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PAPER

PHYSICAL ANTHROPOLOGY

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Beyond Taphonomy: Exploring Craniometric Variation Among Anatomical Material

ABSTRACT: Anatomical crania are occasionally encountered in forensic anthropology laboratories when that material is mistaken for forensically significant human remains. Using craniometric analyses and statistical measures of sample homogeneity, we determine whether anatomical material can be described as a single, homogenous group or as a diverse mix of populations. Twenty-one interlandmark distances were collected from 85 anatomical preparations. Distance measures were calculated between all pairs using a pooled within-sample variance/covariance matrix and then subjected to a Defrise-Gussenhoven test between each paired distance to test whether each pair was drawn randomly from the same population. In the Defrise-Gussenhoven analysis, twenty-two percent (n = 66) of the 300 pairwise combinations were significant at the 0.05 level or below. The level of homogeneity suggests a majority of that material originated from the subcontinent of India or West Asia. Therefore, anatomical material can be viewed as a moderately homogenous group, but with a shared taphonomic history.

KEYWORDS: forensic science, forensic anthropology, Defrise-Gussenhoven, India, craniometric

In the United States prior to 1985, the majority of anatomical material (Fig. 1) used for teaching and education originated from the Republic of India (1,2). In 1985, under pressure from human rights groups, the ruling government of India unequivocally banned the exportation of human remains for any purpose (3). The skeletal material purchased from India prior to that ban continues to be used in classrooms, teaching laboratories, and medical schools around the country. Unfortunately, some of this anatomical material also surfaces during routine forensic anthropological investigations (1,4). When anatomical material is encountered, the forensic anthropologist needs to establish the material as an anatomical preparation and demonstrate that it is not forensically significant. Forensic anthropologists make that determination using nonmetric (macromorphoscopic) traits, metric analysis, and taphonomic indicators of anatomical preparation, including, among others, the presence of reconstruction hardware, evidence of industrial cleaning, a surface patina from repeated handling, and betel nut staining on the teeth (Fig. 2).

To our knowledge, craniometric variation among anatomical specimens has not been approached systematically. Variation (geographic, temporal, genetic, etc.) is difficult to address among anatomical specimens because, in general, (1) provenience information for the individual specimens is lacking and (2) most statistical approaches used to assess craniometric variation for material with no provenience information may not be appropriate as these methods (at least initially) must assume the samples represent populations rather than individuals. The unique history of anatomical preparation and sales, particularly those originating in India, add to these difficulties.

India is a genetically diverse subcontinent with a large amount of variation in phenotype expression (5). This begs the question: Should anatomical material, when encountered in a forensic setting, be viewed as a single, homogeneous group with a shared taphonomic history, or should a more conservative approach be taken in which anatomical material is viewed as a diverse and biologically heterogeneous subsample from larger populations? We attempt to answer this question in several stages. After exploring the history of anatomical preparation in India, we measure the level of homogeneity in a sample of anatomical material purchased prior to the 1985 ban. If anatomical specimens are indeed homogenous, then describing the taphonomic condition of an individual specimen should capture the necessary level of detail. Although these descriptions will say very little about the diversity and/or continuity of anatomical material, they may broadly classify the material appropriately. However, if cranial variation within anatomical material is markedly heterogeneous (as the genetic data suggest), classifications utilizing information beyond the taphonomic profile are necessary. Therefore, the second stage of analysis utilizes nonprovenienced anatomical material tested against skeletal data from known populations in several models. In this way, we hope to demonstrate the utility of classification statistics that minimize any within-group variation and allow for proper identification of geographic ancestry.

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FIG. 1—*Map of India with associated language families and territory boundaries.*

Historical Background of Anatomical Material from India

The history of anatomical specimens in the United States is closely tied to the Republic of India. India began sourcing anatomical skeletal material from Calcutta Medical College in the 1850s, and by the latter half of the twentieth century, it became the world's largest supplier of anatomical skeletons (6). The majority of skeletal material from India originated from the northern states, primarily West Bengal and Bihar and along the Ganges River and its tributaries (7). There, remains brokers purchased skeletons from Doms (*Domba*, or *Chandala*), the low-caste Hindu "untouchables" who even today continue to oversee the transport, cremation, and burial of the dead. The bodies of unclaimed individuals from hospital and police morgues likely provided the majority of skeletons, although bodies were also reportedly pulled from rivers or purchased from mourners who could not afford the cost of wood for cremation.

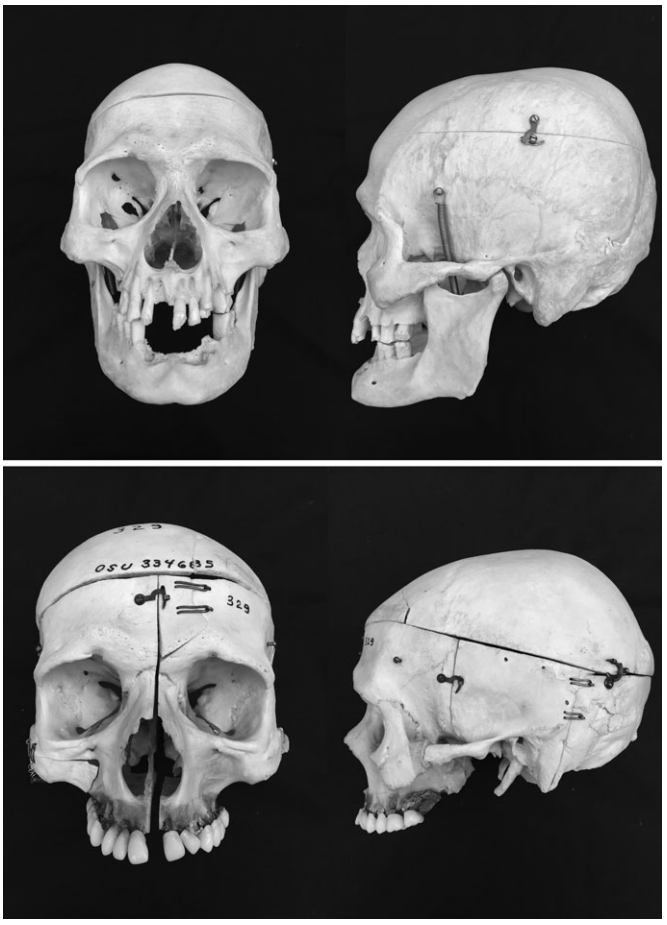

FIG. 2—*Example anatomical preparations showing various taphonomic indicators.*

While India was not the only nation supplying skeletal material, they were the undisputed leader in consistently and effectively meeting the ever-growing demand for educational specimens (6). The educational specimen industry grew even larger after World War II, a consequence of the worldwide shortage in anatomical material (8). For a time, military medical education sustained sales, at least in the United States (9), but by the 1950s, obtaining skeletal material in the United States became more of a challenge (10). Indian exports after the war curtailed, and for a time during this period, Russia was the major supplier of the world's anatomical supplies; although their exports were sufficiently low enough and of such poor quality, they were forced to compete with companies selling plastic replicas in the United States and the U.K. (11,12). By the 1980s, the anatomical market in India had transformed once again, growing in excess of a dozen government-licensed companies in Calcutta, exporting tens of thousands of skeletons and skulls annually, with annual profits in the millions (13).

This explosion in the 1980s was the direct result of the earlier work from companies such as Reknas Ltd of Calcutta, who, as early as the 1930s, began exporting skeletons to Britain (14). Reknas and other export companies, such as Fashiono, Hilton & Co., Sourav, and M.B. & Co., eventually cornered the market on anatomical material, supplying the vast majority of biological/scientific supply companies through sales to museums, physicians, students, and schools around the world. Retailers such as Adam, Rouilly in London and large U.S. companies such as Ward's Natural Science, Kilgore International, Denoyer-Geppert, Clay-Adams, Carolina Biological Supply, and other medical and science supply companies imported thousands of anatomical skeletons from India each year for domestic sales. Indeed, approximately 70 percent of India's sales were to institutions and individuals within the United States (15).

A variety of preparations were available, designed to suit different educational needs and budgets. These preparations ranged from relatively humble articulated hanging and disarticulated skeletons for students (often sold in small trunks or boxes) to intricately painted skeletons showing muscle sites in vibrant blue and red (Fig. 3). Skulls were offered sectioned and unsectioned, typically using swing-hook latches and brass springs and screws for the sectioned crania and associated mandibles. Less frequently, skulls were sectioned sagittally or prepared in the Beauchene style, separated into individual bones (Fig. 4). Fetal and subadult skeletons, individual bones, and articulated hands and feet were also popular. On occasion, skulls were sectioned to expose developing tooth roots, frontal and maxillary sinuses, or inner ear structures (see Fig. 3). Some of the articulations and preparations took place in Calcutta, although several U.S. and U.K. companies, such as Clay-Adams, Inc., hired lineworkers to drill and mount hardware (9), while other companies—such as Kilgore International—contracted European experts to skillfully cut, mount, and prepare specimens.

In 1976, the Indian government enacted its first ban on the export of skeletons (16). This ban was reversed a year later by a new administration under significant pressure from the exporters. This initial ban led to a drastic increase in the price of individual skeletons (17,18) and an increase in the competition between Calcutta's companies. Reknas Ltd, the leading exporter at the time, lost its competitive edge to companies selling skeletons for lower prices, eventually resulting in the company's dissolution in 1983 (15). The increase in competition also meant an increase in the number of reports on unscrupulous business practices, such as grave robbing and looting. In fact, the 1985 human remains exportation ban resulted from such rumors of looted graves, body snatching, decapitation, and even unsubstantiated accounts of child murders (3,19). The 1985 ban effectively ended the export of human skeletons from India and that country's monopoly on the world's supply of anatomical skeletons. However, the distributor's backstock of skeletons may have allowed the sale of remains from India for some time after the ban, and recent investigative reporting by Carney (6) suggests a much smaller, but thriving, black market trade in human remains is once again emerging in India.

After the 1985 ban, China grew into the new leader in human skeleton supplies. However, their reign was short-lived, as shortly before the Beijing Olympics in 2008 China also banned the export of skeletal material due to public outcry and human rights concerns (20). Chinese skeletons were prepared differently than Indian material and are easily recognized as they often lack the characteristic bright-white appearance of bone bleached with hydrogen peroxide (1). Also, Chinese preparations typically lack wire articulation and the suppliers did not offer the range of preparations commonly found during India's monopoly. Schultz (1) outlines the taphonomic modifications and general taphonomic profiles of anatomical material obtained from India and China. He indicates that the quality of Chinese material varies between natural bone and white. Chinese anatomical skulls typically do not have a cut calvarium and lack the articulation hardware commonly found on skulls originating in India. Chinese anatomical preparations also have teeth from other individuals glued into empty sockets, even into alveolar bone where

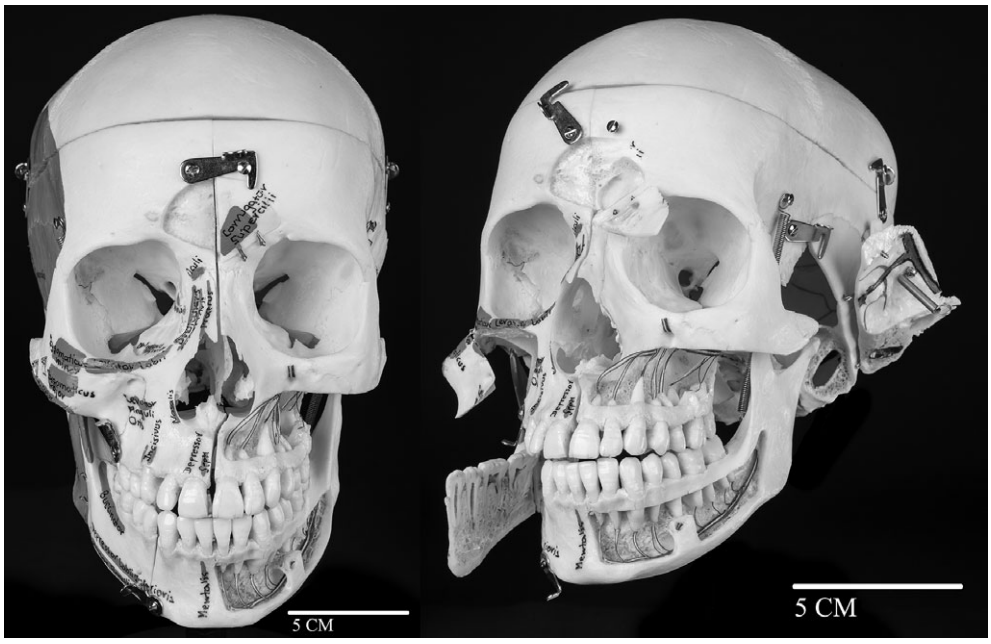

FIG. 3—*Intricately painted cranium showing muscle attachment sites in vibrant blue and red with penned verbiage.*

FIG. 4—*Beauchene-style anatomical preparation with individual elements separated.*

antemortem tooth loss is obvious. Inserting missing teeth to anatomical preparations is a common practice as the presence of teeth increases the selling price.

Anatomical skeletons prepared for hanging display typically have a large hole drilled at the vertex to accommodate a supporting hook. Other modifications to teaching material result from frequent handling and include features like the development of a patina created by oils from the hands and burnishing of prominent surfaces. Students also frequently mark anatomical landmarks on the surface of bones. Damage to the inferior portions of the skull such as the styloid and pterygoid processes and wear on the mastoids is common from frequent placement on hard surfaces (1).

The human skeletons found today in schools, museums, and private collections reflect a complicated and largely undocumented history of shifting international supply and demand for medical education spanning the last two centuries. This material occasionally becomes entangled in forensic investigations, when unsuspecting family members stumble on the material or an individual discards the material and it is later recovered by law enforcement. In an effort to understand the variation within anatomical material, and to see how dominant India was in the exportation of anatomical material, the relationship between craniometric data, taphonomy, and biological affinity among anatomical specimens is explored.

Materials and Methods

Craniometric data for 85 individuals identified as anatomical preparations were obtained from institutions and osteology laboratories throughout the United States to assess the variability within and between these individuals. Ideally, only crania unambiguously demonstrated to originate from India, or minimally from an anatomical supply company prior to the 1985 ban, would be included. Unfortunately provenience data and associated dates were not always available; when possible, laboratory managers, curators, etc. were asked to provide circumstantial evidence for the preban status of individual specimens by indicating the purchase time period and dealer.

Twenty-one interlandmark distances quantifying overall length, breadth, midfacial variation, and facial projection were used (Table 1). Measurements in the original Howells set were excluded when the measurements or landmarks were missing on

TABLE 1—*Interlandmark distances used for the majority of analyses.*

Measurement	Landmark	Landmark	Interlandmark Distance
GOL	Glabella	Opisthocranion	g-op
XCB	Euryon	Euryon	eu-eu
BBH	Basion	Bregma	ba-b
WFB	Frontotemporale	Frontotemporale	ft-ft
STB	Stephanion	Stephanion	st-st
ASB	Asterion	Asterion	asb-asb
FRC	Nasion	Bregma	n-b
PAC	Bregma	Lambda	b-l
OCC	Lambda	Opisthion	l-o
FOL	Basion	Opisthion	ba-o
BNL	Nasion	Basion	n-ba
BPL	Basion	Prosthion	ba-pr
ZYB	Zygion	Zygion	zy-zy
MOW	Zygoorbitale	Zygoorbitale	zygo-zygo
UFHT	Nasion	Prosthion	n-pr
NLH	Nasion	Nasospinale	n-ns
NLW	Alare	Alare	al-al
OBB	Ectoconchion	Ectoconchion	ec-ec
OBH	Ectoconchion	Dacryon	ec-dac
MAL	Prosthion	Alveolan	pr-alv
MAB	Ectomalare	Ectomalare	ecm-ecm

TABLE 2—*Sample distribution.*

Group	Female	Male	Unknown	Total
Andaman Islands	5	7	3	15
Andhra Pradesh	1	3	0	4
Assam	0	2	2	4
Bengal (W. Bengal or Bangladesh)	0	0	12	12
Chhattisgarh	1	1	0	2
Jharkhand	6	13	2	21
Madhya Pradesh	0	1	0	1
Maharashtra or Andhra Pradesh	0	2	0	2
Meghalaya	0	2	0	2
Orissa	9	33	2	44
Sri Lanka	2	8	0	10
Tamil Nadu	0	2	0	2
Unsure, Chota Nagpur	0	5	0	5
Uttar Pradesh	0	1	0	1
West Bengal	5	18	4	27
West Bengal, Darjeeling	4	5	0	9
Anatomical Material	–	–	85	85
Total	33	103	110	246

any one specimen or were considered redundant or uninformative. All interlandmark distances and coordinate data were collected using a 3D digitizer and the computer program 3Skull (21). All 3D data were transformed to interlandmark distances for analysis.

Following data collection, the anatomical material was compared to populations in the Howells (22) craniometric database. The Howells sample represents historic populations from around the world; however, none of those populations include individuals from the Indian subcontinent, with the possible exception of a series of crania from the Andaman Islands, a Union Territory of India in the Bay of Bengal. Therefore, we supplemented the Howells database with craniometric data for 161 Indian individuals from various population groups (Table 2). These data were obtained from historical sources (http://www.19thcentury-science.org/HMSC/HMSC-Reports/Zool-29/htm/doc003.html—accessed 10 November 2014) collected following Broca's methods as outlined by Sir William Turner (23–25). Data collected using methods inconsistent with modern standards were discarded. Populations were grouped geographically by state or region. As a result, the ethnic and morphological diversity inherent in Indian populations was not isolated. For example, generally speaking any populations derived from Meghalaya, the Darjeeling region of West Bengal, and the state of Assam might contain individuals that would be classified as Asian or "Mongoloid" using traditional morphological and typological standards. Likewise, states in the Chota Nagpur region such as Chhattisgarh and Jharkhand contain a significant non-Hindu tribal population and would be expected to contain individuals that would fall into the morphological group historically referred to as "Proto-Australoid." For the population from Bengal, it was not known whether the individuals were from what is today West Bengal or East Bengal (Bangladesh).

The anatomical sample was also compared to populations represented in the Forensic Data Bank in *Fordisc* (26), and populations in *CRANID* (27) via linear discriminant function analysis. The Forensic Data Bank in *Fordisc* is predominately a collection of North American Whites, Blacks, and Hispanics, although smaller samples of American Indian, Central American, and East Asian populations are included. These groups were included because the majority of forensic anthropologists working in the United States would incorporate this tool into their laboratory analysis. *CRANID* was also used in the current analysis. This program is also based largely on the Howells database, but is also supplemented with additional samples from Europe, Patagonia, West Asia, and importantly for this research, two populations from the subcontinent of India, representing a total of 39 different populations from around the globe.

Due to the flexibility built into *Fordisc*, all anatomical crania were examined via linear discriminant function analysis, even when some measurements were missing. Unfortunately, the publicly available version of *CRANID* cannot accommodate missing measurements and requires 29 cranial measurements for analysis. This reduced the number of anatomical crania in our sample for analysis in *CRANID* by nearly half ($n = 45$).

Canonical variate analysis (CVA) was used to explore the relationships between the anatomical sample and other worldwide populations, and CVA provides graphical representations of these data in two dimensions invariant to rotation of their coordinates. In this way, CVA provides a geographic distribution of populations in multivariate space.

Quantifying and documenting the variation within anatomical specimens presents a number of difficulties making a traditional approach less reliable. Without provenience information, each cranium must be initially treated as a unique group with a sample size equal to one. However, working under the assumption that this material represents a single population defined (at least) taphonomically as "anatomical material," the first task is to determine the actual homogeneity within the sample.

To measure homogeneity, the Mahalanobis distances (D^2) between all pairs of crania are calculated using DISPOP. This program does not permit missing data, so for those analyses the total number of craniometric variables is reduced to 18 to maximize sample sizes. DISPOP incorporates the Howells dataset along with samples of American Whites and Blacks. DISPOP calculates D^2 using a vector of cranial measurements and a pooled within-group variance/covariance matrix derived as follows. Recall that that sample size is initially one for each group, so the VCVM is substituted with a matrix representing a genetic structure similar to the population from which the anatomical crania are thought to derive (28). As it is initially unclear from which population anatomical crania are drawn, a conservative approach—recommended by Jantz and Owsley (28)

—uses a pooled within-group variance/covariance matrix derived from the Howells set. This VCVM is appropriate as it incorporates a worldwide sample representing global diversity; however, for that reason, the covariance could be inflated. Using the derived VCVM, interindividual Mahalanobis distances can be calculated and used to assess whether the individuals were drawn from the same population.

The Defrise-Gussenhoven test (29) is used to assess the actual level of homogeneity. This test is based on the expectation that a calculated distance between two individuals drawn at random from the same population follows a predictable distribution: ($\sqrt{(}2p$-1) with $\sigma^2 = 1$, where p is the number of dimensions. This expectation can be used to decide whether the distance between two crania is greater than would be expected if they were drawn from different samples. If a pairwise distance is greater than the calculated threshold value for random expectation, then the two crania *may* originate from two different populations.

In a traditional discriminant function analysis, the posterior and typicality probabilities act as measures for the similarity of an unknown cranium to several reference groups. These probabilities are based on the Mahalanobis distance of the unknown to the centroid of each reference group. Intuitively, the closer the cranium is to the center of a reference group, the more likely it is to belong to that group. In the current application, the posterior probabilities calculated using the Howells set say very little about the anatomical crania derived from India, because Indian craniometrics were not included in the original reference groups. Adding craniometric data from the Indian subcontinent as a reference sample permits the calculation of Mahalanobis distances to these more appropriate reference populations and permits determining whether the anatomical material resembles any Indian groups and, if so, which one(s). These comparisons permit hypotheses about the relationship of the anatomical crania to Indian groups, classification of the anatomical material into population groups, and quantification of any geographic cohesion in the anatomical preparations.

Results

Descriptive statistics for all groups are presented in Table 3. The Mahalanobis distances between each pair of crania are too unwieldy to present in tabular form; however, Table 4 presents a sample of those values. When we reduce the craniometric variables to 18 for the DISPOP analysis, the random expected distance for the Defrise-Gussenhoven (DG) test is 5.92 ($\sqrt{(}2*18)-1$). Any distance greater than 1.65 standard deviations above this value is significant at the 0.05 level or below. In any population, we would expect approximately five percent of the sample to fall above this value (Defrise-Gussenhoven 1967). In this analysis, there are 300 pairwise combinations. Twenty-two percent ($n = 66$) are significant at the 0.05 level or below.

Interpretation of the homogeneity of this sample first requires assessing the power of the DG test. As a measure of the level of homogeneity found within world populations, we applied the DG test to four groups drawn from the Howells dataset and contained in DISPOP: Andaman Islanders, Bergs, Blackfeet, and 19th Century Terry Whites. These groups were selected because they represent either geographically or temporally isolated groups or populations predicted to have high levels of heterogeneity. For each, a subset of the data was culled and treated as an unknown sample for testing with the Defrise-Gussenhoven test. The percentage of significant values varied from a little over 1% for the Andaman Island sample to slightly more than

TABLE 3—*Measurement mean and standard deviation values by population.*

Populations	GOL	XCB	BBH	WFB	STB	ASB	FRC	PAC	OCC	FOL	BNL	BPL	ZYB	MOW	UFHT	NLH	NLW	OBB	OBH	MAL	MAB
Anatomical ($n = 85$)																					
Mean	174.3	N/A	128.6	90.5	108.4	102.2	107.6	110.4	91.8	35.4	96.1	91.8	121.9	56.2	62.0	47.5	25.3	38.3	33.1	51.6	61.6
SD	7.0	N/A	5.0	4.0	6.0	5.0	5.0	6.0	5.0	2.0	4.0	4.0	4.0	5.0	4.0	3.0	2.0	2.0	2.0	6.0	5.0
Indian ($n = 161$)																					
Mean	175.9	131.8	131.4	91.8	106.3	102.1	N/A	N/A	N/A	34.1	97.4	93.7	125.5	N/A	63.6	47.6	24.7	38.0	32.4	50.6	61.6
SD	8.6	6.3	6.4	3.8	7.0	5.1	N/A	N/A	N/A	1.0	2.1	1.5	7.5	N/A	7.4	4.7	2.0	2.4	2.6	5.1	8.2
Whites ($n = 1760$)																					
Mean	183.6	139.0	137.9	95.3	114.3	112.6	112.5	115.8	99.1	36.7	102.5	94.2	126.4	N/A	69.1	51.1	N/A	40.2	33.8	51.9	59.7
SD	9.1	6.5	6.5	7.3	7.1	6.2	6.1	7.2	5.9	2.7	6.0	6.8	7.5	N/A	5.6	3.9	N/A	2.7	2.3	4.5	4.8
Blacks (n = 660)																					
Mean	183.2	135.0	133.0	95.1	108.8	108.3	110.1	115.8	96.4	35.9	100.7	100.9	126.9	N/A	70.2	50.2	N/A	39.7	34.8	56.4	64.7
SD	8.0	5.9	7.1	5.2	7.4	5.8	6.0	7.2	6.2	2.7	5.9	6.7	7.7	N/A	5.6	4.0	N/A	2.5	2.3	4.4	4.9

TABLE 4—*Matrix of D-F distances among subsample of anatomical crania. Note: Bold values are significant at the 0.05 level or below.*

	Anat1	Anat2	Anat3	Anat4	Anat5	Anat6	Anat7	Anat8	Anat9	Anat10	Anat11	Anat12	Anat13	Anat14	Anat15	Anat16	Anat17	Anat18	Anat19	Anat20	Anat21	Anat22	Anat23	Anat24
Anat1	4.511																							
Anat2	6.242	5.310																						
Anat3	7.191	7.000	4.541																					
Anat4	6.141	4.454	4.136	4.311																				
Anat5	6.352	6.240	5.405	6.744	5.874																			
Anat6	5.461	4.270	4.142	6.502	4.392	6.326																		
Anat7	**8.252**	7.626	6.017	**7.866**	7.032	**8.430**	6.061																	
Anat8	6.942	6.270	6.361	7.215	6.348	7.672	6.290	6.551																
Anat9	5.616	5.473	5.875	5.256	5.041	7.077	6.526	**8.492**	7.161															
Anat10	6.297	5.606	4.798	5.253	4.590	4.650	5.335	7.497	5.446	5.489														
Anat11	5.971	6.256	5.806	6.613	5.357	5.415	5.806	**8.136**	**8.599**	7.239	5.738													
Anat12	**7.711**	6.936	6.256	5.110	4.626	**7.980**	6.747	**7.897**	6.234	4.773	5.614	**8.691**												
Anat13	7.511	7.188	5.428	4.558	4.634	6.983	6.648	6.227	6.279	6.406	5.202	7.374	4.018											
Anat14	**7.895**	7.547	6.680	6.917	5.930	**8.072**	7.026	7.518	6.241	5.806	6.224	**8.879**	5.092	5.653										
Anat15	7.362	**7.961**	**8.175**	7.642	7.240	**10.094**	6.619	**9.314**	**9.557**	**8.279**	**9.600**	**9.315**	**8.348**	**8.716**	**9.388**									
Anat16	**7.738**	**7.801**	5.993	5.359	5.855	**8.069**	6.049	7.448	6.065	**7.749**	6.552	**7.790**	6.946	6.323	7.654	7.368								
Anat17	7.685	6.809	5.804	**8.141**	**7.757**	7.178	5.950	7.123	6.992	**8.188**	7.081	**8.851**	**8.983**	**8.786**	**8.620**	**10.411**	7.630							
Anat18	6.579	6.376	5.289	6.078	5.919	6.373	4.696	5.512	6.017	7.177	6.039	7.368	7.027	6.542	**7.832**	6.754	5.442	6.438						
Anat19	**8.718**	**8.010**	7.518	**8.125**	7.549	**7.760**	7.234	**7.742**	7.640	7.696	7.534	**9.816**	7.230	7.703	**8.680**	**9.990**	7.086	6.522	6.280					
Anat20	6.401	7.031	5.770	6.837	5.916	7.613	6.772	**7.919**	**8.081**	7.469	7.316	7.519	6.896	5.338	**8.237**	**8.488**	7.167	**9.178**	**7.996**	**8.194**				
Anat21	5.640	5.642	6.602	6.266	5.630	5.899	6.798	**8.131**	5.664	5.026	4.114	6.853	6.094	5.738	6.405	**9.066**	7.365	**8.967**	6.609	**8.014**	7.255			
Anat22	6.013	5.254	4.728	5.214	4.124	5.376	5.878	7.096	5.999	5.467	5.271	6.710	5.092	4.288	6.233	**8.372**	5.751	7.363	6.099	6.327	4.705	5.304		
Anat23	5.890	6.097	5.565	4.820	4.914	6.781	7.001	**8.472**	6.524	3.448	6.071	7.518	4.873	5.965	6.171	**8.107**	6.940	**8.149**	7.296	7.621	6.419	5.518	4.658	
Anat24	7.462	7.566	5.278	6.586	6.216	7.368	5.552	6.947	6.162	6.848	6.473	**7.794**	7.003	7.573	5.949	**8.832**	6.468	5.813	6.227	**7.891**	**8.896**	**8.242**	7.371	6.345

Note: **Bold** values are significant at the 0.05 level or below.

TABLE 5—*Distribution of significant values using the Defrise-Gussenhoven test at the 0.05 level.*

Population	*n*	% of *N*
Anatomical	66	22.01
Blackfeet	27	9.01
Terry Whites	133	7.5
Berg	86	5.6
Andaman	7	1.2

9% for the Blackfeet. This same model was applied to the anatomical specimens (Table 5). The anatomical specimens demonstrate a much higher level of heterogeneity than is observed in the other samples.

The Defrise-Gussenhoven test quantifies homogeneity within a sample but can also aid in the documentation of outliers. Several crania included in the aforementioned Howells groups deviate significantly from expectation. The Blackfeet and Terry White samples are both considerably more heterogeneous than we would expect from random chance alone. Interestingly, nearly half the significant values in the Blackfeet sample come from a single individual.

The moderate level of heterogeneity identified for the anatomical specimens is consistent with the known genetic makeup of India. So the next step in this analysis is the identification of the various sources for anatomical material, a task that proved more difficult. First, the typicality probabilities of the anatomical material to multiple reference groups were calculated and the cross-validated classification accuracies examined. Using only the Howells dataset for the target groups yielded unremarkable results. In general, the anatomical crania did not show similarity to any one world group and the typicality probabilities were consistently low. However, when we include a sample of known individuals from India, the results are more appealing. Forty-six percent of our sample classified as Andaman Island (15.38%), Punjabi (15.38%), or Indian (15.38%). The relative position (in multivariate space) of the Bedouin sample may explain why a percentage of anatomical crania classified in this group. If we include the Bedouin sample within a pooled Indian group, then slightly over 65% of our sample classified to the Indian subcontinent or West Asia.

When the anatomical crania were compared to the ancestral groups represented in the Forensic Data Bank using *Fordisc*, once again the crania do not demonstrate significant similarity to any one group. Frequencies and percentages of how the crania were classified using *Fordisc* are presented in Table 6, which demonstrates no single ancestral group containing even one-third of the sample. This is not surprising as *Fordisc* does not currently have a reference sample for these groups.

TABLE 6—*Classification frequencies of anatomical crania using Fordisc 3.1.*

Ancestry	Frequency	Percentage
Black	26/85	30.59
Hispanic	20/85	23.53
White	14/85	16.47
Japanese	11/85	12.94
American Indian	7/85	8.24
Guatemalan	4/85	4.71
Chinese	2/85	2.35
Vietnamese	1/85	1.18

TABLE 7—*Populations included in each geographic region for CRANID analysis.*

Geographic Region	Populations	Geographic Region	Populations
Pacific Islands	Southern Australia	East Asian	Ainu
	Easter Island		Andaman
	Guam		Anyang
	Maori		Atayal
	Mokapu (Hawaiian)		Buriat
	Moriori		Hainan
	Sydney (Australia)		Northern Japan
	Tasmania		Southern Japan
	Tolai		Philippines
Africans	Bushman	Native American	Arikara
	Dogon		Eskimo
	Egyptian		Patagonian
	Teita		Peru
	Zulu		Santa Cruz
Europeans	Berg	Indian Subcontinent	India
	Denmark		Punjab
	Italian		
	London		
	Norse		
	Poundbury		
	Zalavar		
West Asian	Bedouin		
	Lachish		

As with the analyses in *Fordisc*, each anatomical cranium analyzed in *CRANID* was classified into the ancestral/population group demonstrating the highest posterior probability. Due to the large number of population groups represented in *CRANID* ($n = 39$), the resulting classifications were compressed into larger geographic regions (Table 7). Frequencies and percentages of how the crania were classified using *CRANID* are presented in Table 8. The classifications from *CRANID* demonstrate the anatomical crania classified into geographic regions across the globe, although there is a relatively large proportion (~40%) classified to the Indian subcontinent. If we again consider West Asia to be a likely source of anatomical material, specifically from Bedouin populations, then nearly 50% of the anatomical material sample is classified into the Indian subcontinent or West Asia.

TABLE 8—*Classifications of anatomical crania by geographic region using CRANID.*

Geographic Region	Frequency	Percentage
Indian Subcontinent	17/45	37.78
East Asian	10/45	22.22
European	2/45	13.33
Pacific Islands	6/45	13.33
African	4/45	8.89
West Asian	4/45	8.89
Native American	2/45	4.44

The between-group Mahalanobis distances calculated during the CVA were all significant at the 0.05 level (Table 9). The CVA utilized anatomical material and ten populations from the Howells dataset to assess relationships between these populations. The anatomical sample is positioned intermediate (Fig. 5) to all other groups. Using a traditional three-group model, the anatomical material is intermediate to the three geographic ancestries (European, African, and Asian). This is not unexpected given the relative geographic position of India between these continents. In the CVA, the anatomical sample is closest to the Andaman Islanders, followed by Zalavar (Hungary/European), Dogon (African), and Japanese (Asian) groups. Classifications derived during the CVA are presented in Table 10 and are similar to those of the other analyses presented above.

Discussion

The range in variation throughout the Indian subcontinent is not well understood or represented in our most commonly used reference samples (e.g., *Fordisc*). Beyond the more simple question of determining forensic significance, the ability to determine

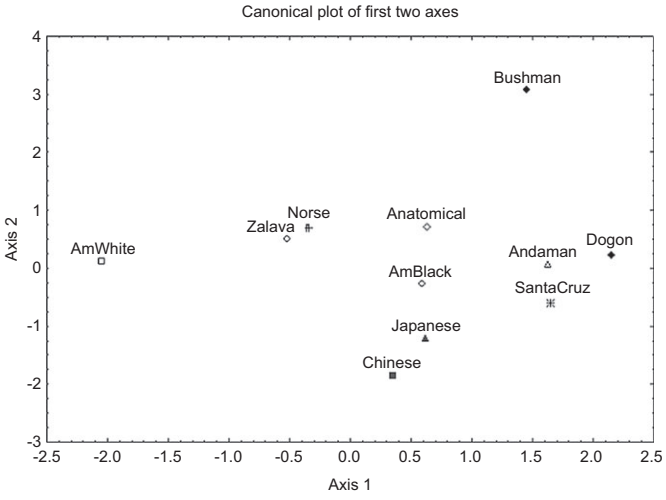

FIG. 5—*Plot of first two axes from the canonical analysis.*

TABLE 9—*Squared Mahalanobis distances, by group.*

	Am. Black	Am. White	Anatomical	Andaman	Bushman	Chinese	Dogon	Japanese	Norse	Santa Cruz	Zalavar
Am. Black	0.000										
Am. White	9.698	0.000									
Anatomical	5.160	8.718	0.000								
Andaman	9.246	16.268	4.181	0.000							
Bushman	15.531	21.584	8.097	13.535	0.000						
Chinese	7.727	11.169	8.831	9.802	26.301	0.000					
Dogon	7.745	19.659	4.942	4.197	11.857	10.529	0.000				
Japanese	4.936	9.549	4.839	6.550	19.920	2.193	6.702	0.000			
Norse	6.004	5.937	5.486	12.609	11.631	10.913	12.964	7.055	0.000		
Santa Cruz	10.363	19.968	12.228	11.404	18.931	11.663	14.226	8.091	9.384	0.000	
Zalavar	6.561	4.045	4.186	10.279	11.833	8.341	11.392	5.292	1.689	11.278	0.000

All distances significant at the $p < 0.05$ level.

TABLE 10—*Classification allocations from the canonical analysis. Note: Bold values represent classification statistics of the Anatomical sample.*

Group	CCR	Am. Black	Am. White	Anatomical	Andaman	Bushman	Chinese	Dogon	Japanese	Norse	Santa Cruz	Zalavar
Am. Black	68.83	170	20	5	1	3	4	6	19	6	8	5
Am. White	85.55	14	361	3	3	0	2	1	12	11	0	15
Anatomical	**32.31**	**5**	**10**	**21**	**5**	**2**	**0**	**10**	**8**	**1**	**1**	**2**
Andaman	68.57	0	2	6	48	0	0	8	3	1	0	2
Bushman	86.67	1	0	2	3	78	0	4	1	1	0	0
Chinese	49.41	6	6	0	1	0	42	0	26	1	2	0
Dogon	70.71	10	0	3	7	1	0	70	7	1	0	0
Japanese	56.18	18	10	6	7	0	14	8	100	3	7	4
Norse	49.09	13	19	2	1	1	0	0	4	54	3	13
Santa Cruz	87.25	3	1	0	3	1	0	1	2	2	89	0
Zalavar	35.71	4	27	0	1	0	0	1	9	20	1	35
Total	67.93	244	456	48	80	86	62	109	191	101	111	76

Note: **Bold** values represent classification statistics of the Anatomical sample.

the geographic place of origin of anatomical specimens would allow the forensic anthropologist greater power in establishing a taphonomic history. By aggregating a large sample of anatomical crania and quantifying homogeneity within the sample, a potential new reference sample for forensic anthropological analyses is available. Because anatomical crania are frequently encountered in forensic anthropological casework, an anatomical reference sample is necessary. The documented anatomical sample is only moderately homogenous, but not to the point of uselessness. While significant values were obtained using the Defrise-Gussenhoven statistic (and therefore suggesting not all individuals were drawn from the same population), the overall homogeneity of the sample indicates it can be used as a pooled reference sample (similar to the pooled sample of Hispanics in the current version of Fordisc) for further craniometric analyses. Although we did not conduct an analysis using the "import database" function in Fordisc 3.1 (FD3) using the derived pooled sample of anatomical material, the results of the D-F test and the independent discriminant function analyses in FD3 and *CRANID* argue for more appropriate reference samples.

The significant results of this research are outlined below. As mentioned, there are indications that not all individuals in the anatomical sample were drawn from the same population. However, the majority (~58%) of significant differences identified by the Defrise-Gussenhoven test within the sample are limited to a single cranium (Fig. 6), clearly different from the other individuals (in taphonomic profile, as well—see below). Seven crania account for about 25% of the remaining significant values. Several possibilities explain these results. First, measurement error introduced during data collection could be responsible, but is unlikely. There are no indications of abhorrent error in these data. Second, the most distinct individual could be from this population but is an outlier. Finally, the individual could belong to another group.

Based on the results of the Defrise-Gussenhoven test, the latter appears to be the most likely explanation. Taphonomically, the cranium is very different from the other anatomical specimens. While this individual shows evidence of anatomical preparation (see Fig. 6), the preparation is not consistent with the taphonomic profiles noted among the other anatomical specimens, such as high-quality hardware, springs, screws, and consistent whitening of the bone surfaces.

Testing group homogeneity using the Defrise-Gussenhoven test relies not only on random expectation, but also on the detection of outliers. Removing potential outliers from an analysis may tell us less about cranial variation among anatomical cranial material. On the other hand, if these individuals are not outliers but are in fact drawn from another group, removing them from further analyses is required.

In spite of limitations encountered in this study regarding the provenience of our sample, the Defrise-Gussenhoven test allowed for quantification of homogeneity. The most significant

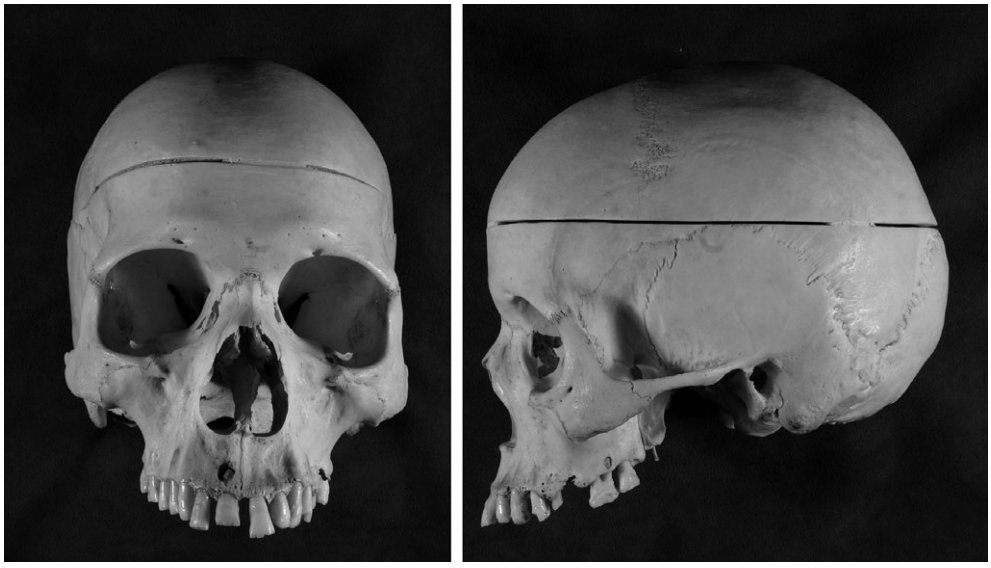

FIG. 6—*The atypical anatomical specimen distinctly different from others in the sample.*

result of this analysis concerns evidence of what is likely a much greater degree of cranial variation among Indian populations and, therefore, anatomical cranial material. Evidence for this variability comes from the classification rates and typicality probabilities among several groups. A majority of these classifications were within the Indian subcontinent, suggesting the level of heterogeneity in the anatomical sample is not necessarily exclusive evidence for non-Indian sources of anatomical specimens. The cranial variability noted among the anatomical crania suggests the variability in India is much higher than previously considered, a finding supported by recent work on cranial variation among modern Indian individuals (30). When anatomical material is encountered in the forensic laboratory, a reference sample is necessary for craniometric comparisons.

Conclusions

The purpose of this research was twofold. First, we wanted to document the history of the taphonomic treatment of anatomical material. While anatomical cranial material shares a taphonomic history, forensic anthropologists should exercise caution when only using taphonomic indicators to make inferences about the likely source of anatomical remains. Second, we set out to document the range in variation of anatomical specimens purchased from biological supply companies in the United States. The historical grouping of anatomical cranial material into a single, homogeneous group with a shared taphonomic history does not fully answer the question of the source for this material. Until precise provenience information is available and additional skeletal material from India is studied, it is impossible to fully understand the implications of the moderate levels of heterogeneity documented in this study. Although the majority of these crania cluster with samples drawn from the Indian subcontinent, a much larger and more fully documented sample of anatomical specimens would permit a more thorough understanding of the craniometric variability of anatomical cranial material. The inclusion of crania of known ethnic, religious, and linguistic origin in future studies may assist in identifying more homogenous clusters within the larger sample.

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