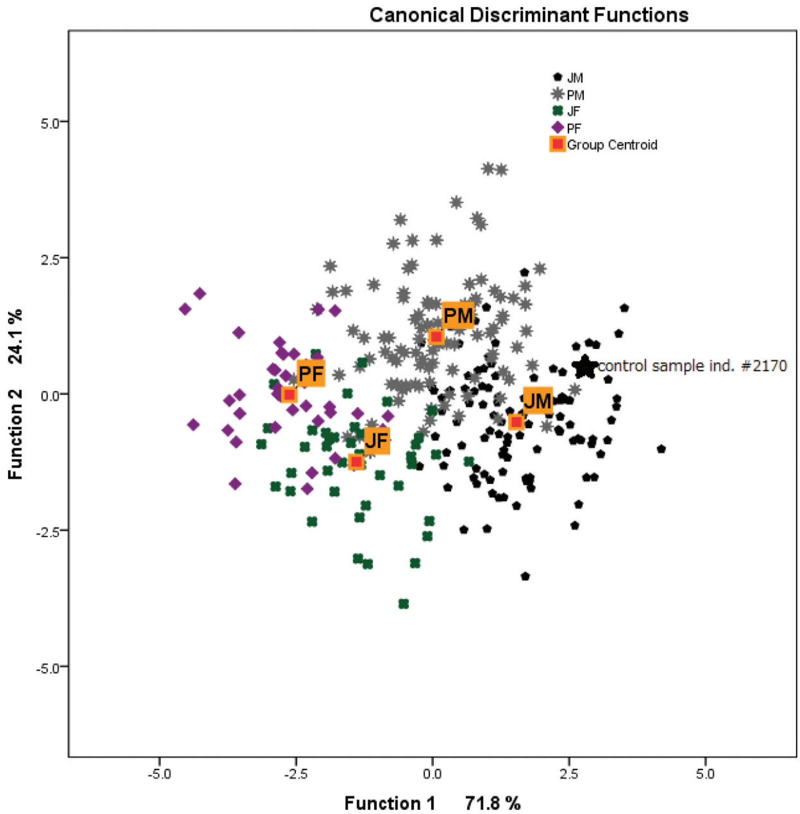

Figure 5. Scatter plots and centroids of Japanese male-JM (F1: 1.537, F2: −0.516), Filipino male-PM (F1: 0.070, F2: 1.048), Japanese female-JF (F1: −1.395, F2: −1.247) and Filipino female-PF (F1: −2.624, F2: −0.015) on Functions 1 and 2. The coordinate of test sample individual #2170 (star) is located closest to the centroid of JM.

cranial shape (i.e. facial and vault breadths) and size dimorphism in Southeast Asian (including Filipino) groups. In the same study, an expected accuracy of 86.8% was achieved in the discriminant analysis of Southeast Asians that used both cranial shape and size. Using only shape, the accuracy of sex discrimination was found to decrease to 77%. More recent research by Tallman[52] using five nonmetric features (nuchal crest, mastoid process, superorbital margin, glabella, and mental eminence) indicated Japanese, Thai, and Filipino crania exhibited reduced sexual dimorphism compared to non-Asian groups. Further, the results of Tallman's study suggested that univariate and multivariate models based on Filipino data could be cautiously applied to other Southeast (e.g. Thai) and East (e.g. Japanese) Asian groups. Both studies stressed the importance of developing population-specific methods for sex determination in Asian groups. Thus the assessment should not be applied as a standard for other groups, such as Europeans and Africans. Using the results of the present study, if an unknown cranium presents gracile features as determined by non-metric analysis, Equation 1 would enhance the clarification of the sex of the Japanese or Filipino groups. Although the standardized canonical discriminant function coefficient of WNB (–0.172) was low, this measurement was still

Table 13. Descriptive statistics and t-tests for 29 cranial measurements (in mm) recorded in 173 Japanese and Filipino male crania by Howells and Pietrusewsky (CI: confidence interval, L: lower limit, U: upper limit).

		Japanese Male n = 86				Filipino Male n = 87					
				95%CI				95%CI			
		Mean	SD	L	U	Mean	SD	L	U	*t*	Sig.
1	GOL	182.20	5.88	180.94	183.46	176.67	6.43	175.30	178.04	5.900	0.000
2	NOL	179.65	5.70	178.43	180.87	174.51	6.41	173.14	175.87	5.579	0.000
3	BNL	101.93	3.97	101.08	102.78	98.84	4.31	97.92	99.76	4.902	0.000
4	BBH	137.41	4.86	136.37	138.45	135.98	4.90	134.93	137.02	1.927	0.056
5	XCB	140.03	4.95	138.97	141.09	140.67	5.17	139.56	141.77	−0.820	0.413
6	XFB	115.97	4.29	115.97	116.88	116.78	4.81	115.76	117.81	−1.178	0.240
7	ZYB	134.58	4.36	133.64	135.52	133.24	5.40	132.09	134.39	1.793	0.075
8	AUB	123.67	4.28	122.75	124.59	123.90	4.64	122.90	124.89	−0.219	0.744
9	WCB	74.70	3.94	73.85	75.54	74.83	3.86	74.00	75.65	2.226	0.827
10	ASB	108.81	4.29	107.90	109.73	107.32	4.53	106.36	108.29	−0.779	0.027
11	BPL	99.35	5.36	98.20	100.50	97.72	4.71	96.72	98.73	2.604	0.036
12	NPH	70.22	3.99	69.36	71.08	67.80	4.01	66.95	68.66	3.972	0.000
13	NLH	52.34	2.93	51.71	52.97	52.68	2.83	52.07	53.28	−0.779	0.437
14	JUB	118.24	4.57	117.26	119.22	116.36	4.95	115.30	117.41	2.604	0.010
15	NLB	26.14	1.82	25.75	26.53	27.29	2.33	26.79	27.78	−3.604	0.000
16	MAB	66.90	3.92	66.05	67.74	64.80	3.14	64.14	65.47	3.876	0.000
17	MDH	30.29	3.15	29.61	30.97	28.13	3.65	27.35	28.90	4.169	0.000
18	OBH	34.23	1.55	33.90	34.56	33.66	1.87	33.26	34.05	2.214	0.028
19	OBB	39.47	1.52	39.14	39.79	40.38	2.28	39.89	40.86	−3.098	0.002
20	ZMB	98.15	4.95	97.09	99.21	98.09	4.32	97.17	99.01	0.084	0.933
21	EKB	98.21	3.75	97.40	99.01	97.22	3.98	96.37	98.07	1.683	0.094
22	IML	34.85	3.18	34.17	35.53	36.01	3.51	35.26	36.76	−2.282	0.024
23	XML	54.14	3.34	53.42	54.85	52.68	3.50	51.93	53.42	2.812	0.005
24	WMH	23.41	2.50	22.87	23.94	22.94	2.22	22.47	23.42	1.294	0.198
25	STB	111.87	6.03	110.58	113.17	113.02	5.58	111.83	114.21	−1.302	0.195
26	FRC	111.21	4.42	110.26	112.16	111.63	4.59	110.65	112.61	−0.617	0.538
27	PAC	113.15	6.00	111.86	114.44	111.46	6.42	110.09	112.83	1.790	0.075
28	OCC	100.36	5.86	99.10	101.62	97.18	5.50	96.01	98.36	3.677	0.000
29	FOL	36.52	2.39	36.01	37.04	34.79	2.48	34.26	35.32	4.669	0.000

considered an important variable for the function. In addition, sexually dimorphic measurements of cranial length (GOL, NOL) and breadth (XCB, ZYB, AUB) were greatly responsible for separating the sex of the two groups.

Influence of gene-exchange by Japanese immigration to the Philippines

Commencing nearly 500 years ago, there have been a limited number of Japanese visitors and Japanese immigrants to the Philippines. Early arrivals to the Philippines from Japan included Christian refugees and traders who settled mainly in the Manila area. By the late 1800s, an influx of labourers resulted in the development of Japanese communities in Baguio and Davao. The identification of a small percentage of common parental haplogroups in mitochondrial DNA[42–44,47] and Y chromosomal DNA in Japanese and Filipinos[45–49] provides supportive evidence of genetic exchange in the Philippines.

An average of 6.4% to 10.9% overlap/misclassification was observed in the first three DF equations generated in this study (Tables 9–11). In the equations for unknown sex and group (four groups pooled), there is an average of 18.0% overlap (Table 12). Of the 106 Japanese males 16 misclassified into PM, and one each misclassified as JF and PF.

Table 14. Descriptive statistics for 29 cranial measurements (in mm) recorded in 40 test Japanese and Filipino male crania by Howells and Pietrusewsky (CI: confidence interval, L: lower limit, U: upper limit).

		Japanese Male n = 20				Filipino Male n = 20			
				95%CI				95%CI	
		Mean	SD	L	U	Mean	SD	L	U
1	GOL	182.55	6.27	179.62	185.48	175.50	6.34	172.53	178.47
2	NOL	179.95	6.01	177.14	182.76	173.05	6.02	170.23	175.87
3	BNL	100.50	4.89	98.21	102.79	97.80	3.55	96.14	99.46
4	BBH	137.95	6.82	134.76	141.14	135.25	4.12	133.32	137.18
5	XCB	140.00	3.99	138.13	141.87	139.20	6.00	136.39	142.00
6	XFB	115.75	4.20	113.78	117.72	114.75	5.46	112.20	117.30
7	ZYB	135.10	4.06	133.20	137.00	129.74	5.36	134.76	134.76
8	AUB	123.75	3.14	122.28	125.22	122.55	5.98	119.75	125.35
9	ASB	108.90	4.96	106.58	111.22	105.65	4.77	103.41	107.88
10	WCB	74.70	3.96	72.85	76.55	73.65	4.21	71.68	75.62
11	BPL	96.70	4.79	94.46	98.94	97.70	5.77	95.00	100.40
12	NPH	69.10	3.14	67.63	70.57	67.55	3.52	65.90	69.20
13	NLH	51.95	2.54	50.76	53.14	52.50	3.09	51.06	53.94
14	JUB	118.15	4.16	116.20	120.10	116.40	5.03	114.05	118.75
15	NLB	25.50	1.67	24.72	26.28	27.35	1.87	26.47	28.23
16	MAB	66.10	3.42	64.50	67.70	64.85	3.83	63.06	66.64
17	MDH	31.00	3.03	29.58	32.42	28.40	3.08	26.96	29.84
18	OBH	34.60	1.43	33.93	35.27	34.00	1.78	33.17	34.83
19	OBB	39.55	1.73	38.74	40.36	40.40	2.37	39.29	41.51
20	ZMB	98.00	4.83	95.74	100.26	100.50	6.30	97.55	103.45
21	EKB	98.15	2.91	96.79	99.51	97.20	4.01	95.32	99.07
22	IML	35.30	2.20	34.27	36.33	36.10	4.32	34.08	38.12
23	XML	53.80	3.44	52.19	55.41	53.80	4.14	51.86	55.74
24	WMH	24.05	3.22	22.54	25.56	23.55	2.44	22.41	24.69
25	STB	112.40	5.55	109.80	115.00	110.50	5.92	107.73	113.27
26	FRC	111.05	5.06	108.68	113.42	110.60	3.60	108.92	112.28
27	PAC	115.70	6.78	112.53	118.87	110.25	4.97	107.92	112.58
28	OCC	100.00	4.78	97.76	102.24	97.10	5.49	94.53	99.67
29	FOL	36.25	1.80	35.41	37.90	35.20	2.24	34.15	36.25

Likewise, of the 104 Filipino males, 10 misclassified as JM, 5 as JF, and 2 as PF. More Filipino males were classified as females than Japanese males, indicating that Filipino male crania possess more gracile features than Japanese males.

In contrast, 11 of the 43 Japanese females were misclassified as JM (3), PM (3), and PF (5). Two of the 42 Filipino females were misclassified as PM, 5 as JF, and none as JM. Six Japanese females were misclassified as JM (3) and PM (3), while only 2 PF were misclassified as PM, indicating Japanese females may have slightly more masculine cranial features than Filipino females. These small overlap/misclassification results are consistent with the historical and genetic evidence and likely reflect gene exchange through intermarriage between the Japanese and Filipinos[6,10]. Over 300 years of Spanish colonization in the Philippines may also be a contributing factor. Regardless, the DF results demonstrate relatively good separation between Japanese and Filipino crania and serve as a useful screening tool for the initial assessment of ancestry for building the biological profile for unidentified human remains.

Latent influential measurements to separate Japanese and Filipinos

Prior to this work, no studies have attempted to discover which standard or non-standard cranial measurements were influential in separating Filipino crania from Japanese crania based on the application of DFA. An unexpected outcome of the present study is the

Table 15. Discriminant function results: classification of individuals into Japanese male (JM) and Filipino male (PM) groups using 29 independent measurements from Howells and Pietrusewsky.

Study sample							
Cross tabulation				Predicted group n = 173			
		JM	PM		JM/%	PM/%	Total %
Actual JM	86	78	8	Original	78/90.7%	77/88.5%	89.6%
Actual PM	87	10	77	Cross-validated	77/89.5%	77/88.5%	89.0%
Test sample							
Cross tabulation				Predicted group n = 20			
		JM	PM	Efficacy test	JM/%	PM/%	Total %
Actual JM	n = 20	17	3		17/85.0%	17/85.0%	85.0%
Actual PM	n = 20	3	17				

Canonical discriminant coefficients		
	Unstandardized Function 1 for **Eq. HP**	Standardized Function 1
GOL	0.065	0.403
NPH	0.191	0.763
NLH	−0.216	−0.623
NLB	−0.169	−0.353
MAB	0.090	0.320
OBH	0.245	0.419
OBB	−0.289	−0.561
ZMB	−0.085	−0.392
IML	−0.243	−0.815
XML	0.224	0.767
FOL	0.123	0.299
Constant	−11.178	

Centroid	
Japanese male	Filipino male
1.259	−1.244

Sectioning point
0.015

Example: test#2170 as unknown individual.
(GOL:184, NPH:69, NLH:25, NLB:25, MAB:70, OBH:33, OBB:39, ZMB:96, IML:35, XML:53, FOL:40) using **Equation HP** to discriminate Japanese male and Filipino male.
(0.065*GOL)+(0.191*NPH)+(−0.216*NLH)+(−0.169*NLB)+(0.090*MAB)+(0.245*OBH)+(−0.289*OBB)+(−0.085*ZMB)+(−0.243*IML)+(0.224*XML)+(0.123*FOL)-11.178 = **1.313**. A value less than 0.015 indicates Filipino male and a value and a greater than 0.015 indicates **Japanese male**.

identification of several cranial measurements for determining sex and group affiliation that are not found in standard variable lists such as those of the FDB (Forensic Data Bank) used in FORDISC 3.1[54]and Standards[55]. It is noteworthy that all equations included the simotic chord, or least nasal breadth (WNB), a variable that contributed to the discrimination of Japanese and Filipino crania in both males and females in the first study. Of the 11 Japanese and Filipino male crania measurements from Howells and Pietrusewsky, two non-standard measurements, inferior malar length (IML), and maximum malar length (XML), were selected by the stepwise DFA for distinguishing Japanese and Filipino males. The benefit of two different equations is if the measurements in Equation HP

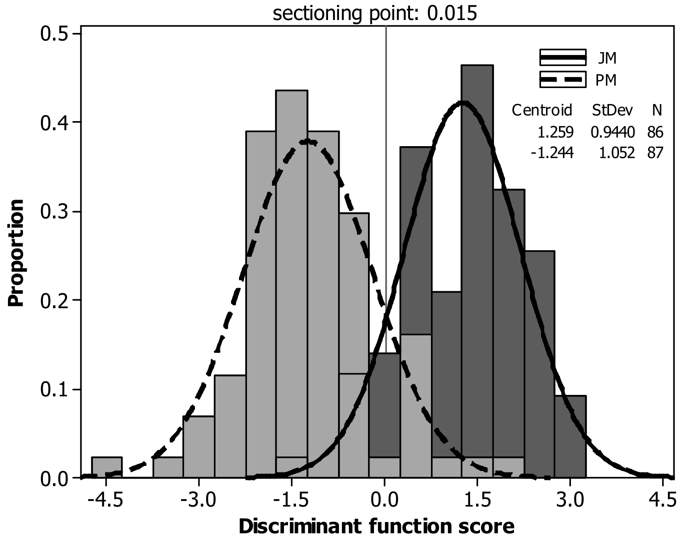

Figure 6. Histogram of two-way discriminant function scores of Japanese males (JM) and Filipino males (PM) based on Equation HP.

(higher precision accuracy than Equation 2) are not available, but available in Equation 2, the assessment still can be made. Moreover, the majority of the Japanese war dead in the Philippines are males.

In summary, Japanese crania are typically higher (especially upper facial height) and have shorter inferior malar lengths compared to Filipino crania. In contrast, Filipino crania exhibit wider nasal bones, wider nasal apertures, and shorter maximum malar lengths. Future research will explore differences between Japanese and other groups using similar procedures, including non-standard measurements like those used in the present study, and increasing the female sample sizes. It is further envisioned that the development of a DFA program similar to FORDISC 3.1, one that includes not only Filipino and Japanese but also other Asian groups, may provide more insightful results.

Conclusion

Given the large number of Japanese war dead still to be discovered in the Philippines, the results of this study provide an accurate means of identifying and sorting Japanese and Filipino war dead using traditional cranial measurements. The probabilities of precision accuracy of three two-way and one multiple group discriminant function equations for separating Japanese and Filipino crania generated in the present study ranged from an average total of 82.0% (cross-validated 77.3%) to 93.6% (cross-validated 92.9%).

Despite gene exchange and their intertwined demographic histories, the results of the present study demonstrate that two Asian groups, Japanese and Filipino, can be identified through the application of discriminant function analysis to traditional measurements recorded using hand-held callipers. The new simple two-way DF equations (Equations 1, 2, 3, and HP) introduced in this study, provide an initial practical way of sorting the crania of Japanese and Filipinos in a field situation. Future research will incorporate craniometric data from neighbouring groups that utilize 2-dimensional and 3-dimensional geometric morphometrics and CT scans.

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Disclosure statement

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