

A test of the Lamendin method of age estimation in South African canines

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Abstract

Age estimation in unknown adult skeletons remains a considerable problem in forensic anthropology. In 1992, Lamendin and colleagues published a non-destructive method of age estimation on single rooted teeth. With this method, periodontosis and root transparency are judged against root height, and these are then used in regression formulae to estimate age. The aim of this study was to test the accuracy of the Lamendin method on a large sample of canines of South Africans, and if necessary to adapt the formulae for this population. A sample of known sex, age and population group was used. This included 537 upper and lower canines from 498 skulls, and included black males, black females, white males and white females. The age of the individuals ranged from 20 to 90 years. The original formulae gave relatively poor results, and in an attempt to obtain better accuracy the formulae were adapted with the current data. Even after adaptation of the formulae, the highest correlation between estimated age and actual age remained low ($R^2 = 0.41$), with mean errors ranging between 12 and 15 years. Periodontosis was better correlated with age than root transparency. The accuracy of the method was found to be much lower than what was originally published, but probably reflects biological reality and is on a par with other methods of adult age estimation.

Key words: canines, root transparency, root height, periodontosis, age estimation, forensic anthropology

1. Introduction

Age estimation in the adult human skeleton remains one of the most difficult challenges in forensic anthropology, and a variety of methods have been developed, tested and adapted to suit various populations. As teeth are the most durable of all human remains, much of the efforts have focused on the human dentition, and of particular interest here is the study published in 1992 by Lamendin et al. [1]. Dental attrition [2], secondary dentin deposition [3-5], and root transparency [6-16] have been among the many characteristics examined.

The Gustafson [17] study was a major landmark in this regard, as Gustafson used a combination of characteristics seen on a dental section to estimate age. His assessment included six features: gingival attachment level, root apex transparency, occlusal wear, amount of secondary dentine, cementum apposition, and root resorption. These were used in a combined formula to estimate age. The Gustafson sample comprised of only 37 teeth from northern Europeans, aged 11 to 69 years [18-20], and has been criticized for its small size and subjective manner in which the scoring was done. The scores (estimated ages) obtained by Gustafson were highly correlated ($R=0.98$) with the known age, and he reported a very small error of estimate.

The Gustafson method or modifications thereof has since been tested and modified by a number of researchers in modern and historic populations [1, 8, 12, 15, 20-41]. Bang and Ramm [8] simplified Gustafson's method and focused on root transparency only. They also used a larger sample, and measured the length of the transparency in roots from intact, longitudinally sectioned specimens 400 μm thick. Three sets of regression formulae were developed. They found that 58% of the test sample was estimated within 4.2 - 4.7 years, and

79% within 9.2 - 10.5 years. As might have been expected, older individuals were underestimated. No difference between the sexes was detected in the degree of transparency. Root transparency as an age indicator has since been the focus of various studies [9-15]. Most research using Gustafson or revised methods reported a standard error ranging from 7.9 to 11.46 years. In general, root translucency showed the best correlation to age in most types of teeth.

The technique published by Lamendin and colleagues [1], broadly based on that of Gustafson, holds some advantages over the Gustafson method as it is not necessary to section a tooth and is easy to use. Two dental features - root transparency and periodontosis- are assessed in single rooted teeth. Both these variables are measured and expressed as an index value by relating these measurements to a fixed tooth measurement (root height). Using multiple regression, they suggested the formula:

$$A (\text{age}) = (0.18 \times P) + (0.42 \times RT) + 25.53$$

where P = periodontosis height x 100/root height, RT = root transparency x 100/root height.

This regression formula was found to be suitable for both sexes and all single rooted teeth, although upper incisors gave the best results in older adults. The value of 25.53 (the constant) reflects the age at which root transparency usually appears, and this feature is said to never appear before the age of 20 [1]. Lamendin et al. [1] found that the mean error between the actual and estimated age was ± 10 years for their working sample, and ± 8.4 years for their control sample. However, they did report large errors for some individuals, especially those under 40 and over 80 years of age.

Subsequent testing of the method or modifications thereof could mostly not demonstrate the same success rates [5, 42-45]. In general, it was found to be more accurate in the middle to older age groups and root transparency had a better correlation with age than periodontal

recession. As is the case with most age estimation techniques, age of older individuals tends to be underestimated, and those of younger individuals overestimated [43]. Post-mortem factors may also influence the results [46].

The aim of this study was to test the accuracy of the Lamendin technique of age estimation in a South African sample. The method published by Lamendin et al. [1] can be used on any single rooted tooth, although they found the best results with upper incisors in individuals between ages 40 and 70. For the current study upper and lower canines were used, as they are the most frequently preserved of the anterior teeth, and have been found to give relatively good results [47]. If necessary, the data obtained will be used to adapt the Lamendin formula to better fit the South African sample so that more accurate age estimates can be obtained.

2. Materials and methods

The sample of skeletons of known sex, age and population group used in this study was obtained from the Pretoria Bone Collection (University of Pretoria, South Africa) [48] and Raymond A. Dart Collection of Human Skeletons (University of Witwatersrand, Johannesburg, South Africa) [49]. Skeletons in these collections come from cadavers used for dissections by medical students and they thus represent modern individuals, mostly of lower socio-economic status. Canines of these individuals were carefully dislodged manually before they were measured.

As is the case with many skeletal collections, older individuals are overrepresented and it is difficult to find a large sample of younger individuals. Although it was attempted to find suitable sample sizes of both black and white South Africans, the final sample lacked sufficient numbers of especially younger white individuals. For this group, the results therefore remain tentative.

Table 1. Number of teeth per age category

Age categories	20-29	30-39	40-49	50-59	60-69	70-79	80+	Total
Black males	31	43	70	46	47	28	3	268
Black females	22	19	22	23	17	3	1	107
White males	-	7	9	23	26	28	9	102
White females	4	-	4	7	12	18	15	60
Total	57	69	105	99	102	77	28	537

The upper and lower canines of 498 individuals were measured (537 teeth). Table 1 shows the number of upper and lower canines that were assessed, per age category, in each of the sex-population groups. Although the Lamendin method is usually used for individuals older than 25, individuals from 20 years of age and onwards may display root transparency [1]. The black males were best represented in all age groups, with a total of 268 teeth assessed. For white females, only 60 canines could be found. In all cases the left canines were used, but where absent were substituted with the right canine. After the teeth were carefully extracted from the tooth sockets, they were gently rinsed to get rid of deposits that could obscure especially the root transparency.

Three measurements were recorded on the labial surfaces of each canine: root height, root transparency and periodontosis [1]. Root height was taken as the distance between the apex of the root and the cemento-enamel junction of the canine. Root transparency was observed by viewing the tooth against a bright light source, like a light box or natural light, and measuring it from the apex of the root to the maximum height of visible transparency within the root. The measurement of periodontal height or periodontosis aimed at recording the gingival tissue degeneration. This was measured as the maximum distance from the cemento-enamel junction to the line left by the soft tissue attachment on the neck and/or root of tooth. Each measurement was repeated three times and recorded in an Excel spreadsheet, and the average was used in analyses. All the measurements were taken to the nearest millimetre.

Another researcher (inter-observer) also measured canines of 30 randomly selected crania. Intra- and inter-observer error tests for repeatability of measurements were done via an Intra Class Correlation, through OLS (ordinary least squares) and t-tests. The Intra Class Correlation (ICC) can fall in the range of greater or equal to zero or smaller or equal to one ($0 \leq \text{ICC} \leq 1$), where closer to one is the best result, i.e. 100% repeatable. The principal investigator could measure all three parameters with ICC values above 0.9, indicating high repeatability. The inter-observer repeatability indicates how well the measurements between the principal investigator and another observer could be repeated. All of these values were above 0.8, except for the periodontosis (ICC 0.7161), which indicates that this measurement was fairly difficult to record reliably. T-tests performed for intra- and inter-observer observations indicated that no statistically significant differences existed between the means for any one of the three dental features as investigated by either the same or the second observer.

Root height, root transparency and periodontal height were plotted against age for upper and lower canines respectively, in each of the four sex-population groups, to determine whether a significant correlation exists between each of the variables and age. Following this, the root transparency and periodontal height were expressed as functions of root height and these variables were substituted into the original Lamendin formula to estimate the age of each of the individuals. These were then plotted against the real age by means of scatter plots, in order to assess the correlation between real and calculated ages. From this it was judged whether it was necessary to adjust the formulae for the specific populations under study.

The STATA package was used for all analyses. Ethics clearance for this research was obtained from the relevant committees.

3. Results

Table 2. Correlation coefficients (R^2) between age and root height, periodontosis and root transparency

	Root height	Periodontosis	Root transparency
Black males			
Upper canines	0.0044	0.3492	0.1267
Lower canines	0.0023	0.1815	0.1049
Black females			
Upper canines	0.0092	0.0680	0.1126
Lower canines	0.0243	0.1136	0.2143
White males			
Upper canines	0.0290	0.0221	0.0492
Lower canines	0.0059	0.0130	0.0705
White females			
Upper canines	0.0028	0.0188	0.0315
Lower canines	0.0298	0.3076	0.0165

Correlation coefficients for each of the measurements with actual age are shown in Table 2. In general all correlation coefficients were low. Root height was weakly negatively correlated with age in especially the white individuals, which indicates that the root may get somewhat shorter with age. Root height in itself thus does not change much with age, indicating that it is a relatively good parameter against which to standardize changes in root transparency and periodontosis. Periodontosis showed the highest positive correlations with advancing age, although only between 1.9% (upper canines, white females) and 34.9% (upper canines, black males) of age could be explained by increasing periodontosis. Only between 1.7% (lower canines, white females) and 21.4% (lower canines, black females) of age changes could be ascribed to increasing root transparency.

Variables for each individual were substituted into the Lamendin formula to obtain a predicted age. Figures 1 to 4 show the scatter plots of calculated ages versus real ages for black males, black females, white males and white females respectively. It includes upper and lower canines, but individuals between 20 and 25 were excluded from these graphs as it is not possible to predict the age of an individual under the age of 25 years using the original Lamendin formulae. Correlations between real and actual ages were weak and ranged between 0.0614 and 0.2583, with the best results obtained for the black males and females.

Fig. 1. Calculated age (Lamendin) versus real age in black males. X-axis=real age, Y-axis=calculated age

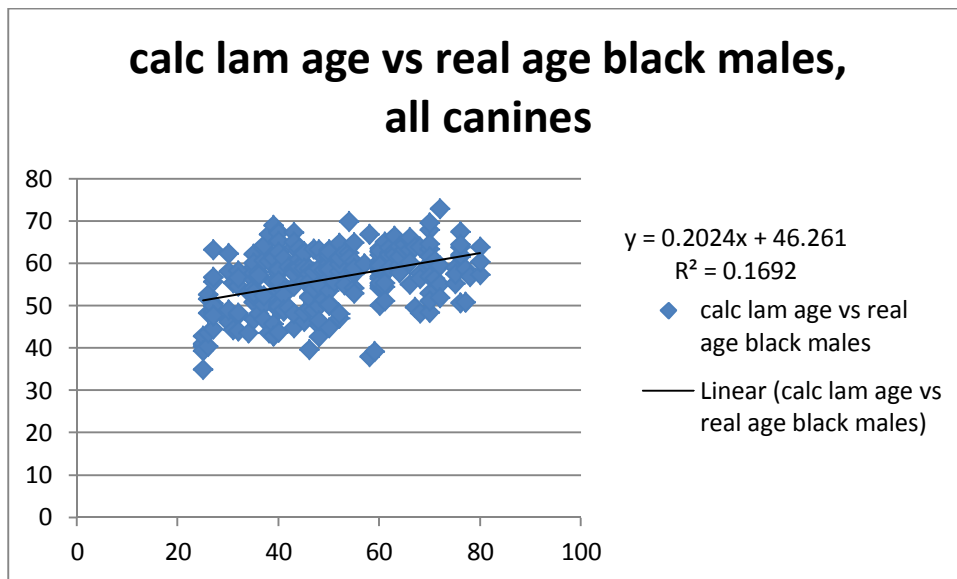
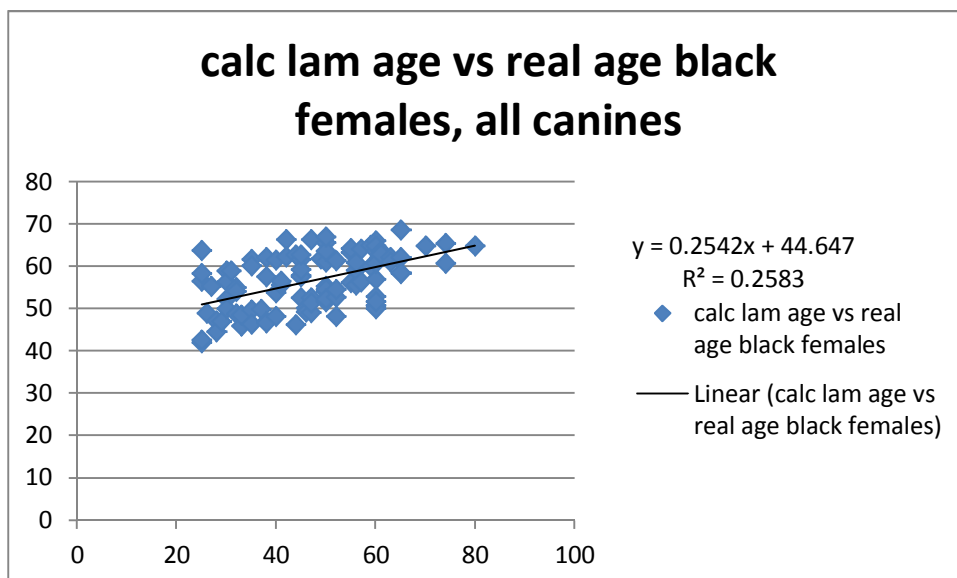


Fig. 2. Calculated age (Lamendin) versus real age in black females. X-axis=real age, Y-axis=calculated age



Lamendin and colleagues [1] reported that the ME (mean error) of their forensic sample by decade was similar to those of their working sample and the global ME was even slightly lower in the forensic sample (8.4 versus 10 years). It was also stated that in individuals under 40 years of age, 46% of cases had an actual age included within the interval determined by the estimated age \pm the ME of the considered decade. However, the same positive results could not be repeated in the current study and poor results were obtained with the existing Lamendin formulae.

Fig. 3. Calculated age (Lamendin) versus real age in white males. X-axis=real age, Y-axis=calculated age

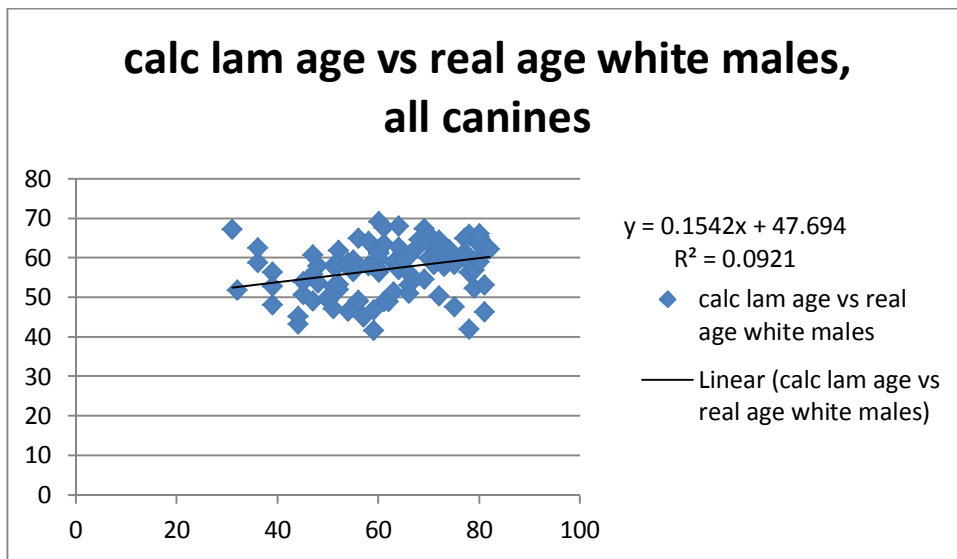
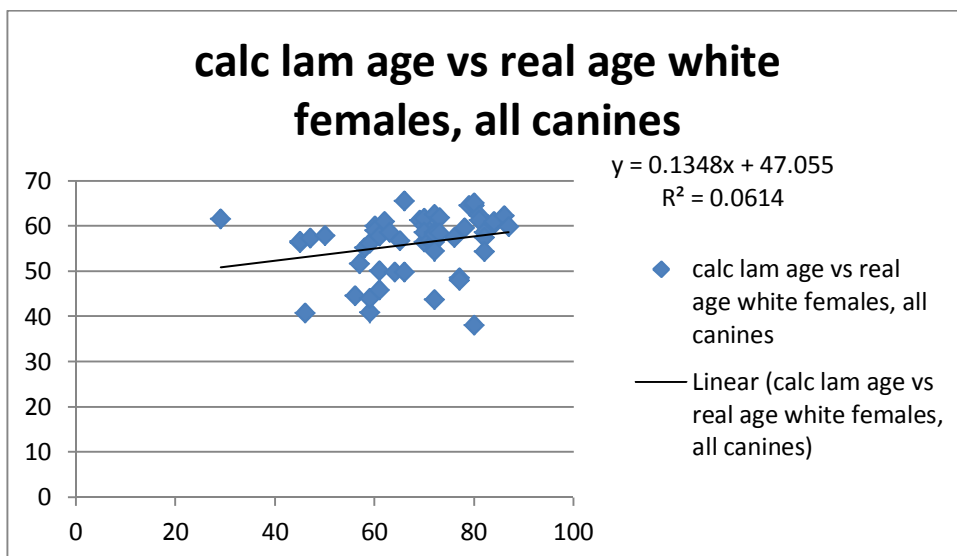


Fig. 4. Calculated age (Lamendin) versus real age in white females. X-axis=real age, Y-axis=calculated age



As some correlation was found to exist between actual age and periodontosis and root transparency, the existing formulae were adapted in an attempt to achieve closer estimates. Once again periodontosis (P) and root transparency (RT) were used as percentages of root height (RH), and regressed against the age. A number of different regression equations (e.g., all canines, sexes separate, upper canines only, lower canines only, etc.) were developed, and these are shown in Table 3. The regression equations for white males and females per individual canine are not shown due to small sample sizes. From these formulae it seems that

Table 3. Revised regression equations for age estimation with canines. P = (periodontosis x100)/ root height; RT = (root transparency x100)/ root height

Formula and sample	Mean error (years)
Complete sample (n=537) Predicted age (A) = 20.68 + (0.57 x P) + (0.27 x RT)	15.10
Complete sample, upper canine (n=239) Predicted age (A) = 14.92 + (0.85 x P) + (0.26 x RT)	13.94
Complete sample, lower canine (n=297) Predicted age (A) = 24.93 + (0.35 x P) + (0.31 x RT)	15.76
South African black, both sexes, upper canine (n=178) Predicted age (A) = 9.89 + (0.79 x P) + (0.31 x RT)	12.39
South African black, both sexes, lower canine (n=196) Predicted age (A) = 14.50 + (0.56 x P) + (0.28 x RT)	12.85
South African white, both sexes, upper canine (n=61) Predicted age (A) = 41.45 + (0.56 x P) + (0.10 x RT)	13.79
South African white, both sexes, lower canine (n=101) Predicted age (A) = 42.28 + (0.33 x P) + (0.23 x RT)	13.54
South African black males, upper canine (n=125) Predicted age (A) = 10.34 + (0.87 x P) + (0.28 x RT)	12.08
South African black males, lower canine (n=142) Predicted age (A) = 18.25 + (0.55 x P) + (0.24 x RT)	13.10
South African black females, upper canine (n=53) Predicted age (A) = 9.08 + (0.44 x P) + (0.38 x RT)	12.71
South African black females, lower canine (n=54) Predicted age (A) = 4.02 + (0.60 x P) + (0.41 x RT)	12.14
South African black males, any canine (n=267) Predicted age (A) = 15.31 + (0.66 x P) + (0.26 x RT)	12.74
South African black females, any canine (n=107) Predicted age (A) = 6.33 + (0.53 x P) + (0.40 x RT)	12.26
South African white males, any canine (n=102) Predicted age (A) = 43.08 + (0.14 x P) + (0.24 x RT), ME = 12.32	12.32
South African white females, any canine (n=60) Predicted age (A) = 39.50 + (0.70 x P) + (0.16 x RT)	15.11

in South African whites, the method can only be used in individuals older than 40 years. In general, the mean errors ranged between about 12 and 15 years. When all individuals and both upper and lower canines were combined, the mean error was on the higher end of the scale at 15.1 years. These mean errors reduced with population-specific equations (i.e. formulae for black and white South Africans). Beyond this there was little advantage as to

whether formulae for specific upper or lower incisors or even different sexes were used, as the mean error remained around 12 to 13 years. The exception here was for the white females, but here limited sample sizes may have played a role.

An example of how these equations are to be used is as follows (using the first equation from Table 3):

If periodontal height = 1.92 mm, root transparency = 8.74 mm, and root height = 14.28:

$$P = (1.92 \times 100) / 14.28 = 13.44$$

$$RT = (8.74 \times 100) / 14.28 = 61.20$$

Therefore,

$$\begin{aligned} \text{Predicted age (A)} &= 20.68 + (0.57 \times 13.44) + (0.27 \times 61.20) \\ &= 44.85 \pm 15.10 \text{ years.} \end{aligned}$$

Correlation coefficients between the actual ages and calculated ages, using the revised formulae, were calculated and ranged between 0.021 and 0.405. For the complete sample, all canines, R^2 was 0.19. The black group gave better results with R^2 values as high as 0.405, in comparison to the white sample with the highest R^2 value of 0.274. These higher values of around 0.4 are better than the 0.266 from the original formulae (Table 2), which suggests that there were some advantages in adapting the original Lamendin formula although these now need to be tested with an independent sample. The result for the white groups remained poor and may be partly due to the small sample sizes. When the correlations were done for a specific canine, the upper canine gave better results for the males of both the black and white groups, whereas the lower canine gave better results for the females of both groups.

The ME (mean error) of the newly adapted formulae (12.02 to 15.76 years) was higher than those originally obtained by Lamendin et al. (1992) (8 to 10 years), but probably reflects the limitations of the method.

4. Discussion

Age estimation in this study was based on the same three measurements that Lamendin et al. [1] used in their original study, although in the current study only canines were used and not a combination of single rooted teeth as in the original study. This approach was taken as canines are more commonly preserved in skeletal remains, because of their longer and more prominent root. One canine was taken as representative of each jaw, preferably the left canine. All measurements were found to be repeatable, but periodontosis proved to be the most difficult to score consistently.

The advances in periodontal disease and increased root transparency with age were judged against root length. Root height in itself was not expected to change with age as it is used in the Lamendin formulae as a standard against which to judge increasing root transparency and periodontosis, although in this study it was found to shorten somewhat with age, especially in white individuals. It is well known that the roots of teeth may shorten with advancing age [18], and this may possibly lead to errors in older people as the increase in root transparency may be somewhat masked by the concomitant shortening of the root itself.

In general, positive but weak correlations were found to exist between periodontosis and root transparency with age. This shows that these features can be used to estimate age, but that the results would not be highly accurate. Root transparency did not obtain the highest results as was found in previous works [5, 8-16] while periodontosis, surprisingly, were found to correlated more with age than root transparency. Hillson [20] also reported that there are large clinical studies that showed a clear relationship between periodontosis and age, and that dental hygiene and care play a big role in the development of periodontal disease.

In this study, the measurements were first used to estimate age using the original Lamendin formula. These, however, were poorly correlated with actual age. There may be several reasons for this, for example the fact that in the current study only canines were used

and not a combination of single rooted teeth. Prince and Ubelaker [42], amongst others, also mentioned that dental hygiene may play a significant role in age estimation techniques where teeth are used, and this is of particular relevance in the current study where the sample of especially the South African blacks were most probably more representative of people of lower socio-economic status with very limited access to dental care. These authors recommended that samples differing in diet and hygiene should be assessed, as was the case here, as these may influence the accuracy of the estimates. The varying dental hygiene of individuals in the study sample probably played a large role in the relatively poor results seen in the current study.

For both measurements, the SA blacks obtained better correlations than the SA whites. The smaller sample sizes of the South African whites may have influenced these results, but it is also possible that better dental care in this group may have played a role. It was also clear from the results that the upper canine gave the best results overall for the males of both populations, whereas the lower canine was best for the female groups.

Megyesi and colleagues [46] used the Lamendin criteria on two historic skeletal samples and found that post-mortem factors affect the applicability of the Lamendin technique to archaeological and historical samples. They reported that the root translucency disappears with time or is obscured by unknown post-mortem taphonomic effects related to the length of internment or post-mortem environment. They stated that caution should be taken when applying this technique to these types of samples or remains. Some of the remains in the skeletal collections used in this study, even though they have not been buried, have been in the collections for a considerable time, and it is possible that the root translucency may have become obscured with time.

In an attempt to improve on these low accuracies and to better represent the South African populations, the formula was adjusted and separate formulae were calculated depending on

the tooth used (upper or lower), sex and ancestry. Although the calculated ages were still not very well correlated to the actual ages, slightly better results were obtained. Slight improvements were observed when the formulae were adjusted for the sexes and populations of origin. However, the main advantage in using the new formulae is the fact that the new mean errors, ranging between 12 and 15 years, probably reflects biological reality more accurately and may better represent the variations pertaining to the specific population.

Although a mean error of about 12 - 15 years is high (and also higher than that reported in previous, similar studies), Keough et al. [50] also reported a mean error of 13.31 to 14.04 years for age estimation with bone histology. When methods based on, for example, the pubic symphysis [51-56] and auricular surface [57-61] are considered, it is clear that their mean errors are also high. It seems that age estimation in adults still remains challenging, and that the Lamendin and modified Lamendin techniques are probably on par with other methods used in adult age estimation. With the possible exception of tooth cementum annulations, this is probably the highest degree of accuracy that can be expected in any single method currently used in adult age estimation.

Recently, much has been written about the choice of a reference sample and its statistical implications when developing age estimation methods [62, 63]. Konigsberg et al. [63] argued that one may not need population-specific data for age estimates, but rather more data from larger samples. Also, the prior distribution of age of the reference sample is most likely responsible for many of the perceived differences in aging between samples, as it is well-known that age estimates tend to mimic the structure of the known-age reference sample [62-64]. Taking research on age estimation from dental structures forward, these are issues that need to be addressed as it is not always clear whether observed differences are due to true population variations (or as is most probable in the current study, dietary and dental hygiene

differences), or variances introduced by other issues such as the age distribution of the reference sample.

In conclusion, this research tested the existing Lamendin formula on a large South African sample of canines, and then adapted it to provide more applicable and somewhat more accurate estimates. Although the mean errors are large and range between 12 and 15 years, they are similar to what can be expected from most other methods used in adult age estimation. In addition, the fact that this method is quick and non-destructive, makes it valuable for use in unknown skeletal cases.

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