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Dental Age Estimation by the Demirjian, Willems and AlQahtani methods in a Brazilian Population

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Abstract

Introduction: Methods for estimation of dental age are highly reliable and their application plays an important role in the forensic field. Nevertheless, controversies remain regarding the accuracy and applicability of these protocols in specific populations. Objective: Evaluate the accuracy and applicability of the dental age estimation methods recommended by Demirjian, Willems and AlQhatani. Methodology: Two calibrated examiners analyzed 330 panoramic radiographs of a Brazilian population of both sexes, with ages ranging from 6 to 16 years (n = 30), according to each method. The values of the estimated ages were compared with the chronological age (Wilcoxon's test: Demirjian and Willems; Pearson's Chi-square test: AlQahtani; $p<0.05$). Results: For the Demirjian method, the estimated age showed no difference concerning the chronological age for the 9- and 15-years groups ($p=0.758$ and $p=0.510$, respectively), with an overestimate rate up to 1.1 years and an influence due to sex. The Willems method did not show differences for the groups from 11- to 15-years ($p=0.5302$, $p=0.3622$, $p=0.9224$, $p=0.9426$ and $p=0.1024$, respectively), regardless of sex, with an overestimate rate of 0.8 years at maximum. For the AlQahtani method, the highest accuracy rates were found for the 6- and 7-years groups (50% and 57%, respectively), with an overestimate rate up to 0.6 years, without any influence due to sex. Conclusions: The dental age estimated by the Demirjian, Willems and AlQahtani methods in a sample of Brazilian children and adolescents showed excellent match with chronological age, with the Willems method showing the greatest precision in the sample as a whole.

Keywords: Age Determination by Teeth; Forensic Dentistry; Radiography; Panoramic.

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Introduction

The age of an individual can be measured in forensic situations to identify both skeletal remains and bodies in decomposition as well as in the civil field to assist in adoption processes, identification of underage offenders, immigration, asylum procedures, and other purposes.[1,2] Teeth have played a decisive role in cases of forensic investigation since they

are naturally preserved even after the disintegration of tissues and bones.[3] In addition, they have specific identifiable features, which means that each individual has teeth with unique morphological characteristics.[4]

Some authors consider that radiographic methods of age estimation are one of the safest and most reliable for attribution of chronological age since dental radiography is a non-destructive technique and teeth are less susceptible to nutritional, hormonal and pathological changes.[5] Among the various protocols used to measure estimated age, those based on the stages of dental mineralization are more reliable when compared to those that rely on bone development since they suffer less interference from factors such as sex, race, and systemic disease.[6,7] According to several authors,[8,9] the state of the art methods for estimating the dental age of children and adolescents are those of Demirjian and colleagues[10] and Willems and colleagues.[11]

Both the Demirjian and colleagues[10] and the Willems and colleagues[11] methods are based on the maturation stages of the seven left lower permanent teeth, although the Willems method is designed to minimize the estimated divergences of the Demirjian method by adapting statistical data. Despite being popular, the Demirjian method has usually presented age overestimations, while the Willems method has been considered to be the most accurate for the estimation of dental age of young individuals.[8,9,12,13] In addition, AlQahtani and colleagues[14] developed the "London Atlas of Human Tooth Development and Eruption" for age estimation, which uses both dental development and alveolar eruption for individuals from 30 weeks of intrauterine life to 23 years old. The number of analyses made using the AlQahtani method remains low.

Discrepancies in tooth mineralization stages have already been found when comparing populations with different racial features.[9,15-18] Cultural and ethnic differences among populations may explain the discrepancies observed in the estimated dental age and this fact has led to the introduction of new scores and classification criteria for specific populations.[7,9]

Therefore, this study aimed to evaluate the accuracy and applicability of the Demirjian, Willems and AlQahtani methods for estimation of dental age in a population of children and adolescents from the southeastern region of Brazil.

Methodology

Experimental design and sample characterization

This study received ethical approval from the Research Ethics Committee on Human Subjects (CAAE 69505017.8.0000.0064, UNICID, São Paulo-SP, Brazil). It consisted of a cross-sectional, blind observational study in which digital panoramic radiographs ("DVI Radiologia Odontológica" Radiology Clinic database, Ribeirão Preto-SP, Brazil) of children and adolescents with chronological age of 6 to 16 years, of both sexes, residing in the southeastern region of Brazil, were subjected to analysis.

Initially, a total of 352 radiographic images were selected, which comprised a sample number of 176 images for each sex. This selection was based on the statistical data from the study of Frítola and colleagues (2015), which used a sample size of 173 males (43%) and 225 females (57%). After applying exclusion criteria, a total of 330 images were used in the present study, with a sample number of 115 images for each sex, distributed into the 11 age analysis groups (n=15 for each sex, in each age group).

The images were selected according to the following inclusion criteria: digital panoramic radiographs of 6- to 16-year old boys and girls, from southeastern Brazil, taken between 2014 and 2017. The exclusion criteria were: images with low clarity, poor quality and/or distortions, without due record of chronological age or sex, with the presence of agenesis or dental extractions, facial trauma or any other type of anomaly or dental development syndromes (n=30; 11 groups).

Calibration of examiners and evaluation of radiographic images

The radiographic images were analyzed by two previously calibrated examiners, in a dark environment, using a 14-inch monitor, through a specific Windows® image visualization program (Microsoft Office 2010, Windows® 8). The inter- and intra-examiner calibration was calculated by the Intraclass Correlation Coefficient (ICC), using IBM SPSS Statistics v22 x64 for Windows® software, with a Cronbach alpha reliability model and a 95% confidence interval.

Calibration was performed for the three methods of age estimation by analysis of 11 panoramic radiographs that were not included in the sample number. Each examiner evaluated the same radiograph three times, with a 48-hour interval between each evaluation. For the intra-examiner analysis, the estimated dental age in each of the three evaluations was compared, while the estimates of dental age made by the two examiners were compared with each other for inter-examiner analysis.

Application of dental age estimation methods

Three methods of dental age estimation were applied, which are based on the analysis of mineralization and permanent teeth eruption: the Demirjian, Willems and AlQahtani methods.

The Demirjian and colleagues[10] method considers the maturation stages of the seven left lower permanent teeth, classified in categories from "A" to "H", which range from the beginning of the coronal crypt mineralization to the fully closed root apex. Subsequently, a numerical value is assigned to each tooth according to the maturation stage and differentiated by sex. These values are summed, resulting in a total “Maturity Score” value, which in turn, is converted to an estimated dental age.

The Willems and colleagues[11] method uses the same maturation stages "A" to "H". However, the process of estimating age is simplified by new statistical calculations. In this case, the “Maturity Score” table is no longer used. The values of the maturation stages for each tooth are summed and this final result is already the estimated age.

AlQahtani and colleagues[14] established “The London Atlas of Human Tooth Development and Eruption” method for estimation of age, which is based only on the maturation of the right side and involves the measurement of dental eruption in relation to the level of the alveolar ridge. The atlas is used for a direct comparison between the panoramic image and its respective compatible image in the atlas.

Radiographic images were blinded, and the digital image files were identified by number and sex. A maximum of 20 images per day were analyzed in order to avoid visual fatigue and a consequent impairment of the analysis.

Statistical analysis

For the Demirjian and Willems methods, agreement between the estimated ages and the chronological age was evaluated using the Wilcoxon non-parametric test (R Core Team 2017), considering the variable age without normal distribution (Kolmogorov-Smirnov). The comparison was performed by age group and sex. For AlQahtani method, the values of the estimated age interval were compared with the chronological age values for each group, and the accuracy rate of the method was measured. In order to evaluate the influence of sex on age estimation, Pearson's Chi-square (R Core Team 2017) was applied. The significance level was set at 5% in all the tests.

Results

The ICC values presented for intra-examiner 1 were 0.991, 0.991 and 1.000, for the Demirjian, Willems and AlQahtani methods, respectively. For intra-examiner 2, the values were 0.978, 0.978 and 1.000, for the same methods, respectively. The ICC values presented for the inter-examiner calibration were 0.993, 0.993 and 0.991, for the Demirjian, Willems and AlQahtani methods, respectively.

For the Demirjian method, when the mean of the estimated ages was compared with the chronological age of the individuals, the only groups that did not present a statistically significant difference for age correlation were 9- and 15-year groups (Wilcoxon test, p>0.05, Table 1).

Table 1. Mean (±s.d.) and median (±s.d.) values of the estimated age (in years), obtained by the Demirjian method, compared with the chronological age for each age group (n=30, 15 male and 15 female).

Age groups	Estimated age, mean	Chronological age, mean	Estimated age, median	Chronological age, median	p value
6 years	7.6 (±0.5)	6.5 (±0.3)	7.5 (±0.5)	6.5 (±0.3)	p=1.81 x 10-6
7 years	8.1 (±0.4)	7.4 (±0.3)	8.1 (±0.4)	7.5 (±0.3)	p=4.43 x 10-6
8 years	9.0 (±0.9)	8.4 (±0.3)	8.6 (±0.9)	8.4 (±0.3)	p=0.005
9 years	9.7 (±1.2)	9.4 (±0.3)	9.2 (±1.2)	9.5 (±0.3)	**p=0.758***
10 years	10.9 (±1.1)	10.5 (±0.3)	10.9 (±1.1)	10.4 (±0.3)	p=0.038
11 years	12.0 (±1.2)	11.5 (±0.3)	11.9 (±1.2)	11.6 (±0.3)	p=0.037
12 years	13.7 (±1.4)	12.5 (±0.3)	13.5 (±1.4)	12.5 (±0.3)	p=7.35 x 10-5
13 years	14.1 (±1.3)	13.5 (±0.3)	14.4 (±1.3)	13.5 (±0.3)	p=0.010
14 years	15.0 (±1.1)	14.5 (±0.3)	15.2 (±1.1)	14.5 (±0.3)	p=0.026
15 years	15.5 (±0.8)	15.4 (±0.3)	16.0 (±0.8)	15.5 (±0.3)	**p=0.510***
16 years	15.7 (±0.6)	16.4 (±0.3)	16.0 (±0.6)	16.4 (±0.3)	p=1.767 x 10-6

Legend: * Bold values with asterisks did not present significant statistical differences (Wilcoxon test, p>0.05).
Source: Comar LP (2023)

When data were analyzed in relation to the percentage of estimation of the method, an average overestimation rate smaller of up to 1.1 years was observed. Furthermore, the estimated and chronological age values were found to present significant differences for both male and female

individuals (Wilcoxon test, p=5.82×10-10 and p=2.82×10-5, respectively) when the sexes were evaluated separately.

The Willems method showed even greater precision than the Demirjian method (observational data) and was statistically accurate in estimating the age of the population in the 11-, 12-, 13-, 14-, and 15-year groups, regardless of sex (Wilcoxon test, p>0.05, Table 2).

Table 2. Mean (±s.d.) and median (± s.d.) values of the estimated age (in years), obtained by the Willems method, compared with the chronological age for each age group (n=30, 15 male and 15 female).

Age groups	Estimated age, mean	Chronological age, mean	Estimated age, median	Chronological age, median	p value
6 years	7.1 (±0.8)	6.5 (±0.3)	7.0 (±0.8)	6.5 (±0.3)	p=0.0003
7 years	8.0 (±0.6)	7.4 (±0.3)	8.1 (±0.6)	7.5 (±0.3)	p=0.00015
8 years	9.3 (±1.0)	8.4 (±0.3)	9.5 (±1.0)	8.4 (±0.3)	p=0.00017
9 years	9.8 (±0.9)	9.4 (±0.3)	9.7 (±0.9)	9.5 (±0.3)	p=0.0368
10 years	10.9 (±0.8)	10.5 (±0.3)	10.8 (±0.8)	10.4 (±0.3)	p=0.0060
11 years	11.5 (±0.8)	11.5 (±0.3)	11.7 (±0.8)	11.6 (±0.3)	**p=0.5302***
12 years	12.9 (±1.3)	12.5 (±0.3)	12.3 (±1.3)	12.5 (±0.3)	**p=0.3622***
13 years	13.5 (±0.9)	13.5 (±0.3)	13.6 (±0.9)	13.5 (±0.3)	**p=0.9224***
14 years	14.4 (±1.2)	14.5 (±0.3)	14.1 (±1.2)	14.5 (±0.3)	**p=0.9426 ***
15 years	15.1 (±1.1)	15.4 (±0.3)	15.8 (±1.1)	15.5 (±0.3)	**p=0.1024***
16 years	15.2 (±0.9)	16.4 (±0.3)	15.8 (±0.9)	16.4 (±0.3)	p=1.804 x 10-6

Legend: * Bold values with asterisks did not present significant statistical differences (Wilcoxon test, p>0.05).
Source: Comar LP (2023)

In relation to the percentage of estimation of the method, an average overestimate rate of up to 0.8 years was observed, with a statistically significant influence for both sexes (Wilcoxon test, p=0.0006 for males and p=0.5155 for females).

In the case of the AlQahtani method, comparisons were made between the mean interval of estimated age and the mean chronological age, with an accuracy rate that varied from 57% (7-year group) to 27% (15-year group), with the highest accuracy rate found in the cases of individuals aged 6 and 7 years (50% and 57%, respectively, Table 3).

In this method, an average overestimate rate of up to 0.4 years was observed, with no significant difference in relation to sex in general, except for the 16-year group, which presented a 60% accuracy for females, significantly differing from the 6.67% accuracy for males (Pearson's Chi-square, p=0.0067).

Table 3. Accuracy rate (%) of the estimated age interval compared to chronological age (in years), mean (±s.d.), by AlQahtani method, for each age group (n=30, 15 male and 15 female).

Age groups	Minimum estimated age, mean	Maximum estimated age, mean	Chronological age, mean	Accuracy % (n=30)*
6 years	6.4 (±0.8)	7.4 (±0.8)	6.5 (±0.3)	50.00%
7 years	7.2 (±0.8)	8.2 (±0.8)	7.4 (±0.3)	56.67%
8 years	8.5 (±1.0)	9.5 (±1.0)	8.4 (±0.3)	36.67%
9 years	9.3 (±1.0)	10.3 (±1.0)	9.4 (±0.3)	33.33%
10 years	10.5 (±1.0)	11.5 (±1.0)	10.5 (±0.3)	40.00%
11 years	11.0 (±1.0)	12.0 (±1.0)	11.5 (±0.3)	40.00%
12 years	12.3 (±1.1)	13.3 (±1.1)	12.5 (±0.3)	36.67%
13 years	13.5 (±0.9)	14.5 (±0.9)	13.5 (±0.3)	43.33%
14 years	14.4 (±1.1)	15.4 (±1.1)	14.5 (±0.3)	33.33%
15 years	15.0 (±1.2)	16.0 (±1.2)	15.4 (±0.3)	26.67%
16 years	15.8 (±0.8)	16.8 (±0.8)	16.4 (±0.3)	33.33%

Legend: * Simple correlation descriptive data (% of accuracy).
Source: Comar LP (2023)

Discussion

In recent years, the evaluation of the chronological age of individuals has grown in importance in the field Forensic Medicine, and tooth analysis has become a valuable diagnostic tool.[3] In Brazil, the age of 12 represents the legal transition between childhood and adolescence; the age of 14 stands for sexual consent, while 16 is the age for relative incapacity, in which individuals become capable of partially exercising their civil rights.[12,19]

The tooth is the most resistant tissue of the human body and can also withstand high temperatures; therefore, it can often be analyzed when all other tissues, including bones, have been destroyed.[3,20] So, teeth are extremely useful for estimating chronological age and are preferable to skeletal methods, because they are durable and resistant in archaeological contexts, and their development is less influenced by environmental factors than bone growth.[6,7]

Radiographic examination of the stages of development and mineralization of human dentition is one of the most common methods used for estimating age.[21,22] Such methods are non-destructive and provide accurate estimates for both living and dead individuals.[22]

The present study evaluated three methods of dental age estimation in which the stages of teeth mineralization and eruption were considered. In the Demirjian and Willems methods, the stages of mineralization of the seven left lower permanent teeth are evaluated, while the AlQahtani method presents an Atlas of Human Tooth Development and Eruption based on the development of teeth on the right side.

The methods were independently analyzed for accuracy and applicability. The Demirjian method was shown to be statistically accurate only for the 9- and 15-year groups, although the overestimation rates observed can generally be considered acceptable. The highest rates of age overestimation were observed in the 6-, 7-, 8- and 12-year groups, with a variation of up to 1.2 years.

The Willems method proved to be more accurate than the Demirjian one since this method shows no statistical differences in a larger population of individuals (11- to 15-year groups), as well as lower rates of overestimation (up to 0.8 years).

The results of the present study align with published data. Urzel and Bruzek[23] found consistent age overestimation rates for the Demirjian method and greater accuracy and reliability for the Willems method in a French population of children aged 4 to 15 years. Ye and colleagues[24] compared the Demirjian and Willems methods in Chinese children aged 7 to 14 years, and observed that the Demirjian method overestimated age by 1.68 years for boys and 1.28 for girls and that the Willems method showed greater precision, with an overestimation of 0.35 years for boys and underestimation of 0.02 years for girls.

Frítola and colleagues,[8] in a comparison of the Demirjian and Willems methods in a young Brazilian population, observed that the Demirjian method overestimated the chronological age by 0.65 years, whereas the Willems method did not present significant differences between estimated and chronological ages, and was therefore more accurate. Similarly, the Willems method also showed reliable results in a population in southern Brazil, confirming its efficacy and proving its applicability in the context of Brazilian forensics.[12]

In a study of German children aged 6 to 14, the Demirjian method showed overestimates for all ages, especially for boys.[25] After a systematic review and meta-analysis, Sehrawat and Singh[22] concluded that the Willems method provides comparatively lower overestimations in comparison with other methods for estimation of dental age and is accurate and reliable enough to be used for forensic purposes.

More recently, Chandail and colleagues[13] compared the Willems and Demirjian methods in an Indian population aged 7 to 14 years and found that the former showed a lower mean percentage error when compared to the results obtained from the Demirjian method. The authors concluded that the Willems method was an effective method of age estimation and was better and more accurate than the Demirjian technique.

For the AlQahtani method, high accuracy rates were observed in individuals up to 13 years old, with the highest accuracy percentages being observed in 6- and 7- year groups (50% and 57%, respectively) and an overestimate up to 0.6 years. Considering that 57% was the highest accuracy rate found, one might assume that this method presented a low accuracy rate for this specific population. However, few studies about AlQahtani method are available for comparison, especially in Brazilian populations, which may be due to the fact that it is relatively new (2010) and also because methods based on image comparisons can be considered less accurate in heterogeneous populations, such as those of Brazil.

AlQahtani and colleagues[26] observed that Schour & Massler, Ubelaker and the London Atlas underestimated ages in a study with skeletal samples aged up to 23 years, but that the London Atlas was the most accurate, with an underestimation of 0.10 years. These results differed from the present study; however, a comparison between the present study and

AlQahtani and colleagues[26] may be impractical since the current work evaluated a Brazilian population of children and adolescents. More recently, Willmann and colleagues[27] evaluated the accuracy of biological age determination in a multiethnic European sample using the Nolla, Demirjian, and the London Atlas (AlQahtani) methods. The authors observed that the most accurate methods were those of the London Atlas, which showed an average absolute deviation 1.2 years.

All three methods evaluated in the present study were shown to be applicable and presented estimated age results very close to the chronological age. The Demirjian and Willems methods may be preferable when gender differentiation is required and the Willems method demonstrated the greatest accuracy in this specific population. The present results agree with a recent review study, in which the authors demonstrated that the Demirjian, Willems and AlQahtani methods were found to be useful in an Indonesian population of children and adolescents, presenting greater accuracy than other methods.[28]

The search for precise methods to estimate the dental age of individuals in specific populations is also based on the importance of its applicability in the forensic context. Several forensic case reports have demonstrated the importance of applying an adequate and accurate method to estimate the dental age of individuals.[9,28-32]

All three protocols analyzed in the present study were considered easy to apply and no major difficulties were found during their application. The Willems method was considered by the examiners to be the simplest and the AlQahtani the most error-prone, despite the Atlas method being easy to analyse. For this reason, interval values of estimated age were adopted for this method.

One relevant limitation is the heterogeneity of the evaluated population since the individuals were not classified by race and origin since these data were inaccessible to the researchers. One should also bear in mind that the development of an individual can be influenced by several factors, which result in differences in the stages of tooth mineralization among individuals of different sex, biotypes and ethnicities.[20]

Therefore, further research with samples from other Brazilian regions and ethnicities should be conducted, with the aim of confirming the accuracy and applicability of the three methods in specific Brazilian populations. Forensic experts should not restrict themselves to a single method of analysis but should invest in the application of different available methods in order to reproduce, as far as possible, the available data and thus estimate more precisely the chronological age of individuals.

The estimates of dental age using the Demirjian, Willems and AlQahtani methods in a sample of Brazilian children and adolescents showed an excellent match with chronological age, with the Willems method showing the greatest precision in the sample as a whole.

Declaration of Interests

The authors declare they have no conflict of interest.

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References

1. Willems G. A review of the most commonly used dental age estimation techniques. J Forensic Odontostomatol; 2001; 19(1), 9-17.
2. Olze A, Reisinger W, Geserick G, Schmeling A. Age estimation of unaccompanied minors: Part II. Dental aspects. Forensic Sci. Int.; 2006; 159, S65-S67. DOI: 10.1016/j.forsciint.2006.02.018.
3. Hofmann E, Robold M, Proff P, Kirschneck C. Age assessment based on third molar mineralisation. J Orofac Orthop; 2017; 78(2). DOI: 10.1007/s00056-016-0063-z.
4. Meinl A, Huber CD, Tangl S, Gruber GM, Teschler-Nicola M, Watzek G. (2008). Comparison of the validity of three dental methods for the estimation of age at death. Forensic Sci. Int.; 2008; 178(2-3), 96-105. DOI: 10.1016/j.forsciint.2008.02.008.
5. Gruber J, Kameyama MM. The role of radiology in forensic dentistry. Brazil. Oral Res., 15, 263-268; 2001; DOI: 10.1590/S1517-74912001000300014.
6. Rai V, Saha S, Yadav G, Tripathi AM, Grover K. Dental and skeletal maturity-a biological indicator of chronologic age. J Clin. Diagn. Res.; 2014; 8(9), ZC60. 10.7860/JCDR/2014/10079.4862.
7. Kotecha, SD. Dental age estimation in children: A review. Forensic Res Criminol Int J; 2016; 3(1), 264-7.
8. Frítola M, Fujikawa AS, Morais FF, Franco A, Fernandes Â. Estimativa de idade dental em crianças e adolescentes brasileiros comparando os métodos de Demirjian e Willems. Rev Bras Odontoleg; 2015; 2(1). DOI: 10.21117/rbol.v2i1.18.
9. De Donno A, Angrisani C, Mele F, Introna F, Santoro V. Dental age estimation: Demirjian's versus the other methods in different populations. A literature review. Med, Sci and the Law, 61(1_suppl); 2021; 125-129. DOI: 10.1177/0025802420934253.
10. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Human biology; 1973; 211-227.
11. Willems G, Van Olmen A, Carels C, Spiessens B. Dental age estimation in Belgian children: Demirjian's technique revisited. J Forensic Sci; 2001; 46(4), 893-895.
12. Franco A, Thevissen P, Fieuws S, Souza PHC, Willems, G. Applicability of Willems model for dental age estimations in Brazilian children. Forensic Sci Int; 2013; 231(1-3), 401-e1. DOI: 10.1016/j.forsciint.2013.05.030.
13. Chandail K, Goyal V, Kaul M, Dutt S, Koul T, Misgar BA. Estimation of dental age using Willems method and comparing it with Demirjian's method in 7–14-year-old children of Uttarakhand. J Indian Soc Pedod Prev Dent; 2022; 40(1), 43-47. DOI: 10.4103/jisppd.jisppd_333_21
14. AlQahtani SJ, Hector MP, Liversidge HM. Brief communication: The London atlas of human tooth development and eruption. Am J Phys Anthropol; 2010; 142(3), 481-490. DOI: 10.1002/ajpa.21258.
15. Oliveira OFD, Fernandes MM, Daruge Júnior E, Melani RFH, Paranhos LR. Estimating age using panoramic radiographs. RGO. Rev Gaúcha de Odontol (Online); 2010; 58(2), 203-206.
16. Oliveira FT, Capelozza ALÁ, Lauris JRP, Bullen IRFR. Mineralization of mandibular third molars can estimate chronological age — Brazilian indices. Forensic Sci Internat; 2012; 219(1-3), 147-150. DOI: 10.1016/j.forsciint.2011.12.013.
17. Gundim ADC, Sousa AP, Silva JC, Oliveira RD, Yamamoto-Silva FP, Silva BSDF. Third molars stage of mineralization and its relation to chronological age: Midwest Brazil sample. Rev Odontol UNESP; 2014; 43, 294-298. DOI: 10.1590/rou.2014.047.
18. Tonin LO, Leite NLP, Galo R, Silva RHA. Age estimation based on the stage of mineralization of third molars on orthopantomograms. Biosci. J.(Online); 2016; 805-812.
19. Cidade R, Santos M, Alves TC, Bueno JM, Soares M, Arakelyan M, Junqueira JLC, Franco A. Radiographic dental age estimation applying and comparing Demirjian's seven (1973) and four (1976) teeth methods. Forensic Sci, Med Pathol; 2023; 1-9. DOI: 10.1007/s12024-022-00563-5.
20. Figueira Junior E, Moura LCLD. The importance of the dental arches in human identification. Revi Bras Odontolog; 2014; 71(1), 22-27.
21. Liversidge HM, Lyons F, Hector MP. The accuracy of three methods of age estimation using radiographic measurements of developing teeth. Forensic science international; 2003; 131(1), 22-29. DOI: 10.1016/S0379-0738(02)00373-0.
22. Sehrawat JS, Singh M. Willems method of dental age estimation in children: A systematic review and meta-analysis. J Forensic Leg Med; 2017; 52, 122-129. DOI: 10.1016/j.jflm.2017.08.017.
23. Urzel V, Bruzek J. Dental age assessment in children: a comparison of four methods in a recent French population. J Forensic Sci; 2013; 58(5), 1341-1347. DOI: 10.1111/1556-4029.12221.
24. Ye X, Jiang F, Sheng X, Huang H, Shen X. Dental age assessment in 7–14-year-old Chinese children: Comparison of Demirjian and Willems methods. Forensic Sci Internat; 2014; 244, 36-41. DOI: 10.1016/j.forsciint.2014.07.027.
25. Wolf TG, Briseño-Marroquín B, Callaway A, Patyna M, Müller VT, Willershausen I, Ehlers V, Willershausen B. Dental age assessment in 6-to 14-year old German children: comparison of Cameriere and Demirjian methods. BMC Oral Health; 2016; 16(1), 1-8. DOI: 10.1186/s12903-016-0315-8.
26. AlQahtani SJ, Hector MP, Liversidge HM. Accuracy of dental age estimation charts: Schour and Massler, Ubelaker and the London Atlas. Am J Phys Anthropol; 2014; 154(1), 70-78. DOI: 10.1002/ajpa.22473.
27. Willmann C, Fernandez De Grado G, Kolb C, Raul JS, Musset AM, Gros CI, Offner, D. Accuracy of Age Estimation

Using Three Dental Age Estimation Methods in a Young, Large, and Multiethnic Patient Sample. Dent J; 2023; 11(12), 288. DOI: 10.3390/dj11120288.

28. Kurniawan A, Chusida AN, Atika N, Gianosa TK, Solikhin MD, Margaretha MS, Margaretha MS, Utumo H, Marini MI, Rizky BN, Prakoeswa BFWR, Alias A, Marya A. The applicable dental age estimation methods for children and adolescents in Indonesia. Internat J Dent; 2022. DOI: 10.1155/2022/6761476.

29. Cornélio Neto WL, Conélio GC, Conceição MB. Estimate the age of the third molars through x-rays: relate case. Revista Gaúcha de Odontologia; 2006; 54(3), 230-233.

30. Silva RF, Marinho DEA, Botelho TL, Caria PHF, Bérzin F, Júnior ED. Determination of age by dental and wrist joint radiograph analyses: a forensic case report. Arq Odontol; 2008; 44(2), 45-50.

31. Silva RF, Mendes SDSC, Rosário Junior AF, Dias PEM, Martorell LB. Documental vs. biological evidence for age estimation–forensic case report. ROBRAC; 2013; 21(60), 6-10

32. Silva RF, Franco A, Dias PEM, Gonçalves AS, Paranhos LR. Interrelationship between forensic radiology and forensic odontology — A case report of identified skeletal remains. J Forensic Radiol Imag; 2013; 1(4), 201-206. DOI: 10.1016/j.jofri.2013.06.005.