Helen Cho,[1] M.A.; Sam D. Stout,[2] Ph.D.; Richard W. Madsen,[3] Ph.D.; and Margaret A. Streeter,[4] M.A.

Population-Specific Histological Age-Estimating Method: A Model for Known African-American and European-American Skeletal Remains

REFERENCE: Cho H, Stout SD, Madsen RW, Streeter MA. Population-specific histological age-estimating method: a model for known African-American and European-American skeletal remains. J Forensic Sci 2002;47(1):12–18.

ABSTRACT: Previously developed histological age-estimating methods have been based on samples lacking interpopulation variability. A comparison of age-associated rib histomorphometrics between an European-American sample and an African-American sample indicates that ethnicity can have a significant effect on osteon population density (OPD), osteon cross-sectional area (On.Ar), and relative cortical area (Ct.Ar/Tt.Ar). Based upon these findings, new histological age-predicting formulae are presented that are recommended when estimating age for African-American or European-American skeletal remains. A general formula that is applicable to remains of unknown ethnicity is also provided.

KEYWORDS: forensic science, anthropology, osteon, histomorphometry, histology, remodeling

Bone remodeling occurs throughout life in humans and involves a coupled sequence of cellular activation, resorption, and formation of bone. In cortical bone, remodeling activity produces histomorphological structures called osteons or Haversian systems, which are the basic structural units of bone remodeling. The continuous production of osteons by the bone remodeling process results in a strong correlation between the age of an individual and the number of osteons per unit area in a cross-section of their bone. This age association is the basis for most histological age-estimating methods.

The value of histological aging methods is most apparent in cases where the human skeletal remains are incomplete or fragmentary. Accordingly, a number of histological methods have been developed that provide age-predicting regression equations that are applicable to various skeletal elements, e.g.,: femur (1); femur, tibia, and fibula (2,3); rib and clavicle (4); femur, tibia, humerus, and ulna (5); and humerus (6). For a review of available histological age predicting methods, see Stout (7) and Robling and Stout (8).

A major limitation to the broad application of histological aging methods is the fact that most of the available methods have been derived from a limited number of genetically homogeneous populations. Although we know very little about the effects of interpopulational variation on bone remodeling, there is evidence that population differences exist for bone mass (9,10), microstructure (5,11–13), and fragility (14). A few histological age-estimating techniques have been modified for specific populations (15), but due to the unavailability of ethnically diverse samples, the applicability of these formulae for age-estimation of individuals from different populations, e.g., African-American or Asian, remains to be determined[5] (16). The purpose of this paper is to present a population-specific histological age-predicting regression formula based upon African-American and European-American rib samples. For age estimation of skeletal remains with indeterminate ethnicity, a separate formula is derived from the combined samples. These formulae were subsequently tested on an independent sample of both African- and European-American ribs for their reliability and accuracy in predicting age-at-death.

Materials and Methods

Sample

Rib samples representing individuals of known African-American and European-American ethnicity were examined in this study. The African-American sample includes 103 individuals from an African-American cemetery,[6] forensic cases, and autopsies. The age range is 17–95 years with a mean age of 50.41 years. The European-American sample is composed of rib samples from 51 individuals. It includes 36 of Stout and Paine's original autopsy samples (4), 4 additional autopsy samples, and 11 rib samples from forensic cases received by the University of Missouri Human Skeletal Identification Laboratory. The age range is 17–82 years with a mean age of 37.82 years (Table 1).

In this study, individuals under the age of seventeen years were excluded from the European-American sample to match the age range of the African-American sample. The deletion was permissible for several biological reasons. Transverse cortical drifts that occur in the ribs of juveniles can result in significant underestimation of chronological age due to removal of osteons. Cortical drift ceases in the early teens, when the effective age of the adult compacta is achieved. In addition, subadult bone remodeling rates differ from adults.

To do statistical analysis, the final total rib sample of 154 individuals was randomly divided into a developmental set composed of 69 African-Americans and 34 European-Americans, and a vali-

[1] Department of Anthropology, University of Missouri-Columbia.
[2] Department of Anthropology, University of Missouri-Columbia.
[3] Department of Statistics, University of Missouri-Columbia.
[4] Department of Anthropology, University of Missouri-Columbia.
Received 25 Jan. 2001; and in revised form 17 March 2001; accepted 18 March 2001.

[5] For a recent review of population variation in bone remodeling as it relates to histological age-estimation, see Stout (16).

[6] During the relocation of part of the Washington Park Cemetery in St. Louis, Missouri, rib samples were submitted by the Missouri Department of Natural Resources to one of the authors (SDS) as autopsy samples for analysis.

TABLE 1—*Age distribution of African-American and European-American rib samples in years (±1 SEM).*

	African-American			European-American		
Sample	*N*	Range	Mean	*N*	Range	Mean
Total ($N = 154$)	103	17–95	50.408 ± 1.807	51	17–82	37.824 ± 2.413
Developmental Set	69	17–95	50.696 ± 2.227	34	17–74	38.118 ± 2.975
Validation Set	34	19–84	49.824 ± 3.137	17	17–82	37.235 ± 4.247

dation set that included 34 African-Americans and 17 European-Americans (Table 1). Randomization was done such that the two ethnic groups were represented in the same ratio (2 African-American: 1 European-American) in the two sample sets. The developmental set was used to develop a regression model for predicting age-at-death. The model was then tested on the validation set to compare the predicted age and known age-at-death.

Histological Methods

Preparation of the rib samples followed the methods in Stout and Paine (4,17). The following histomorphometrics[7] were measured for each individual rib directly using an Olympus BX-50F light microscope (Olympus Optical Co., Ltd., Tokyo, Japan) fitted with a Zeiss Integrationsplatte II (Georgia Instruments, Atlanta, GA) eyepiece reticule:

1. *Mean Osteonal Cross-Sectional Area* in mm^2 (On.Ar), the average area of bone contained within the cement lines of structurally complete osteons for each rib specimen. Osteons were considered to be structurally complete if their reversal lines were intact. Complete osteons with Haversian canals that deviated significantly from circular were excluded. Mean area was calculated as the average cross-sectional area of a minimum of 25 complete osteons per cross-section.
2. *Intact Osteon Density* in $\#/mm^2$ (N.On), the number of osteons per unit area that have 90% of their Haversian canal perimeters intact or unremodeled. Half or more of an osteon's area had to fall within the counting field, i.e., the square grid of the eyepiece reticule, to be counted.
3. *Fragmentary Osteon Density* in $\#/mm^2$ (N.On.Fg), the number of osteons per unit area in which 10% or more of the perimeters of their Haversian canals, if present, have been remodeled by subsequent generations of osteons. This includes interstitial lamellae that are remnants of preexisting osteons and no longer contain a Haversian canal. Fragmentary osteons for which half or more of their area fall within the counting field are counted.
4. *Osteon Population Density* in $\#/mm^2$ (OPD), the sum of N.On and N.On.Fg.
5. *Relative Cortical Area* (Ct.Ar/Tt.Ar), the relative amount of cortical bone in cross-sectional area of bone, or the ratio of cortical bone area (Ct.Ar) to total area (Tt.Ar) of a rib cross section.

Statistical Methods

The goal of this study is to describe the relationship between age and the cortical bone histomorphometrics for the African-American and European-American rib samples, and to determine if the relationship differs between these two samples. Statistical analyses and the generation of predicting equations were accomplished using STATISTICA (StatSoft, Inc., Tulsa, OK) and SAS (SAS Institute, Inc., Cary, NC) software.

There are three predictor variables of interest: OPD, On.Ar, and Ct.Ar/Tt.Ar. As a first step, these variables were examined individually as significant predictors of age-at-death, to determine if there is one "simple" model for predicting age which can be applied to both ethnic groups, or if the model differs for each group. An indicator variable for ethnicity (Group) as well as Group by variable (OPD-Group, On.Ar-Group, Ct.Ar/Tt.Ar-Group) interaction terms were considered. Ethnicity is an indicator variable taking on the value of 0 for African-American and 1 for European-American. If in a regression model only the Group indicator has a coefficient that differs significantly from zero, then there is a simple shift in the regression lines predicting age, i.e., the prediction lines for the two groups are parallel. If only the interaction term has a coefficient that differs from zero, then the lines have the same Y intercept but the slopes differ. Finally, if both the Group indicator and the interaction term differ from zero, then the lines have different intercepts and are not parallel.

The second step in the analysis involved a forward stepwise procedure to develop a model using all three predictor variables, Group indicator, and the three interaction terms. The third step applied the model generated from the developmental set to estimate the age of in the validation set. The estimated ages and known ages-at-death were then compared for accuracy. In the fourth and final step, the developmental and validation sets were pooled and used to obtain final estimates of the regression model's coefficients based upon the larger combined sample.

A separate analysis was undertaken for use in situations where ethnicity is indeterminate. In this model, three predictor variables were used without any interaction terms, since Group indicator is inapplicable. The intent was to look at the sample as having come from the general population (Missouri[8] in this study), but without knowing ethnicity. Since the ethnic proportions for the population of Missouri are about 89% (0.8903) European-Americans and 11% (0.1097) African-Americans, a model was built based on this ratio, rather than of the sample data, which has an unrealistically high proportion of African-Americans. Consequently, the developmental set was used to first estimate the coefficients for individual groups separately. New coefficients based on weighted averages of these coefficients, with weights being the above proportions, were then generated. Using bootstrap methods (19), the data set was sampled at random and with replacement to obtain developmental and validation samples that were 89% European-American and 11% African-American. Similar to the final step where ethnicity is

[7] Symbols and acronyms for variables used in this study conform to those recommended by the American Society for Bone and Mineral Research (18). They, therefore, differ from those used in the Stout and Paine (4,17), with the exception of OPD for which no comparable variable exists in the new system.

[8] Due to the unavailability of other ethnic groups in this study, the populations of European- and African-Americans were scaled to 100%. The 1990 census report for the state of Missouri stated 4 448 465 European-Americans and 548 208 African-Americans.

known, the developmental and validation sets were pooled to obtain final estimates of the coefficients. Finally, due to the possibility that intact cross-sections are not always available for age estimation, a similar analysis was done using only OPD and On.Ar as predictor variables.

Results

Variables as Predictors of Age

Table 2 presents the means for the histomorphometric variables for the African- and European-American ribs in the developmental set only. When each of the variables were examined individually as a predictor of age, with Group as an indicator variable and Group by variable as interaction terms, the following result were produced. For OPD and On.Ar, only the Group indicator has a coefficient that differs from zero ($p < 0.0001$ and $p = 0.0122$, respectively); therefore, the regression lines for African- and European-Americans are parallel (Figs. 1 and 2). When Ct.Ar/Tt.Ar is used to predict age, both the coefficients for Group and Ct.Ar/Tt.Ar-Group differ from zero ($p = 0.0002$, $p = 0.0043$, respectively), indicating that the regression lines for African- and European-Americans exhibit both different intercepts and slopes (Fig. 3).

TABLE 2—*Mean histomorphometrics of African-American and European-American ribs from the developmental set (±1 SEM).*

Variable	African-American	European-American
N	69	34
Mean Age (years)	50.696 ± 2.227	38.118 ± 2.975
Age Range (years)	17–95	17–74
OPD (#/mm^2)	18.695 ± 0.714	20.071 ± 0.975
On.Ar (mm^2)	0.036 ± 0.001	0.039 ± 0.001
Ct.Ar/Tt.Ar	0.350 ± 0.015	0.343 ± 0.023
	(*N* = 61)	(*N* = 33)

Age Predicting Models with Group Variable

Stepwise regression analysis of the developmental set produced a model with four age-predictors: OPD, On.Ar-Group, Ct.Ar/Tt.Ar, and Ct.Ar/Tt.Ar-Group (Table 3). The estimated RMSE (root mean squared error) is 12.22. The RMSE is a measure of the residual variation and an estimate of the standard deviation of the response variables (ages-at-death) around their mean values. Approximately 95% of the ages fall within two standard deviations (±24.44 years) of the predicted mean.

When the predicting model was applied to the validation set and predicted ages were compared to known ages-at-death, the mean difference (age-predicted age) does not differ significantly from

TABLE 3—*Results of the stepwise regression selection of variables and the age-predicting model based on the developmental set.*

Step	Variable Entered	R^2
1	OPD	0.362
2	On.Ar	0.505
3	Ct.Ar/Tt.Ar	0.555
4	Ct.Ar/Tt.Ar-Group	0.589

	DF	Sum of Squares	Mean Square	*F*	*P* > *F*
Regression	4	19306.533	4826.633	32.30	0.0001
Error	90	13449.194	149.436 (RMSE = 12.22)		
Total	94	32755.726			

Variable	Parameter Estimate	Standard Error	*F*	*P* > *F*
Intercept	46.177	8.851	27.22	0.0001
OPD	1.365	0.255	28.59	0.0001
Ct.Ar/Tt.Ar	−64.069	14.908	18.47	0.0001
On.Ar-Group	−849.959	192.326	19.53	0.0001
Ct.Ar/Tt.Ar-Group	59.284	21.468	7.63	0.007

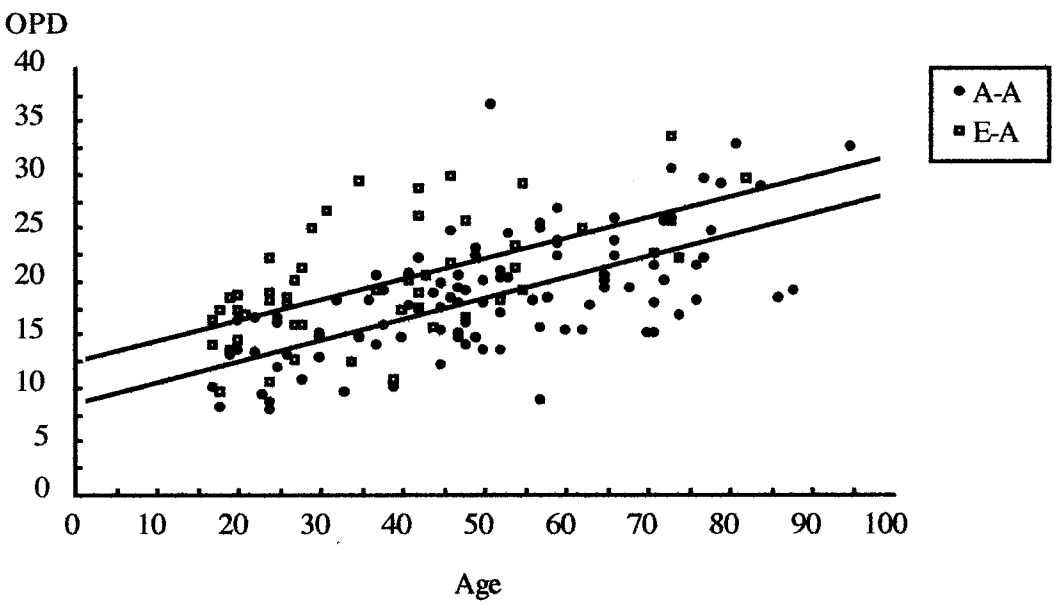

FIG. 1—*Association between osteon population density (OPD) and age-at-death in European-Americans (E-A) and African-Americans (A-A). There is a significant Group effect* ($R^2 = 0.46$).

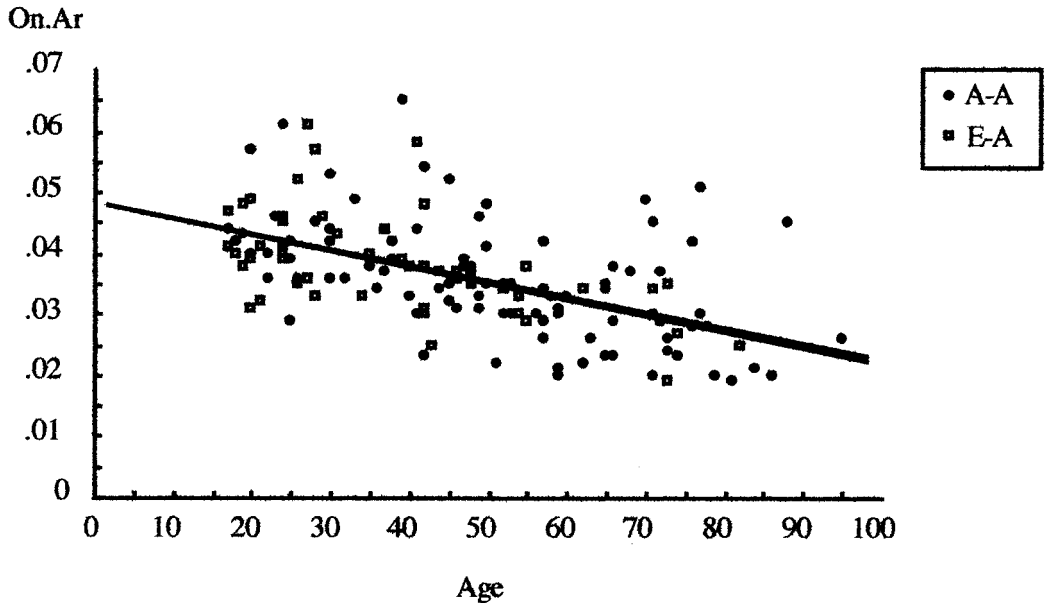

FIG. 2—*Association between osteon area (On.Ar) and age-at death in European-Americans (E-A) and African-Americans (A-A). There is a significant Group effect (*$R^2 = 0.36$).

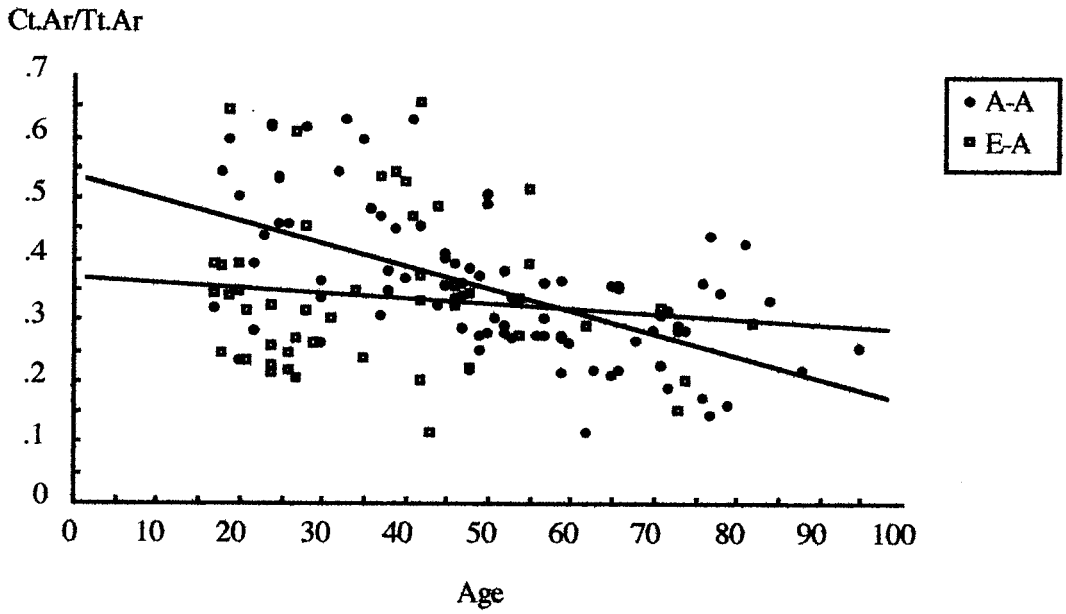

FIG. 3—*Association between relative cortical area (Ct.Ar/Tt.Ar) and age-at-death in European-Americans (E-A) and African-Americans (A-A). There is a significant group and interaction effect (*$R^2 = 0.38$). *The difference in relative cortical area between the two groups is significant for ages under approximately 60 years.*

zero ($p = 0.7644$) (Table 4). Further, the standard deviation is 14.02, which is just slightly higher than the RMSE determined for the developmental set. Approximately 50% of the validation estimates fall within ±11.63 years of actual age. Table 4 also provides descriptive information for the absolute value of the difference between age and predicted age. When the sign of the difference is ignored, the mean amount by which predictions vary is about 11.8 years.

In comparing the estimates of the coefficients of the predictor variables from developmental and validation sets, they do not differ significantly (Table 5). Using $z = (b_D - b_V)/(S^2_{bD} + S^2_{bV})^{1/2}$ as a test statistic (where D and V refer to Developmental and Validation models, respectively), none of the coefficients differ significantly ($p \geq 0.179$ in all cases). The developmental and validation

TABLE 4—*A comparison of predicted age and known age-at-death of the validation set for known ethnicity.*

	Difference	Absolute Difference
N	46	46
Mean	0.623	11.809
Standard Deviation	14.022	7.380
Skewness	−0.102	0.655
Standard Error of Mean	2.067	1.088
$P > \|T\|$	0.764	0.0001
100% Max	28.809	33.434
75% Q3	10.309	16.982
50% Med	1.708	11.629
25% Q1	−12.083	5.745
0% Min	−33.434	0.280

TABLE 5—*A comparison of the estimates of the coefficients of the predictor variables from the developmental and validation sets.*

	Developmental		Validation			
Parameter	Estimate	SD	Estimate	SD	z	P
Intercept	46.177	8.851	27.864	11.546	1.259	0.208
OPD	1.365	0.255	1.995	0.393	−1.344	0.179
Ct.Ar/Tt.Ar	−64.069	14.908	−38.813	19.407	−1.032	0.302
On.Air-Group	−849.959	192.326	−1024.144	270.853	0.524	0.600
Ct.Ar/Tt.Ar-Group	59.284	21.468	63.983	28.785	−0.131	0.896

TABLE 6—*Age-predicting formula and ANOVA results for African-Americans and European-Americans based on the total data set.*

Age = 38.029 + 1.603 (OPD) − 882.210 (On.Ar*Group) − 51.228 (Ct.Ar/Tt.Ar) + 57.441 (Ct.Ar/Tt.Ar*Group)
Group = 0 for African-American
1 for European-American

Source	*DF*	Sum of Squares	Mean Square	*F* Value	$P > F$
Model	4	28839.431	7209.858	44.846	0.0001
Error	136	21864.399	160.768		
Total	140	50703.830			

Root MSE	12.679
Dep Mean	45.809
C.V.	27.680
R^2	0.569
Adjusted R^2	0.556

Variable	*DF*	Parameter Estimate	Standard Error	T for H_0: Parameter = 0	$P > \|T\|$
Intercept	1	38.029	6.890	5.519	0.0001
OPD	1	1.603	0.210	7.649	0.0001
Ct.Ar/Tt.Ar	1	−51.228	11.566	−4.429	0.0001
On.Ar-Group	1	−882.210	154.604	−5.706	0.0001
Ct.Ar/Tt.Ar-Group	1	57.441	16.949	3.389	0.0009

sets were pooled into one set to produce final estimates of the coefficients for the age-predicting regression model with known ethnicity (Table 6).

Age-Predicting Models without Group Variable (Ethnicity Unknown)

When the group variable or its interaction terms must be excluded due to ethnicity being unknown, the model has three predictors: OPD, On.Ar, and Ct.Ar/Tt.Ar (Table 7). Using the developmental set, the regression coefficients were estimated separately for African- and European-Americans. The proportions of the two groups from the 1990 census report for the state of Missouri (0.89 for European-Americans and 0.11 for African-American) were used to calculate new coefficients based on the weighted averages. It is recommended that the estimates of the coefficients be modified when applying the formula to cases from other regions of the United States or when the proportions are known to differ markedly from 0.89:0.11.

The statistics of the developmental model tested on the validation set, when ethnicity is not known, are presented in Table 8. Predicted ages and known ages did not differ significantly from zero ($p = 0.71$), and about 50% of the validation estimates fall within

TABLE 7—*Age-predicting model for indeterminate ethnicity based on the developmental set.*

	Estimates		
Parameter	African-American	European-American	Pooled by 0.11 (A-A) + 0.89 (E-A)
Intercept	41.823	38.498	38.865
OPD	1.492	1.372	1.385
On.Ar	122.988	−694.491	−604.568
Ct.Ar/Tt.Ar	−70.608	−1.239	−8.870

TABLE 8—*A comparison of predicted age and known age-at-death of the validation set for indeterminate ethnicity.*

	Difference	Absolute Difference
N	43	43
Mean	−0.900	15.076
Standard Deviation	16.023	4.987
Skewness	0.046	0.099
Standard Error of Mean	2.443	0.761
$P > \|T\|$	0.714	0.0001
100% Max	25.247	25.247
75% Q3	13.565	18.878
50% Med	5.379	15.138
25% Q1	−16.668	10.696
0% Min	−20.653	5.379

TABLE 9—*Age-predicting formula for unknown ethnicity based on the total data set.*

Age = 29.524 + 1.560 (OPD) + 4.786 (Ct.Ar/Tt.Ar) − 592.899 (On.Ar)

	Estimates		
Parameter	African-American	European-American	Pooled by 0.11 (A-A) + 0.89 (E-A)
Intercept	36.941	28.607	29.524
OPD	1.715	1.541	1.560
On.Ar	25.330	−669.309	−592.899
Ct.Ar/Tt.Ar	−55.925	12.290	4.786

±15.14 years of actual age. When the sign of the difference is ignored, the mean amount by which predictions vary is about 15.1 years. In Table 9, final weighted estimates of the coefficients produced by pooling both data sets and the age-predicting formula for indeterminate ethnicity are provided.

When skeletal remains are extremely fragmented, it may not be possible to measure the variable Ct.Ar/Tt.Ar, since this requires a

TABLE 10—*Age-predicting formula based on the total data set for unknown ethnicity and incomplete rib cross sections.*

Age = 37.982 + 1.400 (OPD) − 670.138 (On.Ar)			
	Estimates		
Parameter	African-American	European-American	Pooled by 0.11 (A-A) + 0.89 (E-A)
Intercept	36.145	38.209	37.982
OPD	1.602	1.375	1.400
On.Ar	−431.917	−699.581	−670.138

complete cross section of the bone. Therefore, a model was developed for use for individuals of indeterminate ethnicity and requiring only two predicting variables, OPD and On.Ar (Table 10).

Discussion and Conclusion

The results of this study indicate that ethnicity has a significant effect on OPD, osteon area, and relative cortical area. These findings are consistent with observations that bone mass is greater in African-Americans compared to European-Americans (20). The observed higher OPD values in European-Americans, compared to African-Americans, is consistent with findings for South African "Blacks" and "Whites" by others (13) and reflects the presence of greater cortical porosity due to a larger number of Haversian canals. Osteon size is also greater in European-Americans than in African-Americans. Research by others has indicated that fatigue resistance and energy dissipation by osteon pullout in bone is dependent on the size and number of osteons. The likelihood of osteon pullout increases with increasing osteon size and osteon number (21). Therefore, with larger mean osteon area and higher mean OPD values in European-Americans, energy absorption capacity of bone declines. Relative to African-Americans, European-Americans appear to have weaker bone due to greater porosity and a propensity for osteon pullout. This is consistent with the medical literature reporting ethnic differences in bone density and strength (10,22–24).

The interaction effect between ethnicity and relative cortical area when they are regressed against age indicates that the slopes of the regression lines for the African-Americans and European-Americans equations are not parallel. It should be noted from Fig. 3 that young African-Americans have a larger relative cortical area than European-Americans and, therefore, exhibit a greater peak bone mass. This difference is significant only for ages less than approximately 60 years. Greater cortical area in African-Americans may also allow more space for osteon creations, thus allowing fewer osteons per unit area for a given number of osteon creations compared to European-Americans. These findings are consistent with reported greater bone mass (22–24) and reduced risk of osteoporotic fractures for African-Americans (14,25–27).

The existence of population differences in age-associated OPD, On.Ar, and Ct.Ar/Tt.Ar indicates that a different age-predicting formula should be applied when estimating age using cortical bone histomorphometry. For cases where ethnicity has established to be European-American or African-American, the multiple regression model presented here should be employed (Appendix 1).

For samples of indeterminate ethnicity, a separate regression equation is provided in which the estimates of the coefficients were weighted by the estimated proportions of African-American and European-Americans in the population (Appendix 1). In this study, the proportions of the two ethnic groups according to the 1990 census report for the state of Missouri were used. In practice, it is recommended that this formula be adjusted to the actual population of the state/region from which the skeletal remains originate (Appendix 2). Since skeletal remains are not always intact in archaeological or forensic contexts, a formula without the relative cortical area variable is also provided.

It should also be noted that histological age estimation might be less accurate for older individuals. It is well established that bone-remodeling rates change (increase) in both males and females in their seventh decade, and decline during the next two decades of life (21). In addition, as the numbers of observable osteons and osteon fragments increase with age, an asymptotic value for OPD is eventually achieved when each newly created osteon removes all evidence of an existing system (28). The age at which this asymptote occurs depends upon the rate at which new osteons are created, osteon size, and cortical area. It has been estimated to usually occur around 60 years of age in the human rib. Such changes in bone remodeling rates in older adults are not well understood, and, therefore, make histological age estimation less reliable for individuals over 60 years of age.

Finally, the multiple regression formulae presented in the paper should be tested on additional independent samples. Similar research on samples comprised of different ethnic groups should also be undertaken to develop additional population-specific formulae to assist in the age estimation of skeletal remains.

Acknowledgments

The State of Missouri Department of Natural Resources made the African-American rib sample from Washington Park cemetery available. Dr. Jay Dix at the University of Missouri-Columbia provided the autopsy rib sample. Dr. Robert Paine and Kristina Lotz provided the relative cortical area data for the Washington Park and autopsy rib samples, respectively.

APPENDIX 1

Estimating Age-at-Death Using the Regression Formulae

Example 1: When the sample is African-American (See Table 6):
Use the predicting formula Age = 38.029 + 1.603 (OPD) − 882.210 (On.Ar*Group) − 51.228 (Ct.Ar/Tt.Ar) + 57.441 (Ct.Ar/Tt.Ar*Group)
Where: Group = *0 for African-American* and 1 for European-American

OPD = 18.84/mm^2
On.Ar = 0.045 mm^2
Ct.Ar = 30.33 mm^2
Tt.Ar = 93.38 mm^2

Age = 38.029 + 1.603 (18.84) − 882.210 (0.045*0) − 51.228 (30.33/93.38) + 57.441 (42.99/93.38 *0) ≈ 52 years

Example 2: When the sample is European-American (See Table 6):
Age = 38.029 + 1.603 (OPD) − 882.210 (On.Ar*Group) − 51.228 (Ct.Ar/Tt.Ar) + 57.441 (Ct.Ar/Tt.Ar*Group)
Where: Group = 0 for African-American and *1 for European-American*

OPD = 18.84/mm^2
On.Ar = 0.045 mm^2

Ct.Ar = 30.33 mm^2
Tt.Ar = 93.38 mm^2

Age = 38.029 + 1.603 (18.84) − 882.210 (0.045*1) − 51.228 (30.33/93.38) + 57.441 (30.33/93.38 *1) ≈ 31 years

Example 3: When the sample is of indeterminate ethnicity (see Table 9):
Age = 29.524 + 1.560 (OPD) + 4.786 (Ct.Ar/Tt.Ar) − 592.899 (On.Ar)
Where: OPD = 18.84/mm^2

On.Ar = 0.045 mm^2
Ct.Ar = 30.33 mm^2
Tt.Ar = 93.38 mm^2

Age = 29.524 + 1.560 (18.84) + 4.786 (30.33/93.38) − 592.899 (0.045) ≈ 34 years

Example 4: When the sample is of indeterminate ethnicity and the rib cross-section is not intact and cortical area cannot be measured (see Table 10):
Age = 37.982 + 1.400 (OPD) − 670.138 (On.Ar)
Where: OPD = 18.84/mm^2

On.Ar = 0.045 mm^2

Age = 37.982 + 1.400 (18.84) − 670.138 (0.045) ≈ 34 years

APPENDIX 2

Adjusting the Ethnic Proportions of the Study Group

For every parameter, each estimate for African-American and European-American samples was multiplied by its corresponding proportion. The two parameter estimates were then summed. For example, from the regression equation in Table 9, the intercept 29.524 was calculated as follows:

Estimate of coefficient for African-American = 36.941
Estimate of coefficient for European-American = 28.607
Proportion of African-Americans in Missouri ≈ 11%
Proportion of European-Americans in Missouri ≈ 89%
Adjusted Intercept = 36.941(0.11) + 28.607 (0.89) = 29.524

If the ethnic proportions of African- and European-Americans from another region or time period are known, the parameter estimates should be adjusted accordingly. For example, if in State X, the proportion of African-Americans is 25% and that of European-Americans is 75%, then

Adjusted Intercept = 36.941(0.25) + 28.607(0.75) = 30.691

References

1. Ericksen MF. Histologic estimation of age at death using the anterior cortex of the femur. Am J Phys Anthropol 1991;84:171–9.
2. Kerley ER. The microscopic determination of age in human bone. Am J Phys Anthropol 1965;23:149–64.
3. Kerley ER, Ubelaker DH. Revisions in the microscopic method of estimating age at death in human cortical bone. Am J Phys Anthropol 1978; 49:545–6.
4. Stout SD, Paine RR. Histological age estimation using rib and clavicle. Am J Phys Anthropol 1992;87:111–5.
5. Thompson DD, Gunness-Hey M. Bone mineral-osteon analysis of Yupik-Inupiaq skeletons. Am J Phys Anthropol 1981;55:1–7.
6. Yoshino M, Imaizumi K, Miyasaka S, Seta S. Histological estimation of age at death using microradiographs of humeral compact bone. Forensic Sci Int 1994;64:191–8.
7. Stout SD. Methods of determining age at death using bone microstructure. In: Saunders SR, Katzenberg, MA, editors. Skeletal biology of past peoples: research methods. New York: Wiley-Liss, Inc., 1992;21–35.
8. Robling AG, Stout SD. Histomorphometry of human cortical bone: applications to age estimation. In: Katzenberg MA, Saunders SR, editors. Biological anthropology of the human skeleton. New York: Wiley-Liss, Inc., 2000;187–213.
9. Ericksen MF. Aging changes in the medullary cavity of the proximal femur in American blacks and whites. Am J Phys Anthropol 1979;51: 563–70.
10. Pollitzer ME, Anderson JJB. Ethnic and genetic differences in bone mass. Am J Clin Nutr 1989;50:1244–59.
11. Richman BA, Ortner DJ, Schulter-Ellis FP. Differences in intracortical bone remodeling in three aboriginal American populations: possible dietary factors. Calcif Tissue Int 1979;28:209–14.
12. Stout SD, Lueck R. Bone remodeling rates and skeletal maturation in three archaeological skeletal populations. Am J Phys Anthropol 1995 ;98:161–71.
13. Pratte DG, Pfeiffer S. Histological age estimation of a cadaveral sample of diverse origins. Canad Soc Forensic Sci 1999;32:155–67.
14. Schnitzler CM. Bone quality: a determinant for certain risk factors for bone fragility. Calcif Tissue Int 1993;53 Suppl 1:27–31.
15. Narasaki S. Estimation of age at death by femoral osteon remodeling: application of Thompson's core technique to modern Japanese. J Anthropol Soc Nippon 1990;98:29–38.
16. Stout SD. The application of histological techniques for age at death determination. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains. Springfield: Charles C Thomas, 1998; 237–52.
17. Stout SD, Paine RR. Bone remodeling rates: a test of an algorithm for estimating missing osteons. Am J Phys Anthropol 1994;93:123–9.
18. Parfitt AM, Drezner MK, Glorieux FH, Kanis JH, Malluche H, Meunier PJ, Ott SM, Recker RR. Bone histomorphometry: standardization of nomenclature, symbols, and units. J Bone Miner Res 1987;2:595–610.
19. Efron B, Tibshirani RJ. An introduction to the bootstrap. New York: Chapman and Hall, 1993.
20. Garn SM, Poznanski AK, Larson K. Metacarpal lengths, cortical diameters and areas from Ten State Nutritional Survey. In: Jaworski ZFG, editor. Proceedings of First Workshop on Bone Morphometry; 1973 Mar 28–31; Ottawa. Ottawa: University of Ottawa Press, 1976;367–91.
21. Martin RB, Burr DB, Sharkey NA. Skeletal tissue mechanics. New York: Springer-Verlag New York, Inc., 1998.
22. Cohn SH, Abesamis C, Yasumura S, Alaia JF, Zanzi I, Ellis K. Comparative skeletal mass and radial bone mass in black and white women. Metabolism 1977;26:171–8.
23. DeSimone DP, Stevens J, Edwards J, Shary J, Gordon L, Bell NH. Influence of body habitus and race on bone mass density of midradius, hip and spine in aging women. J Bone Miner Res 1989;4:827–30.
24. Nelson DA, Feingold M, Bolin F, Parfitt AM. Principal components analysis of regional bone density in black and white women: relationship to body size and composition. Am J Phys Anthropol 1991;86:507–14.
25. Anderson JJ, Pollitzer WS. Ethnic and genetic differences in susceptibility to osteoporotic fractures. Adv Nutr Res 1994;9:129–49.
26. Baron JA, Barrett J, Malenka D, Fisher E, Kniffin W, Bubolz T, et al. Racial differences in fracture risk. Epidemiology 1994;5:42–7.
27. Nelson DA, Kleerekoper M, Peterson E, Parfitt AM. Skin color and body size as risk factors for osteoporosis. Osteoporos Int 1993;3:18–23.
28. Frost HM. Secondary osteon population density: an algorithm for estimating missing osteons. Yrbk Phys Anthropol 1987;30:239–54.

Additional information and reprint requests:
Helen Cho
107 Swallow Hall
University of Missouri
Columbia, MO 65211