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Questionable Affiliation of Five Curated Human Crania: Using MicroScribe 3D Digitizer and FORDISC 3.1 Computer Program to Estimate Ancestry and Sex

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Abstract

Objective: This study attempts to estimate the ancestry and sex of five unknown human crania curated by the Anthropology Department at Bloomsburg University. The fallout caused by curation and public display of human skulls in the Morton Collection, University of Pennsylvania Museum of Archaeology and Anthropology prompted the Bloomsburg University administration to direct the Anthropology Department to assess the affiliation of these crania that had no clear origins.

Method: A MicroScribe G-2X digitizer was used to collect coordinate data from osteometric landmarks, which were simultaneously recorded by an analytical software called ThreeSkull (3Skull) and subsequently imported into the FORDISC 3.1 discriminant functions computer program for processing.

Result: Cranium A12022 is that of a Japanese female with a posterior probability of 0.572; cranium A22022 is that of a Hispanic/Guatemalan male with posterior probabilities of 0.523 and 0.679; cranium A42022 is that of a Guatemalan/Hispanic male with posterior probabilities of 0.48 and 0.679; cranium A52022 is that of an American Indian male with a posterior probability of 0.845; and cranium A62022 is that of a Chinese (Atayal) male with a posterior probability of 0.911.

Conclusion: For the cranium classified as American Indian, further research will continue to uncover details of the original acquisition with the eventual goal of repatriating it to the lineal American Indian descendants for reburial.

Keywords: Cranium • Forensic anthropology • Repatriation • FORDISC 3.1 • Microscribe 3D digitizer • 3D Osteometric coordinate landmarks • Posterior probabilities • Typicality probabilities

Introduction

In the latter part of the 20th century, indigenous and marginalized peoples spoke out against the continued ownership of their biological and cultural materials by U.S. state and federal agencies and institutions. This push culminated with enacting into law the Native American Graves Protection and Repatriation legislation to address long-standing claims by federally recognized tribes that human remains and cultural artifacts-unlawfully removed from pre-contact, post-contact, former, or current Native American homelands-should be returned to lineal descendants for reburial [1]. With the addition of a stiff penalty of 12 months' imprisonment and a $100,000 fine for violation of this law, state and federal institutions are complying. While a hefty fine is a great motivating factor in complying with this law, scientists in these institutions are largely motivated by shame because they know that, historically, documented human skeletal collections were built with the bodies of impoverished and marginalized peoples, and these scientists want to do the right thing by repatriating the remains despite their importance in forensic anthropological research, education, and training in the United States [2].

After the 2020 murder of George Floyd in police custody in the United States, the history of racial injustice perpetrated by 19th- and early 20th century scientists re-emerged with a vengeance. These scientists focused on scientifically "proving" the superiority of the White race over other races by measuring skull size, and in the wake of Floyd's death, academics and activists turned their attention to the Morton human skeletal collection (formerly on display at the University of Pennsylvania Museum of Archaeology and Anthropology) as part of this history-and current perpetuation-of racism [3]. The Morton Collection consists of more than 1,300 skulls, approximately 900 of which were acquired by Philadelphia-based physician Samuel George Morton during the 1830s and 1840s; some of these belonged to enslaved individuals [4]. Now, as in 1991, when more than 400 individuals were reburied after New York City construction uncovered the largest-known African American burial ground in the United States, academics and activists are advocating for an African American Graves Protection and Repatriation Act. The repatriation of Native and African American cultural and biological remains is influencing indigenous and marginalized peoples in other parts of the world to fight for protection of their ancestral remains.

As a result of the renewed reckoning with racism caused by the curation and public display of human skulls in the Morton Collection, the administration at Bloomsburg University-a public university in Pennsylvania-directed this researcher to report on the ancestry of five human crania curated by the Anthropology Department. There are no substantive records on the origins of these five crania. Based on the limited information obtained, these crania were purchased in late 1990 (this researcher arrived at Bloomsburg University in 2005) from an unknown seller, and-while very little clear information exists about the identity of these individuals-they were supposedly East Indian and/or

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Chinese in origin. This researcher is no fan of the bone trade, despite the fact that it is legal and one way to obtain skeletal materials for teaching. It simply continues the tradition of 19th century archaeology and anthropology, when the acquisition of human skulls was the primary goal with little regard to the fact that these skulls once belonged to people. Over the years, this researcher saw no reason to question the India-China grouping, however ambiguous, because the focus in teaching was human anatomy and skeletal variation, but now that the ethical concerns about curation of and research on skeletal remains of marginalized peoples has reached the halls of university administrators, this researcher has decided to approach the problem as a forensic case to assess the origins of these crania.

The aim of this study is to estimate the ancestry and sex of five unknown human crania using the MicroScribe 3D digitizer to collect coordinate data from osteometric landmarks that were simultaneously recorded by analytical software called ThreeSkull (3 Skull) and subsequently imported into the FORDISC 3.1 discriminant functions computer program for processing. Depending on the results, steps will be taken to repatriate any Native American crania to their lineal descendants. All crania were handled in a respectful manner.

Material and Methods

MicroScribe G-2X digitizer

To better capture cranial size and shape, three-dimensional (3D) osteometric landmark coordinate data were collected using a MicroScribe G-2X digitizer. Practitioners have reported that 3D landmark coordinates show greater discrimination among modern cranial sample groups than traditional one-dimensional (linear) measurements and are, therefore, more valuable in a modern forensic setting [5]. Other advantages of 3D landmark data have been reported; for example, more nontraditional measurements (i.e., arcs and angles) can be calculated, a better representation of cranial morphology can be captured, a much lower error rate can be obtained, and conversion to linear measurements is easier, which results in greater data efficiency [6].

A tri-column stand 12.7 centimeters high made of non-hardening modeling clay was placed next to the digitizer and used to hold each of the five crania stationary while digitizing (Figure 1). The proximity of the cranium to the MicroScribe is important because the digitizing arm of the MicroScribe with a stylus attached must be able to reach all landmarks around the cranium. The stylus is used to capture one landmark at a time and must be in the homing position (Figure 1) prior to use in order for coordinates (X-Y-Z) to be accurately recorded [7].

A mirror was placed between the clay columns to assist with collecting osteometric landmarks on the base of each cranium. 3Skull was used to record 3D landmarks coordinates collected by the MicroScribe and to facilitate import of data to FORDISC 3.1. Before placing the cranium on the tri-column stand to begin digitizing, osteometric landmarks were located and marked with a pencil. In this research, the landmarks digitized and collected by 3Skull are listed by landmark, measurement, and brief description in Supplement 1 (S1). Not all of these 111 landmarks are used in craniometric analysis [8]. In fact, the Forensic Data Bank (FDB) in FORDISC 3.1 uses 56 landmarks (out of 111) and William W. Howells' global Craniometric data set [9] (also in FORDISC 3.1) adds 39 new landmarks in addition to the 56 (S1). The osteometric landmarks digitized are indicated in (Figure 2a-g). Cranial interlandmark distances, angles, chords, elevation, radii, and subtenses were automatically calculated by 3Skull (Table 1). If a mandible accompanied any cranium, plexiglass with a bevelled edge and clay were used to hold the mandible stationary for digitizing (Figure 2).

Statistical analysis

FORDISC 3.1 generates the unknown's posterior and typicality probability of membership in each reference group in the database. Posterior probabilities sum to 1 (100 percent) and is based on the unknown's relative similarities (all Mahalanobis distances [D^2]) to all groups) [10]. A high posterior probability, which in turn creates a small distance, indicates a greater similarity than to other groups. Typicality probabilities, in contrast, are the unknown's probability of membership in each group, based on the unknown's absolute similarity. The percentage of correct group allocations-or groups with the typical *profile* of the unknown case-is an indication of how well groups can be separated using the available variables. The word "typical" used above is important because distance probabilities or "typicality probabilities" can be calculated to ascertain whether an individual is typical for a specific group (and not assumed to belong to a respective group, as in posterior probabilities). When the typicality probabilities are uniformly low (i.e., less than 0.01 for each group), the posterior probabilities and classification should be disregarded because classification accuracy is critical in biological evidence for affiliation [11]. An important result is that the D^2 values will follow a chi-square distribution with p degree of freedom.

Additionally, FORDISC 3.1 uses canonical variates to display data in graphic form. Canonical variate analysis is most effective in problems where many variables are used to compare differences among and within many reference groups. It is a technique that uses raw data to produce coefficients (or eigenvectors), and these coefficients are used to obtain new variables called canonical variates which maximize the among-groups variation (eigenvalues) relative to the standardized within-groups variation [12]. The variables (or measurements) are combined into a reduced number of functions to maximize the separation between groups. Such plots provide visual information as to which sample means (or centroids) are close or distant to one another in multivariate space. Moreover, multidimensional data space transforms confidence "intervals" into confidence "spheroids" (or ellipses), which are equidistant with regard to the within-group dispersion. Finally, there are usually several canonical variates, independently, holding biological information. However, it is the earlier variates that will contain information such as differences in overall shape and size.

For this research, the five crania were designated A12022, A22022, A42022, A52022, and A62022, respectively (Figure 3). A12022 and A22022 are the only crania with mandibles.

Results and Discussion

Analysis of Cranium A12022

After 3D osteometric landmark coordinates were collected for this cranium and recorded by 3 Skull, the data were imported to FORDISC 3.1. All cranial, mandibular, and FORDISC 3.1-calculated measurements (i.e., NAA, PRA, BAA, NBA, BBA, BRA) were used in the FDB (Table 1). Since there was no clear information on ancestry and sex for this cranium, all female reference groups (i.e., White females, Black females, Hispanic females, American Indian females, and Japanese females) and all male reference groups (i.e., White

Figure 1. Tri-column clay stands with skull secured on top in close proximity to MicroScribe positioned in the homing position and mandible secured on a piece of plexiglass.

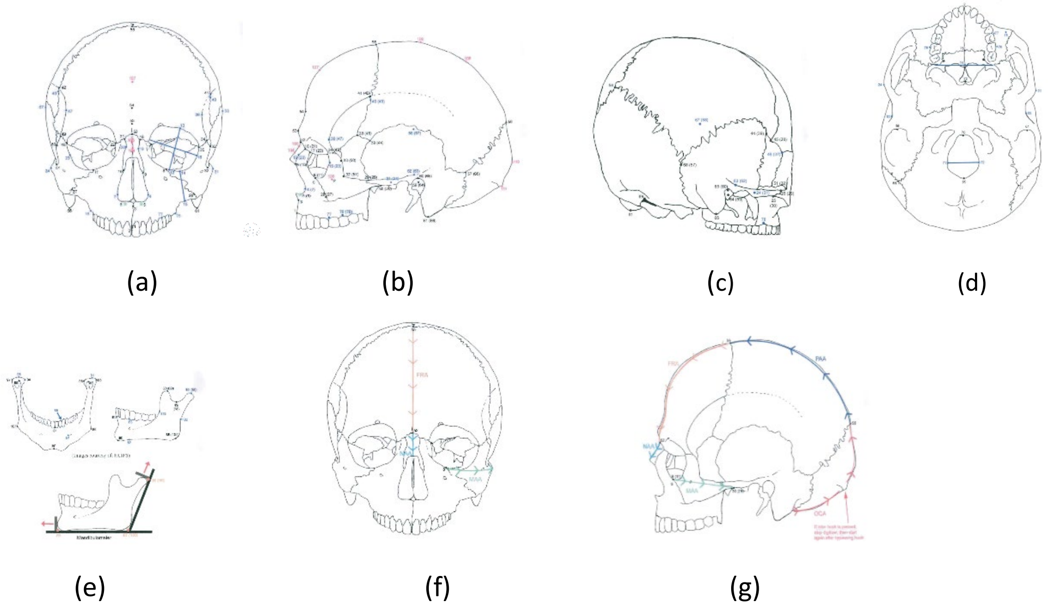


Figure 2 (a-g). Showing osteometric landmarks automatically calculated (red), marked before digitizing (blue), measured on work surface (brown), and arrows depicting digitizing arcs (anterior-posterior, medial-lateral). (Adapted from Fleischman and Crowder 2019).

males, Black males, Hispanic males, Guatemalan males, American Indian males, Japanese males, Vietnamese males, and Chinese males) were used in the analysis. The name "American Indian" (as opposed to Native American) is the language used in the FORDISC 3.1 FDB.

On the first run (or initial processing), FORDISC classified cranium A12022 into the Japanese female (JF) reference group with a posterior probability of 0.572 (Table 2). The typicality probabilities were 0.394 (Typ F, which is dependent on sample size), 0.346 (Typ Chi-which is not dependent on sample size), and 0.221 (Typ R-where the cranium was ranked 88th out 113 individuals within the group). In essence, this cranium is as typical as 78% of Japanese females. However, other typicality probabilities show that this cranium is within the range of variation of the following reference groups: Chinese males, Japanese males, Hispanic females, Guatemalan males, Vietnamese males, and Hispanic males, all having typicality probabilities above .05. The graph of the results depicted in 3D canonical space showed this variation (Figure 4). Cranium A12022, the unknown (indicated by the bold 'X' in the graph) is closest to the Japanese female group centroid but within the ellipses of the aforementioned groups. See Supplement 2 for additional FORDISC descriptive data. In this analysis, 62 percent of the reference groups in FORDISC were classified correctly. A second run was performed using only Chinese males, Japanese males, Japanese females, and Vietnamese males reference groups and there was no change in the Japanese female classification for this cranium.

Analysis of Cranium A22022

All cranial, mandibular, and FORDISC 3.1-calculated measurements (i.e., NAA, PRA, BAA, NBA, BBA, BRA) were used in the FDB (Table 3). As in the previous cranium A12022, there was no clear information on ancestry and sex. Therefore, all female reference groups (i.e., White females, Black females, Hispanic females, American Indian females, and Japanese females) and all male reference groups (i.e., White males, Black males, Hispanic males, Guatemalan males, American Indian males, Japanese males, Vietnamese males, and Chinese males) were used in the analysis.

On the first run, FORDISC classified cranium A22022 into the Guatemalan (GTM) reference group with a posterior probability of 0.523 (Table 4). The typicality probabilities were 0.137 (Typ F), 0.105 (Typ Chi), and 0.119 (Typ R-where the cranium was ranked 59th out 67 individuals within the group). In essence, this cranium is as typical as 88% of Guatemalan males. But, FORDISC also showed that this cranium is within the range of variation of Hispanic males with all typicality probabilities greater than .05. The graph of the results depicted in 3D canonical space showed the unknown cranium A22022 (indicated by a bold 'X') close to the Guatemalan and Hispanic male group centroids but also in the ellipses of Japanese and Chinese male reference groups (Figure 5). See Supplement 3a for additional FORDISC descriptive data. In this analysis, 61 percent of the reference groups in FORDISC were classified correctly.

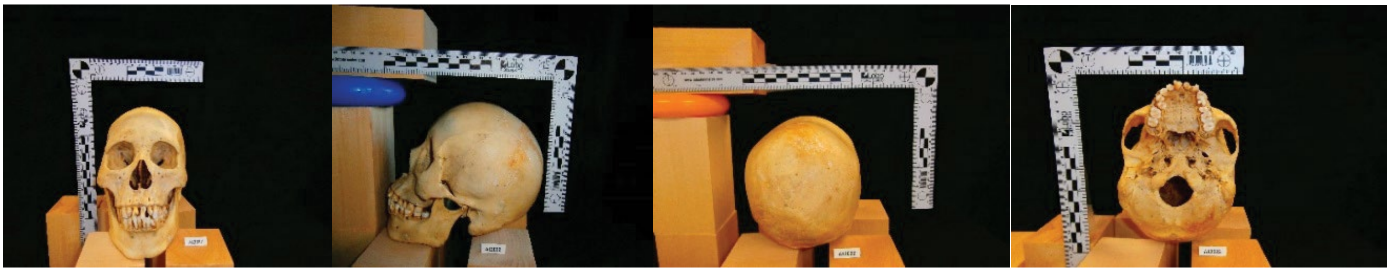
Due to the ambiguous graph in Figure 5, a second run of the data was performed using only male reference groups (White males, Black males, Hispanic males, Guatemalan males, American Indian males, Japanese males, Vietnamese males, and Chinese males). FORDISC classified cranium A22022 into the Hispanic male group with a posterior probability of 0.683. But the typicality Chi was below .05. Measurements PRA, BAA, NLH, and UFHT were one to two standard deviations lower or higher than all group means. NLH and UFHT were instrumentally checked and, along with PRA and BAA, not used in the analysis. On a third run, cranium A22022 was again classified into Hispanic males with posterior probability of 0.736 (Table 5). The typicality probabilities were 0.102 (Typ F), 0.076 (Typ Chi), and 0.166 (Typ R-where the cranium was ranked 131st out 157 individuals within the group). In essence, this cranium is as typical as 83% of Hispanic males.

This cranium is in the range of Guatemalan males, and the graph shows it closest to the Guatemalan and Hispanic male group centroids (Figure 6). See Supplement 3b for additional FORDISC descriptive data. In this analysis, 62 percent of the reference groups in FORDISC were classified correctly.

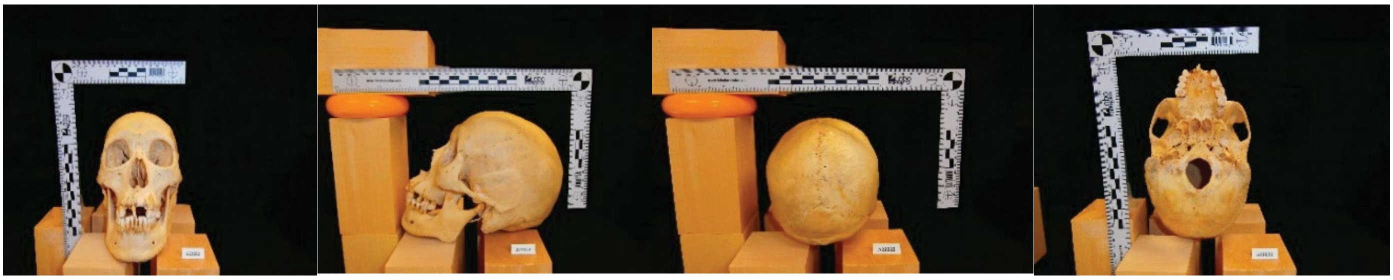
Analysis of Cranium A42022

All cranial and FORDISC 3.1-calculated measurements (i.e., NAA, PRA, BAA, NBA, BBA, BRA) were used in the FDB (Table 6). The shape transformation option was used because there was excessive left occipital sloping of the cranium. As in the previous crania, there was no clear information on ancestry and sex. Therefore, all female reference groups (i.e., White females, Black females, Hispanic females, American Indian females, and Japanese females) and all male reference groups (i.e., White males, Black males, Hispanic males, Guatemalan males, American Indian males, Japanese males, Vietnamese males, and Chinese males) were used in the analysis. There was no mandible available for this cranium.

On the first run, FORDISC classified cranium A42022 into the Guatemalan male (GTM) reference group with a posterior probability of 0.487. The typicality probabilities were 0.171 (Typ F), 0.135 (Typ Chi), and 0.119 (Typ R-where the cranium was ranked 59th out 67 individuals within the group). Therefore, this cranium is as typical as 88% of Guatemalan males (Table 7). Additionally,



A1



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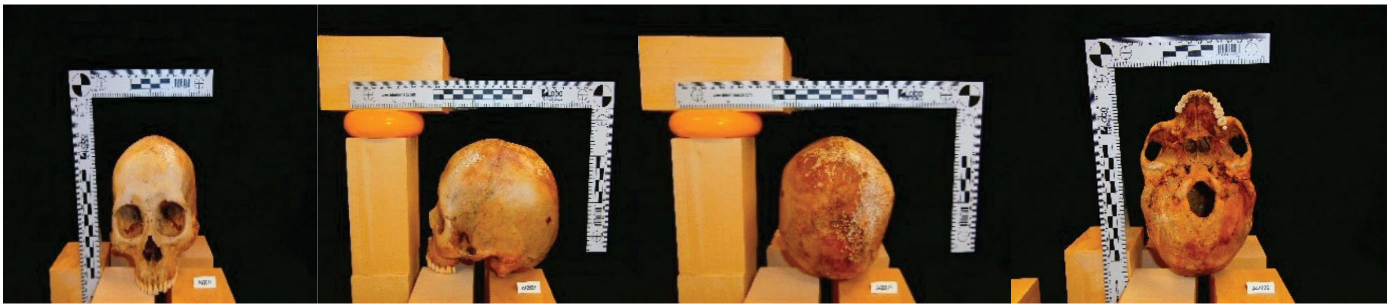

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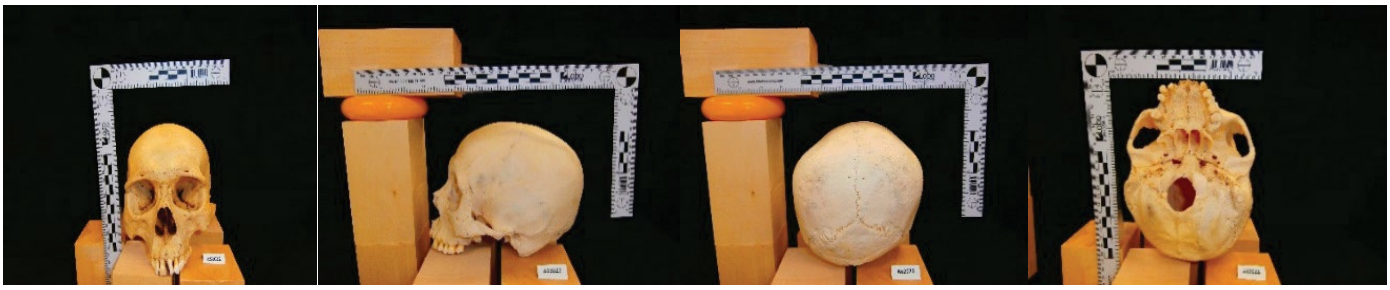

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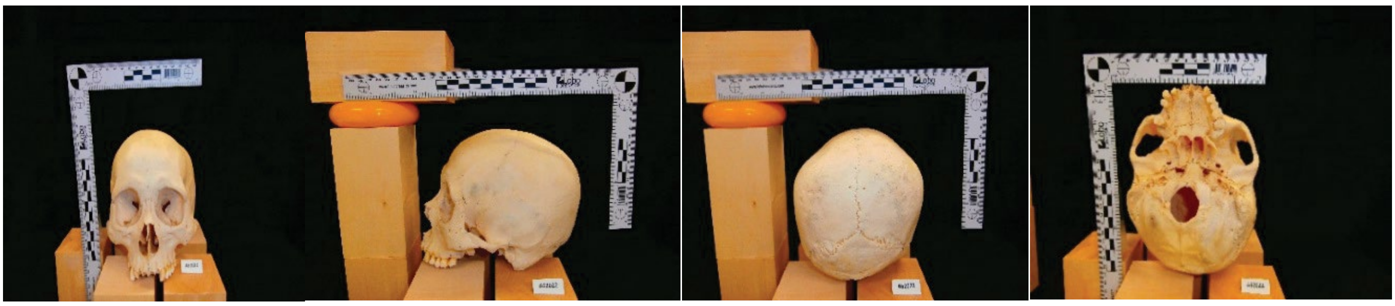

A6

Figure 3. Five crania used in analysis to estimate race and sex. Each cranium is photographed in four views: frontal, left lateral, posterior, and basal (from top to bottom: A12022, A22022, A42022, A52022, A62022).

Table 1. Cranium A12022 osteometric coordinate landmark measurements in millimeters.

Measurement data							
GOL	**170**	**OBB**	**36**	**UFHT**	**71**	OSR	41*
NOL	167	**DKB**	**20**	**FRC**	**105**	BAR	16*
BNL	**97**	NDS	11*	FRS	25*	**GNI**	**33**
BBH	**133**	WNB	8.9	FRF	49*	**HML**	**29**
XCB	**131**	SIS	4.4*	**PAC**	**111**	**TML**	**12**
XFB	104	**ZMB**	**98**	PAS	24*	**GOG**	**93**
WFB	87	SSS	21	PAF	58*	**CDL**	**114**
MOW	**49**	FMB	93	**OCC**	**91**	**WRB**	**38**
ZYB	123	NAS	17	NAR	88*	**XRH**	**68***
AUB	**114**	**EKB**	**92**	SSR	84	**MLT**	**63***
ASB	**103**	DKS	15*	PRR	92*	**MAN**	**113**
BPL	**89**	IML	28	DKR	76*	**NAA**	**63∞**
NPH	66	XML	50	ZOR	76*	**PRA**	**76∞**
NLH	**53**	MLS	12*	FMR	73*	**BAA**	**41∞**
JUB	111	WMH	19	EKR	72*	**NBA**	**82∞**
NLB	**27**	GLS	2	ZMR	66*	**BBA**	**51∞**
MAB	**57**	STB	107	AVR	76	**BRA**	**46∞**
MAL	**53**	**FOL**	**35**	BRR	115	-	-
MDH	**29**	**FOB**	**28**	VRR	115*	-	-
OBH	**36**	**UFBR**	**95**	LAR	96*	-	-

BOLD: Measurements used in cranium A12022 analysis (FORDISC 3.1 FDB)
∞Additional Measurements automatically calculated and only found in FDB in FORDISC 3.1
*Additional measurements automatically calculated and only found in Howells global database in FORDISC 3.1
NAA: Nasion angle; **PRA:** Prosthion angle; **BAA:** Basion angle; **NBA:** Nasion angle; **BBA:** Basion Angle; **BRA:** Bregma Angle; **NDS:** Naso-dacryal subtense-deepest point in profile of nasal bones to the interorbital breadth; **SIS:** Simotic subtense-point from nasal bridge to deepest point in nasal profile; **DKS:** Dacryon subtense-subtense from dacryon to biorbital breadth; **MLS:** point from the convexity of malar to max. length of bone at level of zygomaticofacial foramen; **FRS:** Nasion-bregma subtense-highest point on the convexity of frontal bone; **FRF:** Nasion-subtense fraction-distance along the nasion-bregma chord; **PAS:** Bregma-lambda subtense-highest point on the convexity of parietal bones; **PAF:** Bregma subtense fraction-distance along the bregma-lambda chord; **NAR:** Nasion radius-perpendicular to the transmeatal axis from nasion; **PRR:** Prosthion radius-perpendicular to the transmeatal axis from prosthion; **DKR:** Dacryon radius-perpendicular to the transmeatal axis from left dacryon; **ZOR:** Zygoorbitale radius-perpendicular to the transmeatal axis from left zygoorbitale; **FMR:** Frontomalare radius-perpendicular to the transmeatal axis from the left frontomalare anterior; **EKR:** Ectoconchion radius-perpendicular to the transmeatal axis from the left ectoconchion; **ZMR:** zygomaxillare radius-perpendicular to the transmeatal axis from the left zygomaxillare anterior; **VRR:** Vertex radius-perependicular to the transmeatal axis from the most distant point on the parietals; **LAR:** Lambda radius-perpendicular to the transmeatal axis from lambda; **OSR:** Opisthion radius-perpendicular to the transmeatal axis from opisthion; **BAR:** Basion radius-perpendicular to the transmeatal axis from basion; **XRH:** Maximum ramus height-from gonion to sup. condyle; **MLT:** Mandibular length-distance from the anterior margin of chin in the midline along the posterior border to the mandibular angle at gonion

this cranium is in the range of variation of Hispanic and Japanese male and female reference groups. The graph of the results depicted in 3D canonical space showed this fact, but cranium A42022 is closest to the Guatemalan and Hispanic male group centroids (Figure 7). See Supplement 4a for additional FORDISC descriptive data. In this analysis, 61.2 percent of the reference groups in FORDISC were classified correctly.

A second run was performed using the Guatemalan male group with the Hispanic, Japanese, and American Indian male and female groups. Again, FORDISC classified the cranium into the Guatemalan male group with a greater posterior probability of 0.679, and its range of variation, based on the typicality probabilities, was within the same Hispanic and Japanese reference groups (Table 8). The graph of the results depicted in 3D canonical space showed the same results as in the first analysis: cranium A42022 is closest to the Guatemalan and Hispanic male group centroids (Figure 8). See Supplement 4b for additional FORDISC descriptive data. In this analysis, 63.7 percent of the reference groups in FORDISC were classified correctly.

Analysis of Cranium A52022

All cranial and FORDISC 3.1-calculated measurements (i.e., NAA, PRA, BAA, NBA, BBA, BRA) were used in the FDB (Table 9). As in the other crania in this research, there was no clear information on ancestry and sex. Therefore, all female reference groups (i.e., White females, Black females, Hispanic females, American Indian females, and Japanese females) and all male reference groups (i.e., White males, Black males, Hispanic males,

Table 2. FORDISC 3.1 classification of cranium A12022 in FDB (Forensic Data Bank) [all male and female groups].

Multigroup Classification of Current Case						
Group∝	Classified Into	Distance from	Posterior	Probabilities		Typ R
				Typ F	Typ Chi	
JF	**JF**	28.2	0.572	0.394	0.346	0.221 (88/113)
CHM		29.6	0.287	0.335	0.283	0.270 (54/74)
JM		32.6	0.063	0.207	0.173	0.158 (155/184)
HF		33.9	0.033	0.199	0.137	0.172 (24/29)
GTM		33	0.033	0.176	0.136	0.121 (58/66)
VM		37.2	0.007	0.104	0.072	0.143 (42/49)
HM		38.4	0.004	0.075	0.055	0.175 (113/137)
AF		40.6	0.001	0.064	**0.034**	0.080 (23/25)
BF		45.3	0.000	**0.024**	**0.011**	**0.037 (26/27)**
WF		47.3	0.000	0.011	0.006	**0.011 (94/95)**
AM		48.9	0.000	0.009	0.004	0.184 (40/49)
WM		51.2	0.000	0.004	0.002	**0.015 (192/195)**
BM		51.7	0.000	0.004	0.002	0.096 (47/52)

Current case is closest to JFs

∝Reference groups: JF= Japanese females; CHM= Chinese males; JM= Japanese males; HF= Hispanic females; GTM = Guatemalan males; VM = Vietnamese males; HM= Hispanic males; AF= American Indian females; BF= Black females; WF= White females; AM= American Indian males; WM= White males; BM= Black males
BOLD & red: cranium A12022 not typical for these groups

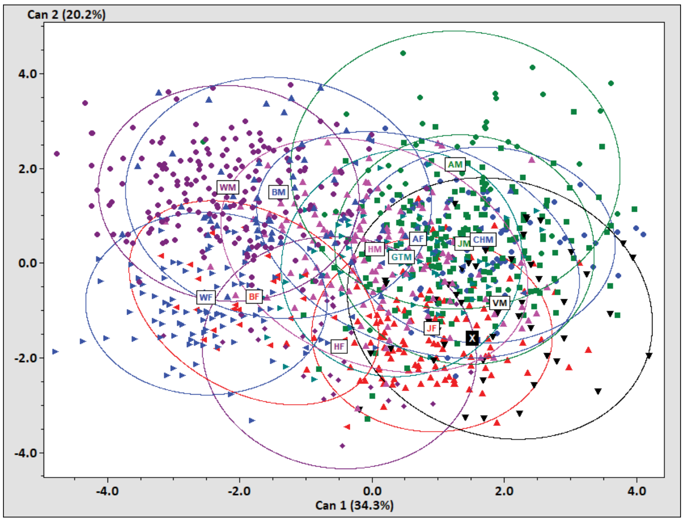

Figure 4. Graph of cranium A12022 FORDISC (FDB) classification results in canonical space (all male and female groups).

Guatemalan males, American Indian males, Japanese males, Vietnamese males, and Chinese males) were used in the analysis. There was no mandible available for this cranium.

On the first run, FORDISC classified cranium A52022 into the American Indian male (AM) reference group with a strong posterior probability of 0.845. The typicality probabilities were 0.180 (Typ F), 0.132 (Typ Chi), and 0.388 (Typ R-where the cranium was ranked 30th out 49 individuals within the group). Therefore, this cranium is as typical as 61% of American Indian males (Table 10). Other typicality probabilities indicate that this cranium is not confidently in the range of variation in any other sample groups. This is shown very clearly in 3D canonical space. This cranium (indicated by a bold 'X') is near the centroid of the American Indian male group and barely in the spheroids of the other reference groups (Figure 9). A second run using only males did not change the results. See Supplement 5 for additional FORDISC descriptive data. In this analysis, 60.8 percent of the reference groups in FORDISC were classified correctly.

Analysis of Cranium A62022

All cranial and FORDISC 3.1-calculated measurements (i.e., NAA, PRA, BAA, NBA, BBA, BRA) were used in the FDB (Table 11). The shape transformation option was used because there was excessive left sloping and left and right parietal bossing when the cranium was viewed from the back. As in the previous crania, there was no clear information on ancestry and sex. Therefore, all female reference groups (i.e., White females, Black females, Hispanic females, American Indian females, and Japanese females) and all male reference groups (i.e., White males, Black males, Hispanic males, Guatemalan males, American Indian males, Japanese males, Vietnamese males, and Chinese males) were used in the analysis. There was no mandible available for this cranium.

On the first run, FORDISC classified cranium A62022 into the Chinese male (CHM) sample group with a posterior probability of 0.359 (Table 12). The typicality probabilities were 0.450 (Typ F), 0.393 (Typ Chi), and 0.311 (Typ R-where the cranium was ranked 51st out 74 individuals within the group). In essence, this cranium is as typical as 69% of Chinese males. However, based on the other typicality probabilities, FORDISC indicated that this cranium was in the range of variation of all reference groups except Black and White male and female groups. The graph of the results depicted in 3D canonical space showed the cranium (indicated by a bold 'X') in the ellipses of the aforementioned reference groups but closest to the Chinese male group centroid (Figure 10). See Supplement 6a for additional FORDISC descriptive data. In this analysis, 62 percent of the reference groups in FORDISC were classified correctly.

A second run was performed using only males with no change in the

Table 3. Cranium A22022 osteometric coordinate landmark measurements in millimeters.

Measurement data							
GOL	**172**	**OBB**	**39**	**UFHT**	**78**	OSR	35*
NOL	169	**DKB**	**23**	**FRC**	**110**	BAR	15*
BNL	**97**	NDS	8*	FRS	27*	**GNI**	**33**
BBH	**135**	WNB	6.5	FRF	49*	**HML**	**30**
XCB	**131**	SIS	3.9*	**PAC**	**105**	**TML**	**10**
XFB	108	**ZMB**	**92**	PAS	24*	**GOG**	**94**
WFB	**90**	SSS	26	PAF	51*	**CDL**	**117**
MOW	**52**	FMB	96	**OCC**	**98**	**WRB**	**31**
ZYB	126	NAS	11	NAR	89*	**XRH**	**67***
AUB	**118**	**EKB**	**90**	SSR	91	MLT	63*
ASB	**110**	DKS	19*	PRR	100*	**MAN**	**113**
BPL	**98**	IML	29	DKR	80*	**NAA**	**63∞**
NPH	77	XML	47	ZOR	79*	**PRA**	**76∞**
NLH	**57**	MLS	11*	FMR	79*	**BAA**	**41∞**
JUB	113	WMH	20	EKR	75*	**NBA**	**82∞**
NLB	**25**	GLS	3	ZMR	70*	**BBA**	**51∞**
MAB	ɤ	STB	110	AVR	82	**BRA**	**46∞**
MAL	**54**	**FOL**	**36**	BRR	120	-	-
MDH	**33**	**FOB**	**31**	VRR	125*	-	-
OBH	**39**	**UFBR**	**97**	LAR	106*	-	-

BOLD: Measurements used in cranium A22022 analysis (FORDISC 3.1 FDB)
*See Table 2 notes
∞See Table 2 notes
ɤRight alveolar at M2 resorbed (no MAB measurement)

Table 4. FORDISC 3.1 classification of cranium A22022 in FDB (all male and female groups).

Multigroup Classification of Current Case						
Group♀	Classified Into	Distance from	Posterior	Probabilities		Typ R
				Typ F	Typ Chi	
GTM	**GTM **	35.3	0.523	0.137	0.105	0.119 (59/67)
HM		36.3	0.321	0.108	0.087	0.216 (116/148)
VM		39.2	0.076	0.069	**0.047**	0.102 (44/49)
BM		40.9	0.031	**0.047**	**0.031**	0.193 (46/57)
JF		41.2	0.027	**0.041**	**0.029**	**0.025** (117/120)
CHM		43.4	0.009	**0.026**	**0.017**	**0.027 (72/74)**
BF		44.1	0.007	**0.029**	**0.015**	**0.036 (27/28)**
JM		44.7	0.005	**0.018**	**0.013**	**0.015 (191/194)**
AF		48.4	0.001	**0.012**	0.005	**0.040 (24/25)**
HF		50.1	0.000	0.007	0.003	**0.029 (33/34)**
AM		50.5	0.000	0.005	0.003	0.184 (40/49)
WM		54.7	0.001	0.009	0.001	0.004 (297/280)
WF		59.5	0.000	0.004	0.000	0.007 (138/139)

Current case is closest to GTMs

♀Reference groups: GTM= Guatemalan males; HM= Hispanic males; VM= Vietnamese males; BM= Black males; JF= Japanese females; CHM= Chinese males; BF= Black females; JM= Japanese males; AF= American Indian females; HF= Hispanic females; AM= American Indian males; WM= White males; WF= White females

BOLD & red: cranium A22022 not typical for these groups

results. A third run was completed using the three sample groups with the highest posterior probabilities: Chinese males, American Indian males, and Japanese males (Table 13). The cranium was, again, classified in the Chinese male reference group with a higher posterior probability of 0.695 with typicality probabilities of 0.450 (Typ F), 0.393 (Typ Chi), and 0.311 (Typ R—where the cranium was ranked 44th out 74 individuals within the group) (Table 14). The graph of the results depicted in 3D canonical space showed a strong separation

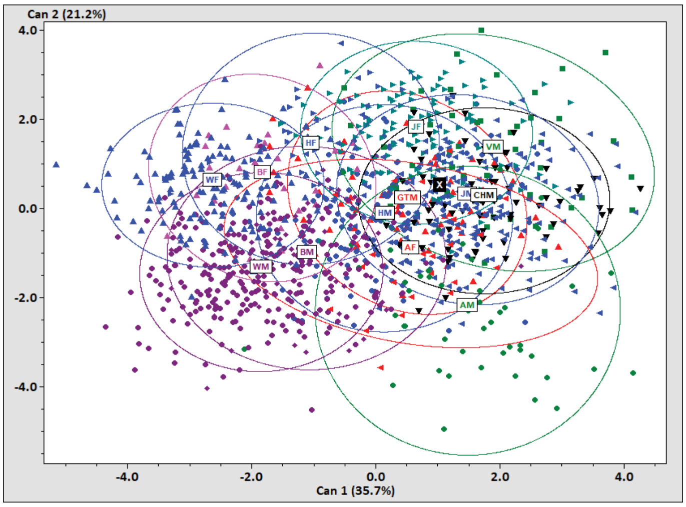

Figure 5. Graph of cranium A22022 FORDISC (FDB) classification results in canonical space (all male and female groups).

Table 5. FORDISC 3.1 classification of cranium A22022 in FDB (male groups only).

Multigroup Classification of Current Case						
Groupα	Classified Into	Distance from	Posterior	Probabilities		Typ R
				Typ F	Typ Chi	
HM	**HM**	35.7	0.736	0.102	0.076	0.166 (131/157)
GTM		38.2	0.216	0.067	**0.045**	0.113 (63/71)
VM		42.7	0.022	**0.027**	**0.015**	0.061 (46/49)
BM		43.4	0.015	**0.023**	**0.012**	0.105 (51/57)
CHM		45.5	0.006	**0.014**	0.007	**0.027 (72/74)**
JM		46.4	0.004	**0.010**	0.006	0.005 (193/194)
AM		47.7	0.002	**0.016**	0.004	0.333 (10/15)
WM		55	0.000	0.001	0.000	0.007 (275/277)

Current case is closest to HMs

φReference groups: HM= Hispanic males; GTM= Guatemalan males; VM= Vietnamese males; BM= Black males; CHM= Chinese males; JM= Japanese males; AM= American Indian males; WM= White males

BOLD & red: cranium A22022 not typical for these groups

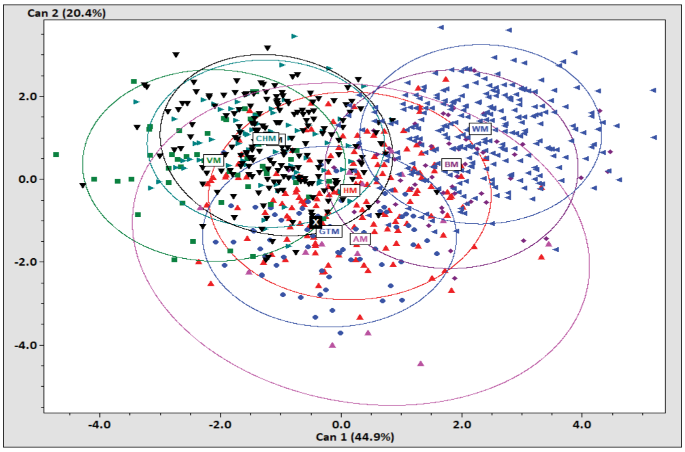

Figure 6. Graph of cranium A22022 FORDISC (FDB) classification results in canonical space (male groups only).

of the Chinese and Japanese male groups from the American Indian male group. But cranium A62022 is very close to the Chinese male group centroid (Figure 11). See Supplement 6b for additional FORDISC descriptive data. In this analysis, 76 percent of the reference groups in FORDISC were classified correctly.

Howells' global Craniometric data set was used to pinpoint this cranium to a region in Asia; only East Asian males were used in the analysis. On the first run, FORDISC did not classify the cranium because some measurements deviated 1 or 2 standard deviations lower or higher than all group means. These measurements were not used (i.e., DKS, DKA, FRA, NAR, ZMR, ZOR). On the second run, FORDISC classified cranium A62022 in the Atayal male sample group with a very high posterior probability of 0.911. The typicality probabilities were 0.335 (Typ F), 0.067 (Typ Chi), and 0.233 (Typ R-where the

Table 6. Cranium A42022 osteometric coordinate landmark measurements in millimeters.

Measurement data							
GOL	**175**	**OBB**	**39**	**UFHT**	**68**	OSR	47*
NOL	172	**DKB**	**18**	**FRC**	**111**	BAR	13*
BNL	**97**	NDS	11*	FRS	29*	**NAA**	**64∞**
BBH	**130**	WNB	5.2	FRF	49*	**PRA**	**76∞**
XCB	**134**	SIS	3.7*	**PAC**	**116**	**BAA**	**40∞**
XFB	112	**ZMB**	**88**	PAS	20*	**NBA**	**77∞**
WFB	**87**	SSS	23	PAF	43*	**BBA**	**56∞**
MOW	**48**	FMB	95	**OCC**	**97**	**BRA**	**47∞**
ZYB	131	NAS	13	NAR	87*	-	-
AUB	**123**	**EKB**	**94**	SSR	83	-	-
ASB	**106**	DKS	16*	PRR	86*	-	-
BPL	**90**	IML	33	DKR	76*	-	-
NPH	65	XML	49	ZOR	73*	-	-
NLH	**50**	MLS	16*	FMR	75*	-	-
JUB	106	WMH	20	EKR	72*	-	-
NLB	**25**	GLS	3	ZMR	68*	-	
MAB	**ɤ**	STB	107	AVR	74	-	-
MAL	**51**	**FOL**	**37**	BRR	117	-	-
MDH	**25**	**FOB**	**30**	VRR	122*	-	-
OBH	**37**	**UFBR**	**98**	LAR	107*	-	-

BOLD: Measurements used in cranium A22022 analysis (FORDISC 3.1 FDB)

*See Table 2 notes

∞See Table 2 notes

ɤRight alveolar at M2 resorbed (no MAB measurement)

Table 7. FORDISC 3.1 classification of cranium A42022 in FDB (all male and female groups).

Multigroup Classification of Current Case						
Groupα	Classified Into	Distance from	Posterior	Probabilities		Typ R
				Typ F	Typ Chi	
GTM	**GTM **	34	0.487	0.171	0.135	0.119 (59/67)
HM		34.9	0.31	0.139	0.114	0.291 (105/148)
JM		37.8	0.072	0.08	0.063	**0.041 (186/194)**
HF		38.3	0.056	0.087	0.056	0.235 (26/34)
JF		38.7	0.046	0.068	0.052	0.058 (113/120)
CHM		40.1	0.023	0.054	**0.038**	**0.041 (71/74)**
BF		44.1	0.003	**0.029**	**0.015**	**0.036 (27/28)**
AF		45.1	0.002	**0.024**	**0.011**	0.080 (23/25)
AM		46.9	0.001	**0.013**	0.007	0.163 (41/49)
WM		47.5	0.001	0.009	0.006	0.018 (275/280)
WF		48.1	0	0.008	0.005	0.700 (138/139)
BM		48.5	0	0.009	0.005	0.070 (53/57)
VM		51.7	0	0.004	0.002	0.041 (47/49)

Current case is closest to GTMs

φReference groups: GTM= Guatemalan males; HM= Hispanic males; JM= Japanese males; HF= Hispanic females; JF = Japanese females; CHM = Chinese males; BF = Black females; AF = American Indian females; AM = American Indian males; WM = White males; White females; Black males; VM = Vietnam males

BOLD & red: cranium A42022 is not typical for these groups

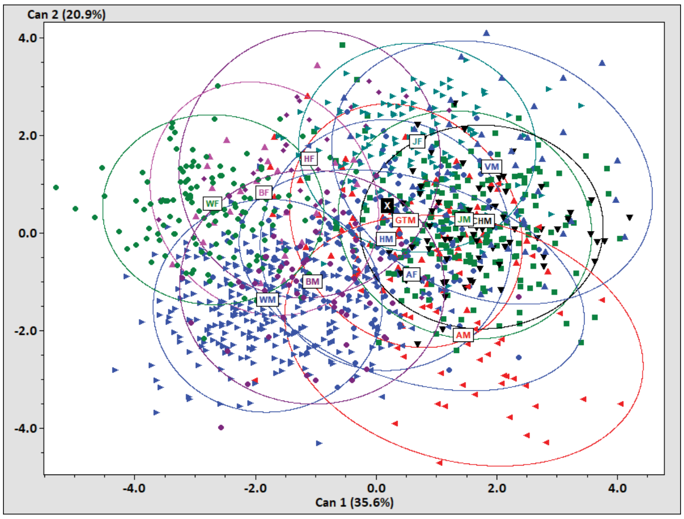

Figure 7. Graph of cranium A42022 FORDISC (FDB) classification results in canonical space (all male and female groups).

Table 8. FORDISC 3.1 classification of cranium A42022 in FDB (Guatemalan, Hispanic, Japanese, and American Indian male and female groups).

Multigroup Classification of Current Case						
Group⍺	Classified Into	Distance from	Posterior	Probabilities		Typ R
				Typ F	Typ Chi	
GTM	** GTM **	32.1	0.679	0.259	0.189	0.119 (59/67)
HM		34.9	0.168	0.161	0.113	0.264 (109/148)
JF		36.7	0.068	0.120	0.079	0.084 (109/119)
JM		37.1	0.058	0.011	0.074	0.052 (184/194)
HF		38.7	0.026	0.098	0.052	0.176 (28/34)
AF		45.5	0.001	**0.029**	**0.010**	0.077 (24/26)
AM		45.5	0.001	0.024	0.010	0.200 (40/50)

Current case is closest to GTMs

⍺Reference groups: ; GTM= Guatemalan males; HM= Hispanic males; JF= Japanese females ; JM= Japanese males; HF= Hispanic females; AF= American Indian females; AM= American Indian males

BOLD: cranium A42022 is not typical for this group

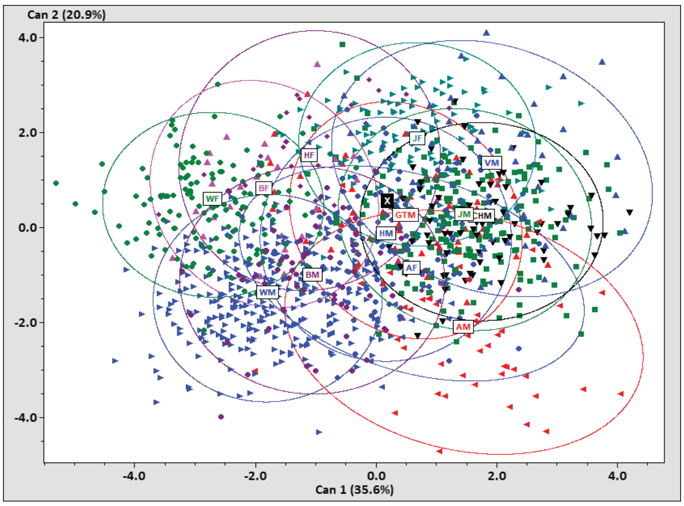

Figure 8. Graph of cranium A42022 FORDISC (FDB) classification results in canonical space (Guatemalan, Hispanic, Japanese, and American Indian male and female groups).

Table 9. Cranium A52022 osteometric coordinate landmark measurements in millimeters.

Measurement data							
GOL	**178**	**OBB**	**44**	**UFHT**	**78**	OSR	37*
NOL	175	**DKB**	**19**	**FRC**	**108**	BAR	14*
BNL	**101**	NDS	5*	FRS	25*	**NAA**	**64∞**
BBH	**132**	WNB	9.1	FRF	50*	**PRA**	**73∞**
XCB	**138**	SIS	2.6*	**PAC**	**110**	**BAA**	**44∞**
XFB	113	**ZMB**	**107**	PAS	25*	**NBA**	**78∞**
WFB	**93**	SSS	20	PAF	56*	**BBA**	**53∞**
MOW	**60**	FMB	105	**OCC**	**95**	**BRA**	**49∞**
ZYB	139	NAS	14	NAR	94*	-	-
AUB	**124**	**EKB**	**90**	SSR	92	-	-
ASB	**118**	DKS	24*	PRR	99*	-	-
BPL	**95**	IML	31	DKR	87*	-	-
NPH	73	XML	50	ZOR	82*	-	-
NLH	**58**	MLS	11*	FMR	82*	-	-
JUB	119	WMH	22	EKR	79*	-	-
NLB	**29**	GLS	4	ZMR	75*	-	
MAB	**57**	STB	115	AVR	84	-	-
MAL	**52**	**FOL**	**34**	BRR	118	-	-
MDH	**30**	**FOB**	**32**	VRR	123*	-	-
OBH	**37**	**UFBR**	**104**	LAR	107*	-	-

BOLD: Measurements used in cranium A52022 analysis (FORDISC 3.1 FDB)
*See Table 2 notes; ∞See Table 2 notes

Table 10. FORDISC 3.1 classification of cranium A52022 in FDB (all male and female groups).

Multigroup Classification of Current Case						
Group⍺	Classified Into	Distance from	Posterior	Probabilities		Typ R
				Typ F	Typ Chi	
AM	**AM**	35.3	0.845	0.180	0.132	0.388 (30/49)
GTM		40.5	0.060	0.068	0.046	0.076 (61/66)
JM		40.6	0.059	0.062	0.045	**0.038 (177/184)**
CHM		42.9	0.019	0.014	0.027	0.027 (72/74)
HM		44.2	0.010	0.030	0.020	0.073 (127/137)
AF		46.0	0.004	0.028	0.013	0.120 (22/25)
JF		47.3	0.002	0.015	0.009	0.009 (112/113)
VM		50.3	0.000	0.015	0.004	**0.041 (47/49)**
WM		53.5	0.000	0.003	0.002	0.005 (194/195)
BM		55.8	0.000	0.002	0.001	0.038 (50/52)
HF		57.2	0.000	0.002	0.001	0.034 (28/29)
BF		61.3	0.000	0.001	0.000	0.037 (26/27)
WF		62.1	0.000	0.000	0.000	0.011 (94/95)

Current case is closest to AMs

⍺Reference groups: AM= American Indian males; GTM= Guatemalan males; JM= Japanese males; CHM= Chinese males; HM= Hispanic males; AF= American Indian females; JF= Japanese females; V= Vietnam males; WM= White males; BM= Black males; HF= Hispanic females; BF= Black females; WF= White females

BOLD & red: Cranium A52022 is not typical for these groups

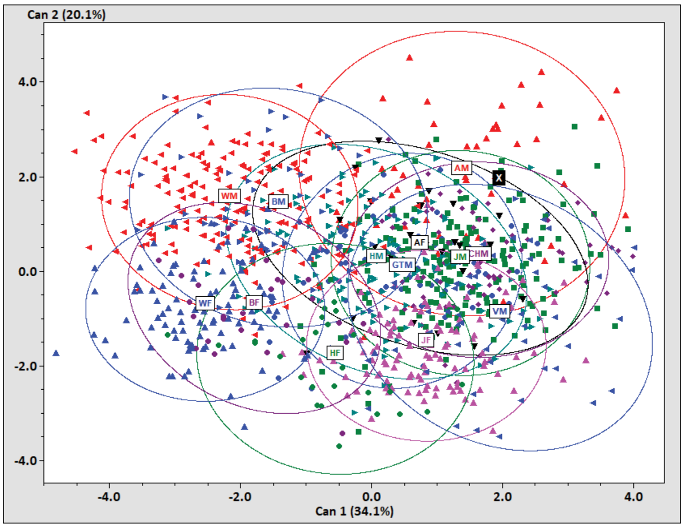

Figure 9. Graph of cranium A52022 FORDISC (FDB) classification results in canonical space (all male and female groups).

Table 11. Cranium A62022 osteometric coordinate landmark measurements in millimeters.

Measurement data							
GOL	167	OBB	37	UFHT	68	OSR	40*
NOL	165	DKB	20	FRC	109	BAR	13*
BNL	96	NDS	9*	FRS	37*	NAA	67∞
BBH	128	WNB	7.2	FRF	49*	PRA	72∞
XCB	142	SIS	3.2*	PAC	106	BAA	41∞
XFB	110	ZMB	100	PAS	27*	NBA	78∞
WFB	87	SSS	27	PAF	53*	BBA	56∞
MOW	60	FMB	98	OCC	90	BRA	45∞
ZYB	138	NAS	14	NAR	83*	-	-
AUB	128	EKB	98	SSR	85	-	-
ASB	110	DKS	21*	PRR	87*	-	-
BPL	90	IML	31	DKR	76*	-	-
NPH	64	XML	51	ZOR	71*	-	-
NLH	54	MLS	11*	FMR	71*	-	-
JUB	116	WMH	22	EKR	67*	-	-
NLB	25	GLS	4	ZMR	60*	-	
MAB	62	STB	99	AVR	72	-	-
MAL	49	FOL	33	BRR	116	-	-
MDH	28	FOB	29	VRR	120*	-	-
OBH	34	UFBR	102	LAR	97*	-	-

*See Table 2 notes
∞See Table 2 notes

Table 12. FORDISC 3.1 classification of cranium A62022 in FDB (all male and female groups).

Multigroup Classification of Current Case						
Group☿	Classified Into	Distance from	Posterior	Probabilities		Typ R
				Typ F	Typ Chi	
CHM	** CHM**	28.4	0.359	0.450	0.393	0.311 (51/74)
AM		28.5	0.330	0.452	0.384	0.490 (25/49)
JM		30.0	0.160	0.360	0.316	0.212 (145/184)
AF		31.1	0.090	0.359	0.266	0.240 (19/25)
VM		34.0	0.021	0.218	0.166	0.245 (37/49)
JF		34.2	0.019	0.199	0.160	0.150 (96/113)
GTM		34.3	0.019	0.204	0.158	0.167 (55/66)
HM		39.0	0.002	0.085	0.063	0.197 (110/137)
HF		41.3	0.001	0.069	**0.039**	0.172 (24/29)
WM		50.4	0.000	0.007	0.004	**0.026 (190/195)**
WF		52.9	0.000	0.004	0.002	**0.011 (94/95)**
BM		55.1	0.000	0.003	0.001	**0.019 (51/52)**
BF		56.1	0.000	0.003	0.001	**0.037 (26/27)**

Current case is closest to CHMs

☿Reference groups: CHM= Chinese males; AM= American Indian males; JM= Japanese males; AF= American Indian females; VM= Vietnam males; JF= Japanese females; GTM= Guatemalan males; HM= Hispanic males; HF= Hispanic females; WM= White males; WF= White females BM= Black males; BF= Black females
BOLD & red: Cranium A62022 is not typical for these groups

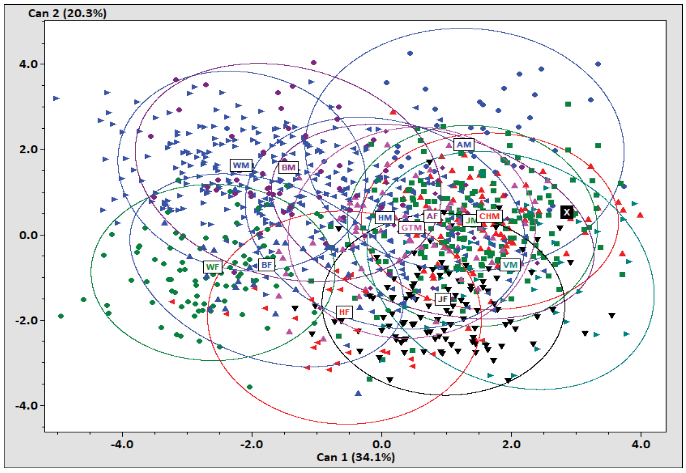

Figure 10. Graph of cranium A62022 FORDISC (FDB) classification results in canonical space (all male and female groups).

Table 13. FORDISC 3.1 classification of cranium A62022 in FDB (Chinese, American Indian, and Japanese male groups).

Multigroup Classification of Current Case						
Group☿	Classified Into	Distance from	Posterior	Probabilities		Typ R
				Typ F	Typ Chi	
CHM	** CHM**	37.3	0.695	0.456	0.239	0.405 (44/74)
JM		38.9	0.304	0.380	0.186	0.364 (117/184)
AM		52.7	0.000	0.184	0.012	0.625 (3/8)

Current case is closest to CHMs

☿Reference groups: CHM= Chinese males; JM= Japanese males; HF= Hispanic females; AM= American Indian males

Table 14. FORDISC 3.1 classification of cranium A62022 in Howells global craniometric data set (East Asian male groups).

Multigroup Classification of Current Case						
Group☿	Classified Into	Distance from	Posterior	Probabilities		Typ R
				Typ F	Typ Chi	
ATAM	** ATAM**	72.6	0.911	0.335	0.067	0.233 (23/30)
NJAM		78.8	0.041	0.178	0.024	0.232 (43/56)
PHIM		80.1	0.022	0.160	0.019	0.078 (47/51)
HAIM		80.4	0.019	0.158	0.018	0.130 (40/46)
ANYM		82.6	0.006	0.128	0.012	0.163 (36/43)
SJAM		87.9	0.000	0.069	0.004	0.098 (46/51)
ANDM		89.4	0.000	0.064	0.003	0.111 (32/36)
AINM		91.5	0.000	0.046	0.002	0.184 (40/49)
BURM		104.5	0.000	0.008	**0.000**	0.054 (53/56)

Current case is closest to ATAMs

☿Reference groups: ATAM= Atayal males; NJAM= North Japanese males; PHIM= Philippines males; HAIM= Hainan males; ANYM= Anyang males; SJAM: South Japanese males; ANDM= Andaman Is. males; AINM= Ainu males; BURM= Buriat males
BOLD & red: Cranium A62022 is not typical for these groups

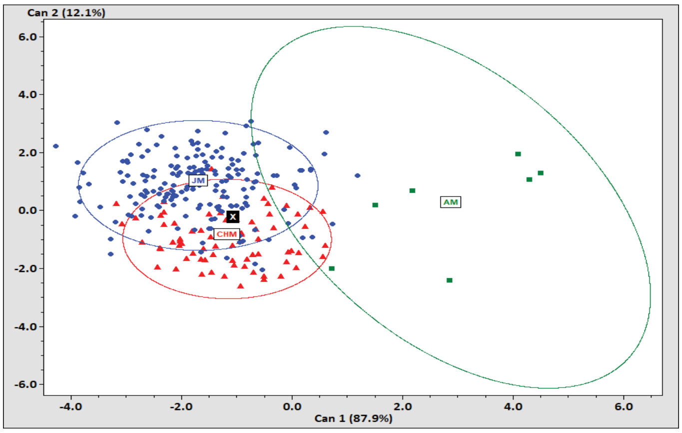

Figure 11. Graph of cranium A62022 FORDISC (FDB) classification results in canonical space (Chinese, American Indian, and Japanese male groups).

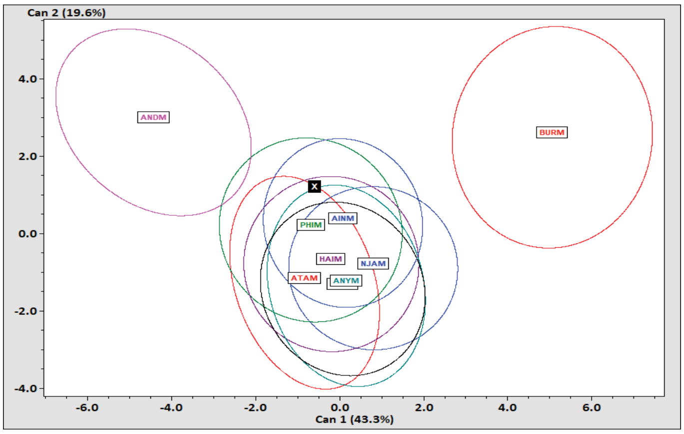

Figure 12. Graph of cranium A62022 FORDISC Howells global craniometric data set classification results in canonical space (East Asian male groups).

cranium was ranked 23rd out 30 individuals within the group (Table 14).

The graph of the results depicted in 3D canonical space showed that cranium A62022 is in the range of variation of all groups except the Andaman Island and Buriat reference groups (Figure 12). See Supplement 6c (S6c) for additional FORDISC descriptive data. In this analysis, 66.3 percent of the reference groups in FORDISC were classified correctly.

Conclusion

After analysis of the osteometric coordinate landmark data for the five crania, collected using a MicroScribe G-2X along with 3 Skull to record 3D landmarks and import them into FORDISC 3.1 for processing, the following results were obtained:

1. The odds are very high that cranium A12022 is Japanese female. Despite the fact that this cranium has posterior probabilities in the Chinese male group, using only Asian males and females in a second analysis did not change the result of Japanese female. Overall, cranium A12022 belonged to an East Asian—most likely female.
2. The odds are very high that cranium A22022 is a Guatemalan male. This cranium also had posterior probabilities in the Hispanic male group. In fact, when all males were used in a second analysis, this cranium was classified in the Hispanic male group. There is tremendous complexity in knowing what is “Hispanic” *vs.* what is “Spanish” because of the Americas’ tremendous admixture in population historically. In short, this cranium belonged to a Guatemalan/Hispanic male.
3. The odds are very high that cranium A42022 belonged to a Guatemalan/Hispanic male (for similar reasons as cranium A22022).
4. The odds are very high that cranium A52022 is an American Indian male. This researcher will dig deeper into the details of the original acquisition with the eventual goal of repatriating this cranium to the lineal Native American descendants for reburial.
5. Finally, the odds are very high that cranium A62022 is a Chinese male. Furthermore, in a global comparison with East Asian reference groups, this cranium classifies into the Atayal or Taiwanese reference group.

As indigenous and marginalized peoples in other parts of the world become awakened to the plight of their cultural and biological remains, in time, all skeletal materials-after respectful analysis-will be repatriated.

Conflict of Interest

None.

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