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The Applicability of the Demirjian and Willems Standards to Age Estimation of 6–9-Year-Old Portuguese Children

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Abstract: This study evaluates the applicability of Demirjian and Willems' methods for age estimation in Portuguese children aged 6–9 years based on orthopantomographs (OPGs). The main objective was to compare the precision of both methods in estimating chronological age (CA). This study analyzed 160 OPGs, equally distributed by sex, and the dental age (DA) was calculated twice, using both methodologies. The findings reveal that Demirjian's method consistently overestimated the chronological age by an average of 1.47 years for males and 1.45 years for females. Similarly, the Willems method also overestimated the age but to a lesser extent, with mean differences of 1.18 years for males and 0.91 years for females. Statistical analysis confirmed that both methods significantly overestimate age, with the most considerable discrepancies observed in 8-year-old individuals. Despite the Willems method providing slightly more accurate results, neither method was reliable, particularly for male subjects. This study highlights the need for further refinement of these methods, considering their tendency to overestimate age, especially in specific age groups. This research improves age estimation techniques in forensic and clinical settings, especially within the Portuguese pediatric population.



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1. Introduction

Estimating age in forensic and clinical contexts is fundamental in cases involving unidentified individuals, legal disputes, or clinical scenarios, especially when minors are involved. These scenarios may include identifying unknown individuals, verifying age in legal disputes, or assessing eligibility for criminal responsibility, asylum claims, sports-related cases, or orthodontic treatment planning and pediatric dentistry (Yusof et al., 2017; Schmeling et al., 2016; Schmeling et al., 2005; Timme et al., 2017). Accurate age estimation is fundamental when no reliable birth records are available or when a child's biological age must be ascertained for medical, legal, or social reasons. This necessity underscores the critical role of age estimation in safeguarding children's rights and ensuring fairness in legal proceedings.

Dental age estimation, mainly using radiographic methods, is widely accepted as one of the most reliable approaches for assessing biological age due to the predictable development stages of teeth (Vila-Blanco et al., 2023). Dental age estimation is a favored method since dental development is less influenced by external factors like nutrition or illness, which can, and often do, affect other biological markers of age (Fins et al., 2017; Marques et al., 2015), than other methods based on sexual or skeletal development.

Demirjian's method has been one of the most frequently applied among the existing methodologies (Hegde et al., 2018). It assesses the development of the seven left mandibular permanent teeth to estimate age (Demirjian et al., 1973). This method has been widely used in various populations and is considered a standard in forensic odontology. However, several studies have demonstrated that this method regularly overestimates chronological age, leading to questions about its applicability across different populations (AlQahtani et al., 2010; Carneiro et al., 2015; Khorate et al., 2014; Mónico et al., 2022). Similar problems were mentioned in skeletal-based age estimates (Kellinghaus et al., 2010; Schmidt et al., 2007). This is problematic in legal contexts, as overestimation could lead to minors being misclassified as adults, with severe implications for their treatment in legal systems. The discrepancies observed have raised concerns about the method's generalizability across different populations, as it was initially developed based on data from a sample of French-Canadian children. Variability in dental development across ethnic, geographical, and environmental backgrounds has led researchers to explore alternative approaches or modifications to improve accuracy.

In response to these discrepancies, Willems et al. proposed a modified version of Demirjian's method to improve age estimation accuracy (Willems et al., 2001). In 2006, Maber et al. initiated the first comparison study on different dental age estimation methods, including Willems' (Maber et al., 2006). This was followed by a series of other studies replicating the use of multiple methods on specific populations (Galić et al., 2011; Grover et al., 2012; Kumaresan et al., 2016; Lee et al., 2011; Pinchi et al., 2012).

The Willems et al. modification has been tested in various populations, yielding varying results, which have sparked discussions about the influence of genetic, environmental, and geographical factors on dental development (Alrashidi et al., 2023; Balgi et al., 2020; Han et al., 2020; Lin et al., 2022; Ozveren & Serindere, 2018; Shivakumar et al., 2021). Several studies have shown that Willems' method reduces the extent of overestimation but does not eliminate it, particularly in male children (Cameriere et al., 2008; Cherian et al., 2020; Pan et al., 2021). Despite these advancements, considerable debate remains over which method offers the most accurate age estimates for different ethnic and regional populations, particularly among pediatric subjects (Chaudhry et al., 2020).

Genetic and environmental factors undoubtedly play a role in dental development, further complicating the search for a universally applicable method. For instance, studies in Indian and African populations have shown significant deviations from the original Demirjian standards, suggesting that population-specific calibrations might be required.

This study aims to assess the applicability and accuracy of both Demirjian's and Willems' methods in a Portuguese pediatric population. By comparing these methodologies, we seek to determine whether the Willems method offers more precise age estimations than Demirjian's, contributing to the ongoing debate regarding their efficacy. Forensic implications are considered, discussing systematic biases, how overestimation impacts legal decisions, and the necessity of population-specific models.

2. Materials and Methods

Orthopantomograms (OPGs) from 160 children attending the Faculty of Dental Medicine of the University of Porto clinical services were analyzed (IV and IMC). Children's ages

varied between 6 and 9 years (mean 7.5 years, standard deviation (SD) = 1.122). The sample's age distribution, divided by sex, is depicted in Table 1. No data regarding socio-cultural information were available, and all children were Portuguese, with Portuguese parents. All identifying data were removed from the OPGs before this study. This was a retrospective study, as the OPGs were not made for this investigation; rather, they already existed in the archive. A convenience sample was used, as this study was, as stated, retrospective, and OPGs are not abundant in these age groups. However, according to data from PORDATA (PORDATA, 2024), the age groups studied accounted for 235,000 people in 2021. This means that our sample of 160 individuals represented the population with a 95% confidence level and a margin of error of 7.74%.

Table 1. Sample's age distribution in years.

Age (In Years)	Male	Female	TOTAL
6	20	20	40
7	20	20	40
8	20	20	40
9	20	20	40
TOTAL	80	80	160

The inclusion criteria were as follows: OPGs belonging to children aged between 6 and 9 years old, Portuguese, with Portuguese parents, with at least one intact mandibular permanent central incisor, lateral incisor, canine, first premolar, second premolar, first molar, and second molar.

OPGs showing gross pathology or low image quality were excluded. Children with systemic diseases that can affect the development of teeth, mandibular hypodontia (except third molars), and those who had lost their teeth on both sides of the mandible were excluded. Also, children aged 10 years and above or 5 and lower were excluded.

Each OPG was classified using the stages defined by Demirjian et al. (Figure 1), and age was calculated first using the Demirjian methodology and then the Willems methodology. Both methodologies are described below.

Using radiographs, the Demirjian method classifies the seven left mandibular permanent teeth (teeth on the left side of the lower jaw). These stages, A to H (Figure 1), represent tooth formation and development stages. Each tooth maturation stage is classified and converted to a specific numerical score. The scores vary depending on the child's sex, as the development rates differ between males and females (Demirjian et al., 1973). The scores for each stage are listed in tables provided by Demirjian et al., with separate tables for males and females (Demirjian et al., 1973). After assigning a numerical score to each tooth based on its developmental stage, the scores for all seven left mandibular permanent teeth are added. This total score is the child's dental maturity score, which is converted to an estimated age using the tables provided by Demirjian. Separate tables are available for males and females, as dental development occurs at different rates.

The Willems method is like Demirjian's but uses revised scoring values to improve the accuracy of age estimation. Like the Demirjian method, an OPG is required, which should display the seven left mandibular permanent teeth. Like Demirjian's method, the Willems method also assigns each tooth to one of eight developmental stages, labeled A to H, based on radiographic appearance. The key modification is using revised score values for each developmental stage (A to H). These revised values are based on studies conducted by Willems et al. to make the scores more accurate for different populations.

The scores are sex-specific, with varying values for males and females, and there is a direct correspondence with age (rather than calculating a dental maturity score) (Tables 2 and 3).

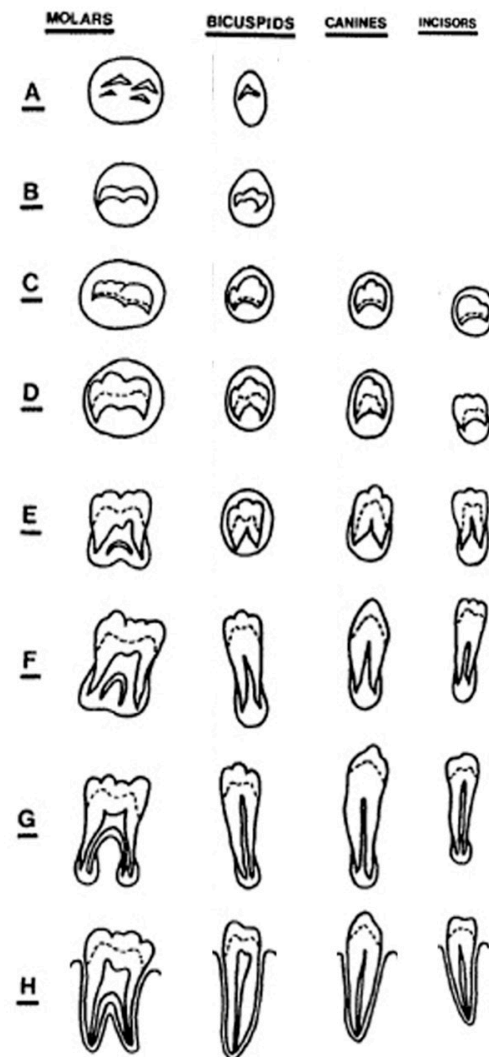


Figure 1. Mineralization stages defined by Demirjian et al. (adapted from [Demirjian et al., 1973](#)).

Table 2. Developmental tooth stages according to Demirjian’s technique with corresponding age scores expressed directly in years for each of the seven left mandibular permanent teeth in males, according to Willems’ method (adapted from [Willems et al., 2001](#)).

Tooth	31	32	33	34	35	36	37	Mean
Central incisor	—	—	1.68	1.49	1.5	1.86	2.07	2.19
Lateral incisor	—	—	0.55	0.63	0.74	1.08	1.32	1.64
Canine	—	—	—	0.04	0.31	0.47	1.09	1.9
First bicuspid	0.15	0.56	0.75	1.11	1.48	2.03	2.43	2.83
Second bicuspid	0.08	0.05	0.12	0.27	0.33	0.45	0.4	1.15
First molar	—	—	—	0.69	1.14	1.6	1.95	2.15
Second molar	0.18	0.48	0.71	0.8	1.31	2	2.48	4.17

Table 3. Developmental tooth stages according to Demirjian’s technique with corresponding age scores expressed directly in years for each of the seven left mandibular permanent teeth in females, according to Willems’ method (adapted from [Willems et al., 2001](#)).

Tooth	31	32	33	34	35	36	37	Mean
Central incisor	—	—	1.83	2.19	2.34	2.82	3.19	3.14
Lateral incisor	—	—	—	0.29	0.32	0.49	0.79	0.7
Canine	—	—	0.6	0.54	0.62	1.08	1.72	2
First bicuspid	−0.95	−0.15	0.16	0.41	0.6	1.27	1.58	2.19
Second bicuspid	−0.19	0.01	0.27	0.17	0.35	0.35	0.55	1.51
First molar	—	—	—	0.69	0.9	1.56	1.82	2.21
Second molar	0.14	0.11	0.21	0.32	0.66	1.28	2.09	4.04

For assessing reproducibility and repeatability, a group of 32 randomly selected OPGs was analyzed twice by an observer within a week interval (IV), and the same 32 OPGs were analyzed by two observers (IV and IMC). Kappa statistics were used to test intra-observer and inter-observer agreement.

Kappa values of the intra-observer agreement for the stages of dental mineralization of the randomly selected OPGs varied from 0.74 for the first molars to 0.90 for the lateral incisor. In contrast, the inter-observer agreement of the same sample ranged from 0.72 for the first molars to 0.88 for the first premolar (Table 4). Kappa values provided the thresholds to indicate what constitutes good agreement.

Table 4. Intra- and inter-observer agreement on the classification of the stages of tooth mineralization (Kappa values).

Tooth	31	32	33	34	35	36	37	Mean
Intra-observer	0.88	0.90	0.87	0.86	0.82	0.74	0.87	0.85
Inter-observer	0.82	0.78	0.82	0.88	0.80	0.72	0.82	0.81

Statistical analysis was performed using SPSS (Social Package for Social Sciences) software, version 26.0. Descriptive analysis was performed, studying the association between dental age and chronological age using both methods, using the Pearson’s chi-square test. The difference between the chronological age (CA) and the dental age (DA) estimated using each method was assessed using the paired samples *t*-test to assess mean age accuracy. The level of significance was set at 5%.

3. Results

The Demirjian method consistently overestimated the age of children of both sexes. The mean overestimation for males was 1.47 years (standard deviation (SD) = 0.86), and for females, it was 1.45 years (SD = 0.80) (Table 5). The differences between DA and CA were statistically significant for both sexes ($p < 0.05$).

The Willems method also led to an overestimation of the chronological age, but the degree of overestimation was less pronounced than that of the Demirjian method. The mean overestimation for males was 1.18 years (SD = 0.84), and for females, it was 0.91 years (SD = 0.75) (Table 6). These differences were also statistically significant ($p < 0.05$).

Table 5. Difference between dental age (DA) and chronological age (CA) estimated using the Demirjian method, in years (SD—standard deviation).

Sex	Mean DA-CA Difference	SD	Minimum	Maximum	<i>p</i> Value
Male	1.47	0.86	−0.40	3.30	<0.001
Female	1.45	0.80	−0.30	3.90	<0.001

Table 6. Difference between dental age (DA) and chronological age (CA) estimated using the Willems method, in years (SD—standard deviation).

Sex	Mean DA-CA Difference	SD	Minimum	Maximum	<i>p</i> Value
Male	1.18	0.84	−0.70	2.95	<0.001
Female	0.91	0.75	−0.65	2.83	<0.001

Further analysis was conducted to evaluate the accuracy of both methods across different age groups. The most considerable discrepancies between chronological age and estimated age occurred in the 8-year-old group for both sexes. Both methods tended to overestimate age more in males than females, with Willems providing slightly more accurate estimations overall (Table 7).

Table 7. Mean differences between dental age and chronological age, by age group, using Demirjian’s and Willems’ methods (in years).

Age Group	Method	Sex	Mean Difference	Standard Deviation (SD)	<i>p</i> Value
6 years	Demirjian	Male	1.63	0.80	<0.001
		Female	1.65	0.75	<0.001
	Willems	Male	1.18	0.60	<0.001
		Female	1.05	0.70	<0.001
7 years	Demirjian	Male	1.23	0.59	<0.001
		Female	1.20	0.68	<0.001
	Willems	Male	1.01	0.71	<0.001
		Female	0.93	0.90	<0.001
8 years	Demirjian	Male	1.66	1.04	<0.001
		Female	1.33	0.94	<0.001
	Willems	Male	1.39	0.89	<0.001
		Female	0.72	0.72	<0.001
9 years	Demirjian	Male	1.37	1.20	<0.001
		Female	1.65	0.78	<0.001
	Willems	Male	1.15	1.10	<0.001
		Female	0.93	0.68	<0.001

4. Discussion

Willems et al. (2001) proposed specific modifications to Demirjian’s method. These modifications were primarily based on re-evaluating and adjusting the scoring system to convert dental development stages into age estimates. The fundamental changes were as follows:

- (1) Revised scoring system, reviewing the numerical scores assigned to each of the eight developmental stages (A to H) for each of the seven left permanent mandibular teeth. The original Demirjian scoring system was based on a Canadian population, and it tended to overestimate the age of children in other populations. Willems et al. recalculated the scores based on a Belgian population sample to improve the method’s

accuracy across a broader range of populations by using data from more modern populations and addressing the secular trend bias arising from changes in developmental timing in modern populations (Cardoso et al., 2010; Heuzé & Cardoso, 2008; Vucic et al., 2014). The new scoring system assigned different numerical values to each developmental stage for both males and females to provide a closer approximation of chronological age.

- (2) Utilization of population-specific values, as the scores proposed by Willems et al. were derived from a European population (Belgium), which addressed some of the discrepancies observed when applying Demirjian's method to other groups. By recalibrating the scores, Willems aimed to correct for the overestimation that was often seen in non-Canadian populations. This recalibration made the method more suitable for use in other regions and ethnic groups, namely in Europe and other parts of the world, as the method, as explained before, collects data from more modern populations. Moreover, results from other studies refer to the multiple efficacy studies of Willems worldwide (Esan et al., 2017; Yusof et al., 2017).
- (3) Sex-specific adjustments: Despite the distinction between males and females being present in Demirjian's method, specific adjustments to the scores for each sex were made. This was important because dental development rates differ between males and females, with tooth development in males generally occurring later than in females. The adjusted scores allowed for a more accurate estimation of age based on sex-specific dental maturation patterns.
- (4) No additional stages, allowing a direct estimate without conversion of a dental maturity score, and thus simplifying the technique.

Both methods consistently overestimated chronological age, with the Willems method yielding slightly more accurate results than Demirjian's. The overestimation was most pronounced in 8-year-olds and males, consistent with findings from other populations (Alqerban et al., 2021; Alrashidi et al., 2023; Balgi et al., 2020; Brkić et al., 2022; Chaudhry et al., 2020; Cherian et al., 2020). While this bias is evident, it is not necessarily systematic across all populations (Esan et al., 2017), reinforcing the need for localized calibration of forensic age estimation models. Overestimating age can have significant consequences in forensic settings, particularly in legal cases involving minors. Incorrect classification as an adult can affect criminal responsibility, asylum status, and eligibility for protective services (Schmeling et al., 2016). However, studies documenting specific legal cases affected by age overestimation remain limited (Schmeling et al., 2011), highlighting the need for further research.

While precision in forensic techniques is desirable, it is unrealistic to expect absolute accuracy (Page et al., 2011). Instead, forensic applications should account for known biases and establish error margins that courts and policymakers can consider in legal proceedings (Schmeling et al., 2011). Our findings suggest that systematic adjustments could mitigate errors, ensuring a more reliable application of these methods in legal contexts.

Given that the Willems method reduces but does not eliminate overestimation (Bagattoni et al., 2019; Stamm et al., 2022; Moca et al., 2022), an important question is whether further refinement is necessary or if existing error margins are acceptable within forensic practice. If forensic experts can systematically account for predictable overestimation errors, the methods may already be sufficiently reliable. Future research should focus on refining adjustments rather than seeking unattainable absolute precision.

The overestimation of age in male subjects observed in this study is consistent with findings in other populations (Esan et al., 2017), suggesting that sex-specific factors in dental development may not be fully accounted for in either method. Studies have shown that males often exhibit more variability in dental maturation compared to females, which

can lead to more critical errors in age estimation ([Marconi et al., 2022](#)). This variability may be influenced by hormonal changes and growth spurts during adolescence, further complicating the application of generalized methods for age estimation ([Soliman et al., 2014](#)).

Additionally, the greatest discrepancies between chronological age and estimated dental age were observed in the 8-year-old group. This is likely due to the increased variability in dental development during this age range, a period marked by significant biological changes. Similar discrepancies were reported in another study of Portuguese children, where age overestimations were also most pronounced around this age ([Kellinghaus et al., 2010](#)). These findings emphasize the need for dental age estimation methods that account for the developmental variability during crucial growth periods ([Lee et al., 2011](#)).

As for the value of both methods for the Portuguese population, given that the Demirjian method shows significant overestimation (mean of ~1.47 years for males and 1.45 years for females) and the Willems method reduces this overestimation (mean of ~1.18 years for males and 0.91 years for females), offering greater precision, one may conclude that Demirjian's general applicability may not cater well to Portuguese children due to the genetic and environmental differences from the original study population. Conversely, the Willems method incorporates recalibrated values, making it more adaptable to Portuguese children while still requiring further refinement.

Several limitations of this study should be considered. Firstly, while the sample size was adequate for the purposes of this study, it may not fully represent the diversity within the Portuguese population. This analysis did not include factors such as socio-economic status, nutrition, and regional differences, which can influence dental development. In fact, although dental development is generally considered less influenced by external factors compared to other markers, such as bone development, it is not entirely immune to environmental influences. One significant factor that can alter dental development is nutrition, as adequate nutrition is critical during the growth and development phases of an individual, and obesity also seems to be linked with a faster dental development ([Gunjalli et al., 2014](#); [Hilgers et al., 2006](#)). Concerns about the socio-economic status influence on tooth development also exist ([Carneiro et al., 2017](#)). This study did not account for other potential environmental and lifestyle factors that could influence dental maturation, such as access to healthcare and fluoride exposure. These factors may contribute to variations in dental development, which could further impact the accuracy of age estimation methods ([De Abreu et al., 2021](#)). Future research should consider these influences to create more comprehensive models for age estimation.

Another limitation is the reliance on manual scoring for assessing dental maturity stages, which can introduce observer bias. Although intra- and inter-observer reliability in this study were high, manual assessments inherently carry a degree of subjectivity, as noted by various authors ([Pillai et al., 2021](#)). Automating this process using artificial intelligence (AI) and machine learning algorithms could reduce observer-related variability and improve the consistency and objectivity of age estimates ([Khanagar et al., 2024](#)). Recent advancements in AI-based dental age estimation have shown promise in improving accuracy by reducing human error ([Mohammad et al., 2024](#)). Future studies should explore these technologies to enhance the reliability of age estimation methods.

As for implications for the future, the findings of this study suggest that generalized methods like Demirjian's may not be fully suitable for forensic use across diverse populations. While the Willems method demonstrated improved accuracy, particularly in female subjects, it still overestimated age in males and certain age groups. These results underscore the importance of developing population-specific standards and refining existing models to reflect regional and sex-specific differences in dental maturation. This

has significant implications for both forensic and clinical applications, where the accurate estimation of age is essential. In fact, a central challenge in forensic age estimation is applying population-specific data. While both Demirjian's and Willems' methods were developed based on European samples, they do not universally translate across all ethnic backgrounds. This issue is particularly relevant when estimating age for individuals whose ancestry differs from the reference population. For instance, estimating the age of a person found in Portugal but not originally from Portugal remains a forensic challenge that extends beyond dental age estimation.

5. Conclusions

This study confirms that both the Demirjian and Willems methods tend to overestimate age in Portuguese children, with the Willems method providing more accurate estimates, particularly for females. However, the overestimation is not necessarily systematic, and forensic applications should focus on accounting for these biases rather than expecting perfect precision. Addressing these issues through population-specific calibrations and improved legal frameworks will enhance the reliability of forensic age estimation in real-world applications.

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Informed Consent Statement: Patient consent was waived due to this study's retrospective nature and because patients could not be identified.

Data Availability Statement: Data regarding this research are available upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

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