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ORIGINAL RESEARCH

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Assessment of two methods to estimate dental age based on dental development for human identification in a Mexican sample

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Abstract

Background: Dental estimation is important in identification processes, and its application to estimate Chronological Age (CA) in living minors for whom a date of birth is not available. This study compares two methods to estimate dental age based on dental development in a sample of Mexican children. **Methods**: A cross-sectional, retrospective study was performed on 568 orthopantomographs corresponding to Mexican children (268 boys and 300 girls) aged 4 to 15 years old of either sex, who met the inclusion criteria. Maturation stages were assigned based on Demirjian and Nolla methodologies. We obtained CA from records and measured accuracy in the Mexican sample using each method. The mean age and standard deviations ($\pm$SD) were calculated by age and sex. Data was analyzed using Kolmogorov-Smirnov, Shapiro-Wilk ($p < 0.001$), Kruskal-Wallis H, Wilcoxon tests and Spearman's correlation coefficient between CA and Dental Age (DA). **Results**: DA obtained by Demirjian method was 10.9 ± 2.9 years, and DA calculated by Nolla was 9.7 ± 3.2 years. The total sample presented DA overestimation with Demirjian method of -0.8 ± 1.4, with significant differences between CA and DA ($p < 0.001$). DA underestimation with Nolla method of 0.4 ± 1.5, with significant differences between CA and DA ($p < 0.001$). DA did not differ significantly between the sexes using either method ($p > 0.05$). **Conclusions**: Both methods estimated CA and DA as correlated. Pediatric dentistry plays a crucial role in determining whether a patient's dental maturation is within the average for their age group. In forensic science, however, the methods must provide an estimated age as close to the real age, as the civil or criminal treatment of the individual depends on it.

Keywords

Dental age; Demirjian method; Nolla method; Dental development; Human identification; Orthopantomographs

1. Introduction

Dental age (DA) is considered a reliable indicator of chronological age (CA) which is managed under a multidisciplinary approach. To determine whether a patient's dental maturation is within the average for their age group, the involvement of a stomatologist/dentist is of great significance, as well as the estimation of age is considered of great interest in forensic dentistry in identifying individuals, mainly victims of a catastrophe or crime [1].

Different methods exist for determining the age of an individual based on biological age, which considers the individual's growth, development and age. Currently, different categories have been developed to determine age, such as skeletal-bone [2], morphological and dental, these can be applied together or separately, to evaluate biological maturity degree of a growing child [3].

Teeth are the hardest body structure, able to withstand external influences, and undergoes the smallest biological changes, also can reveal important information, including age and ethnicity. Tooth development and eruption, postformation changes, and the third molar are key parameters for estimating dental age [4].

A variety of identification methods exist to establish human identities, which are based on the teeth maturation and CA assessment from DA using radiographic methods, including the scoring procedure by Schour and Massler [5]. For comparing the degree of calcification on radiographs from 4 months to 21 years of age, 21 chronological stages were described. Demirjian is considered a simple and reliable method as it

is an orthopantomograph method with good reproducibility and reliable standardization [6, 7]. Nolla method assesses CA by evaluating the calcification of the permanent dentition. Calcification is divided into 10 stages, ranging from the crypt of the tooth formation to closing of the apical foramen closure using the orthopantomograph [8].

However, all these methods were developed based on studies of the non-Mexican population. As different results are obtained in different countries and regions, few validated studies have assessed Demirjian and Nolla methods among Mexican children. The relevant studies available evaluate methods individually [9, 10]; it is necessary to assess two methods to estimate dental age based on dental development in a sample of Mexican children.

2. Materials and methods

2.1 Sample selection

A cross-sectional and retrospective study was carried out using digital orthopantomography. 1080 orthopantomographs of children ages 4 to 15 years old were obtained from the Radiology and Imaging department of the Faculty of Stomatology, Meritorious Autonomous University of Puebla, Mexico. X-rays were taken from 2017 to 2022, and analyzed in 2023.

Inclusion criteria were orthopantomographs of healthy subjects with well-documented CA, with all teeth visible, no variation in teeth number, no impaction or abnormal persistence of deciduous teeth, no extracted or premature loss of deciduous teeth, no deciduous tooth root resorption caused by factors other than its permanent inheritance, no tooth abnormalities or pathologies, and no fixed orthodontic appliances. Orthopantomographs with the presence of seven permanent mandibular and maxillary teeth on the left side are evaluated. Exclusion criteria were orthopantomographs of subjects from other countries aged under, with systemic diseases, syndromes or alterations in dental development, permanent tooth extraction, and poor quality that did not allow the proper visualization of the development degree in lower left permanent teeth.

568 orthopantomographs (268 boys and 300 girls) aged 4 to 15 were included in the final study sample. All orthopantomographs of the subjects were obtained with the same radiographic equipment (PCH-2500 PaX-i, VATECH, Seogu-Dong, Hwaseong-Si, Gyeonggi-Do, Corea) and saved in JPEG format. All images were evaluated by two previously standardized investigators. Orthopantomographs were evaluated on one computer according to the minimum specifications for image display (avoid distortion, grayscale reproduction, luminescence, uniformity, high and low contrast resolution), and 10 orthopantomographs were evaluated each day in a dark room to avoid visual fatigue. Assessments were conducted double-blinded to avoid examiner bias when collecting data. CA and DA were calculated immediately.

2.2 Chronological age (CA)

CA was calculated by subtracting the birth date from the orthopantomograph date after converting to decimal age.

2.3 Dental age (DA)

DA was calculated according to dental development degree using Demirjian [6] and Nolla methods [8]. DA was subtracted from CA and a negative result indicates an overestimation and a positive result indicates an underestimation.

2.4 Demirjian method

It is based on the development of seven left permanent mandibular teeth which are classified on an 8-stage scale represented by the letter “A” through “H”. A statistical model assigns a specific score to each stage of the seven teeth. A conversion table is used to add up the scores from the seven teeth based on sex. Based on another standard table [6], the numerical scores are totaled, and the results corresponding to sex are converted to dental age, as shown in Fig. 1A.

2.5 Nolla method

Based on 0–10 graded stages for tooth development. Development of the seven left permanent mandibular and seven left permanent maxillary teeth were assessed and assigned a stage between 1 (no sign of calcification) and 10 (apical end completed). Based on Nolla’s recommendations, an appropriate fraction (0.2, 0.5 or 0.7) was added if the tooth was between stages. Calculated dental age is equivalent to summing Nolla scores. The sum of scores was compared to the average sum for males or females and dental age was calculated [8], as shown in Fig. 1B.

The scoring of the teeth on an orthopantomography according to Demirjian and Nolla methods are shown in Fig. 1.

2.6 Statistical analysis

Data analysis was performed using SPSS V22 (IBM, Chicago, IL, USA). Descriptive statistics were applied to calculate CA and DA, presenting as mean ± standard deviation. Differences between DA and CA were calculated for each method (a negative result indicated an overestimation and a positive result indicated an underestimation).

Cohen’s kappa coefficient determined inter- and intra-rater reliability. The Kolmogorov-Smirnov test was performed to check the normality of the data, which showed a nonparametric distribution. The Kruskal-Wallis H and Wilcoxon test was applied by age group and sex to compare the CA and DA of each method (Demirjian and Nolla). Spearman’s correlation coefficient was applied to assess the correlation between CA and DA of each method. All tests were performed at a 95% confidence level. $p < 0.05$ indicates statistically significant differences.

3. Results

Kappa values ranged from 0.95 to 1 (kappa > 0.95, good agreement). An average kappa of 0.95 for Demirjian method and 0.94 for Nolla method was recorded as the inter-examiner agreement scores. Intra-examiner agreement gave kappa values of 1.00 and 0.98 for Demirjian and Nolla, respectively for examiner Margarita Benites Hernández and kappa values of 0.98 and 0.97 for Demirjian and Nolla, respectively for exam-

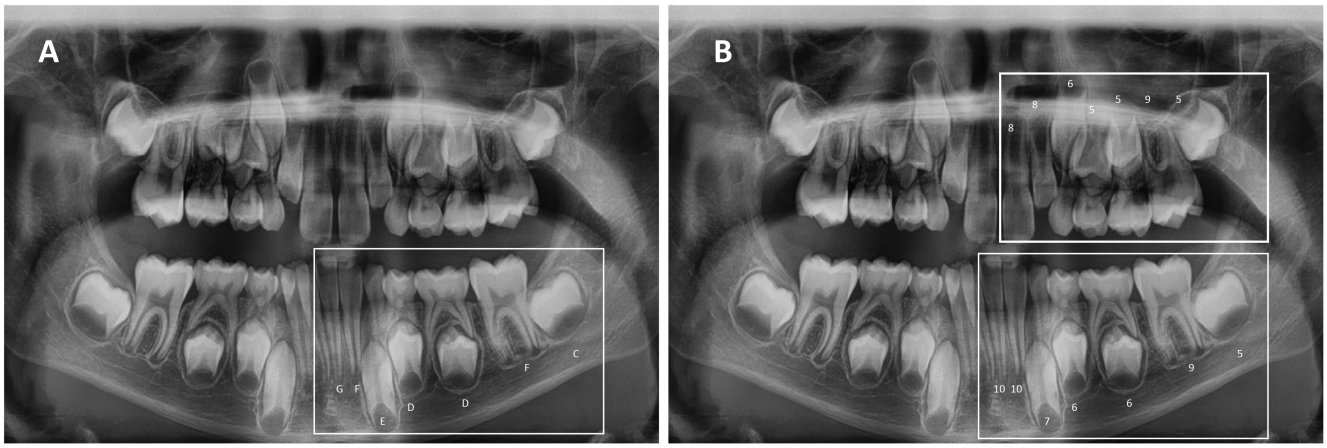

FIGURE 1. Dental Age assessment using (A) Demirjian scale represented by different letters depending on the stage and (B) Nolla method represented by different numbers depending on the stage.

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568 orthopantomographs (268 boys and 300 girls) aged 4 to 15 were included in the final study sample. The mean age was 10.1 years ± 2.6. The distribution by age group of the total sample and according to sex is shown in Table 1.

Comparison of differences between CA and DA calculated with Demirjian and Nolla methods according to different age groups (Tables 2 and 3). Differences were distributed non-parametrically in most age groups according to the Shapiro-Wilk test ($p < 0.05$). The Kruskal-Wallis H test showed significant differences between analyzed groups ($p < 0.001$). The total sample DA overestimation (0.8 ± 1.4) with Demirjian method and DA underestimation (0.4 ± 1.5) with Nolla method concerning CA (Wilcoxon test $p < 0.001$).

Using Demirjian and Nolla methods, we observed that the differences between CA and DA for sex were not significant (Table 4).

Spearman's correlation coefficient between CA and estimated DA demonstrated a significant correlation between Demirjian and Nolla methods ($p < 0.001$) (Table 5).

4. Discussion

There is a great deal of importance placed on age estimation in a variety of medical fields, such as orthodontics and pediatric dentistry, as it influences the appropriate time to begin different medical treatments. Further, in forensics, it is primarily required when determining the identity of individuals, however, there is no consensus on the best method to predict CA [11].

Calculating DA from tooth calcification degree observed in orthopantomographs is one of the most widely used methods to estimate CA, since it varies less than other properties associated with skeletal or sexual growth [12, 13]. This makes it an especially useful scientific technique for estimating chronological age in pediatrics, orthodontics, forensics, anthropology and criminal cases [12, 14].

Chronological age estimation is commonly performed using the Demirjian and Nolla methods. Demirjian method was chosen in this study because it is the most widely accepted estimation method for dental age estimation in children and adolescents. For this reason, this method has been widely applied to different populations [15]. Additionally, Nolla method has been less extensively used and tested in different populations, but it is used in clinical practice and teaching in orthodontic and pediatric dentistry [7].

Various studies have evaluated whether the principal methods used to estimate dental age can be applied to subjects with diverse ethnic, socioeconomic and environmental characteristics. These studies have mostly been conducted on European [7, 14, 16–18], Asian [19–21], African [22] and Oceanic [23] subjects. In Latin America, studies have been conducted on Hispanic children [11, 24–26].

Our results are consistent with most findings reported on DA calculation. In the case of Demirjian's method, we found that this method overestimates the CA as well as in other studied populations around the world [16, 27, 28], along with having the disadvantage of being unable to determine the exact age due to variations in biological rhythm in each individual [29]. In this study, DA is underestimated using the Nolla method, as reported by Brazilians [25] and Spanish [18].

This study demonstrated a contrast in dental age estimates between Demirjian and Nolla, with Demirjian overestimates while Nolla underestimates. This can be used to the variability of dental maturity between individuals; in addition, the ethnicity and genetics of the reference population can't be compared or represented by other populations; and that evaluation methods have limitations, such as evaluating permanent teeth that develop abnormally [10, 16].

The trend of the two methods was observed in different studies, and it remained similar. According to Paz Cortes *et al.* [7], a significant correlation was observed based on the Demirjian and Nolla methods. Correlation between CA and DA was strong linear Rho values range from 0.86 to 0.89 and are significant in all cases ($p < 0.001$). Also, Martínez-Gutiérrez & Ortega-Pertuz employed 512 orthopantomographs of 6–18-year-olds chronologically aged (CA) of both genders in Maracaibo, State of Zulia, Venezuela [26].

We obtained similar results. Because accuracy and results differ depending on the circumstances and conditions of each case. Moreover, many of the current standards are based on

TABLE 1. Subjects distribution by age and sex.

Chronological age (yr)	Total	Mean	SD	M	F
4–4.9	7	4.70	0.25	2	5
5–5.9	19	5.68	0.21	10	9
6–6.9	36	6.56	0.24	12	24
7–7.9	63	7.51	0.36	38	25
8–8.9	92	8.54	0.26	54	38
9–9.9	73	9.52	0.29	33	40
10–10.9	69	10.49	0.29	30	39
11–11.9	65	11.45	0.29	30	35
12–12.9	45	12.47	0.30	28	17
13–13.9	50	13.50	0.29	18	32
14–14.9	37	14.48	0.31	11	26
15–15.9	12	15.41	0.36	2	10
Total	568			268	300

Abbreviations: SD: standard deviation; M: total number of males; F: total number of females.

TABLE 2. Differences between chronological age and Demirjian dental age.

Age Group (yr)	CA with SD (in years)	DA with SD (in years)	CA-DA with SD (in years)	Trend	*p*-value
4–4.9	4.70 (0.25)	6.61 (2.57)	−1.91 (2.75)	O	
5–5.9	5.68 (0.21)	7.02 (0.74)	−1.34 (0.75)	O	
6–6.9	6.56 (0.24)	7.66 (0.76)	−1.10 (0.78)	O	
7–7.9	7.51 (0.36)	8.27 (1.12)	−0.76 (1.09)	O	
8–8.9	8.54 (0.26)	9.05 (1.13)	−0.51 (1.13)	O	
9–9.9	9.52 (0.29)	10.16 (1.44)	−0.64 (1.42)	O	
10–10.9	10.48 (0.29)	11.12 (1.50)	−0.64 (1.51)	O	<0.001
11–11.9	11.45 (0.29)	12.20 (1.64)	−0.75 (1.61)	O	
12–12.9	12.47 (0.30)	13.66 (1.88)	−1.19 (1.88)	O	
13–13.9	13.50 (0.29)	14.52 (1.52)	−1.02 (1.56)	O	
14–14.9	14.48 (0.31)	15.06 (1.33)	−0.58 (1.37)	O	
15–15.9	15.41 (0.36)	15.62 (1.30)	−0.21 (1.25)	O	
Total sample	10.10 (2.60)	10.90 (2.09)	−0.80 (1.40)	O	

Abbreviations: CA: Chronological age; DA: Dental Age; SD: Standard deviation; O: Overestimation.

previous generations that exhibit variations in tooth development. Furthermore, migration introduces potential genetic variability in the age at which certain tooth development stages are achieved that do not correspond to the modern population in the same geographical region.

Choosing the right age estimation methodology should be fundamental. One of them lies in the feasibility of extrapolating and applying proposals developed in specific populations to others of different backgrounds (in terms of estimation error). In this sense, some research has focused on the validation, recalibration or development specific conversion tables and curves for testing its reliability in different methodological proposals in children [7, 18, 27]. The adaptation of Demirjian and Nolla methods in our study population is therefore important, since the characteristics differ from those analyzed in the original and other studies [27].

Pediatric dentistry deals with children with skeletal and dental problems that need to be addressed at an early age. To establish an early orthopedic treatment, they determine their maturity level by estimating their DA at a certain time, correlating their CA, their growth, and their development [30]. For clinical purposes, it is also crucial to analyze and interpret dental development in children. For example, the comparison of dental X-rays with statistical tables designed for specific populations allows us to obtain ages and factors that may affect each individual's development [27].

In forensic odontology, CA of the subjects is crucial. This can be obtained in multiple ways; some are complex, expensive and time-consuming. DA calculation by orthopantomograph is simple and low-cost and concordant with CA, presenting variations by sex and race [13].

The American Academy of Pediatric Dentistry (AAPD) [31]

TABLE 3. Differences between chronological age and Nolla dental age.

Age Group (yr)	CA with SD (in years)	DA with SD (in years)	CA-DA with SD (in years)	Trend	*p*-value
4–4.9	4.70 (0.25)	5.43 (2.51)	−0.73 (2.72)	O	
5–5.9	5.68 (0.21)	5.21 (0.85)	0.47 (0.81)	U	
6–6.9	6.56 (0.24)	6.00 (1.24)	0.56 (1.23)	U	
7–7.9	7.51 (0.36)	7.14 (1.10)	0.37 (1.02)	U	
8–8.9	8.54 (0.26)	7.83 (1.01)	0.71 (0.98)	U	
9–9.9	9.52 (0.29)	8.88 (0.94)	0.64 (0.92)	U	
10–10.9	10.48 (0.29)	9.62 (1.40)	0.86 (1.37)	U	<0.001
11–11.9	11.45 (0.29)	10.74 (2.00)	0.71 (1.94)	U	
12–12.9	12.47 (0.30)	12.38 (2.26)	0.09 (2.27)	U	
13–13.9	13.50 (0.29)	13.78 (2.18)	−0.28 (2.16)	O	
14–14.9	14.48 (0.31)	14.78 (1.65)	−0.30 (1.65)	O	
15–15.9	15.41 (0.36)	15.67 (1.15)	−0.26 (1.10)	O	
Total sample	10.10 (2.60)	9.70 (3.20)	0.40 (1.50)	U	

Abbreviations: CA: Chronological age; DA: Dental age; SD: Standard deviation; O: Overestimation; U: Underestimation.

TABLE 4. Comparison of the differences between chronological age, dental age estimated by the Demirjian and Nolla methods with respect to sex.

	n	Sex		*p*-value
		Male (SD)	Female (SD)	
Chronological age	10.1 (2.6)	9.9 (2.4)	10.3 (2.7)	0.039*
Demirjian dental age	10.9 (2.9)	10.6 (2.7)	11.1 (3.0)	0.072
Nolla dental age	9.7 (3.2)	9.5 (2.8)	9.9 (3.5)	0.546

*Abbreviation: SD: Standard deviation. *$p < 0.05$.*

TABLE 5. Correlation among methods.

	Demirjian	Nolla
Chronological Age (n = 568)	0.88**	0.88**

***The correlation is significant at the 0.01 level (two-sided).*

and the American Society of Forensic Odontology [32], mentioned that dentists could contribute to human identification research with the protection of dental records, photographs, and dental radiographs by providing objective and impartial expert evidence to determine the age for proper identification of a person. Pediatric dentists can therefore retain all the information before and after dental treatment in the pediatric subject by using a digital clinical record. Specifically, radiographs that provide ante-mortem information.

In Mexico, following the recommendations suggested by the protocol for forensic treatment and identification, states that, when dealing with individual and collective graves and/or skeletonized corpses, multidisciplinary approaches must be taken, provided that resources allow it (archaeologist, anthropologist, doctor, dentist, radiologist, among others). Biological profiles, such as age estimation, through dental development, must be included in the expert report. Lamendin's method [33] was developed to estimate root development and root transparency based on DA estimation.

Although the Lamendin method is straightforward, it can only be applied to adults over 20 who have single-rooted teeth free of caries. This is because the hydroxyapatite crystal apposition process starts between the ages of 20 and 25, and it performs better and more accurately in people between the ages of 35 and 50. However, sex and ethnicity are not taken into account, which can significantly limit children [34].

We recruited a small number of subjects within the limitations for estimating the ages of subjects belonging to the youngest age (under 5 years), as radiographic examinations for dental purposes are not advisable for children under 6 years of age in accordance the ALADAIP precautionary principle (As Low As Diagnostically Achievable being Indication-oriented and Patient-specific). Therefore, it is essential to respect the radiological principle of patient-specific justification [35].

Another limitation was that pediatric subjects struggle to remain still during the orthopantomograph examination at an early age. Factors such as behavior can create distorted radiographic images and therefore an adequate interpretation cannot be performed.

Besides, each method presents its complexities and limi-

tations. In a number of studies, Demirjian's score has been evaluated in other populations, obtaining conflicting results and demonstrating a risk of age overestimation [16, 27, 28]. Consequently, it is necessary to conduct specific population reference studies based on the chronological differences in dental maturation among various children populations [7]. Thus, further research is required to examine the accuracy of Demirjian and Nolla methods in various ethnic groups within Mexico.

This study emphasized the use of a single calibrated orthopantomograph to avoid distortions or errors in the image, as well as the use of the appropriate technique when taking orthopantomographs due to its easy execution, the correct positioning of the pediatric subject, post-processing options, and obtaining a digital radiograph as opposed to a conventional one [13].

Dental development shows variability across populations when estimating dental age. Reference tables for estimating age are commonly based on Caucasian populations [6, 8]. This necessitates the creation of representative databases for estimating an individual's age with greater accuracy. There are few or no scientifically validated studies regarding Mexican children.

Therefore, it is suggested to continue researching different Mexican children populations to generate knowledge relevant for age estimation. We need to conduct further studies to determine chronological age based on the relationship between age and open apices measurement in tooth roots using Cameriere methodology, which has been shown to be suitable for dental age estimation in Mexican children [36]. In addition, explore associations between body mass index and dental age, inclusive with other auxiliaries in dental diagnosis, and developed reference tables for this population.

5. Conclusions

Demirjian method overestimates the DA of the Mexican children, while Nolla method underestimates it. Demirjian and Nolla methods differed in their means between CA and AD; therefore, neither one is completely accurate. A direct relationship existed between Demirjian and Nolla methods.

This study reveals the need for a specific dental age estimation method for Mexican children. Auxiliaries are essential for human identification in pediatric dental diagnosis.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

AUTHOR CONTRIBUTIONS

MBH, DFR, MRAPE, JLSB, GJL and MAMB—designed the research study. MBH, DFR, MRAPE, JLSB and MABM—performed the research. BTC, AFL and GJL—analyzed the data. MAMB, BTC, AFL and RJF—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted in conformity with the Declaration of Helsinki and was approved by the Research Ethics Committee, Faculty of Stomatology of the Meritorious Autonomous University of Puebla, Mexico (No. CIFE 2023191/from 22 February 2023). This is a non-experimental study. All data was obtained from the Radiology and imaging area. Informed consent was obtained from the parents of each pediatric subject before taking the orthopantomograph, under consent for clinical and research purposes.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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