Chapter

Accuracy and Limits of Lamendin's Age Estimation Method in a Sample of Nigerian Population

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Abstract

This study compared the accuracy and limits of Lamendin's age estimation method to age estimation by subset regression analysis in a sample of Nigerian population. The research was a cross-sectional study involving 81 single-rooted teeth obtained from 45 females and 36 males between ages 20 and 90 years. Extracted teeth samples were disinfected and stored, and directly measured using a digital vernier caliper on a 16 W X-ray box. Periodontosis (P) and Translucency (T) were derived using standard formulae from the root height (RH), translucency height (TH), and periodontal height (PH). Data were managed in an excel spreadsheet, then analyzed (stratified by sex) using Lamendin's equation (Age = 0.18P + 0.42 T + 25.53) in SPSS (IBM® version 23, Armonk, USA) and Minitab® 2017 (version 18.1) best subset regression for males (Age = 6.23TH + 0.113P + 7.7) and females (Age = 14.90PH + 0.330 T − 2.12). Chi-square analysis tested the distributional deviations from actual age (using error ranges). From the analysis, 33.3% of the total population (M: 30.0% and F: 35.6%) were predicted within the suggested limit compared to 61.7% (M: 75.0% and F: 51.0%) for the best subset model. The distributional errors difference in both methods was not significant for males ($\chi^2_{[df = 3]}$ = 1.810, P = 0.405), females ($\chi^2_{[df = 3]}$ = 1.275, P = 0.528), and total samples ($\chi^2_{[df = 3]}$ = 4.960, P = 0.084). Lamendin's formula did not provide accurate age estimates for a large proportion of sample population. More accurate estimates were limited to age ranged between 30 and 70 years. The study recommended that further studies using a larger sample be conducted to validate the findings of this study.

Keywords: age estimation, Lamendin, best subset, regression, Nigerian population

1. Introduction

Human identification falls under the preview of forensic science, which is simply "the application of science to law" [1]. This means that for forensic science to thrive there must be a legal framework that gives it the spine for functionality, and for the law to truly work, it needs the best practice of forensic science to guide judgment [2]. Unfortunately, this is not globally established. While most developed nations have a legal framework for the practice of forensic sciences, in Nigeria, there is no such law governing forensics, except for the coroner's law that exists in Lagos State, which covers mostly death investigation and not the broader Forensic science application [3]. In the country, there are several lacunae in human identification with little or no database for documentation of such activities.

To solve the puzzles associated with human remains there is the need to determine identity. Therefore, personal identification is necessary for social, legal, and forensic reasons [4]. A massive quest to solve age-related issues about unknown skeletons and living individuals has been on the increase, especially in the field of Forensic Anthropology [5–8]. Matching missing person profiles to biological profiles of unknown remains essential as it provides an informative description for establishing identity. However, this has remained a challenge, especially when there is no comparative information such as dental profile [7, 9].

Over the years, forensic scientists simply match personal information, medical records, and DNA profiling to age [10]. However, in recent times, supplementary methods based on the developing and deteriorating skeleton [11–13], and dental materials [14, 15] have become very useful. Unfortunately, skeletal age indicators are often affected by biological and environmental factors, which vary the rate and degree of age-related changes in the skeleton and can render age estimation inaccurate in adults [16]. Some underlying factors affecting the accuracy of skeletal techniques are high inter- or intra-observer error, higher age ranges, the overlapping of age stages as well as preservation [5, 17]. It is also noted that the discrepancies in age estimation among populations are associated with factors such as economic status, living standards, and pressure of disease, which are known to correlate with age at death [18–20].

In the last 30 years, there has been a significant transformation in forensic odontology, from just occasional dental identification into a wider role, involving building biological profiles [4]. In the living, estimating age in children and adolescents by dental means is usually based on the developmental stages of teeth [21–23], while adults are based on the degenerative changes in teeth like attrition, periodontitis, transparency of the root, secondary dentin, cementum apposition, and root resorption [15, 21, 24–26]. The choice of dental material as an alternative for age estimation becomes necessary when bone-age indicators cannot provide reliable and accurate information [7, 9, 27]. The choice of dental tissues is associated with its self-preserving nature even if the deceased person is skeletonized, decomposed, burnt, or dismembered [28–30]. Thus, dental parameters have become a reliable alternative tool for estimation of sex, age, and ethnicity [19, 31–33].

In 1994, Kvaal and Solheim developed a method for estimating the chronological age of adults based on the relationship between age and the pulp size on periapical dental radiographs [34]. Kvaal et al. method was established by indirectly measuring secondary dentin deposition on radiographs and a number of length and width measurements of teeth and pulp was also proposed. In the Kvaal method, the pulp-to-tooth ratio was calculated using six mandibular and maxillary teeth. They included the maxillary second premolars; maxillary central and lateral incisors; mandibular canine; mandibular lateral incisor; and the first premolar.

Using the pulp-to-tooth ARs in the formula for age determination, age was derived. Using intraoral periapical radiographs, the variables r = complete pulp length/complete tooth length, P = complete pulp length/root length (from enamel-cementum junction [ECJ] to root apex), a = complete pulp length/root width at ECJ level, b = pulp/root width at midpoint level between ECJ level and mid-root level, and c = pulp/root width at the mid-root level and pulp/tooth AR for all six teeth were measured as designed in Kvaal's and Cameriere's methods of age estimation, respectively [34, 35]. Lastly, a simple linear regression analysis was employed, wherein the variables mean (M) (mean of variables complete pulp length/root length [from ECJ to root apex] [p], complete pulp length/complete tooth length [r], complete pulp length/root width at ECJ level [a], pulp/root width at midpoint level between ECJ level and mid-root level [b], and pulp/root width at mid-root level [c]) and the difference between width and length (W − L) were found to contribute significantly to the chronological age estimation and were utilized in the regression equation for Kvaal's method as per the given formula: Age = 129.8 − (316.4 × M) (6.8 × [W − L]). Other Authors like Bosmans et al. [36], Landa et al. [37], and Li et al. [38] used measurements made on a panoramic radiograph instead of periapical radiographs used in the original formula of Kvaal's technique, thus avoiding the cumbersome full mouth radiographs.

Harris and Nortje and Van Heerden evaluated the mesial root of the third molar for age estimation. They argued that eruption of permanent dentition completes by the age of 17 years, after which it becomes problematic to estimate age from dental radiographs age [39, 40]. One major guide to ascertain the age of an individual after such age is through the examination of the development of the third molar. The Harris and Nortje, and Van Heerden methods involve five stages of third molar root development with corresponding mean ages and mean length: the stages include: Stage 1—cleft rapidly enlarging (one-third root formed); Stage 2—half root formed; Stage 3—two-third root formed; Stage 4—diverging root canal walls; and Stage 5—converging root canal walls [41].

Gustafson in 1947 and 1950 first established a technique for age estimation based on the assessment of certain regressive alterations in teeth. This method is mostly employed on single-rooted teeth using histomorphological approaches [24]. Six age-related parameters; attrition (A), secondary dentin formation (S), periodontal recession (P), cementum apposition (C), root resorption (R), and root transparency (T) were macroscopically assessed using the formula: $A_n + P_n + S_n + C_n + R_n + T_n$ = points (0, 1, 2, 3), and found significant correlations [24]. Gustafson deduced that estimating age using these six criteria appeared equally accurate and effective and that the rates at which the individual criteria change are equal, prompting the addition or summation of the obtained data [42–44]. Gustafson's method has had a major impact on the field of forensic odontology, particular with regards to dental age estimation in adults [45, 46]. Ever since, several studies have considered dental translucency as an important age indicator, making it a pivot for various studies [7, 46–49].

Lamendin et al.'s technique utilize two of the characteristics described by Gustafson [24]; however, his technique is less destructive, uses only one single-rooted tooth, and requires no special technical instrument [50, 51]. Lamendin et al. reduced the number of variables by using root height, periodontal recession, and root transparency, and index values based on actual physical measurements made from the labial aspect of the tooth, then applied a multiple regression analysis to develop his equation which was suitable for both sexes. Lamendin's regression formula for age assessment is as follows: A (age) = (0.18 × P) + (0.42 × T) + 25.53; where P = periodontal height × 100/root height, T = translucency height × 100/root height [46]. In the study, they investigated the accuracy of the method on 306 single-rooted teeth of European (French) and African Ancestry origin, and 45 teeth from 24 forensic cases. The result yielded a mean error of 10 years on their working sample and 8.4 years on their forensic control sample. Furthermore, the application of this data set on individuals below age 40 and above age 70 decreased in accuracy, suggesting cautious use of the method for ages below 40 and above 70 years [46].

Prince and Ubelaker [52] modified Lamendin's method of age assessment. Their new regression formulas incorporated root height (RH) into the equation and calculated the variables "P" and "T" in the same manner as Lamendin et al. [46]. The study results from this modification indicated that age estimation was improved when ancestry and sex of the individual are considered. The formulae was given as

Male African Ancestry: Age= 1.04 (RH) +0.31(P) +0.47(T) + 1.70 =4.97 years
Male European Ancestry: Age =15 (RH) + 0.29(P) + 0.39 (T) +23.17 =5.92 years
Female African Ancestry: Age =1.63 (RH) + 0.48(P) + 0.48 (T) + (−8.41) =7.17 years
Female European Ancestry: Age =1.10 (RH) + 0.39(T) +11.82= 6.21 years

The results of this investigation verified this technique and produced a mean error of 8.23 years and a standard deviation of 6.87 years when Lamendin's formula was utilized. Accuracy was best observed between the chronologic ages of 30 and 69. Higher error rates were observed in subjects younger than 30 and older than 69 years of age [52].

A disadvantage of Lamendin's method is its inapplicability in young individuals (since root translucency occurs from the age of 20) but provides acceptable confidence ranges in adults over the age of 30 [50, 53, 54]. This is argued as one of the benefits of the methods over skeletal age estimation methods which lose their accuracy in adults past age 30 [50, 51]. In a separate study of the accuracy of Lamendin's technique on French autopsy sample of individuals of known age at death, Baccino et al. [51] found that the method produced more accurate estimates than some methods such as estimating age from ribs [55–57], the pubic symphysis [58], and long bone cortical histology [59].

2. Study rationale

Since age estimation is a fundamental requirement in biological profiling of the living and dead; this study opens the basis for the development of national database for different accurate age estimation techniques for the Nigerian population. This study would aid in identifying mutilated bodies of a victim and estimating the age of dead persons in cases of mass disaster. In anthropological studies/research, knowledge of age will assist in the designation of age to Cadavers without anti-mortem information as seen in some gross anatomy labs across Nigerian Universities.

Although there is no legal framework for forensic investigation in Nigeria, this study would provide the impetus for the inclusion of dental methods in solving criminal cases, immigration, and juvenile law enforcement. This will ensure that all legal procedures to which an individual's age is relevant can be properly attained.

Lamedine's age estimation remains the most popular and applied dental age estimation technique, however, there have been a varied degree of accuracy in age estimation using Lamendin's method for different populations [5, 12, 28, 52–54, 60–64]. While in other studies it provided valid and accurate estimates [54, 61, 62], in others the results were described as significantly poor [5, 12, 28, 52, 53, 60, 63, 64]. This study, therefore, comparatively evaluates the accuracy and limits of Lamendin's age estimation method in a sample of the Nigerian Population.

3. Materials and methods

3.1 Study design and protocol

The study research adopted a cross-sectional retrospective research design, which involved the use of dental (teeth) samples obtained from the odontology department of hospitals within the South East and Middle Belt Regions of Nigeria between the months of June 2020 to March 2021. Before carrying out the study, ethical approval with reference numbers UPH/R and D/REC/283 and informed consent were obtained from the University of Port Harcourt Research Ethics Committee and the individual dental centers, respectively. The departments also issued consent forms for the individuals whose samples were included in the study, thus, the pool from which teeth samples were collected had a special number associated with the signed consent.

Dental centers that gave consent to participate in the study collected samples from patients referred for essential clinical care such as periodontal, periapical, orthodontic, and prosthesis construction reasons within the duration of the 3-month study period. The study excluded persons who reported mobile tooth due to trauma and fractured tooth, teeth affected by caries, abscess, root resorption, and abrasion or other pathological processes causing exposure of the root to the oral environment, and teeth presenting any alteration in the root apex, such as ankylosis. The study included all the cases involving dental extraction procedures done as part of essential dental care for permanent teeth, males and females of Nigerian origin, single-rooted maxillary and mandibular teeth, extracted tooth with complete root, and the absence of any pathological conditions in the cervical margin of the tooth or dental restorations. They obtained the following medical information; sex, date, and reason for extraction, and age of the subject at extraction.

Extracted teeth were rinsed in running water and any attached tissue to the root was removed using a pair of tweezers and scalpel. The tooth was then disinfected in 3% hydrogen peroxide (H_2O_2) [11], which is a proven dental health hygiene therapeutic agent which break down dental plaque and calculus, clean gingival tissues, and eliminate bacteria without altering the dental formation [65, 66]. Each tooth was closed in separate small plastic tubes filled with normal saline at 4°C [67] to avoid alteration of the mineral concentration of the tooth surfaces, as demineralization interferes with root translucency (RT).

3.2 Data collection and measurements

The dental measurements were taken using a pair of digital vernier calipers by direct observation with a 16 W X-ray box (**Figure 1**). The measurements were made on the labial surface of the extracted tooth without any preparations (no sections, no microscope).

The study obtained a total of 81 single-rooted permanent teeth (maxillary and mandibular) from the dental centers. The teeth sample comprised of 45 females and 36 males of ages 20–90 years. The root height (RH) is the distance between the apex of the root and the cementoenamel junction, measured on the surface (labial) toward the lips [46, 64, 68]. The periodontal height (PH) which is used to describe the gingival tissue degeneration [46, 61, 64] is obtained from the periodontitis, which is the yellowish area that is darker than the enamel, but lighter than the rest of the root [46, 61], and it is the maximum distance from the cementoenamel junction to the line

Figure 1.
Light box-aided collection data from stored teeth samples.

left by the soft tissue attachment on the neck and/or root of the tooth. The translucency height (TH) is traditionally measured manually and it is identified as the length of the transparent zone extending from the junction between the translucent and opaque areas of the root to the tip of the root [46, 69]. That is, the distance between the apex of the root and the cementoenamel junction, measured on the surface (labial) toward the lips (**Figure 2**). The indices were derived using the formulae: $P\ (\text{Periodontosis}) = \frac{PH}{RH} \times 100$ and $T\ (\text{Translucency}) = \frac{TH}{RH} \times 100$ were derived [46].

To assess inter-observer error, two independent observers collected the data twice—on different occasions. Inter-observer precision was determined by comparing the results obtained by the two observers. The study compared the average of both measurements for inter-observer reliability.

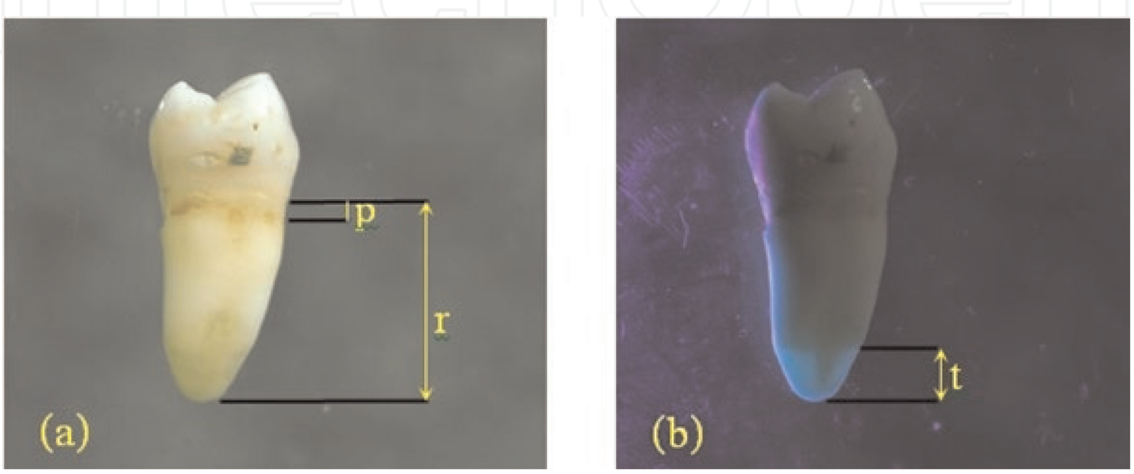

Figure 2.
Measurement of (a) periodontal height (p; PH) and root height (r; RH), (b) translucency height (t; TH) [61].

3.3 Statistical analysis

The measurements were entered into an excel spreadsheet and organized, then imported into Statistical Package for Social Sciences (IBM® version 23, Armonk, USA) and Minitab® 2017 (version 18.1) for statistical analysis. To determine inter-observer precision, paired sample *t*-test evaluated differences in measurements between the two observers. Lamendin's formula was inputted into SPSS and used to estimate age. The set of variables with the most accurate age estimation combinations was determined using Minitab best subset regression, which was used for the regression model. The study employed the Real statistics [70, 71]—directed scatterplot to determine the relationship between the actual age and the estimates from both methods, and the extent of agreement of the two measurements of both methods using Bland–Altman plot [70].

4. Results

The mean age for the male sample was 35.28 ± 20.84 years, while for females the mean age was 41.42 ± 20.89 years. The ratios; periodontitis (P) and translucency (T) entered into Lamendin's equation for age estimation were derived from the linear dimensions. The measurements from both observers yielded a high inter-observer correlation (r) of 0.980, 0.979, and 0.998 for RH, PH, and TH, respectively (**Table A1**).

To determine how well a regression model would estimate age; using both the linear dimensions and ratios, best subset regression was used to build a model that provided a list of the estimates (RH, PH, TH, P, and T), prediction accuracy and regression for variables (single and multiple; **Tables A2** and **A3**). The regression model built for males in **Table A2** yielded low estimate for age using the dental parameters (linear dimensions and ratios). However, the chosen (observed best) estimate was j2, which had an adjusted accuracy of 53.3% and a predicted accuracy of 48.8%. The parameters that produced this model summary were TH (transparency height) + P (periodontosis). The regression model for females that produced the most accurate estimate was g2; with an adjusted accuracy of 51.2% and a prediction accuracy of 46.6%. The parameters that produced this model summary were PH (periodontal height) + T (translucency) (**Tables A3**).

In **Table 1**, the age estimation error differences for Lamendin's method (A [age in years] = 0.18P + 0.42 T + 25.53) and the best subset regression for males (A [age in years] = 6.23 TH + 0.113 P + 7.7) were compared, and there was underestimation using Lamendin's method for males starting at age greater than 40 years, then at age 56 using best subset regression; however, larger estimate error was found in the best subset (age 90; at ±52 and ± 43) when compared to Lamendin's estimate (±50 and ± 45) for the same age. For females, the outcome of the calculations from the regression equation for age estimation using Lamendin's method (A [age in years] = 0.18P + 0.42 T + 25.53) and the best subset regression equation (A [age in years] = 14.90 PH + 0.330 T − 2.12) were compared. The result indicated a constant negative error difference (−actual age) started at age 44 using Lamendin's formulae, but age 28 for the best subset. A larger estimate error for age was found in Lamendin's estimate (±35 to ±42) when compared to the best subset (age 90; at ±23 to ±27) for different ages (**Table 2**).

The distribution of the estimates with the error margin using the Lamendin's range of ≤ ± 10 years obtained from both methods revealed that only about 33.3% of the

Sex	Actual age	Lamedine's Estimation A (age in years) = 0.18P + 0.42 T + 25.53	*d1*	Regression (from Subset) A (age in years) = 6.23 TH + 0.113 P + 7.7	*d2*
M1	20	33	13	24	4
M2	20	35	15	28	8
M3	21	37	16	30	9
M4	21	36	15	29	8
M5	21	37	16	32	11
M6	22	36	14	23	1
M7	22	41	19	39	17
M8	23	36	13	28	5
M9	23	37	14	30	7
M10	24	35	11	23	−1
M11	24	37	13	27	3
M12	25	35	10	27	2
M13	25	35	10	25	0
M14	25	34	9	22	−3
M15	25	35	10	22	−3
M16	25	36	11	27	2
M17	26	38	12	28	2
M18	26	33	7	19	−7
M19	26	40	14	32	6
M20	26	38	12	27	1
M21	27	35	8	23	−4
M22	27	39	12	27	0
M23	27	39	12	33	6
M24	27	39	12	29	2
M25	28	45	17	39	11
M26	30	36	6	32	2
M27	40	58	18	56	16
M28	40	47	7	51	11
M29	56	49	−7	57	1
M30	56	48	−8	56	0
M31	57	55	−2	51	−6
M32	61	41	−20	40	−21
M33	80	57	−23	93	13
M34	80	47	−33	70	−10
M35	90	40	−50	38	−52
M36	90	45	−45	47	−43

Table 1.
Error differences in the estimated age of males using Lamendin's method and best subset regression equation.

Sex	Actual Age	Lamedine's Estimation A (age in years) = 0.18P + 0.42 T + 25.53	*d1*	Regression (from Subset) A (age in years) = 14.90 PH + 0.330 T − 2.12	*d2*
F1	20	32	12	18	−2
F2	20	33	13	31	11
F3	20	38	18	34	14
F4	21	35	14	32	11
F5	21	40	19	29	8
F6	22	38	16	34	12
F7	22	36	14	30	8
F8	23	46	23	44	21
F9	23	49	26	43	20
F10	24	59	35	48	24
F11	24	51	27	41	17
F12	25	37	12	24	−1
F13	25	36	11	32	7
F14	25	38	13	43	18
F15	26	40	14	32	6
F16	27	35	8	31	4
F17	28	42	14	38	10
F18	29	47	18	48	19
F19	30	39	9	30	0
F20	28	36	8	23	−5
F21	29	41	12	44	15
F22	30	36	6	24	−6
F23	34	43	9	31	−3
F24	36	48	12	43	7
F25	36	44	8	31	−5
F26	38	55	17	48	10
F27	42	47	5	35	−7
F28	44	42	−2	27	−17
F29	48	48	0	52	4
F30	49	46	−3	25	−24
F31	50	32	−18	38	−12
F32	50	51	1	57	7
F33	51	44	−7	54	3
F34	53	44	−9	32	−21
F35	55	51	−4	37	−18
F36	56	43	−13	34	−22
F37	56	40	−16	32	−24

Sex	Actual Age	Lamedine's Estimation A (age in years) = 0.18P + 0.42 T + 25.53	*d1*	Regression (from Subset) A (age in years) = 14.90 PH + 0.330 T − 2.12	*d2*
F38	57	65	8	56	−1
F39	66	51	−15	63	−3
F40	75	74	−1	85	10
F41	83	45	−38	56	−27
F42	83	51	−32	60	−23
F43	83	47	−36	56	−27
F44	90	48	−42	77	−13
F45	90	73	−17	82	−8

Table 2.
Error differences in the estimated age of females using Lamendin's method and the regression equation obtained from the best subset.

Variables	Error difference (approximated range) and distribution			χ^2 (*P*-value)
	±1 to ± 10 (%)	±11 to ± 20 (%)	> ± 20 (%)	
Lamendin's method				
Male	11 (30.6)	21 (58.3)	4 (11.1)	1.275 (0.528)
Female	16 (35.6)	21 (46.7)	8 (17.8)	
Total	27 (33.3)	42 (51.9)	12 (14.8)	
Best subset method				
Male	27 (75.0)	6 (16.7)	3 (8.3)	4.960 (0.084)
Female	23 (51.1)	13 (28.9)	9 (20.0)	
Total	50 (61.7)	19 (23.5)	12 (14.8)	

Table 3.
Sex-associated distributional differences in error margins for the estimations using Lamendin's formula and best subset regression.

total population (M: 30.0% and F: 35.6%) fell within the error margin for Lamendin's method and 61.7% (M: 75.0% and F: 51.0%) for best subset regression. The extent of deviation from the actual age ranges for the group ±11 to ±20 years was 51.9% (42 samples) and 23.5% (19 samples) for Lamendin's method and best subset regression, respectively. For the > ± 20 years range, there were equal sample deviations for both Lamendin's method and best subset; 12 samples (14.8%). The difference in the range of sample error in males and females was not significantly different for both methods (Lamendin; χ^2 = 1.275, P = 0.528 and best subset; χ^2 = 4.960, P = 0.084; **Table 3**).

The differences in the proportion of the ranges (error estimate) using both techniques significant for male samples ($\chi^2_{[df = 3]}$ = 15.213, P = 0.0005) and the total samples ($\chi^2_{[df = 3]}$ = 15.542, P = 0.0004) but not females ($\chi^2_{[df = 3]}$ = 3.198, P = 0.202) (**Table 4**). The age ranges 20–24 years, 25–29 years, 30–70 years, and > 30 years were populated and observed for proportion of the Lamendin's estimates that fell within the limit (±10 years). The result showed that age 30–70 years for both males (71.4%) and

Variables	Error difference (approximated range) and distribution			χ^2 (*P*-value)
	±1 to ± 10 (%)	±11 to ± 20 (%)	> ± 20 (%)	
Male				
Lamendin's method	11 (30.6)	21 (58.3)	4 (11.1)	15.213 (0.0005)
Best subset method	27 (75.0)	6 (16.7)	3 (8.3)	
Female				
Lamendin's method	16 (35.6)	21 (46.7)	8 (17.8)	3.198 (0.202)
Best subset method	23 (51.1)	13 (28.9)	9 (20.0)	
Total				
Lamendin's method	27 (33.3)	42 (51.9)	12 (14.8)	15.542 (0.0004)
Best subset method	50 (61.7)	19 (23.5)	12 (14.8)	

Table 4.
Comparison of the distribution of the error differences between Lamendin's methods and best subset regression.

	Limit (±10 years)			
Sex	Age group	within (%)	outside (%)	Total (%)
Male	20–24 years	0 (0)	11 (100)	11 (30.6)
	25–29 years	6 (42.9)	8 (57.1)	14 (38.9)
	30–70 years	5 (71.4)	2 (28.6)	7 (19.4)
	>70 years	0 (0)	4 (100)	4 (11.1)
Female	20–24 years	0 (0)	11 (100)	11 (24.4)
	25–29 years	2 (22.2)	7 (77.8)	9 (20.0)
	30–70 years	13 (68.4)	6 (31.6)	19 (42.2)
	>70 years	1 (16.7)	5 (83.3)	6 (13.3)
Total		27 (33.3)	54 (66.7)	81

Table 5.
Lamendin's estimation using the ±10 years error margin.

females (68.4%); however, lower proportion of the general sample fell within the range (33.3%) (**Table 5**).

The accuracies of the methods are presented in **Figure 3**, while the extent of agreement (Bland–Altman plot) between the two measurements was presented in **Figure 4**. The Scatterplot with regression analysis of the estimated ages using both methods indicated a lower accuracy (R^2) 12.96% for Lamendin's methods when compared to best subset regression (42.62%) (**Figure 3**). The mean difference (bias) for both measures was 3.85 (−12.64 and 20.35 for the lower and upper limits, respectively), and several values were found close to and outside the upper and lower agreement limits (±2SD), which is an indication of discordance in estimates. This was evident as the difference in population mean was statistically significant (t = 3.45; P = 0.001; **Figure 5**).

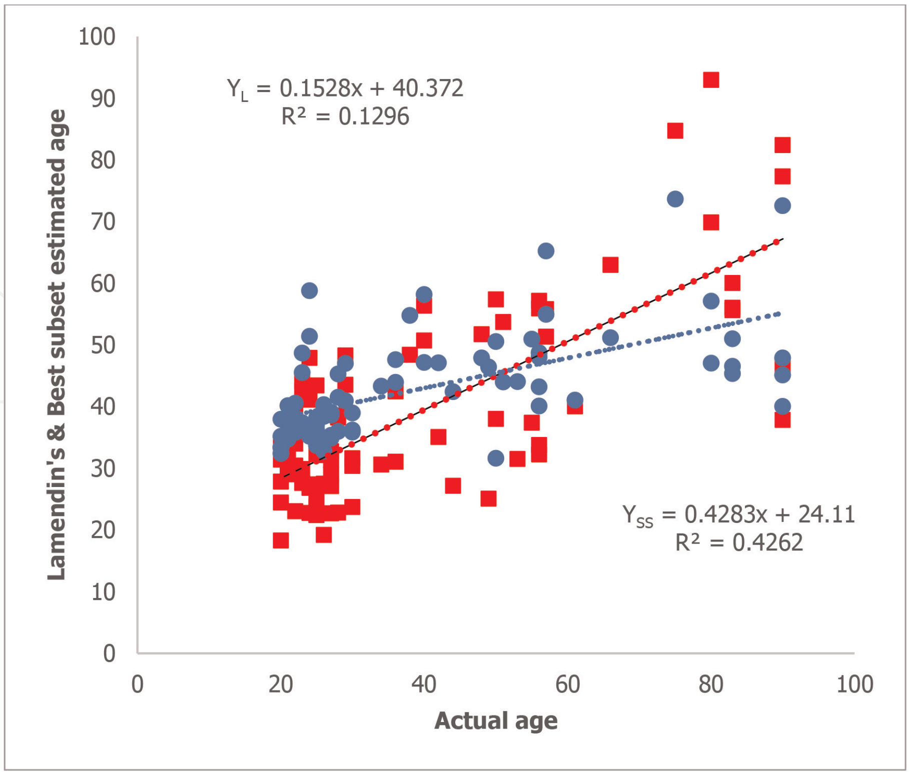

Figure 3.
Scatterplot with regression analysis of Lamendin's (Y_L; blue); best subset (Y_{SS}; red) estimated ages versus Actual age.

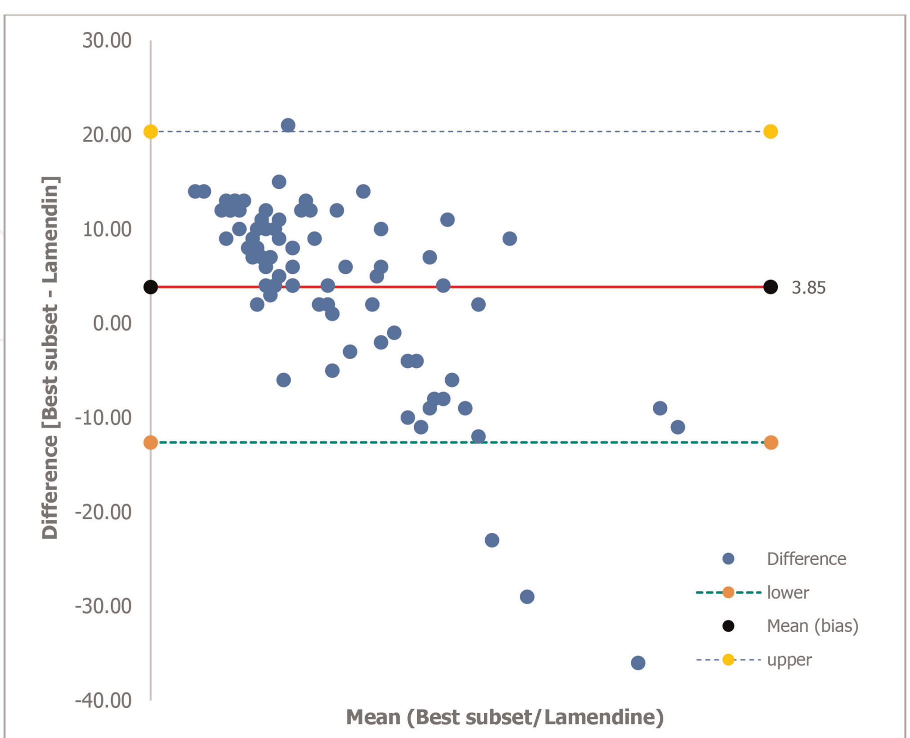

Figure 4.
Bland–Altman plot of the measurement agreement between best subset and Lamendin's method.

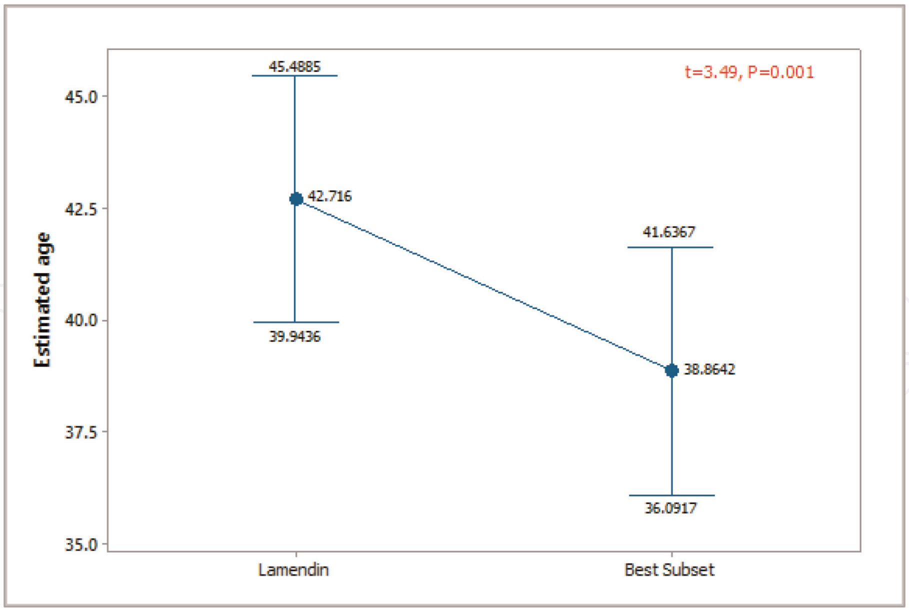

Figure 5.
Interval plot of the mean age prediction for Lamendin's and best subset methods.

5. Discussion

Accuracy and precision are the most important criteria for accepting an age estimation method [50]. This study evaluated the accuracy Lamendin's age estimation method and compared the outcome to that of best subset regression analysis. Although Lamendin et al. (1992) reported unsuitable age estimates for young adults, some studies reported narrower mean error for the estimate [61].

The results for the estimated age using Lamendin's method revealed a wide range of deviations from the error limit (±10 years) of about ±11 to ±20 (51.9%), ≥ ± 21 (14.8%), with 33.3% falling with the ±10 years age range. The distributional differences for males and females were not significant; however, best subset regression produced more estimates that fell within the error limits for males and the general population compared to Lamendin's method. The original research by Lamendin et al. (1992) which analyzed 306 single-rooted teeth aged 22–90 years, of European Ancestry (French), and African Ancestry proposed that an error of ±10 was obtained, however, 66.7% of the study sample fell outside of this error margin. Garizoain et al. [48] and De Angelis [60] reported wide error ranges of 11.88–15.37, and 10.7–36.8 years, respectively, using Lamendin's method. Wide error margins in age estimation methods have been reported in several studies [5, 12, 28, 52, 53, 60, 63, 64].

When the results from Lamendin's estimates were compared to the best subset regression analysis, the margin of error decreased using the best subset; thus, suggesting a poor age estimation by Lamendin's method in the studied population. Nevertheless, some studies found accurate age estimation using Lamendin's formula [5, 28, 61, 63, 72, 73] and improvement in accuracy and variation when the population had individuals between 40 and 45 years, suggesting that the technique for this age group was very efficient [5, 28, 61–63]. Other studies found more estimates with smaller error margins in groups over 50 years of age [12, 52, 74]. Additional studies have yielded poor age estimation using Lamendin's formulae compared to indigenously derived formulae [63, 75].

According to Prince and Ubelaker [52], Lamendin's method yielded the most accurate age estimates for the 30–69-year-old age groups, which is consistent with Lamendin's original study and the Terry Collection sample. In this study, Lamendin's method did not give predictions lower than age 30 and greater than 74 years. In an attempt to further investigate the age limits for accurate estimates using Lamendin's method, the study restricted the age range to ≥25 years and we found that a more accurate estimate (within ±10 years) was between age 30 and 70 years. The tendency to overestimate age in young adults and underestimate it in older ones is well-documented [6, 48, 49, 60]. Prince and Ubelaker [52] found that when samples were below ages 30 and above 70 years, the mean errors significantly increases. The study also noted differences in error estimates at different age ranges with regard to sex and ancestry, suggesting sex and ancestry could have influenced the age estimation. Previous studies found that sex and ancestry influence error estimate margins [52, 64], but a recent study by Garizoain et al. [48] reported that sex had no influence in age estimation.

The study compared the estimates from both methods and found larger proportions of age estimates outside the previously reported error margin by Lamendin's method; however, the differences in the distribution of the error margins were not significant for males, females, and the total populations. In comparing the accuracy of the actual age to estimates of both methods, the accuracy (R^2) of the estimated age using Lamendin's methods and the best subset were 12.96% and 42.62%, respectively, thus, indicating a poor estimate for the study population using Lamendin's methods and wide difference in age estimates for both methods.

6. Conclusion

With only about 33.3% of the sample age estimated within the error limits, it could be concluded that Lamendin's formula was not accurate for estimating the age in the studied sample of the Nigerian population. The observation of Prince and Ubelaker on the age range (30–70 years) for accurate estimate holds true, as found in our population. The study noted that the regression analysis considered ages 80–90 years as outliers and this could be because of static dentine translucency at this age range.

The study, therefore, recommends further studies using larger sample size from both heterogenous and homogenous populations of Nigerian descent, and that samples that are below 25 years and above 70 years may be excluded, as this study found high proportion of over-estimation for ages below 25 years, and under-estimation for samples above age 70.

6.1 Study limitation

The study noted with concern the difficulty in obtaining single-rooted teeth which significantly reduced the sample population. The uneven distribution of the age of the dental samples posed a concern to the researcher.

There are often more stressful logistics challenges associated with approvals from dental clinics to use their facilities and collection and preservation of samples than carrying out the actual dental measurement. Often times one would be required to wait for weeks before approvals are given and samples are available.

Appendices

Pairs	Variable	Paired differences		Paired sample *t*-test			Paired samples correlations		
		N	MD ± SD	*df*	*t*-value	*P*-value	Pair	*r*	*P*-value
Pair 1 (OB_1–OB_2)	RH_1–RH_2	81	−0.076 ± 0.43	80	−1.622	0.109	RH_1 and RH_2	0.986	<0.001
Pair 2 (OB_1–OB_2)	PH_1–PH_2	81	−0.006 ± 0.15	80	−0.352	0.726	PH_1 and PH_2	0.979	<0.001
Pair 3 (OB_1–OB_2)	TH_1–TH_2	81	0.022 ± 0.18	80	1.096	0.276	TH_1 and TH_2	0.998	<0.001

OB, observer; RH, root height; PH, periodontal height; TH, translucency height; N, distribution; MD, mean difference; SD, standard deviation; df, *degree of freedom;* r, *correlation.*

Table A1.
Inter-observer measurement difference (error) and correlation (precision).

Vars		R^2	R^2 (adj)	R^2 (pred)	Mallows Cp	S	RH	PH	TH	P	T
a	1	55.9	54.6	50.3	−1.0	14.1			X		
b	1	43.3	41.6	34.4	7.9	15.9					X
c	1	10.7	8.1	0	30.8	20.0	X				
e	1	6.1	3.3	0	34.0	20.5				X	
f	1	2.3	0	0	36.7	20.9		X			
g	2	56.2	53.6	45.6	0.8	14.2			X		X
h	2	56.2	53.6	46.7	0.8	14.2		X	X		
i	2	56.1	53.4	48	0.9	14.2	X		X		
j	2	56	53.3	48.8	1.0	14.3			X	X	
k	2	53	50.2	44.6	3.0	14.7	X				X
l	3	56.6	52.5	43.7	2.5	14.4		X	X	X	
m	3	56.5	52.5	41.9	2.6	14.4		X	X		X
n	3	56.4	52.3	43.4	2.6	14.4			X	X	X
o	3	56.4	52.3	44.3	2.7	14.4	X	X	X		
p	3	56.3	52.2	45.4	2.7	14.4	X		X	X	
q	4	56.9	51.3	34.3	4.3	14.6	X	X	X	X	
r	4	56.6	51	37.1	4.5	14.6		X	X	X	X
s	4	56.6	51	36.4	4.5	14.6	X	X	X		X
t	4	56.4	50.8	37.6	4.6	14.6	X		X	X	X
u	4	53.3	47.2	31.4	6.9	15.2	X	X		X	X
v	5	57.3	50.2	25.6	6.0	14.7	X	X	X	X	X

RH, root height; PH, periodontal height; TH, translucency height; P, periodontosis; T, translucency.

Table A2.
Best subset regression analysis for age estimation for males using the measured dimensions and derived indices.

	Vars	R^2	R^2 (adj)	R^2 (pred)	Mallows Cp	S	RH	PH	TH	P	T
a	1	43.5	42.2	38.1	7.5	16.0		X			
b	1	35.6	34.1	29.1	14.3	17.1				X	
c	1	26.6	24.9	20.5	22	18.3					X
e	1	21.6	19.7	13.2	26.4	18.9			X		
f	1	1.1	0	0	43.9	21.2	X				
g	2	53.4	51.2	46.6	1	14.7		X			X
h	2	53.2	51	46.4	1.2	14.7			X	X	
i	2	52.7	50.4	46.3	1.6	14.8		X	X		
j	2	48.7	46.3	39.7	5	15.4				X	X
k	2	47.6	45.1	40.3	6	15.6	X			X	
l	3	54.5	51.1	45.3	2.1	14.7	X		X	X	
m	3	54.4	51	44.7	2.2	14.7	X			X	X
n	3	54.1	50.8	45.6	2.4	14.8		X	X	X	
o	3	54	50.7	43.9	2.5	14.8			X	X	X
p	3	53.6	50.3	44.8	2.8	14.9	X	X	X		
q	4	54.6	50	42.1	4	14.9	X	X	X	X	
r	4	54.5	49.9	41.6	4.1	14.9	X	X		X	X
s	4	54.5	49.9	41.7	4.1	14.9	X		X	X	X
t	4	54.2	49.6	40.9	4.3	15.0		X	X	X	X
u	4	53.7	49	41.9	4.8	15.0	X	X	X		X
v	5	54.6	48.8	37	6	15.1	X	X	X	X	X

RH, root height; PH, periodontal height; TH, translucency height; P, periodontosis; T, translucency.

Table A3.
Best subset regression analysis for age estimation for females using the measured dimensions and derived indices.

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