A Test of Meindl & Lovejoy's Method of Estimating Adult Age at Death from Cranial Suture Closure

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ABSTRACT

Nearly two decades ago, Meindl & Lovejoy (1985) introduced a new method of estimating adult age at death from ectocranial suture closure. Using the Hamann-Todd Collection, they recorded the degree of closure at a number of discrete, 1 cm long landmarks distributed over the upper vault and within the infratemporal fossa. These scores are summed, and the sum is then used to generate an age estimate. While widely used by forensic anthropologists and bioarcheologists, the technique has not been extensively tested on 20th century populations. The current study examines a number of issues raised in the original study by using two known-age samples: 100 African- and European-American males and females from the Terry Collection, and 200 European-American males and females from modern forensic cases and cadavers. Each sample was carefully constructed so that each decade from the 20's through the 80's was equally represented, avoiding problems produced by skewed age distributions. Correlation coefficients between single or summed landmarks and age are very similar to those found in the original study. However, analysis of covariance suggests that there are significant differences in suture closure by sex and/or ancestry in the new samples. Furthermore, the landmarks in the infratemporal fossa (the "lateral anterior system") do not appear to be substantially more effective than the landmarks on the vault. Inaccuracy and bias statistics show that mean prediction error is comparable to other methods of age estimation from the skeleton, but the Meindl & Lovejoy method tends to underestimate age at death.

INTRODUCTION

Since the publication of Todd & Lyon's (1924) landmark study on cranial suture closure, skeletal biologists have repeatedly expressed concern that estimating age at death from the sutures is less accurate than other methods. Recent work (for example, Nawrocki 1998) has attempted to clarify the utility of sutures using either anatomical or archeological populations. However, no comprehensive, controlled studies using recent populations have been conducted. The current study is an outgrowth of recent research by our laboratory (Zambrano 2005a, 2005b) designed specifically to fill this gap in the literature.

Meindl & Lovejoy (1985) essentially resurrected the use of cranial sutures in age estimation with a study that used the Hamann-Todd ("H-Todd") Collection of skeletons, derived from anatomical dissecting rooms and now stored at the Cleveland Museum of Natural History. They scored closure at a number of restricted areas on the ectocranial (external) surface of the cranium and constructed estimation tables based on summations of scores from combinations of either 5 or 7 different suture areas. In general, they concluded that (1) ectocranial sutures could indeed give general estimates of age at death with fair accuracy, (2) the sutures of the lateral anterior aspect of the cranium are more accurate than those of the upper vault proper, (3) ectocranial sutures are more accurate than endocranial (internal) sutures, and (4) neither sex or ancestry influenced the accuracy of the age estimations. Because the Meindl & Lovejoy ("M&L") method is used by many forensic anthropologists working with modern populations, a formal test of their method with other samples is warranted.

MATERIALS & METHODS

(1) Terry Collection sample, National Museum of Natural History, Smithsonian Institution, Washington DC:
- **n = 100** African- and European-American individuals (TABLE 1);
- all have known ages at death, sex, & ancestry;
- similar to H-Todd, representing a late 19th & early 20th century lower-class population
- individuals were selected & scored by SPN (see Nawrocki 1998).

(2) Recent sample from various facilities in the U.S.:
- total **n = 200** European-American individuals (TABLE 1);
- Maxwell Museum of Anthropology, Albuquerque NM (**n = 102**);
- Bass Donated Collection, U. of Tennessee, Knoxville TN (**n = 78**);
- University of Indianapolis (**n = 20**);
- all have known ages at death, sex, & ancestry;
- all were from recent forensic cases & cadaver donations;
- specimens from Albuquerque & Knoxville were scored by CJZ for his MS thesis (Zambrano 2005a)
- specimens from Indianapolis were scored by SPN.

(3) Prior to collecting his data, CJZ was carefully trained by SPN in the method of suture scoring and landmark identification, to minimize the possible effects of interobserver error.

(4) Both samples were carefully constructed (FIGURE 1):
- approximately equal numbers of specimens were selected from each decade for each sex & ancestry subgroup;
- ages at death ranged from the early 20's through the late 80's;
- the age distributions are fairly flat & unbiased;
- mean ages for each subgroup are similar (mid-50's; TABLE 1).

Therefore, any differences in performace between subgroups should be real rather than a secondary result of unbalanced samples. Unfortunately, most tests of aging methods do NOT take into account differences in sample composition or mean age (Nawrocki 1998).

(5) No individuals were excluded for any reason barring damage; cases with asymmetrical closure were NOT treated as deviant and were thus included.

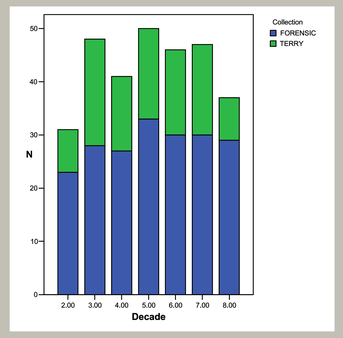
(6) A total of 10 ectocranial landmarks was scored on the right side for each skull (TABLE 2):
- in a few cases, data from the left side were substituted when the right side was missing;
- the M&L method uses 1-cm long areas of suture at each landmark, scoring closure on a 4-point scale, as follows:

0 = no closure
1 = 1 to 50% closure
2 = 51 to 99% closure
3 = total obliteration

TABLE 1: Composition of the Samples by Ancestry, Sex, & Age.

	EUROPEAN	AFRICAN	
TERRY FEMALES:	**n = 25** **mean = 54.8 yr** s = 18.3 yr range = 27 - 84	**n = 25** **mean = 52.6 yr** s = 18.6 yr range = 22 - 83	**TOTAL TERRY:**
TERRY MALES:	**n = 24** **mean = 55.2 yr** s = 17.7 yr range = 27 - 85	**n = 26** **mean = 52.4 yr** s = 19.5 yr range = 21 - 85	**n = 100** **mean = 53.7 yr** s = 18.3 yr range = 21 - 85
RECENT FEMALES:	**n = 70** **mean = 54.6 yr** s = 20.7 yr range = 20 - 89	–	**TOTAL RECENT:**
RECENT MALES:	**n = 130** **mean = 56.4 yr** s = 19.2 yr range = 20 - 89	--	**n = 200** **mean = 55.8 yr** s = 19.7 yr range = 20 - 89

FIGURE 1: Composition of the Samples by Decade.



RESULTS

(1) How do correlations between age and each suture site compare between the 3 samples? TABLE 2 gives Kendall's tau-b correlation values for each of the 10 landmarks individually, both with sexes combined and with sexes separated:
- the overall (**blue**) correlations for the H-Todd and Terry samples are remarkably similar;
- the overall (**blue**) correlations for the Recent sample are nearly always lower than for the 2 older collections;
- for the Terry sample, correlations are generally higher for females;
- for the Recent sample, correlations are generally higher for females for the vault group;
- for the Recent sample, correlations are generally higher for males for the lateral-anterior group;
- **Warning!** Many of the apparent differences between these correlation values are not statistically significant!

TABLE 2: Comparisons of Rank-Order Correlations (Kendall's Tau-b) of Each Suture Landmark with Age. "V" = vault system sutures; "L" = lateral anterior system sutures; bold values indicate the higher correlations in sex comparisons; all correlations are significant at the 0.05 level unless noted as "ns."

Landmark & (system)	H-Todd all n = 236	Terry all (m / f) n = 100 (50 / 50)	Recent all (m / f) n = 200 (130 / 70)
midlambdoid (V)	+0.43	+0.44 (**0.45** / 0.43)	+0.29 (0.16 / **0.46**)
lambda (V)	+0.43	+0.42 (0.42 / **0.46**)	+0.26 (0.17 / **0.36**)
obelion (V)	+0.37	+0.36 (0.28 / **0.45**)	+0.11 (ns / **0.19**)
anterior sagittal (V)	+0.35	+0.31 (0.22 / **0.42**)	+0.25 (0.18 / **0.36**)
bregma (V)	+0.38	+0.37 (0.28 / **0.45**)	+0.30 (0.21 / **0.45**)
midcoronal (V & L)	+0.38	+0.43 (0.33 / **0.54**)	+0.23 (0.18 / **0.34**)
pterion (V & L)	+0.51	+0.50 (0.43 / **0.56**)	+0.33 (**0.40** / 0.20)
sphenofrontal (L)	+0.43	+0.45 (0.40 / **0.48**)	+0.32 (**0.37** / 0.26)
inf. sphenotemp. (L)	+0.34	+0.26 (**0.40** / ns)	+0.32 (**0.40** / ns)
sup. sphenotemp. (L)	+0.29	+0.27 (**0.46** / ns)	+0.29 (**0.38** / ns)

(2) How do correlations between age and summed sutures compare between the 3 samples? TABLE 3 gives Pearson's correlation values for 3 summed suture scores, both with sexes combined and with sexes separated:
- the overall (**blue**) correlations are approximately equal between the vault & lateral-anterior systems for all 3 samples (M&L's values are not significantly different);
- the overall (**blue**) correlations for the Recent sample are markedly lower than for the 2 older collections;
- for the Terry sample, correlations are always higher for females;
- for the Recent sample, correlations are generally higher for females, particularly for the vault system.
- **Note:** M&L do not specify the distributional characteristics nor the mean age of their sample, either in sum or by sex or ancestry; therefore, comparisons between our samples and theirs must be made with caution. For example, the inclusion of a higher proportion of older individuals would tend to reduce correlation Values with age in that sample.

TABLE 3: Comparisons of Pearson's Correlations Between Summed Suture Scores and Age. Following M&L, fully open and fully closed ("inactive") individuals were excluded.

System	H-Todd all n = 236	Terry all (m / f) n = 100 (50 / 50)	Recent all (m / f) n = 200 (130 / 70)
sum for Vault (score = 1 - 20)	+0.50 (n = 199)	+0.59 (0.51 / **0.70**) n = 93 (47 / 46)	+0.41 (0.30 / **0.55**) n = 193 (126 / 67)
sum for Lat Ant (score = 1 - 14)	+0.57 (n = 193)	+0.57 (0.45 / **0.71**) n = 90 (43 / 47)	+0.41 (**0.49** / 0.27) n = 178 (117 / 61)
sum for **All Sutures** (score = 1 - 29)	--	+0.63 (0.55 / **0.74**) n = 97 (48 / 49)	+0.47 (0.47 / **0.50**) n = 195 (127 / 68)

(3) Does SEX or ANCESTRY affect the pattern or degree of suture closure in the Terry sample? TABLE 4 gives the results for Analyses of Covariance (ANCOVA) using the following model:

SUMMED SUTURE SCORE = SEX + ANCESTRY + SEX*ANCESTRY + AGE

where SEX and ANCESTRY are categorical main effects, SEX*ANCESTRY is the interaction between them, and AGE is a continuous covariate. Note that:
- SEX is significant only for all sutures summed, indicating that males & females differ in suture closure patterns &/or rates;
- the interaction SEX*ANCESTRY is significant for the lateral anterior system & for all sutures combined, indicating that at least 1 subgroup (e.g., Euro females) significantly differs from the others in suture closure patterns &/or rates;
- not surprisingly, AGE significantly affects suture closure in all 3 systems;
– similar results were obtained by Nawrocki (1998) using endocranial & palatine sutures – SEX & ANCESTRY were found to significantly affect patterns & rates of suture closure;
- prior testing not reported here indicates no problems with homogeneity of slopes, & so the use of ANCOVA is appropriate.

TABLE 4: Summaries of ANCOVAs on Summed Suture Scores for the Terry Sample. All individuals were included (n = 100 for each test). "Yes" indicates that the effect is significant at the 0.05 level; %'s indicate the total variance in suture closure attributable to that variable (eta-squared); adjusted r-squared values for the model are given in the last column.

System	SEX	ANCESTRY	SEX* ANCESTRY	AGE	adj r^2
sum for Vault (score = 0 - 21)	no	no	no	yes (41%)	0.41
sum for Lat Ant (score = 0 - 15)	no	no	yes (8%)	yes (45%)	0.46
sum for **All Sutures** (score = 0 - 30)	yes (5%)	no	yes (5%)	yes (44%)	0.46

(4) Does SEX affect the pattern or degree of suture closure in the Recent Sample? TABLE 5 gives the results for Analyses of Covariance (ANCOVA) using the following model:

SUMMED SUTURE SCORE = SEX + AGE

- SEX is significant for the lateral anterior system & for all sutures summed, indicating that males & females differ in suture closure patterns &/or rates;
- not surprisingly, AGE significantly affects suture closure in all 3 systems;
- as reflected by the lower correlation values discussed above, the r-squared values for the ANCOVA models for the Recent sample are lower than those obtained for the Terry Sample, indicating that less variability in suture closure can be explained.

TABLE 5: Summaries of ANCOVAs on Summed Suture Scores for the Recent Sample. All individuals were included (n = 200 for each test); see Table 4 for additional details.

System	SEX	AGE	adj r^2
sum for Vault (score = 0 - 21)	no	yes (21%)	0.22
sum for Lat Ant (score = 0 - 15)	yes (10%)	yes (26%)	0.32
sum for **All Sutures** (score = 0 - 30)	yes (7%)	yes (27%)	0.31

(5) How well do M&L's predicted values for AGE perform when applied to the new samples? TABLE 6 presents bias and inaccuracy (mean error) values for each sample using the aging guidelines in M&L. Because the oldest individual in M&L's study was 76 years old, we excluded all individuals older than 76. Inaccuracy is the average error (estimated minus actual) regardless of sign, while bias indicates the typical direction of the errors:
- inaccuracy hovers around 12 to 14 years in the Terry sample; the average age estimate will be off by about that amount;
- bias is always negative, indicating that the M&L method tends to underestimate the age of individuals;
- errors for European males are lower than for females;
- errors for the lateral anterior system are slightly lower than for the vault system but not by very much;
- inaccuracy & bias is higher for the Recent sample, & bias is still negative;
- additional tests not discussed here indicate that bias becomes negative in the 40's in all groups, suggesting that the M&L aging guidelines becomes less applicable by middle age & diverge widely by older age.

TABLE 6: Average Error (Inaccuracy & Bias) for Both Samples Using the M&L Aging Standards . "Inactive" individuals were excluded; numbers in parentheses are sample sizes.

Terry Sample:	Vault System inac	Vault System bias	Lateral Anterior System inac	Lateral Anterior System bias
All subgroups	**13.1** (80)	**-9.8** (80)	**12.5** (77)	**-8.7** (77)
All females	**13.2** (39)	**-11.0** (39)	**12.7** (40)	**-8.9** (40)
All males	**13.0** (41)	**-8.8** (41)	**12.2** (37)	**-8.5** (37)
All Africans	**13.4** (41)	**-9.0** (41)	**13.3** (38)	**-8.7** (38)
African females	**12.3** (20)	**-9.6** (20)	**11.9** (20)	**-7.8** (20)
African males	**14.4** (21)	**-8.5** (21)	**14.8** (18)	**-9.7** (18)
All Europeans	**12.8** (39)	**-10.7** (39)	**11.7** (39)	**-8.6** (39)
European females	**14.2** (19)	**-12.4** (19)	**13.6** (20)	**-9.9** (20)
European males	**11.5** (20)	**-9.1** (20)	**9.8** (19)	**-7.3** (19)
Recent Sample:	**inac**	**bias**	**inac**	**bias**
All Europeans	**14.7** (155)	**-10.5** (155)	**14.3** (141)	**-11.0** (141)
European females	**15.5** (54)	**-10.9** (54)	**16.6** (48)	**-12.8** (48)
European males	**14.3** (101)	**-10.3** (101)	**13.2** (93)	**-10.1** (93)

CONCLUSIONS

(1) Correlations between suture closure and age are similar between the Hamann-Todd and Terry Collections but are notably lower for the modern Recent sample.

(2) The lateral anterior system of suture sites is not better in age estimation than the vault system, contra Meindl & Lovejoy.

(3) There appears to be significant variation in the rate and/or pattern of suture closure between males and females as well as between different ancestry/sex subgroups, contra Meindl & Lovejoy.

(4) Overall error rates for the Meindl & Lovejoy aging criteria are not much different from other macroscopic skeletal aging technique when age ranges between studies are controlled for.

(5) The M&L method strongly underestimates the age of the new samples, and thus revisions to their guidelines are recommended.

LITERATURE CITED

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