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Comparison of Macroscopic Cranial Methods of Age Estimation Applied to Skeletons from the Terry Collection

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ABSTRACT: A total of 963 skeletons (408 Whites and 555 Blacks) from the Terry Collection were studied to examine macroscopic cranial methods of age estimation. The methods of Acsádi and Nemeskéri, Masset, Baker and Meindl and Lovejoy were applied to every skull. The results indicate that the most accurate techniques in this application were those that consider endocranial suture closure. The methods of Acsádi and Nemeskéri and Masset were the most accurate in all the subsamples (by population, sex, sex within population and in total), although the relative accuracy could vary in application to other populations.

KEYWORDS: forensic science; forensic anthropology, physical anthropology, Terry Collection, cranial age estimation, macroscopic methods

Aging has been of scholarly interest throughout time and the world. A large number of researchers have studied this process, hoping to understand its origin, evolution, and consequences, as well as to try to combat it. Usually, people are more conscious of and worried about what happens to the external body, but the aging process affects every part of the organism, at every biological level, including the skeleton. Physical anthropologists have been involved directly in diagnosing the skeletal age of individuals for forensic and archaeological purposes. Some of these specialists have investigated skeletal changes throughout life and have developed various methods to estimate age at death.

This study is part of a research project to examine the accuracy of the most frequently utilized macroscopic methods for diagnosing the age at death of individuals represented by skeletal remains in the Terry Collection. Although many of these age methods have undergone periodic revision, this study tests all of them on the same population of White and Black Americans. This investigation examines age changes in bone that occur throughout the adult years rather than among the immature.

Two multifactorial methods are of special interest. The complex method of Acsádi and Nemeskéri (1), largely employed in Europe, estimates age from observations on cranial suture closure, metamorphosis of the pubic symphysis and radiographic translucency of the proximal femur and humerus. The method of Lovejoy et al. (2) considers pubic and auricular surface metamorphosis, trabecular involution of the proximal femur, cranial suture closure and dental wear. These methods offer superior results to single indicator systems, but frequently their use is limited by incomplete or badly damaged remains. In addition, radiography may not be available to some investigators.

Only results on the cranial suture methods are presented here. Results of our testing of the other aging methods will be published separately.

Materials and Methods

Materials

The Terry Collection contains the skeletal remains of 1700 White and Black dissecting-room cadavers that were assembled at Washington University School of Medicine in St. Louis and later transferred to the Smithsonian Institution in Washington, DC. Although the sample is large and well documented, issues remain regarding the extent to which it represents American populations of today or even from the time that the collection was assembled. Comparative studies conducted with contemporary samples have documented differences that likely represent regional variability or secular change (3). The Terry Collection is composed of individuals originating from the lower socio-economic groups and thus is not representative of total American society or even all individuals from the St. Louis area. Despite these limitations, shared by all other such collections, the Terry Collection offers a splendid opportunity to test different methods of age estimation on individuals of known age at death.

A total of 963 skeletons were studied, of which 408 were Whites and 555 Blacks. These individuals were chosen at random, but selected so that all age categories were represented. It was not possible to examine an equal number of individuals in each age category because of the unequal distribution of ages within the Terry Collection. Considering the limitations of the collection, the age distribution of the sample utilized was the most uniform possible.

As shown in Table 1, Blacks are better represented (larger sample sizes) than Whites in the youngest and oldest ages. When the sample size is analyzed by sex, White males have greater representation between the ages of 36 and 75 years, while White females have more total individuals in the older age categories.

The mean age for the Black and White male and female samples (Table 2) reflects the above discussed limitations of sample size. Mean age is ten years higher for Whites than for Blacks. In both groups, females are older than males. The mean age of the total sample, 54.6 years, is very high as a result of the large number of very elderly individuals.

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TABLE 1—*Age distribution of the Terry Collection sample.*

Age Categories, (Years)	Whites						Blacks					
	Males		Females		Total		Males		Female		Total	
	N	%*	N	%*	N	%*	N	%*	N	%*	N	%*
≤20	5	1.23	0	0.00	5	1.23	15	2.70	9	1.62	24	4.32
21–25	0	0.00	0	0.00	0	0.00	23	4.16	16	2.88	39	7.03
26–30	9	2.21	7	1.72	16	3.92	22	3.96	25	4.50	47	8.47
31–35	6	1.47	5	1.23	11	2.70	20	3.60	22	3.96	42	7.57
36–40	25	6.13	6	1.47	31	7.60	25	4.50	21	3.78	46	8.29
41–45	18	4.41	10	2.45	28	6.86	21	3.78	21	3.78	42	7.57
46–50	19	4.66	11	2.70	30	7.35	21	3.78	21	3.78	42	7.57
51–55	19	4.66	21	5.15	40	9.80	23	4.14	19	3.42	42	7.57
56–60	23	5.64	21	5.15	44	10.78	22	3.96	22	3.96	44	7.93
61–65	18	4.41	20	4.90	38	9.31	22	3.96	21	3.78	43	7.75
66–70	18	4.41	21	5.15	39	9.56	24	4.32	18	3.24	42	7.57
71–75	21	5.15	21	5.15	42	10.29	18	3.24	21	3.78	39	7.03
76–80	16	3.92	18	4.41	34	8.33	12	2.16	20	3.60	32	5.77
81–85	14	3.43	21	5.15	35	8.58	5	0.90	11	1.98	16	2.88
86–90	1	0.25	11	2.70	12	2.94	4	0.72	1	0.18	5	0.90
91–95	0	0.00	3	0.74	3	0.74	1	0.18	5	0.90	6	1.08
≥96	0	0.00	0	0.00	0	0.00	2	0.36	2	0.36	4	0.72
Total	212	51.96	196	48.04	408	100.00	280	50.45	275	49.55	555	100.0

* Denominator is the total for the population.

TABLE 2—*Mean age and other statistics for sub-samples of the Terry Collection.*

Sample	Sex	N	Mean	St.Dev.	Max.	Min.
Whites	♂	212	56.38	16.52	87	18
	♀	196	63.92	15.72	91	27
	T	408	60.00	16.55	91	18
Blacks	♂	280	49.28	19.27	102	17
	♀	275	52.05	20.05	101	14
	T	555	50.65	19.69	102	14
Total	♂	492	52.34	18.45	102	17
	♀	471	56.99	19.27	101	14
	T	963	54.61	18.99	102	14

Methods

Anthropological Methods—Historically, the use of cranial suture closure as an age indicator has received considerable research attention (1,4–14). Published methods of estimating age at death from cranial suture closure utilized in this study are those previously mentioned (1,11–13). All of these focus on the sutures of the cranial vault but only that of Meindl and Lovejoy (13) has incorporated what are termed the ''lateral-anterior sutures.''

Acsádi and Nemeskéri (1) studied a sample of 285 crania with symmetrically closing sutures from dissected cadavers at the Institute of Forensic Medicine of Semmelweis University School of Medicine (Budapest, Hungary). From this sample of Hungarians of known age at death, they developed a practical method of age estimation, jointly calculating the endocranial closure index of the three main sutures. They use six endocranial segments from the coronal (left: C1, C2, C3 and right: C1, C2, C3), four from the sagittal (S1, S2, S3, S4) and six from the lambdoidal (left: L1, L2, L3 and right: L1, L2, L3). Each of these segments is scored using Martin's (10) scale (open = 0, incipient closure = 1, closure in process = 2, advanced closure = 3 and closed = 4). Finally, they calculate the endocranial closure index (EnCI) adding the scores of all segments and dividing the total by 16 (total number of segments). They provided a table to convert the data on suture closure to age at death.

Masset (11) studied a sample of 849 Portuguese crania of known age at death from the Ferraz de Macedo Collection of Lisbon, which contains people who died in 1876. Since this collection contains no specimens over the age of 70, another sample consisting of 65 Portuguese crania over 70 (25 males and 40 females) from the town of Coimbra was added. This sample was more recent than the one from Lisbon, all its individuals having died between 1910 and 1936. Masset proposed a method using the same suture segments as Acsádi and Nemeskéri, but instead of scoring left and right sides, Masset averaged the left and right values to produce a single score from each segment. Accordingly, the Masset system produces scores for only ten segments (C1, C2, C3, S1, S2, S3, S4, L1, L2, L3). The values for converting scores to age are practically the same as those offered by Acsádi and Nemeskéri (1). To score the traits, Masset (11) uses the following classification system: 0 = open, 1 = synostosis affecting less than or approximately one-quarter of the segment, 2 = synostosis affecting more or less half of the segment, 3 = synostosis affecting approximately three-quarters or more of the segment and 4 = closed. He calculates the obliteration coefficient (S) by adding the scores of all the ten fragments and dividing by 10. To estimate the age at death, he offers four equations, two for ectocranial: males and females and two for endocranial: males and females.

Baker (12) studied a sample of 195 (144 males and 51 females) modern individuals of known age at death and different ancestries collected during the years 1981 through 1983 from individuals autopsied at the Department of the Chief Medical Examiner-Coroner in Los Angeles, CA. He proposed a method utilizing five areas of observation along the endocranial sutures as follows:

- Left coronal (Lc) and right coronal (Rc) = Along partes bregmatica and complicata.
- Sagittal (s) = All of the sagittal suture.
- Left lambdica (L1) and right lambdica (R1) = Along partes lambdica and intermedia.

He scores these five areas as being 1 = open, 2 = partially closed, or 3 = totally closed and provides a table to convert the values to age at death.

Meindl and Lovejoy (13) studied a sample of 261 individuals (130 males and 131 females) from the Hamman-Todd Collection of skeletons originating from anatomical dissection and now housed at the Cleveland Museum of Natural History. They evaluate ten areas, 1 cm in length each. Seven of these are from the vault (1. midlambdoid, 2. lambda, 3. obelion, 4. anterior sagittal, 5. bregma, 6. midcoronal, 7. pterion); and five from the lateral-anterior portion of the cranium (6. midcoronal, 7. pterion, 8. sphenofrontal, 9. inferior sphenotemporal, 10. superior sphenotemporal). They classify between 0 and 3 the extent of closure at each location and then sum the values to produce two composite scores (CS). The first score represents the sum of the values from the vault segments and the second score the sum of the lateral-anterior segments. They offer two tables to estimate the age at death.

Lovejoy et al. (2) remark that few of the individuals in their sample are of definitely known age. It appears that age was estimated by the original anatomists (including Todd) from both soft tissues and the skeleton. While Meindl and Lovejoy attempted to minimize this problem by only including individuals for whom the stated age at death by the hospital differed from the anatomists judgment by ± five years or less, undoubtedly some error was introduced into the study that may reduce the accuracy of the age estimations. This problem also has been raised by other researchers (15–17).

While the Acsádi and Nemeskéri (1) and Masset (11) methods have been used largely in Europe for age estimation, the methods of Meindl and Lovejoy (13) and Baker (12) have been recommended by the committee that established the ''data collection procedures for forensic skeletal material'' (18) and have proven to be more popular in the United States.

Statistical Methods—Each of the 53 traits to be analyzed representing the age marker data discussed above (16 from Meindl and Lovejoy, 5 from Baker and 32 from Acsádi and Nemeskéri and Masset), from each of the 963 specimens in the sample were entered into a Lotus 123 worksheet and checked for input accuracy. The Lotus files were imported into a statistical package (SYSTAT version 5, (19)) for summary description and analysis. All analyses were run on a Compaq 386/20 system at the Smithsonian Institution.

The sample size (absolute and relative frequencies) was calculated for each age category in every population group and sex (Table 1). Furthermore, the mean age and other descriptive statistics were also established for every subgroup of the sample (by population, sex and sex within population; Table 2). Note that our use of the term population in this study refers to the classification of individuals in the Terry Collection records as either Black or White; the word is not used in the statistical sense.

The ectocranial and endocranial closure indices (1), the obliteration coefficient (11) and the composite scores from the lateral and vault suture systems (13) were calculated for each of the individuals. We calculated a ''composite score'' (Lc + Rc + s + L1 + R1) from the Baker (12) method for comparisons with the other methods.

The correlation coefficient between age at death and each of the above-mentioned indices, coefficients, and composite scores was calculated by sex and population group and sex within population (Tables 3 and 4). This statistic (R) provides a measure of linear relationship between the two variables. Tests of significance were conducted using the Z transformation of R, which has a standard error of $1/\sqrt{(N - 3)}$. The quantity Z/se is a standardized normal deviate which can be referred to a normal curve table to test the null hypothesis $R = 0$.

Statistical tests were calculated for endocranial-ectocranial, population and sexual differences based upon the difference (20) of transformed correlation coefficients (Table 5). The statistic used, $S' = (Z_1 - Z_2)/\sqrt{(1/N_1 - 3) + (1/(N_2 - 3))}$, is an approximately normal deviate for our sample sizes.

For each method, the estimated age for every specimen of our sample was obtained for comparison with actual age in order to establish the accuracy and bias (2). These quantities were obtained for the total sample and subsamples (by population, sex and sex

TABLE 3—*Correlation coefficient (R) and standardized normal deviate (Z/se) between age at death and suture closure indices.*

		Closure Index Acsádi & Nemeskéri						Obliteration Coefficient† Masset					
		Ectocranial			Endocranial			Ectocranial			Endocranial		
Sample	Sex	N	R	Z/se	N	R	Z/se	N	R	Z/se	N	R	Z/se
Whites	♂	210	0.33*	4.90	210	0.53*	8.39	210	0.34*	5.03	210	0.52*	8.37
								210	0.34*	5.03	210	0.52*	8.37
	♀	194	0.40*	5.92	194	0.37*	5.29	194	0.40*	5.81	194	0.38*	5.48
								194	0.39*	5.74	194	0.37*	5.37
Blacks	♂	278	0.52*	9.53	278	0.66*	13.06	278	0.50*	9.13	278	0.64*	12.65
								278	0.49*	8.87	278	0.64*	12.69
	♀	271	0.47*	8.39	271	0.48*	8.48	271	0.46*	8.10	271	0.48*	8.50
								271	0.46*	8.18	271	0.47*	8.39
Whites	T	404	0.35*	7.25	404	0.43*	9.23	404	0.34*	7.16	404	0.44*	9.43
								404	0.34*	7.02	404	0.44*	9.33
Blacks	T	549	0.50*	12.53	549	0.56*	14.92	549	0.47*	11.95	549	0.56*	14.75
								549	0.47*	11.86	549	0.56*	14.65
Males	T	488	0.46*	11.01	488	0.63*	16.33	488	0.45*	10.70	488	0.62*	15.97
								488	0.45*	10.59	488	0.62*	16.04
Females	T	465	0.46*	10.61	465	0.48*	11.30	465	0.45*	10.28	465	0.48*	11.30
								465	0.45*	10.36	465	0.48*	11.21
Total		953	0.45*	14.94	953	0.55*	19.02	953	0.44*	14.40	953	0.55*	18.88
								953	0.43*	14.33	953	0.54*	18.80

* Highly significant ($p < 0.01$).
† Values are presented for left side, followed by right.

TABLE 4—*Correlation coefficient (R) and standardized normal deviate (Z/se) between age at death and suture closure indices.*

		Composite Score Baker			Composite Scores† Meindl & Lovejoy Ectocranial					
		Endocranial			Vault			Lateral-Anterior		
Sample	Sex	N	R	Z/se	N	R	Z/se	N	R	Z/se
Whites	♂	210	0.49*	7.63	206	0.35*	5.21	206	0.38*	5.70
					209	0.33*	5.25	208	0.36*	5.40
	♀	195	0.42*	6.20	193	0.38*	5.51	194	0.37*	5.37
					193	0.38*	5.51	193	0.39*	5.68
Blacks	♂	279	0.65*	12.79	278	0.50*	9.11	278	0.53*	9.79
					280	0.49*	8.92	280	0.52*	9.59
	♀	273	0.47*	8.40	272	0.44*	7.75	272	0.42*	7.34
					272	0.45*	7.95	272	0.42*	7.34
Whites	T	405	0.46*	9.84	399	0.35*	7.27	400	0.36*	7.51
					402	0.34*	7.07	401	0.35*	7.29
Blacks	T	552	0.56*	14.76	550	0.46*	11.63	550	0.46*	11.63
					552	0.46*	11.65	552	0.46*	11.65
Males	T	489	0.61*	15.63	484	0.45*	10.63	484	0.46*	10.91
					489	0.44*	10.41	488	0.45*	10.67
Females	T	468	0.49*	11.64	465	0.43*	9.89	466	0.39*	8.86
					465	0.43*	9.89	465	0.40*	9.11
Total		975	0.55*	19.32	949	0.43*	13.99	950	0.41*	13.52
					954	0.42*	13.92	953	0.41*	13.54

* Highly significant ($p < 0.01$).
† Values are presented for left side, followed by right.

TABLE 5—*Test for endocranial-ectocranial, population and sexual differences.*

		Acsádi & Nemeskéri		Masset		Baker	Meindl & Lovejoy	
		S′		S′		S′	S′	
Sample	Compared	Ectoc	Endoc	Ectoc	Endoc	Endoc	Vault	Lat-Ant
Total	W-vs-B	−2.65**	−2.70**	−2.34*	−2.43*	−2.10*	−2.00*	−1.82
Whites	♂-vs-♀	−0.87	1.99	0.00	1.84	0.83	−0.35	0.12
Whites ♂	Ec-vs-En	−2.46*		−5.95**				
Blacks	♂-vs-♀	0.72	3.15**	0.19	2.84	3.03**	0.90	1.66
Blacks ♂	Ec-vs-En	−2.50*		−8.95**				
Total ♂	Ec-vs-En	−2.88**		−13.36**				

W-vs-B = Whites versus Blacks; ♂-vs-♀ = males versus females; Ec-vs-En = ectocranial versus endocranial.
Test statistic to compare two transformed correlations: $S' = (Z_1 - Z_2)/\sqrt{(1/N_1 - 3) + (1/(N_2 - 3))}$.
* Significant at $p \leq 0.05$ (this corresponds to a value of the statistic > 1.96).
** Significant at $p \leq 0.01$ (this corresponds to a value of the statistic > 2.58).

within population, Table 6), as well as by age categories (Tables 7 and 8). Means were used to obtain the estimated age, and neither the statistical standard deviation nor the mean deviations were considered since no provision is made for these quantities in the formulae of Lovejoy et al. (2). These definitions are:

$$\text{Inaccuracy (years)} = \sum \left|\text{estimated} - \text{actual}\right|/N$$

$$\text{Bias (years)} = \sum (\text{estimated} - \text{actual})/N$$

Inaccuracy is an absolute deviation value and bias is a deviation value. When these formulas are used to compare the deviation of actual from estimated age for a population, the results reflect a property of the assumed linearity of prediction. That is, statistical theory proposes for each individual's age a prediction that the specimen's estimated age will be relatively closer to the actual population (or subgroup) average age than is its actual age. This is a statistical consequence of the prediction approach, not a law of natural populations.

Results

Correlations Between Age and Indices in the Terry Collection

Closure Index and Age—Statistically significant correlations (Table 3) between age and endocranial closure index (EnCI) and age and ectocranial closure index (EcCI) have been found for all the subsamples as well as for the total. Although endocranial closure index is more correlated with age than EcCI in all the subsamples (the only exception being the White female sample; Table 3), these differences were only statistically significant (Table 5) for males. Population differences were found (Table 3), showing that Blacks from the Terry Collection had significantly greater correlations between the index and age for both EcCI and EnCI (Table 5) than Whites. The ages of the Black males were more highly correlated than females for both EcCI and EnCI, but only for EnCI was this difference significant (Table 5). The differences for Whites between females and males was not significant.

Obliteration Coefficient and Age—All the subsamples have statistically significant correlations (Table 3) between age and the

TABLE 6—*Inaccuracy and bias of the suture closure methods when applied to the Terry Collection. Sex and population differences.*

		Masset						Acsádi & Nemeskéri		
		Ectocranial			Endocranial			Endocranial		
Sample	Sex	N	Inacc.	Bias	N	Inacc.	Bias	N	Inacc.	Bias
Whites	♂	210	12.61	−1.20	210	11.80	1.95	210	11.97	2.86
	♀	195	12.95	−6.57	195	12.68	−5.93	195	13.02	−5.21
	T	405	12.77	−3.79	405	12.22	−1.85	405	12.47	−1.03
Blacks	♂	279	14.14	3.55	279	12.33	3.73	279	12.11	4.56
	♀	273	15.62	3.13	271	14.80	2.25	271	14.85	0.54
	T	552	14.87	3.34	550	13.55	3.00	550	13.46	2.58
Total	♂	489	13.48	1.51	489	12.10	2.97	489	12.05	3.83
	♀	468	14.50	−0.91	466	13.92	−1.18	466	14.08	−1.87
	T	957	13.98	0.33	955	12.99	0.94	955	13.04	1.05

		Meindl & Lovejoy					
		Vault			Lateral-Anterior		
Sample	Sex	N	Inacc.	Bias	N	Inacc.	Bias
Whites	♂	191	18.14	−16.05	163	18.38	−16.35
	♀	164	23.22	−22.81	155	23.93	−23.44
	T	355	20.49	−19.17	318	21.08	−21.07
Blacks	♂	234	15.90	−9.78	205	15.48	−14.97
	♀	209	17.69	−13.64	191	18.31	−14.06
	T	443	16.75	−11.60	396	16.85	−12.27
Total	♂	425	16.91	−12.59	368	16.77	−13.14
	♀	373	20.12	−17.67	346	20.82	−18.26
	T	798	18.41	−14.97	714	18.73	−15.62

Only left side is considered for Masset and Meindl and Lovejoy (no side differences were found).
Inaccuracy (years) = $\sum$ |estimated − actual|/N; symbol || indicates absolute value of the quantity.
Bias (years) = $\sum$ (estimated − actual)/N.

TABLE 7—*Inaccuracy and bias of the cranial closure suture methods when applied to the Terry Collection. Age group differences.*

	Masset						Acsádi & Nemeskéri		
	Ectocranial			Endocranial			Endocranial		
Age Category	N	Inac.	Bias	N	Inac.	Bias	N	Inac.	Bias
≤20	28	20.71	20.71	28	11.88	11.88	28	12.34	12.34
21–25	39	18.14	18.14	38	11.59	10.70	38	8.92	8.92
26–30	62	20.72	20.72	62	19.39	17.65	62	16.37	15.92
31–35	52	17.99	17.88	52	18.30	16.79	52	17.75	15.38
36–40	77	16.10	15.68	77	17.17	15.66	77	16.80	14.75
41–45	68	13.68	12.91	68	15.74	13.15	68	16.14	12.57
46–50	72	10.58	9.55	72	11.63	10.31	72	13.73	10.55
51–55	82	5.26	3.50	82	7.28	6.37	82	9.82	6.73
56–60	87	3.87	−0.93	87	4.33	0.81	87	6.68	1.12
61–65	81	5.94	−5.86	81	3.82	−3.42	81	4.44	−1.99
66–70	81	10.42	−10.42	81	8.15	−8.15	81	7.49	−7.49
71–75	81	15.66	−15.66	81	13.06	−13.06	81	12.45	−12.45
76–80	66	20.15	−20.15	65	18.22	−18.23	65	17.30	−17.30
81–85	51	24.34	−24.34	51	22.42	−22.42	51	21.14	−21.14
86–90	17	31.13	−31.13	17	27.40	−27.40	17	26.85	−26.85
91–95	9	36.09	−36.09	9	32.58	−32.58	9	31.59	−31.59
96–100	4	39.25	−39.25	4	39.24	−39.24	4	36.80	−36.80

Only left side has been used for Masset method. (No side differences were found).
Inaccuracy (years) = $\sum$ |estimated − actual|/N; symbol || indicates absolute value of the quantity.
Bias (years) = $\sum$ (estimated − actual)/N.

TABLE 8—*Inaccuracy and bias of the cranial closure suture methods when applied to the Terry Collection. Age group differences.*

	Meindl & Lovejoy Ectocranial					
	Vault			Lateral-Anterior		
Age Categories	N	Inac.	Bias	N	Inac.	Bias
≤20	8	18.08	18.08	1	19.20	19.20
21–25	18	10.89	10.89	5	15.54	15.54
26–30	41	9.09	9.09	26	11.52	11.52
31–35	39	8.03	7.31	28	7.99	7.99
36–40	70	5.36	1.49	57	5.96	3.47
41–45	61	5.48	−2.32	49	5.10	0.19
46–50	68	6.70	−5.95	60	7.27	−5.30
51–55	78	12.41	−12.88	66	10.05	−10.15
56–60	80	15.90	−15.90	76	14.03	−14.00
61–65	74	20.40	−20.40	72	19.50	−19.50
66–70	70	26.38	−26.38	67	23.12	−23.12
71–75	73	30.31	−30.31	75	29.43	−29.43
76–80	55	35.01	−35.01	60	32.84	−32.84
81–85	44	39.17	−39.17	47	37.13	−37.13
86–90	11	43.93	−43.93	15	40.91	−40.91
91–95	6	51.31	−50.32	6	43.60	−43.60
96–100	4	60.10	−60.10	4	62.55	−62.55

Only left side has been used for Meindl & Lovejoy method. (No side differences were found).
Inaccuracy (years) = $\sum$ |estimated − actual|/N; symbol || indicates absolute value of the quantity.
Bias (years) = $\sum$ (estimated − actual)/N.

obliteration coefficient (S). Although the endocranial obliteration coefficient appears more correlated with age than ectocranial (the only exception being the White female sample; Table 3), these differences were only statistically significant in males (Table 5).

Population age differences were found (Tables 3 and 5), Table 5 shows a significant difference between the White and Black samples in ectocranial and endocranial closure, using the Masset system. However, in both samples actual age is more highly correlated with ages estimated using Masset's endocranial data than with those estimated from ectocranial data.

Statistically significant sexual differences (Tables 3 and 5) were found only for endocranial Blacks, although endocranial Whites are just at the boundary of the 0.05 significance level. So, while Black males have greater correlations between age and endocranial S than Black females, no sexual differences appeared between age and ectocranial S.

Composite Score from Baker and Age—Similar results (Tables 4 and 5) were obtained in the values of R and Z/se between age and Baker's composite score (CS = left coronal + right coronal + sagittal + left lambdica + right lambdica), Acsádi and Nemeskéri's endocranial closure index and Masset's endocranial obliteration coefficient. However, no sexual differences were found for the White population in the Baker data.

Vault and Lateral-Anterior Composite Scores and Age—Just as for the indices described above, all the correlations between age and vault composite score (VCS) and age and lateral-anterior composite score (LACS) were statistically significant.

No significant differences appeared for R and Z/se between right and left sides or between the VCS and the LACS in any subsample (Table 4).

Population differences (Table 4) were found; Blacks from the Terry Collection had greater correlations with age for both the indices than Whites. These differences were only statistically significant (Table 5) for the vault suture system.

No statistically significant sexual differences were found in any population group (Table 5).

If we consider *all the suture closure indices* (Tables 3 and 4) at the same time, the greatest correlations with age were for those that have been derived from the endocranial data. The composite score shows the greatest Z/se, followed with very small differences, by the endocranial closure index and the endocranial obliteration coefficient.

The ectocranial closure index and obliteration coefficient have larger correlations with age than vault and lateral-anterior composite scores.

Evaluation of the Methods on the Terry Collection

Masset—Table 6 shows that the endocranial formulae of Masset are more accurate than the ectocranial when applied to the Terry Collection. Furthermore, these formulae are more accurate for Whites than for Blacks and for males than for females.

Masset's technique was more accurate in the Terry Collection sample when it was applied to the age group between 50 and 70 years (Table 7).

Acsádi and Nemeskéri—Very similar results to those obtained for Masset have been found when the Acsádi and Nemeskéri method was applied to the Terry Collection. In this case only endocranial sutures were used as the authors recommended.

This method is again more accurate in Whites and males (Table 6), as judged by the inaccuracy and bias measures we calculated. Furthermore, this technique was more accurate in the Terry Collection sample when it was applied to the age group between 50 and 70 years (Table 7).

Baker—The Baker method could not be checked for inaccuracy and bias because it does not provide specific formulae or tables for estimating the age at death (12). However, irrespective of sex and population, the two general rules that emerged from his study were examined.

The first rule states that ''if the cranium is completely open endocranially, the individual is 27 years of age or younger.'' In the studied sample from the Terry Collection, 60 specimens have all the sutures open. From these 60 individuals only 37 were 27 years of age or younger, the other 23 were older. In the Baker study of modern autopsy crania, the rule was applicable in 96.0 percent of individuals examined.

According to the second rule, ''if the cranium is completely closed, endocranially, the individual is 26 years of age or older.'' Within the Terry Collection sample, of 357 crania with all of their sutures closed, only one was younger than 26 years (25 years of age). In the Baker sample, the rule was applicable in 98.4 percent of individuals studied.

Meindl and Lovejoy—Inaccuracy (Table 6) is very similar for vault and lateral-anterior suture systems. Both systems are more accurate for Blacks and males in the Terry Collection. Furthermore, this technique was more accurate in the Terry Collection sample when applied to the age group between 25 and 50 (Table 8).

Comparison of All Methods

Table 6 shows that the most accurate methods when applied to the Terry Collection were those which consider endocranial suture closure. The methods of Acsádi and Nemeskéri and Masset were the most accurate in all the subsamples (by population, sex, sex within population and in total). We feel that all methods studied are of value, and that the relative accuracy we found in this study theoretically could vary in application with other populations.

However, if the total sample is considered by age categories (Tables 7 and 8). The most accurate methods were:

- Masset endocranial formulae for individuals of 20 years or younger.
- Acsádi and Nemeskéri table for individuals between 21 and 25 years.
- Meindl and Lovejoy tables for individuals between 26 and 50.
- Masset ectocranial formulas for individuals between 51 and 60 years and endocranial formulas between 61 and 65 years.
- Acsádi and Nemeskéri table for individuals from 66 years or older.

Conclusions

We have learned that while none of the techniques described herein are highly accurate in predicting age at death, the accuracy varies within different age categories. This may suggest that prudent use of the methods collectively may increase the accuracy. Of course, accuracy and/or selection of methodology may be influenced by postcranial indicators, if available.

We also found differences between the sexes and between population groups in the accuracy of the techniques. This suggests that our results may differ from those estimated from skeletal samples of other populations from other geographical areas.

We encourage such research and, in the future, we will compare age estimation from cranial suture closure with estimation from other skeletal indicators in our research of age changes in the Terry Collection.

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