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Root dentin translucency and age at death estimation in adults using single rooted teeth: Update of the Forensic International Dental Database

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A B S T R A C T

Since the publication of Lamendin's age estimation technique, the root dentin translucency has received increasing attention as an important indicator of age. Recently, Parra and colleagues presented the Forensic International Dental Database (FIDB), a proposal to estimate age at death in adults based on Bayes theorem by applying the criteria of Lamendin's technique. The present study aims to update the procedure and to evaluate a new version of the method (named FIDBv2) using two control samples from Colombia and Greece. The performance of this new version was acceptable and suggests that the method is suitable for age at death estimation in adult individuals from different forensic contexts. The best approximations to chronological age were obtained for individuals between 30 and 60 years old, with errors less than 10 years. The age estimations calculated on control samples suggest the adequate

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performance of FIDBv2 on individuals from varied populations. It can be stated that the FIDBv2 constitutes a solid alternative to be used in contexts where no additional data are available. Here we reinforce the initial idea that this model for estimating age at death in adults may be generalizable to any forensic context in the world.

1. Introduction

Age at death estimation in adults has been extensively developed, reviewed, and discussed in the forensic literature [1–7]. It is commonly accepted that greater reliability of estimation results occurs when derived from holistic observations of bone and tooth elements [8–11]. As chronological age increases, the phenotypic variation in the skeletal system of individuals of the same chronological age increases, both within and between populations. This is due to the influence of biological and socioenvironmental factors, which may accelerate or slow down the degenerative processes affecting the organism [12–16]. Nawrocki [16: 88] defines this process as the "trajectory effect", in which the changes that occur in both the skeleton and the dentition throughout life produce that *".the error intervals for each indicator become increasingly broad as one moves through the lifespan"*. This trend is a consequence of the accumulation of biomechanical and physiological processes undergone by an organism that is different for each individual, including intraindividual variations among skeletal indicators. As these differences accumulate during the lifespan, the error in the estimations increases considerably in older adults [16,17]. In this situation, expertise plays a critical role because the level of experience of the forensic practitioner concerning the identification of indicators and the analysis of their variability influences the final results. Besides, the search for extreme accuracy in the estimates is also a relevant limitation for the assessment of the methods. This goal is unnecessary concerning forensic purposes because the construction of adequate age ranges should be one of the main objectives of each process [16,18]. In forensic sciences, the relationship between precision and accuracy, as well as the statistical strength of the methods used, is of major relevance in order to properly arrive to strong conclusions [17,19]. A range of 10 years is generally reliable, as very narrow ranges may exclude possible candidates from missing person lists, while very wide ranges may include unrelated persons, thus hindering the identification process [16,18].

The forensic age at death estimation methods currently available [e.g., 1–3, 6] can be divided into two main groups: those that use qualitative observations based on the analysis of morphological indicators and those that implement quantitative procedures from continuous measurements [16]. The highest reliability has been identified in those that utilize metric variables, at the microscopic, macroscopic, and biochemical levels [16,20,21]. However, not all of them are accessible or easy to apply due to several issues such as technical complexity, preservation of evidence requirements, and the expertise requisites for their proper implementation. Although quantitative methods often provide satisfactory results, priority is usually given to those that can be used easily in daily casework and involve both low implementation costs and quick results. In this sense, methods derived from Lamendin's technique have demonstrated their practical utility in different populations, as described in the next section. This is due to its low technical requirements, high reproducibility and repeatability, and adequate overall performance of the results obtained [11,17,18,22–24].

1.1. Thirty years after the classic publication of Lamendin and colleagues

In 1992, Lamendin and colleagues published one of the most widely used dental age estimation procedures in forensic contexts worldwide. Their main objective was to introduce a rapid, simple and nondestructive technique to aid in estimating the age at death in adult individuals. The proposed method uses three measurements of the labial/buccal surface of a single rooted tooth, recorded in millimeters: (1) root height (RH; maximum distance from the root apex to the cementoenamel junction (CEJ); (2) periodontal regression (PR; maximum distance from the CEJ to the soft tissue attachment line); and (3) root translucency (RT; measured from the root apex to the CEJ). The regression equation generated to estimate age at death is as follows:

$$A=(0\cdot18{*}P)+(0\cdot42{*}T)+25\cdot53$$

where: A is age in years, P = PRx100/RH and T = RTx100/HR. The authors reported a mean error of ± 10 years in their reference sample and of ± 8.4 years in their forensic control sample.

The main criticisms of this method were the inclusion of the periodontal regression as an adequate variable to estimate age and the difficulty in taking the measurements [25]. Despite subsequent studies provided evidence of correlations between chronological age and periodontal retraction (e.g., 22, 25), it was also found that its impact on the age estimation is minimal [22,27,28].

Recently, Parra and colleagues [22] presented a new method of age at death estimation by using the criteria of Lamendin's technique. The authors analyzed a sample of 693 individuals from different contexts (Spain, the USA, Peru, and Colombia) which gave rise to the so-called *Forensic International Dental Database* (FIDB). As expected, some interpopulation differences were found when studying maximum root lengths, periodontal recession, and root translucency. However, age estimates using five different methods derived from Lamendin's technique and that proposed by Bang and Ramm [29] showed a relatively homogeneous behavior, with acceptable margins of error. In their study, the authors agree with Komar and Buikstra [19] and Nawrocki [16] regarding the necessity to identify methodological strategies and criteria which may be applied to different human groups, in order to make the procedures potentially suitable in different population contexts. Parra and colleagues [22] concluded that this technique is relevant to biological anthropology and forensic sciences [1,2,12,16,19].

In the same research, the authors proposed to standardize the Lamendin technique procedure using a Bayesian regression model potentially applicable to all human populations. They stressed that *"there is a difference between the method that can be used, with population-specific algorithms and the algorithms themselves that can be generalized as a model. The Bayesian model uses a FIDB through which specific methods can be operationalized for each population-specific or used as a generalizable or global method for various populations"* [22: 12]. The algorithm generated was applied to a Colombian sample of 150 individuals and the results were compared with those obtained through the methodological proposal of González-Colmenares and colleagues [30], specific to that population. Although no statistically significant differences were identified, the two methods were developed in a statistically different way. While that of González-Colmenares and colleagues [30] was constructed from a statistical regression of 78 observations (R^2 =0.85), the FIDB approach was designed using a Bayesian model and a considerably larger sample (R^2 =0.72), which implies more available information and greater statistical weight to support the results. These findings allow to

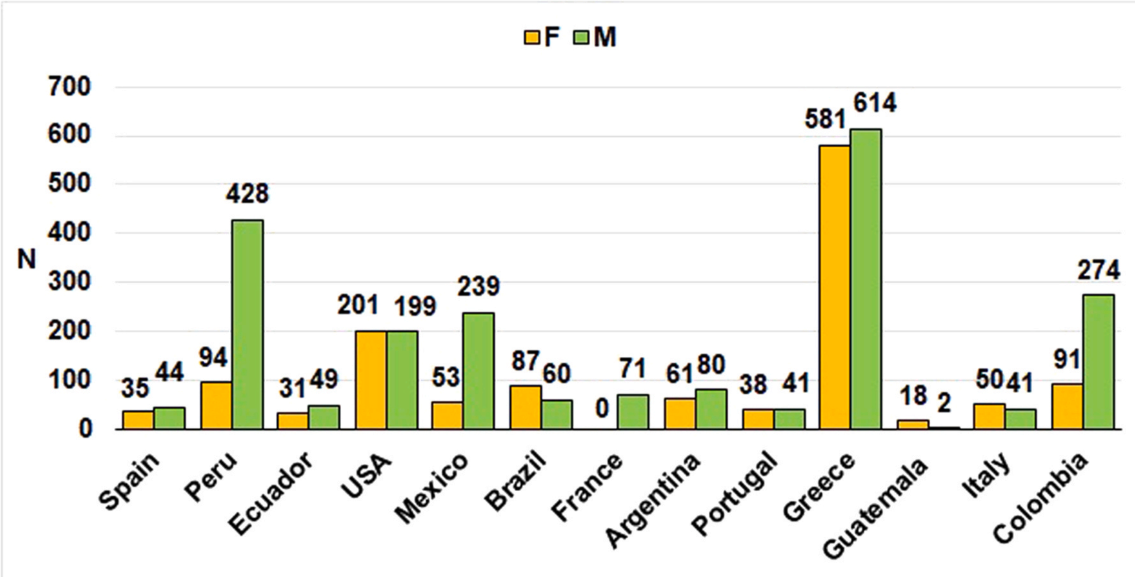

Fig. 1. Percentages of individuals included in the FIDBv2 sample by sex and country of origin.

propose that the FIDB model could be applied in other populations and contexts different from the Colombian sample.

Similarly, Parra and colleagues [23] applied the Bayesian model to a Peruvian sample of 234 individuals, not included in the first version of the FIDB, and compared the results with other methods previously developed from the Peruvian context, such as those proposed by Ubelaker and Parra [28] and Vilcapoma Guerra [31]. The results also showed low differences between them, although as in the Colombian case, those of the FIDB were the most noteworthy. On the other hand, Garizoain and colleagues [18] applied the FIDB to several new samples from Latin American contexts (Argentina, Mexico, Ecuador, Peru, Guatemala, and Colombia) and found similar results with respect to those previously reported for FIDB in Peru and Colombia [22,23]. Furthermore, when analyzing all the Latin American observations in a unified sample, the results were similar to those obtained by Parra and colleagues [22] using the first FIDB proposal. Consequently, that paper highlighted that there is promising evidence that the FIDB model could be generalizable and useful in different populations.

The current research updates and expands FIDB (hereafter FIDBv2) from the original proposal by Parra and colleagues [22]. The new FIDBv2 uses the Bayesian algorithm and incorporates a logarithmic transformation of the variables, which allows a better homogeneity and linearity in the data distribution. Likewise, this FIDB version also includes a greater amount of information for the calculation of probabilities through the analysis of a large number of individuals from different countries around the world. FIDBv2 is applied to two control samples from Greece and Colombia in order to assess the accuracy and precision levels. Finally, the results of the estimates obtained is compared with those generated from a linear and a logarithmic regression, proposed in a previous study by Garizoain and colleagues [32].

2. Materials and methods

The sample size of FIDBv2 was increased from previous research, up to a total of 3482 individuals from contemporary populations from Colombia, Peru, Portugal, Mexico, Argentina, Guatemala, Ecuador, Brazil, Spain, France, Greece, Italy, and the United States (Fig. 1). All individuals have documented information on age and sex. The mean age of FIDBv2 is 51.95 years (median 50.41), with ages ranging from 20 to 99 years. Regarding sex, 1340 individuals are females (mean and median age: 55.24 and 54.20 years, respectively) and 2142 males (mean and median age: 49.90 and 48.00 years, respectively).

Two control samples were also used, composed of 112 Colombian and 100 Greek male and female individuals, on which age estimates were made. As in the previous case, all individuals have documented information on their age and sex. Excluding the Colombian sample, all age groups are represented (Table 1). Table 2 shows the sex distribution of the control samples according to the population of origin. In the Greek sample, the sex frequencies are almost equal (F=51%; M=49%), in contrast to the Colombian (M=85.72%; 14.28%) samples.

The measurements considered in the present research were the maximum root length (RH), the periodontal recession (PR), and the root dentine translucency (RDT). Each of them was recorded according to the procedures proposed by Lamendin and colleagues [33]. Measurements of the control samples were carried out by two of the authors. Eleni Zorba recorded teeth donated to the Department of Forensic Medicine and Toxicology of the National and Kapodistrian University of Athens, Medical School as well as skeletons derived from the Athens Collection. In both cases the skeletal remains belonged to individuals who lived mainly during the second half of the 20th century and came from the cemetery of Athens [34]. On the other hand, Clara Inés Valderrama Leal obtained the information from the Sistema de Información Red de Desaparecidos y Cadáveres (SIRDEC) of the Instituto Nacional de Medicina Legal y Ciencias Forenses de Colombia (INMLCF), which includes corpses and adult human remains identified by forensic practitioners between 2009 and 2021. The statistic procedure implemented here to estimate age at death according to Lamendin's technique is an upgrading of the first proposal used by Parra et al. [22]. As previously mentioned, the present research introduces in a complementary

Table 1
Age distribution of the control samples.

Range ages (years)	Greece		Colombia	
	n	Mean	n	Mean
20–30	15	25.20	28	27.25
31–40	14	35.07	39	34.61
41–50	16	45.50	21	45.71
51–60	14	55.07	14	55.28
61–70	14	64.92	6	64.50
71–80	14	75.35	4	74.00
> 80	13	88.92	-	-

Table 2
Number of individuals, mean and median ages at death of control samples.

Countries	Females				Males				Total		
	n	%	Mean	Median	n	%	Mean	Median	n	Mean	Median
Greece	51	51.00	55.52	53.00	49	49.00	54.20	55.00	100	54.88	53.50
Colombia	16	14.28	40.68	33.50	96	85.72	40.40	37.00	112	40.44	37.00

Table 3
Results of the normality tests of the variables considered in the control samples. The only case where a normal distribution was not reported is highlighted in bold. E (Chronological Age), BLR (Bayesian logarithmic regression), LR (Linear regression), LogR (Logarithmic regression).

Countries	E		BLR		LR		LogR	
	Z	p	Z	p	Z	p	Z	p
Colombia	**1.64**	**0.00**	0.59	0.86	1.28	0.08	0.70	0.70
Greece	0.68	0.73	0.64	0.80	1.05	0.29	0.92	0.36

Table 4
Results of the intraclass correlation coefficients between the estimated and the chronological for both samples (95% confidence interval). References: E (Chronological Age), BLR (Bayesian logarithmic regression), LR (Linear regression), LogR (Logarithmic regression).

	BLR			LR			LogR		
	Mean	Low. Limit	Upper Limit	Mean	Low. Limit	Upper Limit	Mean	Low. Limit	Upper Limit
Colombia	0.85	0.78	0.90	0.82	0.72	0.88	0.83	0.74	0.89
Greece	0.87	0.81	0.91	0.81	0.72	0.87	0.80	0.70	0.86

way the logarithmic transformation of the data (named BLR) in order to refine the calculation procedure and consequently to improve the reliability of the estimates, where:

Age=ln(Age)

RH=ln(RH)

PR=ln(PR+1)

RTD ln(RDT+1)

Age estimation by this new method was made using the open-source R software, version 4.01 (available at https://www.r-project.org). On the other hand, estimates using the formulae proposed by Garizoain and colleagues [32]) were obtained according to the authors' indications. Both regressions (one linear and the other logarithmic, named here LR and LogR, respectively) use only root dentinal translucency and root length, which is used as a reference to evaluate the increase in dental root translucency.[12]

Parametric statistical analyses were used with SPSS software (IBM SPSS Statistics for Windows, Version 24. IBM corp., Armonk, NY) and the results of the estimates were analysed both for the whole sample and by age cohorts. The paired samples T test and the intraclass correlation coefficient were used to analyse differences and agreement between chronological and estimated age. Sex was not considered in the analysis, as previous studies have shown that it does not influence the estimates [18,22,24,35]. For each case, the age estimation interval was calculated using the standard error of the estimates provided by Parra and colleagues [22]. The number of times that the chronological age of the individuals was included within the interval was quantified, as a proxy of a correct age estimate. The intra- and interobserver errors were not calculated, since a high degree of reproducibility of the measurements was corroborated in previous works [22,24].

3. Results

As the results of the normality tests indicate that all the considered ages (except for the chronological age of the Colombian sample) are normally distributed, parametric statistics were used. Table 3 shows the results of the normality tests for each control sample.

3.1. Colombian control sample

Age at death estimations obtained by means of the Bayesian logarithmic regression did not offer statistically significant differences with chronological age ($t = 0.84$; $p = 0.41$) and showed a bias and an imprecision of 0.78 and 6.65 years, respectively. The percentage of correct estimates calculated from the 95% confidence interval was 85.4%. Concerning the linear regression, the difference between the estimated and the documented ages was statistically significant ($t = -2.86$; $p = 0.00$), with errors of −2.66 (bias) and 7.34 (imprecision) years and the percentages of correct estimates were 88.8%. Finally, using the logarithmic regression, no statistically significant differences were obtained between the estimated and the chronological ages ($t = -0.89$; $p = 0.73$), with a bias −0.94 years, an imprecision of 9.94 years and 88.8% of correct estimates. The intraclass correlation coefficient calculated in order to assess the agreement between the chronological and the estimated ages from the three formulae indicates high and statically significant correlations for all of them (Table 4).

The differences between the estimated and the documented ages are not statistically significant in all age cohorts (excepting for the 31–40 years old cohort) for at least one equation (Table 5). Also, for the three formulae the biases in the estimates tend to overestimate age in young adults, although from 40 years old onwards the overall average errors show an underestimation of the calculated ages. Moreover, the absolute mean errors (accuracy) between 20 and 60 years of age are less than 9.65 years, and for the 61–70 years cohort, between 7.82 and 10.77 years (Table 5; Fig. 2). The lowest value (3.73 years) corresponds to the linear regression for the age range between 41 and 50 years. Finally, percentages of correct estimates above 75% are reported only for individuals less than 60 years (except for the LogR formula in cohort 61–70); those obtained between 20 and 60 years of age are highlighted, with values between 76.9% and 100% (Table 5).

[12] The formulae developed by Garizoain and colleagues [32] consist of a logarithmic regression (LogR), where $Age = (LnT*25.63) - 34.39$, and of a linear regression (LR), where $Age = (T-0.71) + 29.9$. In both cases, $T = DRT/RH* 100$.

Table 5
Results of the estimates according to the age groups considered in the Colombian control sample. References: BLR (Bayesian logarithmic regression), LR (Linear regression), LogR (Logarithmic regression).

Age group	Formula	n	Mean documented age	Mean estimated age	Bias	Accuracy	t	p	% of correct estimates
20–30	BLR	23	27.65	28.79	-1.13	5.06	-0.94	0.35	100
	LR			36.36	-8.71	8.71	-10.56	*0.00*	82.60
	LogR			28.89	-1.24	9.65	-0.48	0.63	82.60
31–40	BLR	32	34.25	37.93	-3.58	6.10	-2.36	*0.02*	81.30
	LR			40.71	-6.46	6.74	-6.97	*0.00*	96.90
	LogR			39.90	-5.65	7.80	-4.05	*0.00*	90.60
41–50	BLR	13	45.76	38.91	6.85	7.33	3.77	*0.00*	76.90
	LR			42.57	3.19	3.73	3.32	*0.00*	100
	LogR			43.33	2.43	4.69	1.66	0.12	100
51–60	BLR	13	55.07	52.93	2.14	4.46	1.45	0.17	100
	LR			51.97	3.10	5.42	1.97	0.07	100
	LogR			54.58	0.49	4.18	0.34	0.73	100
61–70	BLR	4	64.25	54.22	10.02	10.47	2.46	0.09	50
	LR			53.47	10.77	10.77	3.53	*0.03*	50
	LogR			56.42	7.82	7.82	2.8	0.06	75
71–80	BLR	4	74.00	60.52	13.47	16.42	1.74	0.18	50
	LR			62.65	11.35	18.75	1.05	0.36	25
	LogR			59.90	14.05	15.15	1.90	0.15	50

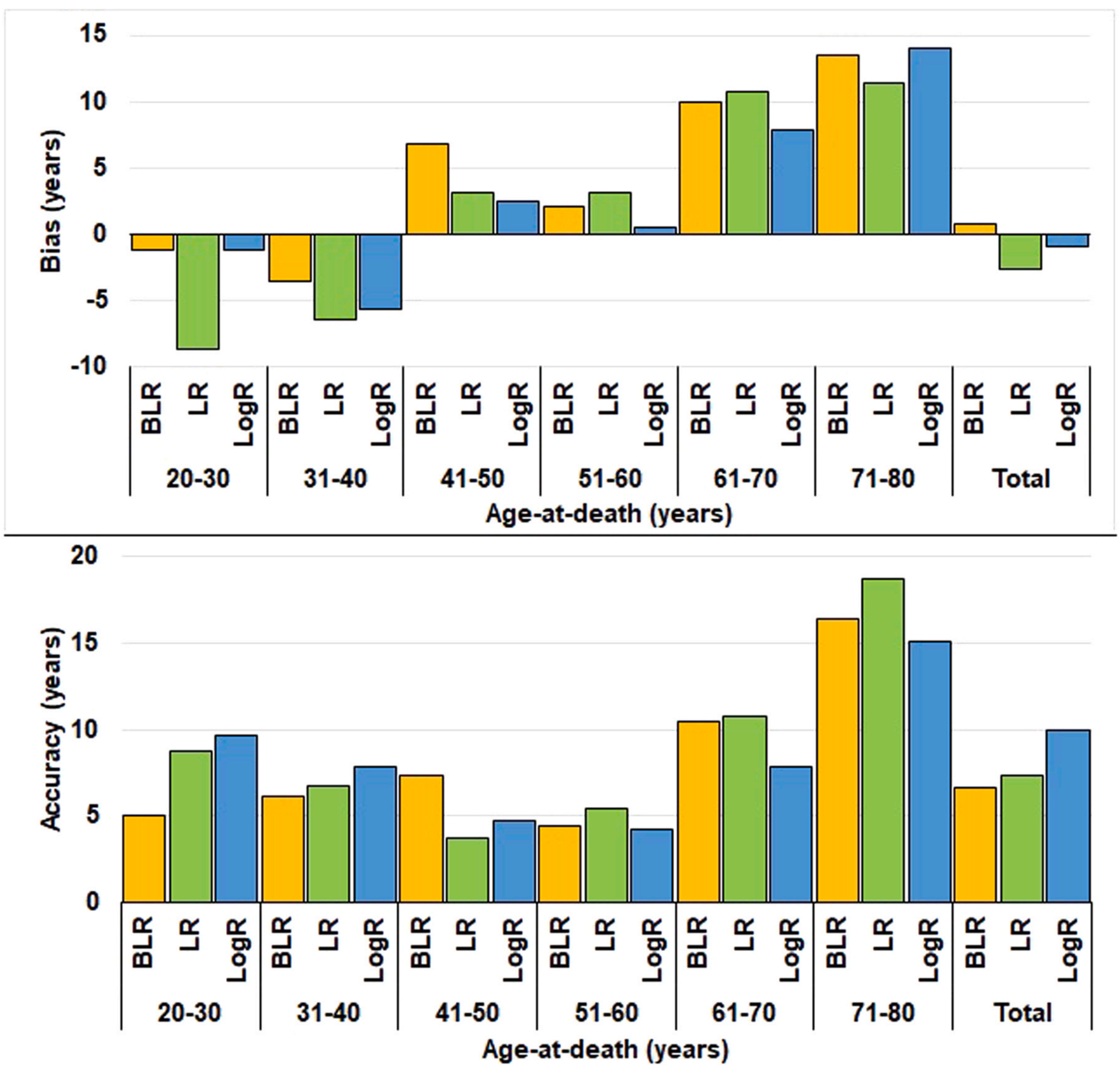

Fig. 2. Bias and accuracy for the Colombian sample using the FIDBv2 algorithm and formulae proposed by Garizoain and colleagues [32]. BLR (Bayesian logarithmic regression), LR (Linear regression), LogR (Logarithmic regression).

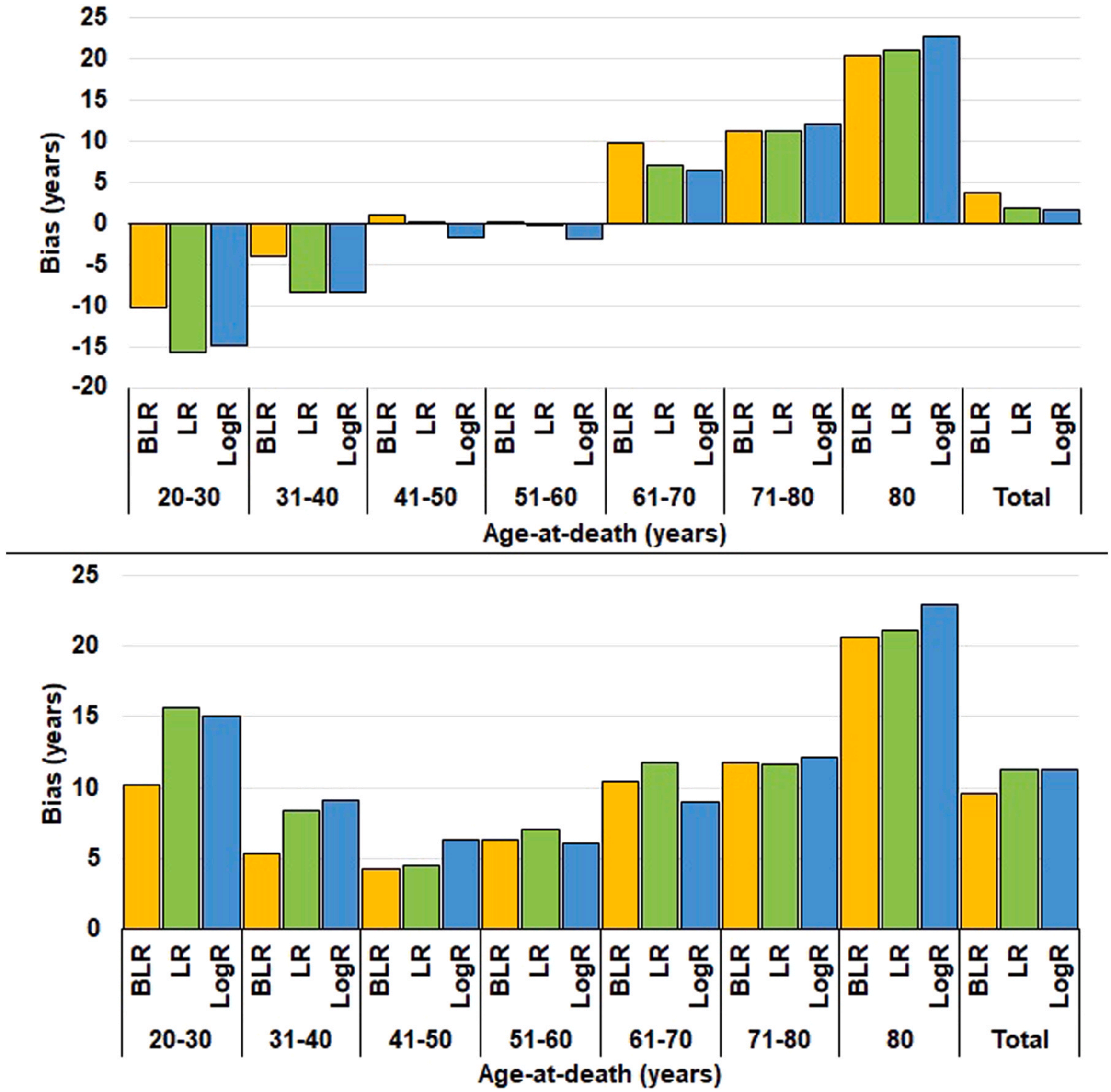

Fig. 3. Bias and accuracy for the Greek sample using the FIDBv2 algorithm and formulae proposed by Garizoain and colleagues [32]. BLR (Bayesian logarithmic regression), LR (Linear regression), LogR (Logarithmic regression).

3.2. Greek control sample

When using the FIDBv2 for the calculation of age (BLR), the difference between the estimated and the documented ages was statistically significant ($t = 3.11$; $p = 0.00$), with a bias of 3.70 years and an accuracy of 9.62 years. Correct age estimations reach 63% of the cases. For the linear regression (LR), differences between the estimated and the chronological ages were not statistically significant ($t = 1.28$; $p = 0.20$). The bias of the estimates with this formula was 1.77 years, while accuracy 11.23 years, and the percentage of correct estimation was 59%. Finally, when using the logarithmic regression (LogR), no statistically significant differences were found between the estimated and the chronological ages ($t = 1.17$; $p = 0.21$). The error in the estimates resulted in a bias of 1.62 years and an accuracy of 11.31 years. For this formula, the percentage of correct estimations was 58%. The intraclass correlation coefficient showed a high degree of agreement between the chronological and the estimated ages for all the formulae (Table 4).

As for the analysis by age groups, the differences between the estimated and the documented age were not statistically significant only for the 41–60 years cohort. The values of bias and accuracy of the estimates were less than ten years between the ages of 30 and 60 (Fig. 3) and the percentages of correct estimates were higher than 71.4% on individuals between 31 and 60 years old (Table 6).

4. Discussion

The evaluation of the performance of the FIDBv2 algorithm and the formulae proposed by Garizoain and colleagues [32] in both control samples (without discriminating by age cohorts) provided values of biases and inaccuracies in the estimates of less than 10 years (except for the LR and LogR in the Greek control sample, with values around 11 years), and percentages of correct estimates that vary between 58% and 88.8%. When comparing the estimated age and the documented ages, the differences were not statistically significant in four of the analysed comparisons. These findings suggest that the procedure could be applied to different samples from around the world, with the best results in the two formulae based on logarithmic regressions. This also supports what was originally proposed by Parra and colleagues [22], who indicated that

Table 6
Results of the estimates according to the age groups considered in the Greek control sample. References: BLR (Bayesian logarithmic regression), LR (Linear regression), LogR (Logarithmic regression).

Age group	Formula	n	Mean documented age	Mean estimated age	Bias	Accuracy	t	p	% of correct estimates
20–30	BLR	15	25.20	35.39	-10.19	10.19	-9.67	*0.00*	60
	LR			40.82	-15.62	15.62	-17.39	*0.00*	20
	LogR			40.53	-14.85	15.03	-7.96	*0.00*	26.70
31–40	BLR	14	35.07	39.13	-4.06	5.37	-2.52	*0.02*	85.70
	LR			43.45	-8.37	8.37	-5.94	*0.00*	71.40
	LogR			43.52	-8.45	9.08	-4.33	*0.00*	78.60
41–50	BLR	16	45.50	44.53	0.96	4.27	0.73	0.47	93.80
	LR			45.43	0.06	4.52	0.04	0.96	100
	LogR			47.19	-1.69	6.28	-0.88	0.39	93.80
51–60	BLR	14	55.07	57.87	0.19	6.27	0.08	0.93	78.60
	LR			55.22	-0.15	6.99	-0.06	0.94	85.70
	LogR			57.01	-1.93	6.02	-1	0.33	85.70
61–70	BLR	14	64.92	55.18	9.74	10.4	4.77	*0.00*	57.10
	LR			57.87	7.05	11.78	2.2	*0.04*	42.90
	LogR			58.46	6.46	9	2.75	*0.01*	64.30
71–80	BLR	14	75.35	64.07	11.28	11.77	4.22	*0.00*	50
	LR			64.12	11.23	11.6	3.84	*0.00*	64.30
	LogR			63.23	12.12	12.12	4.28	*0.00*	50
80 <	BLR	13	88.92	68.34	20.57	20.57	8.86	*0.00*	7.70
	LR			67.86	21.06	21.06	9.02	*0.00*	23.10
	LogR			66.02	22.9	22.9	13.91	*0.00*	0

Lamendin's technique and all the methods derived from it would be applied to any human population. The present confirmation of the global application of this procedure contributes positively to mitigating forensic problems around the estimation of age at death in adult individuals [16,19,36].

The study shows that the chronological age considerably influences the results and that the trends for error (both bias and inaccuracy) increase with documented age (Fig. 2) ("trajectory effect"; [16]), as previously stated in numerous research studies [18,22–24,27,28,30,34,35,37–41, among others]. When dividing the analyses of the estimates by 10-year age cohorts, the average errors obtained are less than 10 years up to the age of 60 years old (except for linear and logarithmic regressions in the Greek sample between 20 and 30 years of age). Concerning the percentages of correct estimates, a good performance is observed between 31 and 60 years. As in the age comparisons, in the 20–30 age cohort of the Greek sample and individuals older than 61, percentages of correct estimates of less than 75% are observed.

On the other hand, a trend toward the underestimation is observed in the older age groups (over 61 years old) for the three formulae, which is consistent with the "trajectory effect" mentioned above. The values of the standard errors of the estimates are consistently higher than in younger age groups, which implies that when making an estimate and using the standard error, the age intervals generated present a large amplitude and may include several age groups. This diminishes its relevance in age estimation in these groups, although it does not render it useless.

These trends are similar to those observed in previous research that applies Lamendin's technique. All the studies also report a high positive correlation between the errors of the estimations and the chronological age [18,22–31], and the increasing of underestimation in older ages (Figs. 2 and 3), which indicate that with root translucency would cease to be useful as a good estimator for individuals older than 60 years old [22–24]. Parra and colleagues [22:18] argued that when the translucency approaches the coronal region *"the dental area in this region is much wider than in the apical portion of the tooth root, and the physiological mechanism of inorganic salt deposits probably requires more time to generate translucency. At the apex level, the effect is exactly the opposite, as there is less dentinal area, the process of inorganic salt deposits is much faster, and the translucency is more quickly noticeable"*. In addition, the accumulation of mineral deposits within the dentinal tubules, a process that directly influences dentinal root translucency, is not only the direct result of the passive precipitation of the hydroxyapatite crystals contained in the peritubular dentine. The fact the odontoblasts have an active role in their precipitation [42] and that the aging process of these cells, which results in a functional decrease, leads to a deceleration of translucency generation [43–45], must be considered as important factors affecting adult age estimation. The results obtained in the present study support these interpretations.

Nevertheless, although the impact of the "trajectory effect" cannot be eliminated, it could be mitigated in the 20–60 age range by using Bayesian statistics in the analyses, as originally proposed by Prince and Konigsberg [38]. These authors obtained more accurate results compared to classical methods that use regression statistics, similar to the research published by Schmitt and colleagues [46], who applied different statistical approaches (ordinary least squares, regression, multinomial logistic regression, and Bayesian statistics). In addition to the Bayesian approach, it might be possible to improve precision and reduce estimation error by other means, such as adding discrete phases from other methods on a continuous scale and calculating them together [16]. Some researchers have tried to apply such corrections, with interesting results [47–49]. Moreover, the use of logarithmic regressions as an alternative to linear regressions offers acceptable average errors in the estimates up to the age of 70, as demonstrated in the present study. This constitutes a positive aspect concerning the problems derived from the "trajectory effect" [48]. Our findings show that, in general, regressions based on a logarithmic model provide better results (in terms of the error in age at death estimates) than traditional linear regressions.

The population origin of the individuals that constitute the sample used to develop the methods, as well as those in which the procedure is applied, are crucial aspects that must be considered when analyzing the results. While there is currently no doubt that dentinal translucency increases with age, there is still much research to be done on interpopulation and individual variation of this relationship and the impact it has on age estimation. This aspect has been highlighted in numerous studies, which have reported some degree of interpopulation variation in the relationship between translucency and chronological age [38,41]. However, despite this, previous work that has used the Lamendin [29] technique agrees that it performs properly in samples from diverse provenience [18,22–24,27,28,30,34,37,39]. In general terms, the different methodological proposals offer adequate estimates in the age range between 30 and 59 years, regardless of the population on which they are applied [18,22–24,27,28,30,34,37,39]. The FIDBv2 application offers the opportunity to unify criteria for age estimation in adults using the Lamendin technique and to establish a standardized calculation system that can be used in different contexts around the world [18,22].

5. Conclusion

Thirty years after the publication of Lamendin and colleagues [33], we know much more about its advantages for forensic practice, in contrast to its potential limitations [18,22]. Although the original calculation method has been modified and adjusted according to specific local experiences [e.g., 27, 30, 32, 37] and the generalization of a particular model that can potentially be standardized both locally and globally [18,22,23], the original Lamendin technique did not lose its relevance and importance due to its simplicity, easy accessibility, reproducibility and repeatability.

In this sense, the performance of the FIDBv2 algorithm in the control samples was acceptable and suggests that the procedure is suitable for estimating age at death in adult individuals from several forensic contexts. Likewise, the logarithmic regression proposed by Garizoain et al. [18], offered similar results to the FIDBv2 algorithm, making it an interesting alternative in cases where it is only possible to measure dental root translucency. On the other hand, the linear regressions tended to have higher estimation errors compared to the other two formulas evaluated.

The best approximations to chronological age were obtained for individuals between 30 and 60 years old, with errors of less than 10 years. These findings are consistent with previous studies using the first version of the FIDB and with the results reported by other researchers using different statistical procedures. This report also concludes that the results obtained for individuals between 60 and 80 years of age using FIDBv2 improved the estimation performance compared to previous methods, thus mitigating the trajectory effect.

The estimations obtained on the control samples suggest the adequate performance of the FIDBv2 algorithm on individuals from varied populations. The applicability of this procedure in contexts where no previous studies have been conducted to verify the use of methods derived from Lamendin technique may be reliably useful. However, it is recommended, whenever possible, to use this method in conjunction with other age indicators. In this way, considering a multifactorial analysis, it is possible to focus on the construction of reliable age intervals, thus achieving a better approximation to the chronological age of the individual, and consequently a better contribution to the identification process.

Comparing the results obtained in the present study with others that have previously validated Lamendin proposal in other populations, it can be stated that the FIDBv2 is consolidating as a solid methodological alternative. This proposal gathers information from different populations around the world, performs a rigorous statistical treatment of the data, and offers results suitable for forensic purposes. Consequently, it is highlighted as an analytical tool that will allow the generation of estimates of adult individuals from different geographical origins. Moreover, the procedure is freely available online at https://iisap.odontologia.uba.ar/unidad-de-investigacion-en-bioarqueologia-y-antropologia-forense/, the webpage of the Bioarchaeology and Forensic Anthropology Research Unit (UIBAF; Unidad de Investigación en Bioarqueología y Antropología Forense, that belongs to the Institute of Public Health Research, Faculty of Odontology, University of Buenos Aires, Argentina), thus promoting a greater availability of the method in an effort to contribute to the improvement of the quality of the forensic practice in different regions of the world.

CRediT authorship contribution statement

Gonzalo Garizoain: Conceptualization, Formal analysis, Investigation, Resources, Writing - original draft. **Roberto Parra:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Funding acquisition, Project administration, Supervision, Writing - original draft. **Claudia Aranda:** Methodology, Investigation, Resources. **Eleni Zorba:** Resources. **Konstantinos Moraitis:** Resources. **Karen Escalante-Flórez:** Resources, **Retana Fernando**: Resources. **Lucio Condori:** Resources. **Clara Valderrama-Leal:** Resources. **Pablo Rodríguez:** Methodology, Resources. **Leandro Luna:** Conceptualization, Methodology, Investigation, Resources, Writing - original draft, Writing - review & editing.

Declarations of interest

The authors declare no conflict of interest in the writing of this article.

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