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Application of Lamendin's Adult Dental Aging Technique to a Diverse Skeletal Sample

REFERENCE: Prince DA, Ubelaker DH. Application of Lamendin's adult dental aging technique to a diverse skeletal sample. J Forensic Sci 2002;47(1):107–116.

ABSTRACT: Lamendin et al. (1) proposed a technique to estimate age at death for adults by analyzing single-rooted teeth. They expressed age as a function of two factors: translucency of the tooth root and periodontosis (gingival regression). In their study, they analyzed 306 singled rooted teeth that were extracted at autopsy from 208 individuals of known age at death, all of whom were considered as having a French ancestry. Their sample consisted of 135 males, 73 females, 198 whites, and 10 blacks. The sample ranged in age from 22 to 90 years of age. By using a simple formulae ($A = 0.18 \times P + 0.42 \times T + 25.53$, where A = Age in years, P = Periodontosis height × 100/root height, and T = Transparency height × 100/root height), Lamendin et al. were able to estimate age at death with a mean error of ± 10 years on their working sample and ± 8.4 years on a forensic control sample.

Lamendin found this technique to work well with a French population, but did not test it outside of that sample area. This study tests the accuracy of this adult aging technique on a more diverse skeletal population, the Terry Collection housed at the Smithsonian's National Museum of Natural History. Our sample consists of 400 teeth from 94 black females, 72 white females, 98 black males, and 95 white males, ranging from 25 to 99 years. Lamendin's technique was applied to this sample to test its applicability to a population not of French origin. Providing results from a diverse skeletal population will aid in establishing the validity of this method to be used in forensic cases, its ideal purpose.

Our results suggest that Lamendin's method estimates age fairly accurately outside of the French sample yielding a mean error of 8.2 years, standard deviation 6.9 years, and standard error of the mean 0.34 years. In addition, when ancestry and sex are accounted for, the mean errors are reduced for each group (black females, white females, black males, and white males).

Lamendin et al. reported an inter-observer error of 9 ± 1.8 and 10 ± 2 years from two independent observers. Forty teeth were randomly remeasured from the Terry Collection in order to assess an intra-observer error. From this retest, an intra-observer error of 6.5 years was detected.

KEYWORDS: forensic science, skeletal age at death, adults, teeth, Lamendin

Lamendin's Adult Aging Technique Applied to the Terry Collection

This research analyzed the accuracy of the Lamendin et al.'s (1) adult dental aging technique. Lamendin et al. (1) used two of Gustafson's (2) factors to estimate age at death for adults: translucency of the tooth root and periodontal regression. Their sample consisted of 306 teeth extracted from 208 individuals all considered as having a French ancestry. The sample ranged from 22 to 90 years and consisted of 135 males and 73 females, of which 198 were white and 10 were black.

Periodontosis, or gingival regression, is caused by "the degeneration of the soft tissue surrounding the tooth (as) it progresses from the neck of the apex of the root (and) appears as a smooth and yellowish area below the enamel and darker than it but clearer than the rest of the root" (1). This measurement was taken from the labial surface and recorded the "maximum distance between the cementoenamel junction and the line of soft tissue attachment" (1).

Transparency of the tooth root is a physiologic feature that does not appear before age 20 (1). Transparency is a result of the deposition of hydroxyapatite crystals in the dentin tubuli and is emphasized when the tooth is placed on a light-box (1). In the original study, transparency was measured from the labial surface with the assistance of a negatoscope (Power 16 watts). Lamendin chose the labial surface to take measurements because the translucency "is usually the highest (there) and . . . (periodontosis) is less susceptible to be influenced by pathologic factors such as infections" (1).

The final measurement that was recorded was the root height. The root height measurement was the distance "between the apex of the root and the cementoenamel junction" (1), also measured on the labial surface.

From multiple regression analysis, Lamendin et al. (1) established the following equation for the determination of age at death from dental features: $A = (0.18 \times P) + (0.42 \times T) + 25.53$, where A represents age in years, P represents the periodontosis measurement X 100/root height, and T represents the measurement of transparency of the root X 100/root height. In their study, the researchers stated that the central incisors rated best at age estimation using this technique.

This study applied the Lamendin et al. (1) method to the Terry Collection. This skeletal collection is housed at the National Museum of Natural History, in Washington, D.C. The skeletons were collected between 1900 and 1965 and contain over 1600 disarticulated individuals of known sex, ancestry, age at death and in most cases, cause of death (3). The purpose of this study was to determine the accuracy, precision, and applicability of this method when applied to a diverse, nonFrench skeletal sample. Ancestry and sex were tested for their significance and effect on estimating age at death using Lamendin's formula.

Materials

The sample consisted of 400 single rooted teeth (distribution Table 1), 205 maxillary, and 195 mandibular, extracted from 359 individuals (age 25 to 99 years, with a mean age of 52.67 years and

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Received 29 Jan. 2001; and in revised form 16 April 2001; accepted 16 April 2001.

TABLE 1—*Frequency of Terry Collection tooth distribution.**

Frequencies Level	Count
LC	30
LC_	26
LI1	34
LI1−	23
LI2	29
LI2−	22
LP3	6
LP3−	16
LP4	4
LP4−	12
RC	32
RC_	27
RI1	38
RI1−	16
RI2	20
RI2−	20
RP3	5
RP3−	19
RP4	7
RP4−	14
Total	400
20	Levels

*Mandibular teeth are presented by a dash symbol after the tooth.

a standard deviation of 14.95 years): 94 black females (age 25 to 99 years, mean 52.10, standard deviation 17.36), 72 white females (age 27 to 90 years, mean 56.95, standard deviation 14.11), 98 black males (age 26 to 76 years, mean 47.76, standard deviation 12.96) and 95 white males (age 27 to 85 years, mean 53.88, standard deviation 13.72). Two teeth, both from white females (804R, 1106) were extracted by applying acetone. All other teeth had either already separated from the alveolus or were manually dislodged. When permitted, maxillary teeth were chosen over mandibular and central incisors were also chosen over other teeth, in accordance with the original research. A sliding digital caliper was used to take measurements in millimeters. A light-box was used to illuminate the translucency of the tooth root. All data were analyzed using the SAS statistical package JMP-IN (4).

Methods

The Terry Collection number, sex, and ancestry of each individual were recorded, followed by the measurements taken from each tooth. Following the technique outlined in Lamendin et al. (1), the root height and periodontosis (Fig. 1) were measured under a desk lamp. The tooth was then placed on the light-box to obtain the translucency measurement (Fig. 2). All measurements were recorded in millimeters and taken from the labial surface. The formula used by Lamendin et al. (1) was applied to estimate age at death. The data were analyzed using two-way crossed ANOVA in order to determine if sex and ancestry had any effect on the accuracy of estimating age at death using Lamendin's formula.

Results

Applying Lamendin's technique to the Terry Collection produced a mean error of 8.23 years, with a standard deviation of 6.87 years, and a standard mean error of 0.34. Figure 3 shows the distribution of the difference between the estimated age and the actual age. The black line simulates a normal curve, which the distribution fits well, with a slight negative skew.

Table 2 is a comparison of the results obtained by Lamendin et al. (1) and the results from the Terry Collection, both samples grouped into age cohorts. The results from the Terry Collection approximate the Lamendin original results, and in some cases (25 to 50-year-old groups), the Terry Collection yielded slightly lower mean errors. This table reveals that this technique is most accurate with the 30 to 69-year-old groups. Outside of this range, younger than 30 and older than 69, the mean errors are much higher. This holds true for Lamendin's original results, as well as the results from the Terry Collection.

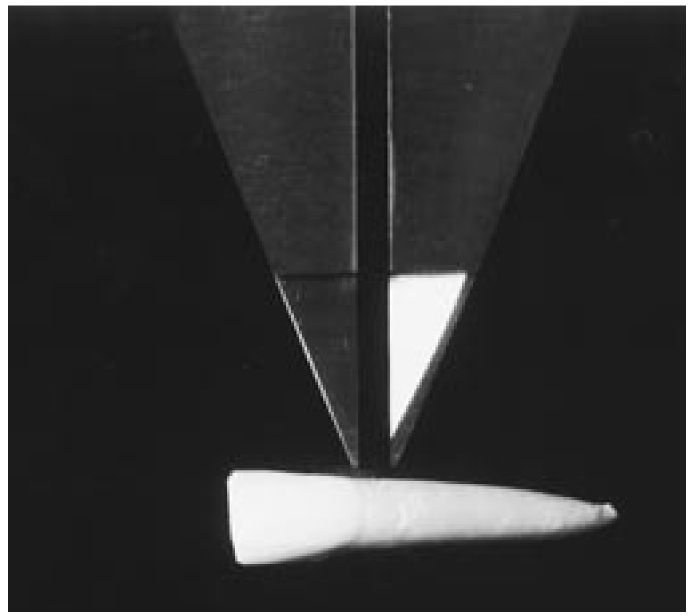


FIG. 1—*Periodontal regression measurement, which is the maximum distance from the cementoenamel junction to the line of soft tissue attachment.*

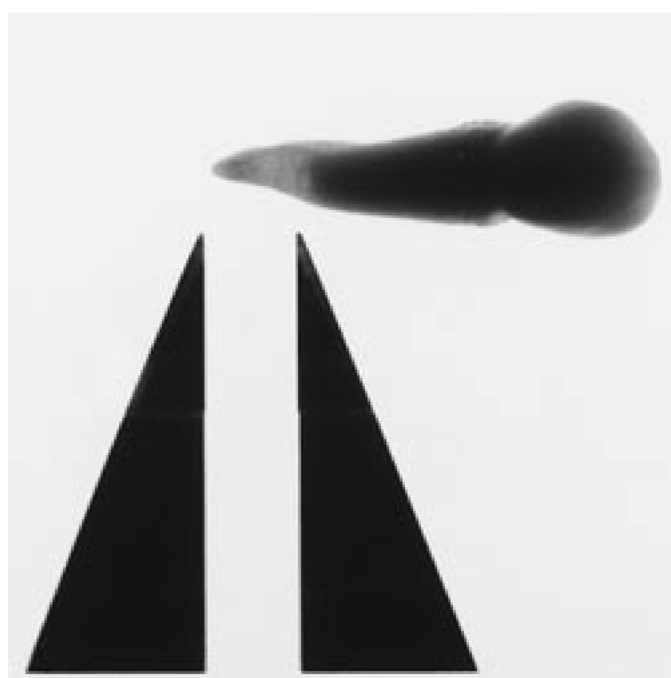


FIG. 2—*Measurement of the translucency of the tooth root.*

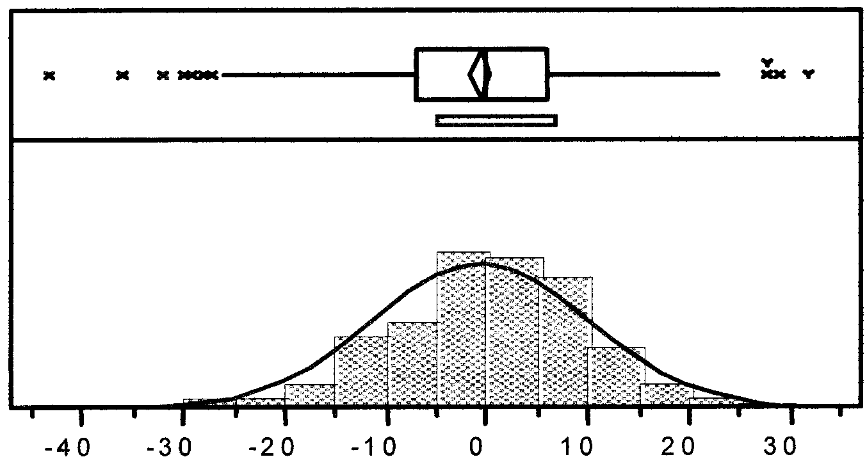


FIG. 3—*Distribution of differences (Estimated age-Actual age).*

TABLE 2—*Comparison of Mean Error (ME) between the results from Lamendin's original study* (L) *and the results from the Terry Collection* (T).

Age Intervals, Years	25 to 29	30 to 39	40 to 49	50 to 59	60 to 69	70 to 79	80 to 89	90 to 99	Total
Number of teeth	5 (L) 19 (T)	42 (L) 65 (T)	39 (L) 84 (T)	90 (L) 99 (T)	65 (L) 73 (T)	46 (L) 43 (T)	19 (L) 12 (T)	0 (L) 5 (T)	306 (L) 400 (T)
ME (years) Lamendin's	24.8	15.5	9.9	7.3	6.3	11.6	18.9	—	10
ME (years) Terry Collection	13.2	9.0	5.6	5.2	7.2	12.3	20.3	32.6	8.2

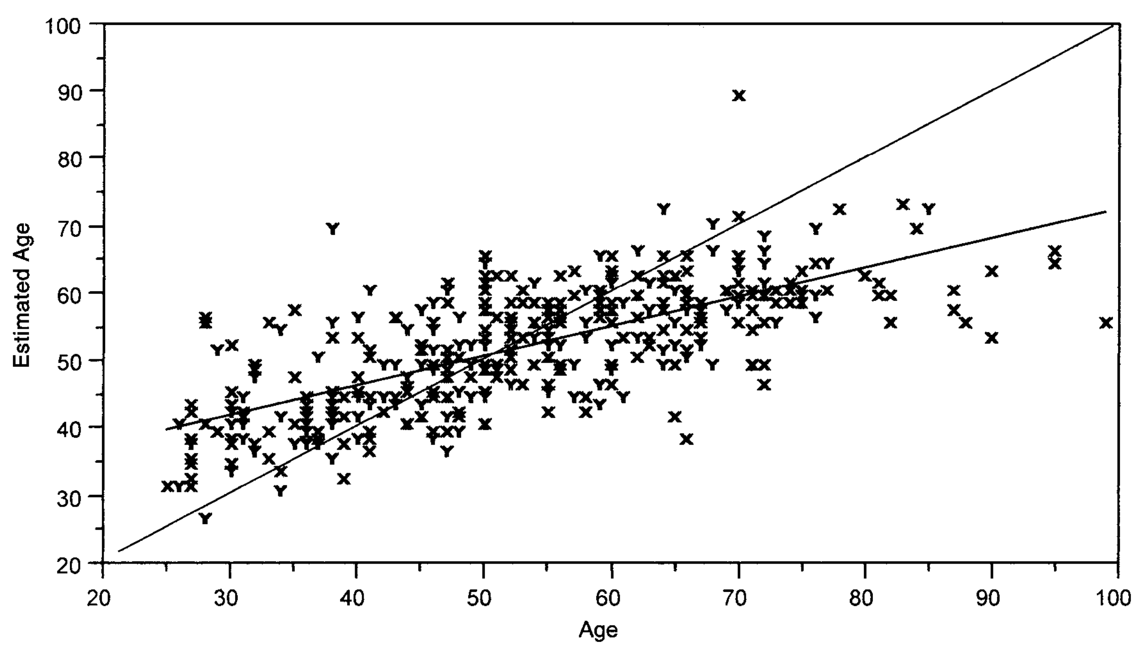


FIG. 4—*Estimated age plotted against Actual Age.*

Figure 4 is a scatterplot of the data where actual age is plotted along the horizontal axis and the predicted age using Lamendin's formula is plotted on the vertical axis. In the plot, the Xs represent the female subjects and the Ys represent the male subjects. This graph represents all 400 teeth analyzed. The black line going across the plot is the line of best fit. This plot shows that the younger individuals were overestimated in age while the older individuals were underestimated in age. From regression correlation, an R^2 of 0.49 was obtained, with a p-value less than 0.001.

Figure 5 represents the mean error (the average difference between estimated age and actual age) for the four groups (these values are also shown in Table 7). The black females have the highest mean error of 9.63, while the black males have the lowest mean error of 7.17. The white females and white males show a similar trend. The white females have a higher mean error than the white males: 8.46 and 7.66 respectively. The ages of black females are slightly underestimated, while the ages of black males are overestimated on average. Both white populations are underestimated on average. (One white male #45R is identified as white, but records also mention a Mexican ancestry. This individual is excluded from certain ancestry analyses due to this factor). The black line running horizontally is the mean difference (8.23).

Ancestry and sex were also assessed individually. Figure 6 represents the effect that ancestry alone has for estimating age at death. The mean difference for the first group (black sample) is 8.36; standard deviation 7.08; standard error mean 0.50 and for the second group (white sample) the mean difference is 8.06; standard deviation 6.62; standard error mean 0.47.

Figure 7 shows the effect of sex using Lamendin's dental aging method. The mean error for the female group is 9.05; standard deviation 7.86; standard mean error 0.56 and the mean error for the

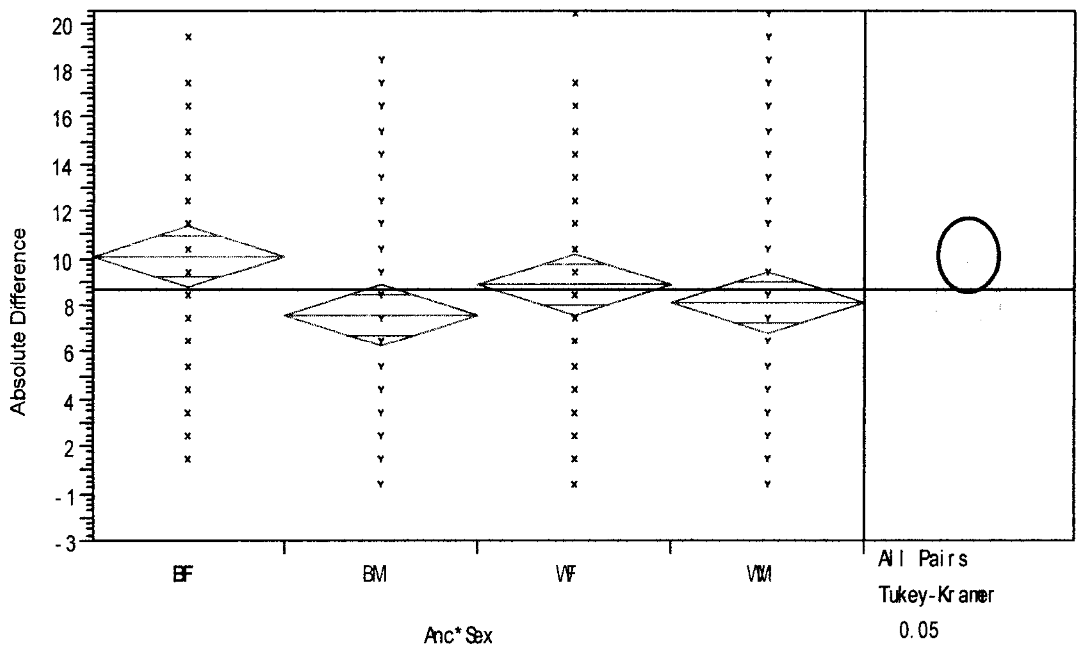


FIG. 5—*The effect of ancestry and sex on Lamendin's Technique (Black females highlighted).*

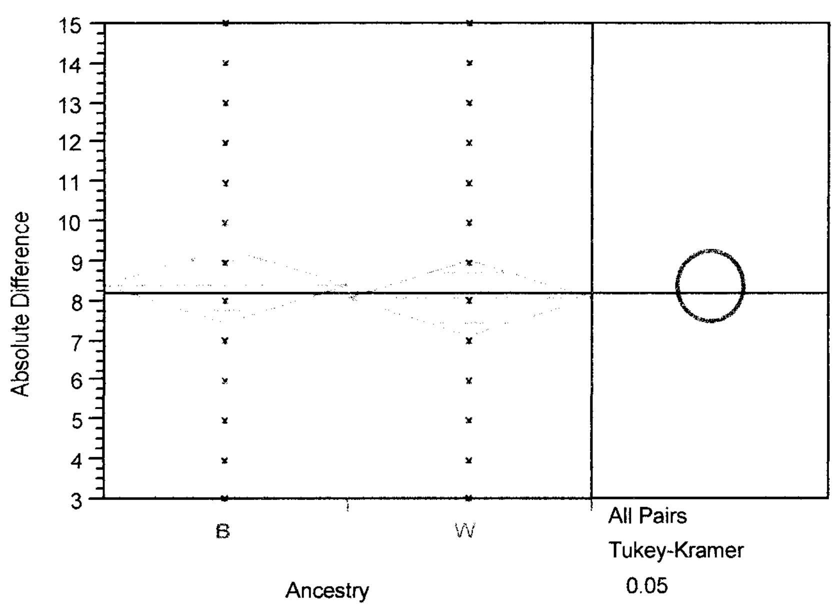


FIG. 6—*Nonsignificance of ancestry using Lamendin's Technique.*

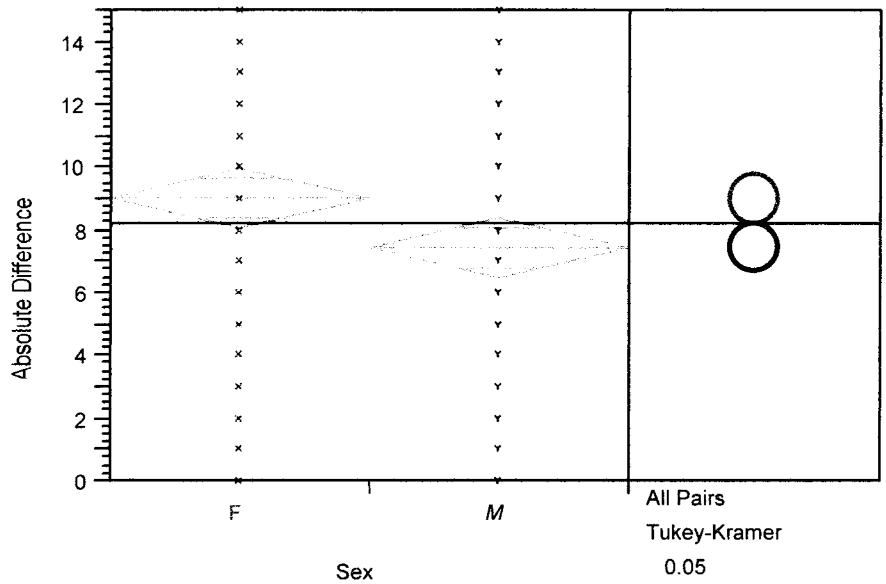


FIG. 7—*Significance of sex on Lamendin's Technique.*

male group is 7.41; standard deviation 5.62; standard mean error 0.40.

Discussion

In Figs. 5–7, the diamonds show the mean difference for each group. The circles to the right of the graph are another representation of the diamonds. The circles overlapping one another represent some similarity. In Fig. 5 the diamonds reveal that the means of each group are relatively close, with the black females having the most divergence. The circle highlighted in thick black corresponds with the black females. The circles with the thin black lines correspond with the other three groups, indicating that there is not a significant difference between the four groups.

Figure 6 is similar, suggesting that ancestry does not have an effect on age estimation using this technique. It suggests that ancestry alone need not be considered when estimating age at death using Lamendin's technique and formula. The diamonds show the mean difference for each group and the circles to the right reveal that the two groups are not significantly different from one another. Ancestry alone does not have an effect on estimating age at death with this method. This is shown by the dramatic, almost complete overlap of the circles.

Figure 7 reveals that sex alone does have a significant difference at the 0.05 level on the estimate of age using Lamendin's formula on the Terry Collection. This is marked by the black circles to the right of the figure not overlapping with one another. This figure suggests that sex must be considered when employing this dental technique to estimate age at death. Sex, especially seen with the black female group, had a highly significant effect on the estimated age at death, at the 0.05 significance level, represented most clearly in Fig. 7 and Tables 3 to 6. Figure 5 illuminates that ancestry and sex combined do not have a significant effect on estimating age using Lamendin's formula.

The Lamendin technique faired well overall, but it was shown that sex may be a factor when employing this method, as revealed in Fig. 7. Lamendin et al. (1) did not find sex to be a significant factor in the original study using French subjects (135 males, 73 females). In the original study, Lamendin did not partition the subjects by age for the males and females. A possible suggestion for sex yielding a significant difference with the Terry Collection is the age distribution. Table 3 partitions the Terry Collection by age and Fig. 4 shows the male/female partitioning by age. Table 3 reveals that the older age groups (80 to 89; 90 to 99) have extremely high mean errors, 20.3 and 32.6 years, respectively. Referring to Fig. 4, most of the older specimens who belong to one of these two groups (80 to 89; 90 to 99) are female: 16 out of 17. Therefore, these specimens are affecting the overall mean errors for the two female groups; causing them to be high. Further research must be employed to determine if this sex difference (Fig. 7) is an actual sex difference or a result of an uneven sample distribution. Figure 4 also reveals a tendency to overestimate age on younger specimens and underestimate age older specimens. The trend to overestimate the young and underestimate the older subjects holds constant across all four subpopulations (black females, white females, black males, and white males).

This French technique produced a surprisingly low overall mean error and low mean errors for each of the four groups involved in the study. Even though the mean errors were relatively low, new equations separating the individuals by sex and ancestry lower the mean errors for each group. Modified equations relative to sex and ancestry are presented below. When working with forensic or archeological samples, sex and ancestry should be determined first, if possible. Although, ancestry was not a significant factor, the mean error is reduced when both factors (sex and ancestry) are considered.

The black males had the lowest mean error when compared to the other subgroups. Table 3 shows the parameters for the black male group. Using similar features from Lamendin's technique, the following formula was created to lower the mean difference for the black males: $A = 1.04(RH) + 0.31(P) + 0.47(T) + 1.70$.

In all the new equations, A represents the estimated age at death in years, RH is the measurement of root height in mm, P is the periodentosis measurement in mm $\times$ 100/root height, and T is the root translucency measurement in mm $\times$ 100/root height.

The new mean difference for this group is 6.24 years, standard deviation 4.97, standard mean error 0.50. The new mean differences are compared to the original mean differences in Table 7.

TABLE 3—*New formula for black male sample.*

Summary of Fit

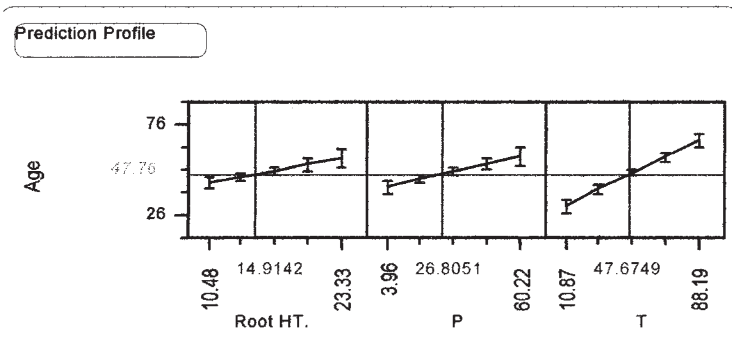
RSquare	0.619542
RSquare Adj	0.607653
Root Mean Square Error	8.115402
Mean of Response	47.76
Observations (or Sum Wgts)	100

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	10295.705	3431.90	52.1092
Error	96	6322.535	65.86	Prob>F
C Total	99	16618.240		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	1.7013392	5.403575	0.31	0.7536	-9.024732	12.427411
Root HT.	1.0488111	0.297041	3.53	0.0006	0.4591867	1.6384354
Calc. P	0.3054263	0.076013	4.02	0.0001	0.1545416	0.456311
Calc. T	0.4662727	0.044704	10.43	<.0001	0.3775362	0.5550091



This new equation yields a mean difference of 8.11 years, standard deviation 6.22, standard mean error 0.62 for the white females. The equation for the white females, as outlined in Table 4 is: $A = 1.10(RH) + 0.31\ (P) + 0.39\ T) + 11.82$. Table 5 outlines the formula for the black females: $A = 1.63(RH) + 0.48(P) + 0.48\ (T) + (-8.41)$. The new mean difference for the black females is 9.19 years, standard deviation 7.17, standard mean error 0.71. The white male sample is outlined in Table 6, and the new formula is:

$$A = 0.15(RH) + 0.29(P) + 0.39(T) + 23.17.$$

The new mean difference is 7.25 years, standard deviation 5.93, standard mean error 0.60. This equation is by far the closest to the original formula that Lamendin used. All the new formulas include root height in the equation. In Lamendin's original formula, root height was only used in calculation with periodontosis and translucency. Root height does lower the mean difference when incorporated into the formula.

Translucency is the most significant estimator of age, which is shown in Tables 3 to 6. Translucency, which is shown in the last graph in each table (T in mm), has the largest slope, which corresponds to the most significant effect in the formula.

A histogram of the difference estimates is portrayed in Fig. 8. The new mean difference is 7.70, standard deviation 6.19, and standard error of the mean 0.31 for the new residual ages. The new formulas reduced all parameters, 8.23, 6.87, and 0.34, respectively.

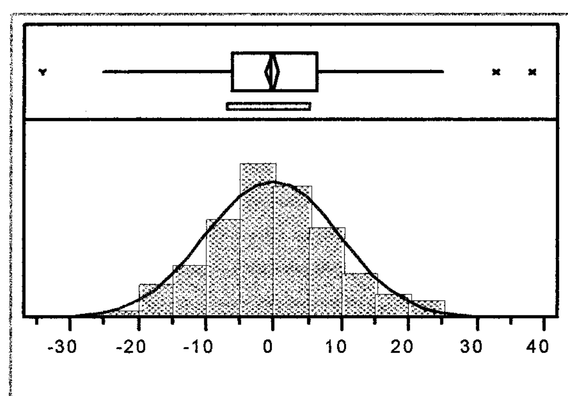


FIG. 8—*Distribution of new differences (New estimated age-Actual age).*

Figure 9 is a scatterplot of the predicted age using the new formula plotted against the actual age. Again, the Xs represent the female subjects and the Ys represent the male subjects. All 400 teeth are represented in the plot. As previously mentioned, the new formula lowered the mean errors and standard deviations for each group. A paired T-Test was run to determine if there was a significant difference between estimating age from the new and old formula on the Terry Collection. This was significant with a p-value less than 0.001. Applying the new formula to the Terry Collection, an R^2 of 0.56 was obtained with a p-value less than 0.001. As com-

TABLE 4—*New formula for white female sample.*

Summary of Fit

RSquare	0.472216
RSquare Adj	0.455722
Root Mean Square Error	10.41143
Mean of Response	56.95
Observations (or Sum Wgts)	100

Analysis of Variance

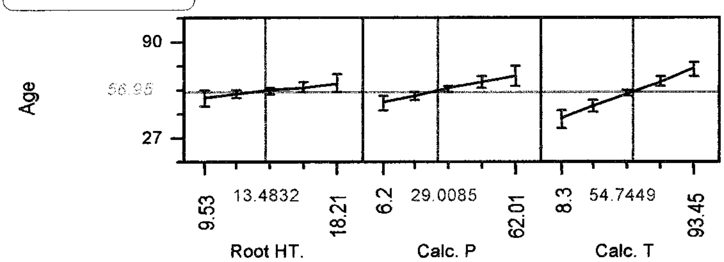
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	9310.558	3103.52	28.6308
Error	96	10406.192	108.40	Prob>F
C Total	99	19716.750		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	11.816207	8.172067	1.45	0.1515	-4.405309	28.037722
Root HT.	1.0998269	0.552127	1.99	0.0492	0.0038578	2.1957961
Calc. P	0.3133784	0.091338	3.43	0.0009	0.1320724	0.4946843
Calc. T	0.3875059	0.057361	6.76	<.0001	0.2736438	0.5013679

Effect Test

Prediction Profile



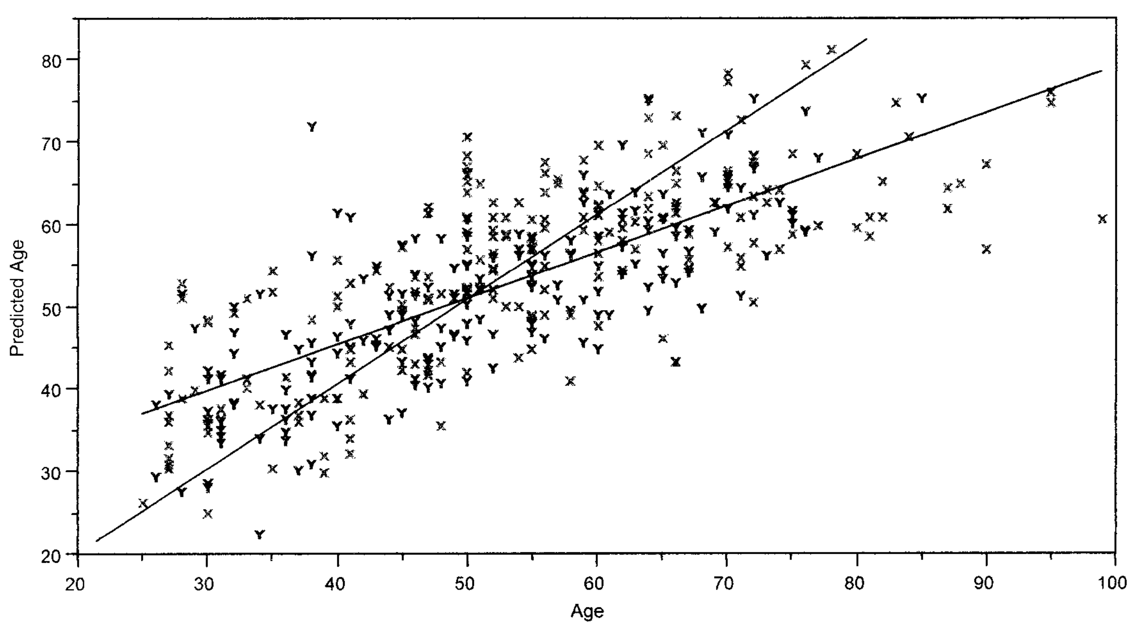


FIG. 9—*Predicted Age plotted against Actual Age using new formula.*

TABLE 5—*New formula for black female sample.*

Summary of Fit

RSquare	0.544623
RSquare Adj	0.530393
Root Mean Square Error	11.89553
Mean of Response	52.1
Observations (or Sum Wgts)	100

Analysis of Variance

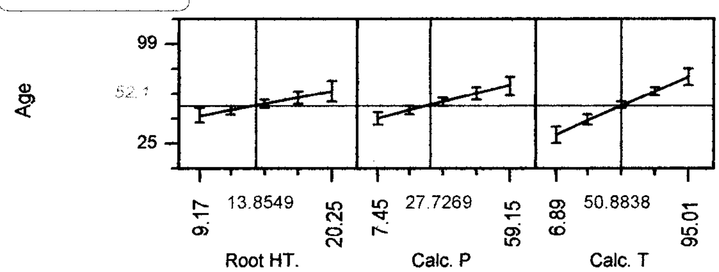
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	16246.660	5415.55	38.2715
Error	96	13584.340	141.50	Prob>F
C Total	99	29831.000		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	-8.407472	8.650278	-0.97	0.3335	-25.57823	8.7632916
Root HT.	1.6290258	0.543451	3.00	0.0035	0.5502785	2.7077731
Calc. P	0.4801214	0.104351	4.60	<.0001	0.2729844	0.6872585
Calc. T	0.4839498	0.063525	7.62	<.0001	0.357853	0.6100466

Effect Test

Prediction Profile



pared to the original scatterplot, the new formula produced a higher correlation between predicted age and actual age.

As mentioned above, Table 7 depicts the differences between the new formula statistics and the original results from the Terry Collection. In all groups the mean difference (the estimated − the actual age) is lower with use of the new formulas.

Conclusions

The research conducted on the Terry Collection employing Lamendin et al.'s (1) technique produced good results, comparable and lower in some cases, to the original French results, but it was demonstrated that sex and ancestry, especially sex, should be considered when estimating age at death using these dental features. When the new formulas accounted for sex and ancestry, the mean errors were reduced (Table 7). Sex should be taken into consideration when employing this dental technique to estimate age at death.

Age also has an effect on the accuracy of this method. In the original estimates, the young specimens were overestimated while the older specimens were underestimated in age. This technique is more accurate for the 30 to 69-year-olds (Table 2). Specimens younger than 30 and older than 69 produced much higher mean errors.

New formulas were created for each of the four subpopulations in the sample, even though ancestry was shown not to be a significant factor. The mean differences were lowered when ancestry was considered in addition to sex.

Incorporated into the new formulas was root height. In the original formula, this feature was used only in calculating the periodontosis (periodontosis in mm × 100/root height) and translucency (translucency in mm × 100/root height) factors to be used in the formula. Although root height was not significant at the 0.05 level, it did reduce the mean error when calculated in to the new formulas. Translucency was the most significant factor of the three (root height, periodontosis, and translucency), as shown in the graphs in Tables 3 to 6.

Factors that may contribute to error when employing this method would be hygiene, as mentioned in previous dental techniques, diet, and inter-observer error. Good hygiene, which is usually population specific, can contribute to the amount of periodontosis. Dental surgeries, such as gum grafting, may also effect true measurements of periodontosis. Diet may also be a confounding factor. For example, diet higher in sugars or acidity may effect the periodontosis measurement.

TABLE 6—*New formula for white male sample.*

Summary of Fit

RSquare	0.52009
RSquare Adj	0.504935
Root Mean Square Error	9.576177
Mean of Response	54.10101
Observations (or Sum Wgts)	99

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	9441.189	3147.06	34.3179
Error	95	8711.801	91.70	Prob>F
C Total	98	18152.990		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	23.167865	6.879174	3.37	0.0011	9.5109016	36.824828
Root HT.	0.1587159	0.396417	0.40	0.6898	-0.628276	0.9457076
Calc. P	0.2918081	0.079735	3.66	0.0004	0.133513	0.4501032
Calc. T	0.3850359	0.054312	7.09	<.0001	0.2772134	0.4928585

Effect Test

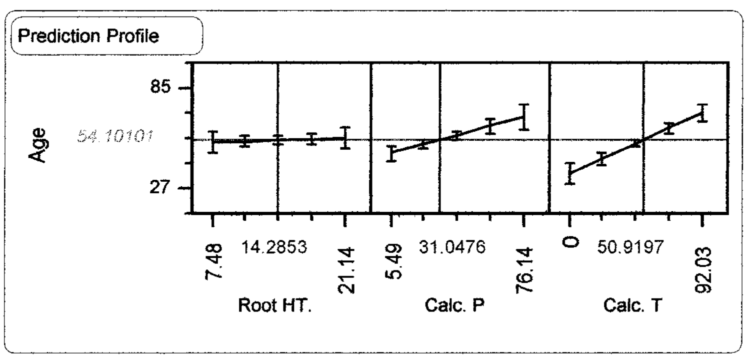


TABLE 7—*Comparison between Lamendin's Formula applied to the Terry Collection and New Formulas Applied to the Terry Collection.*

Group	New Mean Difference	Original Mean Difference	New Standard Deviation	Original Standard Deviation	New Standard Error Mean	Original Standard Error Mean
BF	9.19	9.63	7.17	8.37	0.71	0.84
BM	6.24	7.17	4.97	5.42	0.50	0.54
WF	8.11	8.46	6.21	7.31	0.62	0.73
WM	7.25	7.66	5.92	5.86	0.60	0.59
Overall	7.70	8.23	6.19	6.87	0.31	0.34

It has been shown (2) that the root resorbs with age. Measurements of root height may be mismeasured due to this change. This may be a factor in the error found in the older specimens in the sample.

Lamendin et al. (1) reported an inter-observer error of 9 ± 1.8 and 10 ± 2 years from two independent observers. Forty teeth were randomly remeasured from the Terry Collection by the first author in order to obtain an intraobserver error. From these measurements, an intraobserver error of 6.5 years was detected.

To examine interobserver error, 30 of the teeth utilized in the test for intraobserver error were examined by three individuals. These included one individual (*A*) who had some prior experience with the technique and two graduate students with no previous experience with the technique. Age was assessed using the original Lamendin technique by each observer independently. The resulting age estimates were then compared with those generated by the first author on her initial attempt. For Observer A, the interobserver error was 11 years with a standard deviation of 9.57 and a range of 0 to 37 years. For Observer B, the values were mean 6 years, with a standard deviation of 5.32 and range from 0 to 20 years. For Observer C, the values were mean 13 years, standard deviation 10.19 and a range from 0 to 37 years.

Although this method represents an important contribution to the estimation of adult age at death in forensic contexts, the data reported here and in the original study suggest that significant error may be possible with individual cases. The features described on some teeth are subject to varied interpretation and this can lead to variable age estimates (note the extreme example of 37 years reported above). Accordingly, we recommend that this technique be utilized in conjunction with others, especially in individual cases in which the two central attributes are difficult to interpret.

Future Research

Employing dental features has proven to be an accurate method of estimating age at death. Since the teeth are durable and are sometimes the only evidence available, further research in estimating age at death from dental features should be pursued. Using the method above, samples differing in hygiene and diet should be explored in addition to research assessing the effect of root resorption. As mentioned previously, the skeletons in the Terry Collection were obtained during the middle and first half of the twentieth century. Analysis should be conducted on a diverse contemporary sample to account for secular change.

Gustafson (2) pointed out that translucency of the tooth root and secondary dentin were the best correlated dental features to produce the most accurate age at death estimations. Further research should be conducted using these two features. Periodontosis is hard to determine sometimes and was considered one of the poorer indicators of age when compared to Gustafson's original six dental features.

When possible, all parts of the skeleton should be taken into consideration if they are available. Several adult aging techniques (1,5 to 14) should be consulted when estimating the age at death of an adult individual, as conferred by the studies incorporating multifactoral methods (15 to 17).

Acknowledgments

The authors thank the following individuals from the Smithsonian's Natural History Museum: Dr. David Hunt for assistance with the Terry Collection records, Dr. Douglas Owsley for loaning us his lighting equipment, and Kristin Montaperto and Sally Graver for assisting with the interobserver error study and manuscript preparation. Drs. Lyle Konigsberg and Joseph Skwish assisted with the statistical analysis, Dr. Bernard Wood critiqued various copies of the manuscript, and Dr. Murray Marks provided valuable feedback and assistance in manuscript preparation and photography.

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