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Ontogeny of Femur Subtrochanteric Shape in Native Americans and American Blacks and Whites*

ABSTRACT: Femur subtrochanteric size and shape can be used to differentiate between adult Native Americans and American Blacks and Whites, but little is known about when shape differences are established during growth and development. Ontological changes in subtrochanteric shape were examined using 74 Native American and 61 American Black/White subadult femora. At birth, the proximal femur diaphysis is relatively circular in both groups. Between birth and 5 years, the diaphysis becomes more mediolaterally broad, especially in Native Americans, due to differential growth between the mediolateral and anteroposterior planes. This change may be due to biomechanical stresses associated with developing a mature gait pattern. After the age of 5, growth occurs more equally in the two planes and shape does not change significantly. The adult shape of the proximal femur is established by *c.* 5 years of age and can be used to discriminate between Native American and American Black/White femora in older subadults.

KEYWORDS: forensic science, forensic anthropology, femur, platymeric index, platymeria, eurymeria

The estimation of group affiliation or ancestry is often critical in forensic anthropological investigations to determine the medicolegal significance of skeletal remains and to help establish personal identity (1–4). Numerous metric and nonmetric methods have been developed to assist investigators in determining ancestry from adult skeletal remains, but few studies have focused on morphological variation between groups in subadult (immature) skeletons (5–7). As a result, there is little understanding of when or why adult morphological characteristics used to determine group affiliation appear in the subadult skeleton. However, as pointed out by St. Hoyme and Işcan (7), it is vital that forensic anthropologists expand their knowledge of the ontogeny of skeletal morphology related to ancestry.

Several studies (8–10) have demonstrated the validity of using proximal femur diaphyseal shape below the lesser trochanter (subtrochanteric) to distinguish between Native American and American Black/White adult femora in medicolegal and bioarchaeological contexts. On average, Native American adults have mediolaterally broad or platymeric subtrochanteric femoral diaphyses, while American Black and White adults are more circular or eurymeric at subtrochanteric (8,10,11). Gilbert and Gill (8) provided a bivariate plot of adult Native American and American Black/White subtrochanteric anteroposterior (*x*-axis) and mediolateral (*y*-axis) dimensions with a sectioning line drawn that places most Native Americans on the left side and all American Blacks/ Whites on the right side of the line. Gill and Rhine (9) also used a bivariate plot based on a larger and more geographically diverse sample of Native Americans and American Whites. Their sectioning line was established to yield the best separation between groups (11). Wescott (10) examined group differences in proximal femur shape among American Blacks, American Whites, Hispanics, Native Americans, and Polynesians. He also investigated variation within Native Americans based on subsistence strategy, physical terrain, and geographical region, and tested the reliability of distinguishing between adult Native Americans and American Blacks/Whites using discriminant function analysis based on dimensions of the femur. Wescott (10) found significant group differences in proximal femur shape, with Native Americans and Polynesians being more platymeric than American Blacks, American Whites, or Hispanics. He also reported that subsistence strategy and geographical region had a significant effect on subtrochanteric shape among Native Americans. However, these affects were not great enough to obscure group differences. Finally, Wescott (10) determined that using shape (ratio of the anteroposterior divided by mediolateral) alone provided the same accuracy in discriminating between adult Native Americans and American Blacks/Whites as using both subtrochanteric shape and size, but that the percentage of individuals correctly classified increased when femur length and head diameter (12) were used in discriminant functions. The results of these studies demonstrate that the difference in proximal femur shape between Native American and American Black/White adults is great enough that the two groups can be discriminated with *c.* 80% accuracy using proximal femur shape alone, and when combined with femur head size and maximum length, the accuracy improves to 85% (10).

Gill (11) and Miller (13) asserted that subtrochanteric shape is established early in life and is highly heritable. These authors (11,13) also suggested that proximal femur diaphyseal shape may be useful for assessing group affiliation in subadult skeletons. To understand the ontogeny of femur diaphyseal morphology, patterns of change in subtrochanteric shape and size during growth and development were examined in Native American and American Black and White subadult samples. The validity and accuracy of estimating group affiliation in subadult skeletons using proximal femur shape was investigated using proximal femur shape (10), the Gilbert and Gill (8) and Gill and Rhine (9) sectioning lines, and discriminant function analysis.

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Materials and Methods

Samples and Measurements

Femur subtrochanteric anteroposterior and mediolateral diameters (APD and MLD, respectively) and diaphyseal length (12), measured to the nearest millimeter, were acquired for 74 Native American, 17 American Black, and 44 American White subadult femora (Table 1). Native Americans are represented by protohistoric and historic Arikara (14), a northern Plains horticultural tribe, while the American Black and White data were obtained from the Forensic Data Bank (FDB) (15). The Arikara were used in this study because there is a relatively large sample of subadults available for study and the population is similar to the Native American sample used by Gilbert and Gill (8), Gill and Rhine (9), and Wescott (10). Furthermore, there has been no significant temporal change in subtrochanteric shape among Northern Plains Native Americans over the past three centuries (11,13), and Wescott and Srikanta (16) found that adult individuals in the FDB with ancestry reported as Native American classified with the same accuracy as archaeologically derived Native Americans. Left femora were preferentially used, but the right femur was used if the left was absent or damaged. Interobserver error in subtrochanteric measurements has been previously discussed by Adams and Byrd (17) and Wescott (10), and has little effect on the validity of discriminating between Native American and American Black/White adults using proximal femur shape (10). Femora used in the study come from individuals ranging in age-at-death from birth to 18 years (Table 1). Age was estimated from long bone length, dental development, and epiphyseal closure for the Native American sample (18). Individuals in the FDB have documented age. The general shape of the proximal femur diaphysis was estimated using the platymeric index (PI), which was calculated by multiplying the ratio of APD and MLD by 100 (PI = APD/MLD × 100). Because sex cannot be validly estimated without chromosomal analysis in subadult remains and a previous study (10) found no significant sexual dimorphism in adult subtrochanteric shape (PI), males and females were pooled for analyses. American Blacks and Whites were also pooled for analyses because Wescott (10) discovered no statistical difference in subtrochanteric shape between Black and White adults.

Statistical analyses were conducted using SAS 9.1 (19). Changes in subtrochanteric size and shape with age were examined using regression analyses, which provide information about the strength and form of the relationship between variables. Group differences

TABLE 1—*Sample characteristics and variable* summary statistics.*

			APD		MLD		PI	
Ancestry	Age† (years)	*N*	Mean	SD	Mean	SD	Mean	SD
Native American (*N* = 74)	0	13	7.9	1.5	8.4	1.3	92.1	5.1
	1	7	11.4	1.4	12.3	1.1	92.6	7.4
	2	9	13.3	1.2	15.8	1.0	85.8	6.3
	3	8	13.9	1.1	17.5	2.1	79.8	7.8
	4	0	—	—	—	—	—	—
	5	5	15.2	0.8	18.8	0.8	81.4	4.5
	6	6	16.8	1.5	20.5	2.0	80.8	2.3
	7	5	16.8	1.5	22.6	1.1	75.2	4.6
	8	5	19.0	0.0	24.6	1.0	76.4	3.2
	9	3	18.7	1.1	24.7	0.6	76.0	3.6
	10	1	18.0	—	26.0	—	70.0	—
	11	4	19.7	3.5	24.7	3.6	80.0	5.0
	12	1	20.0	—	24.0	—	81.0	—
	13	2	22.5	2.1	24.5	0.7	90.0	9.9
	14	0	—	—	—	—	—	—
	15	2	21.0	0.0	27.0	0.0	78.0	0.0
	16	0	—	—	—	—	—	—
	17	2	22.5	3.5	30.0	1.4	76.5	14.8
	18	1	22.0	—	28.0	—	79.0	—
American Black/White (*N* = 61)	0	2	8.0	2.8	8.5	3.5	95.5	6.4
	1	0	—	—	—	—	—	—
	2	2	13.0	0.0	16.0	2.8	82.5	14.8
	3	2	13.0	0.0	16.0	1.4	81.5	7.8
	4	1	14.0	—	19.0	—	74.0	—
	5	2	18.0	1.4	20.0	0	90.0	7.1
	6	1	18.0	—	21.0	—	86.0	—
	7	2	17.5	2.1	21.0	1.4	83.0	4.2
	8	2	18.0	0.0	22.5	2.1	80.5	7.8
	9	1	19.0	—	23.0	—	83.0	—
	10	2	21.5	0.7	26.5	0.7	81.0	0
	11	4	22.7	3.9	25.5	2.1	88.7	10.0
	12	3	23.3	3.5	27.3	3.5	85.0	2.0
	13	4	24.2	1.3	28.2	2.2	86.0	5.7
	14	5	25.2	1.3	27.4	0.9	91.8	4.4
	15	12	23.7	1.7	27.9	2.9	86.0	9.6
	16	9	25.0	1.7	29.0	1.5	86.2	7.5
	17	7	25.4	3.0	29.7	3.2	85.7	5.3
	18	0	—	—	—	—	—	—

*APD, subtrochanteric anteroposterior diameter; MLD, subtrochanteric mediolateral diameter; PI, platymeric index (APD/MLD × 100).
†Age estimated for Native American subadults; Known age for American Black/White.

were evaluated by examining differences in the regression slope using analysis of covariance (ANCOVA), which combines features of regression and analysis of variance. The validity and accuracy of estimating ancestry in subadult skeletons was tested using four methods: (1) the PI sectioning point (10), (2) the Gilbert and Gill (8) sectioning line, (3) the Gill and Rhine (9) sectioning line, and (4) discriminant function with cross-validation. Discriminant function analysis was conducted to test whether the other three methods provide the greatest discriminating ability. Individuals were assessed using each method and then the percent correctly classified was tallied. To test the PI section point validity, individuals with a PI of 82 or less were classified as Native American, while those with a PI of 83 or greater were classified as American Black/White. The PI sectioning point was determined by the mean (mean PI = 83) of the pooled sample. To examine the validity of the Gilbert and Gill (8) and Gill and Rhine (9) sectioning lines, APD and MLD were plotted (APD on the x-axis and MLD on the y-axis) for each individual and the sectioning lines were extended to incorporate the small subadult diameters. Individuals who fell left of the lines were classified as Native American and those right of the line as American Black/White (8,9). Discriminant function analysis with cross-validation using APD and MLD was also performed. Within group differences are maximized in discriminant function analysis, and cross-validation reduces bias by omitting the case being classified.

Results

Shape and Size Changes

Femur subtrochanteric dimension and PI summary statistics are presented in Table 1. There is a significant age change in PI ($p \leq 0.0001$), which generally decreases (becomes more platymeric) from birth to about 5 years of age and then levels off in both groups. While there is a significant change in PI with age among both groups, there is also a statistically significant difference in slopes between Native Americans and American Blacks/White ($p = 0.001$). To explore the age pattern more thoroughly, subadults 5 years of age and less and subadults 6 years or older were examined separately. There is a significant ($p = 0.005$) negative correlation between PI and age in subadults 5 years and under in both groups. Changes in the PI are greater, although not significantly ($p = 0.4291$), in Native Americans than in American Blacks/Whites (Fig. 1). The lack of significance between groups may be due to the small American Black/White sample size ($N = 9$, see Table 1) in subadults 5 years of age or younger.

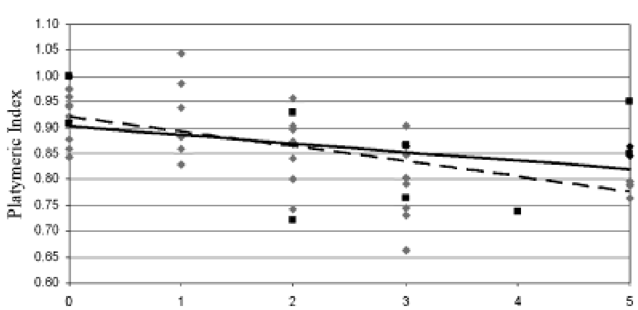

FIG. 1—*Age changes from birth to 5 years of age in the platymeric index among Native American (diamonds, dashed line) and American Black/White (squares, solid line) subadults. See Table 1 for sample sizes.*

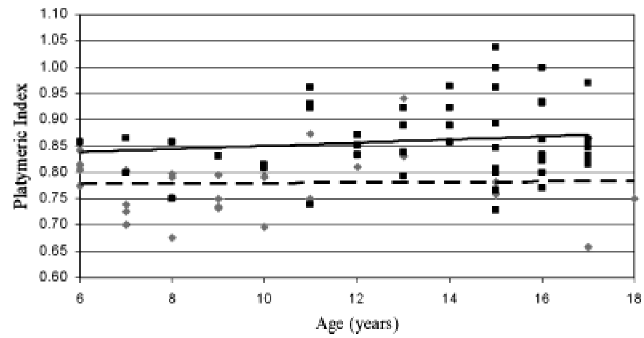

FIG. 2—*Age changes from 6 to 18 years of age in the platymeric index among Native American (diamonds, dashed line) and American Black/White (squares, solid line) subadults. See Table 1 for sample sizes.*

After the age of 6 years, there is no statistically significant age change ($p = 0.4746$) in the PI for either group (Fig. 2). There are significant group differences in the PI among 6–18 year olds but no significant group and age interactions. That is, Native Americans and American Blacks/Whites differ in subtrochanteric shape from 6 to 18 years of age because of changes that occurred earlier in ontogeny but there is no significant change in PI with age in either group.

An examination of the subtrochanteric dimensions reveals that between birth and 5 years of age, MLD increases more rapidly than APD in both groups (Fig. 3). However, the difference is again more dramatic in Native Americans. The MLD increases more rapidly ($p = 0.0609$) in Native American than American Black/White subadults 5 years of age and less. The group differences in MLD growth are somewhat obscured in Fig. 3 because age differences between Native Americans and American Blacks/Whites in femur length are not accounted for. However, Fig. 4, which plots subtrochanteric diameters against femur length, shows that changes in APD with femur length are nearly identical for both groups, but MLD changes more rapidly in Native Americans compared with American Blacks/Whites. The more rapid deposition of bone on the mediolateral (ML) plane relative to the anteroposterior (AP) plane continues after 5 years of age but at a greatly reduced rate, and group differences are not significant ($p = 0.8503$). In individuals 6–18 years of age, APD and MLD increase in size with age at approximately the same rate in Native American and American Black/White subadults (Fig. 5). The more rapid change in MLD relative to APD in younger subadults (birth to 5 years of age) compared with older subadults (6–18 years) can be seen by comparing the regression lines in Figs. 3 and 5.

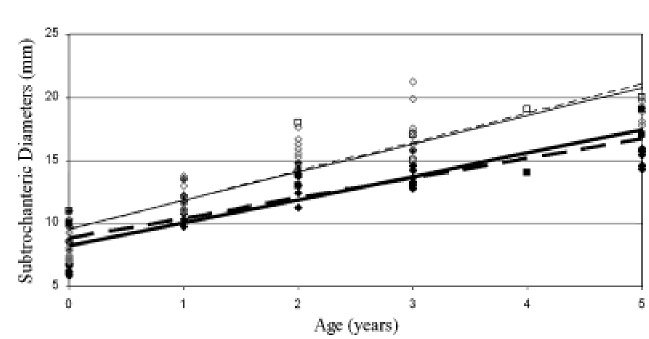

FIG. 3—*Age changes from birth to 5 years of age in anteroposterior (heavy line) and mediolateral (light line) subtrochanteric diameters among Native American (diamonds, dashed lines) and American Black/White (square, solid lines) subadults. See Table 1 for sample sizes.*

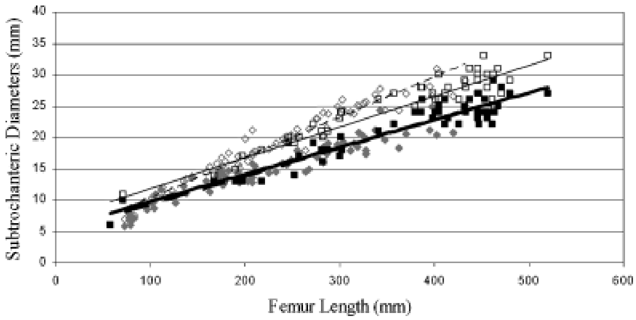

FIG. 4—*Relationship between changes in femur length and increases in anteroposterior (heavy lines) and mediolateral (light lines) subtrochanteric diameters among Native Americans (diamonds, dashed line) and American Black/White (squares, solid lines).*

Validity and Accuracy of Estimation

Four methods (PI (10), Gilbert and Gill (8), Gill and Rhine (9), and discriminant analysis) were used to test the accuracy of using the proximal femur diaphysis to assess ancestry in subadults. The percent correctly classified for each ancestral and age group is provided in Table 2. A combined percent average of the Native Americans and American Blacks/Whites correctly classified (percent Native Americans correctly classified plus percent American Blacks/Whites correctly classified divided by two) is also provided to show the overall accuracy of the method. The percentages were averaged as sample sizes are not equal between the two ancestral groups. As most subadults 5 years and under have relatively circular proximal femur shafts (Table 1), none of the methods can discriminate between groups with any accuracy at this stage of development (Table 2). The PI method, which accounts for shape differences only, classifies the majority of subadults 5 years and under as American Black/White because most young subadults have nearly circular proximal femur diaphyses. The Gilbert and Gill (8) and Gill and Rhine (9) methods, on the other hand, classify all subadults 5 years of age and less as Native Americans because of size; their small APD places them to the left of the sectioning line. Subadults 6 years and older are correctly classified with moderate validity using all methods, but the Gilbert and Gill (8) sectioning line and discriminant function methods provide the most accurate results (Table 2). The Gill and Rhine (9) sectioning line misclassifies most American Blacks/Whites and therefore is not useful for discriminating between groups using subadult femora. Using an extension of the Gilbert and Gill (8) sectioning line, however, 85.4% of subadults over the age of 5 years were correctly classified, with nearly equal percentages for both groups (Table 2; Fig. 6).

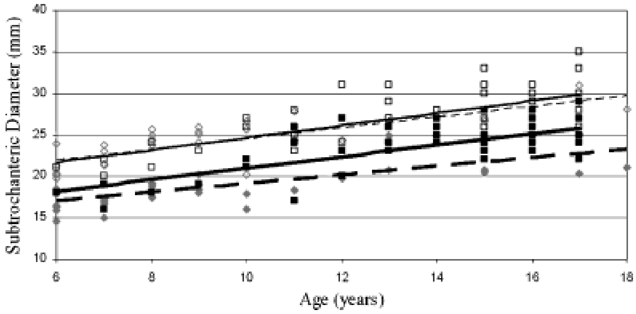

FIG. 5—*Age changes from 6 to 18 years of age in anteroposterior (heavy lines) and mediolateral (light lines) subtrochanteric diameters among Native Americans (diamonds, dashed lines) and American Blacks/Whites (squares, solid lines).*

TABLE 2—*Percent correctly classified by age group and ancestry.*

	Age Group			
	≤ 5 Years		≥ 6 Years	
	CC*	%	CC*	%
PI sectioning point†				
Native American	11/42	26.2	27/32	84.4
Black/White	6/9	66.7	37/52	71.1
Overall	17/51	32.7	60/84	76.2
Average‡		46.5		77.5
Gilbert and Gill (8) sectioning line				
Native American	42/42	100.0	27/32	84.4
Black/White	0/9	0.0	45/52	86.5
Overall	42/51	82.3	72/84	85.7
Average‡		50.0		85.4
Gill and Rhine (9) sectioning line				
Native American	42/42	100.0	30/32	93.7
Black/White	0/9	0.0	24/52	46.1
Overall	42/51	82.3	54/84	64.3
Average		50.0		69.9
Discriminant function				
Native American	21/42	50.0	27/32	84.4
Black/White	2/9	22.2	45/52	86.5
Overall	23/51	45.1	72/84	85.7
Average‡		36.1		85.4

*Number individuals correctly classified/*N*.
†PI ≤ 82 classified as Native American; PI ≥ 83 classified as American Black/White.
‡Average = Average of Native American and American Black/White percentages ([Native American % + Black/White %]/2).

Discussion

Ontogeny

Femur subtrochanteric shape changes rapidly from relatively circular at birth to platymeric (mediolaterally broad) by the fourth or fifth year of postnatal growth, especially in Native Americans, primarily due to more rapid bone deposition along the ML compared with the AP plane of the femur shaft. After the fifth year, growth occurs more equally in the ML and AP planes but there is a slight increase toward circularity (high PI), especially among American Blacks/Whites. This chronology of femur diaphyseal shape change closely parallels that of developmental features

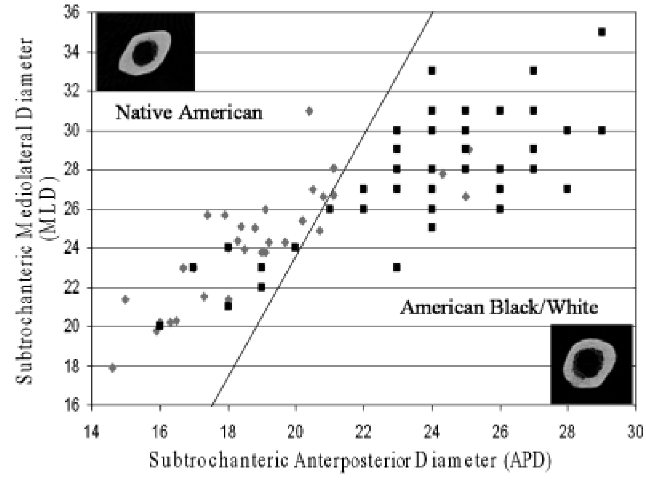

FIG. 6—*Bivariate plot of anteroposterior and mediolateral subtrochanteric diameters illustrating separation of Native American (diamonds) and American Black/White (squares) subadults 6 years and older using the Gilbert and Gill (8) sectioning line.*

associated with the acquisition of mature gait in subadults. Infants (birth to 3 years) begin to walk independently around 1 year of age but do not achieve a mature gait pattern until childhood or *c.* 5 years of age (20). Characteristics of a mature gait include a reduced base support (ratio of pelvic breadth to ankle span), smooth movements with minimal oscillations around the center of gravity, and reciprocal arm swing (20). All of these characteristics require a developed musculoskeletal and neuromotor systems, which are not present in infants (20).

The early increased growth in MLD relative to APD is probably related to changes in the biomechanical stresses placed on the femur as the child learns to walk and develops a mature gait. Bone is a dynamic tissue that responds to mechanical stimuli by altering the size and shape of the shaft, especially in subadults, to adapt to biomechanical forces (21–23). Compared with adults, infants and young children walk with greater knee flexion, more externally rotated and tilted hips, and with their feet more widely spaced (20). In addition, they have a higher step frequency and relatively shorter steps (20). As the base support, knee flexion, and pelvic rotation reduce during gait maturation, larger ML relative to AP loads are placed on the proximal femur, resulting in greater bone deposition in the ML plane. After 5 years, a mature gait is established and the femur becomes adapted to the biomechanical stresses associated with bipedalism (21). The femur diaphysis becomes larger and stronger in older subadults (6–18 years) due to fairly equal deposition of bone in the AP and ML planes as body size increases (24–26), but there is no major change in femur shape.

Age changes in femur subtrochanteric shape also parallel other bony changes that are thought to be associated with independent bipedal locomotion and the attainment of a mature gait. Ruff (27) found that femur midshaft diaphyseal strength (femur subtrochanteric shape was not examined) increased rapidly in infants between the first and third years. After 3 years of age, subadults experienced a slow increase in strength until adult proportions were reached during late adolescence (27). The early rapid increase in femur midshaft strength is thought to correspond to changes in biomechanical stresses related to the infant learning to walk (27). Before 3 years of age, increases in diaphyseal strength do not correlate well with femur length or body weight, suggesting that the diaphysis is responding to biomechanical stresses. After 5 years of age, however, increases in femur midshaft strength are positively correlated with growth in body size and mass (27). This is the same general pattern seen at subtrochanteric.

Development of the bicondylar or tibiofemoral angle also follows a pattern similar to ontological changes observed in subtrochanteric shape (28,29). From birth until *c.* 1 year of age, the bicondylar angle is near 0°. From 1 to 3 years of age, the bicondylar angle steadily becomes valgus, reaching *c.* 10° (29). The angle then slightly decreases again until the normal adult angle (8°) is reached by 6 or 7 years of age (28,29). Age changes in the bicondylar angle are due to biomechanical loads placed on the distal physis of the developing femur as a child learns to walk and develops a mature gait pattern (30). The differential biomechanical forces on the medial and lateral condyles cause greater growth and ossification on the medial than the lateral side, resulting in the bicondylar angle (30), which does not develop in nonambulatory individuals (29).

Between-Group Variation

Gill (11) suggests that the differences between Native Americans and American Blacks and Whites are due to a high heritability in femur diaphyseal morphology. However, the difference between groups appears to be the interaction of genetic and environmental factors. While there is undoubtedly a genetic component to femur diaphyseal shape, the major ontological changes in femur diaphyseal shape are due to plastic responses to mechanical loadings associated with bipedal gait development (25) and are very similar for both groups. As Native Americans tend to have shorter femora relative to hip breadth (31) compared with American Blacks/Whites, there would be greater ML stress at the subtrochanteric region during bipedal locomotion in Native Americans than American Blacks/Whites (31). As a result of this genetic/environmental interaction, Native Americans tend to develop more platymeric or ML broad proximal femoral diaphyses.

Validity of Discriminating Ancestry

Methods using femur subtrochanteric variables (PI, APD, and MLD) have been shown to be reliable and simple approaches for distinguishing between Native American and American Black/White adult femora in forensic anthropological and bioarchaeological cases (8,10,11). The results of this study suggest that subtrochanteric dimensions can also be used to separate the two groups in subadults 6 years and older. Wescott (10) found no significant differences in the accuracy of estimating ancestry in adults using raw APD and MLD (shape and size) compared with PI (shape) only. However, in subadults, the PI sectioning point does not discriminate between Native Americans and American Blacks/Whites as well as using raw measurements in a bivariate plot (Table 2). An extension of the Gilbert and Gill (8) sectioning point (Fig. 6) seems the most appropriate for differentiating between older Native American and American Black and White subadults. The Gilbert and Gill (8) sectioning line is easy to use, widely available to forensic scientists, and provides the same results as more complicated discriminant functions. Individuals who fall to the left of the line classify as Native American, while individuals who fall to the right of the line classify as American Black/White. However, individuals with an APD less than 19 mm are more likely to be classified as Native American regardless of group affiliation using an extension of the Gilbert and Gill (8) sectioning line. Most of the individuals in the 6–18 year age group who were incorrectly classified using the Gilbert and Gill (8) method were American Black/White subadults between 6 and 9 years of age with anteroposterior diameters less than 19 mm. In these cases, the small APD resulted in the individual automatically falling left of the sectioning line regardless of diaphyseal shape. Therefore, the Gilbert and Gill (8) method works best on subadults greater than 9 years of age.

While Native American and American Black/White subadults could be differentiated with over 85% accuracy in this study using the Gilbert and Gill (8) sectioning line, it is important to note that the Arikara, the Native American sample used in this study, are among the most platymeric of Native American groups (10) and are an archaeological population. Forensic scientists may find the accuracy of the Gilbert and Gill (8) method reduced in geographical regions outside the Great Plains (see reference (10) for discussion). Forensic anthropologists and bioarchaeologists, therefore, should adjust the Gilbert and Gill (8) sectioning line depending on the degree of platymeria present in their local Native American population (see reference (10) for discussion). Furthermore, while there does not appear to be a significant temporal change in subtrochanteric shape among Native Americans (11), the degree of temporal change in femur length has not been sufficiently examined. A significant secular change in femur length among Native Americans could have an effect on the development of subtrochanteric shape, and therefore influence the accuracy of using the Gilbert and Gill (8) method to discriminate between Native Americans and American Blacks/Whites. Finally, individuals from groups other than Native American and American Black/White likely overlap with these two groups and therefore cannot be distinguished (10). Gill (11) has suggested that populations with Asian ancestry are generally more platymeric than those of European or African ancestry, but this hypothesis has not been tested.

Conclusions

Femur subtrochanteric shape develops in relationship with biomechanical stresses associated with the development of an adult gait pattern. Reduction of base support, knee bending, and pelvic rotation during gait maturation results in greater mechanical loads on the subtrochanteric region of the femur in the ML than the AP plane. As a result, growth in the ML plane exceeds growth in the AP plane from birth to 5 years of age. After gait maturation, femur subtrochanteric shape does not change significantly in Native American or American Black/White subadults.

The results of this study make evident that proximal femur diaphyseal shape can be used to distinguish between platymeric Native American femora and more eurymeric American Black/White femora in subadults over the age of 6 years with as much as 85% accuracy using the Gilbert and Gill (8) and discriminant function methods. The published Gilbert and Gill (8) method is easy to use but may be inaccurate in very small (APD <19 mm) individuals. Subadults, like adults, exhibit great variation within groups (Table 1) probably due to activity-induced biomechanical stress placed on the femur (10,20,21) and environmentally influenced temporal changes. This variation should be considered when using femur subtrochanteric shape alone to determine ancestry in medicolegal investigations.

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