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Metric Variation in the Human Occipital Bone: Forensic Anthropological Applications

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ABSTRACT: Sex and race variation of the occipital bone have been previously investigated, but particular examination of the effect of age and ancestry on sexual dimorphism has not been addressed. This paper examines morphological variation associated with sex and ancestry in the condylar region of the occipital bone and the effect of age and ancestry on the estimation of sex. Models previously published by Holland (1,2) are also tested, and methodological problems are addressed. The results indicate that age does not have an effect on sexual dimorphism, but that whites exhibit greater, although not significantly, more sexual dimorphism than blacks. Significant sex and ancestry variation is present in the condylar region of the occipital bone, but neither sex nor ancestry could be estimated accurately using measurements of this anatomical region defined by Holland (1,2).

KEYWORDS: forensic science, forensic anthropology, skeletal anatomy, occipital bone, sex, ancestry

The cranium is frequently used for the estimation of sex, and almost always for ancestry, in medicolegal investigations of the human skeleton. Visual observations are often used but craniometry is also frequently employed in skeletal analyses (3–5). In the early 1960s, Giles and Elliot published discriminant function equations based on cranial measurements for assessing sex (6) and ancestry (7). They found that sex could be correctly assigned with 82 to 89% accuracy, and ancestry could be correctly classified in males and females with 82% and 88% accuracy, respectively. Numerous subsequent publications have utilized other collections, measurements, and techniques (8–14). Some have supported Giles and Elliot's results, while others have been critical. The effect of age (15–20), secular change (21), and measurement error (22) on the estimation of sex and ancestry using craniometry has also been investigated.

In the mid 1980s, Holland published discriminant and multivariate regression equations for the estimation of sex (2) and ancestry (1) using the condylar region of the occipital bone. The advantage of Holland's method over methods such as those proposed by Giles and Elliot (6,7) is that sex and ancestry can be estimated using a fragmentary cranium. With the exception of FORDISC (23), which calculates customized discriminant functions for each case, most metric methods for estimating sex and ancestry from the cranium require a complete skull.

Based on a sample of pooled black and white crania from the Terry Collection, Holland (2) found that measurements of the occipital could correctly classify the sex of an individual with 71 to 90% accuracy. On a test sample of crania not used in the formulation of his equations, he observed that sex was classified correctly with 70 to 85% accuracy. Holland (1) also found that ancestry could be correctly classified with 70 to 86% accuracy using the occipital bone.

Williams (24) used Holland's cranial base measurements to estimate sex in an archaeological sample of Arikara from South Dakota. She used 149 crania with associated pelvic bones as a calibration sample to develop discriminant functions customized for the Arikara. She then used these functions to estimate the sex for her calibration sample and an additional "test" sample composed of 26 crania with no associated pelvic bones. Sex was estimated for the "test" sample using standard cranial features. Williams (24) found that the functions she developed using the Arikara could correctly classify sex in 76% of her calibration sample and in only 58% of her test sample. She also tested the functions developed by Holland (1) on her Arikara sample, and observed that sex could only be correctly classified with 52% accuracy, barely better than random assignment.

The inability of Holland's functions to correctly classify sex in Arikara skeletons is easily explained by differences in the sexual dimorphism between the Native American sample and the Terry Collection sample, but Williams (24) also suggested several factors that may have contributed to the differences between her study and Holland's (1). First, because her sample was composed of archaeological material, sex had to be estimated from pelvic and cranial morphology. Therefore, her sample was composed of individuals of estimated sex, while Holland's sample was of known sex. Second, an age effect may be present as the cranium often enlarges with advanced age, especially in females (16–20,25). Williams did not estimate the age of her sample. If there was a significant difference between the age of Williams' sample and Holland's sample, this could account for some of the difference. Finally, Williams suggested that differences in the health of the two samples might have contributed to the differences. Angel (26) and Angel et al. (27) have suggested that cranial base is sensitive to health related factors.

The purpose of this study is to investigate the reliability of sex and ancestry estimation using the condylar region of the occipital bone, and to examine the effect of age and ancestry on the estimation of sex. Intra- and interobserver error in measurements of the occipital bone used by Holland (1,2) is also evaluated, as are his

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TABLE 1—*Occipital measurements.*

Measurement	Abbreviation	Holland's Abbreviation*	Reference†
Maximum Condyle Length	MLC	MLC	Droessler (31)
Maximum Condyle Breadth	MWC	MWC	Droessler (31)
Minimum Distance Between Condyles	MND	MnD	
Bicondylar Length	BCB	MxD	
Maximum Interior Distance Between Condyles	XID	MxID	
Foramen Magnum Length‡	FML	LFM	Martin (30)
Foramen Magnum Breadth‡	FMB	WFM	Martin (30)
Basilar Process Length‡§	LBP	LBP	
Basion–Hormion Length‖	BHL	LBP	Martin (30)
Distance Between Condylar Foramen	BFD	DF	

* Measurement abbreviation used in Holland (2,28).
† Reference source cited in Holland (2,28).
‡ Defined differently in Holland (2) than Holland (1,28). See text.
§ Measurement defined in Holland (2).
‖ Measurement defined in Holland (1,28).

discriminant and multiregression functions for the estimation of sex and ancestry.

Materials and Methods

A sample of 389 white and 133 black adult crania (20 to 80 years of age) from the Terry and Hamann-Todd anatomical cadaver collections were used in this study. Ten dimensions (Table 1) of the occipital bone were measured using digital sliding calipers to the nearest 0.1 mm according to the definitions provided by Holland (2). These measurements include length and breadth of the occipital condyles and foramen magnum, length of the basilar process, and four measurements that describe the intercondylar relationship across the cranial base. The left side was used for bilateral structures whenever possible.

A multivariate analysis of variance (MANOVA) procedure was completed for the main effects of sex, ancestry, collection and age, and the interactions sex* ancestry and sex* age. The MANOVA procedure evaluates the relationship of the continuous variables to the independent classification variables. Discriminant function analysis was used to evaluate the effectiveness of the occipital bone at estimating sex and ancestry, and a stepwise procedure was used for variable selection. The stepwise procedure selects a subset of variables that has the greatest amount of discriminating ability. Evaluation of the discriminating ability of the variables selected was then conducted using a cross-validation procedure implemented in SAS.

Tests for intra- and interobserver error were also performed. Twenty crania were subjected to two separate measurement trials and the difference was used to calculate a percentage of intraobserver error (22). To evaluate interobserver error, we compared 20 individuals from the Terry collection that were measured by both Holland (28) and the first author.

Results

Measurement Error

As seen in Table 2, the percent of intraobserver error is within reason except for the measurement MWC, but the interobserver error is relatively high for six of the ten measurements. This suggests that measurements of the condylar region, especially the breadth of the condyle, are difficult to replicate. The most reliable measurements are BFD, FML, FMB, BCB, and MLC.

Besides a high interobserver error, we also found other discrepancies in several of the measurements used by Holland. First, Holland defines the measurements LBP differently in his two publications. Holland (1) first described LBP as the distance from basion to hormion (BHL in the present study) and then later (2) as the length "measured from basion to the midpoint of the basilor [sic] suture" (p. 204). Clearly these are different measurements. We measured LBP according to both definitions on a number of the same Terry Collection specimens that Holland (28) measured, and discovered that he probably measured to the spheno-occipital synchondrosis or basilar suture (LBP). This likely accounts for the high interobserver error for BHL (See Table 2). Unfortunately, the intraobserver measurement error is slightly greater when measuring to the midpoint of the spheno-occipital synchondrosis compared to hormion (BHL). This is primarily because the spheno-occipital synchondrosis is often obliterated and difficult to locate. We also found both measurements (LBP and BHL) difficult to take using sliding calipers because of the position of the palate, especially in white individuals (29). As a result, LBP was recorded for only 71% of the specimens. Holland (28) was able to record LBP for all specimens in his study.

Holland also describes FML and FMB differently. In one paper (1), he described FML as the "maximum length of the foramen magnum as measured from basion to opisthion along the mid-sagittal plane" (p. 722) and FMB as the maximum width perpendicular to the mid-sagittal plane. He (2) then describes them as the maximum internal length and breadth of the foramen magnum, respectively. Again these can be quite different measurements, and we are unclear as to which he actually used.

Another discrepancy we found is that the condylar foramen was absent, at least on one side, in over 40% of the crania measured in this study. As a result, 44% of the individuals in our sample have no value for the measurement BFD. It is unclear if Holland estimated BFD in the absence of condylar foramina, but

TABLE 2—*Intra- and interobserver error.*

	Intraobserver			Interobserver		
Variable	% Error*	Mean	SD	% Error*	Mean	SD
MLC	1.8	0.45	0.31	3.8	0.50	0.95
MWC	5.4	0.66	0.52	5.2	−0.14	0.72
MND	2.7	0.52	0.36	4.7	−0.87	2.06
BCB	1.5	0.80	0.90	2.0	−0.26	1.40
XID	2.0	0.88	0.51	5.6	0.06	1.46
FML	1.1	0.41	0.41	0.7	0.03	0.33
FMB	1.3	0.40	0.52	1.2	−0.09	0.57
LBP	2.9	0.72	0.77	6.4	0.16	2.06
BHL	2.7	0.17	0.69	9.9	−2.70	2.12
BFD	0.8	0.32	0.36	2.9	−0.05	1.84

* Percent Error = $\frac{\Sigma\, |Xi_1 - Xi_2| \,/\, n * 100}{(\bar{X}_1 + \bar{X}_2)/2}$

TABLE 3—*Summary statistics by ancestry and sex (in millimeter).*

	Black Females			Black Males			White Females			White Males		
Measurement	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
AGE	66	40.6	12.0	67	39.9	12.1	188	51.2	16.1	201	49.9	17.0
MLC	66	22.0	2.3	67	23.2	2.9	188	22.8	2.2	201	24.7	2.7
MWC	66	12.0	1.5	67	12.8	1.2	188	11.7	1.3	201	12.3	1.2
MND	65	18.6	2.5	66	20.1	3.0	181	19.2	2.0	196	20.9	2.4
LBP*	59	24.2	2.4	56	25.3	2.6	147	24.8	2.4	116	25.9	2.8
BHL†	55	30.5	2.7	51	31.7	3.0	151	28.5	2.5	155	29.9	3.0
BCB	65	47.3	4.1	65	49.6	3.8	187	49.8	2.9	200	51.9	3.2
XID	…	…	…	…	…	…	187	41.6	3.0	200	43.3	3.3
BFD	24	40.8	3.4	27	43.2	4.4	128	41.1	3.5	112	43.9	4.4
FML	64	34.8	2.5	65	36.0	2.9	184	34.6	2.3	201	36.7	2.5
FMB	66	28.4	2.3	66	29.8	2.3	203	29.8	2.0	201	31.6	2.4

* Length of the basilar process as defined by Holland (2).
† Length from basion to hormion as defined by Holland (1).

the measurement was recorded for each individual in his (28) study.

Statistical Results

Simple statistics are given in Table 3 by sex and ancestry. As expected, males are larger than females in all dimensions recorded. Also, sexual dimorphism is greater in whites than blacks for most variables, and both male and female whites are generally larger than blacks in all dimensions except MWC and BHL. That is, whites have longer but narrower condyles and wider intercondylar dimensions. Whites also have a slightly rounder foramen magnum.

Two MANOVA procedures were conducted. The first MANOVA used all ten variables, but in order to increase the number of observations, LBP, BHL, BFD, and XID were not used in the second MANOVA procedure. Wilks Lambda statistics for the hypothesis of no overall effect of collection, age, sex, and ancestry for the second MANOVA are presented in Table 4. The hypothesis is rejected for sex and ancestry but not for collection or age. While the dimensions of the cranial base show significant sex and ancestry differences, there is no significant sex* ancestry interaction for any of the variables. In other words, while there are race differences in the occipital bone, the pattern of sexual dimorphism does not differ significantly between blacks and whites.

Stepwise selection was employed to develop models of measurements displaying the maximum amount of discriminating ability. For sex, FML, MND, MLC, BHL, and MWC provide the greatest discriminating ability (Table 5). However, the total squared canonical correlation is only 0.292. For ancestry, the inclusion of six variables only yields a total squared canonical correlation of 0.248, with BCB and BHL providing the most variation (Table 6). The low canonical correlation values indicate that most of the variation in the occipital bone is not due to sex or ancestry.

Discriminant function equations were calculated, with the prior probabilities set equal, to estimate sex and ancestry using the variables selected by the stepwise procedure. Because there is an uneven number of blacks and whites in our sample, ancestry means were centered on zero when running discriminant analyses for sex, as were sex means when running discriminant analyses for ancestry. In the cross-validation test, the percent of males and females correctly classified is only 76%, with females being correctly classified slightly more often than males (Table 7). Whites were correctly classified with greater accuracy than blacks. Ancestry

TABLE 4—*Wilks' lambda statistics for the test of no overall effect.*

Classification Variable	Value	*F* Value	$Pr > F$
Collection	0.9942	0.47	0.8288
Age	0.9870	1.06	0.3828
Sex	0.9263	6.42	0.0001
Ancestry	0.8975	9.22	0.0001

TABLE 5—*Stepwise selection for sex.*

Variable	Partial R^2	*F* Statistic	*P* Value	Squared Canonical
FML	0.131	59.05	<0.0001	0.131
MND	0.089	38.22	<0.0001	0.208
MLC	0.068	28.45	<0.0001	0.262
BHL	0.026	10.48	0.0013	0.281
MWC	0.015	5.98	0.0149	0.292

TABLE 6—*Stepwise selection for ancestry.*

Variable	Partial R^2	*F* Statistic	*P* Value	Squared Canonical
BCB	0.106	46.77	<0.0001	0.106
BHL	0.092	39.98	<0.0001	0.189
FMB	0.024	9.73	0.0019	0.209
FML	0.024	9.50	0.0022	0.228
MLC	0.017	6.62	0.0104	0.240
MWC	0.010	3.94	0.0479	0.248

TABLE 7—*Discriminant function cross-validation results for sex.*

	Percent Correctly Classified		
	Males	Females	Total
Whites Only	73.0	79.0	76.4
Blacks Only	60.4	66.7	63.6
Pooled Race	73.0	79.0	76.0

TABLE 8—*Discriminant function cross-validation results for ancestry.*

	Percent Correctly Classified		
	Blacks	Whites	Total
Males only	72.3	73.6	72.9
Females only	70.4	75.2	72.8
Pooled sex	73.3	77.0	75.2

was correctly classified with 75% accuracy (Table 8). In this analysis, whites were correctly classified more often than blacks.

We also tested Holland's multiple regression sex (2) and ancestry (1) models. Sex was correctly classified with 73, 71, 68, 72, 65, and 68% accuracy, respectively for models 1–6. Holland (2) found that these models could correctly classify sex with 90, 79, 79, 77, 76, and 71% accuracy, respectively. The high interobserver error of the measurement MWC may play a role in the decreased accuracy of these models, and the high interobserver error of XID and LBP may have affected models 1 and 3. Therefore, for ancestry, only Holland's (1) Eq 4 was tested, as this was the only model that did not include these measurements. Multiple regression Eq 4 correctly assigned ancestry with 61% accuracy using our data. Blacks were correctly classified with 78% accuracy, but whites were only classified correctly 56% of the time. Holland (1) found this model correctly classified ancestry with 70% accuracy, but he did not break his results down by race. These results differ from the discriminant analyses ran in this study, which correctly classified whites slightly more often than blacks (Table 8).

Discussion

Measurements of the condylar region of the occipital bone used by Holland (1,2) appear difficult to measure with precision. Three of his nine measurements (FML, FMB, and BHL) are defined by Martin (30), two (MLC and MWC) were developed by Droessler (31), and the remaining four were developed by Holland for his master's thesis (28) (See Table 1). Similar to Holland (28), we found the measurements of the foramen magnum to be among the most reliable, with only BFD exhibiting less intraobserver error. While we found fairly high intraobserver error in the measurement MWC (5.4%), Holland (28) and Droessler (31) did not, finding 2.81% and 2.29%, respectively. Part of this discrepancy is probably associated with time between measurement trials. For this study, there was nearly two years time between the two trials.

Williams (24) also found dimensions of the cranial base difficult to measure, especially BFD. She (24) found MND, BCB, and MLC to be the most reliable and BFD to be the most unreliable measurement. She also discovered in her sample, as we did in ours, that many crania do not have condylar foramina. In cases where one foramen was absent, she estimated the position of the contralateral foramen in order to take the measurement. In this study, BFD was only measured on crania with both foramina, which probably accounts for the lower intraobserver error. As we did, Williams (24) found it difficult to measure the basilar process length due to obliteration of the spheno-occipital synchondrosis. To correct for this problem, she measured from "basion to the midpoint of the traberculum sellae portion of the sphenoid bone" (p. 9).

While measurements of the occipital are difficult to replicate, our greatest concern is Holland's (1,2,28) inconsistencies in measurement definition. Holland describes LBP, FML, and FMB differently in his two articles (1,2), but he cites Martin (31) as the primary source for these measurements. Holland also does not state if he estimated some of his measurements. However, the low frequency of bilateral condylar foramen in our sample suggests that he must have estimated BFD for many of his specimens.

Measurements of the cranial base also appear to only moderately estimate sex and ancestry. Neither sex nor ancestry can be correctly classified with more than about 76% accuracy using this anatomical region. Williams (24) found similar results using Native American crania. In her study, she developed four discriminant functions for the Arikara, which could only correctly classify sex with 73 to 76% accuracy. The results of the present study suggest that the archaeological nature of Williams' sample and the effect of age and health did not play a major role in the reduced accuracy she observed for the Arikara.

Age does not have any apparent effect on the estimation of sexual dimorphism in this region. However, ancestral differences, although not significant, are evident. This probably explains why only 52% of the Arikara in Williams' (24) study were correctly sexed using the functions developed by Holland (2). Regarding the question of ancestral differences in sexual dimorphism, we observed that whites exhibit slightly greater sexual dimorphism in the condylar region than do blacks. Because whites are generally larger than blacks, white females and black males are the most closely aligned groups. This presents a problem when estimating sex from a skeleton of unknown ancestry. First estimating ancestry and then using separate models for blacks and whites could solve the problem. However, because the ability to predict ancestry based on measurements of the occipital bone is not highly reliable, models developed on a pooled race sample are probably more appropriate.

One of the main intents of Holland's (1,2) study was to develop a method for estimating sex and ancestry using fragmentary crania. However, Williams (24) found that damage to the cranial base, especially the occipital condyles, was common among the Arikara. This suggests that the occipital condyles may be easily damaged due to taphonomic processes. If such damage has occurred to the cranial base, then the accuracy in sex and race estimation could be further reduced.

Secular changes observed in the crania may also reduce the accuracy of models published by Holland (12,21,32). Jantz and Meadows Jantz (33) and Moore-Jansen (21) have demonstrated significant temporal change, especially in size, for both blacks and whites. These studies suggest that sex and ancestry models developed on the Terry and Hamann-Todd collections may not be appropriate for recent medicolegal cases. Hopefully new models can be developed in the future on more appropriate skeletal collections.

In conclusion, Holland's (1,2) models provide a moderately accurate method for the estimation of sex and ancestry using fragmentary crania, but should be used with caution. The dimensions used by Holland (1,2) are inconsistently defined and difficult to measure with precision. Also, neither sex nor ancestry can be estimated with more than about 76% accuracy, and this accuracy may be reduced in recent forensic cases due to secular change. We recommend that measurements of the cranial base not be used for the estimation of sex or ancestry if other methods can be employed.

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