Journal Pre-proof

Estimation age-at-death in adults and verification of a forensic international methodology using single rooted teeth: An approach for Peruvian population

Roberto C. Parra, Daniel G. Suárez-Ponce, Karen J. Escalante-Flórez, Lucio A. Condori, Oswaldo Calcina-Mendoza, Liz M. Peralta-Cerro, Glicerio A. Rosas-Moyano

PII: S2665-9107(21)00007-4

DOI: https://doi.org/10.1016/j.fsir.2021.100176

Reference: FSIR 100176

To appear in: *Forensic Science International: Reports*

Received Date: 5 November 2020

Accepted Date: 13 January 2021

Please cite this article as: { doi: https://doi.org/

Estimation age-at-death in adults and verification of a forensic international methodology using single rooted teeth: An approach for Peruvian population

Roberto C. Parra[1], Daniel G. Suárez-Ponce[2], Karen J. Escalante-Flórez[3], Lucio A. Condori[4], Oswaldo Calcina-Mendoza[4], Liz M. Peralta-Cerro[3], Glicerio A. Rosas-Moyano[4].

[1] 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.

[2] Departamento Académico de Estomatología Médico Quirúrgico. Facultad de Odontología, Universidad Nacional Mayor de San Marcos, Lima, Perú.

[3] Especialidad en Odontología Forense, Facultad de Estomatología, Universidad Científica del Sur, Lima, Perú.

[4] Instituto de Medicina Legal y Ciencias Forenses del Perú, Ministerio Público, Lima, Perú

Roberto C. Parra
ropachi@gmail.com

Abstract

From a forensic perspective, estimation age-at-death in adults is a constant problem that impacts the development of investigations regarding the unidentified dead bodies and the need to identify them. Several procedures for estimation age-at-death 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 levels of precision and accuracy of these procedures. The methods derived from the Lamendin technique have been widely used in Peru since the beginning of the year 2000, which have been validated and the levels of applicability and confidence of the method are known. However, a new estimation system using the Lamendin technique has been developed through a Bayesian model. This model stores the information measured in a Forensic International Dental Database (FIDB) that contains information of several populations which also contributes to assessing the levels of applicability of the procedure. In this way there is more information that can contribute to strengthen the calculation and the final results. The results of this research have shown that the Bayesian model has a homogeneous behavior when it is applied in the Peruvian population, it even adjusts better than the procedures designed for the Peruvian specific population. Our research recommends using the Bayesian model for the forensic estimation of age in this population. Use of the Lamendin's technique and its methodological derivatives may be candidates 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, application procedure guides.

Keywords:

Palabras claves:

Radicular Dental Translucency Peruvian population Forensic odontology Forensic anthropology Quality management

Introduction

From a forensic perspective, estimation age-at-death in adults is a constant problem that impacts the development of investigations regarding the 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, the recognition of degenerative indicators in the skeleton, the description and comparison of morphological variants, which are generally called "phases or stages" or the measurement of certain morphological variants, as is the case of the physiological process of Root Dentin Translucency (RDT). The estimation concept has been traditionally used because the 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, which can take a value from 0 to 110 years [1]. However, Nawrocki [1] has called the "trajectory effect" the effect of the degrees of error in early ages that are usually always greater than chronological age (overestimation of age) than in older adults (underestimation of age) where 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. As is also known, these variables are conditioned by extrinsic and intrinsic factors, so the degree of error in estimating age is inevitable. There is a consensus that recommends that if the entire body of an individual is available, all the age estimation methods available should be applied [2,3] because each age indicator has something significant to contribute, since which represents the constant variation of a particular trait to which each individual is subjected [1].

Regarding the estimation age-at-death in adult form Peruvian population, a technique and method developed in the French population, known as Lamendin et al., [4] was applied in 2002 during the beginning of forensic operations to the recovery and analysis of human remains of disappeared persons in Peru. Subsequently, in 2003, other methods with similar characteristics to Lamendin et al., [4] and which had been validated for a black and white population in the United States [5], were also applied in Peru. In 2007, the method de Bang and Ramm [6] using the intact tooth technique was also applied. These methods were used in the Peruvian forensic context not only on skeletonized human remains, but also these methods were extended to unidentified dead bodies analysis to national level, inclusive in the bioarchaeological field.

The methodological accessibility and the feasibility of applying this technique, due to the fact that it does not require further training and sophisticated technology, since it only requires the use of a calibrator and an appropriate light to record the RDT [7] has facilitated that these procedures are widely applied in Peru. However, when new analysis methods are used in a forensic context, they must be subjected to specific tests to ensure that such methods produce valid results and consistent with the intended target, or invalidate their use. 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 of Lamendin et al., [4], at least ten types of variability conditions have been measured as calibration elements of the method for the application of the Lamendin's technique and its derived methods. Variability conditions for methodology calibration include but are not limited to: 1) calculation differences between different 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 or vestibular and lingual or palatal surfaces; 4) inter- and intra-observer differences in the application of the technique; 5) measurement procedure and light medium generated by RDT; 6) the behavior of the variables and the correlation with age; 7) the sex of the observed individual; 8) population variation; 9) statistical strength and, 10) taphonomic impact and postmortem interval. Currently there is more knowledge about the variability of the types of conditions and their significance for the calibration of the methods that are derived from the Lamendin's technique [4].

Regarding the first condition, Foti et al., [8] when studying a sample of 52 French individuals using the Lamendin's technique [4], found that there were no statistically significant measurement differences for the estimation of age between the teeth, either at the level of maxillary or mandibular pieces (second condition). Similar results have been reported by other researchers when they applied the same technique, who also did not find statistically significant differences [9,10]. These investigations are supporting the idea that there is no significant evidence to choose a special type of single-rooted tooth that offers better results in estimating age, since all of them would offer similar results regardless of whether they come from the mandible or the maxilla; results that differ with the suggestion made by Lamendin et al., [4] who indicated that the upper central incisors would offer better results.

Third condition, the study by Lamendin et al., [4] suggested using the buccal surface because on this surface the RDT is higher than 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. Ubelaker and Parra [11] took the initiative to compare both tooth surfaces, and concluded that the differences were minimal and that both offered good results, although they noted that the buccal surface could offer somewhat more accurate results. In a recent study by Garizoain et al., [9], using a larger sample than that of Ubelaker and Parra [11], they concluded in the same way, where the buccal surface offered more exact results, but that the differences in the result end are minimal. Garizoain et al., [9], also show that there are morphological differences between buccal RDT and lingual RDT, where buccal RDT would be higher than lingual RDT, similar to what was initially suggested by Lamendin et al., [4], while that Parra et al., [12] find the same observations. These observations would explain the reason why the buccal surface would have an even 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 the reasons 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.

Fourth condition, 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 measurement equipment (Intraobserver) [13]; while the reproducibility condition is the 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 by different observers (reproducibility) or the same observer (Repeatability) at different times is very important, because the reliability of the results and the calibration of the methods will depend on these evaluations.

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

Fifth condition, to measure the transparency zone, direct techniques have been used on the sectioned tooth [18,19,20,21,22] and indirect techniques, where observations are made on the intact tooth [4,5,6,9,11,23,24,25]. The evaluations have been quantified by subjective indices [18,19], directly measuring translucency [26], measuring the area of translucency [27], the translucency expressed over the length of the tooth [21], the area of the translucency 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 et al., [25] compared two techniques to measure root translucency, one of them using computerized densitometric technology and on the other hand a simple calibrator; the aforementioned techniques were applied to a sample of 152 teeth, including incisors, canines and premolars. They found no significant differences between the two techniques, so the measurement of root translucency with a simple caliper would provide data as reliable as complex technologies.

On the other hand, Adserias-Garriga et al., [7] were the first to carry out a study on the light condition 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 established that 1600 lx illumination is the correct setting to perform root transparency measurements. 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 et al., [8] reported a 16w X-ray viewer, as did Retamal and Ubelaker [24] who also used a X-ray viewer; and Garizoain et al., [26] who used an LED X-ray viewer. Adserias-Garriga et al., [7] have recommended that appropriate lighting should be taken into account when measuring root translucency because it contributes to better results.

Sixth condition, the translucency of root dentin is a physiological marker of aging with a high degree of correlation with age [12] which is remotely influenced by internal and external factors [12]. However, the physiological translucency of dentin could suffer pathological attack from bacterial agents that can cause tubule filling with similar characteristics as physiological translucent dentin [28,29,30,31,32,33,34]. The choice of one or more healthy teeth for the application of the Lamendin’s technique [4] is very important because the prevalence of this type of caries has been observed mainly in adults [35,36,37,38].

On the other hand, although it has been reported that periodontosis has a positive correlation with age [39,40,41]. Periodontosis is more influenced by external and internal factors [36,42,43,44]. Ubelaker and Parra [11] have indicated that periodontosis could affect the accuracy of the method because it is conditioned by the factors mentioned above. Tadjoedin et al., [45] observed that chronic gingival and periodontal disease predominate among young adults and middle adults, while aggressive periodontitis tends to prevail in older adults. However, they have argued that periodontal disease tends to be related to age, as was also observed by Parra et al., [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 the Lamendin's technique [4]. Although the periodontal disease for the particular Peruvian case is epidemiologically varied [46], even in areas where coca leaf chewing is frequent [47,48] the impact on the final results would be minimal [11].

Seventh condition, some reports have mentioned that root transparency may be affected by biological sex [5,27,49], but other authors have shown that the condition of sex is minimal [9,11,17,23,50], it does not even represent any significant difference [8]. Parra et al., [12] corroborate that the behavior of the translucency of the root dentin does not present statistically significant differences related to sex and they show that sex only significantly influences root height, which is the variable that less explains the age of the individual.

Eighth condition, Whittaker and Bakri [22] and Parra et al., [12] studied the behavior of the population variation on the translucency of the root, which is the main variable used by the methods derived from the Lamendin's technique [4]. Both investigations agreed that there are population differences in the behavior of the RDT. Parra et al., [12] indicated that all the variables measured have a variable impact with respect to the population type. However, despite these results are not significantly influenced in the final result [10,11,12,15,17,23,24,51,52].

Parra et al., [53] Ubelaker and Parra [54] and Prince and Ubelaker [5] opened the debate regarding the estimation of age in adults and the impact of population variation using a method derived from the Lamendin´s technique [4]. Ubelaker and Parra [54] and Parra et al., [53] argued that these procedures could behave in a homogeneous way in any type of population in the world.

Subsequently, various investigations have confirmed these observations [9,10,17,24]. Recently, Parra et al., [12] also confirm these findings by using a Forensic International Dental Database (FIDB) that combines several types of populations and a Bayesian methodology for calculating age estimates, which seems to have a generalizable scope for diverse population types. When Parra et al., [12] applied this methodology in a Colombian sample, the method had an appropriate performance above the specific methods for that population.

Ninth condition, the foundation and the statistical solidity has been one of the main discussions that have been held to avoid bias in the estimates of age in adults [55,56,57,58,59,60,61,62,63,64,65,66,67]. The Rostock manifesto has been one of the consensus that has directed the debate towards the use of the Bayesian approach [63,68,69]. These classical calibration models for age-at-death in adults have been developed and seem to offer good results minimizing biases in the estimates, mainly in older adults [51,68,69,70].

In forensic sciences, age estimation procedures have been used in adults that have been based on inverse calibrations using reference samples not properly distributed. In other words, most of the methods that have been developed to date 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 the Lamendin's technique [4], the same has been happening, where the formulation of estimation methods has been generated from inappropriate reference samples. According to Prince and Konigsberg [51], this type of procedure is inappropriate, "unless the target sample has a similar age-at-death distribution as the reference sample" [51: 579]. Appropriate information will be required to minimize biases in the estimates, which implies developing new strategies that contribute to the best distribution of the sample, which could involve the combination of various population types to build robust samples [1].

Parra et al., [12] built a database of 693 individuals combining various population samples as a priori information which can be feed with more information. They used a Bayesian regression model to calculate the estimate of adulthood where the confidence intervals for the Bayesian regression coefficients for Periodontal Height (PH) and Root Translucency Height (RTH) are relatively small, indicating that these estimated coefficients 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, a determination coefficient of R^2 0.58 was obtained with a mean error of 3.08.
Prince and Konigsberg [51], applied Bayesian analysis in a population sample from the Balkans. They found that the Bayesian approach offered the most appropriate statistical analysis for that sample. They also determined that there was a significant difference between the real 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 et al., [50] it has been shown that the application of Bayes' theorem tends to minimize the underestimation of age in the elderly. However, according to Parra et al., [12] all the procedures would lose their potential possibility of estimation age-at-death in adults from 80 years of age, because the main variable that explains age loses its correlation with age biological due to the slow physiological behavior of the RDT which would be stationed in a constant plateau [12].

Tenth condition, the environment and the post-mortem interval play an important role in the diagenesis of dental tissue, which may constitute an impediment to the use of RDT as a source for the estimation of adulthood at death [67,71,72,73,74]. The translucent properties of RDT and their visual evaluation, as well as biases in the metric of the properties in question can be affected by taphonomic forces such as water, the chemical composition of the soil, pH, temperature and humidity, as well as activities of microorganisms [12,49,71,74,75,76].

In 1995, Lucy et al., [67] noted changes to the internal microstructure that obliterated translucency dentin of sectioned tooth roots from a mediaeval 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] have pointed out that there may be colonization and proliferation of microorganisms during the post-mortem interval. Although the exact fungal group is not yet known, data suggest that it is 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 dissolution of the inorganic component and destruction of the histological structure.

Sengupta et al., [71] studied the RDT of the Spitalfields collection (London), consisting of individuals who lived during the 19th century. They pointed out that most teeth had a clayish or chalky appearance, and that these characteristics had a negative impact on age estimation; although Tang et al., [72] noted that the observations developed by Sengupta and colleagues [71] did not appear to have a relationship with the post-mortem interval and instead was thought to be caused by the post-mortem environment. In 1999, Kvaal y During [74] conducted a study on remains that had been underwater on a sunken ship for over 300 years. They noted that root translucency had been affected by the aquatic environment. The nature of these biochemical mechanisms of action are not well known.

Although both the Lamendin 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 [67,71,72,73,74,79,80,81] but, although translucency is observed, there are also findings of wide biases that would 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 with may therefore not always indicate a young age but rather an advanced degree of postmortem change [72].

Megyesi et al., [73] found that when the Lamendin’s technique was applied to two historic populations from London during the 18th and 19th centuries, the mean error increased substantially. The same results was found by Marcsik et al., [82] in a study of 250 teeth from the 8th and 10th centuries. When Tang et al. [72] studied historical samples using root transparency, through the Bang and Ramm procedure, 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 indicator may also be affected, since the longer the post mortem interval, the greater subjectivity would be obtained to determine the periodontal regression marker, even 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 the 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 postmortem interval under various types of conditions. De Angelis et al. [95] when studying a sample of 21 adult individuals who were buried for 16 years in Cimitero Maggiore di Milano, concluded that the postmortem interval, even for a short time (16 years) can significantly influence in the applicability of Lamendin's technical [4]. Observations developed in Peru, with bodies buried between 25 and 30 years old, would not have suffered modifications in the morphology of the RDT, and periodontosis 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 Peru

Ubelaker and Parra [11], validated the methods of Bang and Ramm [6], Prince and Ubelaker [5], and Lamendin et al., [4] to estimate the age in an adult population sample from 17 different regions of the Peru. They established that the method of Prince and Ubelaker [5] offered better results, and based on the principles of 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 for the male sample it was 6.08 years with a standard deviation of 5.86 years. They did not find statistically significant differences to use this methodology regardless of the sex of the individual analyzed. The total mean error was 6.29 years with a standard deviation of 5.97 years for the total sample. Later, other studies on Peruvian samples have confirmed the initial findings [83,84,85,86,87]. However, the main contribution of Ubelaker and Parra study [11], was to show that although the Peruvian population is clearly different from the French population, 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 investigations that have been reported for other population contexts [5,23,51,52].

On the other hand, Peru is located in the Midwest of South America, with one of the most diverse, geographical and ecological climates in the world, from the tropical or subtropical desert to the glaciers in the high Andes mountains and the Amazon rainforest. In a diverse country like Peru, which brings together Amazonian populations, from the central Andes mountain range, and from the desert coast of the Pacific Sea, it includes a varied heterogeneity of genetic load [88,89,90,91], different phenotypes and varied cultural traditions [92,93]; It could be interpreted that, due to its population diversity, specific forensic age estimation methods are required for each group or subgroup, which is absolutely unnecessary [1]. For example, an age estimation procedure is unnecessary for each Peruvian region (Jungle, Coast, Mountains and High Mountains) and even less for each specific locality (Cusco, Puno, Lima, Iquitos, Huanuco, etc.). Forensic sciences do not focus on describing and interpreting population diversity and variability, that is an area of study for biological anthropologists. We are interested in knowing the level of accuracy and precision of the analysis method [94] to demonstrate the quality of the results obtained.

The objective of this research is to verify on a contemporary Peruvian sample the level of accuracy and precision of the Bayesian model that was proposed by Parra et al., [12] as well as to study the behavior of degenerative physiological variables such as RDT and the marker of periodontal disease. To address this issue, samples have been collected from three regions of Peru, which were contrasted with five inverse calibration methods with the intention of verifying the behavior of their results. The results of the analysis of the observed variables will be incorporated into the BDI in order that they continue to serve as a source of information for future analyzes and calculations for estimation age-at-death in adults.

Materials and methods

Samples

The sample was collected in six different regions of Peru, from individuals with known identity. The sample is between 18 and 85 years old, with an average age of 45.94 years and a standard deviation of 12.77 years.

The sample comes 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 region.

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

Methods

The measurements of these studies were based on the technique described by Lamendin et al., [4] which implies the measurement of the variables (root height, periodontosis height and root transparency). A digital caliper (with the values recorded in millimeters) was used to obtain the measurements. (See figure 1).

The measurements were developed by specialized professionals: Peralta [87] with samples collected from the Central Morgue in Lima of the Institute of Legal Medicine and Forensic Sciences of Peru (ILMFSP); García [84] with samples taken from living people during clinical interventions; Murrieta and Vela [85] collected data that were documented between 2014 and 2018 in the Medical Legal Division II (Iquitos Morgue – ILMFSP); Zegarra and Olgado provided samples collected from the Medical Legal Division II (Cusco Morgue – ILMFSP). To estimate dental age, the methods proposed by Lamendin et al., [4] (LBHTNZ), Prince and Ubelaker [5] (PU), Ubelaker and Parra [11] (UP), Vilcapoma [83] (V) and Parra et al., [12] (INT Bayesian) were applied.

Finally, the variables RTH, Root Height (RH) and PH were evaluated for different age categories within the sample. The calculation of the method of Parra et al., [12] (INT), was performed using the R System version 4.0.1. For data processing and statistical analysis, the IBM SPSS version 25 program was used.

Results

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

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

Table 5 shows that RTH has a positive linear correlation with the 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 an R 0,10 shows a very low correlation with chronological age, with $p>0,05$, which indicates 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 in the group of 18-29 years found a mean error of -14.62, followed by the group of 30-39 years with a mean error of - 4.41, the 40-49 year group a mean error of 0.54, the 50-59 year group a mean error of 3.25, the 60-69 year group a mean error of 3.35, the group of 70-79 years a mean error of 12.34 and the group <80 a mean error of 14.43; these results are favorable in the age categories 30 to 69 years in comparison with the mean errors found in the original study by Parra et al., [12] where they are favorable for the 30 to 79 years age category and in In the <80 years category, the mean errors were also higher than those proposed by the method. The Bayesian model (INT) offers the lowest total mean error (2.12 years), these results, like those of the study by Parra et al., [12] (6.83 years) indicate that its predictive behavior is more homogeneous than the other methods.

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

Discussion

One of the degenerative indicators that has shown important utility in adult individuals has been RDT, but its combination with other markers such as PH and RH have strengthened the analysis method [4]. Regarding the methods derived from the Lamendin's technique [4], all of them have shown mean absolute errors of between 6 and 13 years in several forensic context [4,5,11,23,51,24,17,10,12]. When Ubelaker and Parra [11] found that other methodologies developed for another type of population could be used in the Peruvian forensic scenario, which offered acceptable results, as well as the procedure specially designed for Peru. Meanwhile, table 7 shows the comparison of the mean error and standard deviation of the methods Lamendin et al., [4], Prince and Ubelaker [5], Ubelaker and Parra [11] and Vilcapoma [83] that were applied by local investigations such as Vilcapoma [83]; Peralta [87]; García [84] and Murrieta and Vela [85] which support the initial report by Ubelaker and Parra [11]. Table 3 shows what was found by this research with similar findings. 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 trend [83] to offer greater accuracy, but of all the methods analyzed, it is the method with the least precision. The best performance in terms of efficacy is the method proposed by Parra et al., [12] which sees a better balance between accuracy and precision. Knowing the margin of error for the methodological precision for estimation age-at-death in adults is of greater relevance than its closeness to the real age (accuracy); that is, knowing the precision of the results is more important than the accuracy of the results, which is irrelevant. Nawrocki [1] has highlighted that narrow error intervals could exclude people who have been wanted and 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 investigators have also noted this problem [3,50]. Practical experience in various settings around the world certainly reflects this problem, so 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, offers quality of results, greater efficiency and therefore greater probative value.

In our study we show the levels of statistical solidity of the analyzed methods, which are represented in table 5. There we observe that the method of Parra et al., [12] shows greater statistical solidity than the other methods studied, where the Vilcapoma's method [83] is the one with the least statistical solidity, the greatest imprecision, but paradoxically with the highest accuracy.

Trajectory effect

Parra et al., [12] have reported that the methods derived from the Lamendin's technique behave homogeneously in accuracy and precision between 30 to 69 years of age, so there is a reliable balance to estimate age in adult individuals. It is important to note that among the age categories 20 to 59 years of age, most methods tend to overestimate age. The overestimation of age is more evident among young individuals aged 20 to 29 years, and the underestimation of age would start from 60 years of age, where 60 to 79 years the methods offer reasonably acceptable results. Meanwhile, in individuals between 80 to 110 years of age, none of the methods was reliable to estimate age. The control sample used by Parra et al., [12] confirms the trajectory effect in individuals aged 60 to 110 years as in young individuals aged 20 to 29 years. The results of this investigation coincide with all the aforementioned reports (see table 6).

Ribeiro Lopes et al., [15] when they applied the Lamendin method on the Brazilian population, they found a mean error of 7.55 years in the age category of 40-59 years, and a mean error of 21.06 years in individuals who are above the 60 years, similar results were shown by the study by Zorba et al., [17] on modern Greek population showing a bias of 7 years in the range of 50-59 years and mean errors of between 16 and 26 years in older individuals to 60 years. Retamal and Ubelaker [24], studied the behavior of various methods in a sample of the Chilean population and found mean errors of between 7 and 13 years in individuals aged 51 to 60 years and mean errors between 15 and 31 years in individuals older than 60 years. Garizoain et al., [9] applied the Lamendin method in an Argentine sample and found a mean error of 10.63 years in the age category from 51 to 65 years, and a mean error of 19.38 years in individuals from 66 to 80 years. Age estimation methods such as Lamendin et al., [4 Prince and Ubelaker [5], González-Colmenares et al., [23] Ubelaker and Parra [11] and Sarajlic et al., [52] including those methods that use Bayesian statistics such as those of Prince and Konigsberg [51], Schmitt et al., [50] and recently Parra et al., [12] show results that in groups of adults over 50 years of age 110 years, chronological ages are always underestimated; and in groups of young adults under 40 years of age, chronological ages are usually overestimated.

This research found the following results for the Bayesian model (INT), in individuals aged 18 to 29 years a mean error of -14.62 years, a mean error of 12.34 years in individuals aged 70 to 79 years and in older individuals of 80 years a mean error of 14.43 years (see table 6).

Regarding the physiological factors that would explain the trajectory effect for this type of dental methods, our work agrees 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 et al., [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 dentin area, the process of inorganic salt deposits is much faster, and the translucency is noticeable more quickly”. This research agrees with Parra et al., [12] who showed that the RDT follows a linear and ascending behavior until the eighth decade of age, after this constant rise threshold, it seems that the RDT reaches a plateau where this indicator of age loses its usefulness. (See figure 3).

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 from the criteria of the Lamendin's technique [4]. The RDT has shown that the correlation with chronological age is the main indicator 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 various calibration conditions are known for the use of the Lamendin's technique [4], which have been examined over the years, and all seem to agree positively on the benefits of the procedure for estimation age-at-death in adults; the use of the Lamendin's technique [4] and its methodological derivatives may be candidates 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 BDI proposed by Parra et al., [12] which will be included as a priori information with prior knowledge of the quality of the data, which have been reported in this work.

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.

Acknowledgment

The authors of this article want to acknowledge Humanitarian and Human Rights Resource Center of the American Academic 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 by sponsorship provided. The authors want to acknowledge to the Instituto de Medicina Legal y Ciencias Forenses del Perú - Ministerio Público. The authors wish to thank Alejandro Zegarra, Sharon Olgado Ponce, Sergio Vela, Luis Murrieta y Katherine García for providing us with the data that has been part of this research.

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, DH. Ubelaker, LC Hayek, A. Zerilli. Evaluation of seven methods of estimating age at death from mature human skeletal remains. J Forensic Sci. 44 (1999) 931-36.

[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. https://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] P. Foti, M. Adalian, Y. Signoli, O. Ardagna, G. Dutour, Leonetti Limits of the Lamendin method in age determination, Forensic Sci. Int. 122 (2001) 101–106. https://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 Science International: Reports 2 (2020) 100060. https://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. Parra C., 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.

[12] R.C. Parra, D.H. Ubelaker, J. Adserias-Garriga, K.J. Escalante-Flórez, L.A. Condori, J.E. Buisktra, Root Dentin Translucency and International Dental Database: Forensic methodology for estimation age-at-death in adults using Single-Rooted Teeth. Forensic Science International. (In review).

[13] ISO 11352:2012, Water quality. Estimation of measurement uncertainty base on validation and quality control data, ISO, Geneva.

[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. https://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 (2008) 594–600.

[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 - Journal of Comparative Human Biology (2018). https://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 Science International. 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. The Forensic Oral Pathology Journal, 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. Miles, Dentition in the estimation of age, Journal of Dental Research. 42 (1963) 255–263.

[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 edition. New Delhi: Reed Elsevier India Private Ltd 2010; 211.

[29] M. Selvamani, G.S. Madhushankari, P.S. Basandi1, M. Donoghue, V. Nayak, G. Diwakar, Effect of Vitality on Translucent Dentine-A Study, Journal of International Oral Health. 5(2) (2013) 1-7.

[30] G. Daculsi, R.Z. LeGeros, A. Jean, B. Kerebel, Possible physicochemical processes in human dentin caries, J Dent Res. 66 (1987) 1356–9.

[31] J.C. Voegel, R.M. Frank, Ultrastructural study of apatite cristal dissolution in human dentine and bone, J Biol Buccale. 5 (1977) 181–94.

[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 (2005) 7650–7660.

[33] A.V. Zavgorodniy, R. Rohanizadeh, M.V. Swain, Ultrastructure of dentine carious lesions. Archives of oral biology. 53(2) (2008) 124–132. https://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 biomaterialia, 4(5) (2008) 1427–1439. https://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, 98(4) (2009)38–43. https://doi.org/10.17116/stomat20199804138

[36] L. AlQobaly, W. Sabbah, The association between periodontal disease and root/coronal caries. International journal of dental higiene. 18(1) (2020) 99–106. https://doi.org/10.1111/idh.12422

[37] J. Zhang, D. Sardana, M. Wong, K. Leung, E. Lo, Factors Associated with Dental Root Caries: A Systematic Review. JDR clinical and translational research. 5(1) (2020) 13–29. https://doi.org/10.1177/2380084419849045

[38] J. Zhang, K. Leung, D. Sardana, M. Wong, E. Lo, Risk predictors of dental root caries: A systematic review, Journal of dentistry. 89 (2019) 103166. https://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, 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 (2017) S39- S51.

[43] S. Jepsen, J. Blanco, W. Buchalla, 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 (2017) S85- S93.

[44] R. Durand, A. Roufegarinejad, F. Chandad, Dental caries are positively associated with periodontal disease severity. Clin Oral Investig. 23(10) (2019) 3811- 3819.

[45] F.M. Tadjoedin, A.H. Fitri, S.O. Kuswandani, B. Sulijaya, Y. Soeroso, The correlation between age and periodontal diseases, Journal of International Dental and Medical Research. 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. The Scientific World Journal. (2019) 2357013. https://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. PhD dissertation, The University of Tennessee, Knoxville, TN. D.A. Prince, 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, Journal of Forensic Sciences. 55(3) (2010) 590–596. https://doi.org/10.1016/0379-0738(80)90174-7.

[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. Parra C., 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. https://doi.org/10.1016/S0047-2484(82)80023-7

[56] J.P. Bocquet-Appel, C. Masset, Paleodemography: Resurrection or ghost? J. Hum. Evol. 14 (1985) 107–111. https://doi.org/10.1016/S0047-2484(85)80001-4

[57] J.P. Bocquet-Appel, C. Masset, Paleodemography: Expectancy and false hope, Am. J. Phys. Anthrop. 99 (1996) 571–583. https://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, American Anthropologist. 87 (2) (1985) 316–333. https://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, American Journal of Physical Anthropology. 68 (1985) 87–106.

[61] D.P. Van Gerven, G.J. Armelagos, Farewell to paleodemography? Rumors of its death have been greatly exaggerated, Journal of Human Evolution. 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, Journal of Archaeological Science. 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. https://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 (2006) 363–367.

[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 (1999) 170–181.

[75] Parra, R.C. (2009) 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.

[76] A. Sillen, Diagenesis of the inorganic phase of cortical bone. In: Price, T.D. (Ed.), The Chemistry of Prehistoric Human Bone. Cambridge University Press, Cambridge, 1989. pp. 211–229.

[77] D. Poole, E. Tratman, Post-mortem changes in human teeth from late upper Paleolitic/mesolithic occupants of an English limestone cave, Archives of Oral Biology. 23 (1978) 1115–1120.

[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. Vlĉek, 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 an- thropology. In: Smith P, Tchernov E, editors. Structure, func- tion, and evolution of teeth. Tel Aviv: Freund Publishing House, Ltd., 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] Iannacone, G. C., & Parra, R. C. (2020). Genetic structure and kinship analysis from the Peruvian Andean area: Limitations and recommendation for DNA identification of missing persons. En 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., pp. 473-489). Wiley.

[89] G.C. Iannacone, R.C. Parra, M. Bermejo, M., Peruvian genetic structure and their impact in the identification of Andean missing persons: A perspective from Ayacucho. Forensic Science International: Genetics Supplement Series, 3 (2011) e291–e292.

[90] J.R. Sandoval, D.R. Lacerda, O. Acosta, The genetic history of Peruvian Quechua- Lamistas and Chankas: Uniparental autochthonous DNA patterns among Amazonian and Andean Populations. Annals of Human Genetics, 80 (2) (2016) 88–101.

[91] J.R. Sandoval, A. Salazar- Granara, O. Acosta, Tracing the genomic ancestry of Peruvians reveals a major legacy of pre- Columbian ancestors. Journal of Human Genetics, 58 (9) (2013) 627–634.

[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] De Angelis, D, Mele, E., Gibelli, D., Merelli, V., Spagnoli, L., & Cattaneo, C. 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.

TABLES AND FIGURES

Table 1. 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. 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	,57735
Total	234	100,00	18,00	85,00	45,941	12,775

Table 3. Estimation of the accuracy and precision of 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 the behavior in millimeters (mm) root height (RH), periodontal height (PH), and root transparency height (RTH) by age category.

		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

Table 5. Correlation of the variables that estimate age.

Variable	***n***	***r***	***r²***	***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

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 the 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

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

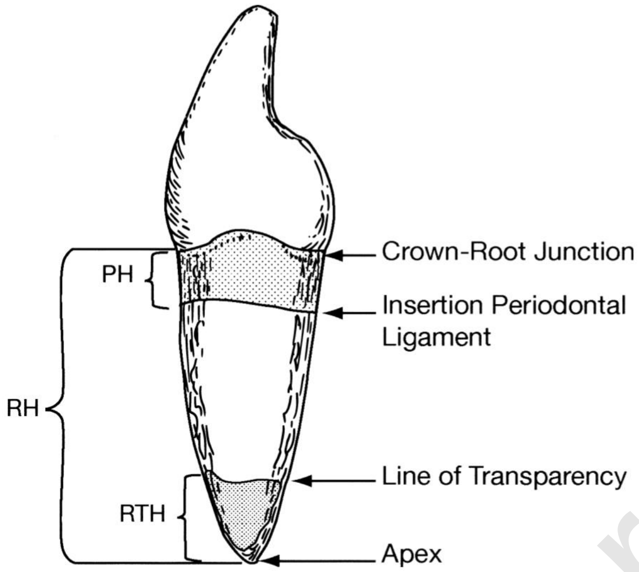

Figure 2. Root transparency height in millimeters by Age grouped (IDB 234)

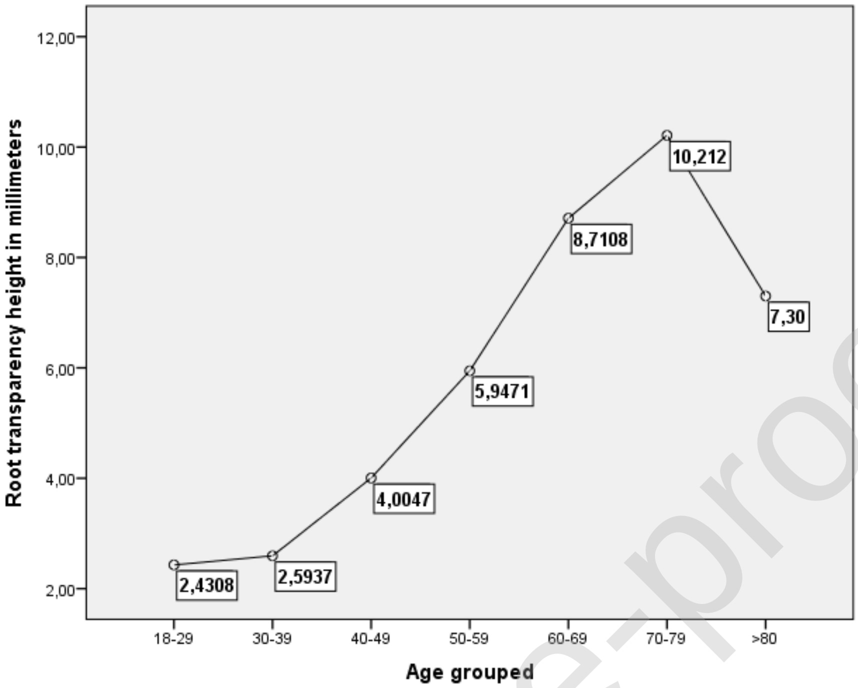

Figure 3. Comparison of RTH by age category between this investigation and that of Parra et al., [12].