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PAPER

ANTHROPOLOGY

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Humeral and Femoral Head Diameters in Recent White American Skeletons

ABSTRACT: Osteologists often rely on single measurements, such as humeral and femoral head diameters, to estimate sex, especially when skeletons are incomplete. Measurements of 237 Bass Donated Collection skeletons provide a means of distinguishing white American females from males based on a modern sample: humeral head, female mean 42.1 mm, male mean 49.0 mm; and femoral head, female mean 42.2 mm, male mean 48.4 mm. Probabilities that bones at 1-mm increments came from females (p_f) are estimated ($p_m = 1 - p_f$). An overrepresentation of one sex in the skeletons that are examined influences the probability that a bone of a certain size is from a female or male. So, probabilities are also estimated for samples consisting of an unequal number of males and females. Sample composition has its greatest effect when one sex dominates the remains that are the subject of investigation.

KEYWORDS: forensic science, forensic anthropology, skeletal sex estimation, probability estimates, humeral head diameter, femoral head diameter

Sex estimation is an essential part of forensic and archaeological studies of skeletons. Females are commonly distinguished from males by experience-based assessments and various bone measurements. The latter can range from single measurements to combinations of two or more of them, including complex multivariate analyses. In general, more measurements are commonly believed to yield better results, as they can capture a sense of shape as well as size, whereas individual dimensions only indicate the latter. Single measurements, however, still have a place in sex estimation for three practical reasons: data are quick to collect; they can be reasonably accurate indicators of sex; and skeletal remains are often fragmented or incomplete, greatly reducing the number of measurable sex-informative structures.

Here, we present information on the sizes of humeral and femoral heads for 237 modern white Americans who died during the past three decades. Decision making—determining whether a skeleton is likely to have been from a female or male—is facilitated by providing the probability that a bone of a given size is from a female (p_f). This procedure departs from the common practice of giving a single sectioning point that separates the two sexes or specifying a middle ground where nothing can be said about sex. It follows the lead of analyses, most notably FORDISC (1), that provide a measure of the certainty about an outcome, in our case, an estimate of sex.

In addition to bone size, the ratio of females to males in the forensic or archaeological sample that is investigated also plays a part in estimating sex. The effect of sample composition on the probability that a bone of a given size belongs to a female or male can be important, especially when the group of skeletons being studied is heavily weighted toward one sex or the other. Advance knowledge of the sex ratio might occur in disaster-related work where a passenger list is available or in a genocide investigation where victims were mainly drawn from a certain part of a community (e.g., adult males). The procedure is broadly similar to the calculation of predictive values in epidemiological screening tests (2). The general problem posed by the study sample's sex composition has been mentioned only occasionally in the osteological literature (3–5).

Osteologists faced with situations where the sex ratio can be estimated independently can use tables, provided here, that list the probabilities of being female for humeral and femoral heads measured at 1-mm intervals. Different sets of estimates are given for samples where women comprise 0.1–0.9 of the study materials, at increments of 0.1, as well as 0.01 and 0.99. Corresponding figures for being male can be obtained with little additional effort ($p_m = 1 - p_f$). A computer program, available on the Internet, allows researchers to specify other frequencies of females in the samples being investigated.

Materials and Methods

An age-stratified random sample of skeletons was selected from white individuals in the Bass Donated Collection at the University of Tennessee. These people, who died at some point during the past three decades, were between the ages of 25 and 101. Sex was not known when measurements were taken, as identifying information on boxes was covered well beforehand, typically several days earlier.

One of us (GRM) measured both the left and right humeral and femoral heads. The humeral head dimension was taken from the most superiorly and laterally located margin of the articulation surface to the most inferior and medial point, following Buikstra and Ubelaker (6, p. 80, Fig. 49) and Moore-Jansen et al. (7, p. 63, Fig. 31) (Fig. 1). The maximum diameter of the femoral head conformed to how it is defined in Buikstra and Ubelaker (6, p. 82,

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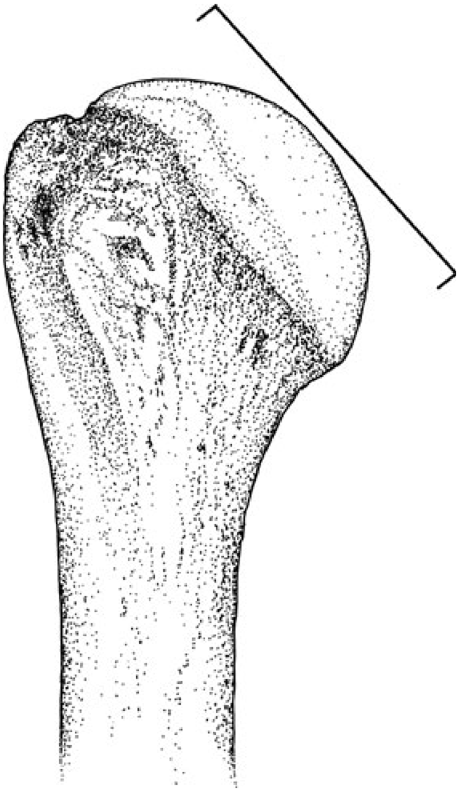

FIG. 1—*Humeral head diameter, measured from the most superior to inferior margins of the articulation surface.*

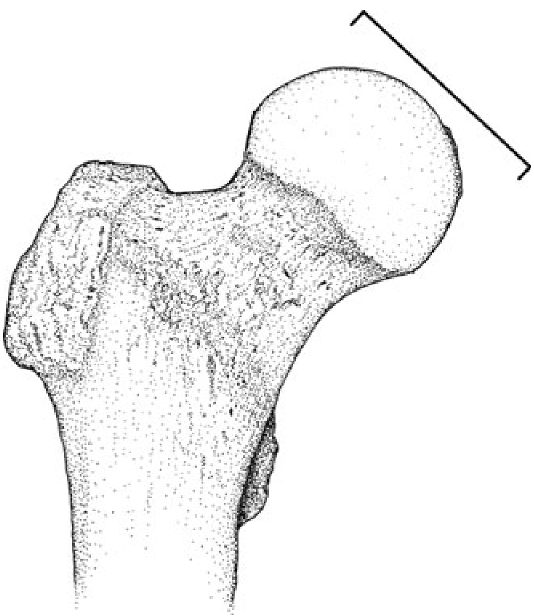

FIG. 2—*Femoral head diameter, with the longest dimension occurring anywhere around the circumference of the head.*

Fig. 54). It is the largest dimension of the head, regardless of whether it was vertically or transversely oriented, or anywhere in between (Fig. 2).

The left bone was used whenever possible. The right side was substituted for the left when the latter was not available—the bone was missing or damaged, it was deformed because of trauma or disease, or there was a prosthetic joint. That was possible because the left and right sides were not statistically different: paired *t*-tests; humerus, 95 females, $p = 0.29$, 97 males, $p = 0.63$; and femur, 96 females, $p = 0.92$, 112 males, $p = 0.23$. For the femora, 226 individuals had measurements for at least one of two sides, with 10 right bones being used in place of a missing or damaged left bone. Corresponding figures for the humerus were 220 individuals and 16 right side measurements. In all, humeral or femoral measurements, usually both, were available for 115 females and 122 males.

Measurements for each sex did not deviate significantly from normal, considerably simplifying analyses as means and standard deviations (SD) could be used to estimate size distributions. Expected frequencies of females (E_f) and males (E_m) were calculated from the sex-specific cumulative normal frequency distributions. Intervals were centered on values as $(x - 0.5)$ to $(x + 0.5)$, with x ranging from the smallest to largest measurement, in millimeters, in the Bass sample. The females expected for each head diameter were calculated from the estimated frequencies of individuals of both sexes, taking into account the prior overall frequency of females in the sample.

The procedure is straightforward, as long as there is an equal representation of the two sexes; that is, when $p_f = p_m = 0.5$. A minor adjustment is needed for samples that deviate from that situation. Expected frequencies at each 1-mm increment were altered by the representation of females and males in the sample. If, for example, one had some reason to believe that females made up only 30% of the study skeletons ($E_f = 0.3$), then the expected frequency of females at each 1-mm interval was reduced by multiplying by 0.3. Corresponding figures for males were increased by multiplying by 0.7 ($E_m = 0.7$).

Results

The two dimensions were highly correlated with one another—$r = 0.90$ for the combined sexes and $r = 0.71$ for both males and females considered separately—with no obvious outliers (Fig. 3). Females, on average, had smaller femoral and humeral heads than males: humerus, 106 females, mean = 42.1 mm, SD = 1.9, 114 males, mean = 49.0 mm, SD = 2.6; and femur, 107 females, mean = 42.2 mm, SD = 2.1, 119 males, mean = 48.4 mm, SD = 2.6. Of the two measurements, the one for the humerus provided a somewhat better discrimination between the sexes. A combination

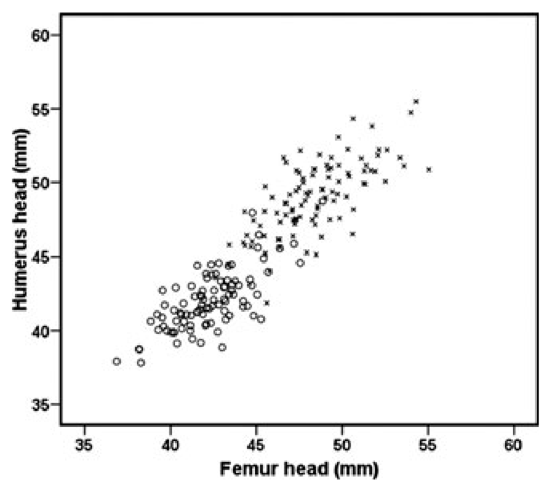

FIG. 3—*Correlation between femoral and humeral head diameters: females (o) and males (x).*

of the two bones did not yield results that were an improvement on the humerus alone.

The expected frequency of females for humeral and femoral heads of different sizes, increasing at 1-mm intervals, can be read directly from Tables 1 and 2. Male estimates are obtained by simple subtraction using the female figures ($p_m = 1 - p_f$). The middle column (50%) should be used if there is reason to believe there is an equal chance that a skeleton drawn at random from the study sample would be male or female. In other words, the skeletal sample under investigation is thought to be composed of equal numbers of males and females.

If one sex predominates in the sample, then the column that most closely approximates the known or suspected percentage of females should be used instead of the middle (50%) column. If, for example, one has advance knowledge that roughly 80% of the remains are likely to be from females, then the 80 column should be used to obtain the frequency of females expected for bones of a particular size. To take this example one step further, if 20 humeri in this female-dominated sample measured 45 mm, then roughly 17 bones were likely to have been from women (females = 20*0.849). But, if the opposite was true—males made up 80% of the sample, with females being 20%—then one might expect that only about five of the same group of humeri were from females (females = 20*0.261). If one has very specific information on the sex ratio of the sample being investigated, a computer program can be used to estimate the probability that a bone of a given size came from a person of one sex or the other (http://www.ADBOU.DK/sexestimation and http://www.anthro.psu.edu/projects_labs/bioarch/bioarch_lab.shtml).

The tables show that when the representation of females in the study sample shift up or down, so too do the expected frequencies of females at each humeral or femoral head diameter. So, as the female fraction of a skeletal sample increases, the probability that a large femoral or humeral head came from a woman also increases. That can be seen graphically in Figs 4 and 5, where humeral and femoral head diameters corresponding to an equal chance of being a male or female are shown for samples composed of 1–99% females; that is, the curve corresponds to the sizes

TABLE 1—*Females expected for humeral head diameters at 1-mm intervals in samples consisting of 1–99% females.*

Humerus Head (mm)	Percentage Females in Sample										
	1	10	20	30	40	50	60	70	80	90	99
35	0.981	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
36	0.972	0.997	0.999	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000
37	0.957	0.996	0.998	0.999	0.999	1.000	1.000	1.000	1.000	1.000	1.000
38	0.926	0.993	0.997	0.998	0.999	0.999	0.999	1.000	1.000	1.000	1.000
39	0.864	0.986	0.994	0.996	0.998	0.998	0.999	0.999	1.000	1.000	1.000
40	0.747	0.970	0.987	0.992	0.995	0.997	0.998	0.999	0.999	1.000	1.000
41	0.553	0.932	0.968	0.981	0.988	0.992	0.995	0.997	0.998	0.999	1.000
42	0.320	0.838	0.921	0.952	0.969	0.979	0.986	0.991	0.995	0.998	1.000
43	0.139	0.641	0.800	0.873	0.915	0.941	0.960	0.974	0.985	0.993	0.999
44	0.048	0.357	0.556	0.682	0.769	0.833	0.882	0.921	0.952	0.978	0.998
45	0.014	0.136	0.261	0.377	0.485	0.585	0.679	0.767	0.849	0.927	0.993
46	0.004	0.039	0.083	0.134	0.194	0.265	0.351	0.457	0.590	0.764	0.973
47	0.001	0.009	0.020	0.034	0.053	0.077	0.111	0.163	0.250	0.429	0.892
48	0.000	0.002	0.004	0.007	0.012	0.017	0.026	0.039	0.065	0.136	0.633
49	0.000	0.000	0.001	0.001	0.002	0.003	0.005	0.008	0.013	0.029	0.247
50	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.005	0.053
51	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.009
52	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
53	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TABLE 2—*Females expected for femoral head diameters at 1-mm intervals in samples consisting of 1–99% females.*

Femur Head (mm)	Percentage Females in Sample										
	1	10	20	30	40	50	60	70	80	90	99
35	0.936	0.994	0.997	0.998	0.999	0.999	1.000	1.000	1.000	1.000	1.000
36	0.912	0.991	0.996	0.998	0.999	0.999	0.999	1.000	1.000	1.000	1.000
37	0.871	0.987	0.994	0.997	0.998	0.999	0.999	0.999	1.000	1.000	1.000
38	0.802	0.978	0.990	0.994	0.996	0.998	0.998	0.999	0.999	1.000	1.000
39	0.692	0.961	0.982	0.990	0.993	0.996	0.997	0.998	0.999	1.000	1.000
40	0.535	0.927	0.966	0.980	0.987	0.991	0.994	0.996	0.998	0.999	1.000
41	0.352	0.857	0.931	0.958	0.973	0.982	0.988	0.992	0.995	0.998	1.000
42	0.192	0.723	0.854	0.910	0.940	0.959	0.972	0.982	0.989	0.995	1.000
43	0.087	0.512	0.703	0.802	0.863	0.904	0.934	0.957	0.974	0.988	0.999
44	0.034	0.281	0.468	0.601	0.701	0.778	0.841	0.891	0.934	0.969	0.997
45	0.012	0.118	0.231	0.341	0.445	0.546	0.644	0.738	0.828	0.916	0.992
46	0.004	0.041	0.087	0.140	0.203	0.276	0.364	0.471	0.604	0.774	0.974
47	0.001	0.012	0.027	0.046	0.069	0.100	0.143	0.206	0.308	0.501	0.917
48	0.000	0.003	0.007	0.013	0.020	0.029	0.043	0.065	0.107	0.213	0.748
49	0.000	0.001	0.002	0.003	0.005	0.007	0.011	0.017	0.029	0.063	0.425
50	0.000	0.000	0.000	0.001	0.001	0.002	0.003	0.004	0.007	0.015	0.145
51	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.003	0.035
52	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.007

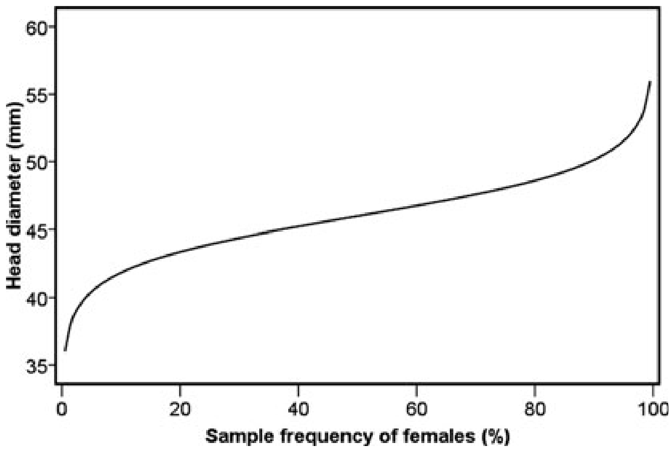

FIG. 4—*The size of humeral heads (mm) corresponding to an equal probability of being either female or male (50%) varies according to the fraction of the studied skeletal remains that were female, from 1 to 99%.*

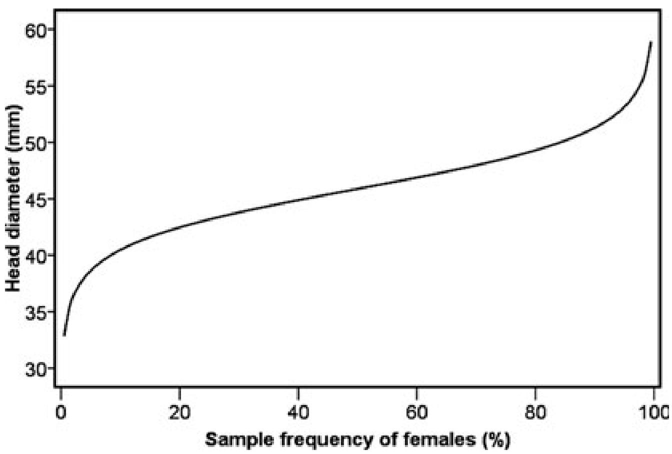

FIG. 5—*The size of femoral heads (mm) corresponding to an equal probability of being either female or male (50%) varies according to the fraction of the studied skeletal remains that were female, from 1 to 99%.*

of bones where one can expect that one-half of the measured specimens came from females, with the rest from males. So, if females happened to be disproportionately represented in the sample a researcher happens to be studying, the 50% point shifts upward, as do all other values. At the upper end of the sample composition distribution, where virtually everyone is suspected to be female at the outset, even very large bones are likely to be from women. With respect to the size distribution of all female skeletons, they are outliers that would be misclassified if one did not correct for sample composition.

Discussion

A high correlation between humeral and femoral head diameters was not surprising, as both track body size, with men being, on average, larger than women. The humerus worked a bit better than the femur for separating women from men, consistent with Stewart's (8) earlier observation for Terry Collection skeletons, also from the United States. Nevertheless, both bones can contribute much to the differentiation of one sex from the other. Nothing was gained by combining the two measurements; so, for the modern American population that gave rise to this sample, there is little to be gained by measuring a femur when a humerus is also present.

The Bass data generally conform to the results of other studies of people of European ancestry, where bones were measured similarly (Tables 3 and 4). In fact, the correspondence among studies is remarkable considering the possibility of sampling error, as most of the other samples are no more than one-half the size of the Bass sample, as well as inter-observer measurement error. Furthermore, the skeletal samples are dissimilar, despite being composed of individuals of European extraction. It can be expected that various regional populations within Europe contributed unequally to the individuals in the various collections, living conditions affecting growth were not identical in the sampled groups, and different selection biases played a part in the development of the skeletal assemblages.

For these two measurements, the correspondence among samples is close enough to suggest that their efficacy when applied to a new group of skeletons of European ancestry would often have as much to do with the sex ratio of the skeletons being investigated, as it does with the particular study one should choose as the basis for estimating sex. Researchers usually do not take the composition of the study sample into account when estimating the sex of the skeletons that are measured. That is not a trivial omission, as it can have a big effect on the inferences drawn from exactly the same measurement data, as shown by Figs 4 and 5. It is important to note, however, that the middle portions of both of the $p_f = p_m = 0.5$ lines are relatively flat. The ends corresponding to large and small percentages of females are what curve dramatically up or down. What is shown is consistent with Albanese et al.'s (3) suggestion that as long as samples are sufficiently large, reasonably good results can be obtained from their approach to estimating sectioning points in univariate analyses if the sex ratio of the study sample does not deviate too far from an equal mix of males and females.

Independently derived prior knowledge of a sample's composition, of course, is often not available, as commonly happens with archaeological remains. Yet, there are situations where such information exists, especially in forensic investigations, and one should make full use of it. Advance knowledge of the sex composition of a group of skeletons could come from a list of victims, such as might be available in the aftermath of a disaster. Another such situation would be the investigation of mass graves when there is reason to believe that most of the individuals were one sex or the

TABLE 3—*Humeral head diameters (mm) for several samples of skeletons classified as white, including the number examined (*N*), mean (Mean), and standard deviation (SD).*

Ancestry	Sex	*N*	Mean	SD	Source
Crete	M	84	46.4	2.5	9: Table 1
South Africa-DP*	M	55	49.0	3.2	10: Table 1
South Africa-D	M	48	47.2	3.0	11: Table 4
South Africa-P	M	48	48.0	2.8	11: Table 4
South Africa-C	M	36	48.2	2.5	11: Table 4
United States-T†	M	84	48.4	2.9	12: Table 1
United States-B	M	114	49.0	2.6	This study
Crete	F	84	41.2	2.4	9: Table 1
South Africa-DP	F	48	43.2	2.5	10: Table 1
South Africa-D	F	48	41.7	2.2	11: Table 4
South Africa-P	F	48	42.8	2.0	11: Table 4
South Africa-C	F	36	41.8	1.7	11: Table 4
United States-T	F	76	42.2	2.0	12: Table 1
United States-B	F	106	42.1	1.9	This study

*South African collections: Dart (D), Cape Town (C), and Pretoria (P).
†United States collection: Bass (B) and Terry (T).

TABLE 4—*Femoral head diameters (mm) for several samples of skeletons classified as white, with the exception of the Terry Collection that includes both white and black individuals, including the number examined (*N*), mean (Mean), and standard deviation (SD).*

Ancestry	Sex	*N*	Mean	SD	Source
South Africa-DP*	M	56	48.5	2.7	13: Table 1
United States-H†	M	54	48.2	2.3	14: Table 1
United States-T	M	50	48.0		8: p. 120
United States-B	M	119	48.4	2.6	This study
South Africa-DP	F	50	43.0	2.4	13: Table 1
United States-H	F	53	42.2	2.3	14: Table 1
United States-T	F	50	42.0		8: p. 120
United States-B	F	107	42.2	2.1	This study

*South African collections: Dart (D) and Pretoria (P).
†American collections: Bass (B), Hamann-Todd (H), and Terry (T); Terry sample includes white and black skeletons.

other, as could happen when a particular segment of a community was specifically targeted for execution.

To illustrate the seriousness of this issue, it is useful to return to the previous example where 20 humeri measuring 45 mm were from a sample dominated by one sex or the other. If no accommodation is made for the sample's composition, then the researcher would reasonably conclude that about 12 of the 20 bones were from women (20*0.585). That figure could still be wide of the mark, despite the investigator's best efforts in selecting an appropriate reference sample, using measuring instruments skillfully, and recording error-free data, all of which commonly and deservedly receive considerable attention. If we imagine that the skeletal sample of interest actually consisted of either 20% or 80% women, then either five or 17 humeri, not 12 of them, were likely to have been from females. Misclassification, in this instance, would be unacceptably high. If there was some reason to believe that the sex ratio was indeed as imbalanced as in this example, the researcher would be well advised to take into account the sex composition of the sample under investigation.

The effect of the sample's composition on the inferences drawn, rightly or wrongly, from the same set of measurements is not limited to actual forensic or archaeological investigations. It can also influence the outcome of validation studies, hence our perception of a measurement's capacity to predict sex correctly. A method's usefulness is commonly evaluated by the number of correct sex assignments relative to all examined individuals. The outcome, however, is heavily dependent on the sex composition of the skeletal collection chosen for testing purposes. As can be seen from the example discussed previously, quite different conclusions about the same measurement's effectiveness in discriminating between the sexes can be reached by simply altering the number of females relative to males in the study sample. What, in effect, is typically done is to use the middle column in Tables 1 and 2 when calculating the departure from the expected number of each sex at each measurement. The same logic underlies the use of a simple sectioning point separating females from males, or an interval in the middle of the distribution with limits encompassing skeletons classified as being of unknown sex. Returning once again to our example, one would expect 12 of 20 humeri measuring 45 mm to be from women, if there were the same number of females and males in the skeletal sample used for the validation study. But, if the sex composition of the validation sample was as unequal as 20% or 80% females, then there should instead be either five or 17 females represented by bones of this size, respectively. So, a method that actually performs equally well on all three samples could produce what would appear to be quite different outcomes in terms of the number of correct assignments of sex. Thus, an effective measurement might be dismissed as ineffective or, worse, a rather inaccurate measurement could be thought to perform better than it really does.

It might be argued that in a validation study, it would be unusual to have sex ratios as unequal as the ones in the previous example (20% or 80% females), but it is quite common to have somewhat more of one sex than the other. So, any conclusion drawn from the literature about the effectiveness of a particular skeletal dimension (or group of them) for sex estimation should be assessed in light of the sex composition of the validation study sample; that is, in addition to the usual concerns about strict adherence to measurement protocols, data entry accuracy, and blind trials.

Conclusion

While only two measurements commonly used to distinguish females from males are discussed, the rationale behind the estimation procedure is equally applicable to other skeletal dimensions. In essence, all one has to do is to identify the size distributions of the two sexes, which are approximated here as normal distributions based on reasonably large samples of measured bones. For every increment in increasing size, here each millimeter, it is then possible to estimate the number of each sex that is likely to occur if it is assumed that females equal males in overall sample ($p_f = p_m = 0.5$). Any other sex ratio can be likewise accommodated by accounting for the total number of females relative to males in the sample that is under investigation (e.g., if $p_f = 0.8$ then $p_m = 0.2$).

It must be remembered that the specific probabilities in Tables 1 and 2 only pertain to modern white Americans. Nevertheless, they are not much different from other samples of skeletons of European extraction, to judge from published summary figures. More importantly, the Bass measurements highlight an issue that has received scant attention: the need to account for the sex composition of the sample under investigation when estimating which individuals are likely to be of one sex or the other. Without knowledge of the sex ratio of the skeletal sample being studied, reasonably precise estimates for a bone of a particular size being from a female (or male) are not possible. The same could be said for accurate sectioning points for separating females from males, or the limits of an intermediate range of values where sex cannot be determined.

In situations where there is only an estimate of a sample's sex composition, it would be appropriate to use the column in the tables that most closely approximates the suspected percentage of females. If the female-to-male ratio is known exactly, one can use a computer program, based on these data, that is available on the Internet. Fortunately, it is possible to include such information in many investigations of skeletal samples, especially those of forensic interest, as well as validation studies designed to measure a procedure's effectiveness.

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