Forensic Science International: Reports 3 (2021) 100176

Contents lists available at ScienceDirect

Forensic Science International: Reports

journal homepage: www.elsevier.com/locate/fsir

Forensic Anthropology

Age-at-death Estimation in Adults and Verification of a Forensic International Methodology using Single-Rooted teeth: An Approach for a Peruvian Context

Roberto C. Parra [a,*], Daniel G. Suárez-Ponce [b], Karen J. Escalante-Flórez [c], Lucio A. Condori [d], Oswaldo Calcina-Mendoza [d], Liz M. Peralta-Cerro [c], Glicerio A. Rosas-Moyano [d]

[a] Specialized Forensic Team, Office of the High Commissioner for Human Rights (UN Human Rights), The United Nations Organization Stabilization Mission in the Democratic Republic of the Congo
[b] Departamento Académico de Estomatología Médico-Quirúrgica. Facultad de Odontología, Universidad Nacional Mayor de San Marcos, Lima, Peru
[c] Especialidad en Odontología Forense, Facultad de Estomatología, Universidad Científica del Sur, Lima, Peru
[d] Instituto de Medicina Legal y Ciencias Forenses del Perú, Ministerio Público, Lima, Peru

ARTICLE INFO

Keywords:
Radicular dental translucency
Peruvian population
Forensic odontology
Forensic anthropology
Quality management

ABSTRACT

From a forensic perspective, age-at-death estimation in adults is a constant concern that impacts the development of investigations regarding unidentified dead bodies and the need to identify them. Several procedures for age-at-death estimation in adults have been introduced in Peru, and are used in various fields such as bioarcheology and forensics, but very little is known about the precision and accuracy levels of these procedures. Methods derived from the Lamendin's technique, validated and the levels of applicability and confidence of the method, have been widely used in Peru since the year 2000 are known. However, a new estimation system using the Lamendin's technique has been developed through a Bayesian model. This model stores the information measured in a Forensic International Dental Database (FIDB), which contains information of several populations and also contributes to assessing the applicability levels of this procedure, resulting in more information that can contribute to strengthen the calculation and the outcome. Results show that the Bayesian model has a homogeneous behavior when it is applied to a Peruvian population, and it shows a better adjustment than previous procedures designed for Peruvian populations. Our research recommends using the Bayesian model for forensic age estimation in this population. Lamendin's technique and its methodological derivatives may contribute to start thinking about the global standardization of the method based on forensic Quality Management criteria, which include –but are not limited to– interlaboratory measurement controls, calibration of measurement sources, and application procedure guides.

Introduction

From a forensic perspective, age-at-death estimation in adults is a constant concern that impacts the development of investigations regarding unidentified dead bodies and the need to identify them. It is known that estimating age-at-death in adults includes –but is not limited to– recognizing degenerative indices in the skeleton, describing and comparing morphological variants, which are generally called "phases or stages", or measuring other morphological variants, such as the physiological process of Root Dentin Translucency (RDT). Estimation has been traditionally used because age-at-death in adults can be calculated using an algorithm that represents the behavior of the continuous variable, or the combination of the various continuous variables, resulting in a value ranging from 0 to 110 years [1]. However, Nawrocki [1] has pointed out the importance of the "trajectory effect", or the effect of the degrees of error that are usually always larger than chronological age in younger individuals (overestimation of age) than in older adults (underestimation of age), when the biomechanical and physiological forces are more constant; therefore, the margins of error are usually very wide depending on the physiological marker and the chosen method. In addition, these variables are conditioned by extrinsic and intrinsic factors, resulting in an inevitable degree of error when estimating age. Consensus recommends that, if the whole body of an individual is available, every available age estimation method should be applied [2,3], given that each age index has something significant to contribute and that each represent the constant variation of a particular trait to which each individual is subjected [1].

Regarding age-at-death estimation in Peruvian adults, both a technique and a method known as Lamendin et al. [4] and developed in French populations were applied in 2002, during the beginning of forensic operations for the recovery and analysis of human remains corresponding to missing persons in Peru. Subsequently, in 2003, other

* Corresponding author.
E-mail address: ropachi@gmail.com (R.C. Parra).

http://doi.org/10.1016/j.fsir.2021.100176
Received 5 November 2020Accepted 13 January 2021
Available online 20 January 2021
2665-9107/© 2021 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

methods similar to the one proposed by Lamendin and colleagues [4], and validated for a black and white population in the United States [5], were also applied in Peru, and in 2007 the Bang and Ramm method [6] using the intact-tooth technique was also used. These methods were used in the Peruvian forensic context both on skeletonized human remains, and unidentified dead bodies analysis on a national level.

The higher accessibility and feasibility of these techniques, given that they do not require further training or sophisticated technology and only involve the use of a caliper and an appropriate light to record the RDT [7], have facilitated their wide application in Peru. However, when new analytical methods are used in a forensic context, they must be subjected to specific tests to ensure their validity and consistency and consistent with the intended target. Validation is related to the precision and accuracy of a method applied on a population other than the reference sample; therefore, if the results obtained agree with the descriptions of the original method on another population, the method would be validated for its applicability.

Variability conditions for methodology calibration

Since the initial approach by Lamendin and colleagues [4], at least ten types of variability conditions have been measured as calibration elements for the application of this technique and its derived methods. Such variability conditions for calibration include but are not limited to: 1) differences between single-root teeth; 2) differences between the upper (maxillary) and lower (mandibular) arches where the tooth comes from; 3) differences at the level of the buccal, vestibular, lingual, or palatal surfaces; 4) inter- and intra-observer differences in the application of the technique; 5) measurement of the light generated by RDT; 6) variable behavior and its correlation with age; 7) sex of the analyzed individual; 8) population variation; 9) statistical strength, and 10) taphonomic impact and postmortem interval.

Regarding the first condition, when studying a sample of 52 French individuals using Lamendin's technique [4], Foti and colleagues [8] found that there were no statistically significant differences for age estimation between the teeth, either at the level of maxillary or mandibular pieces (second condition). Similar results have been reported by other researchers using the same technique [9,10]. These studies support the idea that there is no significant evidence to favor any single-rooted tooth, since all of them would offer similar results in estimating age regardless of whether they come from the mandible or the maxilla. Interestingly, these results differ from the ones obtained by Lamendin and colleagues [4], who suggested that upper central incisors would offer better results.

Concerning the third condition, Lamendin and colleagues [4] suggested using the buccal surface because the RDT is higher there than on the lingual surface, and because the periodontal insertion on the buccal surface "is less susceptible to be influenced by pathologic factors such as infections" ([4]: 1375). In this regard, Foti et al. [8] took the issue with caution and recommended further research to clarify the matter. Additionally, Ubelaker and Parra [11] compared both tooth surfaces, and concluded that the differences were minimal and that both of them offered good results, although they noted that the buccal surface could offer somewhat more accurate results. In a recent study by Garizoain and colleagues [9], using a larger sample than Ubelaker and Parra [11], the authors concluded similarly that the buccal surface offered more exact results, but that differences in outcomes are minimal. Garizoain and colleagues [9], also showed that there are morphological differences between buccal RDT and lingual RDT –where buccal RDT is higher than lingual RDT–, similar to what was initially suggested by Lamendin and colleagues [4], and Parra and colleagues [12] report the same observations. This would explain why the buccal surface presents a higher determination performance (R^2 0.74) compared to the lingual surface (R^2 0.69), as reported by Ubelaker and Parra [11], although both are not statistically significant. However, to date there is no evidence to explain physiologically why this region would have a greater degenerative development, which would be closer to explaining physiological age. For forensic purposes, these differences are statistically insignificant and both would have the same probative value.

With respect to the fourth parameter, repeatability conditions are observations in which independent measurement results are obtained with the same technique and with identical measurement elements by the same operator, using the same exact equipment (intraobserver) [13], while reproducibility conditions are observations in which independent measurement results are obtained with the same technique and with identical measurement elements, but with different operators using different measurement equipment (interobserver) [13]. Controlling the variability of the measurements conducted by different observers (reproducibility) or the same observer (repeatability) at different times is very important, because the reliability of the results and the method calibration will depend on these evaluations.

Several studies have focused on this type of variability and have shown that it is statistically insignificant [7,9,11,12,14–17]. Ackermann and Steyn [14], after analyzing a control sample of 30 teeth randomly chosen, concluded that there were no statistically significant differences at the intra- and inter-observer level. Ribeiro Lopes and colleagues [15] also reported that their results were statistically similar after analyzing 10 randomly chosen samples. Garizoain and colleagues [9], using 44 randomly chosen teeth, demonstrated that the Intraclass Correlation Coefficients (ICC) show a high correlation between measurements. Similarly, Parra and colleagues [12] evaluated these same criteria in a control sample of 47 teeth; they also demonstrated that the ICC of the measurements obtained by the main observer and by two different observers were very high. In addition, Kimmerle and colleagues [16] show that their repeatability levels coincide with the results of Ubelaker and Parra [11] and Prince and Ubelaker [5], who suggested that the impact of both observer-to-observer biases and same observer's bias in the final results is minimal.

In terms of the fifth condition, direct techniques have been used to measure the transparency zone on sectioned teeth [18–22], as well as indirect techniques in the case of intact teeth [4–6,9,11,23–25]. The evaluations have been quantified by subjective indices [18,19], directly measuring translucency [26], measuring the translucent area [27], the translucency expressed over the length of the tooth [21], the translucent area expressed over the area of the root [20,25], and the height of the translucency expressed over the length of the root [4,5,11]. Drusini and colleagues [25] compared two techniques to measure root translucency: one using digital densitometric technology and one using a simple caliper; both of these techniques were applied to a sample of 152 teeth, including incisors, canines, and premolars. The authors found no significant differences between the two techniques, which means that the measurement of root translucency with a simple caliper could provide data as reliable as the ones provided by complex technologies.

On the other hand, Adserias-Garriga and colleagues [7] were the first to carry out a study on light conditions in measurements of root transparency. They applied three different types of lights: 6500 lx (microscopic light), 3000 lx (negatoscopic light), and 1600 lx (equivalent to daily sunlight), and concluded that a 1600 lx lighting is the more adequate setting to perform root transparency measurements. Noticeably, few authors have reported in their research the type of light they used to measure root translucency. Initially, the use of a light box was reported for these measurements [4,5,11,15,17,24], while Foti and colleagues [8] reported a 16 w X-ray viewer, as did Retamal and Ubelaker [24], and Garizoain and colleagues [26], who used an LED X-ray viewer. Adserias-Garriga and colleagues [7] have recommended that appropriate lighting should be taken into account when measuring root translucency because it contributes to better results.

Regarding the sixth condition, root dentin translucency is a physiological marker of aging [12] and only remotely influenced by internal and external factors [12]. However, the physiological translucency of dentin could suffer attacks from bacterial agents that can cause tubule filling and produce similar appearance of translucency [28–34].

The choice of one or more healthy teeth for the application of Lamendin's technique [4] is very important because the prevalence of this type of caries has been observed mainly in adults [35–38].

On the other hand, although it has been reported that periodontal recession has a positive correlation with age [39–41], this pathology is more influenced by external and internal factors than dentin translucency [36,42–44]. Ubelaker and Parra [11] have indicated that periodontal recession could affect the accuracy of the method because it is conditioned by the factors mentioned above. Tadjoedin and colleagues [45] observed that chronic gingival and periodontal disease are predominant among young and middle aged adults, while aggressive periodontitis tends to prevail in older adults. However, the authors argue that periodontal disease tends to be related to age, as was also observed by Parra and colleagues [12], who found an important coefficient of determination for this variable (R^2 0.59) and that it contributes to a better performance of the methods derived from Lamendin's technique [4]. Although periodontal disease for the particular Peruvian case is epidemiologically varied [46], even in areas where coca leaf chewing is frequent [47,48], its impact on the final results seems to be minimal [11].

Concerning the seventh condition, some studies report that root transparency may be affected by biological sex [5,27,49], but other authors have shown that the impact of this variable is minimal [9,11,17,23,50], and that it does not represent a significant difference [8]. Parra and colleagues [12] corroborate that the behavior of root dentin translucency does not present statistically significant differences related to sex, and show that sex only significantly influences root height, which is the variable that less explains the age of the individual.

In respect to the eighth condition, Whittaker and Bakri [22] and Parra and colleagues [12] studied the behavior of population variation on root dentin translucency, which is the main variable used by the methods derived from Lamendin's technique [4]. Both studies agreed that there are population differences in the behavior of RDT. Parra and colleagues [12] point out that all the variables measured have a variable impact with respect to the population type. However, these do not influence the final result in a significant way [10–12,15,17,23,24,51,52].

Parra and colleagues [53], Ubelaker and Parra [54], and Prince and Ubelaker [5] opened the debate regarding age estimation in adults and the impact of population variation using a method derived from Lamendin's technique [4]. Ubelaker and Parra [54] and Parra and colleagues [53] argued that these procedures could behave in a homogeneous way in any type of population in the world. Subsequently, several studies have confirmed these observations [9,10,17,24]. Recently, Parra and colleagues [12] also confirmed these findings by using a Forensic International Dental Database (FIDB) –which combines several types of populations– and a Bayesian methodology, which seems to have a generalizable scope for diverse population types, for calculating age estimates. When Parra and colleagues [12] applied this methodology in a Colombian sample, the method had an adequate performance above the level of specific methods for that population.

In terms of the ninth condition, statistical strength and consistency have been part of the main concerns when considering biases in age estimates in adults [55–67]. The Rostock manifesto has been one of the consensus loci that have directed the debate towards the use of the Bayesian approach [63,68,69]. These classic calibration models for age-at-death estimation in adults seem to offer good results minimizing biases in the estimates, mainly in older adults [51,68–70].

In forensic sciences, age estimation procedures based on inverse calibrations using reference samples not properly distributed have been used in adults. Most of these methods have been developed on linear or multiple regression equations with limited control for bias, error, and statistical weight of the estimates. In the case of the methods derived from Lamendin's technique [4], the same situation occurs, and the formulation of estimation methods has been based on inadequate reference samples. According to Prince and Konigsberg [51], this type of procedure is unsatisfactory, "unless the target sample has a similar age-at-death distribution as the reference sample" [51: 579]. Adequate information will be required to minimize biases in the estimates, and this implies developing new strategies that contribute to an optimal sample distribution, which could involve the combination of various population types to build robust samples [1].

Parra and colleagues [12] built a database composed by 693 cases combining various population samples as *a priori* information and the flexibility to incorporate additional information. They used a Bayesian regression model to calculate adulthood estimates where the confidence intervals for Bayesian regression coefficients for Periodontal Height (PH) and Root Translucency Height (RTH) are relatively small, indicating that these estimates are very close to the coefficients of a population regression. The coefficient of determination for this method was R^2 0.72 with a mean error of 2.06 years. When this method was applied to a sample of Peruvian individuals for this study, results showed a determination coefficient of R^2 0.58 and a mean error of 3.08.

Prince and Konigsberg [51] applied Bayesian analysis in a population sample from the Balkans, and found that the Bayesian approach offered the most adequate statistical analysis for that sample. They also determined that there was a significant difference between the real age and the estimated age, but that this result was trivial, with a determination coefficient of R^2 0.53 and a mean error of 1.51 years. According to Prince and Konigsberg [51] and Schmitt and colleagues [50], it has been shown that the application of Bayes' theorem tends to minimize age underestimation among the elderly. However, according to Parra and colleagues [12], all these procedures would lose their potential for age-at-death estimation in adults over 80 years old, because the main variable that explains age loses its correlation with biological age due to the slow physiological behavior of the RDT, which would be stationed in a constant plateau [12].

Finally, concerning the tenth condition, environmental conditions and post-mortem interval play an important role in dental tissue diagenesis, which may constitute an impediment to the use of RDT as a source for the estimation of adulthood at death [67,71–74]. The translucent properties of RDT and their visual evaluation, as well as biases in the measurement of the properties in question, can be affected by taphonomic forces, such as water, soil chemical composition, pH, temperature, and humidity, as well as microbial activity [12,49,71,74–76].

In 1995, Lucy and colleagues [67] noted changes to the internal microstructure that obliterated dentin translucency in sectioned tooth roots from a medieval cemetery. They highlighted that such changes were generated by the effect of diagenesis, and that these effects could destroy RDT. Some of these post-mortem changes have been recorded as diffuse decay and eroded surfaces [71]. Poole and Tratman [77] pointed out that colonization and proliferation of certain microorganisms might occur during the post-mortem interval. Although the exact fungal group is not yet known, data suggest that it is most likely an acidogenic microorganism, highly harmful for the dissolution of inorganic substances. Sillen [76] suggested that acidogenic microorganisms attack collagen and excrete organic acids. Such mechanisms can cause the dissolution of the inorganic component and destruction of the histological structure.

Sengupta and colleagues [71] studied the RDT of the Spitalfields collection (London), consisting of individuals who lived during the nineteenth century. They pointed out that most teeth in this sample had a clayish or chalky appearance, and that this characteristic had a negative impact on age estimation, although Tang and colleagues [72] noted that the observations described by Sengupta and colleagues [71] did not seem to be associated with the post-mortem interval and were thought to be caused by the post-mortem environment instead. In 1999, Kvaal and During [74] studied remains that had been underwater on a sunken ship for over 300 years, and noted that root translucency had been affected by the aquatic environment. The nature of these biochemical mechanisms of action is not adequately known.

Although both the Lamendin's and the Bang and Ramm techniques are very useful when applied to samples from recently-deceased individuals [3,5,11,23,51,78], their usefulness may be limited in contexts in which diagenesis is a threat. Dentinal diagenetic changes have been found by

several researchers to significantly reduce our ability to predict age through RTH in archaeological material [67,71–74,79–81]; however, although translucency is observed, there are also findings of wide biases that could be impacting the results, not for physiological reasons, but rather for external forces [73]. On the other hand, if translucency is not observed in intact historical teeth, it may therefore not always indicate a young age but rather an advanced degree of postmortem change [72].

Megyesi and colleagues [73] found that when Lamendin's technique was applied to two historic populations from London during the eighteenth and nineteenth centuries, the mean error increased substantially. Similar results were reported by Marcsik and colleagues [82] in a study of 250 teeth from the eighth and tenth centuries. When Tang and colleagues [72] studied historical samples using root transparency and the Bang and Ramm technique, they found that in those teeth that did not suffer the impact of diagenesis the procedure could be used in a way more comparable to the results of contemporary samples. In bioarchaeological samples, the application of such age estimation procedures should be taken with caution.

On the other hand, the periodontal index may also be affected, since a longer post mortem interval correlates with greater subjectivity applied to determine the periodontal regression marker, even if this could be imperceptible [72]. Although more research is required on these issues, it is increasingly argued that this type of procedure using the methods derived from Lamendin's technique [4] could be ineffective for historical contexts, and even more so in bioarchaeological contexts. It is not yet clear what are the biochemical modifications that dentin translucency undergoes during the post-mortem interval under various types of conditions. De Angelis and colleagues [95], when studying a sample of 21 adult individuals who were buried for 16 years in Cimitero Maggiore di Milano, concluded that the post-mortem interval, even for a short time (16 years), could significantly influence the applicability of Lamendin's technique [4]. Observations in the Peruvian case, with bodies buried during 25–30 years, would not have suffered modifications in RDT morphology and periodontal regression is still perceptible. The margin of error has been shown to be minimal with respect to the correlation with chronological age, both in terms of precision and accuracy.

Procedure validation for the Peruvian case

Ubelaker and Parra [11] validated the methods of Bang and Ramm [6], Prince and Ubelaker [5], and Lamendin and colleagues [4] to estimate age in an adult population sample from 17 different regions of Peru. They established that the method proposed by Prince and Ubelaker [5] offered better results and, based on this method, they formulated a new multiple regression equation specially adapted for the Peruvian population. The results of Ubelaker and Parra [11] using this new methodology were 6.84 years with a standard deviation of 6.32 years for the female sample and 6.08 years with a standard deviation of 5.86 years for the male sample. The authors did not find statistically significant differences regarding of the sex of the individual analyzed. The mean error was 6.29 years with a standard deviation of 5.97 years for the total sample. Other subsequent studies on Peruvian samples have confirmed these initial findings [83–87]. However, the main contribution of Ubelaker and Parra [11] was to show that, although the Peruvian population is clearly different from French populations as well as European and African descendants from the United States, there did not seem to be a relevant impact on population variation. Likewise, the results coincide with other reported outcomes and population contexts [5,23,51,52].

On the other hand, Peru has one of the most diverse geographical and ecological climates in the world, ranging from the tropical or subtropical desert to the glaciers in the high Andes mountains and the Amazon rainforest. A country with such diversity brings together populations from the Amazonian region, the central Andes mountain range, and the desert Pacific coast, and consequently it includes a highly heterogeneous genetic load [88–91], different phenotypes, and varied cultural traditions [92,93], it could be inferred that, due to its population diversity, specific forensic age-estimation methods are required for each group or subgroup, but in fact that is absolutely unnecessary [1]. For example, an age estimation procedure for each Peruvian region (Jungle, Coast, Mountains and High Mountains) is unnecessary, and even less one for each specific locality (such as Cusco, Puno, Lima, Iquitos or Huanuco). Forensic sciences do not focus on describing and interpreting population diversity and variability; rather, that is an area of study for biological anthropologists. We are interested instead in determining the level of accuracy and precision of the method [94] to validate the quality of the obtained results.

The goal of this research is to verify the precision and accuracy levels of the Bayesian model proposed by Parra and colleagues [12] on a contemporary Peruvian sample, as well as to study the behavior of degenerative physiological variables, such as RDT and periodontal disease. To address this issue, samples from several regions of Peru were collected and contrasted with five inverse calibration methods. These results will be incorporated into the FIDB in order to guarantee that they continue to serve as a source of information for future analyses and age-at-death calculations in adults.

Materials and methods

Samples

The sample was collected in six different regions of Peru, from individuals with known identity. Individuals in the sample were between 18 and 85 years old, with an average age of 45.94 years and a standard deviation of 12.77 years. Data come from studies carried out by Peralta [87] on individuals from the Lima region. Murrieta and Vela [85] from Iquitos, García [84] from Cusco, and samples provided by Alejandro Zegarra and Sharon Olgado from the Cusco, Puno, Arequipa, and Apurímac regions.

Table 1 shows the sample distribution by biological sex (10 females and 224 males) according to their region of origin. Female individuals comprise 4.27 % of the sample, including 9 individuals from Cusco (3.85 %) and 1 individual from Puno (0.42 %). The 224 male individuals represent 95.73 % of the total sample, including 90 individuals from Lima (38.46 %), 90 from Iquitos (38.46 %), 39 from Cusco (16.6 %), 2 from Arequipa (0.85 %) and 2 from Apurímac (0.85 %). Table 2 shows the sample distribution by age category.

Methods

Measurements in these studies were based on the technique described by Lamendin and colleagues [4], which involves measuring Root Height, Periodontal Height, and Root Translucency Height. A digital caliper was used for this procedure and all values were recorded in millimeters. (Fig. 1).

All measurements were performed by specialized professionals,

Table 1
Sample distribution by sex and region of origin.

	Sex					
	Female		*Male*		*Total*	
Region/ Origin	***n***	***%***	***n***	***%***	***n***	***%***
Apurímac	0	0	2	0,85	2	0,85
Arequipa	0	0	2	0,85	2	0,85
Cusco	9	3,85	39	16,6	48	20,51
Iquitos	0	0	90	38,46	90	38,46
Lima	0	0	90	38,46	90	38,46
Puno	1	0,42	1	0,42	2	0,85
Total	10	4,27	224	95,73	234	100,00

Table 2
Sample distribution by age category.

Age category	N°	%	Minimum age	Maximum age	Mean	SD
18–29	13	5,56	18,00	29,00	23,4615	3,52646
30–39	62	26,50	30,00	39,38	34,5044	2,87367
40–49	73	29,91	40,00	49,95	44,2396	2,87427
50–59	60	26,92	50,00	59,00	53,9908	2,80551
60–69	12	5,13	60,00	68,00	63,3333	2,77434
70–79	10	4,27	71,00	79,00	73,9000	2,42441
>80	4	1,71	84,00	85,00	84,5000	0,57735
Total	234	100,00	18,00	85,00	45,941	12,775

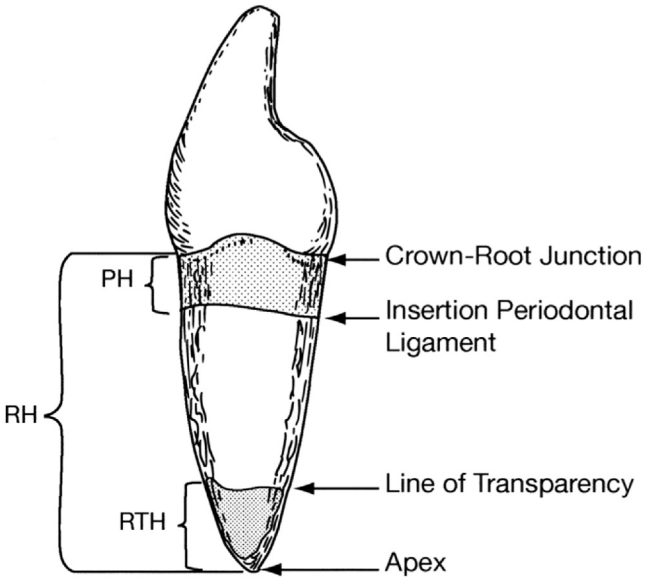


Fig. 1. Dental features used for age estimation. Adapted from Ubelaker and Parra [11].

including Peralta [87] in samples collected from Lima's Central Morgue, under the supervision of the Institute of Legal Medicine and Forensic Sciences of Peru (ILMFSP), and García [84] in samples taken from living people during clinical interventions. In addition, Murrieta and Vela [85] collected data between 2014 and 2018 in the Medical Legal Division II (Iquitos Morgue – ILMFSP), and Zegarra and Olgado provided samples collected from the Medical Legal Division II (Cusco Morgue – ILMFSP). To estimate dental age, the methods proposed by Lamendin and colleagues [4] (LBHTNZ), Prince and Ubelaker [5] (PU), Ubelaker and Parra [11] (UP), Vilcapoma [83] (V), and Parra and colleagues [12] (INT Bayesian) were applied.

Finally, Root Translucency Height (RTH), Root Height (RH), and Periodontal Height (PH) were evaluated for different age categories within the sample. The calculation of the method proposed by Parra and colleagues [12] (INT) was performed using version 4.0.1 of the R software. For data processing and statistical analysis, IBM SPSS v.25 software was used.

Results

Table 3 shows precision and accuracy estimates for each method (INT, LBHTNZ, PU, UP, and V). For the Bayesian model (INT), results show a mean of 3.09 and standard deviation of 8.24; for the LBHTNZ methods, the mean was 3.52 and standard deviation was 8.52; a mean of 2.43 and standard deviation of 8.41were obtained for PU; a mean of 1.04 and standard deviation of 8.75 were obtained for UP, and a mean of -0.9 and standard deviation of 8.93 was obtained for V. An analysis of precision according to the INT, LBHTNZ, PU, UP and V methods found that the Bayesian model (INT) shows the highest precision in predicting the age of an individual among all analyzed methods, with an R of 0, 76 and an R^2 of 0.57.

Table 4 shows the descriptive statistical data of RH, PH, and RTH according to age category. The results of the mean RTH errors found are shown in Fig. 2.

Table 5 shows that RTH has a positive linear correlation with chronological age, with an R 0.69 and with a $p < 0.05$, indicating that there is an increase in translucency as age advances. PH with an R 0.31 and with a $p < 0.05$, and RH with a R 0.10 and with $p > 0.05$, show a very

Table 3
Estimation of accuracy and precision for each method.

Methods	Statistical indicators						
	N°	r	r^2	Mean	SD	Concordance CCI	p
INT Bayesian	234	0,761	0,579	3,088	8,242	0,847	p < 0,05
LBHTNZ	234	0,749	0,561	3,520	8,524	0,830	p < 0,05
PU	234	0,737	0,543	2,429	8,412	0,832	p < 0,05
UP	234	0,745	0,555	1,036	8,748	0,856	p < 0,05
V	234	0,687	0,472	−0,089	8,929	0,825	p < 0,05

Table 4
Descriptive statistics of Root Height (RH), Periodontal Height (PH), and Root Transparency Height (RTH) by age category (with measurement values expressed in millimeters).

		RH (mm)		PH (mm)		RTH (mm)	
Age category	**N°**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
18–29	13	16,123	2,945	2,338	0,828	2,431	0,907
30–39	62	14,631	2,525	2,445	0,781	2,594	0,793
40–49	70	15,063	2,617	2,729	0,870	4,005	1,596
50–59	63	14,743	2,014	3,062	1,181	5,947	2,492
60–69	12	13,498	3,565	2,555	0,998	8,711	3,867
70–79	10	16,085	2,781	2,495	0,694	10,212	5,492
>80	4	11,800	0,577	7,300	3,464	7,300	3,464
Total	234	14,829	2,562	2,781	1,196	4,629	2,986

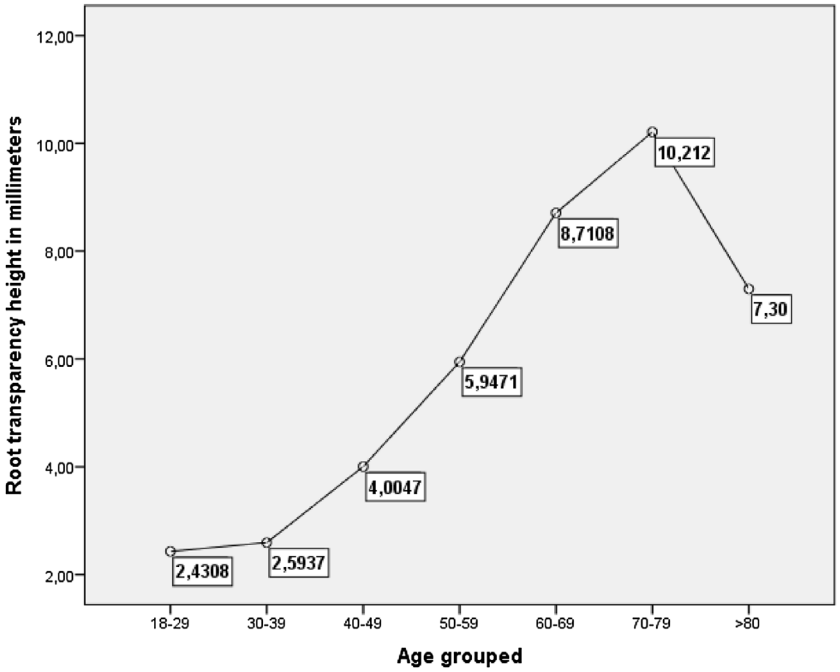


Fig. 2. Root Transparency Height (in millimeters) by age group (FIDB 234).

Table 5
Correlation of the variables that estimate age.

Variable	n	r	r^2	p
RTH	234	0,69	0,47	$p < 0,05$
PH	234	0,31	0,10	$p < 0,05$
RH	234	0,10	0,01	$p > 0,05$
RTH & PH	234	0,75	0,56	$p < 0,05$

low correlation with chronological age, indicating that there is no increase in root resorption as age advances.

Table 6 shows that the application of the Bayesian model (INT) according to the age category found a mean error of -14.62 in the group of 18−29 years, followed by a mean error of - 4.41 in the group of 30−39 years, a mean error of 0.54 in the 40−49 year group, 3.25 in the 50−59 year group, 3.35 the 60−69 year group, 12.34 the group of 70−79 years, and a mean error of 14.43 in the group <80. These results are favorable in the age categories from 30–69 years in comparison with the mean errors found in the original study by Parra and colleagues [12], where they are favorable for the 30–79 years age category, and the mean errors were also higher than those proposed by the method in the <80 years category. The Bayesian model (INT) offers the lowest total mean error (2.12 years); these results, like those reported by Parra and colleagues [12] (6.83 years), indicate that the predictive behavior of INT is more homogeneous than the other methods.

There is a closer relationship between chronological age and estimated age in individuals who are in the range of 30–69 years old, where no significant differences were found ($p > 0.05$), while in individuals older than 70 the relationship is more dispersed, where most of the estimates are lie below chronological age and the differences were significant ($p < 0.05$).

Discussion

One of the degenerative indices that have shown utility and relevance in adult individuals has been RDT, but its combination with other markers such as PH and RH has strengthened the analysis [4]. Regarding the methods derived from Lamendin's technique [4], all of them have shown mean absolute errors of between 6 and 13 years in several forensic contexts [4,5,11,23,51,24,17,10,12]. Ubelaker and Parra [11] found that methods developed for other population types could be used in the Peruvian forensic scenario with results as good as the ones obtained through procedures specifically designed for Peruvian contexts.

Table 6
Mean error and standard deviation of the estimated age in all age categories.

Age category	N°	INT Bayesian		LBHTNZ		PU		UP		V	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
18−29	13	−14,62	4,28	−14,50	3,54	−13,87	4,02	−13,58	6,94	−13,40	6,21
30−39	62	−4,41	3,41	−4,88	2,51	−4,91	2,91	−4,88	5,09	−5,75	4,37
40−49	70	0,54	4,06	0,53	3,76	0,52	3,64	0,12	5,41	0,22	5,00
50−59	63	3,25	7,05	3,45	7,61	3,50	6,83	3,10	8,45	3,62	8,23
60−69	12	3,35	8,11	2,85	8,53	2,92	8,07	6,82	8,92	5,09	8,24
70−79	10	12,34	15,05	12,87	16,44	13,73	15,79	16,33	15,73	16,66	17,93
>80	4	14,43	20,16	18,43	15,83	13,90	17,94	7,66	30,32	14,94	18,34
TOTAL	234	2,13	6,37	2,68	5,78	2,26	6,06	2,22	9,01	3,05	5,91

Table 7
Comparison between the methods applied by researchers.

			LBHTNZ		PU		UP		V	
AUTHOR	N°	REGION	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Vilcapoma 2012	50	LIMA	5.6	5.61	5.49	5.02	7.01	4.24	3.7	3.53
Peralta 2020	90	LIMA	4,62	4,91	3,57	4,58	2,18	3,66	0,15	4,46
García 2018	30	CUSCO	3,66	4,20	1,11	4,56	2,02	4,50	−2,0	3,87
Murrieta y Vela 2018	90	IQUITOS	4,26	11,71	1,37	11,63	−1,04	12,49	1,17	12,83

Meanwhile, Table 7 shows the comparison of mean error and standard deviation among the methods proposed by Lamendin and colleagues [4], Prince and Ubelaker [5], Ubelaker and Parra [11], and Vilcapoma [83] that were applied in local studies, such as the ones conducted by Vilcapoma [83], Peralta [87], García [84], and Murrieta and Vela [85], which support the initial report by Ubelaker and Parra [11]. Table 3 shows the levels of accuracy and precision for all the mentioned methods. Both tables highlight that all the methods applied in Peruvian samples do not differ significantly between them, and it seems that they behave homogeneously. However, of all the results observed, Vilcapoma [83] tends to offer higher accuracy, although it also shows the least precision. The best performance in terms of efficacy is the method proposed by Parra and colleagues [12], which offers a better balance between accuracy and precision. Knowing the margin of error for the methodological precision in age-at-death estimations in adults is of greater relevance than its closeness to real age (accuracy); that is, knowing the precision of the results is more important than the accuracy of the results, which turns out to be irrelevant.

Nawrocki [1] has highlighted that narrow error intervals could exclude people who could potentially be relevant candidates. On the other hand, too wide a range may include other people who should not necessarily be candidates. Other researchers have also noted this problem [3,50]. Practical experience in various settings around the world certainly reflects this problem, hence it is much more relevant to find a balance between levels of accuracy and precision of the method. Therefore, if the methods used are behaving in a balanced way and there are solid statistics, it can be highlighted that the method is reliable, and offers a higher quality of results, greater efficiency and –consequently– higher probative value.

In our study, we show the levels of statistical strength of the analyzed methods, which are presented in Table 5. There we observe that the method proposed by Parra and colleagues [12] shows greater statistical strength than the other ones, while Vilcapoma's method [83] is the one with the least statistical strength and the lowest precision, although –somewhat paradoxically– it offers the highest accuracy.

Trajectory effect

Parra and colleagues [12] have reported that the methods derived from Lamendin's technique behave homogeneously in accuracy and precision in the categories of 30–69 years old, so there is a reliable balance to estimate age in adult individuals. It is important to note that most methods tend to overestimate age for the categories ranging from 20 to 59 years. Age overestimation is more evident among young individuals from 20–29 years old, and age underestimation seems to start around the 60 years mark, with most methods offering reasonably acceptable results for the 60–79 years interval. Meanwhile, none of the methods was reliable to estimate age in individuals ranging from 80 to 110 years old. The control sample used by Parra and colleagues [12] confirms the trajectory effect in individuals aged 60–110 years, and in young individuals aged 20–29 years. These results coincide with all the aforementioned reports (see Table 6).

When Ribeiro Lopes and colleagues [15] applied the Lamendin method on a Brazilian population, they found a mean error of 7.55 years in the 40−59 years category, and a mean error of 21.06 years in individuals older than 60 years. Similar results were reported by Zorba and colleagues [17] from a modern Greek population, showing a bias of 7 years in the 50−59 years range and mean errors of between 16 and 26 years in individuals older than 60 years. Retamal and Ubelaker [24] studied the behavior of various methods in a Chilean sample and found mean errors of between 7 and 13 years in individuals aged 51–60 years, and mean errors between 15 and 31 years in individuals older than 60 years. Garizoain and colleagues [9] applied the Lamendin's method in an Argentinian sample and found a mean error of 10.63 years in the 51–65 category, as well as a mean error of 19.38 years in individuals ranging from 66 to 80 years old. Age estimation methods such as the ones proposed by Lamendin and colleagues [4], Prince and Ubelaker [5], González-Colmenares and colleagues [23], Ubelaker and Parra [11], and Sarajlic and colleagues [52], including those methods that use Bayesian statistics such as those of Prince and Konigsberg [51], Schmitt and colleagues [50] and more recently Parra and colleagues [12], show that chronological age is always underestimated in groups of adults older than 50 and up to 110 years, while the same variable is usually overestimated in groups of young adults under 40 years. In terms of the Bayesian model (INT), this study found a mean error of -14.62 years in individuals aged 18–29, a mean error of 12.34 years in individuals aged 70–79, and a mean error of 14.43 years in individuals older than 80 years (see Table 6).

Regarding the physiological factors that would explain the trajectory effect for this type of dental methods, we agree with Bang and Ramm [6], who argued that the development of translucency is slower as it approaches the coronal region, where the physiological process could be further delayed. Along the same line of thought, Parra and colleagues [12] have argued that the trajectory effect for this type of method can be explained because close to the coronal portion of the root "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". This research results agree with Parra and colleagues [12], who showed that RDT follows a constant linear ascending behavior until the eighth decade of age; after this threshold, it seems that RDT reaches a plateau and this indicator of age then loses its usefulness (Fig. 3).

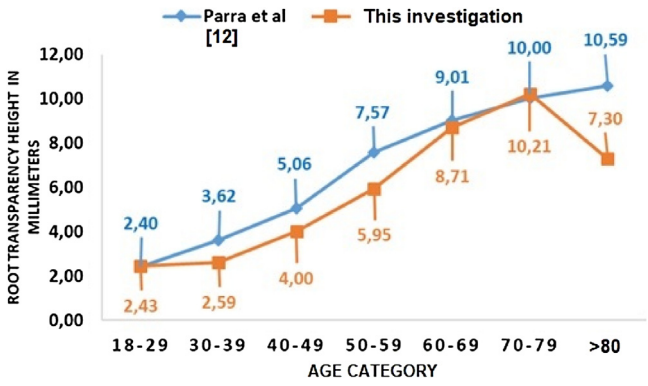


Fig. 3. Comparison of RTH by age category between this study and that of Parra and colleagues [12].

Conclusion

This study examined the forensic applicability of a Bayesian model using Root translucency Height (RTH) and Periodontal Height (PH) as a means of estimating age at death in adults based the criteria proposed by Lamendin's technique [4]. RDT has shown that correlation with chronological age is the main index of adulthood (r = 0.69), and periodontal regression contributes positively to the calculation (r = 0.31). The combination of both criteria has provided an acceptable correlation (r = 0.75), particularly for people between 30 and 69 years old. The results confirm that the overestimation can be reduced but not eradicated due to strictly physiological factors.

Due to the fact that several calibration conditions are known for an optimal use of Lamendin's technique [4], and that there is a positive consensus on the benefits of the procedure for age-at-death estimation in adults, the use of Lamendin's technique [4] and its methodological derivatives might be the perfect reason to start thinking about the global standardization of the method based on quality management criteria, which include but are not limited to, interlaboratory measurement controls, calibration of measurement sources, application procedure guides, as well as systems for storing and calculating historical information or a priori data. This research contributes to the FIDB proposed by Parra and colleagues [12], which will be included as a priori information concerning data quality.

Declaration of Competing Interest

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

Acknowledgments

The authors of this article want to acknowledge the Humanitarian and Human Rights Resource Center of the American Academy of Forensic Science and the National Institute of Justice through their Forensic Technology Center of Excellence Program, RTI International of U.S. Department of Justice, for the sponsorship provided. In addition, they also acknowledge the support of the Instituto de Medicina Legal y Ciencias Forenses del Perú - Ministerio Público. Finally, the authors want to thank Alejandro Zegarra, Sharon Olgado Ponce, Sergio Vela, Luis Murrieta and Katherine García for providing the data used for part of this study.

References

[1] S.P. Nawrocki, The nature and sources of error in the estimation of age at death from the skeleton, in: K.E. Latham, M. Finnegan (Eds.), Age Estimation of the Human Skeleton, Charles C. Thomas Publisher, LTD, Illinois, 2010, pp. 79–101.
[2] E. Baccino, D.H. Ubelaker, L.C. Hayek, A. Zerilli, Evaluation of seven methods of estimating age at death from mature human skeletal remains, J. Forensic Sci. 44 (1999) 931–936.
[3] L. Martrille, D.H. Ubelaker, C. Cattaneo, F. Seguret, M. Tremblay, E. Baccino, Comparison of four skeletal methods for the estimation of age at death on white and black adults, J. Forensic Sci. 52 (2) (2007) 302–307, doi:http://dx.doi.org/10.1111/j.1556-4029.2006.00367.x.
[4] H. Lamendin, E. Baccino, J.F. Humbert, J.C. Tavernier, R.M. Nossintchouk, A. Zerilli, A simple technique for age estimation in adult corpses: the two criteria dental method, J. Forensic Sci. 37 (1992) 1373–1379.
[5] D.A. Prince, D.H. Ubelaker, Application of Lamendin's adult dental aging technique to a diverse skeletal sample, J. Forensic Sci. 47 (2002) 107–116.
[6] G. Bang, E. Ramm, Determination of age in humans from root dentin transparency, Acta Odontol. Scand. 28 (1970) 3–35.
[7] J. Adserias-Garriga, L. Nogué-Navarro, S.C. Zapico, D.H. Ubelaker, Setting the light conditions for measuring root transparency for age-at-death estimation methods, Int. J. Legal Med. 132 (2017) 637–641.
[8] B. Foti, P. Adalian, M. Signoli, Y. Ardagna, O. Dutour, G. Leonetti, Lamendin method in age determination, Forensic Sci. Int. 122 (2001) 101–106, doi:http://dx.doi.org/10.1016/S0379-0738(01)00472-8.
[9] G. Garizoain, S. Petrone, M. Plischuk, A.M. Inda, M.N. Garcia, Evaluation of Lamendin's age-at-death estimation method in a documented osteological collection (La Plata, Argentina), Forensic Sci. Int. Rep. 2 (2020) 100060, doi:http://dx.doi.org/10.1016/j.fsir.2020.100060.
[10] D. Dulabutr, C. Plodprong, Estimation of Thai adult age by dental root translucency and periodontosis, Srinagarind Med. J. 34 (3) (2019) .
[11] D.H. Ubelaker, R.C. Parra, Application of three dental methods of adult age estimation from intact single rooted teeth to a Peruvian sample, J. Forensic Sci. 53 (2008) 608–611, doi:http://dx.doi.org/10.1111/j.1556-4029.2008.00699.x.
[12] R.C. Parra, D.H. Ubelaker, J. Adserias-Garriga, K.J. Escalante-Flórez, L.A. Condori, J. E. Buisktra, Root dentin translucency and forensic international dental database: methodology for estimation age-at-death in adults using single-rooted teeth, Forensic Sci. Int. 317 (2020) 110572, doi:http://dx.doi.org/10.1016/j.forsciint.2020.110572.
[13] ISO 11352, Water Quality. Estimation of Measurement Uncertainty Base on Validation and Quality Control Data, ISO, Geneva, 2012.
[14] A. Ackermann, M. Steyn, A test of the Lamendin method of age estimation in South African canines, Forensic Sci. Int. 236 (2014) 192.e1–192.e6, doi:http://dx.doi.org/10.1016/j.forsciint.2013.12.023.
[15] J. Ribeiro Lopes, S. Borges Braga dos Santos Queiroz, M. Marques Fernandes, L.A. Saavedra de Paiva, R. Nogueira de Oliveira, Age estimation by teeth periodontosis and transparency: accuracy of Lamendin's method on a Brazilian sample, Braz J. Oral Sci. 13 (1) (2014) 17–21, doi:http://dx.doi.org/10.1590/1677-3225v13n1a04.
[16] E.H. Kimmerle, D.A. Prince, G.E. Berg, Inter-observer variation in methodologies involving the pubic symphysis, sternal ribs, and teeth, J. Forensic Sci. 53 (3) (2008) 594–600, doi:http://dx.doi.org/10.1111/j.1556-4029.2008.00715.x.
[17] E. Zorba, N. Goutas, C. Spiliopoulou, K. Moraitis, An evaluation of dental methods by Lamendin and Prince and Ubelaker for estimation of adult age in a sample of modern Greeks, HOMO – J. Comp. Hum. Biol. (2018) , doi:http://dx.doi.org/10.1016/j.jchb.2018.03.006.
[18] G. Gustafson, Age determinations on teeth, J. Am. Dent. Assoc. 41 (1950) 45–54.
[19] G. Johanson, Age Determination from human teeth: a critical evaluation with special consideration of changes after fourteen years of age, (1971) .
[20] L. Vasiliadis, A.I. Darling, B.G. Levers, The histology of sclerotic human root dentine, Arch. Oral Biol. 28 (1983) 693–700.
[21] V.K. Kashyap, R.N. Koterwara, A modified Gustafson method of age estimation from teeth, Forensic Sci. Int. 47 (1990) 237–247.
[22] D.K. Whittaker, M.M. Bakri, Racial variations in the extent of tooth root translucency in ageing individuals, Arch. Oral Biol. 41 (1) (1996) 15–19.
[23] G. González-Colmenares, M.C. Botella-López, G. Moreno-Rueda, J.R. Fernández-Cardenete, Age estimation by a dental method: a comparison of Lamendin's and Prince & Ubelaker's technique, J. Forensic Sci. 52 (2007) 1156–1160.
[24] R. Retamal, D.H. Ubelaker, Evaluation of three methods of adult age estimation based on root translucency height, periodontosis height and root height in a Chilean sample, Forensic Oral Pathol. J. 2 (4) (2011) 16–19.
[25] A. Drusini, I. Calliari, A. Volpe, Root dentine transparency: age determination of human teeth using computerized densitometric analysis, Am. J. Phys. Anthropol. 85 (1991) 25–30.
[26] A.E.W. Miles, Dentition in the estimation of age, J. Dent. Res. 42 (1) (1963) 255–263, doi:http://dx.doi.org/10.1177/00220345630420012701.
[27] M. Lorentsen, T. Solheim, Age assessment based on translucent dentine, J. Forensic Odontostomatol. 7 (1989) 3–9.
[28] A. Nanci, Dentine-Pulp Complex, Ten Cate's Oral Histology: Development, Structure, and Function, 7th (Ed.), Reed Elsevier India Private Ltd, New Delhi, 2010, pp. 211.
[29] M. Selvamani, G.S. Madhushankari, P.S. Basandi, M. Donoghue, V. Nayak, G. Diwakar, Effect of vitality on translucent Dentine-A study, J. Int. Oral Health. 5 (2) (2013) 1–7.
[30] G. Daculsi, R.Z. LeGeros, A. Jean, B. Kerebel, Possible physico-chemical processes in human dentin caries, J. Dent. Res. 66 (8) (1987) 1356–1359, doi:http://dx.doi.org/10.1177/00220345870660081401.
[31] J.C. Voegel, R.M. Frank, Ultrastructural study of apatite cristal dissolution in human dentine and bone, J. Biol. Buccale. 5 (3) (1977) 181–194.
[32] A.E. Porter, R.K. Nalla, A. Minor, J.R. Jinschek, C. Kisielowskia, V. Radmilovica, J.H. Kinney, A.P. Tomsia, R.O. Ritchie, A transmission electron microscopy study of mineralization in age-induced transparent dentin, Biomaterials 26 (36) (2005) 7650–7660, doi:http://dx.doi.org/10.1016/j.biomaterials.2005.05.059.
[33] A.V. Zavgorodniy, R. Rohanizadeh, M.V. Swain, Ultrastructure of dentine carious lesions, Arch. Oral Biol. 53 (2) (2008) 124–132, doi:http://dx.doi.org/10.1016/j.archoralbio.2007.08.007.
[34] A.V. Zavgorodniy, R. Rohanizadeh, S. Bulcock, M.V. Swain, Ultrastructural observations and growth of occluding crystals in carious dentine, Acta Biomater. 4 (5) (2008) 1427–1439, doi:http://dx.doi.org/10.1016/j.actbio.2008.04.010.
[35] A.K. Iordanishvili, O.L. Pikhur, M.S. Malina, S.Y. Tityuk, Rasprostranennost' i kliniko-morfologicheskie osobennosti kariesa kornia zuba u vzroslogo cheloveka [Prevalence, clinical and morphological features of tooth root caries in the adult human], Stomatologiia (Mosk) 98 (4) (2009) 38–43, doi:http://dx.doi.org/10.17116/stomat20199804138.
[36] L. AlQobaly, W. Sabbah, The association between periodontal disease and root/coronal caries, Int. J. Dent. Hygiene 18 (1) (2020) 99–106, doi:http://dx.doi.org/10.1111/idh.12422.
[37] J. Zhang, D. Sardana, M.C.M. Wong, K.C.M. Leung, E.C.M. Lo, Factors associated with dental root caries: a systematic review, JDR Clin. Trans. Res. 20 (10) (2019) 1–17, doi:http://dx.doi.org/10.1177/2380084419849045.
[38] J. Zhang, K.C.M. Leung, D. Sardana, M.C.M. Wong, E.C.M. Lo, Risk predictors of dental root caries: a systematic review, J. Dent. 89 (2019) 103166, doi:http://dx.doi.org/10.1016/j.jdent.2019.07.004.
[39] S. Hillson, Dental pathology, in: M.A. Katzenberg, S.R. Saunders (Eds.), Biological Anthropology of the Human Skeleton, Wiley-Liss, New York, 2000, pp. 249–286.
[40] S. Hillson, Dental pathology, in: M.A. Katzenberg, S.R. Saunders (Eds.), Biological Anthropology of the Human Skeleton, Wiley-Liss, New York, 2008, pp. 301–340.

[41] G.C. Nelson, A host of other dental diseases and disorders, in: J.D. Irish, G.R. Scott (Eds.), A Companion to Dental Anthropology, John Wiley & Sons, Inc., 2016, pp. 465–483.
[42] I.L. Chapple, P. Bouchard, M.G. Cagetti, G. Campus, M.C. Carra, F. Cocco, L. Nibali, P. Hujoel, M.L. Laine, P. Lingstrom, D.J. Manton, E. Montero, N. Pitts, H. Rangé, N. Schlueter, W. Teughels, S. Twetman, C. Van Loveren, F. Van der Weijden, A.R. Vieira, A.G. Schulte, Interaction of lifestyle, behaviour or systemic diseases with dental caries and periodontal diseases: consensus report of group 2 of the joint EFP/ORCA workshop on the boundaries between caries and periodontal diseases, J. Clin. Periodontol. 44 (18) (2017) S39–S51, doi:http://dx.doi.org/10.1111/jcpe.12685.
[43] S. Jepsen, J. Blanco, W. Buchalla, J.C. Carvalho, T. Dietrich, C. Dörfer, K.A. Eaton, E. Figuero, J.E. Frencken, F. Graziani, S.M. Higham, T. Kocher, M. Maltz, A. Ortiz-Vigon, J. Schmoeckel, A. Sculean, L.M. Tenuta, M.H. Van der Veen, V. Machiulskiene, Prevention and control of dental caries and periodontal diseases at individual and population level: consensus report of group 3 of joint EFP/ORCA workshop on the boundaries between caries and periodontal diseases, J. Clin. Periodontol. 44 (18) (2017) S85–S93, doi:http://dx.doi.org/10.1111/jcpe.12687.
[44] R. Durand, A. Roufegarinejad, F. Chandad, P.H. Rompré, R. Voyer, B.S. Michalowicz, E. Emami, Dental caries are positively associated with periodontal disease severity, Clin. Oral Investig. 23 (10) (2019) 3811–3819, doi:http://dx.doi.org/10.1007/s00784-019-02810-6.
[45] F.M. Tadjoedin, A.H. Fitri, S.O. Kuswandani, B. Sulijaya, Y. Soeroso, The correlation between age and periodontal diseases, J. Int. Dent. Med. Res. 10 (2) (2017) 327–332.
[46] A. Sabogal, J. Asencios, A. Robles, E. Gamboa, J. Rosas, J. Ríos, F. Mayta-Tovalino, Epidemiological profile of the pathologies of the oral cavity in a Peruvian population: a 9-Year retrospective study of 18,639 patients, Sci. World J. (2019) 2357013, doi:http://dx.doi.org/10.1155/2019/2357013.
[47] R.B. Condori Canaza, Características clínicas del periodonto por el consumo de sustancias psicoactivas en pacientes de los centros de rehabilitación de la ciudad del Cusco, Facultad de Ciencias de la Salud, Escuela Profesional de Odontología, Universidad Nacional de San Antonio Abad del Cusco, Cusco, 2019.
[48] L.L. Montes Merma, Relación entre la enfermedad periodontal en pacientes puérperas y el peso de los neonatos del departamento de ginecología y obstetricia del hospital regional del Cusco en el mes de noviembre, año 2019, Facultad de Ciencias de la Salud, Escuela Profesional de Odontología, Universidad Nacional de San Antonio Abad del Cusco, Cusco, 2020.
[49] D.A. Prince, Estimation of adult skeletal age-at-death from dental root translucency, University of Tennessee, Knoxville, TN, 2004.
[50] A. Schmitt, B. Saliba-Serre, M. Tremblay, L. Martrille, An evaluation of statistical methods for the determination of age of death using dental root translucency and periodontosis, J. Forensic Sci. 55 (3) (2010) 590–596, doi:http://dx.doi.org/10.1111/j.1556-4029.2010.01341.x.
[51] D.A. Prince, L.W. Konigsberg, New formulae for estimating age-at-death in the Balkans utilizing Lamendin's dental technique and Bayesian analysis, J. Forensic Sci. 53 (2008) 578–587.
[52] N. Sarajlić, Z. Cihlarz, E.E. Klonowski, I. Selak, H. Brkić, B. Topić, Two-criteria dental aging method applied to a Bosnian population: comparison of formulae for each tooth group versus one formula for all teeth, Bosn. J. Basic Med. Sci. 6 (3) (2006) 78–83.
[53] R.C. Parra, J.E. Buikstra, D.H. Ubelaker, Dental aging methods and population variation: methodology for international applications on human remains from forensic contexts, Proceeding of the International Association of Forensic Science, Funcha-Madeira (Portugal), 2011.
[54] D.H. Ubelaker, R.C. Parra, Dental aging methods and population variation as demonstrated in a Peruvian sample, AAFS 60th Anniversary Scientific Meeting, Washington, D.C. (2008) .
[55] J.P. Bocquet-Appel, C. Masset, Farewell to paleodemography, J. Hum. Evol. 11 (1982) 321–333, doi:http://dx.doi.org/10.1016/S0047-2484(82)80023-7.
[56] J.P. Bocquet-Appel, C. Masset, Paleodemography: resurrection or ghost? J. Hum. Evol. 14 (2) (1985) 107–111, doi:http://dx.doi.org/10.1016/S0047-2484(85)80001-4.
[57] J.P. Bocquet-Appel, C. Masset, Paleodemography: expectancy and false hope, Am. J. Phys. Anthropol. 99 (4) (1996) 571–583, doi:http://dx.doi.org/10.1002/(SICI)1096-8644(199604)99:4<571:AID-AJPA4>3.0.CO;2-X.
[58] M. Cox, Ageing adults from the skeleton. Human osteology, in: M. Cox, S. Mays (Eds.), Archaeology and Forensic Science, Greenwich Medical Ltd., London, 2000, pp. 61–81.
[59] J.E. Buikstra, L.W. Konigsberg, Paleodemography: critiques and controversies, Am. Anthropol. 87 (2) (1985) 316–333, doi:http://dx.doi.org/10.1525/aa.1985.87.2.02a00050.
[60] R.P. Mensforth, C.O. Lovejoy, Anatomical, physiological, and epidemiological correlates of the aging process: a confirmation of multifactorial age determination in the Libben skeletal population, Am. J. Phys. Anthropol. 68 (1985) 87–106.
[61] D.P. Van Gerven, G.J. Armelagos, Farewell to paleodemography? Rumors of its death have been greatly exaggerated, J. Hum. Evol. 12 (1983) 353–360.
[62] J.P. Bocquet-Appel, Explaining the neolithic demographic transition, in: J.P. Bocquet-Appel, O. Bar-Yosef (Eds.), The Neolithic Demographic Transition and Its Consequences, Springer, Dordrecht, 2008, pp. 35–55.
[63] R.D. Hoppa, J.W. Vaupel, The Rostock manifesto for paleodemography: the way from stage to age, in: R.D. Hoppa, J.W. Vaupel (Eds.), Paleodemography: Age Distributions from Skeletal Samples, Cambridge University Press, Cambridge, 2002, pp. 1–8.
[64] G.R. Milner, J.W. Wood, J.L. Boldsen, Paleodemography, in: M.A. Katzenberg, S.R. Saunders (Eds.), Biological Anthropology of the Human Skeleton, Wiley-Liss, New York, 2000, pp. 467–497.
[65] L.W. Konigsberg, S.R. Frankenberg, Estimation of age structure in anthropological demography, Am. J. Phys. Anthropol. 89 (1992) 235–256.
[66] L.W. Konigsberg, S.R. Frankenberg, Deconstructing death in paleodemography, Am. J. Phys. Anthropol. 117 (2002) 297–309.
[67] D. Lucy, A.M. Pollard, C.A. Roberts, A comparison of three dental techniques for estimating age at death in humans, J. Archaeol. Sci. 22 (1995) 417–428.
[68] J.L. Boldsen, G.R. Milner, L.W. Konigsberg, J.W. Wood, Transition analysis: a new method for estimating age from skeletons, in: R.D. Hoppa, J.W. Vaupel (Eds.), Paleodemography Age Distributions from Skeletal Samples, Cambridge University Press, Cambridge, UK, 2002, pp. 73–106.
[69] G.R. Milner, J.L. Boldsen, Skeletal age estimation: where we are and where we should go, in: D.C. Dirkmaat (Ed.), A Companion to Forensic Anthropology, Blackwell, 2012, pp. 224–238.
[70] E.A. DiGangi, J.D. Bethard, E.H. Kimmerle, L.W. Konigsberg, A new method for estimating age-at-death from the first rib, Am. J. Phys. Anthropol. 138 (2008) 164–176.
[71] A. Sengupta, D.K. Whittaker, R.P. Shellis, Difficulties in estimating age using root dentine translucency in human teeth of varying antiquity, Arch. Oral Biol. 44 (1999) 889–899.
[72] N. Tang, D. Antoine, S. Hillson, Application of the Bang and Ramm age at death estimation method to two known-age archaeological assemblages, Am. J. Phys. Anthropol. 155 (3) (2014) 332–351, doi:http://dx.doi.org/10.1002/ajpa.22566.
[73] M.S. Megyesi, D.H. Ubelaker, N.J. Sauer, Test of the Lamendin aging method on two historic skeletal samples, Am. J. Phys. Anthropol. 131 (3) (2006) 363–367, doi:http://dx.doi.org/10.1002/ajpa.20446.
[74] S.I. Kvaal, E.M. During, A dental study comparing age estimations of the human remains from the Swedish warship Vasa, Int. J. Osteoarchaeol. 9 (3) (1999) 170–181, doi:http://dx.doi.org/10.1002/(SICI)1099-1212(199905/06)9:3<170::AID-OA470>3.0.CO;2-A.
[75] R.C. Parra, Métodos de estimación de edad en dientes y variación poblacional: metodología para aplicaciones internacionales en restos humanos de contextos forenses, Tesis de Maestría. Pontificia Universidad Católica del Perú, Lima, 2009.
[76] A. Sillen, Diagenesis of the inorganic phase of cortical bone, in: T.D. Price (Ed.), The Chemistry of Prehistoric Human Bone, Cambridge University Press, Cambridge, 1989, pp. 211–229.
[77] D.F.G. Poole, E.K. Tratman, Post-mortem changes in human teeth from late upper Paleolitic/mesolithic occupants of an English limestone cave, Arch. Oral Biol. 23 (1978) 1115–1120, doi:http://dx.doi.org/10.1016/0003-9969(78)90117-6.
[78] H. Soomer, H. Ranta, M.J. Lincoln, A. Penttilä, E. Leibur, Reliability and validity of eight dental age estimation methods for adults, J. Forensic Sci. 48 (2003) 149–152.
[79] M.M. Cremasco, Dental histology: a study of ageing processes in root dentine, Boll. Soc. Ital. Biol. Sper. 74 (1998) 19–28.
[80] G.M. Robbins, Dental Histology and Age Estimation at Damdama: an Indian Mesolithic Site, Department of Anthropology, University of Oregon, Eugene, 2000.
[81] E. Vlček, L. Mrklas, Modification of the Gustafson method of determination of age according to teeth on prehistorical and historical osteological material, Scripta Med. 48 (1975) 203–208.
[82] A. Marcsik, F. Kosa, G. Kocsis, The possibility of age determinations on the basis of dental transparency in historical anthropology, in: P. Smith, E. Tchernov (Eds.), Structure, Function, and Evolution of Teeth, Freund Publishing House, Ltd., Tel Aviv, 1992, pp. 527–538.
[83] H. Vilcapoma, Método dental modificado para la estimación de la edad en individuos adultos, UNMSM 15 (2) (2012) 27–30.
[84] J.K. García, Estimación de la edad cronológica en adultos mediante tres métodos dentarios 2017, Facultad de Ciencias de la Salud, Escuela Profesional de Estomatología, Universidad Andina Cusco, Cusco, 2018.
[85] L. Murrieta, S. Vela, Comparación de la técnica de Lamendin, Vilcapoma y Colmenares para estimación de edad de occisos amazónicos en el Ministerio Público División Médico Legal II Iquitos 2014-2018, Facultad de Ciencias de la Salud, Programa Académico de Estomatología, Universidad Científica del Perú, San Juan Bautista Maynas Loreto, 2018.
[86] I. Sánchez, Método de transparencia radicular para la estimación de la edad en cadáveres adultos Huánuco 2017, Facultad de Ciencias de la Salud, Escuela Académico Profesional de Odontología, Universidad de Huánuco, Huánuco, 2018.
[87] L.M. Peralta, Exactitud de los métodos de transparencia radicular para estimar la edad dental en cadáveres adultos 2020, Facultad de Ciencias de la Salud, Carrera Profesional de Estomatología, Universidad Científica del Sur, Lima, 2020.
[88] G.C. Iannacone, R.C. Parra, Genetic structure and kinship analysis from the Peruvian Andean area: limitations and recommendation for DNA identification of missing persons, in: R.C. Parra, S.C. Zapico, D.H. Ubelaker (Eds.), Forensic Science and Humanitarian Action: Interacting With the Dead and the Living, 1.a ed., Wiley, 2020, pp. 473–489.
[89] G.C. Iannacone, R.C. Parra, M. Bermejo, Y. Rojas, C. Valencia, M. Portugues, M. Medina, A.R. Vallejo, A. Prochanow, Peruvian genetic structure and their impact in the identification of Andean missing persons: a perspective from Ayacucho, Forensic Sci. Int. Genet. Suppl. Ser. 3 (1) (2011) e291–e292, doi:http://dx.doi.org/10.1016/j.fsigss.2011.09.008.
[90] J.R. Sandoval, D.R. Lacerda, O. Acosta, M.S. Jota, P. Robles-Ruiz, A. Salazar-Granara, P.P. Vieira, C. Paz-Y-Miño, R. Fujita, F.R. Santos, Genographic Project Consortium, The genetic history of Peruvian Quechua-Lamistas and Chankas: uniparental DNA patterns among autochthonous Amazonian and Andean populations, Ann. Hum. Genet. 80 (2) (2016) 88–101, doi:http://dx.doi.org/10.1111/ahg.12145.
[91] J.R. Sandoval, A. Salazar-Granara, O. Acosta, W. Castillo-Herrera, R. Fujita, S.D. Pena, F.R. Santos, Tracing the genomic ancestry of Peruvians reveals a major legacy of pre-

Columbian ancestors, J. Hum. Genet. 58 (9) (2013) 627–634, doi:http://dx.doi.org/10.1038/jhg.2013.73.
[92] C.I. Degregori, No hay país más diverso: Compendio de Antrolopología Peruana, Instituto de Estudios Peruanos, Lima, 2016.
[93] C.I. Degregori, P.F. Sendón, P. Sandoval, No hay país más diverso: Compendio de Antropología Peruana II, Instituto de Estudios Peruanos, Lima, 2016.
[94] D.A. Komar, J.E. Buikstra, Forensic Anthropology: Contemporary Theory and Practice, Oxford University Press, Oxford, 2008.
[95] D. De Angelis, E. Mele, D. Gibelli, V. Merelli, L. Spagnoli, C. Cattaneo, The applicability of the Lamendin method to skeletal remains buried for a 16-Year period: a cautionary note, J. Forensic Sci. 60 (1) (2014) 177–181.