Age-at-death assessed with Lamendin's original and population-specific models in a modern Brazilian osteological collection

Andrea Baz[1], Suzana Mantovani[1], Bianca Santos[1], Leandro Grecco[2], Giuliano Gonçalves[2], Marianna Arakelyan[3], Jeidson Marques[4], Ademir Franco[1,2]

[1]Division of Forensic Dentistry, Faculdade Sao Leopoldo Mandic, Campinas, Brazil. [2]Laboratory of Human Anatomy, Faculdade Sao Leopoldo Mandic, Campinas, Brazil. [3]Department of Therapeutic Stomatology, Sechenov University, Russia. [4]Department of Dentistry, State University of Feira de Santana, Brazil.

Corresponding author: franco.gat@gmail.com

The authors declare that they have no conflict of interest.

KEYWORDS

Age at death;
Age estimation;
Forensic Dentistry;
Lamendin;
Teeth

J Forensic Odontostomatol
2022. Dec;(40): 3-45:51
ISSN :2219-6749

ABSTRACT

Background: Estimating the age at death is a common procedure in the fields of forensic human identification and anthropological/archaeological investigations. Root translucency and periodontosis are regressive parameters used to estimate the age of adults, more specifically in Lamendin's method – established in 1992 in a French population. This study aimed to test the applicability and validity of Lamendin's method in a Brazilian osteological collection.

Methods: The sample consisted of 74 single-rooted teeth obtained from 50 skeletal remains (mean age: 53.20 ± 16.17 years) from Southeast Brazil. Lamendin's method was applied to enable a comparison between chronological (CA) and estimated ages (EA). A new population-specific equation was designed for the studied sample and the outcomes were compared with those obtained with Lamendin's original equation.

Results: The original methods led to a general underestimation of 11.32 years (8.83 years in males and 15.91 years in females). The method had a better performance among individuals between 40 and 59 years (mean differences between CA and EA: 4.8 years). The population-specific equation led to a mean overestimation of -2.04 years in males, and a mean underestimation of 3.77 years in females. Underestimations were considerably higher in other age groups.

Conclusion: Despite the apparent improvements, both the original and the population-specific equations revealed coefficients of concordance that were constantly low between CA and EA. These outcomes suggest restrictions to the application of Lamendin's method in the forensic field, especially for human identification. The method, however, seems to be applicable for anthropological/archaeological applications.

INTRODUCTION

The lack of developmental features in adults makes dental age estimation a challenging procedure in the forensic field.[1] Attrition, deposition of secondary dentin, periodontosis, cementum apposition, root resorption, and root translucency represent regressive dental features commonly assessed in adults.[2,3] While some of the features can be assessed by means of radiographic examination, such as the deposition of secondary dentin (visualized through the progressive reduction of the pulp chamber of root canal),[4] other features, such as cementum apposition require invasive techniques for proper assessment.[5] When it comes to invasive techniques, their application is only postmortem (restricted to cadavers and skeletal remains) and can be destructive or not.[6] Destructive techniques require tooth sectioning for the direct macroscopic or microscopic visualization of internal dental features.[7] In this process, tooth specimens are destroyed and, for this reason, these techniques are not always applicable to archeological samples (given their historical value). Gustafson's[2], Johanson's,[3] and Dalitz's[8] approaches are examples of invasive-destructive methods used for dental age estimation. Non-destructive techniques, on the other hand, enable the assessment of regressive age-related features with a visual inspection of external features – reason why these techniques can be tested in osteological collections of museums, educational institutions, and anthropological facilities.[9] Lamendin's[10] method (1992) advocates the use of periodontosis and root translucency as regressive features for the estimation of the age at death.

Over the last 30 years, Lamendin's method has been tested in samples from several countries,[11] including France,[12] the United States,[13] Peru,[14] Brazil,[15] Argentina,[16] and Greece.[17] A systematic review from 2015 rated the method "effective" for the assessment of the age at death but revealed error rates that increase considerably after the age of 60 years.[11] Based on the methodological heterogeneity of the eligible studies and the different outcomes across studies, the authors encouraged the population-specific validation of Lamendin's method in order to understand better how it will respond.[11] Specifically in Brazil, Lamendin's method has been tested in a sample of 49 teeth collected from 26 dry skulls.[15] The authors observed that the method performs better among young adults and should be used carefully given the higher error rates among individuals between 45 and 60 years.[15] A deeper look into the Brazilian population, however, is necessary given the continental size of the country and the large population.

In order to explore this gap, the present study aimed to perform an observational (cross-sectional) research on the use of Lamendin's method to assess the age at death of Brazilian dry skulls of females and males with known documental information. This study takes into account Lamendin's original formula and the possibility of calculating a population-specific model.

MATERIAL AND METHODS

Ethical approval was obtained from the institutional committee of ethics in human research (protocol: 49933621.1.0000.5374; approval number: 080986/2021). The study method was observational, analytical, and cross-sectional.

The sample consisted of 74 unirradicular permanent teeth of 50 dry human skulls of Brazilian females and males (mean age: 53.20 ± 16.17 years). Per age category, the teeth were divided as follows: 9 teeth in the age interval between 25 and 39 years, 38 teeth between 40-59 years, 18 teeth between 60-79 years, and 9 teeth between 80 and 89 years. The skulls belonged to identified skeletal remains of the modern Osteological Collection FSLM. The collection has skeletal remains donated from individuals that were born in the early twentieth century (30's) and has a database of personal information that includes the date of birth, date of death, sex, and self-declared ancestry (classified into white, black, and mixed). The skeletal remains donated to the collection come from the Southeast region of Brazil, predominantly from the State of Sao Paulo.

The inclusion criteria consisted of unirradicular teeth from modern skulls of female and male Brazilians. The exclusion criteria consisted of decayed teeth,[16] fractured crowns, restorations or prosthetic crowns, teeth with anatomic variations, and teeth from individuals missing a complete set of documental information in the collection database. Teeth that met the eligibility criteria were manually dislodged from the sockets before they were measured[18] (and positioned back to the socket after analysis).

The main observer, a forensic odontologist with 5 years of experience in practice, analyzed the entire sample set according to Lamendin's[10] method. The analysis included measurements of root translucency (T), root height (H), and periodontosis (P). All the measurements were performed on the labial surface of each tooth using a sliding caliper set in millimeters. Root translucency was measured against a lightbox with proper lux units[19]. The T measurement is performed from the apex of the root to the maximum height of the translucent region observed within the root. The H measurement also starts from the apex and extends to the cemento-enamel junction on the labial surface of the root. Finally, measurement *P* takes into account the degradation of soft tissue on the root surface and is assessed from the cemento-enamel junction towards the apex following a yellowish discoloration of the root (darker than enamel, but lighter than the dentinal root)[15]. During the assessment of *P*, soft surface probing was implemented to eventually detect a rough area on the root and contribute to the measurement. The measurements were tabulated for the application of Lamendin's original formula.

After 30 days, the main observer repeated the measurements (T, H and P) in 20 teeth (24%) randomly selected from the sample. These measurements enable the calculation of intra-observer agreement tests. In parallel, a second observer was recruited (another forensic odontologist with 5 years of experience in the field) to analyze the same 20 teeth so the inter-observer agreement tests would be calculated. The reproducibility within (intra-) and between (inter-) observers was quantified with the Intraclass Correlation Coefficient (ICC).

The age estimated with Lamendin's original formula was compared with the know chronological age using Lin's coefficient of concordance. The concordance was tested for the general sample, and for the sample categories based on sex (male/female), self-declared ancestry (classified into white, black, and mixed), and age group (25-39, 40-59, 60-79, 80-89 years). Lin's coefficient of concordance established a scale from -1 to 1, in which the latter represents full concordance. In addition to the concordance estimates, we calculated the concordance's confidence interval (95%). Pearson's correlation coefficient was used to assess the correlation between *T*, *H* and *P* variables and the chronological age. The null hypothesis is that the correlation coefficient is 0 (on a scale between -1 and 1) – indicating a lack of correlation. The test the null hypothesis, *p* values were calculated considering the significance level of 5%. Finally, a linear regression model was adjusted considering the estimated age as the outcome and *T*, *H* and *P* as the predictors. An equation to predict the chronological age was designed for the present sample. Based on the new equation, comparisons between estimated and chronological ages were performed again (and quantified with Lin's coefficient of concordance) considering the pre-established categories based on sex, self-declared ancestry, and age group.

RESULTS

ICC showed intra-observer agreement values of 0.984, 0.996, and 0.997 for the variables *T*, *H,* and *P*, respectively. Inter-observer agreement values were 0.774, 0.840 and 0.957, respectively (Table 1).

Table 1. Intraclass correlation coefficient for the intra- and inter-observer agreement considering translucency (*T*), root height (*H*), and periodontosis (*P*)

Parameters	**Agreement**			
	Intra-observer		**Inter-observer**	
	ICC	**IC95%**	**ICC**	**IC95%**
Translucency	0.984	0.960; 0.993	0.774	0.521; 0.902
Root height	0.996	0.989; 0.998	0.957	0.898; 0.982
Periodontosis	0.997	0.994; 0.999	0.840	0.647; 0.932

The comparison between chronological and estimated ages for the general sample led to a mean difference (underestimation of 11.32 years) (Lin's coefficient of concordance = 0.149). In males (n = 48 teeth), the mean difference was 8.83 years, while in females (n = 26 teeth), the difference was 15.91 years (Lin's coefficient of concordance = 0.270 and -0.018, respectively). Regarding the self-declared ancestry, the mean differences between chronological and estimated ages were 13.87, 10.35, and 7.28 years, for self-declared whites, black and mixed, respectively (Lin's coefficient of concordance was below 0.199). Analyses based on age groups showed mean differences of -10.22 years for the age group 25-39 years, and 4.8 years for the individuals between 40-59 years. For older age groups, the mean difference between chronological and estimated ages was considerably high, and Lin's coefficient of concordance was below 0.200. (Table 2).

Table 2. Application of Lamendin's original equation, and respective estimated ages per sex group, age group, and self-declared skin colour group

		Age			Concordance	
	n	**CA (SD)**	**EA (SD)**	**ME**	**ϱ**	**CI95%**
Total	74	53.20 (16.17)	46.89 (5.91)	11.32	0.149	0.047; 0.250
Sex						
Male	48	55.79 (16.57)	46.96 (5.64)	8.83	0.270	0.145; 0.396
Female	26	62.65 (14.69)	46.75 (6.50)	15.91	-0.018	-0.165; 0.129
Skin colour						
White	36	60.53 ± 16.69	46.66 ± 5.98	13.87	0.160	0.030; 0.290
Mixed	20	56.00 ± 19.85	45.65 ± 6.70	10.35	0.199	-0.012; 0.409
Black	18	56.00 ± 9.35	48.72 ± 4.57	7.28	-0.088	-0.343; 0.166
Age group						
25-39	9	30.22 ± 4.79	40.44 ± 3.20	-10.22	0.079	-0.078; 0.237
40-59	38	52.68 ± 4.82	47.88 ± 4.40	4.8	0.200	-0.004; 0.405
60-79	18	70.78 ± 6.77	47.22 ± 6.28	23.56	-0.011	-0.073; 0.051
80-89	9	84.33 ± 3.12	48.46 ± 9.00	35.87	0.036	-0.001; 0.073

Age expressed in years; n: sample size; CA: chronological age; EA: estimated age; CI: confidence interval.
SD: standard deviation; ME: mean error = chronological age – estimated age.
ϱ: Lin's coefficient of concordance.

Pearson's correlation coefficient (r-values) for the variables T, H, and P were 0.238 ($p = 0.041$), -0.071 ($p = 0.548$), and 0.362 ($p = 0.002$), respectively. Based on the outcomes of the original formulae and the correlations values detected in our study, an adjusted equation was obtained for our sample: $Age = 31.13 + (0.97*P) + (0.26*T)$.

The new equation increased Lin's coefficient of concordance to 0.310 in the general population. The difference between chronological and estimated ages was -2.04 years for males (Lin's coefficient of concordance = 0.458) and -3.77 years for females (Lin's coefficient of concordance = -0.037). In self-declared whites, black and mixed, Lin's coefficient of concordance was between 0.269 and 0.362. Analyses based on age groups showed the smallest mean differences between chronological and estimated ages for the age groups 40-59 years (-6.32 years) and 60-79 (10.41 years). The remaining age groups had significantly higher age differences (Table 3).

Table 3. Application of the population-specific original equation, and respective estimated ages per sex group, age group, and self-declared skin colour group

		Age			Concordance	
	n	CA (SD)	EA (SD)	ME	ϱ	CI95%
Sex						
Male	48	55.79 ± 16.57	57.84 ± 6.86	-2.04	0.458	0.321; 0.595
Female	26	62.65 ± 14.69	58.88 ± 7.13	3.77	-0.037	-0.335; 0.260
Skin colour						
White	36	60.53 ± 16.69	58.01 ± 6.78	2.52	0.269	0.065; 0.474
Mixed	20	56.00 ± 19.85	55.98 ± 6.95	0.02	0.362	0.143; 0.581
Black	18	56.00 ± 9.35	61.05 ± 6.53	-5.05	0.337	-0.003; 0.676
Age group						
25-39	9	30.22 ± 4.79	48.90 ± 3.27	-18.68	0.047	-0.016; 0.109
40-59	38	52.68 ± 4.82	59.00 ± 5.21	-6.32	0.171	-0.007; 0.349
60-79	18	70.78 ± 6.77	60.37 ± 6.86	10.41	-0.065	-0.286; 0.155
80-89	9	84.33 ± 3.12	59.79 ± 9.36	24.54	0.066	-0.004; 0.136

Age expressed in years; n: sample size; CA: chronological age; EA: estimated age; CI: confidence interval.
SD: standard deviation; ME: mean error = chronological age − estimated age.
ϱ: Lin's coefficient of concordance.

DISCUSSION

Estimating the age at death of adult skeletal remains is a challenging procedure in forensic odontology. The scarce dental parameters available for age estimation normally increase the error rates compared to developmental parameters used in children and adolescents. Lamendin's method emerged as an option to anthropological and forensic investigations that require the estimation of the age at death. This method was tested and validated by population-specific studies worldwide. The present study revisited the method 30 years after its publication to investigate the Brazilian population.

When it comes the discussion of the methodology addressed in our study, it must be clarified the Lamendin's methods was selected because it is considered a simple tool with an overall performance that is acceptable in practice. The method is invasive, since it requires extraction of the tooth from the socket, but is non-destructive – which allowed us to accomplish sampling from a modern osteological collection (preserving cultural, social, and historical values). A systematic literature review[11] on Lamendin's method listed several studies that sampled teeth from osteological collections. This scenario enables a controlled comparison between estimated and chronological age since the latter can be accurately retrieved from death records.

The preliminary outcomes of the present study showed important underestimation in the total sample, which is justified by the low concordance between chronological and estimated ages. The difference was nearly twice higher in females. These outcomes are similar to those presented by Lopes et al.[15], which revealed mean underestimations of 7.65 years in Brazilian males (our study = 8.83 years) and 11.28 years in females (our study 15.91 years). Ubelaker and Parra[14] also found higher mean differences between chronological and estimated age in Peruvian females. From the perspective of South American populational studies, authors from Argentina[16] have explained that the apparent influence of sex in adult age estimation using Lamendin's method may be justified by the unbalanced distribution of males and females across studies. This may be the case of our study, in which 48 (54%) and 26 (46%) specimens of males and females were collected, respectively. The same was observed in the study by Lopes et al.[15] (60% males and 40% females) and Ubelaker and Parra[14] (61.12% males and 38.88% females). Our outcomes became more similar to those obtained by Garizoain et al.[16] only after applying the new equation designed for our sample. In this case, the equation led to means differences between chronological and estimated ages of -2.04 (overestimation) and 3.77 (underestimation) for males and females, respectively. Of course, these outcomes must be carefully interpreted because they solely reflect the internal performance of our equation. A similar adjustment of the method was accomplished by Lopes et al.[15] leading to improved applications for their sample. Future external testing (validation) is needed to translate the method performance to other samples. Sampling osteological collection arbitrarily by analyzing all the available skeletal remains is a common practice. The overcome the influence of sex in future analysis, we assessed age at death using skin colour and age group subcategories regardless of sex.

The subgroup analysis based on self-declared skin colour was based on the study of Prince and Ubelaker.[13] The authors compared groups of black and white individuals and observed higher error rates among black females (9.63 years), followed by white females (8.46 years), white males (7.66 years) and black males (7.17 years). In our study, we used three self-declared skin colour groups, and we found lower error rates in blacks (7.28 years), followed by mixed skin colour (10.35 years), and whites (13.87 years). In our study, statistically significant differences between skin colour were not detected. This outcome may suggest a broader application of the methods across specimens with different ancestry. The scientific literature corroborates this finding by explaining that Lamendin's original mean error rates maintained similar outside the French population – indicating that there a "*minimal impact*" of population variation over the studied parameters (translucency and periodontosis).[14] Hence, equations based on skin colour were not designed in our study.

Regarding the age group subcategory, we observed the best outcomes of Lamendin's original method among individuals between 40-69 years (underestimation of 4.8 years), followed by those between 25-39 years (overestimation of -10.22 years). In the older age groups, the estimated age was too far (over 20 years of difference) from the chronological age. Our outcomes converge with those presented by Lopes et al.[15], which found better performances of the method among younger individuals. It must be noted that both the present and the previous[15] studies respected the constant of Lamendin's original equation to set eligibility criteria based on age. In other words, individuals younger than 25.53 years were not sampled in Brazilian studies. This quality-control procedure is not unanimous in the scientific literature and can lead to skewed statistics. From an international perspective, our results are similar to those obtained in samples of skeletal remains from the United Kingdom in the age interval between 25-49 years.[21] According to the authors[21], Lamendin's method led to mean errors of 10.9 years or less among young adults, while the error rates increased considerably in older age groups. It must be noted, that the application of our population-specific equation led to error rates that were more appropriate in middle-aged adults, namely from 40-59 years, and even in older adults between 60-79 years.

A consistent phenomenon in our study was the low values observed with Lin's coefficient of concordance, which can endorse the fact the regressive age estimation parameters used in adults are indeed limited for age estimation. Lamendin's methods, for instance, is based on parameters that never reached a Pearson's correlation coefficient higher than 0.362 (constantly weak) in our sample. These outcomes indicate that chronological age (and hence age at death) can be investigated from translucency and periodontosis, but their accuracy may not be as good as necessary for forensic application. The field of physical anthropology can benefit from the estimation of the age at death to understand historical and cultural events, but the application of Lamendin's method in the present sample showed limitations to be considered if a forensic question needs to be answered, for example in cases of human identification during criminal investigations.

CONCLUSIONS

Lamendin's original method reached the best error rates among young adults – with overestimations of around 10 years in adults between 25-39 years and around 5 years in adults between 40 and 59 years. Self-declared skin colour did not play a significant part on method's performance, while sex seemed to have an effect that could be related to sample distribution. The development of a population-specific equation led to evident improvements of the method performance among adults in the age interval between 40-79 years, but this equation solely reflects the response of the methods adjusted for the present sample.

So far, applications for historical-anthropological practice seem to be acceptable, while the method shall not be applicable for criminal forensic practice in human identification given the current level of evidence available.

REFERENCES

1. Boedi RM, Shepherd S, Manica S, Franco A. *CBCT in dental age estimation: A systematic review and meta analysis. Dentomaxillofac Radiol* 2022;51(4):20210335.
2. Gustafson G. *Age determinations on teeth. J Am dent Assoc* 1950;41:45-54.
3. Johanson G. *Age Determination from human teeth. Odontologisk Revy* 1971;22(Supp):126.
4. Kvaal S, Solheim T. *A Non-Destructive dental Method for age estimation. J Forensic Odontostomatol* 1994;12(1):6-11.
5. Maples WR. *An improved technique using dental histology forthe estimation of adult age. J Forensic Sci* 1978;23(4):764-70.
6. Bang G, Ramm E. *Determination of age in human from rootdentine transparency. Acta Octalgia Scandinavica* 1970:28:3-35.
7. Maples WR, Rice PM. *Some difficulties in the Gustafson dental age estimations. J Forensic Sci* 1979;24:168–172.
8. Dalitz GD. *Age determination of adult human remains by teeth examination. J Forensic Sci Soc* 1962;3:11-21.
9. Martrille L, Ubelaker DH, Cattaneo C, Seguret F, Trem -blay M, Baccino E. *Comparison of four skeletal methodsfor the estimation of age at death on white and black adul-ts. J Forensic Sci* 2007;52(2):302-307.
10. Lamendin H, Baccino E, Humbert JF, Tavernier JC, Nossintchouk RM, Zerilli A. *A simple technique for age estimation in adult corpses: the two criteria dental method. J Forensic Sci* 1992;37(5):1373-1379.
11. Lopes JR, Fernandes MM, Michel-Crosato E, Melani RFH, Oliveira RN. *Systematic review of Lamendin's dental ageestimation method. Clin Lab Res Den* 2015;21(2):99-109.
12. Foti B, Adalian P, Signoli M, Ardagna Y, Dutour O, LeonettiG. *Limits of the Lamendin method in age determination. Forensic Sci Int* 2001;122(2-3):101-106.
13. Prince DA, Ubelaker DH. *Application of Lamendin's adultdental aging technique to a diverse skeletal sample. J ForensicSci* 2002;47(1):107-16.
14. Ubelaker DH, Parra RC. *Application of three dental methodsof adult age estimation from intact single rooted teeth to a Peruvian sample. J Forensic Sci* 2008;53(3):608-611.
15. Lopes JR, Queiroz SBBS, Fernandes MM, Paiva LAS, Oliveira RN. *Age estimation by teeth periodontosis and transparency: accuracy of Lamendin's method on a Brazilian sample. Braz J Oral Sci* 2014;13(1):17-21.
16. Garizoain G, Petrone S, Plischuk M, Inda AM, Garcia MN. *Evaluation of Lamendin's age-at-death estimation method in a documented osteological collection (La Plata, Argentina). Forensic Sci Int Rep* 2020;2:100060.
17. Zorba E, Goutas N, Spiliopoulou C, Moraitis K. *An evaluation of dental methods by Lamendin and Prince and Ubelaker for estimation of adult age in a sample of modern Greeks. Homo* 2018;69(1-2):17-28.
18. Ackermann A, Steyn M. *A test of the Lamendin method of age estimation in South African canines. Forensic Sci Int* 2014, doi:10.1016/j.forsciint.2013.12.023
19. Adserias-Garriga J, Nogué-Navarro L, Zapico SC, Ubelaker DH. *Setting the light conditions for measuring root transparency for age-at-death estimation methods. Int J Legal Med* 2018;132(2):637-641.
20. González-Colmenares G, Botella-López MC, Moreno-Rueda G, Fernández-Cardenete JR. *Age estimation by a dental method: a comparison of Lamendin's and Prince & Ubelaker's technique. J Forensic Sci* 2007;52(5):1156-1160.
21. Megyesi MS, Ubelaker DH, Sauer NJ. *Test of the Lamendin aging method on two historic skeletal samples. Am J Phys Anthropol* 2006;131:363-367.