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Age at Death in the Human Skeleton: A Combined Analysis of Four Phase-Based Aging Systems to Determine Effieciency and Accuracy in Multifactorial Age Range Assignments

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AGE AT DEATH IN THE HUMAN SKELETON: A COMBINED ANALYSIS OF FOUR PHASE-BASED AGING SYSTEMS TO DETERMINE EFFICIENCY AND ACCURACY IN MULTIFACTORIAL AGE RANGE ASSIGNMENTS

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Abstract

Analyses of human skeletal remains by physical anthropologists in the contexts of both modern forensic cases and archaeological populations necessitate precise methods for the determination of age at death. Physical anthropologists have long recognized that the most accurate estimation of age at death will be produced from evaluation of multiple indicators of age in the skeleton. To this end, three skeletal sites, the auricular surface, pubic symphysis, and right fourth sternal rib end, which show progressive metamorphic changes throughout life, are often evaluated for age in adult skeletal remains. However, as of yet, no statistically based method of combining the sometimes different estimates of age provided at these sites has been reported.

The auricular surfaces, pubic symphyses, and right fourth sternal rib ends of 49 females and 77 males from the Hamann-Todd collection were evaluated for age at death. Using regression analyses, the relationship between the estimates of age provided through evaluation of the skeletal sites and actual age was assessed. Furthermore, regression analyses were used to combine the estimates of age in an effort to provide an accurate estimate of age at death.

Results of the regression analyses show that a relationship exists between the respective estimates of age provided at each site and actual age. The values of R for regressions on the male and female samples reflect an 85% and 90% correlation between the actual ages of individuals and the predicted ages resulting from combination of the respective estimates through linear regressions. However, the large predicted age ranges associated with predicted ages make the results of the regressions questionable for forensic use. Although mean absolute differences between the predicted and actual ages

for the male and female samples are low, 4.35 and 5.62 years, respectively, the large maximum absolute differences demonstrate the vast amount of variability possible in indicators of age in the human skeleton.

An exception to the problem of large predicted age ranges produced through regression analysis occurred for the sample characterized as young adult males. This group showed both narrower predicted age ranges of roughly 11 years and a maximum absolute difference between actual and predicted age of 8.43 years. However, none of the other sectioned samples showed similar results, making the method useful for only a small sample of human skeletal remains submitted for analysis.

Regression analyses performed after the removal of outliers on samples divided into young and mature adults did provide more accurate estimates of age at death and smaller more useful predicted age ranges. However, use of these models requires that outliers be recognizable in a laboratory context without comparative data, which may not be practical.

Ultimately, the possibility of using additional skeletal indicators of age at death could serve to narrow the predicted age ranges provided by regression analyses. This research question should be addressed in future studies.

Introduction

Analysis of human skeletal remains by physical anthropologists in the contexts of both forensics and skeletal biology necessitates accurate methods for the determination of age at death. In a forensic context, age at death is a key descriptive element in the identification of an unknown individual (İşcan et al. 1984a,b). The skeletal biologist may use age at death in analyses of paleodemography, estimation of morbidity and mortality rates, or to make inferences about the health and stresses of different groups within a population (Brooks 1955). To this end, methods for accurate estimation of age at death have remained a central investigative concern among physical anthropologists for the span of the last century.

While evaluation of dental development, epiphyseal closure, and long bone growth can provide reasonably precise estimates of age in subadults (Bass 1995; Brooks 1955; Todd 1920), evaluation of age in adult individuals is more difficult. The problem arises from the vast amount of variation in the aging process that stems from numerous internal and external factors (İşcan 1997). Destruction or loss of skeletal elements due to perimortem and postmortem trauma, disturbance, and natural taphonomic processes further complicates age assessment for adult remains. Damaged or incomplete skeletal remains constitute a substantial portion of the samples submitted for analysis (İşcan 1997; Lovejoy et al. 1985b). Therefore, there is a demand for a variety of age assessment methods that can be applied to disparate areas of the skeleton.

In response to these issues, physical anthropologists have evaluated a number of age-related conditions that occur throughout the skeleton and, hence, numerous techniques have been devised for age determination. However, owing to variation in the expression of age-related changes observed in the human skeleton, several of these techniques have been proven unreliable (Brooks 1955; Meindl et at. 1985). Indicators such as endo- and ectocranial suture closure and dental wear patterns can be used to substantiate assessments of age at death, but are too variable within populations to provide accurate estimates of age (McKern and Stewart 1957; Todd 1920). Other, more reliable methods such as cortical bone histology require the destruction of bone, as well as specialized training and equipment, making these methods less desirable to some practitioners. Currently, physical anthropologists frequently rely upon methods that evaluate progressive metamorphic changes at three disparate sites in the human skeleton to determine age at death. These methods are applied to the right fourth sternal rib end, the pubic symphysis, and the auricular surface.

A recurrent theme reported almost universally by researchers in age-at-death studies is the necessity of utilizing several methods for accurate age assessments (Bedford et al. 1993; Brooks 1955; Katz and Suchey 1986). Dubbed “multifactorial analysis” by Lovejoy and colleagues (1985a), physical anthropologists recognize that age assessment will be most successful if multiple age indicators are utilized. The pubic symphysis, auricular surface, and right fourth sternal rib end tend to be the most prominently relied upon indicators. However, as of yet, there has been no statistically based methodology suggested for correlating respective estimates of age at death from these three sites into a single precise age range. In an idealized skeleton, the respective estimates from the three sites would show considerable overlap and correlate closely. Yet, due to the extensive amount of variation in the human skeleton and the effect of this variation on indications of age, respective age estimates from these sites can differ, showing limited overlap or none at all. Therefore, a system for correlating respective estimates is prudent. The purpose of the current study is twofold. First, the relationship, if any, between the estimates of age at death provided through evaluation of each site will be assessed. Secondly, the researcher will examine a statistical approach for combining the respective estimates, based on said relationship, to ultimately provide the most accurate estimate of age at death.

Literature Review

Todd (1920) initially described the pubic symphysis as a site suitable for age determination. Based on observations of 306 specimens housed at the Western Reserve University, Todd described, at length, regular metamorphic changes at the symphysis, which he separated into 10 progressive model phases. Each phase corresponds to a period of age and, hence, has a related age range based on the actual ages of the specimens in which he observed these conditions. Todd published descriptions of the criteria distinguishing the phases along with illustrations of model standards for each phase. The Todd system is then applied by matching observations of a pubic bone to the appropriate criteria and illustration to determine the phase. The corresponding age range is then assigned to the specimen in question.

Todd (1921a,b,c) evaluated separately black males, white females, and black females to determine if race and sex affect the progression and appearance of age-related changes initially observed in white males. With regard to race, Todd (1921a: 26) concluded that, "stock [race] has strikingly little influence upon pubic metamorphosis." Differences were noted for female specimens, namely a slightly accelerated schedule of age-related changes. However, Todd noted that the small sample size (47 white females) was too limited to make final judgment of the sex factor (Todd 1921b). Further, differences were of such a limited nature that Todd did not require a separate set of model phases for the groups.

Since the development of pubic symphyseal aging by Todd (1920), the pubic symphysis has retained wide acceptance as a site appropriate for age assessment in human skeletal remains. However, beginning in the 1950s, researchers testing the Todd method reported problems. Brooks (1955) evaluated Todd's method for pubic symphyseal aging along with cranial suture closure. She identified a trend to overage individuals using Todd's method, and suggested modifications to the technique to correct for this tendency.

McKern and Stewart (1957) devised a three-component system to be applied instead of Todd's ten-phase system. Their system combined nine of the central features identified by Todd (1920) into three major components. The procedure outlined by the authors provides that the development of each of the three components be graded on a one to five scale. The scores are then discriminately weighted to derive a likely age range. In this manner, the authors sought to circumvent the typological approach of the Todd method. Because Todd based his age ranges on a developmental process that he considered typical, any pubic symphyses showing a varied condition could not be accurately aged. The three-component system allows for any combination of development for key features, and, therefore, alleviates this problem.

Gilbert and McKern (1973) reported that age related changes to the female pubic symphysis differed significantly from those of males in both rate and locality. These researchers suggested a separate standard for aging female pubic symphyses to be used in conjunction with a three-component system equitable to that developed for males.

Suchey (1979) tested the Gilbert-McKern method for aging the female pubic symphysis. The study required 23 professional forensic anthropologists to age 11 pubic bones using the method. Responses varied widely among the anthropologists and only 51% of the responses proved accurate. Suchey concluded that the variation and inaccuracy in the responses stemmed from difficulties in understanding and applying the complex method.

Katz and Suchey (1986) evaluated both the Todd (1920) and McKern and Stewart (1957) methods utilizing a large sample of pubic bones from 739 males assembled by the County of Los Angeles Medical Examiner-Coroner's office. The researchers reported problems with both methods. Namely, the Todd system tended to overage individuals and was developed on a sample highly skewed toward older individuals. Furthermore, Katz and Suchey (1986) argued that the Western Reserve (Hamman-Todd) collection comes from an indigent population with highly questionable age documentation. Therefore, actual age for these individuals may not be certain, making the population unsuitable for development and testing of an age evaluation method. The sample utilized by McKern and Stewart (1957) originated from military males of the Korean War; so age documentation of this sample was found to be acceptable by the researchers. However, contrary to the concerns with the Todd sample, the McKern and Stewart sample was highly skewed toward young males in their twenties. Furthermore, Katz and Suchey (1986) note that the three-component system suggested by McKern and Stewart is more difficult to utilize and that both systems are ill equipped to deal with age variability in advanced pubic bone patterns.

Instead of these systems, the researchers suggest a modified Todd system that reduces the ten original Todd phases into six model phases (Katz and Suchey 1986). Like the Todd system, the system suggested by Katz and Suchey provides corresponding age range assignments for each phase. However, Katz and Suchey differ from Todd's original format in that the age range assignments contain a significantly greater number of years and, in that, there is great overlap in the years assigned to each phase (Table 1). These differences occur because the methodology used by Katz and Suchey to define their phases differed significantly from that of Todd. Todd defined his model phases morphologically based on observations of pubic symphyses and then assigned the corresponding age ranges based on the actual ages of the individuals found to be contained in those phases. However, Todd discarded any individuals that varied significantly from the typical development found in each phase. Hence, if the typical age range for individuals found to show the criteria of phase 7 was 35-39, and a specimen with that condition was actually 53, Todd would remove the individual from the sample. He then reported that the specimen was retarded or accelerated in his development. Katz and Suchey, in an effort to account for the total variability observed in their sample, included all individuals, regardless of age, and only truncated the sample by 5% to construct a 95% range. Therefore, the full range of variability they observed is mirrored in their age range assignments.

Table 1- Phase and Age Ranges for Suchey-Brooks and Todd Systems

	Suchey-Brooks Phase	Suchey-Brooks Age Range	Todd Phase	Todd Age Range
	1	15-23	1	18-19
	2	19-34	2	20-21
	3	21-46	3	22-24
	4	23-57	4	25-26
	5	27-66	5	27-30
	6	34-86	6	30-35
			7	35-39
			8	39-44
			9	45-50
			10	50+

Suchey and colleagues (1988) provided a separate set of phase models and descriptions for female specimens developed from a sample of 273 pubic bones taken at autopsy from people of know age. The study followed the same methodology utilized in the previous male study. The researchers report that the female sample differed importantly from the male sample in morphology, as well as age progression. While both sexes show parallel changes that can be sectioned into a six-phase system, the female sample demonstrated advanced ages for each phase compared to the males. Therefore, a separate set of models and corresponding age ranges was suggested for female specimens. Additionally, Katz and Suchey (1989) identified racial differences for age assessment of male pubic bones. Discrepancies in the age-related metamorphoses of the pubic symphysis are reported for three racial groups analyzed: white, black, and Mexican. The researchers suggest that appropriately modified age range assignments be utilized in conjunction with phase assignments.

There are problems resulting from Katz and Suchey's methodology when the system is put into practice. Essentially, the large age ranges that are provided are not inherently useful, because they are too wide to be of any descriptive use. Katz and Suchey (1986, 1989; Suchey et al. 1988) provided a mean age for each phase in addition to the age ranges. These means can roughly be equated with successive decades of life, following about age 18. Therefore, some forensic anthropologists have adopted a practice of constructing an age range about this mean that is more suitable for their needs. However, there is no statistical basis for this practice, nor is it recommended or condoned in the literature. Conversely, Katz and Suchey report that the method's usefulness in assessing age is limited to the first two phases which have relatively narrow age ranges compared to the latter phases (Katz and Suchey 1986). They further report, "Failure to note modern variability may result in failure to identify a forensic case" (Suchey et al. 1988:8).

Lovejoy and colleagues (1985b) suggested a method for the evaluation of age at death from metamorphic changes in the auricular surface of the ilium. The researchers proposed formal phase categories for the changes designated in the study corresponding with eight successive age ranges. Young adults are characterized by an undulating auricular surface that becomes progressively smoother with advancing age. Eventually, the smooth surface becomes porous with bony lipping at the edges (Lovejoy et al. 1985b). Lovejoy and colleagues performed tests of the method in the same article and reported accuracy for the technique equivalent to systems for pubic symphyseal aging, which are widely utilized. However, the researchers point out that the technique is more complex than pubic symphyseal aging and is harder to apply. Benefits of this technique include higher preservation rates of the auricular surface over those for the pubic symphysis and the capacity for application of the technique beyond the fifth decade of life.

In 1984, İşcan and colleagues first proposed a phase technique for the determination of age from the right fourth sternal rib end. Drawing from radiographic, histologic, and osteological studies, İşcan noted definite age related changes at the rib's sternal end (İşcan et al. 1984a,b). İşcan and colleagues used component analysis to associate observed changes in pit depth, pit shape, and rim configuration. Finally, the researchers applied phase analysis to show the progression of these metamorphic changes. The method was tested by İşcan and Loth (1986a). Using the proposed phase method, 25 physical anthropologists evaluated 15 ribs. Interobserver error was evaluated with consideration for level of expertise and found to be minimal. Accuracy of the method was reasonably good, with most observations scoring within one phase of the correct age.

İşcan et al. (1985) further tested for disparities between the sexes in the progression and appearance of the metamorphic changes. Using a sample of 86 female skeletons of known age, İşcan and colleagues noticed a difference in both the rate and pattern of metamorphic change. The phase models were then appropriately modified and alternate descriptions and photographs were submitted for comparative analysis in female specimens. İşcan et al. (1986b) performed a test of the method following the methodology utilized in the male test. Results of the test were almost identical to those for the males, showing minimal interobserver error and phase assignments within one phase of the correct age.

A final study analyzed the possibility of differences in rib metamorphosis between races (İşcan et al. 1987). The techniques developed previously concentrated on all white samples. The analysis of an American black sample revealed identical results in phases one through four, but varied after the age of twenty toward accelerated changes in the sternal rib aspect. Contrary to these results, however, a test performed by Russell et al. (1993) showed a non-significant trend for delayed changes in black individuals.

Materials and Methods

Skeletal materials utilized for the study were selected from the Hamann-Todd collection housed at the Cleveland Museum of Natural History. Due to concerns voiced by previous researchers in age at death studies about the validity of age at death documentation for Hamann-Todd specimens (Katz and Suchey 1986), I took care to evaluate case information in collection files. Following Meindl and collegues' (1990) methodology for selecting specimens with appropriate age at death confirmation from this collection, I chose only individuals for whom Todd noted that "stated age is most probably or certainly correct." Further preference was given to specimens with hospital, sanitarium, or city hall records. This researcher feels that this procedure for screening potential specimens should act to waylay concerns centered on the accurate nature of age information for comparative purposes.

This researcher made efforts to select equal numbers of male and female specimens, with equal numbers of black and white individuals for each sex. Due to concerns that the collection is heavily weighted toward older individuals (Katz and Suchey 1986), I chose equal numbers of specimens for each decade of life, beginning at age 20 and terminating at age 70. Therefore, my initial goal was to create a sample with 100 individuals of each sex, 50 of each race within each sex, and 10 within each decade of life for these four subcategories. Ultimately, my target sample size would total 200 individuals. However, due to difficulties in meeting acceptable age documentation, as well as problems with preservation of skeletal materials (particularly the right fourth sternal rib end), the final sample contained fewer specimens than originally sought. A breakdown of the final sample is shown in Table 2.

Table 2- Sample Distribution by Age, Sex, and Race

	20-29	30-39	40-49	50-59	60-69	Totals
Black Male	11	10	10	3	6	40
White Male	8	10	8	7	4	37
Black Female	8	10	6	1	3	28
White Female	5	5	7	3	1	21
Totals	32	35	31	14	14	126

After choosing the sample, I selected the innominates for the male specimens and covered the pubic symphyses and auricular surfaces with aluminum foil. Care was taken to prevent knowledge of actual age for the specimens, so that observations of these sites would be made blindly. I began by evaluating all pubic symphyses by both the Todd (1920) and Suchey-Brooks systems. Both left and right sides were evaluated for each individual. Most specimens scored identical phases for the left and right sides. However, when discrepancies occurred, the researcher made notes of the respective conditions and a final judgment for the individual into a phase was recorded. With regard to age range assignments, male specimens evaluated by the Suchey-Brooks system were assigned two age ranges, the first corresponding to refined data reported for males (Suchey et al. 1988) and the second corresponding to the race-specific data (Katz and Suchey 1989). Upon completion of the evaluation of all male pubic symphyses, this researcher replicated the process with the auricular surfaces, using the appropriate models provided by Lovejoy et al. (1985b). Subsequent to assessment of all auricular surfaces, the right ribs for each specimen were assembled. A determination of the fourth rib was made for all individuals, and these were evaluated following the İşcan et al. (1984a, 1984b) method.

No consideration was given to ribs other than the right fourth. Again, the appropriate phase and corresponding age range were recorded for each specimen. This methodology was then repeated for the female specimens.

SPSS was used in the statistical analysis. Linear regressions were performed using each of the four estimates of age as predictor variables and actual age as the dependent variable. The regressions performed were specific to sex, since both the Suchey-Brooks and İşcan systems require sex-specific evaluations. However, the sample was not segregated by race for the purposes of performing linear regressions. In instances where the race-specific Suchey-Brooks system was applicable, that data was substituted for regression analyses. Because regression analysis does not permit use of age ranges as variables, the mean age for each phase assignment was substituted. The mean age provided by the Suchey-Brooks system is based on the actual ages of individuals from that sample with respect to phase. The İşcan system reports mean ages within the 95% confidence intervals for each phase. Means for both the Todd system and Lovejoy system were calculated by this researcher by taking the average for each age range for the respective phases.

Further regressions were performed to test the effect of utilizing only three of the four systems in different combinations. Therefore, four regressions were performed by excluding a single variable from each model. Again, the analyses were sex specific, but samples were not divided by race.

Results

The results of regressions for the female sample are summarized in Table 3. Test numbers distinguish each of the five regressions and these titles are maintained for all regressions reported in this manuscript. Test 1 is the regression of all four systems. Test 2 is the regression of all variables excluding the Todd system. Test 3 includes all variables excepting the Suchey-Brooks data. Lovejoy data are omitted in Test 4. Finally, the İşcan data are excluded for Test 5.

Table 3- Results of Regression Analysis on Female Sample

		Test 1	Test 2	Test 3	Test 4	Test 5
	R	.848	.839	.848	.837	.836
	Std. Error of the Estimate	6.77	6.89	6.70	6.93	6.94
Unstandardized Coefficients	**B- (constant)**	-5.785	-3.903	-5.506	-3.181	-4.939
	B- Suchey-Brooks	-.152	.574	N/A	-.227	-.217
	B- Todd	.842	N/A	.678	1.028	.988
	B- Lovejoy	.253	.300	.257	N/A	.356
	B- İşcan	.215	.244	.218	.297	N/A
Standardized Coefficients	**β- Suchey-Brooks**	-.133	.502	N/A	-.199	-.189
	β – Todd	.687	N/A	.553	.838	.806
	β – Lovejoy	.202	.240	.206	N/A	.285
	β – İşcan	.197	.224	.200	.272	N/A
	t- (constant)	-1.307	-.898	-1.280	-.746	-1.094
	t- Suchey-Brooks	-.326	4.659	N/A	-.479	-.455
	t- Todd	1.613	N/A	5.048	1.966	1.869
	t- Lovejoy	1.752	2.087	1.808	N/A	2.618
	t- İşcan	1.811	2.049	1.860	2.662	N/A
	N	49	49	49	49	49

R describes the correlation between the observed and predicted values of age. The value of R is highest for Tests 1 and 3, which share a value of 0.848. The standard error of the estimate is slightly lower for Test 3 compared to Test 1. The lower value would indicate a slightly narrower or more precise predicted age range. β-coefficients and t statistics are relied upon to demonstrate the relative effect of each variable in a model. When both Suchey-Brooks and Todd variables are included in a model, as in Tests 1, 4, and 5, the Todd variable affects the model more extensively than the Suchey-Brooks variable. The β-coefficients are higher for Todd in each of the three tests mentioned above. However, according to the t-statistic, neither variable acts as a highly useful predictor of age at death in these models. Values of t above 2 or below –2 are considered to indicate variables that act as useful predictors of age (i.e., $p \leq 0.05$). Notably, exclusion of either variable related to the pubic symphysis from the model causes the effect of the remaining variable to increase. This is demonstrated in Tests 2 and 3 where t-statistics for the Suchey-Brooks and Todd variables increase to 4.659 and 5.048, respectively.

Tests 2, 4, and 5 show R-values of 0.848, 0.837, and 0.836, respectively. Standard error of the estimate is highest for Test 5 at 6.94. The İşcan system shows the highest t-values for all tests where both methods for aging the pubic symphysis are included, except Test 5 where the rib is excluded as a variable. However, when only a single variable for aging the pubic symphysis is included for a test, that variable shows the highest t-value.

The results of regression analyses for the male sample are shown in Table 4. The regressions are again categorized as Tests 1-5 and show identical combinations of variables for the respective tests. Suchey-Brooks data utilized for these regressions were

Table 4- Results of Regression Analysis on Male Sample

		Test 1	Test 2	Test 3	Test 4	Test 5
	R	.900	.900	.898	.888	.838
	Std. Error of the Estimate	5.84	5.80	5.87	6.13	7.27
Unstandardized Coefficients	**B- (constant)**	-7.55	-.970	-2.252	2.219	1.755
	B- Suchey-Brooks	.321	.284	N/A	.365	.600
	B- Todd	-.04099	N/A	.278	-.03946	-.124
	B- Lovejoy	.238	.237	.245	N/A	.470
	B- İşcan	.485	.486	.503	.583	N/A
Standardized Coefficients	**β- Suchey-Brooks**	.317	.281	N/A	.361	.593
	β - Todd	-.038	N/A	.256	-.004	-.114
	β - Lovejoy	.222	.221	.228	N/A	.438
	β - İşcan	.503	.503	.521	.604	N/A
	t- (constant)	-.260	-.380	-.839	.777	.490
	t- Suchey-Brooks	1.310	3.765	N/A	1.421	2.000
	t- Todd	-.160	N/A	3.489	-.015	-.389
	t- Lovejoy	2.921	2.936	2.992	N/A	5.168
	t- İşcan	6.411	6.471	6.718	8.188	N/A
	N	77	77	77	77	77

taken from the refined statistics provided by Suchey et al. (1987). Therefore, the data are not specific to race. For the male sample, Tests 1 and 2 show the greatest R value at 0.900 and standard errors of the estimates are 5.84 and 5.80, respectively. Again, the inclusion of both the Suchey-Brooks and Todd variables in Test 1 indicate that neither acts as highly useful predictors of age. However, when Todd is excluded as a variable in Test 2, the Suchey-Brooks variable becomes a useful predictor, and visa versa for Test 3.

While the highest R-value in the female sample occurred with the exclusion of the Suchey-Brooks variable, the exclusion of the Todd variable in the male sample corresponds to the highest R-value. The results of excluding the Suchey-Brooks data in Test 3 for males produces an R-value of 0.898 which is very near that of Test 2.

The İşcan data have the highest values for both β and t in all tests of the male sample, except for Test 5 where the rib is excluded. When either system for aging the pubic symphysis is omitted, the remaining method ranks second in both β and t values for the model. Auricular surface affects the prediction of age in all tests in which it is included.

The regressions on the male sample were run a second time so that consideration could be given to the race-specific modifications to the Suchey-Brooks system. For these tests the race-specific data are substituted for the refined data used in the previous tests. Results of these regressions are provided in Table 5. Tests 1 and 2 produced the highest R-values, each scoring 0.901. These scores are slightly higher than the values produced for Tests 1 and 2 using the Suchey-Brooks system that does not consider race. The lowest standard error of the estimate occurred in Test 2 with a value of 5.78. In general, the results obtained using the race-specific Suchey-Brooks system mirror those of the refined system without consideration of race. The İşcan system showed the highest β and t-values for every test except Test 5. The Lovejoy system acted as a useful predictor of age in every test except Test 4. Finally, the Suchey-Brooks and Todd variables have the most effect upon the models when only one of the two is included as a variable.

Scatterplots corresponding to each of the five tests showed actual age plotted against the adjusted predicted age for each individual in the sample. The points on the diagrams are much more closely clustered for values below about age 35 for Tests 1, 2, and 3. After age 35, the plots fan out more widely. Due to the trend evident in Tests 1-3 for the male sample, the data were sectioned into two parts; a young adult category and a mature adult category. Because actual age is not known to researchers when age assessments are made, sectioning the sample based on actual age did not seem

Table 5- Results of Regression Analysis on Male Sample Using Race Specific Suchey-Brooks Data

		Test 1	Test 2	Test 3	Test 4	Test 5
	R	.901	.901	.898	.888	.839
	Std. Error of the Estimate	5.82	5.78	5.87	6.12	7.25
Unstandardized Coefficients	**B- (constant)**	-1.598	-1.303	-2.252	1.254	.07813
	B- Suchey-Brooks	.222	.270	N/A	.231	.380
	B- Todd	.06158	N/A	.278	.135	.102
	B- Lovejoy	.242	.247	.245	N/A	.478
	B- İşcan	.484	.485	.503	.586	N/A
Standardized Coefficients	**β- Suchey-Brooks**	.228	.278	N/A	.237	.390
	β – Todd	.057	N/A	.256	.125	.094
	β – Lovejoy	.226	.230	.228	N/A	.446
	β – İşcan	.501	.503	.521	.607	N/A
	t- (constant)	-.593	-.508	-.839	.473	.023
	t- Suchey-Brooks	1.508	3.833	N/A	1.489	2.104
	t- Todd	.376	N/A	3.489	.749	.499
	t- Lovejoy	2.987	3.098	2.992	N/A	5.309
	t- İşcan	6.429	6.486	6.718	8.289	N/A
	N	77	77	77	77	77

reasonable. Therefore, the sample was divided according to Suchey-Brooks phase assignments. All individuals assigned a phase of 3 or lower were included in the young adult category and those assigned phase 4 and above were categorized as mature. The five regression analyses were then run on each sub-sample.

Results for the young adult males are summarized in Table 6a. For Test 1, the R-value, 0.900, is equal to that of Test 1 prior to sectioning the sample. However, the standard error of the estimate was reduced greatly to 2.69. An R-value of 0.900 also occurred in Test 4, but the standard error of the estimate is lower at 2.63.

Table 6a- Results of Regression Analysis on the Young Adult Male Sample

		Test 1	Test 2	Test 3	Test 4	Test 5
	R	.900	.899	.897	.900	.766
	Std. Error of the Estimate	2.69	2.64	2.67	2.63	3.88
Unstandardized Coefficients	**B- (constant)**	3.085	2.651	4.729	3.144	2.195
	B- Suchey-Brooks	.325	.520	N/A	.324	.237
	B- Todd	.180	N/A	.420	.184	.636
	B- Lovejoy	.006621	.09952	.004269	N/A	.09155
	B- İşcan	.401	.413	.398	.403	N/A
Standardized Coefficients	**β- Suchey-Brooks**	.214	.343	N/A	.214	.156
	β – Todd	.153	N/A	.357	.156	.540
	β – Lovejoy	.009	.017	.007	N/A	.152
	β – İşcan	.630	.649	.625	.633	N/A
	t- (constant)	.804	.719	1.473	.855	.398
	t- Suchey-Brooks	.800	2.900	N/A	.818	.405
	t- Todd	.537	N/A	2.817	.565	1.369
	t- Lovejoy	.083	.151	.064	N/A	.974
	t- İşcan	4.859	5.308	4.871	5.181	N/A
	N	25	25	25	25	25

The İşcan variable retained the highest β and t-values for all tests where it was included, and the Suchey-Brooks and Todd variables affect the model substantially when one is used exclusively, rather than in combination.

Disparities between the results of regressions on the sectioned sample and original sample occurred for the auricular surface in all tests. Both β and t-values are considerably lower for Tests 1-4. These values increase in Test 5, but are still lower than those of the other variables in that model.

Tests 1 and 2 were also performed for the sectioned sample using the race-specific Suchey-Brooks system. These results are summarized in Table 6b. R-values are slightly lower for both tests relative to the corresponding tests in Table 6a. Also, standard error of the estimate rose in both tests. Values for β and t indicate that the İşcan variable affected the model greatly and acted as a useful predictor of age. Conversely, the effect of the Lovejoy system was minimal. The values of β and t for the Suchey-Brooks variable are lower than those presented in Table 6a, indicating a reduced effect on the model for predicting age.

Table 7a outlines the results of the regression analyses for the mature male sample. The R-values are highest for Tests 1 and 2 which each scored 0.821. The smallest standard error of the estimate is 6.69 in Test 2. Values of t for the İşcan variable are well above 2.0 for Tests 1-4. The results for the mature males differ from those of the young males in the effect of the Lovejoy system in the models. Values of t for the auricular surface show that the variable acted as a useful predictor of age in all tests where it was included. The β-coefficients for the auricular surface are higher than those of Suchey-Brooks and Todd in all tests.

Table 6b- Results of Regression Analysis on Young Male Sample Using Race Specific Suchey-Brooks Data

		Test 1	Test 2
	R	.897	.877
	Std. Error of the Estimate	2.73	2.90
Unstandardized Coefficients	**B- (constant)**	5.765	2.447
	B- Suchey-Brooks	-.08327	.409
	B- Todd	.468	N/A
	B- Lovejoy	.004192	.02246
	B- İşcan	.392	.482
Standardized Coefficients	**β- Suchey-Brooks**	-.043	.213
	β - Todd	.398	N/A
	β - Lovejoy	.007	.037
	β - İşcan	.616	.757
	t- (constant)	1.099	.465
	t- Suchey-Brooks	-.253	1.867
	t- Todd	1.921	N/A
	t- Lovejoy	.061	.311
	t- İşcan	4.505	6.181
	N	25	25

Table 7a- Results of Regression Analysis on Mature Male Sample

		Test 1	Test 2	Test 3	Test 4	Test 5
	R	.821	.821	.819	.784	.717
	Std. Error of the Estimate	6.76	6.69	6.72	7.27	8.16
Unstandardized Coefficients	B- (constant)	-3.820	-3.467	-5.728	4.610	.950
	B- Suchey-Brooks	.211	.236	N/A	.328	.605
	B- Todd	.02963	N/A	.249	-.04172	-.234
	B- Lovejoy	.342	.342	.351	N/A	.593
	B- İşcan	.481	.480	.497	.612	N/A
Standardized Coefficients	β- Suchey-Brooks	.170	.190	N/A	.264	.488
	β – Todd	.021	N/A	.172	-.029	-.162
	β – Lovejoy	.297	.296	.305	N/A	.514
	β – İşcan	.509	.507	.526	.648	N/A
	t- (constant)	-.526	-.602	-8.69	.643	.109
	t- Suchey-Brooks	.646	2.042	N/A	.939	-.541
	t- Todd	.082	N/A	1.928	-.107	1.583
	t- Lovejoy	2.924	2.956	3.044	N/A	4.696
	t- İşcan	4.790	4.885	5.148	6.341	N/A
	N	52	52	52	52	52

Table 7b presents the results of Test 1 and Test 2 regressions on mature males using the race-specific Suchey-Brooks data. The performance of all four variables is equivalent to those presented in Table 7a. Similarly, there is little difference in values of R or standard error of the estimate between the models presented in the two tables.

Table 7b- Results of Regression Analysis on Mature Male Sample Using Race Specific Suchey-Brooks Data

		Test 1	Test 2
	R	.823	.823
	Std. Error of the Estimate	6.72	6.65
Unstandardized Coefficients	**B- (constant)**	-5.055	-4.152
	B- Suchey-Brooks	.194	.239
	B- Todd	.06499	N/A
	B- Lovejoy	.350	.353
	B- İşcan	.471	.469
Standardized Coefficients	**β- Suchey-Brooks**	.163	.202
	β - Todd	.045	N/A
	β - Lovejoy	.304	.306
	β - İşcan	.498	.496
	t- (constant)	-.763	-.716
	t- Suchey-Brooks	1.018	2.182
	t- Todd	.292	N/A
	t- Lovejoy	3.036	3.093
	t- İşcan	4.714	4.751
	N	52	52

Based on observations of scatterplots of each test for the mature male sample, obvious outliers were identified. Outliers were identified as values that were markedly separate from the rest of the plots, so that little agreement between the predicted and actual values of age occurred. Only one such outlier was identified from scatterplots.

That case was deleted from the data set and Tests 1-5 were subsequently performed. Results of these regressions are given in Table 8.

Table 8- Results of Regression Analysis on Mature Male Sample after Removal of Outliers

		Test 1	Test 2	Test 3	Test 4	Test 5
	R	.852	.852	.850	.841	.697
	Std. Error of the Estimate	6.03	5.97	6.00	6.16	8.16
Unstandardized Coefficients	**B- (constant)**	2.490	1.689	.669	7.808	3.524
	B- Suchey-Brooks	.203	.148	N/A	.259	.638
	B- Todd	-.0652	N/A	.145	-.118	-.291
	B- Lovejoy	.197	.199	.205	N/A	.567
	B- İşcan	.613	.615	.629	.702	N/A
Standardized Coefficients	**β- Suchey-Brooks**	.167	.122	N/A	.214	.526
	β - Todd	-.046	N/A	.102	-.083	-.205
	β - Lovejoy	.172	.174	.179	N/A	.496
	β - İşcan	.666	.668	.683	.762	N/A
	t- (constant)	.371	.317	.109	1.277	.388
	t- Suchey-Brooks	.695	1.399	N/A	.876	1.663
	t- Todd	-.201	N/A	1.221	-.355	-.665
	t- Lovejoy	1.756	1.800	1.854	N/A	4.391
	t- İşcan	6.335	6.461	6.72	8.325	N/A
	N	51	51	51	51	51

Values of R for regressions on the adjusted data set increased for every test except Test 5. Furthermore, the standard error of the estimate decreased for Tests 1-5, relative to regressions that included the outlier. An increase in values of t occurred for the İşcan variable in Tests 1-4, as did a decrease in values of t for the auricular surface. The lower value of R, 0.697, in Test 5 may be linked to the increased effect of the İşcan variable in predicting age for the modified data set.

The female sample was also sectioned into young and mature adults, using Suchey-Brooks phase assignment as the distinguishing criteria. The regression analyses for the young female sample are outlined in Table 9. Contrary to the results of sectioning

Table 9- Results of Regression Analysis on Young Female Sample

		Test 1	Test 2	Test 3	Test 4	Test 5
	R	.745	.672	.740	.727	.742
	Std. Error of the Estimate	5.64	6.08	5.52	5.63	5.51
Unstandardized Coefficients	**B- (constant)**	-13.585	-5.546	-13.677	-12.438	-12.513
	B- Suchey-Brooks	-.400	.757	N/A	-.296	-.248
	B- Todd	1.818	N/A	1.380	1.855	1.515
	B- Lovejoy	.187	.202	.171	N/A	.174
	B- İşcan	-.125	.256	-.05250	-.08416	N/A
Standardized Coefficients	**β- Suchey-Brooks**	-.201	.380	N/A	-.148	-.125
	β - Todd	.893	N/A	.678	.911	.744
	β - Lovejoy	.189	.204	.173	N/A	.176
	β - İşcan	-.124	.255	-.052	-.084	N/A
	t- (constant)	-1.333	-.554	-1.370	-1.230	-1.293
	t- Suchey-Brooks	-.557	1.777	N/A	-.417	-.401
	t- Todd	1.929	N/A	2.715	1.973	2.349
	t- Lovejoy	.974	.978	.920	N/A	.939
	t- İşcan	-.451	1.225	-.219	-.308	N/A
	N	21	21	21	21	21

the male sample, values of R for the young female sample decreased for every test relative to the values associated with the unsectioned female sample. However, the standard error of the estimate also decreased for every test. The values of t in all tests indicate that no single variable acted as a highly useful predictor of age, but the Todd variable showed the highest value of t in all tests in which it was included. Also, t-values of 2.715 and 2.849 in Tests 3 and 5, respectively, indicate that the Todd variable acted as

Table 10- Results of Regression Analysis on Young Female with Outliers Removed

		Test 1	Test 2	Test 3	Test 4	Test 5
	R	.849	.829	.849	.834	.832
	Std. Error of the Estimate	2.73	2.79	2.64	2.75	2.76
Unstandardized Coefficients	**B- (constant)**	1.399	4.671	1.431	2.121	-.576
	B- Suchey-Brooks	-.04717	.333	N/A	-.008624	-.257
	B- Todd	.661	N/A	.605	.723	1.123
	B- Lovejoy	.110	.124	.109	N/A	.114
	B- İşcan	.177	.328	.187	.182	N/A
Standardized Coefficients	**β- Suchey-Brooks**	-.039	.278	N/A	-.007	-.215
	β - Todd	.532	N/A	.487	.582	.904
	β - Lovejoy	.179	.202	.177	N/A	.184
	β - İşcan	.298	.552	.315	.306	N/A
	t- (constant)	.262	.971	.278	.397	-.112
	t- Suchey-Brooks	-.133	1.614	N/A	-.024	-.827
	t- Todd	1.296	N/A	2.166	1.415	3.416
	t- Lovejoy	1.117	1.239	1.148	N/A	1.137
	t- İşcan	1.173	3.340	1.485	1.195	N/A
	N	19	19	19	19	19

a useful predictor of age in these models. The β values also indicate that the Todd variable was more heavily weighted than the other variables in the regression models.

Two outliers were identified in the young female sample and were removed from the data set. Tests 1-5 were then run for the adjusted data set and these results are given in Table 10. Values of R for Tests 1-5 increased relative to those obtained prior to excluding the outliers. Also, the standard error of the estimate decreased in all tests, with the lowest value of 2.64 resulting from Test 3. Again, the Todd variable scored the highest values of t in all tests except Test 2. However the values of t indicate that the variable was a highly useful predictor of age for Test 3 and 5 only. According to β-coefficients, the İşcan variable had the greatest effect on predictions of age when the Todd variable was removed in Test 2.

Table 11 presents the results of regression analyses on the mature female sample. Values of R decreased relative to those resulting from regressions on the entire female sample. Also, the standard error of the estimate for all tests increased relative to those from the entire sample. The Suchey-Brooks and Todd variables act as useful predictors of age when either is used exclusively, rather than in combination. Generally, the effects of the variables on predictions of age mirror those seen in regressions of the entire female sample.

The adjusted predicted age for a case can be calculated when that case is excluded from the calculation of the regression coefficients. Hence, the said case is treated as an unknown and a predicted value of age for the case is determined from the regression model based on the remaining sample. Adjusted predicted values for age were calculated

Table 11- Results of Regression Analyses on Mature Female Sample

		Test 1	Test 2	Test 3	Test 4	Test 5
	R	.759	.746	.759	.743	.728
	Std. Error of the Estimate	7.84	7.85	7.67	7.89	8.07
Unstandardized Coefficients	**B- (constant)**	-11.384	-8.958	-11.390	-10.223	-8.984
	B- Suchey-Brooks	-.06745	.646	N/A	-.286	.112
	B- Todd	.832	N/A	.761	1.184	.659
	B- Lovejoy	.259	.347	.264	N/A	.441
	B- İşcan	.253	.231	.251	.349	N/A
Standardized Coefficients	**β- Suchey-Brooks**	-.043	.412	.461	-.183	.072
	β - Todd	.504	N/A	N/A	.717	.399
	β - Lovejoy	.217	.290	.221	N/A	.370
	β - İşcan	.262	.238	.259	.361	N/A
	t- (constant)	-1.078	-.870	-1.102	-.967	-.835
	t- Suchey-Brooks	-.092	2.717	2.967	-.400	.150
	t- Todd	1.025	N/A	N/A	1.567	.796
	t- Lovejoy	1.142	1.654	1.233	N/A	2.215
	t- İşcan	1.561	1.432	1.599	2.500	N/A
	N	28	28	28	28	28

for each case of all samples corresponding to Test 2 of Tables 3-11. Test 2 was addressed exclusively because it includes observations of all three skeletal sites. The absolute difference between the adjusted predicted age and actual age was then calculated for each case following the formula: Absolute Difference = │adjusted predicted age-actual age│. Finally, the mean absolute difference, minimum and maximum absolute differences, and standard deviation were determined for each sample. These results are provided in Table 12.

Table 12- Absolute Difference Between Adjusted Predicted Age and Actual Age Based on Test 2 Regressions for Samples Corresponding to Those in Tables 3-11

	Mean	Minimum	Maximum	Std. Deviation	N
3- Female Sample	5.6190	.06	20.43	4.4625	49
4- Male Sample	4.3517	.15	23.40	4.2440	77
5-Race Specific Male	4.4248	.19	22.80	4.1574	77
6a- Young Adult Male	2.3973	.06	8.43	2.0435	25
6b- Race Specific Young Male	2.7434	.30	8.25	2.1966	25
7a- Mature Male	5.2306	.10	24.67	4.9834	52
7b- Race Specific Mature Male	5.2464	.01	24.22	4.9361	52
8-Adjusted Mature Male	4.8273	.09	14.86	3.9199	51
9-Young Adult Female	4.7523	.06	19.73	5.1144	21
10- Adjusted Young Female	2.7581	.13	6.22	1.8133	19
11-Mature Female	6.8652	.25	23.21	4.9090	28

The lowest mean absolute differences occur for the young adult males. The young adult male sample regressed using the refined Suchey-Brooks system scores slightly lower than the same sample regressed using the race-specific Suchey-Brooks system. The young adult female sample adjusted to exclude outliers also shows a relatively low mean absolute difference. Mature females have the highest mean absolute difference, with a score of 6.8652 years. The lowest absolute maximum difference occurs for the adjusted young female sample. Also, both groups of young adult males show relatively low maximum absolute differences. Both groups of mature adult males have maximum absolute differences exceeding 20 years. However, the adjusted mature male group, for which outliers were excluded, has a reduced maximum absolute difference of 14.86 years. Generally, all groups not sectioned as young show high maximum absolute differences. The standard deviations for absolute difference were lowest for the adjusted young females and the young adult males. Standard deviations are highest for mature males and females and the unsectioned males and females.

Discussion

The results on regression analyses on the complete male and female samples indicate that either the Suchey-Brooks or Todd system should be used to evaluate the pubic symphysis, but the systems should not be used in combination to obtain predicted age from regression analyses. This is not surprising, since the Suchey-Brooks system is derived from the Todd system (Katz and Suchey 1986). However, regressions on the female sample favor the Todd system slightly while regressions on the male system favor the Suchey-Brooks system in R, t, and standard error of the estimate. Therefore, neither system can be judged as superior for use in regression analysis.

The high values of R show that the correlation between predicted and actual age is almost 85% for females and 90% for males. These results seem encouraging. However, when standard error of the estimate is considered, the analyses seem less useful. The standard error of the estimate acts as an approximate indicator of the predicted age range for the regression models. The predicted age range roughly equates to predicted age +/- two times the standard error of the estimate. Hence, the lowest predicted age range for the female sample is approximately 26.80 years and 23.20 years for the male sample. These ranges are considerably wide and would be nearly useless in forensic contexts, especially for younger individuals. For example, Test 3 from the female sample shows that there is an 85% correlation between predicted and actual ages for that regression, with an associated 26.80 year range about the predicted age. Therefore, a person of predicted age 30 would likely range from 16.6 to 43.4 years of actual age. As forensic anthropologists use age as a descriptive criterion for identification purposes, this range is wider than ideally sought.

The regressions on the male sample using the race-specific Suchey-Brooks system indicate that the race-specific system improves both the correlation between predicted and actual age and the effect of the Suchey-Brooks system as a useful predictor of age. Therefore, the race-specific system should be utilized. However, values of R, t, and standard error of the estimate using the refined system are sufficiently near those of the race-specific system to warrant use of the refined system when race cannot be determined.

Values of t for the male sample indicate that the pubic symphysis, auricular surface, and right fourth sternal rib end act as useful predictors of age. This statement is only true of Test 2 for the female sample. However, the sample size of the female group is smaller than that of the male group. The smaller sample size may affect the results of the regressions indirectly, because individuals showing pathological conditions at the skeletal sites evaluated or having significantly accelerated or retarded aging at one or more of the sites will have a greater impact on the model. The Hamann-Todd collection is composed of indigent persons that died in the Cleveland area between 1912 and 1938 (Meindl et al. 1990). The collection includes many individuals that died in sanitariums and hospitals from a variety of causes, including chronic illnesses that cause pathological conditions in bone. Also, because the population was considered indigent, the general health of the population, or at least members of the population, may have been poor. This researcher did not control for these possibilities when selecting the sample for this study. While individuals of poor health status would be included in both the male and female samples, their inclusion in the admittedly small female sample would have a greater impact on the regressions.

Sectioning the male sample was effective for the young male group. The values of R remained at or about 90% and the standard error of the estimate was greatly reduced in all tests, so that the predicted age ranges would be roughly 11 years. An 11-year age range is not unreasonable for use by forensic anthropologists, in general. However, it is commonly assumed that age for younger individuals can be assessed more precisely than for older individuals (Angel et al. 1986, Bedford et al. 1993, İşcan 1997). Unfortunately, while systems used independently suggest narrower age ranges for young adults (İşcan et al. 1984b, 1985; Katz and Suchey 1986; Lovejoy et al. 1985b; Todd 1920), the results of this analysis do not show that these systems can be combined to provide a more precise age assignment. Notably, only the Suchey-Brooks system takes into account the total variability seen in the expression of age in the human skeleton (Katz and Suchey 1986). The 95% confidence intervals provided by İşcan and colleagues (1984b) may not reflect the variation seen in the age-related metamorphosis at the sternal rib end. Further, the system for aging the auricular surface accounts for variability by acknowledging that specimens may not fit discretely into a particular phase. Therefore, researchers should place differential importance on the changing features at the site. This process is subjective and open to at least some error.

This researcher is of the opinion that the variability observed in age-related metamorphosis at these sites is linked with the moderately wide age ranges derived from regression analyses. Therefore, it is not surprising that systems not accounting for total variability would suggest more discrete age ranges for younger individuals. However, in practice, a single system will not always capture the actual age of the individual in question. Therefore, evaluation of all three sites is presumably favorable for age assessments. Alternate indicators of age at death are available for young individuals. Skeletal indicators of age, such as epiphyseal closure at the iliac crest and medial clavicle and basilar suture closure, occur at somewhat regular intervals for young adults (Angel et al. 1986). These techniques were not utilized in the present study, but could help to narrow the age ranges produced by regression analyses.

The substitution of the race-specific Suchey-Brooks system for the young male sample resulted in lower values of R and increased standard error of the estimate. Values of β and t decreased greatly as well. This suggests that the race-specific system does not correlate predicted and actual ages as well in young males. Furthermore, the race-specific system does not act as a highly useful predictor of age in young males. Therefore, when using a regression analysis for males scoring a Suchey-Brooks phase 3 or lower, the refined system is preferable to the race-specific system.

The higher value of R and lower standard error of the estimate in Test 1 compared to Test 2 of the race-specific regressions may be related to the inclusion of the Todd system for that model. The Todd system does not employ race-specific age ranges and provides six phases that are reduced to three in the Suchey-Brooks system. While the years contained in the total phases overlap, the regressions were preformed on the mean of each phase assignment. Test 1 weighted the Todd variable above the Suchey-Brooks variable according to the β-coefficients, and t-values for the Todd variable are much higher, as well. Hence, the Todd system seems to correct for the Suchey-Brooks variable in the model.

The regression on the mature male sample produced lower values of R and higher standard errors of the estimates relative to regressions on the complete male sample and the young male sample. While removing outliers improved the results some, the regressions on the total sample were still superior. For young males, the pubic symphysis and rib end acted as the most useful predictors of age. However, all three sites proved useful in age predictions for the mature male sample. Furthermore, while the race-specific Suchey-Brooks system decreased R and increased the standard error of the estimate for the young male sample, the opposite effect occurred for the mature male sample. The differences between the race-specific means provided by Katz and Suchey (1989) for black and white groups are 0.6 years, 1.3 years, and 1.0 years for Phases 1, 2, and 3, respectively. The differences for Phases 4, 5, and 6 are 3.6 years, 9.7 years, and 3.5 years, respectively. The small differences between the means for the young males and larger differences for the mature males seem to show that race has a greater impact on age-related changes to the pubic symphysis later in life. The results of this study appear to confirm this premise.

The removal of outliers from the mature male sample served to increase R and decrease the standard error of the estimate. However, the effectiveness of the model for use by forensic anthropologists must be addressed. In order for the model to be practical, anthropologists aging unidentified skeletons would have to be able to recognize outliers. This researcher was conservative and removed only one outlier, where actual age differed from predicted age by more than 20 years. The case removed was drastically over-aged by the model. When a full skeleton is available for analysis, a young individual might be discerned through indicators other than the four used in this study. Also, conditions that might affect the aging processes at one or more of the sites would be more readily recognizable. Therefore, outliers could be discerned as inappropriate for use with the mature male regressions. However, any failure to recognize such outliers would make the model invalid.

While the regression analyses on the young female sample were not highly successful, the removal of outliers greatly improved the results. The higher values of R and low standard errors of the estimates make these regressions more meaningful for forensic use. Yet, this model also depends on the recognition of outliers, which is somewhat questionable for application in a laboratory. Regressions on the mature female sample were also disappointing, as the sectioning of the sample did not serve to raise values of R and lower standard errors of the estimates. Therefore, regressions on the total sample were the most successful for females, omitting the young female group for which outliers were removed.

The mean absolute differences for each of the regression sets are encouraging, as all mean differences are relatively low. This indicates that the predicted ages for specimens were, on average, well below the outside boundaries of the predicted age ranges. Nevertheless, the high maximum absolute differences demonstrate the full effect of variability on age predictions. For 6 of 11 tests, the maximum absolute differences exceeded 20 years. The young adult male results show that this group can be aged fairly reliably by combining results of the three techniques through regression analysis. Regressions on all other groups will produce predicted age ranges that are wider and less useful if total variability is considered.

Conclusions

The present study demonstrates that there is a relationship between age estimates derived from the pubic symphysis, auricular surface, and right fourth sternal rib end and age at death for both male and female samples. The respective estimates provided from each site can be successfully combined through linear regression to formulate a predicted value of age at death for unidentified individuals. Further, the predicted values of age at death for both males and females show a high correlation with actual age. This correlation is higher for the male group.

Despite the high correlation between predicted age and actual age, the predicted age ranges produced by regression analyses are larger than ideally sought for the descriptive purposes of forensic anthropologists. Only when outliers are removed from regression samples do predicted age ranges narrow adequately to be highly useful in forensic contexts. However, the recognition of outliers for an unknown individual may not be possible in case-by-case analysis. Therefore, the regressions on the adjusted sample may not be practical.

Results of regression analyses may be improved upon by evaluation of additional skeletal indicators of age. Such indicators can distinguish younger individuals from older individuals, and act to truncate the predicted age ranges provided by regression analysis. This supposition should be tested in future studies.

References Cited

Angel, J.L., Suchey, J.M., İşcan, M.Y., and Zimmerman, M.R. (1986) Age at death estimated from the skeleton and viscera. In M.R. Zimmerman and J.L. Angel (eds.) Dating and Age Determination of Biological Materials. Croom Helm: Dover, NH pp. 179-220.

Bass W.M. (1995) Humam Osteology. Missouri Archeaological Society, St.Louis.

Bedford, M.E., Russel, K.F., Lovejoy, C.O., Meindl, R.S., Simpson, S.W., and Stuart-Macadam, P.L. (1993) Test of multifactorial aging method using skeletons with known ages-at-death from the Grant Collection. American Journal of Physical Anthropology 65:147-156.

Brooks, S.T. (1955) Skeletal age at death: The reliability of cranial and pubic age indicators. American Journal of Physical Anthropology 13:567-597.

Gilbert, B.M., and McKern, T.W. (1973) A method of aging the female os pubis. American Journal of Physical Anthropology 38:31-38.

İşcan, M.Y. (1997) The scope of forensic anthropology. In W.G. Eckert (ed.) Introduction to Forensic Sciences, second edition. CRC Press Inc: NY, NY. pp. 348-352.

İşcan, M.Y., Loth, S.R., and Wright, R.K. (1984a) Age estimation from the rib by phase analysis: White Males. Journal of Forensic Sciences 29(4): 1094-1104.

İşcan, M.Y., Loth, S.R., and Wright, R.K. (1984b) Metamorphosis at the sternal rib end: a new method to estimate age at death in white males. American Journal of Physical Anthropology 65: 147-156.

İşcan, M.Y., Loth, S.R., and Wright, R.K. (1985) Age estimation from the rib by phase analysis: White Females. Journal of Forensic Sciences 30(3): 853-863.

İşcan, M.Y., and Loth, S.R. (1986a) Determination of age from the sternal rib in white males: A test of the phase method. Journal of Forensic Sciences 31(1): 122-132.

İşcan, M.Y., and Loth, S.R. (1986b) Determination of age from the sternal rib in white females: A test of the phase method. Journal of Forensic Sciences 31(3): 990-999.

İşcan, M.Y., Loth, S.R., and Wright, R.K. (1987) Racial variation in the sternal extremity of the rib and its effects on age determination. Journal of Forensic Sciences 32(2): 452-466.

Katz, D. and Suchey, J.M. (1986) Age determination of the male os pubis. American Journal of Physical Anthropology 80:167-172.

Katz, D., and Suchey, J.M. (1989) Race differences in pubic symphyseal aging patterns in the male. American Journal of Physical Anthropology 80:167-172.

Lovejoy, C.O., Meindl, R.S., Mensforth, R.P., and Barton, T.J. (1985a) Mutifactorial determination of skeletal age at death: A method and blind tests of its accuracy. American Journal of Physical Anthropology 68:1-14.

Lovejoy, C.O., Meindl,R.S., Pryzbeck, T.R., and Mensforth, R.P. (1985b) Chronological metamorphosis of the auricular surface of the ilium: A new method for the determination of adult skeletal age at death. American Journal of Physical Anthropology 68:15-28.

McKern, T.W., and Stewart T.D. (1957) Skeletal age changes in young American males. Natick, MA: Quartermaster Research and Development Command, Technical Report EP-45.

Meindl, R.S., Lovejoy C.O., Mensforth R.P., and Walker R.A. (1985) A revised method of age determination using the os pubis, with a review and tests of accuracy of the other current methods of pubic symphyseal aging. American Journal of Physical Anthropology 68:29-45.

Meindl, R.S., Russell, K.F., Lovejoy, C.O. (1990) Reliability of age at death in the Hamann-Todd Collection: Validity of subselection procedures used in blind tests of the summary age technique. American Journal of Physical Anthropology 83:349-357.

Russell, K.F., Simpson, S.W., Genovese, J., Kinkel, M.D., Meindl, R.S., and Lovejoy, C.O. (1993) Independent test of fourth rib aging technique. American Journal of Physical Anthropology 92:53-62.

Stewart, T.D. (1957) Distortion of the pubic symphyseal surface in females and its effect on age determination. American Journal of Physical Anthropology 15:9-18.

Suchey, J.M. (1979) Problems in the aging of females using the os pubis. American Journal of Physical Anthropology 51:467-470.

Suchey, J.M., Brooks, S.T., Katz, D. (1988) Instructions for use of the Suchey-Brooks system for age determination of the female os pubis. Instructional materials accompanying female pubic symphyseal models of the Suchey-Brooks system. Distributed by France Casting: Fort Collins, Co.

Todd, T.W. (1920) Age changes in the pubic bone. I. The male white pubis. American Journal of Physical Anthropology 3:285-339.

Todd, T.W. (1921a) Age changes in the pubic bone. II. The pubis of the male Negro-White hybrid. American Journal of Physical Anthropology 4:1-25.

Todd, T.W. (1921b) Age changes in the pubic bone. III. The pubis of the white female. American Journal of Physical Anthropology 4: 26-39.

Todd, T.W. (1921c) Age changes in the pubic bone. III. The pubis of the female Negro-White hybrid. American Journal of Physical Anthropology 4: 40-64.

Vita

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