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Forensic Anthropology Population Data

Evaluation of Lamendin's age-at-death estimation method in a documented osteological collection (La Plata, Argentina)

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ABSTRACT

Age estimation is one of the main biological parameters to be determined for constructing an individual biological profile. In contexts where bones are poorly preserved, the use of teeth becomes relevant. Translucency of dentine has become relevant in recent decades, since the publication of the method proposed by Lamendin et al. (1992). In the local context, studies validating age-estimation methods from the permanent dentition are lacking. For this reason, it was decided to evaluate the performance of the age-estimation method proposed by Lamendin et al. (1992) in a sample of adult individuals with documented age belonging to the Lambre collection from the Municipal Cemetery of the city of La Plata. It was found that estimated age according to Lamendin et al.'s (1992) method varies by tooth type and age, being age the one that influences the estimates the most. On the other hand, sex has no influence in the estimation of age. The results showed no differences in the estimation in individuals between 35–50 years old, while exhibiting a tendency to overestimate age in young adults and to underestimate it in older ones.

Introduction

Age estimation from the analysis of human bones constitutes one of the main biological parameters to be established in an individual biological profile, and is of great importance for forensic anthropology in particular [1–4]. In contexts where bone-age indicators are poorly preserved, the use of teeth becomes relevant [3,5,6]. One of the dental indicators of age that has become most relevant in recent decades has been the translucency of the dentine [7–17], mainly since the publication of the method proposed by Lamendin et al. [18]. This proposal is applied on uniradicular dentition and uses the total extension of the translucency measured from the apex of the root, and the retraction of the periodontium measured from the cement enamel junction, both measurements being taken on the labial surface.

Subsequent studies focused on evaluating the performance of the proposal in different populations [7,8,10,11,16,17]. An interesting precedent of this kind of studies is the one carried out in the Terry collection [7,8] on 400 dental pieces belonging to 359 adult individuals (166 females and 193 males aged between 25–99 years). The results of the estimates showed the application of Lamendin et al.'s proposal [18] to yield a good result. They also reported age and sex differences [7,8]. Regarding age, they exhibited a tendency to overestimate it in young adult individuals and underestimate it in older adults. As for the differences by sex in the estimates, the study reported that they were higher in females [7,8].

The validation studies of Lamendin et al.'s [18] proposal carried out in the Terry collection have not been the only ones. Several validation studies of the method posed by Lamendin et al. [18] have coincided with the results obtained in the Terry collection. These investigations also reported a tendency to overestimate age in young individuals and underestimate it in older ones [7,12,16,17,19,20,21,22]. As to the influence of sex on the estimates, the results are varied. Some authors report statistically significant differences in estimates by sex [7,8,23], while others do not find such variation [11,17,24]. Little has been investigated regarding differences in translucency and periodontal retraction depending on tooth surface (labial/lingual). Lamendin et al. [18] recorded these variables on the labial surface, since it would be less affected by pathological processes. However, Foti et al. [24] point out the need to increase the number of studies that considers the differences in estimates by type of tooth surface.

In the local context, studies validating age-estimation methods from permanent dentition are lacking [25], and the existing ones have been

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performed on undocumented archaeological samples [26], comparing teeth as estimators of age in relation to another skeletal element (i.e., pubic symphysis). Given the lack of knowledge regarding the performance of age-estimation methods from teeth in local samples, it was decided to evaluate the performance of the age-estimation method proposed by Lamendin et al. [18] in a sample of adult individuals with documented age belonging to the Lambre collection of the Municipal Cemetery of the city of La Plata.

Materials and methods

The Lambre collection is composed of 420 individuals from the Municipal Cemetery of the city of La Plata (Argentina) who died during the late twentieth century, 262 of which belong to adult individuals. Documentary information of the individuals that comprise the collection (age, sex, nationality, and date and cause of death) was obtained from the records of the cemetery.

All researchs carried out in the Lambre collection were approved by the Bioethics Committee of the Faculty of Medical Sciences of the National University of La Plata [27]. Likewise, the study, conservation, and management of human remains in this research were in agreement with current national and international ethic codes [28].

For this study, a total of 457 uniradicular teeth belonging to 91 adult individuals (57 male and 34 female) aged between 18 and 91 years were selected (Fig. 1). Mean age of the sample is 54.93 years, while the median is around 57 years. As an exclusion criterion, all teeth with associated pathologies that made it impossible for them to be included in this study were ruled out (i.e., caries).

Translucency, periodontal retraction and root length were recorded according to [18], both on labial and lingual surfaces, taking into account the observations made by Foti et al. [24] with regard to the absence of information on the differences between these surfaces (Fig. 2). All measurements were taken macroscopically, using a digital caliper (precision 0.01 mm). An LED X-ray viewer was used to measure translucency. Translucency is defined as the maximum extension of the translucent zone of the root measured from the apex. Periodontal retraction is observed as a yellowish zone darker than the enamel and of a different color from the rest of the root, measured from the union cement enamel [18]. On the other hand, root length is measured from the apex to the union cement enamel on the middle axis of the root [25].

Intra- and inter-observer error analyses of pairs of measures corresponding to 44 randomly selected teeth were made. For these analyses Student's *t*-test for related samples and Intra-class Correlation Coefficient were selected in order to establish the reliability of the recorded measurements. Measurements were taken with an interval of two weeks by one of the authors (GG) for intra-observer error, and by two of the authors (GG, SP) for inter-observer error analysis.

Age was estimated using the formula developed by Lamendin et al. [18], and dividing the sample by tooth type and surface. Translucency and periodontal retraction correlation with age was first evaluated using the Pearson's correlation coefficient. This method was then evaluated by comparing the differences between estimated age (EA) and chronological age (CA) through the Student's *t*-test for related samples, analyzing the bias (defined as the mean differences between EA and CA) and accuracy (defined as the mean absolute differences between EA and CA) of the estimates and counting the number of times that age could be estimated correctly [29,30]. This last analysis was carried out by estimating age and calculating the prediction interval (in the case of the evaluated method, the only data offered to estimate this interval is the mean error), and counting the number of times chronological age falls within the prediction interval.

Finally, the influence of age and sex on the estimates was analyzed in order to assess whether these factors should be taken into account when applying this method. In order to analyze the influence of age on the estimates, the sample was divided (distinguishing by type of tooth and considering all teeth together) into 5 groups (<35; 36–50; 51–65; 66–80; >81 years). Chronological ages and estimated ages in each age cohort were then compared in order to assess the differences between the two, and the number of correct age estimates in each group was quantified. Regarding sex, given the disproportion between them, a comparison was made of the differences in the estimates between female and male individuals, in order to assess whether such differences are due to the sex of the individual.

On the other hand, analyses carried out in previous studies showed that periodontal retraction, root lenght and dental translucency are normally distributed [25,31,32]. For this reason, the statistics used in this work were parametric.

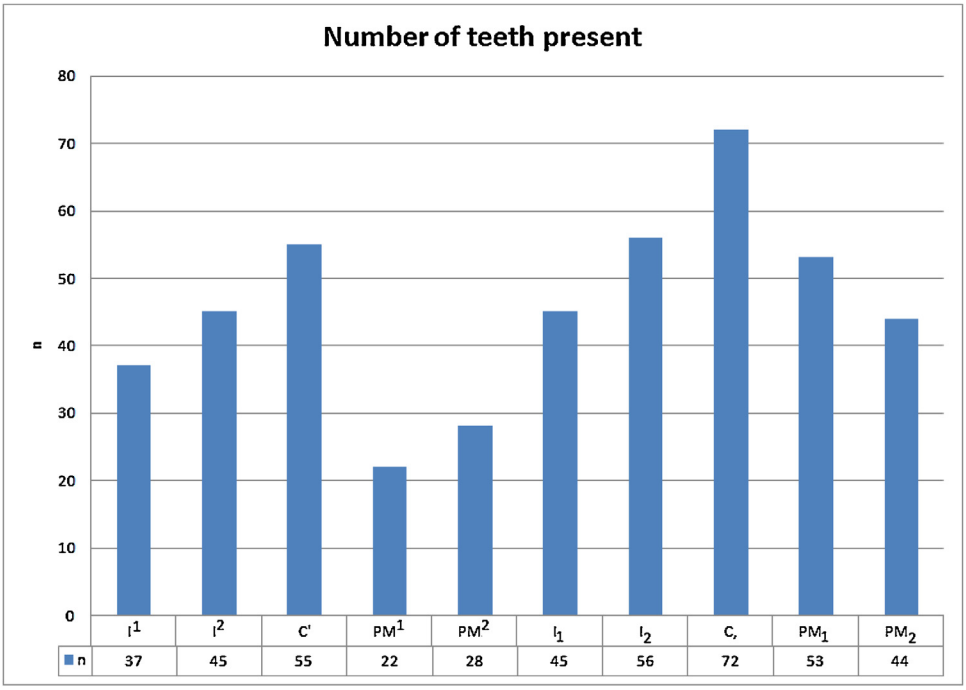

Fig. 1. Distribution by tooth type of the dental pieces included in the study.

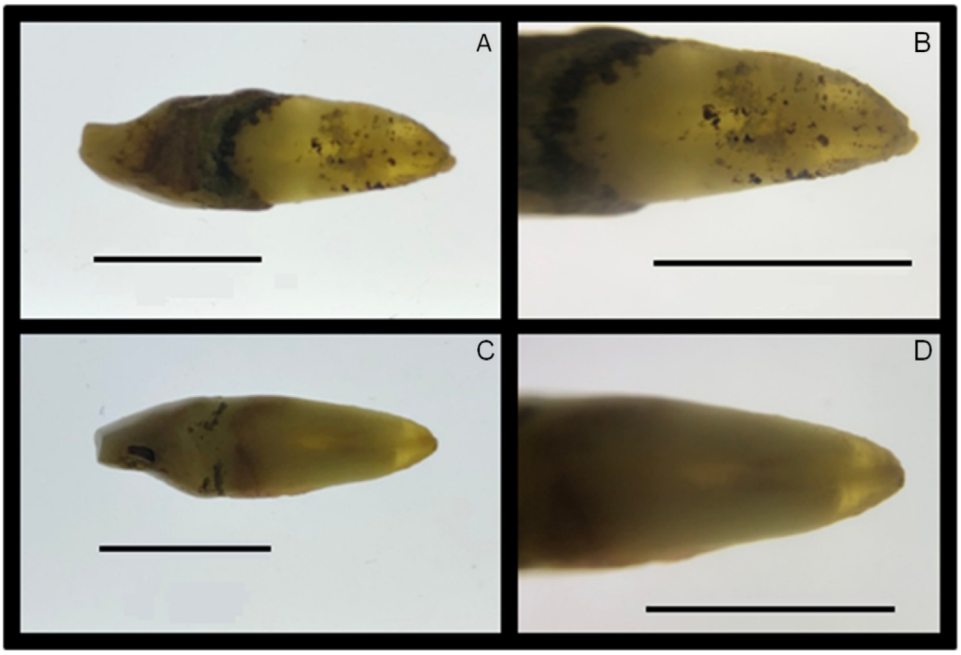

Fig. 2. The figure represents the dental translucency as seen macroscopically in an LED X-ray viewer. A–B show a tooth that exhibits equal amount of dental translucency in both labial and lingual surfaces. On the other hand C–D represent a tooth where lingual surface exhibits a slightly greater amount of dental translucency in comparison to the labial surface. The black line represents 1 cm.

Table 1
Results of intra- and interobserver error tests (*t*-test for paired samples and intraclass correlation coefficient). *$p < 0.05$.

		Studen's t-paired test		Intra-class correlation coefficient	
	n	t	*p*	r	*p*
PR GG1-GG2	44	0.91	0.36	0.98	0.00*
DTGG1-GG2	44	0.69	0.48	0.99	0.00*
RLGG1-GG2	44	−0.72	0.32	0.99	0.00*
PR GG-SP	44	1.79	0.08	0.99	0.00*
DTGG-SP	44	−0.45	0.65	0.99	0.00*
RLGG-SP	44	0.92	0.36	0.99	0.00*

Results

Intra- and interobserver error analyses showed no differences for the variables, as shown in Table 1. Likewise, the intraclass correlation coefficients show a high correlation between the measures surveyed by different observers (GG-SP) and by the same observer (GG1-GG2) (Table 1).

Results of the correlation analysis by tooth type and tooth surface between the variables surveyed and age are presented in Table 2. They showed that in all teeth there was a significant correlation of translucency with age (at least in one of the analyzed tooth surfaces). The correlation coefficients obtained vary between values of 0.35 and 0.62, with the majority of values being greater than 0.40. Conversely, periodontal retraction correlated poorly with age, as evidenced by the small number of teeth in which this correlation was statistically significant and by the low values of the correlation coefficients obtained.

As for the comparison between estimated and chronological age by tooth type and surface, the results are shown in Table 3. Likewise, the average of the differences between CA-EA (Labial) and CA-EA (Lingual) is 13.50 and 13.17 years respectively.

No statistically significant differences were found between estimated and chronological ages in upper first premolars (both surfaces), upper canines (both surfaces), lower central incisors (both surfaces) and upper lateral incisors (lingual surface). The mean of the differences in all cases presented values lower than ten years, while the absolute average of the differences was between 11.88 and 15.37 years of error.

The results obtained with respect to the number of times that the estimates were able to correctly predict age, for each type of tooth and tooth surface, are shown in Table 4. In general, in none of the cases did the

Table 2
Correlation coefficients of Pearson between age and PR and DT measured on labial (lab) and lingual (lin) surfaces by type of tooth. *$p < 0.05$. PR refers to periodontal retraction while DT refers to dental translucency.

		PR_{lin}	DT_{lin}	PR_{lab}	DT_{lab}
I_1	*n*	45	44	43	42
	r	0.27	0.51*	0.19	0.40*
	p	0.06	0.00	0.21	0.00
I^1	*n*	37	37	37	37
	r	0.44*	0.43*	0.56*	0.60*
	p	0.00	0.00	0.00	0.00
I_2	*n*	56	55	56	55
	r	0.30*	0.52*	0.27*	0.44*
	p	0.02	0.00	0.04	0.00
I^2	*n*	45	45	45	45
	r	0.41*	0.26	0.44*	0.35*
	p	0.00	0.08	0.00	0.01
C,	*n*	72	71	72	71
	r	0.00	0.39*	0.07	0.46*
	p	0.95	0.00	0.55	0.00
C'	*n*	54	53	55	54
	r	0.19	0.42*	0.18	0.58*
	p	0.15	0.00	0.18	0.00
PM_1	*n*	53	51	53	51
	r	0.27*	0.37*	0.06	0.35*
	p	0.04	0.00	0.64	0.01
PM^1	*n*	22	19	22	19
	r	0.35	0.50*	0.12	0.42
	p	0.10	0.02	0.58	0.07
PM_2	*n*	44	43	44	43
	r	0.17	0.62*	0.0,8	0.62*
	p	0.26	0.00	0.60	0.00
PM^2	*n*	28	27	28	27
	r	0.39*	0.33	0.36	0.42*
	p	0.04	0.08	0.05	0.02

Table 3
Comparison between CA and EA by tooth type and tooth surface. Absolute and signed differences are presented as measures of accuracy and bias, respectively. *$p < 0.05$. EA refers to estimated age while CA refers to chronological age.

		Abs. Mean	Mean	SD	MEE	95 % CI		t	df	p
						Lower	Upper			
I_1	CA - EA_{lin}	12.72	3.36	15.79	2.38	−1.44	8.16	1.41	43	0.16
	CA - EA_{lab}	13.39	4.45	16.86	2.6	−0.8	9.71	1.71	41	0.09
I^1	CA - EA_{lin}	13.19	5.97	15.85	2.61	0.68	11.25	2.29	36	0.02*
	CA - EA_{lab}	12.17	5.47	14.94	2.46	0.49	10.45	2.23	36	0.03*
I_2	CA - EA_{lin}	13.17	8.82	14.9	2.01	4.80	12.85	4.39	54	0.00*
	CA - EA_{lab}	13.6	9.37	15.66	2.11	5.14	13.61	4.44	54	0.00*
I^2	CA - EA_{lin}	12.67	4.18	14.89	2.22	−0.30	8.65	1.88	44	0.06
	CA - EA_{lab}	12.45	5.21	14.51	2.16	0.85	9.57	2.41	44	0.02*
C,	CA - EA_{lin}	14.36	7.48	16.78	1.99	3.51	11.45	3.76	70	0.00*
	CA - EA_{lab}	15.37	9.66	16.16	1.92	5.83	13.48	5.03	70	0.00*
C'	CA - EA_{lin}	12.78	3.22	16.13	2.20	−1.19	7.62	1.4	53	0.14
	CA - EA_{lab}	12.4	3.53	15.5	2.11	−0.70	7.76	1.67	53	0.10
PM_1	CA - EA_{lin}	12.78	4.25	15.28	2.14	−0.04	8.55	1.99	50	0.05
	CA - EA_{lab}	13.85	6.43	15.94	2.23	1.94	10.91	2.88	50	0.00*
PM^1	CA - EA_{lin}	11.88	3.32	14.5	3.24	−3.47	10.11	1.02	19	0.31
	CA - EA_{lab}	12.26	2.29	15.69	3.6	−5.27	9.86	0.64	18	0.53
PM_2	CA - EA_{lin}	12.9	7.5	14.75	2.25	2.97	12.04	3.34	42	0.00*
	CA - EA_{lab}	13.5	7.33	15.02	2.29	2.70	11.95	3.2	42	0.00*
PM^2	CA - EA_{lin}	13.78	8.04	15.02	2.84	2.21	13.86	2.83	27	0.00*
	CA - EA_{lab}	14.11	8.38	14.6	2.81	2.61	14.1	2.98	26	0.00*

Table 4
Number and percentages of correct estimates of age by type and tooth area.

	Lingual				Labial			
	Correct		Incorrect		Correct		Incorrect	
	n	%	n	%	n	%	n	%
I^1	13	35.13	24	64.87	14	37.87	23	62.13
I^2	17	37.77	28	62.23	17	37.77	28	62.23
C'	29	53.70	25	46.3	29	53.70	25	46.30
PM^1	12	60	8	40	11	57.89	8	42.11
PM^2	14	50	14	50	15	55.55	12	44.45
I_1	24	55.81	19	44.19	22	52.38	20	47.62
I_2	32	58.18	23	41.82	31	56.36	24	43.64
C,	35	49.29	36	50.71	30	42.25	41	57.75
PM_1	31	60.78	20	39.22	26	50.98	25	49.02
PM_2	25	58.13	18	41.87	23	53.48	20	46.52

percentages of correct estimates exceed 60 %.On the other hand, higher percentages of correct estimates are observed in lower teeth. As for tooth surface, although no great differences were observed, higher values were found on the lingual surface.

When evaluating the influence of sex on the estimates, it was found that there were no differences in the error of the estimates for both lingual and labial surfaces ($t_{lingual} = -0.57$ p = 0.56; $t_{labial} = -0.93$ p = 0.34). On the other hand, when considering age as a factor of interference in the result of age estimation, the results showed that only in the group of individuals aged 36–50 years, the differences between estimated and documented ages were not statistically significant, with an average of the differences of less than 1 year of error and an absolute mean of about 5 years. In the remaining age cohorts, EA and CA differed statistically with errors exceeding 10 years and tending to increase in groups of older adults (Table 5).

When separating the estimates by age group and type of tooth, a trend similar to the previous analysis is observed. In the group aged 36–50 years, no teeth, except for the upper first premolar, presented statistically significant differences between estimated and documented ages. On the other hand, both in the younger group of individuals (<35) and in those older than 51 years, the differences between estimated and documented ages were significant, with an increase in the error of the estimates as age increases, regardless of tooth type (Table 6). Also, it is observed that the mean and absolute mean of the differences between CA and EA by type of tooth vary in all age groups.

It was also decided to graph the bias in the estimates in relation to chronological age in order to see the variation of this type of error in the estimation of age per individual in both surfaces (Figs. 3 and 4). In the first place, it is possible to observe that in the younger individuals age is overestimated, with this error approaching 0 in individuals in their fifth decade of life. Then, the observed tendency is an increase of the error towards an underestimation of chronological age. On the

Table 5
Comparison between chronological age (CA) and estimated age (EA) by age group. *$p < 0.05$.

		Abs. Mean	Mean	SD	MEE	95 % CI		t	df	P
						Lower	Upper			
G1 (<35)	CA - EA_{lin}	16.06	15.64	8.60	1.01	−17.66	−13.62	−15.43	71	0.00*
	CA - EA_{lab}	16.12	−16.12	6.67	0.80	−17.72	−14.52	−20.09	68	0.00*
G2 (36–50)	CA - EA_{lin}	5.50	−0.96	6.00	0.56	−2.06	0.14	−1.73	153	0.08
	CA - EA_{lab}	5.24	−0.20	6.47	0.52	−1.24	0.83	−0.39	153	0.69
G3 (51–65)	CA - EA_{lin}	10.91	10.63	6.95	0.67	9.31	11.97	15.83	106	0.00*
	CA - EA_{lab}	10.74	11.57	7.01	0.68	10.24	12.93	17.08	106	0.00*
G4 (66–80)	CA - EA_{lin}	19.37	19.38	7.95	90.00	17.59	21.17	21.54	77	0.00*
	CA - EA_{lab}	20.66	20.66	7.27	0.83	19.01	22.31	24.92	76	0.00*
G5 (>81)	CA - EA_{lin}	32.54	32.48	7.39	1.21	30.02	34.95	26.74	36	0.00*
	CA - EA_{lab}	33.07	33.07	7.17	1.18	30.69	35.47	28.07	36	0.00*

Table 6
Comparison between chronological age and estimated age by type of tooth in each age group. *$p < 0.05$.

	Tooth	n	Abs. Mean	Mean	t	p
G1 (<35)	I^1	7	13.59	15.40	−8.51	0.00*
	I^2	9	14.48	14.48	−5.58	0.00*
	C'	14	15.20	14.51	−5.76	0.00*
	PM^1	4	16.30	13.69	−2.03	0.13
	PM^2	4	10.49	7.95	−1.79	0.17
	I_1	9	17.12	15.12	−6.81	0.00*
	I_2	5	11.48	11.48	−4.41	0.01*
	C,	10	18.70	18.70	−8.53	0.00*
	PM_1	7	20.88	20.88	−8.87	0.00*
	PM_2	4	16.17	16.17	−4.29	0.02*
G2 (36–50)	I^1	12	4.47	1.18	−0.76	0.46
	I^2	15	5.57	0.60	−0.34	0.73
	C'	20	4.59	−0.12	0.10	0.91
	PM^1	6	5.04	5.02	−3.66	0.01*
	PM^2	11	8.75	−1.11	0.35	0.72
	I_1	15	5.28	1.70	−0.99	0.34
	I_2	20	5..16	0.43	−0.30	0.76
	C,	21	4.83	−1.52	1.31	0.20
	PM_1	16	5.24	1.83	−1.40	0.18
	PM_2	17	5.80	1.23	−0.71	0.48
G3 (51–65)	I^1	9	13.94	−14.01	6.21	0.00*
	I^2	14	13.35	−13.30	8.76	0.00*
	C'	11	11.95	−11.95	5.35	0.00*
	PM^1	5	8.11	−8.11	4.00	0.01*
	PM^2	7	12.82	−12.82	4.22	0.00*
	I_1	8	10.13	−8.56	2.50	0.04*
	I_2	13	10.13	−9.48	4.16	0.00*
	C,	17	11.29	−11.27	8.36	0.00*
	PM_1	13	9.74	−9.64	10.58	0.00*
	PM_2	8	10.82	−10.86	4.53	0.00*
G4 (66–80)	I^1	6	20.04	−20.05	5.62	0.00*
	I^2	5	19.42	−19.42	5.22	0.00*
	C'	8	22.56	−22.56	8.57	0.00*
	PM^1	4	20.90	−20.92	4.11	0.02*
	PM^2	4	22.53	−22.53	6.80	0.00*
	I_1	8	15.35	−15.35	7.08	0.00*
	I_2	9	21.16	−21.19	10.00	0.00*
	C,	15	21.56	−21.56	14.50	0.00*
	PM_1	10	18.53	−18.53	8.02	0.00*
	PM_2	9	18.60	−18.60	8.05	0.00*
G5 (>81)	I^1	3	26.02	−26.02	8.67	0.01*
	I^2	2	33.72	−33.72	9.35	0.06
	C'	2	34.79	−34.79	8.73	0.07*
	PM^1	4	18.31	16.17	−4.29	0.02*
	PM^2	2	33.91	−33.91	9.76	0.06
	I_1	4	36.31	−35.73	9.71	0.00*
	I_2	7	34.70	−34.07	10.70	0.00*
	C,	7	35.25	−35.25	11.57	0.00*
	PM_1	4	31.88	−31.88	12.82	0.00*
	PM_2	5	30.03	−30.03	14.05	0.00*

other hand, no differences in this type of trend between dental surfaces are observed.

Finally, when counting the number of correct age estimates for each age group, it was found that only in the cohort of individuals between 36–50 years did the number of correct estimates present high values, with 89.61 % and 93.50 % of correct estimates for the lingual and labial surfaces respectively. In the remaining groups, these percentages decrease. Notably, in none of the cases in the older group did the estimate predict the documented age of the individuals (Table 7).

Discussion

Methodological validation studies carried out on documented osteological collections are of utmost importance, as they allow us to evaluate the error of a method in a population different from the one in which it was developed [12,30,33–36]. Methods for estimating age or other biological characteristics should be presented to the scientific community for peer review; their error should be evaluated using appropriate statistics and should be sufficiently precise and accurate for forensic practice [37]. In Argentina the lack of studies of this nature constitutes a situation to be reverted, and in this sense, in the last few years this kind of research has increased [25]. For this reason, the present study validates the proposal developed by Lamendin et al. [18] in a sample of adult individuals belonging to the Lambre collection (La Plata, Argentina).

Firstly, it was possible to observe that the process of translucency of the root dentin occurs in a systematic and constant way, maintaining correlation with individual age up to a certain point. Another relevant aspect is that Pearson's correlation coefficients of translucency and periodontal retraction vary according to tooth type, which seems to indicate a priori that the increase in translucency/periodontal retraction does not occur in the same way in all teeth. This aspect has been highlighted by other authors who report such variation by tooth type [11,13,17]. In the present study, the Pearson's correlation coefficients obtained vary between 0.350 (I^2) and 0.625 (PM_2), revealing this interdental variation in dentin translucency.

As for periodontal retraction, the results of the correlations obtained indicate that the incorporation of this variable is at least problematic. In this study it was found that this feature correlates significantly with age in few teeth. Also, in cases where this correlation was significant, the values obtained were low compared to translucency (Table 2). Low correlation of periodontal retraction could be due to the interference of extrinsic factors [2,12,38]. Historically, periodontal retraction has been considered a result of the normal aging process. However, this assumption has been called into question in recent years [38]. Periodontal retraction may increase with age, but this does not imply that it is inherent in aging. Some of the factors that increase the distance the gingiva recedes are excessive occlusal or incisal wear, chronic trauma (resulting from inadequate daily brushing), chronic inflammation due to periodontal disease and treatment [11,17,38,39]. These seem to present the retraction of the periodontium as a multifactorial process, in which age might have a lower preponderance in its development [11,25]. In fact, previous studies carried out on the same sample demonstrate this, since it was found that most of the individuals that constitute the collection are affected by periodontitis [31,32,40]. Similarly, a national epidemiological study conducted by the Argentine Society of Periodontology during 1999 and 2000 reported that 96.8 % of the cases surveyed required some type of periodontal treatment. It also informed of insufficient instruction on oral hygiene [41,42]. As can be seen, the results presented here could support the need to rule out periodontal retraction in age estimation formulas.

When evaluating the formula by Lamendin et al. [18] disparate results were found according to type of tooth. As can be seen in Table 3, PM^1, C' and I_1 showed no statistically significant differences between the EA and CA, while in I^2 and PM_1 no differences were found on the labial surface. This demonstrates, a priori, that there is an interdental variation in how age is estimated, with better results on the previously mentioned pieces [10,11,43]. Likewise, the percentages of correct estimates could support the foregoing assertion and report a poor performance of the formula in the analyzed sample. As can be seen in Table 4, these percentages in the analyzed teeth barely exceed 60 %, which would be tantamount to stating that this method has practically the same probability of estimating age correctly as of making a mistake [44]. On the other hand, the small differences found between estimated and chronological ages between dental surfaces seem to imply that using either the labial or the lingual surface to survey the variables would not suppose any inconvenience.

However, when considering age as a factor of influence in the estimates, the conclusion regarding the performance of the formula changes. When comparing the estimated ages with those documented by age group, age is observed to have an effect on the estimates. In the 36–50 age group, no differences between the estimated and documented ages were noted, while in the remaining age groups, ages differed statistically. The effect of age on the estimates is most noticeable when analyzing the percentages of the estimates that correctly predicted the chronological age in each age cohort. In the group

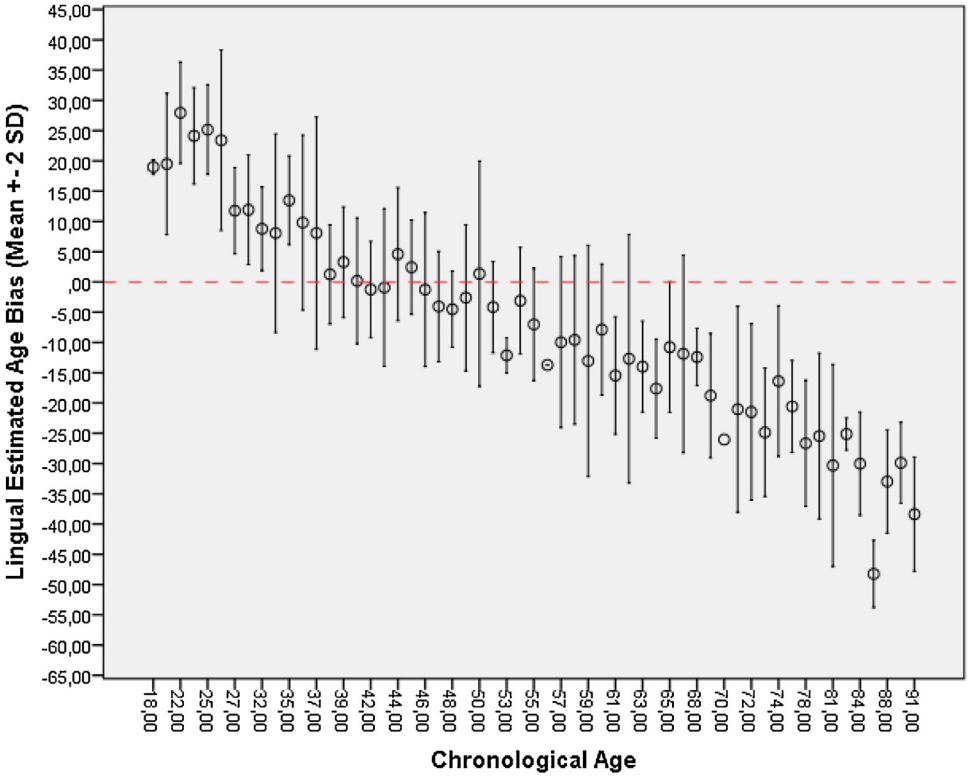

Fig. 3. Bias of the estimations (lingual surface) plotted against chronological age.

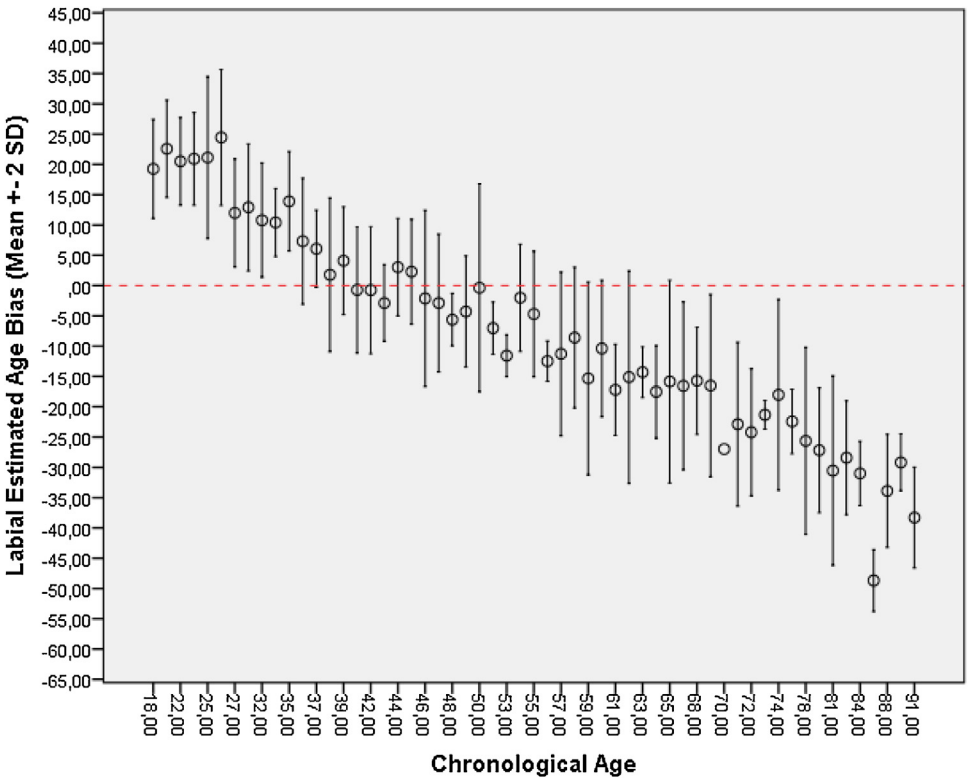

Fig. 4. Bias of the estimations (labial surface) plotted against chronological age.

of individuals aged 36–50 years, correct estimates of 93.50 % and 89.61 % for the labial and lingual surfaces respectively were obtained. In subsequent age groups, percentages of correct estimates decrease until no correct age estimation is made in the group of individuals over 81 years old (for both dental surfaces). On the other hand, when considering the bias and accuracy of estimates based on age, there is an increase in error along with age, particularly, a tendency to underestimate age in older individuals, as opposed to overestimating it in younger ones. As can be seen in Table 5, in the group of

Table 7
Number and percentages of correct estimates by tooth area in each age group analyzed.

	Lingual				Labial			
	Correct		Incorrect		Correct		Incorrect	
	n	%	n	%	n	%	n	%
G1 (<35)	22	30.98	49	69.02	19	27.53	50	72.47
G2 (36–50)	138	89.61	16	10.39	144	93.50	10	6.50
G3 (51–65)	58	54.20	49	45.80	47	43.92	60	56.08
G4 (66–80)	14	17.94	64	82.06	8	10.38	69	89.62
G5 (>81)	0	0	37	100	0	0	37	100

young people under 36 years of age, a bias tending to overestimate 15.64 and 16.12 years was observed in the lingual and labial surfaces respectively. In the next group (36–50), bias decreases to values less than one year of error, while in subsequent cohorts, bias always tends to underestimate age and increase inaccuracy (increase in the absolute mean of the error). This trend towards overestimation in young individuals and underestimation of age in older adult ones has already been reported by several previous studies, and explained as a result of the statistics used for the development of this class of predictive age equations [2,7,10–12,14,17]. Prince and Koninsberg [2] explain this phenomenon as the result of regressing around the average, presented by this type of formula, which might generate this kind of bias in the estimation of age [2,45,46].

Likewise, if we consider age and type of tooth (taken together) as a factor of error in the estimates, we observe that the first one has a greater importance on them. Table 6 shows how errors in estimates (both bias and accuracy) vary in each age group by tooth type, indicating that there is greater variation in errors between age groups than between teeth of the same age cohort. On the other hand, Figs. 2 and 3 graph the bias of the estimates in relation to individual chronological age, highlighting even more the increment of this type of error in the estimates along with age, particularly towards an underestimation of age in older individuals. Even observing the bias, it is possible to visualize what Nawrocki [44] calls the "trajectory effect", since with increasing age the error of the estimates increases considerably [44]. When segmenting the sample for the analysis by age group and tooth, the sample number decreases considerably in some cases. Nevertheless, the agreement in the results obtained with previous analyses focusing only on the influence of age on the estimates, allows us to state that age influences the estimates more than the type of tooth [2,14,17].

As for the influence of sex on the estimates, when comparing the differences between CA and EA according to sex, it was found that these were not statistically significant. These results coincide with those reported by other studies where sex does not seem to be a factor of interference in the estimation of age [11,14,18]. We believe that in those cases in which sex differences in the estimates were reported, these could have been caused by biases in the sample [12,16], due to either a higher proportion of male than female individuals or a differential representation of female/male individuals in age groups (e.g., in older age groups, where errors in estimates tend to be greater). For this reason, in order to assess the influence of sex on the estimates, it should be borne in mind that a similar proportion of female and male individuals is needed in all the age groups analyzed.

Conclusion

The methodological proposal evaluated was that of Lamendin et al. [18], which showed good results in individuals aged between 36–50 years. These findings are consistent with other studies indicating good performance of this formula in middle-aged age groups [20]. When comparing chronological age and estimated age, the results obtained indicate that there are no major differences by type of tooth. This is also confirmed in the number of times it was possible to predict the age, depending on the type of tooth used. Conversely, age was a more prevalent factor in the estimates, since it was possible to determine that error in estimation increases significantly with age, regardless of tooth type. On the contrary, sex did not affect the outcome of the estimates. Based on the above, we recommend that the age estimation method proposed by Lamendin et al. [18] be mainly applied to estimate the age of individuals in the 36–50 age range. Finally, we emphasize the need to validate age estimation methods developed in other populations, since the refinement and knowledge of the errors of such methods is a key aspect in the practice of forensic anthropology. For this purpose, documented osteological collections are very useful, as they corroborate the reliability of these methods.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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