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Age Estimation from the Human Os Coxa: A Test on a Documented Italian Collection*

ABSTRACT: Current standards for age at death estimation from the pelvis are based on Americans of European and African ancestry. Our limited understanding of population variability hampers our efforts to apply these techniques to the various skeletal populations around the world, especially in global forensic contexts. However, documented skeletal samples are rare, limiting our ability to test our techniques. This study tested the Suchey-Brooks pubic symphysis aging method and the auricular surface method originally developed by Lovejoy et al. on a large sample ($n = 404$) of known sex and age from the Sassari Collection, housed at the Museum of Anthropology at the University of Bologna, Italy. The results indicate that for both methods, bias and inaccuracy increased with age and actual age tended to be underestimated over the age of 40. The auricular surface method performed slightly better, exhibiting slightly lower levels of bias and inaccuracy, especially for males.

KEYWORDS: forensic science, forensic anthropology, skeletal age estimation, pubic symphysis, auricular surface

Age at death is an essential biological parameter necessary for the identification of human remains. The most reliable methods for determining age at death from adult skeletal remains are based on the identification of morphological and degenerative changes in bones and teeth throughout life. The rate and degree of change is determined by a complex set of continual interactions between genes, culture, and the environment that contribute to each individual's life history (1). These variable biological and environmental influences occurring during the course of an individual's lifetime have a substantial effect on age at death assessment. Fundamental to all comparative work in skeletal biology is the question as to whether age changes are uniform across populations and researchers have urged testing of these methods in print (2). However, the existing reference samples, which are collections composed of individuals with a known age at death, were used to define many of the original methods and very few other known age at death collections of sufficient sample size exist for testing purposes. This is especially true for collections outside of the United States. Additionally, variation in the aging process increases during the third decade of life between individuals and within a single skeleton (3). The error in age estimation can be quantified only when a method is tested on individuals of known chronological age (3).

Two of the most common locations for examination of the morphological changes related to the aging process are the pubic symphyseal joint and the auricular surface of the ilium. Suchey and Katz (4), Katz and Suchey (5), and Brooks and Suchey (6) present a refined technique for age determination from the pubic symphysis, which was tested on modern autopsied remains from the Los

Angeles County Coroner. They concluded that sex- and population-based differences have a considerable impact on the reliability of the method. However, for American samples, this method (4–6) is considered the best way to estimate the age at death of an individual and is routinely used in forensic and bio-archaeological contexts (7–11). Despite this popularity, age assessment from the pubic symphysis has not received complete support in the literature in studies based on modern French autopsy individuals (12), Canadian pioneers (13), and Portuguese (14), demonstrating biased age estimates and difficulty in determining age of individuals over 35 years.

The age-related changes of the auricular surface of the ilium were described by Lovejoy et al. (15) using American cadaver collections from the early twentieth century. The method was considered advantageous because this region of the pelvis is often preserved in fragmented remains and the morphological changes continue well into the sixth decade of life. Lovejoy et al. (16) argue that the auricular surface exhibits a highly unusual phylogenetic and embryological development with a uniquely prolonged metamorphosis. The auricular surface method has also suffered some criticism, especially when applied to populations outside the United States. Murray and Murray (17) tested the auricular surface aging technique on another American cadaver collection and found significant differences in the age distribution of the reference sample and the estimates obtained with the auricular surface method. Saunders et al. (13) used a small, documented population from Belleville, Ontario and reported overall agreement with Lovejoy et al. (15), but the reliability of the method decreased after age 45. Santos' (14) report on Portuguese individuals found similar results. Using the Grant collection at the University of Toronto, Bedford et al. (18) found that the auricular surface method overestimated the ages of younger individuals and underestimated the ages of individuals over 50 by as much as 5–10 years. The method received some support from Schmitt et al. (1) who reported that in their cross-continental sample the auricular surface worked better as a single age indicator than combining multiple indicators. However, population specificity was mentioned. Even more recently, Schmitt (19) provided a test of both of these methods using a small sample of modern Thai people. The author reported that both pubic

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symphysis and auricular surface methods exhibited bias and inaccuracy that increased with age and that the true age tended to be underestimated. She does not recommend the use of either method on Asian populations.

The research reported here examines the morphological changes with increasing age for both indicators in a blind study on a large, documented collection of twentieth-century Italians. The relative success of each method is evaluated using standard measures of efficiency and bias on a sample with known age at death. These particular techniques were chosen because of their popularity in forensic and bio-archaeological contexts.

Materials and Methods

The Sassari Collection (Sardinia, Italy) is part of the Frassetto collections (Museum of Anthropology, University of Bologna, Italy) (20,21) and it consists of 606 complete well-preserved skeletons of individuals who died in the first half of the twentieth century that were exhumed from municipal cemeteries. The cemetery registers provide the sex, age, and date of death of most individuals and in many cases their date of birth and occupation. In particular, the age-at-death is documented for 253 females and 312 males (21). It is very rare to find such a large, well-documented collection that may be used for testing or developing identification standards.

The study sample consists of 404 adult individuals for which pelvic indicators of age could be scored. For the ilia, the sample consists of 204 males aged 18–86 (mean age = 48.5 years) and 200 females aged 17–98 (mean age = 45.1 years). Slightly fewer pubic symphyses remained intact (*n* = 390) although the age ranges were identical for each sex (male mean = 47.6 years, female mean = 44.5 years). The age distribution of the sample is shown in more detail in Table 1. Sample sizes were excellent. Juveniles, as indicated in the accompanying documentation and by epiphyseal fusion, unsexed individuals, and pathological cases were excluded.

Both left and right sides were scored where available. Paired *t*-tests revealed no significant side differences for the pubic symphysis for males and females (males: *p* = 0.286, *df* = 194; females: *p* = 0.386, *df* = 167). For the auricular surface, no significant side differences were found in males (*p* = 1.85, *df* = 195). However, a significant difference was found between sides for the females (*p* = 0.00046, *df* = 195) indicating that variability exists between the sides. The left side was used for all analyses and the right side was used as a substitute when the left was unavailable. In reconstruction of past populations, age identification typically focuses on mean values. The pubic symphysis technique reports mean values for each age interval (4), while the midpoint of each age interval was used for the auricular surface method. For both methods, when morphologic phases were different between left and right sides, the mean age between both sides was calculated.

All individuals were examined for age-related changes of the *os pubis* and assigned to one of six phases as defined in the literature

TABLE 1—Sample age distribution.

Age Interval	Pubic Symphysis		Auricular Surface	
	Males	Females	Males	Females
17–29	36	51	38	57
30–39	34	36	35	40
40–49	37	36	39	37
50–59	37	19	38	20
60+	58	46	54	46
Total	202	188	204	200

(4–6). Additionally, individuals were assigned into one of eight phases according to the auricular surface aging system (15). All skeletal remains were initially handled by a student assistant, and actual age was unknown to the single, experienced observer (SH) maintaining a blind study.

Reliability for both methods was tested using standard measures of bias and inaccuracy (following current studies, e.g., 14, 17, 19). Bias is the mean over- or under-prediction, i.e., $\Sigma(\text{estimated age} - \text{actual age})/n$; whereas inaccuracy is the average absolute error of age estimation, without reference to over- or under-prediction, i.e., $\Sigma|\text{estimated age} - \text{actual age}|/n$. Correlation between stage and age was also calculated for each method. All statistical analyses were run using Microsoft Office Excel, 2003 (Microsoft Corp., Redmond, WA).

Results

The overall correlation of pubis symphysis stage with age is 0.64 for males and 0.50 for females, suggesting there may be large amounts of variability within each stage. Table 2 presents the results for bias and inaccuracy by age interval and sex for the Suchey-Brooks method. The degree of bias and inaccuracy generally increases with age. Up to age 39, there is almost no bias in age estimation for males, and females show almost no bias up to age 29. There is a shift in both sexes from slight overestimation of age to underestimating age after age 40. Age predictions over age 60 are drastically underestimated. While overall inaccuracy is similar for the sexes, females show less bias than males in the older age categories and overall. Figures 1 and 2 graphically

TABLE 2—Bias and inaccuracy from the Suchey-Brooks pubic symphysis age estimates.

Known Age	Males			Females		
	<i>n</i>	Bias	Inaccuracy	<i>n</i>	Bias	Inaccuracy
17–29	36	0.6	4.9	51	1.1	4.0
30–39	34	−0.0	7.3	36	6.3	10.5
40–49	37	−7.8	8.9	36	−2.8	8.2
50–59	37	−13.8	14.4	19	−9.1	12.3
60+	58	−25.2	25.2	46	−32.0	32.0
Overall	202	−11.1	13.6	188	−7.8	13.8

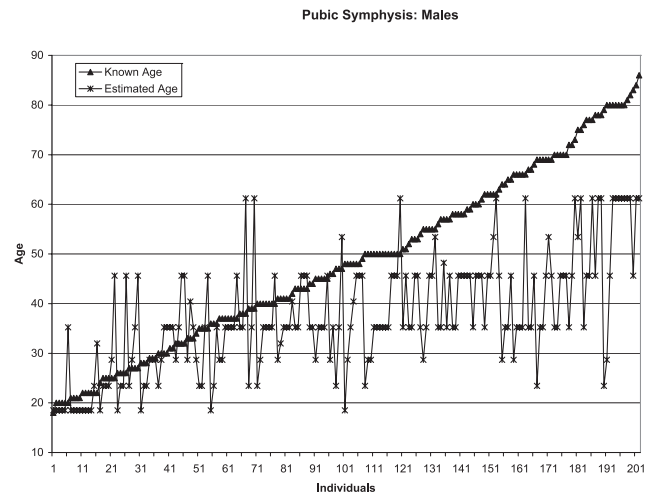


FIG. 1—Comparison of known age and estimated age for each male pubic symphysis. Degree of over- or under-prediction may be seen in estimated points that fall over or under the known age line of points.

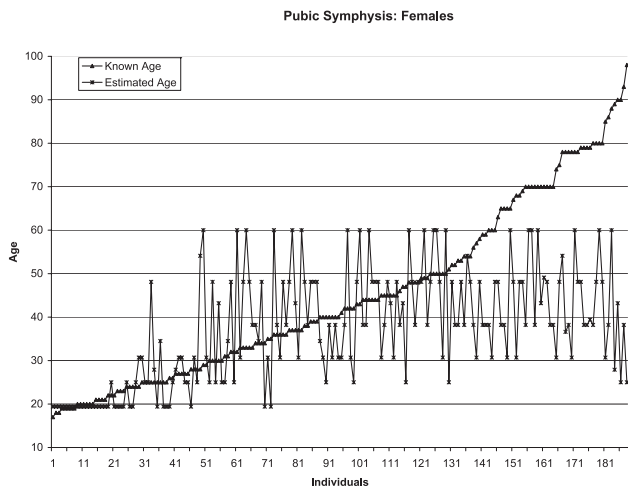


FIG. 2—Comparison of known age and estimated age for each female pubic symphysis. Degree of over- or under-prediction may be seen in estimated points that fall over or under the known age line of points.

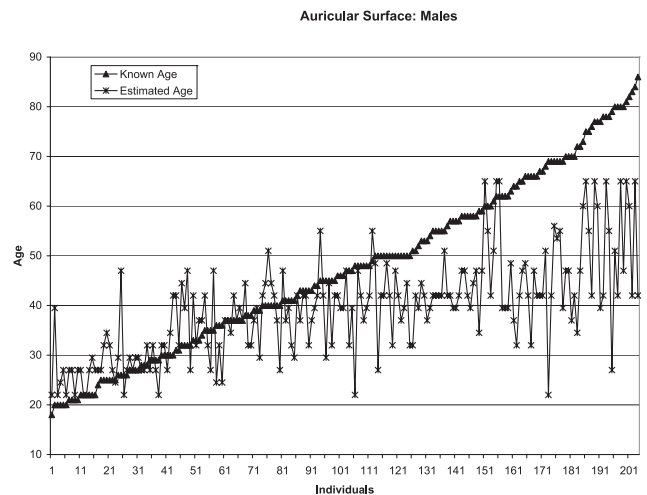


FIG. 3—Comparison of known age and estimated age for each male auricular surface. Degree of over- or under-prediction may be seen in estimated points that fall over or under the known age line of points.

TABLE 3—Bias and inaccuracy from the Lovejoy *et al.* auricular surface age estimates.

Known Age	Males			Females		
	<i>n</i>	Bias	Inaccuracy	<i>n</i>	Bias	Inaccuracy
17–29	38	3.5	4.4	57	3.8	4.6
30–39	35	1.3	5.4	40	3.2	7.4
40–49	39	–4.1	6.5	37	–5.9	9.1
50–59	38	–12.3	12.3	20	–12.5	15.4
60+	54	–22.8	23.1	46	–29.3	29.3
Overall	204	–8.2	11.4	200	–7.4	12.8

display these results. Each individual pubic symphysis is plotted on the graph with the known age and the estimated age so that the degree of bias and inaccuracy may be visualized.

The overall correlation of stage with age for the auricular surface method is slightly higher than for the pubic symphysis, 0.67 for males and 0.55 for females (0.55 for left side, 0.56 for right side). The degree of inaccuracy and bias are presented in Table 3. There is a general increase of each with age. Similarly to the pubic symphysis method, the ages from the auricular surface are slightly overestimated for both sexes under age 39, but are increasingly underestimated over age 40. The poor results for the oldest age category may be temporized by the fact that the midpoint of the age interval was estimated at 65 years, although in the original study, the final age category was 60+ years of age, with no upper limit. This may be represented by increasing underestimation of ages for the oldest individuals. However, in comparison with the pubic symphysis results, the auricular surface shows less bias and inaccuracy over age 40 for both sexes and overall, especially for males. Figures 3 and 4 graphically display these results. The known age and estimated age is plotted for each individual auricular surface. The degree of over- or under-prediction may be visualized.

Discussion

In this study, two common aging methods were assessed for bias and inaccuracy on a large, well-documented sample from Sardinia (Italy). The advantage of the large sample cannot be

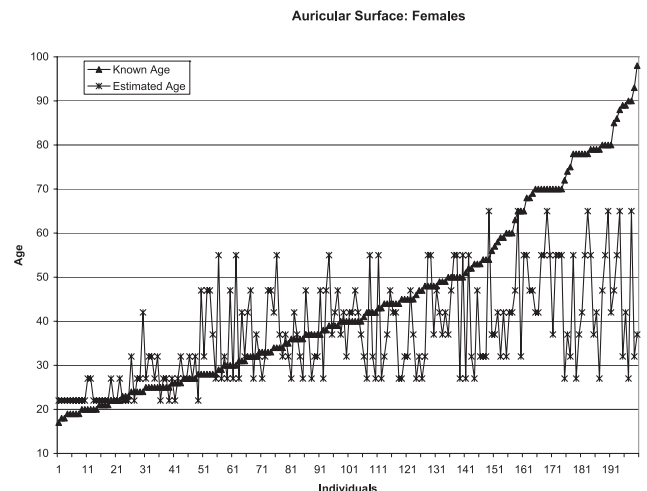


FIG. 4—Comparison of known age and estimated age for each female auricular surface. Degree of over- or under-prediction may be seen in estimated points that fall over or under the known age line of points.

overstated. Each sex and age interval was well represented by a large number of cases. While asymmetries were found between left and right sides in both techniques, they were nonsignificant for the pubic symphysis and significant only for the female auricular surface scores. However, correlations of stage with age for the female auricular surface were nearly identical for left and right sides.

The Suchey-Brooks pubic symphysis scoring technique performed quite well for the youngest age interval, 17–29. Measures of inaccuracy were off by 7–10 years for the 30–39 age group; however, bias was especially low for males while female ages were overestimated by up to 6 years. After age 40, ages for both sexes were underestimated, especially so for the oldest age group. The Italian sample used here showed lower levels of bias and inaccuracy overall than the Thai sample used by Schmitt (19) and the male Canadian sample (13), although the inherent trends described were similar. Considering that the ventral rampart of the pubic symphysis fuses by age 35, this leaves only degenerative changes afterwards (3), which are much harder to interpret and are likely to

show considerable variation because of lifestyle, environment, and genetics of the population (13).

The age estimation method using the auricular surface overestimated ages of individuals up to 39 years by *c.* 1–4 years. Subsequently, ages for middle and older adults were underestimated, exhibiting a 12-year bias in the 50–59 age category and a 23+ year bias over age 60. As mentioned previously, this bias in the oldest category partially reflects the low mean age calculated for the interval indicating that bias is likely not as severe in the oldest age group as that reported here. While seriation is considered an excellent technique, severe space limitations precluded our ability to seriate the ilia as suggested by Lovejoy et al. (15). However, this is not considered a serious drawback to the method as it was utilized here as space limitations are quite common, inhibiting most researchers for carrying out this technique. Additionally, individual forensic cases obviously cannot be seriated, thus the ability of the auricular surface to accurately estimate age without seriation is relevant. The original auricular surface method for estimating age as described by Lovejoy et al. (15) did perform slightly better overall than the Suchey-Brooks method, demonstrating slightly more accuracy and less bias. The values for bias and inaccuracy for the Italian sample were higher than those reported for combined sexes in the Canadian sample (13), but lower than those reported by others for the Terry Collection (17) and Thai (19), which could potentially be because of the observer's familiarity and experience with the method. The results of this study support the conclusions of other studies that compared the two methods on one population (13,18,19) finding that the auricular surface method performed better than the pubic symphysis method, especially in older age ranges.

The changes to the auricular surface with age are more complex than those occurring in the pubic symphysis and exhibit a subtlety that many inexperienced observers may find challenging to identify. The revised method of Buckberry and Chamberlain (22) has the potential to ease scoring of the auricular surface changes and decrease interobserver error, potentially improving age estimation. Analyses of this method on the Italian sample are currently underway.

This study confirms the work of previous researchers that indicates the age/indicator relationship is variable between populations from different geographic areas. The morphologic changes because of the aging process differ between samples due to genetic and nongenetic factors, supporting the claim that a single standard of senescence for populations of different origins is not appropriate (19) and population models are absolutely necessary.

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