George W. Gill,[1] Ph.D.

Racial Variation in the Proximal and Distal Femur: Heritability and Forensic Utility

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ABSTRACT: The femur has been studied successfully by physical anthropologists for many years. Such traits as femoral head diameter and bicondylar width have been examined extensively and are of great value to forensic anthropologists and other skeletal biologists in sex identification. A number of studies over the past decade by the author and his former students have shown marked racial differences in the shape of the proximal femur and in at least one trait of the distal femur—intercondylar notch height. Anterior-posterior (AP) diameter of the proximal femur is much greater among Whites and Blacks than among East Asians and American Indians. Blacks have slightly greater intercondylar notch height than Whites. Other features, such as torsion, also differ between the major geographic racial populations. Current analysis suggests that the East Polynesians fall close to the American Indians and East Asians in the degree of flatness of the proximal femur.

One study has tracked the degree of change in flatness during individual development, and finds little change within major populations from the youngest to the oldest individuals. Temporal changes within populations are likewise minimal. Two studies have examined sex differences within populations, which are also found to be very slight. Racial differences, on the other hand, are quite significant, and individuals of admixed ancestry fall intermediate between the two parental populations. Such suggestions of high heritability in the shape of the proximal and distal femur make these traits very useful in assessing ancestry in forensic contexts.

KEYWORDS: forensic science, physical anthropology, racial variation, femur, heritability, Ellis R. Kerley

Ellis R. Kerley was a scholar and scientist with knowledge and experience in many different areas. He provided important breadth to the successful biological anthropology program at University of Kansas during his tenure there. As one of his students during that time, I gained immensely from my contacts with him. He was on my dissertation committee, assisted greatly with paleopathological analysis of my skeletal collection from tropical Western Mexico, and provided me with a foundation in important areas completely outside of skeletal biology. A valuable colleague relationship continued in all the years after my graduation from Kansas. Those important contacts with Ellis and the friendship that developed from them will be greatly missed. It is most appropriate that this symposium of papers covering such a wide range of forensic anthropology subjects be given in his honor.

[1] Department of Anthropology, University of Wyoming, P.O. Box 3431, Laramie, WY.

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During the late 19th century, Thomas Dwight, the father of American forensic physical anthropology, studied femoral head diameter and found it useful in sex identification (1). Later, Ingalls (2) conducted a thorough study of the femur (35 measurements), which included 100 pairs of femora of known (documented) White males. More recently Stewart (3) describes anterior femoral curvature and also briefly discusses torsion of the femur, focusing upon racial variations in these characteristics. Olivier (4) discusses torsion in addition to the sex-specific traits of the femur and mentions significant differences between Whites and other groups studied. Gilbert (5) expands upon the approaches of Stewart with regard to racial assessment from anterior femoral curvature.

The standard human osteology textbooks all cover traits of the femur with regard to sex determination, race attribution, and stature calculation (1,6–9). The treatment of racial variation in the femur, however, in these texts is quite limited, compared to the treatment of sex differences and the estimation of living stature.

My own attention to the femur began in the early 1970s when I discovered striking contrasts between the proximal femora of Northwestern Plains Indians and those of pioneer Whites (Fig. 1). This led to a "visual method" of assessing race that proved quite effective in separating Northwestern Plains Indians from Whites in forensic and bioarchaeological contexts (see introduction section of Gilbert and Gill (10)). Later, with the assistance of B. Miles Gilbert and Randi Gilbert, this visual approach was modified to a metric one, and extended to a wide sample of Blacks, Whites, and American Indians from various parts of North America (10). Inspired by the success of the new metric approach, J. Stanley Rhine and I extended its application to additional samples of both Whites and American Indians, and experimented with new cut-off values to enhance the metric separations between these two populations (11).

Concurrently Scott J. Baker and I began work with David Keiffer, an orthopedic surgeon, focusing on intercondylar notch variations between clinical samples (individuals with ruptures of the anterior cruciate ligament, or ACL) and samples of normal, healthy individuals. During this work Baker discovered differences in notch height between Blacks and Whites that are significant enough to be of forensic value (12). Later Emily Craig (13) examined radiographically a related region of the distal femur, the intercondylar shelf angle, and compared large samples of American Blacks and Whites. She experimented with different subsamples and cut-off values and was able to correctly classify a very high percentage of individuals (85 to 90%).

By the mid-1990s, studies by Theodore Cole and Christopher Ruff had shown that aspects of femur morphology (such as robusticity and midshaft density) could be attributed to biomechanics (14,15). Cole cautions, however, that observed differences could also be due to genetics as well as environment (14). Other environ-

FIG. 1—*Left femora of two adult White males (left) and two adult American Indian males (right) viewed medially in order to contrast the thick subtrochanteric anterioposterior diameter of the Whites to the thin diameter characteristic of the American Indians.*

mentally related differences can appear because of dietary deficiencies which can manifest in the form of retardation of growth and even rickets (16). Such considerations have inspired two of our most recent studies (17,18), which have been designed to test the effects of environment versus genetics on both femoral platymeria and torsion. Some results of these tests will be discussed below, as well as methods for determining torsion and platymeria in forensic contexts.

By 1997 Charles M. Clow and I had measured a large sample of East Polynesians from Easter Island in order to test for both degree of platymeria and amount of torsion in that population (19). Voulgaris has conducted a similar study on an additional large sample of Easter Island femora (20).

Materials and Methods

Within the related femur studies conducted at the University of Wyoming, much care has been taken to insure that the same techniques have been utilized by the various investigators involved. All intercondylar notch height measurements (from a single study only) were taken by Scott J. Baker, the individual who devised that measurement (12). This quick and very simple measurement is taken from the surface upon which the condyles of the femur rest to the highest point along the rim of the anterior outlet of the intercondylar notch (12). A standard sliding caliper is used. Baker's assessments of notch height are based upon 250 adult femora from the Smithsonian Institution's Terry Collection: 118 Whites (72 males and 46 females) and 132 Blacks (82 males and 50 females). He found no discernible morphological variations between right and left notch heights of the same individual, and therefore obtained each individual's notch height value from the femur that best preserved the outline of the notch.

All of the other University of Wyoming femur studies have involved assessment of either platymeria or torsion. In each case, I either collected these data myself or worked closely with the investigators who did and conducted reevaluations (spot checks and rechecks) of all metrics. Few errors were ever encountered, partly due, we believe, to the simplicity of these approaches.

In order to ascertain the degree of femoral platymeria, only two measurements are needed. These two measurements, anterior-posterior (AP) and medial-lateral (ML) diameter, are taken just below the lesser trochanter of the proximal femur according to the methods outlined in Bass (8). They are taken with the standard anthropometric sliding caliper. In the first study utilizing these measurements (10) they were applied to 102 Blacks and 59 Whites from the Smithsonian Institution Terry Collection. An additional 113 American Indian femora were measured as well from prehistoric samples at Smithsonian. A subsequent expansion of that sample (11) included 120 American Indians and Whites (60 Amerindians; 60 Whites; equally divided male and female) from collections at Maxwell Museum and University of Wyoming.

Miller (17) extended these same measurements to a sample of 19 Whites, five historic Chinese, and 52 Northwestern Plains Indians (including subadults as well as adults). Part of Miller's adult Amerindian sample does overlap that of Gill and Rhine (11).

Denise Royer and Rick L. Weathermon subsequently devised an expedient method for evaluation of femoral torsion (18) which consists of merely measuring the maximum height of the femoral head from the surface upon which the femur is placed. In numerous test procedures, this raw measurement has been plotted against platymeric index (calculated in part from the Gill and Rhine femoral metrics) in order to attempt an even greater effectiveness in separating Whites from American Indians. For these tests, 83 femora have thus far been measured (56 Amerindian; 27 White). Comparisons have been made with regard to sex, race, temporal period, and side of the body (i.e., rights versus lefts). All measurements are taken with a standard sliding caliper. In addition to bivariate plots, *t*-tests have been utilized to test for statistically significant differences.

Some trivariate plots have been made as well with these same torsion and platymeria data. In these cases, each of the three raw measurements is used independently without index calculations. For this, a Hewlett Packard Pentium 166 has been configured for Windows 95, the data plotted in SPSS Release 7.0, then exported into Word Perfect 6.0a for the graphics shown below.

Results

Figure 2 shows the results of Baker's plots of intercondylar notch height of femora of American Blacks and Whites. Table 1 shows the percentage of known sex individuals correctly classified into the American Black and White populations using this single measurement. It seems that this method, which has been available since 1990, has not been used extensively by forensic anthropologists (even in our own lab). This is probably because forensic anthropologists prefer methods that yield a slightly higher percentage of correct placement. As can readily be seen from the Fig. 2 histograms, however, accuracy improves considerably just 1 to 2 mm away from the sectioning values, so that an individual who does not place particularly close to the sectioning point can be placed rather securely with regard to ancestry.

The method detailed in Gill and Rhine (11) is more commonly used for distinguishing between the femora of American Indians and Whites. The proximal diaphyseal shape is assessed just below the position of the lesser trochanter, as shown in Fig. 1, either by visually assessing the degree of flatness and ridging in that area (Fig. 3) or by utilizing measurements at that same location. Both the Gilbert and Gill study (10) and the Gill and Rhine study (11) utilize metrics (Fig. 4). Both provide bivariate plots of the medial-lateral versus the anterior-posterior measurements of the proximal femur. Most forensic anthropologists prefer the placement of the sectioning line in the Gill and Rhine graph, which achieves the

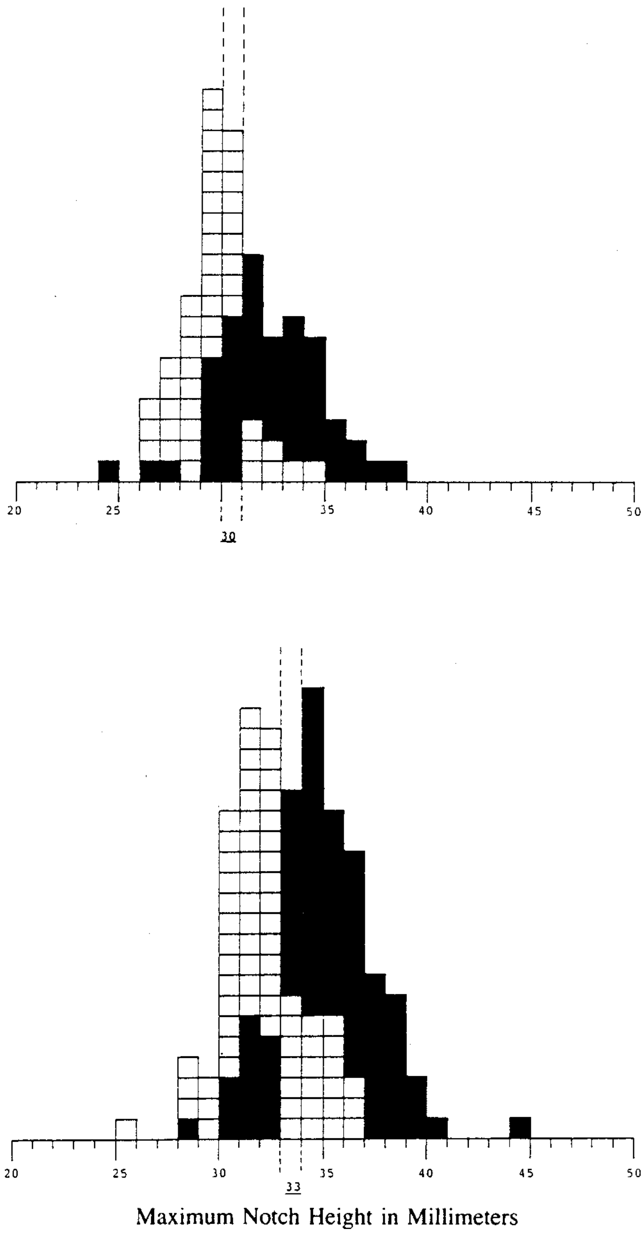


FIG. 2—*Maximum intercondylar notch heights of female Whites and Blacks (above) and male Whites and Blacks (below). Whites are indicated with open cubes, Blacks with solid cubes. (Adapted from Baker et al. 1990).*

TABLE 1—*Percentage of known sex individuals correctly classified as to race using maximum notch height.*

Males	Females
≥34 mm = Black 79.2% ≤32 mm = White 76.9%	≥31 mm = Black 82.5% ≤29 mm = White 76.9%

Adapted from Baker et al. 1990.

highest possible resolution for both groups (rather than attempting to exclude nearly two-thirds of American Indians from 100% of Blacks and Whites). In both studies (and the two graphs shown in Fig. 4) the sectioning lines were established by eye (to yield the best results) and are not mathematically derived discriminant lines.

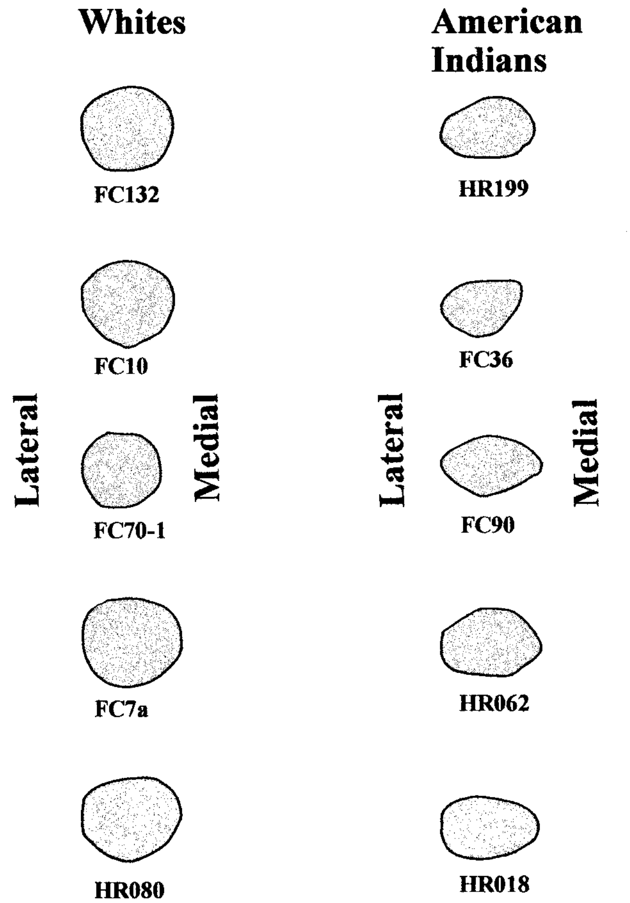
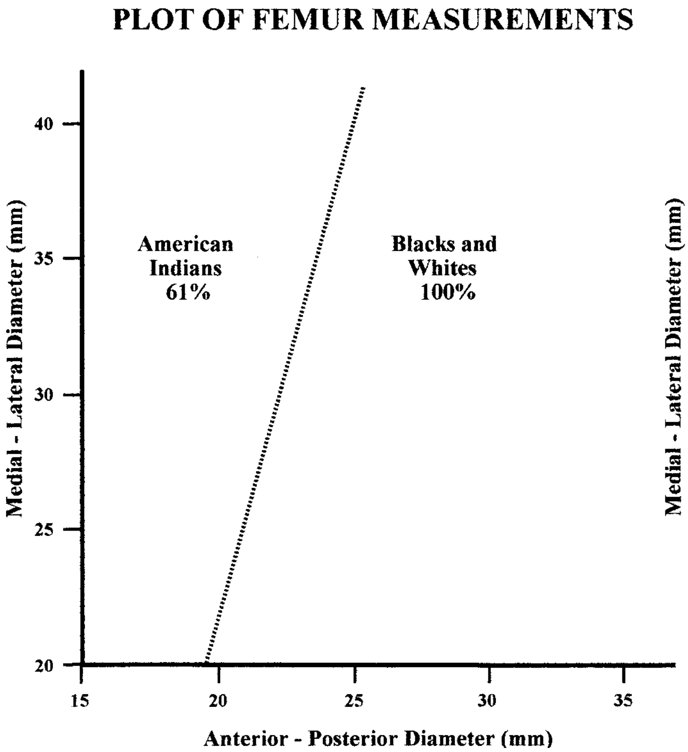


FIG. 3—*Subtrochanteric cross sections of left femora of five male Whites (left) and one female (FC90) and four male American Indians (right). In two cases where right femora had to be used the images are reversed.*

Figure 5 is adapted from the unpublished manuscript of Miller (17). The primary plot points are platymeric index values for Northwestern Plains Indian children compared to those for adults from the same populations. Statistically significant differences (using Mann-Whitney tests) are found between the means of the children and the adults (significant at the .05 level). As the adults are further broken out into young, middle-age, and older age categories, smaller differences are seen that could suggest a continued slight drop in mean platymeric index throughout life (17). These slight differences between the three adult age groups, even though suggestively unidirectional, are however not statistically significant.

By contrast, in Miller's comparison of her sample of adult Northwestern Plains Indians to a sample of pioneer Whites (Fig. 6) striking differences are observed. No statistically significant differences in platymeric index are found between the males and females within each population sample, but the differences between racial groups are statistically significant. As may be seen in Fig. 6 the platymeric Plains Indian femora provide a sharp contrast numerically to the heavy eurymeric and stenomeric femora of Whites.

Femoral torsion also differs markedly between Whites and American Indians (Whites have low torsion; Amerindians high) therefore, as torsion height measurements are factored in, and plotted against platymeria (Fig. 7), White-Amerindian separations are even more striking (18). We have tried a similar exercise with a tor-



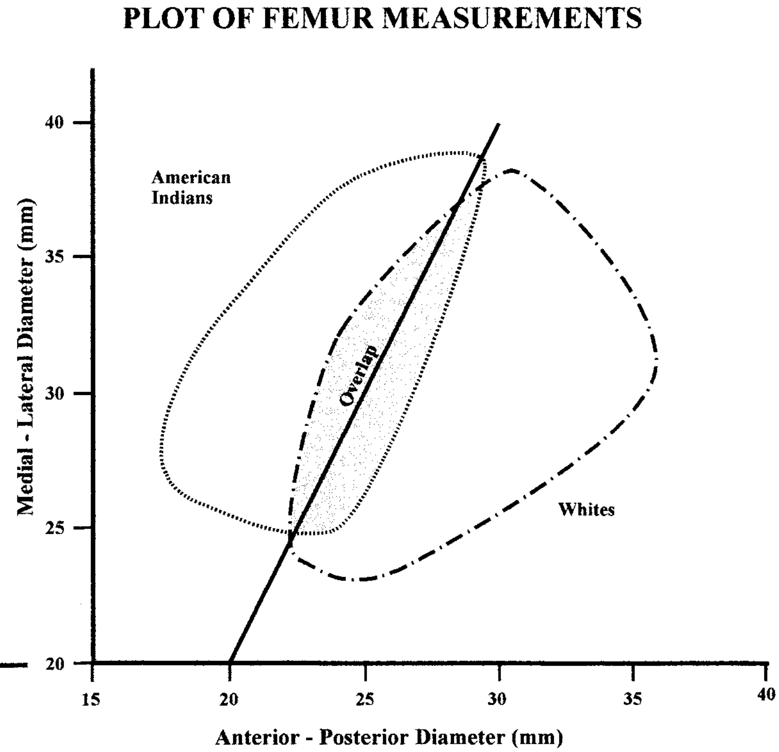


FIG. 4—*Distributions of plot values from femur measurements by Gilbert and Gill (left) and by Gill and Rhine (right). The Gill and Rhine study includes only American Indians and Whites while the Gilbert-Gill study includes Blacks as well.*

sion index value (femur head diameter × 100 divided by torsion height) to reduce the effect of size. As shown in Fig. 8 the separation obtained between the two populations is still impressive. The descriptive statistics from this study are presented in Appendix A. The lines of separation in Figs. 7 and 8 are not discriminant lines, but, as in the case of the Fig. 4 graphs, are placed by hand to provide the highest percentage of correct placement within the existing samples.

Perhaps even more powerful separations will be obtained with trivariate plots like the one shown in Fig. 9. This allows the forensic investigator to utilize all three raw variables (ML and AP diameters and torsion height) without eliminating size. This may prove to be the best as our samples are increased, since size is another factor that varies between these two populations. Whites tend to have larger femora with larger head diameters. Another way to handle these three variables in future research would be through a discriminant function method, which would enhance forensic utility.

Preliminary analysis of the femora from Easter Island measured by Clow and Gill has been completed. These proximal femora are even more platymeric than those of the Plains and Southwest Indians. Utilizing the same separation line (from Whites) that Gill and Rhine have used to distinguish Amerindians from Whites (Fig. 4), Clow and Gill have correctly separated 99.04% of the Easter Island Polynesians from Whites. It has been earlier reported (19) that the percentage of correct separation of Easter Islanders from Whites is 92.1%, but that figure is incorrect, and the actual percentage of correct placement of the Easter Island sample is 99.04%.

Torsion values have likewise been collected for all of the Easter Island sample, and male islanders, like the American Indians, have high torsion values. For some reason Easter Island females show torsion values less than those of the males and more similar to those for White females.

Discussion

Effective separation of Blacks and Whites based upon the height of the intercondylar notch of the distal femur suggests reasonable forensic utility, at least in those cases when the individual in question is not too near the sectioning point between the two populations (and as long as the sex of the individual is known). The reason for the higher intercondylar notch of Blacks is not entirely known, but has been attributed to the lower anterior femoral curvature of the diaphysis in that population (12). Theoretically low curvature could cause an upward rotation of the condyles of the femur thus producing an elevated notch. This has not been tested; however, it would be an easy correlation to test for in a well-controlled future study.

Forensic separations between the American Indians on the one hand, and Whites and Blacks on the other, based upon the extreme subtrochanteric flatness (in AP diameter) of the former are easily accomplished. Based upon a very small sample of historic Chinese, this may be true for the East Asians as well. A large sample of Easter Island femora clearly show the same trend but an even more extreme divergence from the White norm. An important next step in the Polynesian study of platymeria will be to see how far across Polynesia this femoral morphology extends. Does it extend to all of Polynesia, just East Polynesia, or only Easter Island? Also, does the sexual dimorphism regarding torsion height extend to other parts of Polynesia, or is it a peculiarity of the Easter Islanders? These are questions that can be answered through conducting further studies on already available Polynesian skeletal materials. A reasonable tentative hypothesis is that extreme platymeria will be found

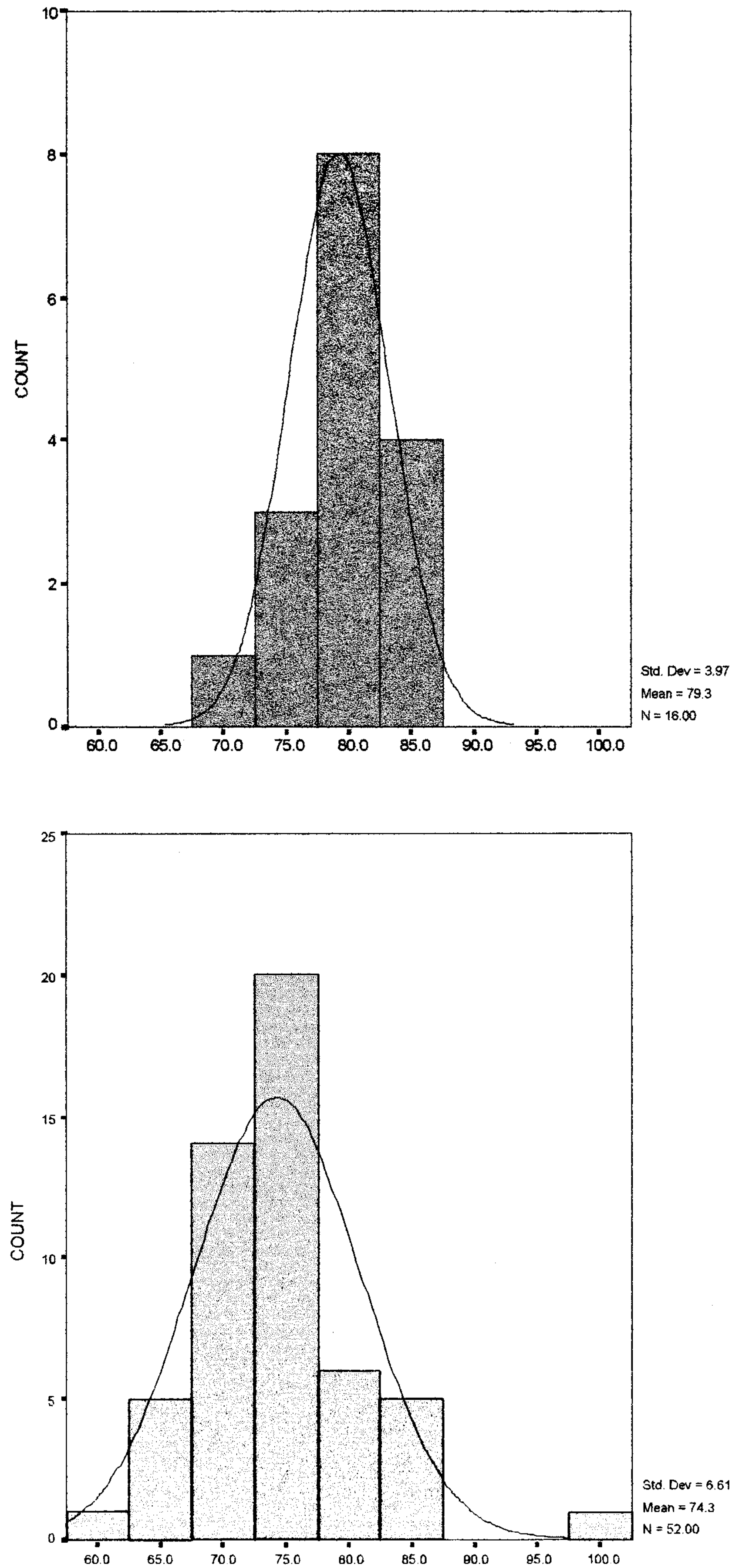


FIG. 5—*Plot values of platymeric index for American Indian children (above) and for all ages of American Indians (below) (adapted from Miller 1995).*

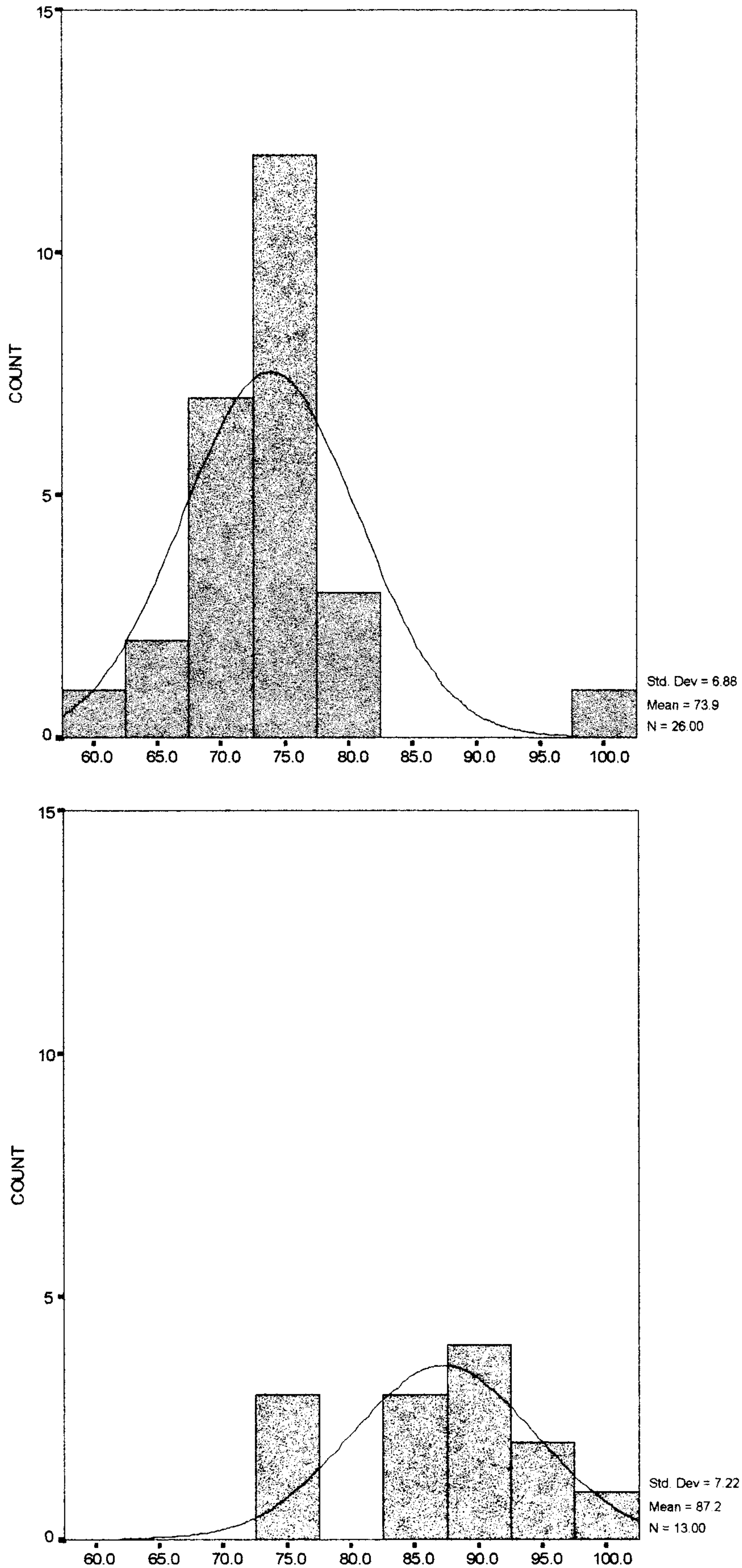


FIG. 6—*Plot values of platymeric index for American Indian males (above) and White males (below), revealing the much higher index values for the Whites (adapted from Miller 1995).*

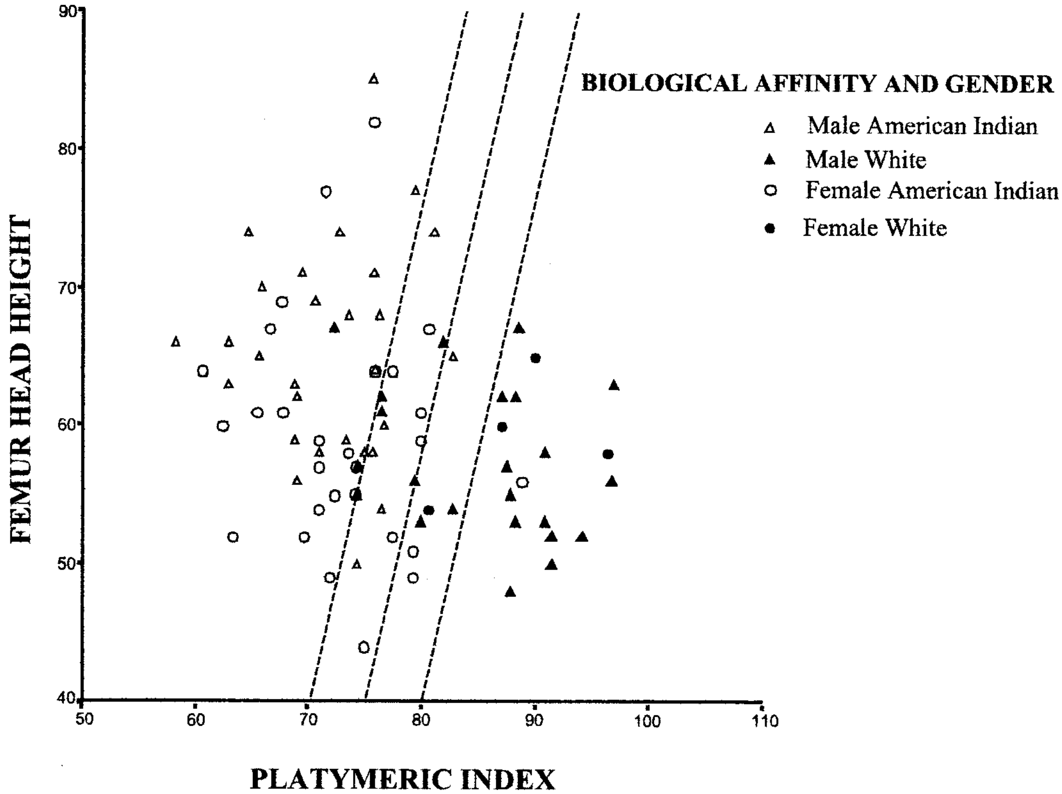


FIG. 7—*American Indian and White separations as platymeric index is plotted against torsion height (adapted from Royer et al. 1997).*

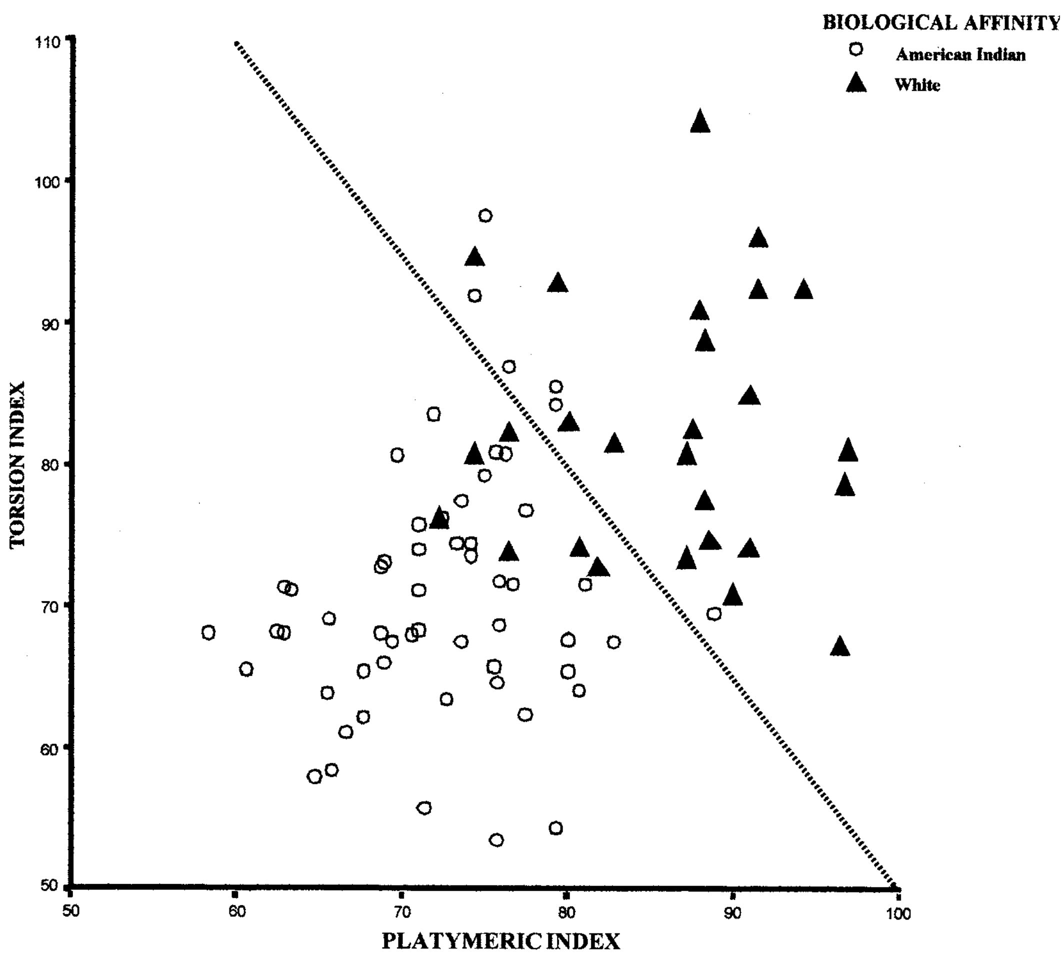


FIG. 8—*American Indian and White separations when platymeric index is plotted against torsion index.*

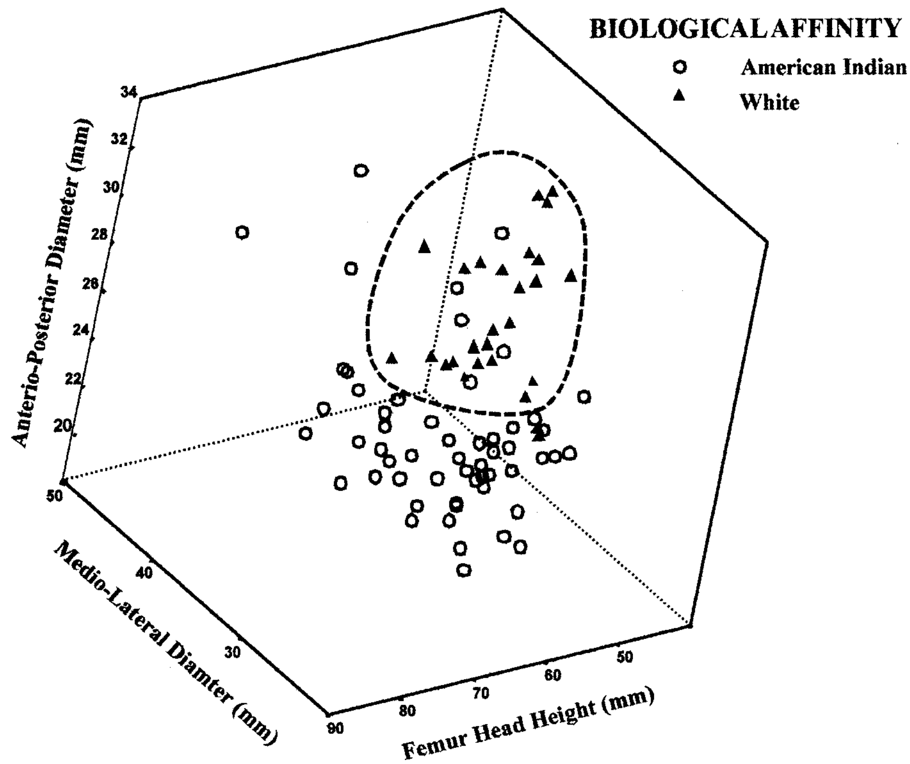


FIG. 9—*American Indian and White separations as all three basic measurements (A-P, M-L and torsion height) are plotted against each other.*

among other Polynesians as well since all other groups examined thus far, with even remote East Asian origins show platymeric femora.

Even though torsion, as exhibited through the torsion height measurement, may have less forensic utility than femoral platymeria, at least in the case of White/Polynesian separations it seems to have some value in sorting out the males within those two populations. However, it is clearly more useful for sorting out Whites from American Indians. Samples need to be expanded, but it looks as though trivariate plots incorporating both subtrochanteric measurements and torsion height may produce the best discrimination between Whites and American Indians.

Considerable light has been shed on the important question of the degree of heritability of platymeria by Miller's investigation of changes in its expression during the course of individual development. She also looked for temporal changes over quite a long period of Northwestern Plains prehistory (which spanned the time of the introduction of the horse) and found no significant differences. These findings suggest that some quite major alterations in environmental stresses have had very little, if any, effect upon platymeria within these populations. Whites of both sexes, on the other hand, show statistically significant differences from the Plains Indians in this proximal area of the femur. Not surprisingly, then, the femora from individuals from burials near the historic Bordeaux trading post (assumed from other osteometric evaluations (21) to be admixed White/Plains Indian) fall intermediate between the White and American Indian means regarding platymeria. These factors, coupled with earlier observations from forensic contexts (22) that modern Northwestern Plains Indians (who follow contemporary life styles) likewise show platymeric femora, provide very strong evidence for a high heritability of this condition.

Careful examination of Miller's results does not show environment to be totally meaningless with regard to this trait. Significant differences have been found between children and adults in the Northwestern Plains, with platymeria becoming more extreme with age. And even though the differences among adults (younger to older) are not statistically significant, a slight trend in the same direction of increasing platymeria is indicated.

The fact that both genetic and environmental factors may be shaping the expression of this trait should certainly not be surprising. It should also not be surprising that under normal circumstances one of these forces appears to be more operative upon the phenotype than the other. From all evidences here, the greater force is genetics. Therefore the traits of the femur discussed above, particularly the subtrochanteric anterior-posterior and medial lateral dimensions, should be expected to be of great utility in assessing ancestry in forensic (and bioarchaeological) contexts.

Acknowledgments

I wish to thank Mr. Rick L. Weathermon, research scientist with the University of Wyoming Department of Anthropology, who assisted with data analysis and several of the graphs in this paper. He also had an important role in some of the original student research projects discussed here. I also want to thank Maxine J. Miller, forensic technician with the Sarasota County Sheriff's Office, Sarasota, FL, for providing data from her earlier Northwestern Plains research project for use in this publication.

APPENDIX A—DESCRIPTIVE STATISTICS

American Indians

Variable	*n*	Min	Max	Mean	S.D.
Platymeric index	56	58.33	88.89	72.41	6.07
Torsion height	56	44.00	85.00	62.15	8.54
Torsion index	56	42.37	58.57	52.46	3.25

Whites

Variable	*n*	Min	Max	Mean	S.D.
Platymeric index	27	72.22	96.88	85.92	7.19
Torsion height	27	48.00	67.00	57.63	5.29
Torsion index	27	42.74	53.28	48.58	2.88

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Additional information and reprint requests:
George W. Gill, Ph.D.
Dept. of Anthropology
University of Wyoming
P.O. Box 3431
Laramie, WY 82071-3431