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Analysis of Age-at-Death Estimation Through the Use of Pubic Symphyseal Data*

ABSTRACT: The question of whether age parameters derived from an American population will reliably estimate age-at-death for East European skeletal populations is important since the ability to accurately estimate an individual's age-at-death hinges on what standard is used. A reference sample of identified individuals with known ages-at-death from the regions of the Former Yugoslavia (n = 861) is used to determine the age structure of victims and serves as the prior in the Bayesian analysis. Pubic symphyseal data in the manners of Todd (Am J Phys Anthropol, 3 [1920], 285; Am J Phys Anthropol, 4 [1921], 1) and Suchey-Brooks (Am J Phys Anthropol, 80 [1986], 167) were collected for n = 296 Balkan males and females and for n = 2078 American males and females. An analysis of deviance is calculated using an improvement chi-square to test for population variation in the aging processes of American and East European populations using proportional odds probit regression. When males and females are treated separately, there is a significant association among females and the population (df = 1, chi-square likelihood ratio = 15.071, p = 0.001). New age estimates for Balkan populations are provided and are based on the calculated age distribution from the Gompertz-Makeham hazard analysis and the ages-of-transition. To estimate the age-at-death for an individual, the highest posterior density regions for each symphyseal phase are provided.

KEYWORDS: forensic science, Balkans, age estimation, pubic symphysis, Bayesian statistics

American standards developed for determining the skeletal ages-at-death from pubic symphyseal morphology began with T. W. Todd in 1920. Todd first created standards for American White males (1) and later for White females and Black males and females (2). Since his initial work, many studies have been conducted on the accuracy and application of his method for various populations. Most notable are the modifications to his technique by Brooks, Katz, and Suchey, beginning with Brooks (3). According to Katz and Suchey (4) the problem with the original Todd method is that it overestimates the age-at-death for most individuals, particularly those under the age of 40 years; does not account for individual variation; and does not accurately age older individuals. These researchers, along with many others, e.g., Gillet (5), Galera et al. (6), and Kemkes-Grottenthaler (7), found that the modified six-phase system is a more accurate estimator than the original Todd system. Consequently, the Suchey-Brooks system (4,8) is currently used throughout the world as the standard for estimating age from the pubic symphysis.

The modifications made to the Todd method did not end the controversial issues surrounding age estimation in terms of variation between the sexes or among different populations, inter-observer error, or method reliability. Originally, Todd noted that there were no racial differences in the aging process of the pubic symphysis and only minor differences between males and females. The primary difference he noted was that females appeared to age "faster" or "older" than their male counterparts due to trauma resulting from pregnancy and childbirth. He argued that females age two to three years later in phases III and VI in regard to development of the ventral aspect of the pubic symphysis, but appear two to three years younger in respect to dorsal flattening. Since Todd's work, other researchers have found similar differences between males and females. The review by Kemkes-Grottenthaler (7) cites numerous studies that report female age estimation is less reliable than that for males. All of these studies attribute such differences to pregnancy and childbirth. For example, Gilbert and McKern (9) argued that the female pubic symphyseal face appears about 10 years older than those of their male counterparts. More recently, Hoppa (10) looked into this issue using actual data on parity but found no relationship with parity and aging. In contrast, he found that female pubic symphyses appeared younger than males after the age of 40 years in several different populations, and that they did not exhibit greater variation than males. Hoppa attributed this finding to differences in the aging processes of the samples used and points out that one reference sample does not work for estimating age in all populations. Most differences noted between males and females have been observed for those over the age of 40. Kemkes-Grottenthaler (7) point out that apparent population differences may also be the result of extrinsic factors such as material culture (i.e., health care access, nutrition, or activity) which may affect bone density or degeneration, particularly among older aged individuals which may also explain differences between older males and females. It is most likely that the skeletal remains of females (including the pubic symphysis) may appear *older* in some populations due to nutritional differences, bone mineral density, and osteoporosis.

The question of whether there are substantial ethnic or population differences in the morphological aging process of the pubic symphysis has remained open to debate. This question is important since our ability to accurately estimate age among different populations hinges on the issue of what standard to use. The problem of

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whether one standard will work on populations that differ in time or space is important for successful age estimation and individual identification. However, age parameters biased in the direction of the reference sample, age mimicry, have resulted in unreliable age estimators (11,12). In the forensic context, the accuracy and reliability of all methods must be demonstrated to the scientific community, as well as the court. Therefore, the guidelines established by the court for the scientific presentation of evidence must be met for each method or technique used. Across populations and a variety of legal contexts, the evidentiary rules for the admissibility of evidence vary. However, the rules set out in the American Federal case law, *Daubert v. Merrell Dow Pharmaceuticals, 509 US 579 1993,* offer conservative scientific standards by which most international courts should apply similar reasoning (13).

The study presented here investigates age estimation based on the pubic symphysis using the Suchey-Brooks six-phase system. This calibration is based on a set of Bayesian statistical methods and utilizes the Gompertz-Makeham model (14,15). Using this statistical approach allows for estimation in the level of accuracy and precision. New point estimates for calculating individual ages-at-death are provided that can be used in the field at the time of autopsy/examination or may be applied to cases retroactively. This study is based on the prior work of Kimmerle (15).

Materials

A reference sample comprised of individuals with known ages-at-death (15–98 years) from Kosovo, BiH, and Croatia (n = 861) was used to determine the age structure of genocide victims in the Bayesian analysis. The Balkan skeletal data came from a subset of this reference sample. Balkan male (n = 212) and female (n = 84) pubic symphyses were scored in the manner of Suchey-Brooks (4,8). Data from this sample were collected by Kimmerle. Permission to use this data was given by the ICTY to UT who entered into a working relationship with the expressed goal of sharing data and results that would aid OTP in their investigations as well as other agencies working on human identification in the region. An essential component of this effort was the publication of scientific findings to ensure the admissibility of any new method or revised biological parameters for existing methods in court.

A comparative American sample was used consisting of White and Black individuals aged 15–102 years. American male (n = 1560) and female (n = 518) pubic symphyses were scored in the manner of Todd (1,2) and were converted from the Todd ten-phase system to the Suchey-Brooks six-phase system, as recommended by Katz and Suchey (4) for comparative purposes. These data came from numerous American forensic and anatomical reference collections including The University of Tennessee Forensic Data Bank (FDB), Gilbert-McKern skeletal data (data collected by L. Konigsberg) and McKern-Stewart Korean War Dead data (data collected by L. Konigsberg, NP Herrman, DJ Wescott), Los Angeles County Medical Examiner's Office forensic skeletal materials (16), and the Robert J. Terry Anatomical Skeletal Collection (data collected by L. Konigsberg, NP Herrman, DJ Wescott). For the Los Angeles County Medical Examiner's Office forensic skeletal materials the scoring on the Todd ten-phase system was done by Dr. Judy Suchey, who later presented the data (16) in her six-phase system. Table 1 lists the frequency of males and females from each of these sources. A comparison of these methods revealed no difference between using the original Todd ten phases or the converted Suchey-Brooks six phases for this investigation. Figure 1 illustrates the frequency of male individuals for each sample, summarized into five and ten year age cohorts. Figure 2

TABLE 1—*Sample size and sex distribution of comparative American and Balkan samples.*

Data	Males (n)	Females (n)	Total (n)
Balkan reference sample			
Kosovo	592	97	689
BiH	55	1	56
Croatia	116	0	116
Total (n)	763	98	861
Balkan skeletal sample			
Kosovo	106	83	189
BiH	55	1	56
Croatia	51	0	51
Total (n)	212	84	296
American skeletal sample			
FDB	41	43	84
Gilbert-McKern	0	147	147
Korean War Dead	258	0	358
Los Angeles medical examiner	739	0	739
Robert J. Terry Anatomical Collection	422	328	750
Total (n)	1560	518	2078

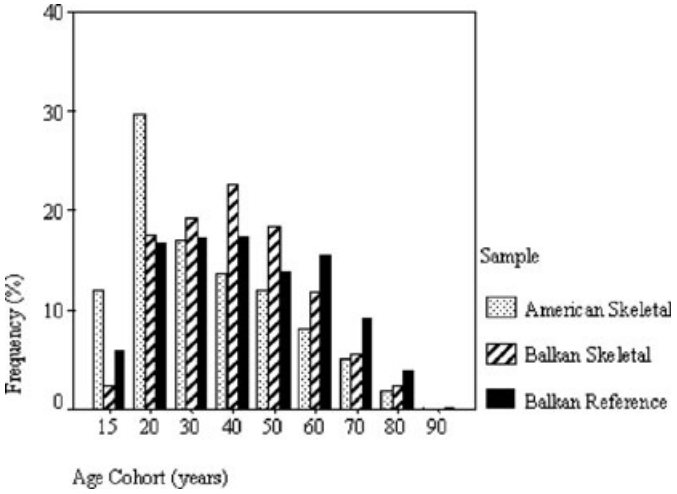

FIG. 1—*The frequency of male individuals in each age cohort represented by sample. The 15–20 year cohort is a five year interval. All other age cohorts are ten year intervals.*

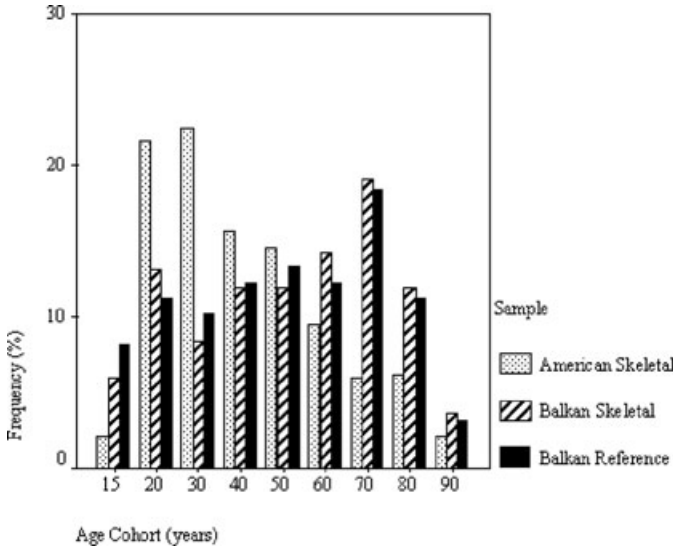

FIG. 2—*The frequency of female individuals in each age cohort represented by sample. The 15–20 year cohort is a five year interval. All other age cohorts are ten year intervals.*

TABLE 2—*Descriptive statistics for pubic symphyseal phases, Balkan sample.*

Phase	*n*	Mean Age (years)	95% CI Mean Age	Standard Deviation	Observed Age Range
Males					
I	13	20.3	18.9–21.7	2.25	17.0–25.9
II	6	24.2	19.1–29.2	4.79	20.0–33.0
III	21	30.5	27.0–33.9	7.53	22.0–45.0
IV	66	42.6	39.7–45.5	11.88	24.0–74.0
V	71	48.7	45.9–51.4	11.47	23.7–74.0
VI	37	62.7	58.2–67.2	13.42	34.0–85.0
Females					
I	9	20.3	17.7–22.9	3.39	17.0–28.0
II	1	22.0	–	–	–
III	7	30.3	23.4–37.1	7.43	21.0–44.0
IV	9	44.2	34.1–54.3	13.11	26.0–65.0
V	9	53.6	40.8–66.4	16.65	27.0–79.0
VI	49	68.1	63.8–72.3	14.79	33.0–96.0
Total					
I	22	20.3	19.1–21.5	2.69	17.0–28.0
II	7	23.9	19.8–28.0	4.56	21.0–33.0
III	28	30.4	27.6–33.3	7.37	21.0–45.0
IV	75	42.8	40.0–45.5	11.95	24.0–74.0
V	80	49.2	46.5–51.9	12.13	23.7–79.0
VI	86	65.8	62.7–68.8	14.39	33.0–96.0

TABLE 3—*Descriptive statistics for each Suchey-Brooks symphyseal phase, American sample.*

Phase	*n*	Mean Age (years)	SE (mean)	95% CI (mean)	Standard Deviation	Observed Age Range
Males						
I	318	19.9	0.19	19.6–20.4	3.462	15.0–65.0
II	215	26.6	0.57	25.5–27.7	8.364	17.0–78.0
III	95	31.5	1.00	29.5–33.5	9.772	22.0–70.0
IV	386	40.4	0.65	39.1–41.7	12.726	20.0–88.0
V	399	51.7	0.76	50.2–53.2	15.140	21.0–98.0
VI	145	61.3	1.19	58.9–63.6	14.361	23.0–92.0
Females						
I	46	21.9	0.65	20.6–23.2	4.435	16.0–40.0
II	79	31.7	1.19	29.4–34.1	10.603	18.0–74.0
III	24	36.5	2.39	31.5–41.5	11.739	20.0–66.0
IV	146	44.3	1.09	42.1–46.4	13.223	22.0–95.0
V	110	55.7	1.74	52.2–59.1	18.210	22.0–101.0
VI	113	59.8	1.94	56.0–63.7	20.619	21.0–102.0
Total						
I	364	20.2	0.19	19.8–20.6	3.647	15.0– 65.0
II	294	28.0	0.54	26.9–29.0	9.286	17.0–78.0
III	119	32.5	0.95	30.6–34.4	10.343	20.0–70.0
IV	532	41.5	0.56	40.3–42.6	12.968	20.0–95.0
V	509	52.5	0.71	51.2–53.9	15.920	21.0–101.0
VI	258	60.6	1.08	58.5–62.8	17.360	21.0–102.0

demonstrates the frequency of female individuals in each age cohort represented by sample. Tables 2 and 3 provide the descriptive statistics for the Balkan and American samples, by symphyseal phase.

Statistical methodology

The purpose of this study was to assess whether population differences in aging, as observed in the pubic symphysis, occurs among American and East European populations and consequently, what age parameters are most appropriate for use in Balkan populations. Variation in the aging processes of East European and American populations was tested and a Bayesian analysis was used to establish accurate age parameters. The probability of age, given a particular phase and probability density functions for estimating the age-at-death distribution was derived from the Gompertz-Makeham hazard parameters estimated from a Balkan reference sample for whom the actual ages-at-death were known. Statistical models used to establish the ages-of-transition were run in the Fortran based program Nphases developed by Dr. Lyle Konigsberg (2003, http://konig.la.utk.edu). Descriptive statistics and general data management were run in SPSS (Systat, 1998). All other statistical procedures were run in the statistical program "R" (http://www.r_project.org).

Models for estimating the ages-of-transition

The models used to calculate the mean, standard deviation, log-likelihood, and standard error of the ages-of-transition for each phase were the unrestricted cumulative probit model for the Balkan male skeletal sample and the log-age cumulative probit model (also known as proportional odds probit analysis) for the Balkan female skeletal sample (17). The ages-of-transition, or what Boldsen and co-workers (17:74) refer to as "transition analysis" is, "an estimation procedure that allows inferences about the timing of transition from one stage to another." These statistics were used to calculate the chi-square for population variation and the probability density functions for estimating individual age. Ideally, the unrestricted cumulative probit model would have been used for both males and females; however the sample size of one ($n = 1$) for phase II among females prohibited its effective use. Unlike the unrestricted cumulative probit model, the log-age cumulative probit model assumes a constant standard deviation on the log scale for all transition distributions.

Testing for population variation

A proportional odds probit regression analysis and an improvement chi-square test were used to test for variation among American and East European populations in the morphological aging process of the pubic symphysis. Proportional odds probit regression analysis was used to compare the aging processes of two populations by measuring the association between the proportion of cases that exhibited a particular pubic symphyseal phase and age for each population (18). The population (American or Balkan sample) was used as a dichotomous dummy variable (0 = American population, 1 = Balkan population). The symphyseal phase was regressed onto the log-age, population, and the interaction between the log-age and population. The model was run twice, once with the interaction term and once without the interaction term, for the total sample, males, and females. An analysis of deviance was used to test the adequacy of the model (18). In the manner of Fox (18), the analysis of deviance was calculated using an improvement chi-square based on the two models. This test compared the observed frequencies of pubic symphyseal phases from both the American and Balkan samples to ascertain whether they contained the same proportion of pubic symphyseal phases conditional on age. The degrees of freedom were calculated as the difference in the number of parameters for the two models.

Bayes' Theorem

The probability that an individual is an exact age at the time of death is estimated from a particular phase conditional on age, using Bayes' Theorem (12,17,19,20). The posterior probability is proportional to the product of the prior probability and the likelihood. Bayes' Theorem can be written as:

$$f(A|S) = \frac{Pr(S|A)*f(A)}{\int Pr(S|A)*\ f(A)} \qquad (1.1)$$

In equation (1.1) Pr(S|A) is the probability of obtaining the observed symphyseal stage from someone who is exactly *A* years old. This probability is found from the probit model. f(A) is a probability density function (PDF) for age, starting at age 15 years (the minimum age we consider) and running to ω, the maximum possible age (for which we take 100 years), which is estimated by fitting a Gompertz hazard model to the known ages.

The Bayesian approach to estimate age is based on a "classical regression" method and thereby avoids the problem of "regression to the mean" (20) where the mean refers to the reference sample. Instead, the method takes the Gompertz-Makeham model as an informative prior.

Hazard analysis

Kaplan-Meier (KM) survivorship analysis is a nonparametric method of calculating life tables that estimates the survival function from ages-at-death. A parametric model, the Gompertz-Makeham (GM) (15,20), was used to estimate the age-at-death distributions and was compared to the Kaplan-Meier survivorship curve to determine whether the hazard model could adequately fit the nonparametric survivorship. The Gompertz-Makeham hazard model has three parameters (α_2, α_3, β_3) and is expressed as:

$$h(t) = \alpha 2 + \alpha_3 \exp(\beta_3 t)$$

$$s(t) = \exp(-\alpha_2 t + \alpha_3/\beta_3(1 - \exp(\beta_3 * t))) \qquad (1.2)$$

where h = the hazard rate, t = age shifted by 15 years, and s = survivorship (20). The 95% confidence intervals were placed around the KM survivorship curves of known ages for each sample. These parameters were used to calculate the distribution of age, f*(age)*.

Estimating individual ages-at-death

A Bayesian approach requires that the distribution of age, f*(age)*, be estimated. This distribution is the PDF. Therefore, the results from a Bayesian analysis are not "point estimates," but rather the posterior distribution. As more cases become available, the posterior distribution changes. However, individual estimates can be obtained from the distribution, and are known as the highest posterior density regions. To estimate the age-at-death for an individual, the highest posterior density regions for each symphyseal phase were calculated (20). These age estimates were based on the GM hazard parameters and the ages-of-transition between one pubic symphyseal phase to the next. The PDF was calculated by multiplying the survivorship to an age with the hazard rate at that age: f(*age*) = h(*age*)*s(*age*); where f(*age*) = PDF, s(*age*) = survivorship, and h(*age*) = hazard rate.

Results

Modeling pubic symphyseal ages-of-transition

The unrestricted cumulative probit model was used to calculate the mean ages-of-transition for Bosnian males. Each line in Fig. 3 represents the normal distribution of one phase transitioning into the next. The varying dispersion of each distribution indicates that the standard deviation for each transition is not constant, reflecting the age variation among phases. The considerable overlap among the phases reflects the wide range of observed ages for each phase. An attempt to use the unrestricted cumulative probit model to calculate the mean ages-of-transition for Balkan females was made (Fig. 4). However, because there was only one case in phase II, the distributions involving this phase were omitted. For comparison, Figs. 5 and 6 illustrate the unrestricted cumulative probit models

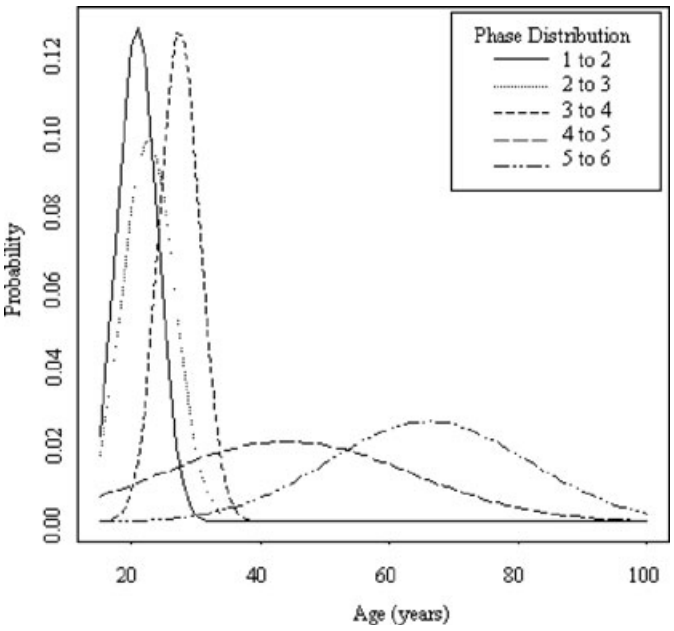

FIG. 3—*Age-of-transition distributions derived from the unrestricted cumulative probit model for Suchey-Brooks phases among Balkan males.*

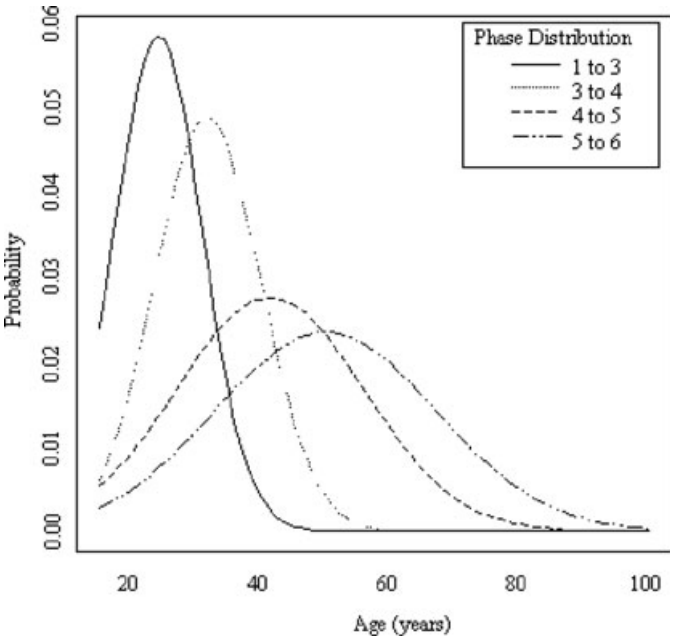

FIG. 4—*Age-of-transition distributions derived from the unrestricted cumulative probit model for Suchey-Brooks phases among Balkan females. Note that the distribution for phase II to III is absent as a result of the small sample size of phase II.*

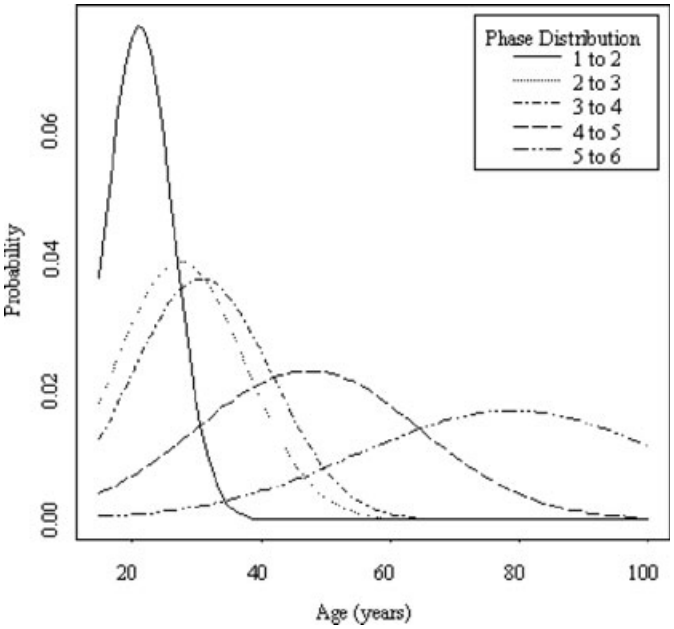

FIG. 5—*Age-of-transition distributions derived from the unrestricted cumulative probit model for Suchey-Brooks phases among American males.*

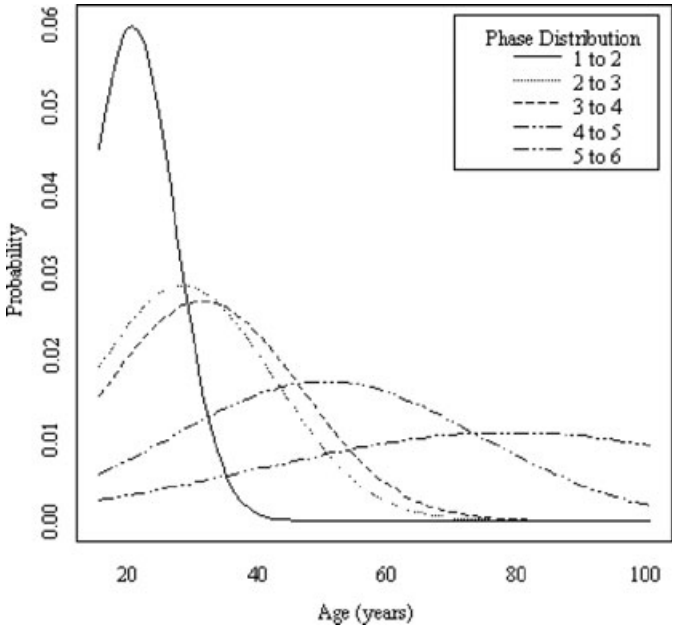

FIG. 6—*Age-of-transition distributions derived from the unrestricted cumulative probit model for Suchey-Brooks phases among American females.*

used to calculate the mean ages-of-transition for American males and females.

Population variation

To test for population variation in the aging process, a proportional odds probit regression analysis and improvement chi-square test were used to compare the aging processes of two populations by measuring the association between the proportion of cases that exhibited a particular pubic symphyseal phase and age for each population (18). There is not a significant association between the aging process of pubic symphyses and population when testing the two populations (df = 1, chi-square likelihood ratio = 3.209, $p = 0.073$). However, when males (df = 1, chi-square likelihood ratio = 0.7428, $p = 0.389$) and females are treated separately, there is a significant association among females (df = 1, chi-square likelihood ratio = 15.071, $p < 0.001$).

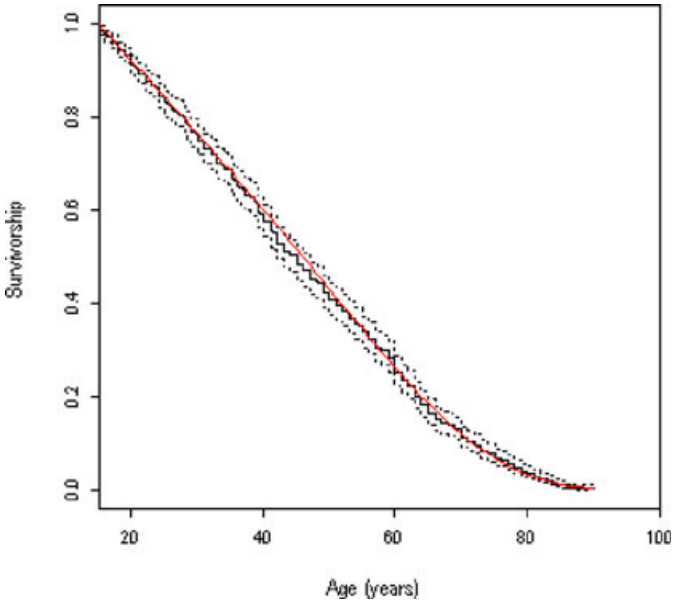

FIG. 7—*Kaplan-Meier survivorship plot for Balkan males. The straight line represents the Gompertz-Makeham hazard curve, estimated from the Balkan reference sample. Survivorship above 15 years of age.*

Hazard analysis

Survivorship analysis comparing the GM hazard models demonstrates that the GM hazard model accurately estimates the population parameters from the Balkan reference sample. Figures 7 and 8 illustrate the survivorship from the GM model for Balkan males and American males, respectively and are plotted against the Kaplan-Meier models. In these figures, the red lines represent the GM survivorship curve. It is demonstrated that the Gompertz-Makeham model is a good fit for the Balkan sample, when a Balkan prior is used. The GM hazard parameters for Balkan males ($\alpha_2 = 0.012482505$, $\alpha_3 = 0.003543657$, $\beta_3 = 0.058074052$) and Balkan females ($\alpha_2 = 0.0140656844$, $\alpha_3 = 0.0003480993$, $\beta_3 = 0.0866711354$) are used to calculate the probability density function for estimating individual ages-at-death. However, a Balkan prior is not a good fit for the American sample. Figure 8 demonstrates that the Gompertz-Makeham model, derived from a Balkan reference sample does not estimate the distribution of the American skeletal samples.

Estimating individual ages-at-death

To estimate age, PDFs for the posterior distributions of age at each symphyseal phase are calculated. The age estimates are based on the calculated age distribution from the GM hazard analysis and the ages-of-transition. To estimate the age-at-death for an individual, the highest posterior density region for each symphyseal phase is calculated. These figures summarize the Bayesian estimates for the probability of age. Four different regions are provided (95%, 90%, 75%, and 50%). Since this is an estimation of the most likely

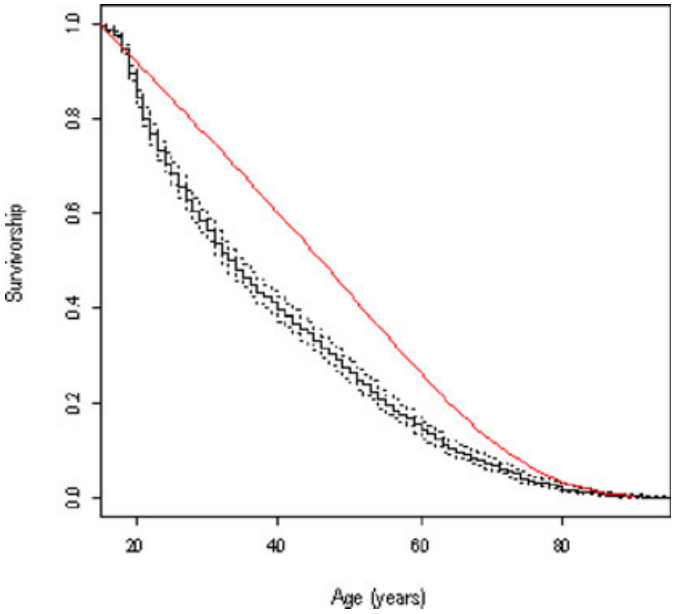

FIG. 8—*Kaplan-Meier survivorship plot for American males. The straight line represents the Gompertz-Makeham hazard curve, estimated from the Balkan reference sample. Survivorship above 15 years of age.*

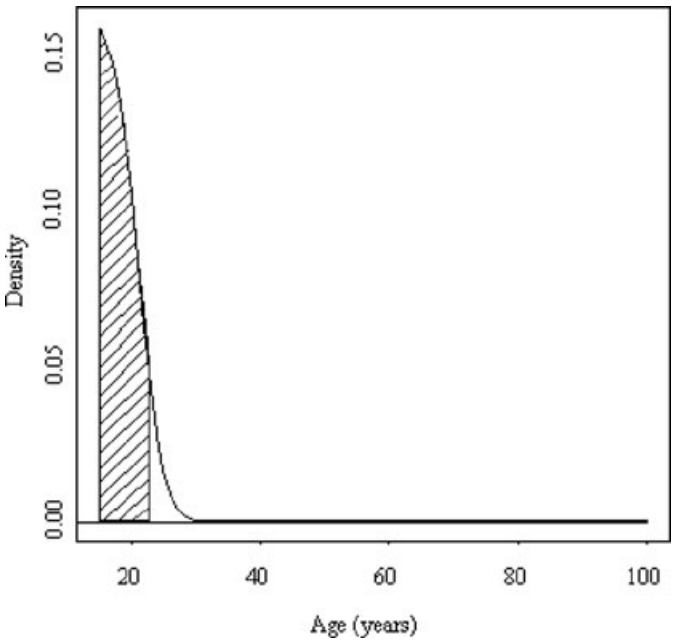

FIG. 9—*Phase I maximum density of age-at-death for Balkan males. Note that because survivorship begins at age 15, phase I is truncated.*

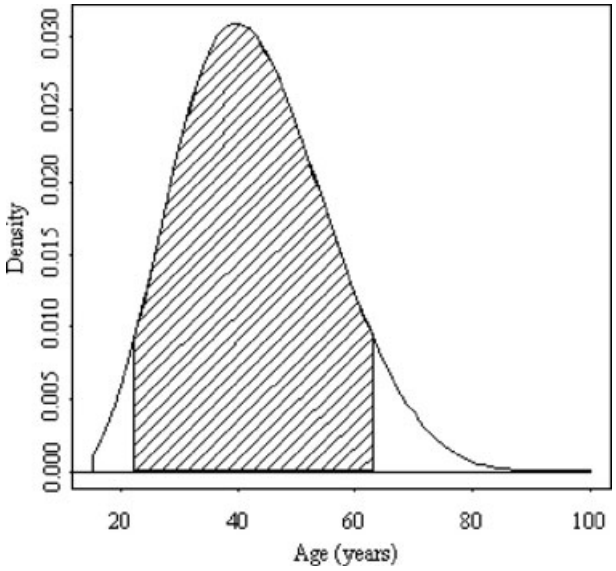

FIG. 10—*Phase IV maximum density of age-at-death for Balkan males, 39.7 years.*

TABLE 4—*Descriptive statistics for Balkan age-of-transition distributions from one phase to the next for males and the total sample based on the unrestricted cumulative probit model.*

Phase	Mean Age (years)	SE (mean)	Standard Deviation
Males			
I to II	20.94	0.81	3.13
II to III	22.65	0.86	4.01
III to IV	27.61	1.42	3.08
IV to V	44.33	1.85	19.16
V to VI	66.18	2.67	15.66
Males and females			
I to II	21.49	0.69	3.50
II to III	22.99	0.70	3.97
III to IV	28.63	1.14	8.76
IV to V	43.53	1.51	17.18
V to VI	61.12	1.61	15.22

TABLE 5—*Statistics for Balkan females using the log-age cumulative probit model.*

Phase	Intercepts	SE (intercepts)	Coefficient
I to II	14.44454	1.9893	4.564325
II to III	15.89327	2.1666	4.564325
III to IV	16.20693	2.2034	4.564325
IV to V	17.02723	2.3080	4.564325
V to VI	17.73458	2.3689	4.564325

age-at-death, not a confidence interval of the mean age, the distributions are asymmetrical (Figs. 9 and 10). Consequently, the youngest individuals, in phase I (also phase II among females) have truncated age intervals beginning at age 15 years, whereas the oldest members of the group in phase VI are given upper and lower bounds (Fig. 10).

Table 4 provides descriptive statistics, including the mean ages-of-transition, standard deviations, and standard errors for each transitional distribution for the total sample and males, using the unrestricted cumulative probit model. Table 5 lists the statistics from the log-age cumulative probit regression applied to Balkan females. In this table the mean log-ages to transition can be recovered by dividing the appropriate intercept by the regression coefficient. For example, the mean log-age of transition between phases I and II is 14.44454/4.564325 = 3.164660711, which on the original scale is exp(3.164660711) = 23.68070807 years. The common standard deviation on log scale is one over the intercept, or 1/4.564325 = 0.219090446 log years.

Tables 6, 7, and 8 summarize the Bayesian estimates for the probability of age, given a particular phase for the total sample, males, and females. These tables associate with the posterior

TABLE 6—*Highest posterior density region for each pubic symphyseal phase ~ unisex standard combining males and females.*

Pubic Symphyseal Phase	Posterior Density (years)	CI (%)	Lower–upper Bound (years)
Phase I	–	95	15.0–24.8
		90	15.0–23.4
		75	15.0–21.1
		50	15.0–18.7
Phase II	23.3	95	16.6–30.1
		90	17.6–29.2
		75	19.2–27.4
		50	20.9–25.7
Phase III	28.0	95	20.0–42.9
		90	20.9–39.5
		75	22.6–35.7
		50	24.6–32.2
Phase IV	39.7	95	20.6–64.6
		90	23.1–61.5
		75	27.4–54.8
		50	32.1–48.3
Phase V	50.9	95	20.8–74.5
		90	25.3–71.6
		75	33.1–66.2
		50	40.6–60.3
Phase VI	67.3	95	39.8–88.7
		90	44.5–85.7
		75	51.8–80.7
		50	58.4–75.4

TABLE 7—*Highest posterior density region for each pubic symphyseal phase among males.*

Pubic Symphyseal Phase	Posterior Density (years)	CI (%)	Lower–upper Bound (years)
Phase I	–	95	15.0–23.9
		90	15.0–22.6
		75	15.0–20.5
		50	15.0–18.4
Phase II	23.2	95	17.4–29.9
		90	18.2–28.9
		75	19.6–27.0
		50	21.0–25.4
Phase III	27.8	95	20.1–41.9
		90	20.9–39.4
		75	22.5–35.4
		50	24.5–31.9
Phase IV	39.7	95	19.9–67.4
		90	22.4–63.1
		75	26.8–55.9
		50	31.7–48.9
Phase V	52.8	95	20.6–76.3
		90	25.4–73.6
		75	33.7–68.3
		50	41.9–62.4
Phase VI	69.0	95	42.3–89.6
		90	47.0–86.7
		75	54.0–81.9
		50	60.5–76.8

TABLE 8—*Highest posterior density region for each pubic symphyseal phase among females.*

Pubic Symphyseal Phase	Posterior Density (years)	CI (%)	Lower–upper Bound (years)
Phase I	–	95	15.0–31.9
		90	15.0–28.6
		75	15.0–23.9
		50	15.0–19.9
Phase II	22.4	95	15.0–38.9
		90	15.0–35.1
		75	16.3–30.6
		50	18.5–26.9
Phase III	26.5	95	15.0–47.0
		90	16.2–43.8
		75	18.7–37.8
		50	21.6–32.6
Phase IV	35.3	95	19.7–66.1
		90	21.4–60.1
		75	24.7–51.2
		50	28.5–43.8
Phase V	44.9	95	26.2–77.9
		90	28.4–72.9
		75	32.2–64.3
		50	36.7–55.7
Phase VI	74.9	95	40.6–93.3
		90	45.5–91.2
		75	54.5–87.5
		50	63.6–83.2

density plots for each symphyseal phase. Through the use of a PDF, the age distribution of each phase is estimated.

Discussion and recommendations

The first step in the identification process is to establish the initial parameters that limit the pool of potential matches, using the sex of the skeletal remains and broad age categories. The second step is to make a presumptive or positive identification and will depend on dental charts, DNA, or other means of linking the remains with the specific antemortem data from a missing person. Within that initial step, the objectives of the investigator may vary such as establishing broad age cohorts for identification or creating a demographic profile for a whole site, all of which may influence how the age parameters are defined. Therefore, the level of CI used to estimate an individual case is left up to the investigator and should be approached on a case-by-case basis. This approach differs from typical forensic casework encountered in the United States but reflects the context of violations to international humanitarian law where the pool of missing persons may include several thousand victims. This approach also enables the anthropologist to quantify their findings and provide a level of certainty to the court, which is important for all scientific standards.

The question of whether American standards for age-at-death estimation will produce reliable aging parameters on an East European population was raised during the legal proceedings of the *Prosecutor v. Radislav Krstić (IT-98-33)*, when Krstić's defense lawyer asked whether "could it be said of the Bosnian population that they develop earlier or quicker?" (21). To investigate this question, variation in the aging processes of the two populations was tested through proportional odds probit regression and an analysis of deviance using an improvement chi-square. While no significant association between the aging process of pubic symphyses and the total population was found, there was a significant association among females and population. There are two possible explanations for this observed population variation. First, it may be that there are biological differences among the populations that affect the aging process of females. Kemkes-Grottenthaler (7) suggests significant biological variation in the aging processes of various populations resulting from environmental differences that affect the metabolic rate such as caloric intake and osteoporosis. The consistent patterns observed for males and females throughout this

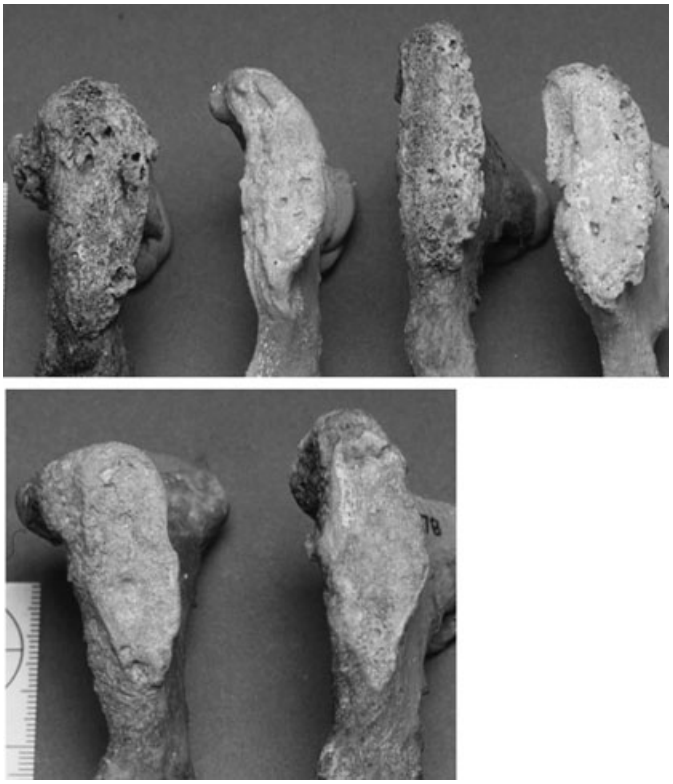

FIG. 11—*Variation in pubic symphyseal morphology among a) females and b) males aged 81–86 years. Morphological differences appear in the presence and amount of porosity, symphyseal lipping, and bone density. Such differences were observed consistently and may provide insight into inter-observer variation.*

investigation suggest these morphological and statistical differences may be attributed to such biological factors (Fig. 11). The question about population variation in aging is a basic question for biological anthropologists. The fact that the question was raised in court, as applied to legal questions about human identification and population demography is important for future applications of biological methods across populations. This study demonstrates that for males, there are no population differences. Among females variation is present and may be attributed to extrinsic factors such as health or diet. Investigators in the field using this method have the added benefit of a Bayesian statistical approach to estimate age and the population's age distribution. Therefore, the estimates presented here have levels of accuracy and reliability that is quantified for the Balkan populations, regardless of the etiology of population or sex differences. So while marginal differences have been found among females from the two populations, a revised calibration for estimating age among both males and females offers the most accurate parameters. Further, the appendix provides a photographic essay of morphological variation of pubic symphyseal morphology at various ages, expanded in range from those illustrated in Fig. 11. This atlas serves to provide a reference for investigators and illustrates the morphological variation at various ages.

Disclaimer

This study does not represent in whole or in part the views of the United Nations but those of the authors.

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Appendix

Atlas of morphological variation of the pubic symphyseal face as a function of age

One of the goals set forth in the collaboration between the ICTY, the Office of the Prosecutor (OTP), and the Forensic Anthropology Center (FAC) at the University of Tennessee, as described in the associated publications in this volume, was to create a photographic essay illustrating the morphological variation of various skeletal traits at different ages. One of the challenges in accurately estimating age-at-death is differentiating morphological features into particular phases. As specific morphological traits gradually change over time, various features may be associated with different ages, making it difficult for the investigator to choose which "phase" is most reflective of the particular bone. The purpose of a photographic essay is to provide investigators with a visual representation of the variation in morphology, observed at different ages throughout the adult life span. Figures A1–A16 demonstrate the variation in morphology observed at different ages for males and females. The morphological variation is demonstrated at different age intervals. This atlas represents human variation and is not dependent on any specific aging methods. Further, the cases chosen were randomly selected for each age cohort.

FIG. A1—*Female pubic symphyseal morphology, ages 20–28 years.*

FIG. A2—*Male pubic symphyseal morphology, ages 15 (left) and 13 (right) years. Note the formation of the upper and lower aspects (left), typical of phase II, present at 15 years of age.*

FIG. A3—*Female pubic symphyseal morphology, ages 30–36 years.*

FIG. A4—*Male pubic symphyseal morphology, ages 25–27 years.*

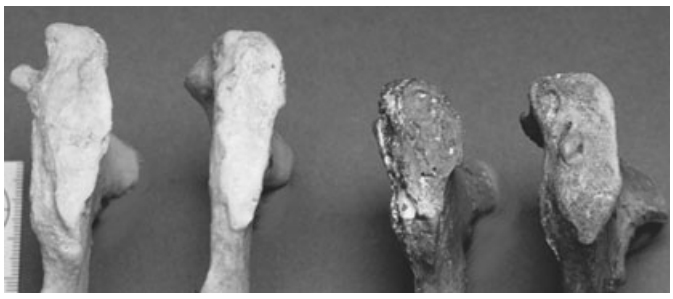

FIG. A5—*Female pubic symphyseal morphology, age 44 years.*

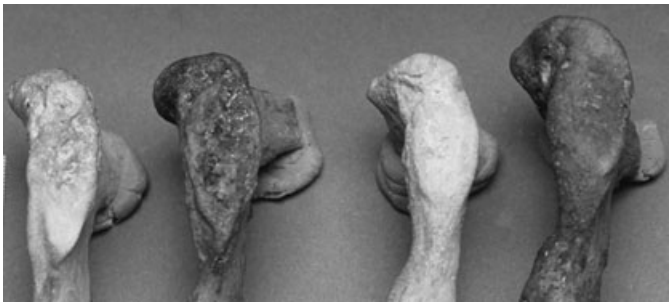

FIG. A6—*Male pubic symphyseal morphology, ages 30–35 years.*

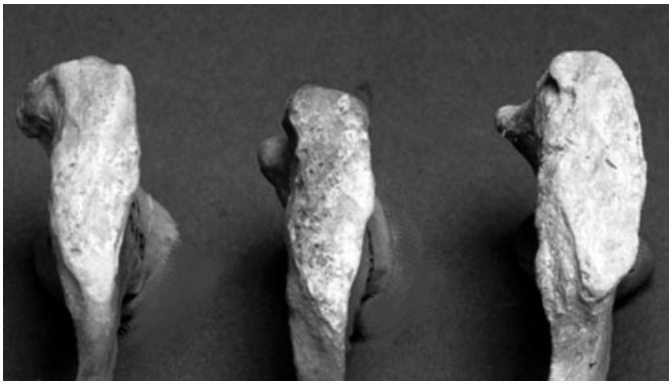

FIG. A7—*Female pubic symphyseal morphology, ages 45–48 years.*

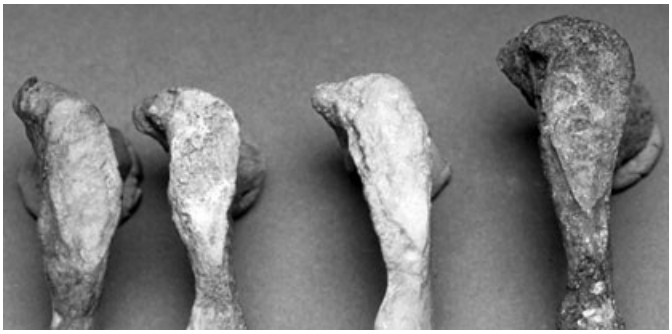

FIG. A8—*Male pubic symphyseal morphology, ages 40–46 years.*

FIG. A9—*Female pubic symphyseal morphology, ages 50–55 years.*

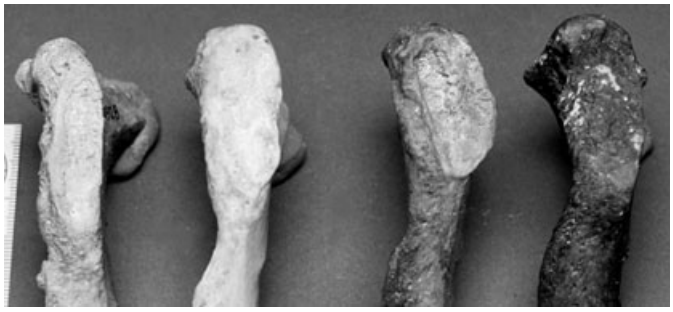

FIG. A10—*Male pubic symphyseal morphology, ages 50–55 years.*

FIG. A11—*Male pubic symphyseal morphology, ages 60–65 years.*

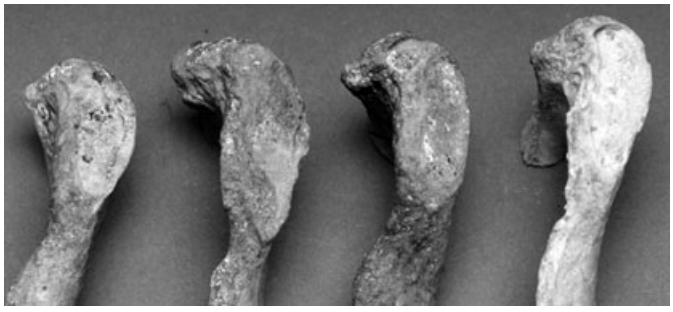

FIG. A12—*Female pubic symphyseal morphology, ages 60–66 years.*

FIG. A13—*Female pubic symphyseal morphology, ages 81–86 years.*

FIG. A14—*Male pubic symphyseal morphology, ages 70–74 years.*

FIG. A15—*Female pubic symphyseal morphology, ages 90–96 years.*

FIG. A16—*Male pubic symphyseal morphology, ages 81–85 years.*