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Forensic Dental Age Estimation of North Indian Children Using Three Radiological Scoring Methods

تقدير الطب الشرعي للعمر السني لدى أطفال شمال الهند باستخدام ثلاث طرق للتقييم الإشعاعي

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Abstract

Although believed to be reliable in children, dental age estimations have reportedly shown variations in their accuracy levels, indicating regional differences. The present paper aims to study the error threshold of the Nolla, Demirjian and Willems methods for age estimation of North Indian children.

Digital orthopantomograms of 168 children aged 3-15 years were analyzed for the three methods. Demirjian dental age was found to be closest to the mean chronological age, as indicated by the p-value of paired t-test. The error range for the Willems and Demirijian methods was ±5 years with 87.5% of cases showing error within the range of ±2 years, and it was ±6 years with 84.5% of cases showing error within ±2 years using the Nolla method. The mean absolute error for the Nolla, Demirjian and Willems methods was 1.09, 1.10 and 0.97 years, respectively.

The Willems method was better suited for dental age estimation of the studied population, though none of the methods precisely estimated the age of the partici-

Keywords: Forensic Science, Forensic Medicine, Odontology, Age estimation, North Indian, Radiological Scoring.

المستخلص

على الرغم من الاعتقاد بأن تقدير العمر السني لدى الأطفال هو تقدير موثوق به، فقد أظهر اختلافات في مستويات الدقة وهو ما يشير إلى وجود اختلافات إقليمية. يتمثل الهدف من هذه الورقة العلمية في دراسة حدود الخطأ في طرق نولا (Nolla)، وديميرجيان (Demirjian)، وويليمس (Willems) المُستخدمة لتقدير العمر لدى أطفال شمال الهند.

تم إجراء تحليل لصور شعاعية بانورامية رقمية للأسنان لدى 168 طفلًا تتراوح أعمارهم بين 3 - 15 سنة ليتم استخدامها في الطرق الثلاث المذكورة. وقد تبين أن تقدير العمر السني بطريقة ديميرجيان (Demirjian) هو الأقرب إلى متوسط العمر الزمني، كما اتضح من قيمة (P) في اختبار (paired t-test). وبلغ نطاق الخطأ في طريقتي ويليمس (Willems) وديميرجيان (Demirjian) ±5 سنوات في 87.5٪ من الحالات التي أظهرت خطأ في نطاق ±2 سنة، في حين بلغ نطاق الخطأ ±6 سنوات في 84.5٪ من الحالات التي أظهرت خطأ في نطاق ±2 سنة باستخدام طريقة نولا (Nolla). وبلغ متوسط الخطأ المطلق في الطرق الثلاث نولا (Nolla) وديميرجيان (Demirjian) وويليمس 1.09 (Willems)و1.10 و 0.97 سنة على التوالي.

كانت طريقة ويليمس (Willems) هي الطريقة الأكثر ملاءمة لتقدير العمر السني لمجتمع الدراسة، على الرغم من عدم تمكن أي من الطرق الثلاث من تقدير أعمار المشاركين في الدراسة بدقة. قد تُعزى

الكلمات المفتاحية: علوم الأدلة الجنائية، الطب الشرعي، طب الأسنان الشرعي، تقدير العمر، شمال الهند، التقييم الإشعاعي.

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pants. Wide variations in age estimates of varied population groups may be due to differences in statistical methods or genetic factors. Thus, comparison of the methods for different populations by the same researcher is suggested to reduce certain biasness (statistical methodology) in the study.

الاختلافات الكبيرة في التقديرات العمرية لمجموعات سكانية متنوعة إلى الاختلافات في الأساليب الإحصائية المُستخدمة أو إلى نواحٍ ذات علاقة بالسكان. وبالتالي، فإنه يُقترح مقارنة الطرق الثلاث المذكورة على مجموعات سكانية مختلفة بواسطة نفس الباحث؛ وذلك من أجل الحد من وجود قدر معين من التحيز في نتائج الدراسة.

1. Introduction

Age estimation is a vital element in the biological profiling of an individual, living or deceased. It is also an important component to be considered while analyzing other aspects such as sex, stature, nutrition, etc. Other than in identification, the age of a child holds importance in scenarios involving legally establishing the person as a minor or adult for certain criminal/civil cases, child trafficking, pornography, immigration, adoption, etc. The age estimation methods for children are considered to be more accurate than those for adults, since the former are based on the continuous development or growth occurring in the child at an almost defined rate. The biological markers mostly utilized for this purpose are bones and dentition; the development of all these is divided into different stages. The skeletal development processes such as diaphyseal growth and epiphyseal union of long bones are utilized for assessing age in a child but are less reliable, as they are easily susceptible to genetics, environmental and external factors such as nutrition, activity level, and diseases, to name a few [1]. Teeth are believed to be better suited than bones due to their tolerance to destruction and degradation and comparative resistance to the earlier discussed environmental and external factors. Thus, with lesser variability in development, they are considered to be more accurate for age estimation [2]. Various useful techniques in assessing age through teeth are dental morphology (teeth emergence), histology (Gustafson method), radiological (atlas methods, Nolla, Demirjian, etc.) and chemical methods (aspartic acid racemization, carbon dating, telomere methylation, etc.) [3]. Radiological methods are more widely used due to their non-invasive nature, which is suitable for living as well as deceased persons. In the past few decades, orthopantomograms (OPTs) have gained importance in forensic odontology, since they provide a composite view of the upper and lower jaws, making it easier to assess the overall dental growth. Consequently, different radiology-based dental development methods have been proposed or formulated till now such as the Schour and Massler, Nolla, Morrees, Haaviko, Demirjian, Willems, Cameriere, and London atlas methods however, the results have been found to be variable [3].

The objective of this study was to assess dental age using the Nolla, Demirjian and Willems methods and to study their applicability in a North Indian population. It also aimed to explore the underlying reasons for the variations in the results.

2. Materials and Methods

2.1 Materials

168 digital OPTs of children (59 girls and 109 boys) aged 3-16 years were collected from an oral health centre belonging to the North Indian region comprising Himachal Pradesh, Punjab, Haryana and Chandigarh (UT) (Table-1). Ethical clearance was obtained from the Institutional Ethics Committee (IEC/2018/148), prior to the sample collection. Written consent of the guardians accompanying the minors was taken for OPT collection along-with the essential demographic details, as per the standards of the Declaration of Helsinki. The participants in-

Table 1- *Descriptive analysis of the chronological and dental ages.*

CA/DA	Mean±SD	Minimum	Maximum	SEM	Skewness	Kurtosis
CA	9.99±3.26	3.90	15.98	0.25	- 0.006	- 0.953
NollaDA	9.32±3.11	3.00	16.00	0.24	0.325	- 0.442
DemDA	9.94±3.05	3.20	16.00	0.24	0.255	- 0.711
WillDA	9.65±3.09	3.55	16.03	0.24	0.099	- 0.600

cluded the patients who visited the oral health centre on their own accord as part of routine checkup or treatment.

Exclusion criteria: Teeth were excluded from the study if they were extracted or missing bilaterally, treated, affected by trauma, restored, badly rotated, and if they showed a high degree of attrition or abnormal dentition. Also, the unclear, blurred OPTs were excluded from the study.

A Planmeca Promax panoramic machine (Planmeca Oy, Asentajankatu Flensinki, Finland), with image magnification 1.3, was used to take the digital OPTs, and these were saved as high resolution images in JPEG standard format. The personal identification details (other than sex) were obscured and were replaced with random serial numbers to avoid bias. The images were imported to the ImageJ software (ImageJ 1.46r Wayne Rasband, National Institutes of Health, USA), and its tools were used to make the image magnified or sharper where required. For standardized analysis, permanent teeth (except 3rd molar) of the left side of the mandible were selected for all the methods.

2.2 Methods

2.2.1 The Nolla method [7]

For this method, the development stages of the 7 permanent teeth of each OPT were identified and numbered as per the method. These stages ranged from the development of crypt to the completion of root development. For a tooth showing development between the two designated stages, a value of 0.5 was added to its lower stage. In a similar manner, values of 0.2 and 0.7 were added to the lower stage value in case the tooth exhibited slightly more development than the lower stage or slightly less development than the upper stage, respectively (Figure-1). The numbers in the figure indicates the development stage of tooth as per the method. These stage values for all 7 teeth were then added and the sum was tallied with the sex-specific tables given by Nolla to obtain the dental age.

2.2.2 The Demirjian method [10]

The 7 permanent teeth were examined in each OPT, and the stage for each tooth was determined as described in the Demirjian method, which shows 8 stages (A-H) from calcification initiation to tooth development completion. The corresponding value for each stage was noted from the given sex-specific tables and those were summed up for all seven teeth (Figure-2). The numbers in the figure indicates the development stage of tooth as per the method. The calculated maturity score was tallied against the sex-specific tables to obtain dental age.

2.2.3 The Willems method [11]

This method is a variation of the Demirjian method. Therefore, as in the Demirjian method, the seven mandibular permanent teeth were staged ranging from A to H. Each stage had a certain value in sex-specific tables for the Willems method (Figure-3). The numbers in the figure indicates the de-

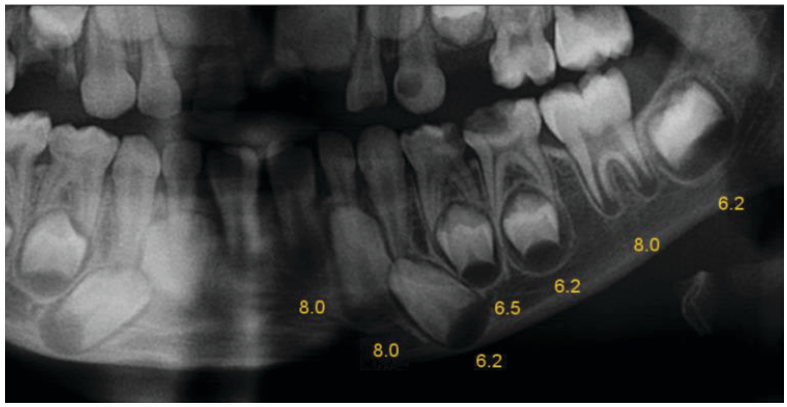

Figure 1- *OPT showing teeth rated as per Nolla stages.*

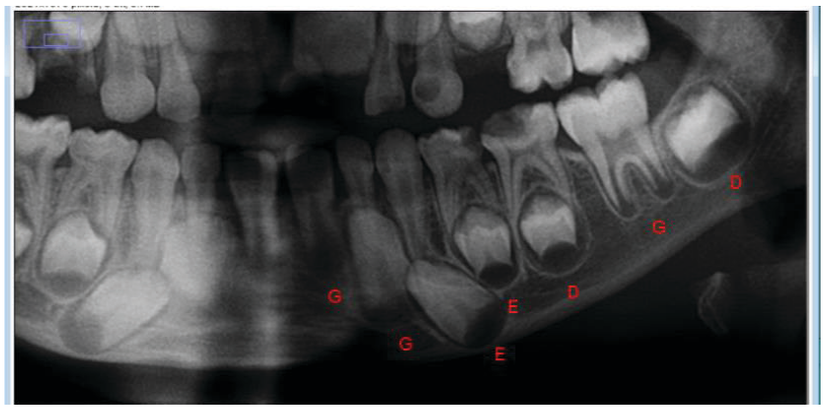

Figure 2- *OPT showing left mandibular permanent teeth at different Demirjian stages.*

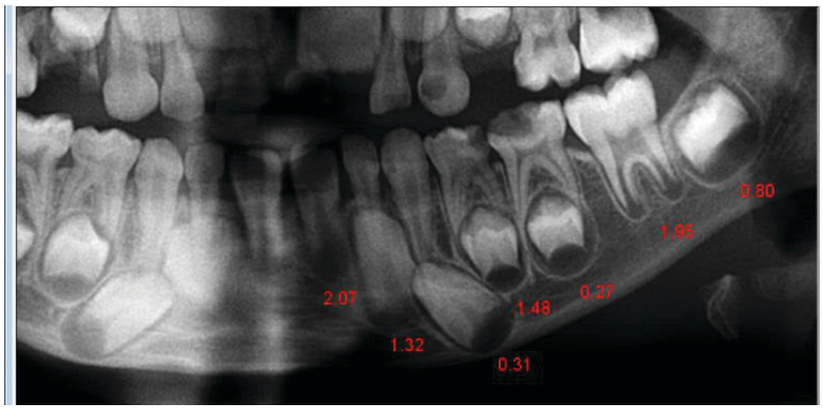

Figure 3- *OPT showing scoring of left mandibular permanent teeth as per Willems method.*

velopment stage of tooth as per the method. These values were directly summed up to obtain the dental age of the participant.

2.3 Statistical analysis

The obtained values (scores and estimated dental ages or DAs) for each participant were entered into a Microsoft excel sheet, along with the demographic details. The chronological age (CA) was calculated in decimals using the date of birth and date of radiograph exposure, and the data was further analyzed statistically using the IBM SPSS Statistics software (Version 20.0, IBM). Descriptive analysis was carried out for the CA as well as the estimated DAs. The efficiency of the methods was tested by comparing the estimated ages with CA and amongst themselves using the paired t-test, and the descriptive analysis of the error was calculated by subtracting CA from DA, (DA-CA).

A sub-set of 30 samples selected randomly were re-analyzed for a combination of the three methods by the first author (DS) after almost a month of initial analysis to observe the intra-observer variability. Another sub-set of 30 samples was analyzed by the second author (JS) to ascertain inter-observer bias in assessing the development stages for all methods. The average Cohen-kappa coefficient values for intra- and inter-observer variation were 0.944 and 0.866, respectively, and thus found to be satisfactory.

3. Results

The mean chronological age (CA) for the participants was 9.99±3.26 years and the mean dental age obtained using the three methods was similar (Table-1). Demirjian DA (DemDA) was closely related to CA, followed by Willems DA (WillDA) and Nolla DA (NollaDA). The distribution of the respective ages is shown in Figure-4(a-d). The paired t-test of CA with NollaDA, DemDA and WillDA indicated that significant differences exist between the CA and DAs of the Nolla and Willems methods, since their p-value was found to be less the 0.05 (Table-2). On the contrary, the p-value for DemDA and CA was more than 0.05; therefore, the null hypothesis that there is no considerable difference between the two could not be rejected. The paired t-test suggested that the Demirjian method is better than the others.

The description of errors and absolute errors calculated by subtracting chronological age from dental age (DA-CA) is shown in Table-3 and Table-4. Overall, all the methods underestimated the mean value of CA, which was highest for the Nolla method and lowest for the Demirjian method. 26.8% and 73.2% samples over- and underestimated the CA using the Nolla method. The over- and underestimation using the Demirjian method was shown in 55.4% and 44.6% of samples, respectively. Whereas in the Willems method, only one sample age was accurately assessed, and 42.5% and 57.5% of samples were over- and underestimated in age. But the MAE (mean absolute error) indicated the Willems method (0.97±0.93) to be better than the Nolla (1.09±0.98) and the Demirjan (1.10±0.91) methods. Both the Nolla and Demirjian methods showed similar values for MAE, but the range of errors indicated that the Demirjian method performed better than the Nolla method.

Table-5 displays the percentage of samples that showed errors in different ranges. More than half of the samples in all three methods showed error in the range of ±1 year. Based on this assessment, the Willems method appears to be better suited for age estimation for the population.

4. Discussion

Age estimation in children is believed to be more accurate. Despite that, the methods have shown con-

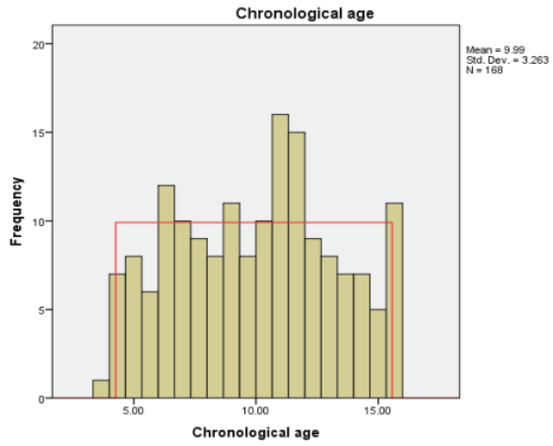

Fig 4(a)

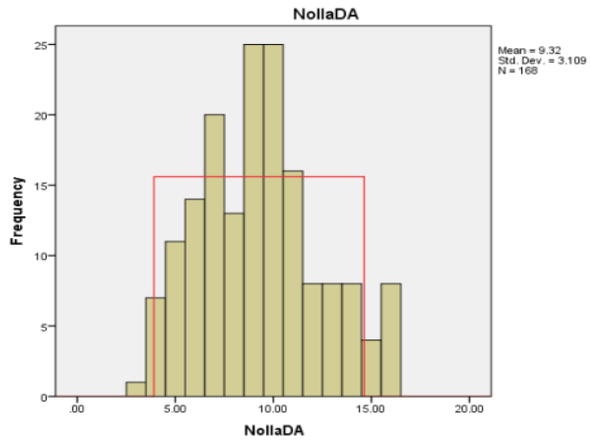

Fig 4(b)

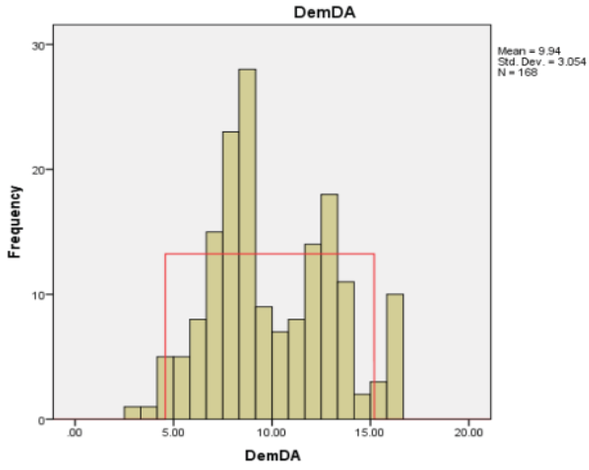

Fig 4(c)

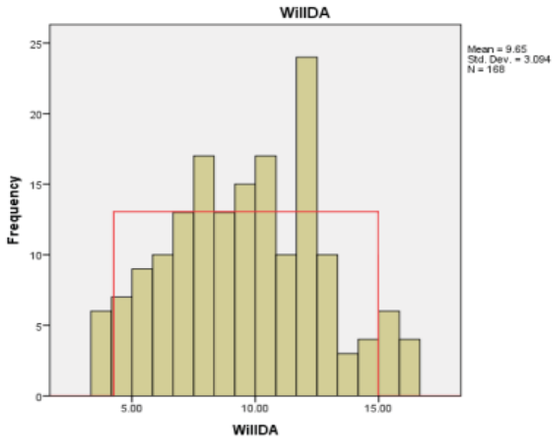

Fig 4(d)

Figure 4- *Histograms showing distribution of ages (CA and DAs). 4(a) Chronological age; 4(b) Nolla DA; 4(c) Demirjian DA; 4(d) Willems DA.*

Table 2- *Paired t-test for different ages.*

Pairs	Mean±SD	SEM	95% CI of difference		t-test	p-value
			Lower	Upper		
NollaDA-CA	0.68±1.31	0.10	0.476	0.874	6.70	0.001
DemDA-CA	0.05±1.36	0.11	- 0.156	0.258	0.49	0.626
WillDA-CA	0.34±1.25	0.10	0.152	0.533	3.55	0.001

Table 3- *Descriptive analysis of errors and absolute error of dental ages (DA).*

Error/Absolute error (DA-CA)	Mean±SD	Minimum	Maximum
NollaError	-0.68±1.31	-5.92	3.33
DemError	-0.05±1.34	-4.12	3.46
WillError	-0.34±1.25	-4.94	2.89
NollaAbError	1.09±0.98	0.02	5.92
DemAbError	1.10±0.91	0.02	4.12
WillAbError	0.97±0.93	0.00	4.94

Table 4 – *Sex-wise descriptive analysis of dental age (DA) errors.*

Errors	Sex	Mean±SD	SEM	Minimum	Maximum
NollaDA	Girl	-0.84±1.36	0.177	-5.92	2.02
	Boy	-0.58±1.27	0.122	-4.97	3.33
DemDA	Girl	-0.15±1.43	0.169	-4.12	2.12
	Boy	0.03±1.33	0.118	-3.47	2.89
WillDA	Girl	-0.33±1.30	0.186	-4.97	2.33
	Boy	-0.35±1.23	0.127	-4.94	3.46

Table 5- *Percentage of samples showing errors in different ranges for three dental ages (DA).*

Error	yrs (1-0)±	yrs (2-1)±	yrs(3-2)±	yrs (4-3)±
NollaError	59.52	25	10.12	4.17
DemError	58.93	28.57	7.14	4.76
WillError	61.68	25.75	10.18	1.20

siderable variance when used in different populations over a period of time. This study analyzed the OPTs using three scoring-based methods, the Nolla, Demirjian and Willems methods, for the specified North Indian population.

In the present study, Nolla method underestimated mean CA by 0.84±1.36, 0.58±1.27 and 0.68±1.31 years in girls, boys and combined samples, respectively, and the MAE for combined sample was 1.09±0.98 years. Of the previously conducted studies on different Indian populations, Rajasthani [7] girls and boys showed underestimation of the mean age by 0.30±0.82 and 0.13±0.80 years, respectively. The mean underestimating error for the combined samples of girls and boys belonging to Northern India [8] (Lucknow region) was found to be 0.97±1.36 years, which was in agreement with our results. Whereas, studies indicating overestimation included the South Indian population [9] where mean error and MAE was found to be 0.63 and 0.75 years in girls and 0.31 and 0.56 years in boys, respectively, and the Haryana [10] population where the mean value overestimated for girls and boys was 0.27 and 0.29 years, respectively.

Most of the non-Indian studies conducted so far have also reported underestimation of chronological age [11-13] while some overestimated [14,15].

Demirjian method, although widely applied, has been recommended to be used with population specific modifications due to differing results. The current study implied underestimation of mean CA in combined samples of North Indian children by 0.05±1.34 years, and MAE was 1.10±0.91 years. But the result in girls and boys differed; girls showed underestimation of age by 0.15±1.43 years, whereas boys indicated overestimation by 0.03±1.33 years. Two South Indian studies showing underestimations were similar to our study where the MAE of one population was 0.83 years [16] and in the other, girls showed overestimation by 0.43 years and boys indicated underestimation by 0.23 years [9]. All other Indian studies overestimated mean CA, as in South Indian [17] and Lucknow [8] populations by 0.05 and 0.02 years, respectively. Studies on North Indian (Faridabad) [18] and Haryanvi [10] girls and boys presented overestimation of 0.56 and 0.66 years and 0.15 and 0.18 years, respectively. Similar overestimations were found in Rajasthani [7] and Odisha [19] children. Gross overestimation was reported in meta-analysis of the Demirjian method applied to different Indian populations with a weighted mean difference of 0.45 years [20].

In non-Indian populations, only a few reported underestimations [21,22-24] and most reported overestimations [25-31].

Willems method, a modification of Demirjian method, is believed to be more accurate than the original. In the present population, this method underestimated the mean CA of combined samples by 0.34±1.25 years, and MAE was 0.97±0.93 years. The mean underestimations for girls and boys were 0.33±1.30 and 0.35±1.23 years, respectively. In other Indian studies, underestimations were observed in South Indian populations with mean CA errors being 0.15 and 0.25 years [9] and 0.69 and 0.39 years [17] in girls and boys, respectively. Meta-analysis of Indian studies [20] also suggested underestimation of mean CA with a weighted mean difference (WMD) of 0.09 years for a combined sample. Overestimations were reported in Rajasthani [7], South Indian [32], North Indian populations (Faridabad) [18] and Haryanvi [10] girls and boys by 0.08 and 0.09 years, 0.19 and 0.41 years, 0.24 and 0.36 years, and 0.24 and 0.25 years, respectively.

Underestimations by Willems method was seen in some non-Indian populations [22,23,27,28,31,33] whereas a few more overestimated CA [12,14,34-38]. Meta-analysis [39] conducted for Asians indicated underestimation of overall mean CA. But no significant difference was observed between the mean CA and estimated DA in the South African population [40] and in meta-analysis [1] conducted on 28 studies.

The paired t-test indicated no significant difference between the mean CA and mean estimated DA using Demirjian method. But the method presented under- and over-estimations of varied magnitude in both sexes; the t-test using mean value was found to be misleading. The Demirjian and Willems methods showed error in the range of ±5 years, which was ±6 years for the Nolla method. More than 80% of the samples in all the three methods showed error within the range of ±2 years (84.5% for the Nolla method and 87.5% for the Demirjian and Willems methods), signifying the Nolla method as the least accurate method of the three for the studied population. The mean absolute error and the distribution of the estimated ages for the Willems method indicated this as a better method than the Nolla and Demirjian methods, as is shown in most of the Indian studies [7,8,10,12,14,17,18,20] and other population studies [25,26,28].

But none of the tested methods was found to be suitable for the concerned population, due to their wide error range. This may be due to variable dental development owing to an interplay of factors such as varying nutrition and dietary habits, socio-econom-

ic status, miscellaneous environmental effects and genetic influence which may or may not be population specific. Most of the studies have explained the variation being a consequence of population specific development variability in addition to the environmental and other external factors, thereby suggesting the need for population specific correction factors [18,23,29], whereas some indicate secular changes as a major contributor to the variations [31,35,40].

In the present study, Willems method, which is almost two decades old but more recent than the other two methods, was found to be more suitable. But at the same time, a minimal difference was observed between the outcome of the Demirjian and Willems methods, which have a gap of 2-3 decades of formulation. Statistical factors such as sample size, sample and age distribution, statistical tools and analytical tools used for result interpretation are also known to influence the variations as they differ for each study, as implied in some studies [41,42]. The same has been observed in the reviewed literature where most of the studies have measured or computed accuracy in terms of mean error instead of mean absolute error, which is misleading due to loss of directionality of the errors. Also, the statistical tools and their result formats as well as the distribution varied among the studies. Thus, a poorly performing method may appear accurate due to inter-cancellations of over- and underestimations. Some more recent studies have presented mean absolute error and only a few have illustrated the range of errors and gross percentage of errors within an acceptable error range (considered to be ±1 or ±2 years) and beyond. Thus, lack of standard statistical (analytical) tools also influences the variations in the outcome of the methods.

Limitations of the present study included a small sample size, non-uniform distribution of cases in different age groups and a gap in the number of cases processed for both sexes.

Since the variations in the outcomes have been observed both intra- and inter-populations, this makes these methods unsuitable for age estimation in cases where population or ethnic affiliation of the person is unknown and accuracy is of the utmost importance. But these are useful in narrowing down the identity of a person where no valid information for the person is known or in combination with other methods, keeping in view the error range for the concerned methods until a general consensus is reached regarding its accuracy and causes of variations.

5. Conclusion

The three methods (Nolla, Demirjian and Willems) were found to be unsuitable for the population under study in terms of accuracy, due to wider error range presented by them. Of all these, the Willems method performed better but must be used cautiously and preferably in conjunction with other age estimation methods. New standards need be developed encompassing all populations, which requires a thorough understanding of the causes of variations and the extent of their contribution. Thus, more research in the area must be encouraged to understand the lacunae and to work towards the advancement of the current methods.

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Conflict of Interest

None

References

1. Esan TA, Yengopal V, Schepartz LA: The Demirjian versus the Willems method for dental age estimation in different populations: a meta-analysis of published studies. PLOS ONE 2017;12(11):e0186682. http://doi.org/10.1371/journal.pone.0186682
2. Ubelaker DH, Khosrowshahi: Estimation of age in forensic anthropology: historical perspective and recent methodological advances. Forensic Sciences Research 2019;4(1):1-9. https://doi.org/10.1080/20961790.2018.1549711
3. Harris EF, Mincer HH, Anderson KM, Senn DR: Age estimation from Oral and Dental Structures. In: Senn DR, Stimson PG, eds. Forensic Dentistry. 2nd ed. Boca Raton, FL: CRC Press; 2010: 263-304.
4. Nolla CM: The development of the permanent teeth. Journal of Dentistry for Children Fourth Quarter, 1960.
5. Demirjian A, Goldstein H, Tanner JM: A new system of dental age assessment. Human Biology 1973;45(2):211-27.
6. Willems G, Olmen AV, Spiessens B, Carels C: Dental age estimation in Belgian children: Demirjian's technique revisited. Journal of Forensic Sciences 2001;46(4):893-5.
7. Hegde S, Patodia A, Dixit U: A comparison of the validity of the Demirjian, Willems, Nolla and Haavikko methods in determination of chronological age of 5-`5 year-old Indian Children. Journal of Forensic and Legal Medicine 2017;50:49-57. http://dx.doi.org/10.1016/j.jflm.2017.07.007
8. Sinha S, Umapathy D, Shashikanth MC, Misra N, Mehra A, Singh AK: Dental age estimation by Demirjian's and Nolla's method: a comparative study among children attending a dental college in Lucknow (UP). Journal of Indian Academy of Oral Medicine and Radiology 2014;26(3):279-286. http://doi.org/1 0.4103/0972-1363.145005
9. Mohammed RB, Sanghvi P, Perumalla KK, Srinivasaraju D, Srinivas J, Kalyan S et al: Accuracy of four dental age estimation methods in Southern Indian children. Journal of Clinical and Diagnostic Research 2015;9(1):HC01-08. http://doi.org/10.4103/0976-237X.149283.
10. Rai B, Anand SC: Tooth developments: an accuracy of age estimation of radiographic methods. World Journal of Medical Sciences 2006;1(2):130-2.
11. Altunsoy M, Nur BG, Akkemik O, Ok E, Evcil MS: Dental age assessment: validity of the Nolla method in a group of Western Turkish children. Marmara Dental Journal 2013; 2:49-52. http://doi.org/10.12990/MDJ.201317508
12. Khoja A, Fida M, Shaikh A: Validity of different dental age estimation methods in Pakistani orthodontic patients. Australian Journal of Forensic Sciences 2015;47(3):283-92. https://doi.org/10.1080/00450618.2014.957347
13. Paz Cortés MM, Rojo R, Martínez MRM, Pérez MD, Prados-Frutos JC: Evaluation of the accuracy of the Nolla method for the estimation of dental age of children between 4-14 years old in Spain: a radiographic study. Forensic Science International 2019;301:318-25. https://doi.org/10.1016/j.forsciint.2019.05.057
14. Kumaresan R, Cugati N, Chandrasekaran B, Karthikeyan P: Reliability and validity of five radiographic dental-age estimation methods in a population of Malaysian children. Journal of Investigative and Clinical Dentistry 2014;5:1-8. http://doi.org/10.1111/jicd.12116
15. Luz LCP, Anzulovic D, Benedicto EN, Galic I, Brkić H, Biazevic MGH: Accuracy of four dental age estimation methodologies in Brazilian and Croatian children. Science & Justice 2019;59:442-447. https://doi.org/10.1016/j.scijus.2019.02.005

16. Kiran CHs, Reddy RS, Ramesh T, Madhavi NS, Ramya K: Radiographic evaluation of dental age using Demirjian's eight-teeth method and its comparison with Indian formulas in South Indian population. Journal of Forensic Dental Sciences. J Forensic Dent Sci 2015;7(1):44-48.
17. Patnana AK, Vabbalareddy RS, Vanga NRV: Evaluating the reliability of three different dental age estimation methods in Visakhapatnam children. International Journal of Clinical Pediatric Dentistry 2014;7(3):186-191. http://doi.org/10.5005/jp-jounals-1005-1262.
18. Grover S, Marya CM, JA, Pruthi N: Estimation of dental age and its comparison with chronological age: accuracy of two radiographic methods. Med Sci Law 2012; 52: 32-35. http://doi.org/10.1258/msl.2011.011021
19. Mohanty I, Panda W, Dalai RP, Mohanty N: Predictive accuracy of Demirjian's, modified Demirjian's and India specific dental age estimation methods in Odisha (Eastern India) population. Journal of Forensic Odonto-Stomatology 2019;37(1):32-39.
20. Prasad H, Kala N: Accuracy of two dental age estimation methods in the Indian population- a meta-analysis of published studies. Journal of Forensic Odonto-Stomatology 2019;37(3):2-11.
21. Erdem AP, Yamac E, Erdem MA, Sepet E, Aytepe Z: A new method to estimate dental age. Acta Odontologica Scandinavia 2013;71:590-98. http://doi.org/10.3109/00016357.2012.700062
22. Zhai Y, Park H, Han J, Wang H, Ji F, Tao J: Dental age assessment in a Northern Chinese population. Journal of Forensic and Legal Medicine 2016;38:43-49. http://dx.doi.org/10.1016/j.jflm.2015.11.011
23. Wang J, Bai X, Wang M, Zhou Z, Bian X, Qiu C et al: Applicability and accuracy of Demirjian and Willems methods in a population of Eastern Chinese subadults. Forensic Science International 2018;292:90-96. https://doi.org/10.1016/j.forsciint.2018.09.006
24. Lan LM, Yang ZD, Sun SL, Wen D, Kureshi A, Zeye MMJ et al: Application of Demirjian's and Cameriere's method in dental age estimation of 8-16 years old adolescents from Hunan Han nationality. Fa Yi Xue Za Zhi 2019;35(4):406-10. http://doi.org/10.12116/j.issn.1004-5619.2019.04.005.
25. Akkaya N, Yilanci HO, Göksülük D: Applicability of Demirjian's four methods and Willems method for age estimation in a sample of Turkish children. Legal Medicine 2015;17:355-359. http://dx.doi.org/10.1016/j.legalmed.2015.04.003
26. Ozveren N, Serindere G: Comparison of the applicability of Demirjian and Willems methods for dental age estimation in children from the Thrace region, Turkey. Forensic Science International 2018;285:38-43. https://doi.org/10.1016/j.forsciint.2018.01.017
27. Duangto P, Janhom A, Prasitwattanaseree S, Mahakkanukrauh P, Iamaroon A: New prediction models for dental age estimation in Thai children and adolescents. Forensic Science International 2016;266:583.e1-e5. http://dx.doi.org/10.1016/j.forsciint.2016.05.005
28. Kelmendi J, Vodanovic M, Kocani F, Bimbashi V, Mehmeti B, Galic I: Dental age estimation using four Demirjian's, Chaillet's and Willems' methods in Kosovar children. Legal Medicine 2018;33:23-31. https://doi.org/10.1016/j.legalmed.2018.04.006
29. Alassiry A, Alshomrani K, hasi SA, Albasri A, Alkhathami SS, Althobaiti MA: Dental age assessment of 3-15 year old Saudi children and adolescents using Demirjian's method- a radiographic study. Clin Exp Dent Res 2019;5:336-42. http://doi.org/10.1002/cre2.186

30. Esan TA, Schepartz LA: The timing of permanent tooth development in a Black population using the Demirjian method. International Journal of Legal Medicine. 2019;133:257-68. https://doi.org/10.1007/s00414-018-1968-4
31. Ranasinghe S, Perera J, Taylor JA, Tennakoon A, Pallewatte A, Jayasinghe R: Dental age estimation using radiographs: towards the best method for Sri Lankan children. Forensic Science International 2019;298:64-70. https://doi.org/10.1016/j.forsciint.2019.02.053
32. Balla SB, Baghirath PV, Vinay BH, Kumar JV, Babu DBG: Accuracy of methods of age estimation in predicting dental age of preadolescents in South Indain children. Journal of Forensic and Legal Medicine 2016;43:21-25. http://dx.doi.org/10.1016/j.jflm.2016.07.004
33. Nemsi H, Daya MB, Salem NH, Masmoudi F, Bouanéne I, Maatouk f et al: Applicability of Willems methods and Demirjian's four teeth method for dental age estimation: cross sectional study on Tunisian sub-adults. Forensic Science International 2018;291: 281.e1-e9. https://doi.org/10.1016/j.forsciint.2018.08.007
34. Kihara EN, Gichangi P, Liversidge HM, Butt F, Gikenye G: Dental age estimation in a group of Kenya using Willems' method: a radiographic study. Annals of Human Biology 2017;44(7):614-21. https://doi.org/10.1080/03014460.2017.1371794
35. Esan TA, Schepartz LA: Accuracy of the Demirjian and Willems methods of age estimation in a Black Southern African population. Legal Medicine 2018;31:82-89. https://doi.org/10.1016/j.legalmed.2018.01.004
36. Bedek I, Dumančić J, Lauc T, Marušić M, Čuković-Bagić I: New model for dental age estimation: Willems method applied on fewer than seven mandibular teeth. International Journal of Legal Medicine 2020;134(2):735-43. https://doi.org/10.1007/s00414-019-02066-5
37. Kiş HC, Görürgöz C, Başol M, Canger EM, Öztas B: Evaluation of the Willems and Cameriere's dental age estimation methods in Turkish children- a modified version of Cameriere's method. Forensic Science International: Reports 2020;2:1-8. http://doi.org/10.1016/j.fsir.2020.100105
38. Han M, Jia S, Wang C, Chu G, Chen T, Zhou H et al: Accuracy of the Demirjian, Willems and Nolla methods for dental age estimation in a Northern Chinese population. Archives of Oral Biology 2020;118:1-9. http://doi.org/10.1016/jarchoralbio.2020.104875
39. Yusof MYPM, Mokhtar IW, Rajasekharan S, Overholser R, Martens L: Performance of Willems' dental age estimation method in children: a systematic review and meta-analysis. Forensic Science International 2017;280:245.e1-e10. https://doi.org/10.1016/j.forsciint.2017.08.032
40. Willems G, Lee SS, Uys A, Bernitz H, Llano-Pérula MC, Fieuws S et al: Age estimation based on Willems method versus new country-specific method in South African Black children. Int J Legal Med 2018;132:599-607. http://doi.org/10.1007/s00414-017-1686-3
41. Liversidge HM, Smith BH, Maber M: Bias and accuracy of age estimation using teeth in 946 children. American Journal of Physical Anthropology 2010;143:545-54. https://doi.org/10.1002/ajpa.21349
42. Ortega-Pertuz AI, Piña-D'Abreu: Comparison of the Willems I and Willems II methods for forensic age estimation in Venezuelan children. Spanish Journal of Legal Medicine 2020;46(1):4-11. https://doi.org/10.1016/j.reml.2018.11.004