

Review Article

Is there a Need for an India Specific Dental Age Estimation Formula for Children and Adolescents? - A Critical Review

Rachana Prabhu^{1*}, Laxmikant Chatra¹, Prashant Shenoy¹, and Vishnudas Prabhu²

¹Department of Oral Medicine & Radiology, Yenepoya University, India

²Department of Oral & Maxillofacial Pathology, Yenepoya University, India

***Corresponding author**

Rachana Prabhu, Department of Oral Medicine & Radiology, Yenepoya Dental College, Yenepoya University, India, Tel: 91-8147020203; Email: drrachanaacharya@rediffmail.com

Submitted: 05 September 2020

Accepted: 28 September 2020

Published: 29 September 2020

ISSN: 2378-9476

Copyright

© 2020 Prabhu R, et al.

OPEN ACCESS**Keywords**

• Forensic odontology; Dental age; Age estimation; Radiographic methods

Abstract

Age estimation plays a prime role in forensic identification especially in absence of concerned documents and in unknown dead or living individuals. Its importance is priceless in a country like India where in, on one hand birth records of 10 million children every year go unregistered and on the other hand there is significant rise in involvement of minors in various crimes. Ideal method of age estimation is a constant search for the forensic odontologist. Delivery of justice can be appropriately made if the age is determined accurately and hence the accurate method of age estimation plays a pivotal role in correct justice being done. Literature provides many population specific methods of dental age estimation. Further validation and modification of these models is required in various populations before considering it for legal applications. The present article reviews the most commonly used radiographic methods of age estimation in children and adolescents and their accuracy in general and in Indian population in particular.

INTRODUCTION

For any forensic identification and medico – legal purposes, age estimation plays a significant role in narrowing the search possibilities for unidentified dead as well as the living individuals. It helps in delivering justice to a person involved in civil and the criminal legal actions [1]. An individual's Chronological age (CA) can be obtained from the birth date and confirmed with the birth registration certificates. But unfortunately, birth registration is not followed strictly in various parts of the world. According to the data between 2006 and 2016 recorded by United Nations Children's Fund (UNICEF) [2], the registered rate of birth for children under 5 in South Asia was 60 per cent and in India [3] it was only 72% which means out of 26 million children born every year, around 10 million children go unregistered.

According to the NCRB (National Crime Records Bureau) [4] report the number of juveniles in conflict with law under the Indian Penal code section showed increase from 17,819 in year 2003 to 31,725 in 2013. There is significant rise in involvement of minors in the crimes such as rapes, kidnapping, and murder. Also higher numbers of children are involved in the age disputes mostly in the domains of child labor and child marriage. Based on the age of an accused, trial or sentencing is conducted in the adult or juvenile justice courts. Hence knowing accurate age of an individual is of prime importance in the field of forensic dental and medical practice [5].

Saunders in 1837 [6] revealed the significance of dentition in age estimation through his research presentation, entitled "Teeth

A Test of Age". Later in nineteenth century several methods of dental age estimation were proposed. These methods are found to have their own advantages and disadvantages. Ideal method of age estimation is a constant search for the global as well as for an Indian forensic odontologist. Most of the proposed methods are population specific and based on western population which has been studied by Indian researchers in Indian children with various degrees of accuracy. It is considered that the dental development differs in various geographical regions due to the genetic factors and the cultural background [7].

The present article aims to review the most commonly used dental age estimation methods in children and adolescents and their applicability in various populations which will help us to understand the need for India specific formula for dental age estimation.

Need for age estimation

Age estimation is necessary for both dead and the living, civil as well as criminal litigation [8]. Among various dental disciplines, dental age (DA) assessment is essential for orthodontists in treatment planning of the children with malocclusion [9] and pedodontists for identifying the dental maturity of a child to rule out the systemic disturbances [10]. Its importance in bio-archaeology and human anthropology is priceless as it gives significant information regarding ancestors [7]. In forensic dentistry, age estimation is needed for various medico-legal purposes like personal identification, criminal cases and also in cases of various natural disaster victim identifications [11]. Age

estimation is also a very important in disclosing the facts about the age frauds in sports [5]. The medical and the dental experts are always called for estimating the age of players involved in age frauds by the Sports Authority of India (SAI) and the Ministry of Youth Affairs. In their report on "National Code against Age Fraud in Sports," age estimation evaluation includes dental examination and orthopantomogram (OPG) along with other medical and radiological examination [12].

Legal implications of age in India

As per the criminal law under Indian Penal Code, section 82, a child <12 years is not capable of committing any offence, according to the Indian adoption law, child > 12 years cannot be adopted, according to Article 24, Prohibition of Employment of Children in Factories, a child <12 years shall not be employed in any factory or mine or any hazardous work places, according to Child Labor Prohibition and Regulation Act 1986, children <14 years are considered as child labors, according to Section 3, Indian Majority Act 1875, 18 years of age is considered as the age of attaining majority, according to The Child Marriage Restraint Act 1929, for boys legally permissible age is 21 years and for girls it is 18 years. According to section 375 Indian Penal Code, the right age of consent to decide the criminality of the offence of rape is 16 years except in Manipur where it is 14 years [13].

Significance of teeth in age estimation

During the growth process, our physiologic systems such as skeletal system and the dentition pass through a series of changes before arriving at maturity. Although the maturity rate of our physiologic system differs from that of the chronologic age in different individuals, a correlation between the two has been observed [14]. Hence when the chronologic age is unknown or disputed, it can be inferred based on various parameters like dentition, skeleton, mental status of an individual, and other physiological factors like change in voice, attainment of height and weight etc [15].

Among all these indicators, dental maturity indicators are considered to be more reliable and the least variable bio-indicator for age assessment. This is because of its low variability to the endocrine & nutritional state of the child, high durability, resistant nature to fire, chemicals and putrefaction and unique nature of incremental formation and periodic mineralization [16-18].

Development of teeth begins as early as 4-6 months of embryonic life and continues till 23 years of age. Thus teeth development can be assessed from the radiographs for a long period of time and also during the periods when no eruption takes place i.e from 2 ½ to 6 years and 12 – 18 years of age. Another reason for considering dental development for age assessment especially in the first two decades of life is that it remains unaffected by local factors such as infection or decreased space unlike tooth emergence [18].

Significance of radiographs in dental age estimation

There are various methods of dental age estimation like clinical or visual method, morphological, histological, biochemical and radiological methods. Clinically the age can be estimated

by visualizing the emergence of the tooth in the oral cavity and also based on the regressive changes in the teeth like attrition. It is a convenient method but has several limitations as there are various clinical interpretations of emergence such as, piercing of gingival and exposure of the crown, bony emergence through the alveolar bone or attainment of occlusion by the teeth. Secondly the exact timing of emergence also may be missed and lastly the eruption of the teeth is influenced by the local factors like infection, space in the arch and early tooth loss [14,19].

Morphological and histological methods depend upon the microscopic preparation of the extracted teeth. This may lead to ethical, religious and cultural problems. The time needed for these methods is also longer. They require sophisticated laboratory equipment's, and hence expensive too so these methods may not be acceptable [14,19].

Whereas the radiographic methods of age estimation are simple, rapid, non-invasive, non – destructive and reproducible and hence can be used in living as well as in unknown dead individuals. Dental Radiography includes simple techniques that are used almost daily in dental practice [20].

Radiographic dental age assessment can be done based on the various parameters like prenatal formation of jaw bones, appearance of tooth germs, initiation of mineralization, degree of crown completion, crown eruption, amount of root completion, amount of root resorption of primary teeth, open apices measurement, pulp tooth ratio, secondary dentine formation and development of third molar [21].

Most of these methods are based on either "Atlas method" in which the developmental stages of the teeth are compared to the given standard or "Scoring method" in which the various stages of the teeth are assigned scores and then statistically analysed [21].

Methods applicable for children and adolescents

There are many methods of dental age estimation based on the radiographic indicators. Methods which are applicable and more commonly used for the children and adolescents [21] are Schour and Masseler method [22], Nolla's method [23], Moorees, Fanning and Hunt method [24], Demirjian, Goldstein and Tanner method [9], Willems method [25], Chaillet method [26], Acharya's method [27], Camerier's method using open apices [28], Modified Camerier's Indian formula [29] and London atlas method [30].

Schour and Masseler method

Schour and Masseler published an atlas in 1941 which described 21 chronological steps from 4 months to 21 years that described the development of deciduous as well as the permanent teeth [22].

The age was predicted directly by comparing the calcification stages of teeth on radiographs with the standards. It is one of the oldest and the most well-known atlas method. It was popular because of its simplicity [31].

Applicability

Lower accuracy and precision was observed in comparative studies conducted in New Zealand [32] and by AlQahtani SJ on

1506 skeletal remains [33]. Although this method was found to be reliable in a study by Boel T [34] in Indonesia and by George GJ et al [35], in Mangaluru, India, both these studies are based on a smaller sample size. Further studies are needed on a larger sample size in India to check its reliability.

Limitations

Although it is a simpler method of age estimation it has several limitations. The materials and method including the information on analysis is not available in the literature. The tooth stages and the eruption levels are not defined and the age range is small [36]. There are no separate charts for the two different genders. Furthermore, the gaps in the sequence of age categories; for example, after 12 years the chart directly refers to 15 years that affects the accuracy of this method. It does not mention the various stages of root development of third molar too [33].

Nolla's method

In 1960 Nolla [23] developed a method by assessing the development of each maxillary and mandibular tooth. He assessed the mineralization of permanent teeth using a 10 stage formula. A score is assigned to each tooth after a comparative evaluation of a figure found by Nolla with the developing stages of the teeth on the radiograph. A reading of the maxillary and mandibular teeth is obtained and then compared with the Nolla's table [36]. Here the advantage is that the assessment of age of girls and boys are done separately and it can be assessed without the third molars.

Applicability

Nolla's method was found to be more suitable as compared to that of Demerjian in a Brazilian study conducted in 2018 [38]. Studies conducted in Spain by Paz Cortés MM in 2019 [39] and Melo M in 2017 [40] in different age groups of 4-14 years and 7-21 years respectively concluded that the Nolla's method resulted in underestimation of the age in Spanish children. Whereas overestimation of the age was observed using Nolla's method in Malaysian children of age group 5-15 years [41].

The applicability of Nolla's method in Indian population is inconsistent as in one of the studies conducted by Mohammed RB [42] among the children of age group of 6-16 years in Andhra Pradesh observed that Nolla's method overestimated the age whereas another study conducted in Rajasthan by Hegde S [43] showed underestimation of assessed age.

Limitations

With this method the age estimation can be done only up to 16 years.

Moorees, Fanning and Hunt method

Moorrees, Fanning and Hunt in 1963 [24] published the charts representing various developmental stages of the deciduous and permanent teeth. The method is based on the radiographic survey of a North American population with age range from 6 months upto the development of the mandibular third molar [24]. The charts indicates an average age with two standard deviations and illustrates 14 stages of mineralization and the mean age for the corresponding stage for developing single and multicrooked permanent teeth. This method is very simple to apply and also

the only standard method that is based on the analysis of data for both the sets of dentition from the same series of children. It provides separate charts for males and females. It is one of the methods recommended by the American Society of Forensic Odontology (ASFO) for age estimation in sub-adult individuals [44].

Applicability

Underestimation of the age has been reported when assessed by Moorees, Fanning and Hunt method in studies conducted at various places like USA [45], Vanezuala [46], South Africa [47] and in Hubli, karnataka- India [48].

Limitations

Underestimation of the age in most of the studies

Demirjian, Goldstein and Tanner method

It is the most widely used method in various countries proposed by Demirjian Goldstein and Tanner⁹ in 1973. It is based on the developmental stages of seven left mandibular permanent teeth of 2928 French - Canadian subjects (1446 boys and 1482 girls). The approach is similar to the one used for studying the skeletal maturity by Tanner- Whitehouse [49,50].

The same method was later updated by Demirjian and Goldstein in 1976 [5] in which they added two more methods based on four teeth.

The original study [9] proposed 8 stages of tooth development and included teeth from mandibular central incisor to second molar. The detailed description of all the stages is mentioned very clearly in the literature [9]. These stages indicate dental maturity of each tooth on a scale of 0-100 on percentile charts. The total maturity scores (S) is then converted into dental age by referring the standard table or by substituting the scores in the regression formula separately for males and females, given by the author [9,20,37].

The method allows the use of opposing side tooth if the concerned tooth is absent and the readings of the central incisor if the first molar is missing [9].

Applicability

It is the most preferred method for dental age estimation in children and adolescents. Descriptions with the radiographic illustrations have been described in detail. It is relatively simple and more précised. But significant overestimation of the age was observed when the method was tested in North Germany [51], Egypt [52] and Brazillian children and adolescents [53]

A meta-analysis by Esan TA in 2018 [54] included 18 published studies comparing Demerjian's method with that of Willems also observed significant overestimation ($p < 0.05$) of the chronological age with Demirjian's method compared to the Willems method.

Utility of Demirjian's method remains unclear in Omani children [55] since in some age groups it overestimated whereas in some it showed underestimation. In a comparative study in Kosova by Kelmendi J 2018, better accuracy was observed with Demerjian's four teeth methods than 7 teeth methods.

When the applicability of Demerjian's method with respect to the Indian population is considered, it is observed that there was overestimation and significant difference between the chronological age and dental age in Mumbai [56,57] and Udaipur studies [58,59]. A meta analysis by Prasad in 2019 [60] that included 20 Indian studies also observed consistent overestimation of the age with Demerjian's method in Indian population, irrespective of the gender.

Limitations

Literature shows that in most of the studies it overestimates the age. Secondly there is no inclusion of the developing third molar in the survey and it requires presence of the mandibular teeth [20].

Revised Demerjian's methods

- **Willems method**

Since a significant overestimation of age was observed with Demerjian's formula on Belgian Caucasian children, Willems et al [25], modified the dental scores based on Demerjian's scores and proposed a modified method for dental age estimation for children of both the genders.

Applicability

A meta analysis by Sehrawat JS [61] and Esan TA [54] which included 15 and 18 published studies respectively showed overestimation of children's' age with Willem's method but to a lesser extent than the Demerjian method.

In Indian children, the comparative studies [60] found that Willem's method underestimates the age but it is more accurate than Demerjian's method. So the studies concluded that there is a need of population-specific formula for better accuracy of determination of age rather than using a universal method that is developed on other populations

Limitations

Overestimation of age in various population.

- **Chaillet method (Demerjian 8 teeth method)**

The original Demerjian's method could be used only till 16 years of age representing the completion of the root of second molar. Due to the unpredictability of anatomy, formation and eruption of the third molar it was excluded from the survey [9].

But the only radiographic parameter which can be used for determination of the age from 16 to 23 years is the third molar [62]. Hence in the late adolescence, inclusion of the third molar helps in providing the information on likelihood of the person to be of 18 years of age [63].

Based on this fact and existing limitations of the original Demerjian's method [9] the third molar was incorporated in a modification by Chaillet and Demerjian in 2001 [26]. Two additional stages of non-formation of tooth (Stage "0") and crypt development (Stage "1") were also added in the modified formula. Developmental stages of the teeth were assigned numerals from 0-9 and multiple regression formula was developed [26].

Applicability

Age assessed was underestimated using Chaillet or Demerjian 8 teeth method in Nepalese population [63] and also was found to be not suitable for Kosovar [56] and Tibetan young adults [64]. Indian studies [42,65] too found underestimation of the age using this formula.

Limitations

Underestimation of age in various population.

- **Acharya's method**

In 2010 Acharya [27] proposed a revised method using Demerjian's 8 teeth scores based on archives of 547 radiographs (348 females, 199 males) aged 7-25 years from an institution in Karnataka. He derived an Indian specific formula that is separate for males and females using regression analysis.

Applicability

According to Acharya [27], the regression equations derived yielded better accuracy with Mean absolute error (MAE) of 0.87 years than the original Chaillet and Demerjian method in the study population.

When Acharya's formula for evaluated for its accuracy in Odisha population [66,67] of 522 children and adolescent of age group 5-18 years and another study among 106 children and young adults belonging to the age group of 7-23 years, it was found that the MAE was more than 2 years and 1.3 years respectively which showed lower accuracy .

Similar lower accuracy results were also found in comparative studies carried out in Bhivaram, AP [68] and in Telangana [69] wherein there was overestimation of the age using Acharya's method. Acharya's formula of dental age estimation was found to be more effective in a Chennai comparative study [70] in 100 subjects of age group of 5-24 years.

Limitations

Lower accuracy has been found with Acharya's model [27] when studied in various Indian populations. The study was based on the data availed retrospectively from only one institution so there could be a bias in the selection of sample so whether the model can be generalized to the entire population is questionable. Secondly the study [27] is based on French Canadian weighted scores. The use of population specific maturity scores would have improved the age predictions of the study population.

Camereiere method of age estimation using open apices

Demerjian's method which is the most commonly used method worldwide is based on the progressive sequence of teeth development which are then coded and scored. These maturity scores serve as a function of age within the acceptable error limits. Hence it is believed that this method is basically designed to study the deviation of dental maturity i.e. whether it is advanced or delayed from normal in an individual with known age [71]. Secondly recent studies have also shown that there is a change in the growth trend of the current generation demanding for formulation of a newer method of dental age assessment [72].

In 2006 [28] a new concept of dental age assessment was proposed by Cameriere et al. in children. It is based on the measurement of open apices of seven mandibular teeth on radiographs of 455 Italian Caucasian children.

By measuring the ratio of the width between the open apices to that of the length of the teeth with open apex, and the number of teeth with closed apices, they derived a regression model using variables like gender, sum of the normalised open apices, number of teeth with closed apex and measurements of mandibular left 2nd pre molar which showed the best fit.

Applicability

A study by Cameriere R [73] carried out in 2,652 European Caucasian healthy children (1,382 boys, 1,270 girls) belonging to a heterogenous group aged between 4 and 16 years found residual error rate to be less than 1 year and no statistical significant difference was found between chronological age and the estimated age in the countries studied. Hence it concluded that a single regression equation could be used for all the Caucasian samples.

In a comparative study in 2008 [74] it was found that Cameriere's method was more accurate than Demerjian and Willem's method in Italian, Spain and Croatian children. Cameriere's method was also found to be accurate and more suitable in Mexican children [75].

But when the same formula was checked for its accuracy in Saudi Arabian [76], South African [77], Brazilian [78], North German [79], North China [80] and in Indian children [69,81], it showed underestimation of the assessed age highlighting the significant role of geography, nutrition, and genetics in the different regions in children's growth.

Whereas in two Indian pilot studies which were carried out to evaluate the accuracy of Cameriere's method in Kerala [82] and in Mangalorean children [83] significant correlation was found between the chronological age and the estimated age.

Findings of these studies open a scope for a research on a larger sample size to further confirm its reliability in Indian population.

Limitations

Age estimation with this method is possible till the age of 15 years as it is based on 7 teeth and the apices of the roots of second molar closes by this age.

- **Camerier's modified formula for India**

When it was studied that Camerier's method results in underestimation of the age in Haryana population [81], Balwant Rai in 2010 [29], reported a new model for Indian children based on Camerier's method. In this study the author included the sample subjects belonging to the age of 3-15 years and tried to include the sample from North, Center and South Indian states to represent it as an Indian population.

Applicability

In a comparative study carried out in 60 children of west Godavari district [84] belonging to the age group of 9-14 years, no

significant difference was obtained between the chronological age and the estimated age using modified Cameriere's formula than the Cameriere's and Demerjian's method. Significant correlation was found between the chronological age and the age assessed by modified Cameriere's method in Davangere study [85]. But both these studies are carried out in a smaller sample size. Further studies are essential on a larger sample size to confirm the reliability of modified Cameriere's population-specific regression equation.

Limitation

Although Rai B [29] has attempted to give an equation for Indian children, the study neither mentions the clarification on the size of the sample nor the reasoning of selection of the study sample from only few states of the country. So whether we can generalize this equation to the whole population needs to be studied further by considering a larger sample size. There is no separate model for males and females as the author or feels that the dental maturation rate is almost the same in males and females whereas as per the literature [24,86] the dental maturity is far ahead in girls than in boys.

London Atlas method

In 2010 a wide-ranging atlas of tooth development stages was developed by AlQahtani et al. [30] based on Moorrees et al.'s [24] and Bengston's [87] tooth Developmental stages. The atlas was based on the examination of mixed Bangladeshi and white British individuals of age ranging from 28 weeks intrauterine to 23 years.

The London Atlas [30] assessed deciduous as well as permanent dentition. The atlas is easy to visualize and recognize all the tooth development stages as it represents clear pictures of each stage of the teeth development with its clear description. After the first year of life, assignment of age with a range of one year has been presented in the atlas. So it is easier to use and less time consuming too.

This method when further tested by AlQahtani et al in 2014 [33] along with Schour and massler and Ubelaker charts in Bangladeshi and white British sample, authors obtained good accuracy measures for all the age groups with London atlas.

In a Thai study [88] a maximum of 1.3 years of discrepancy was found when the chronological age was compared to that of the estimated age with London Atlas method. A discrepancy of lower than 2 years was observed in a Brazilian study [89] with overestimation in some groups and underestimation in some.

In a comparative study carried out in Saudi Arabia [90] London atlas method consistently underestimated the age but no significant difference was observed between the chronological and the estimated age. London atlas method infect was found to be more accurate than Cameriere's method. A study conducted in Germany [91] on comparison of London Atlas method with that of Willem's and Demirjian's observed that a combination of London atlas and Willem's method gives more precise results rather than applying any single method.

London atlas method was found to be accurate in Iranian and Hispanic children whereas low accuracy was observed when evaluated in a modern American population representing

multiple ancestry groups [92] and also in New Zealand population [32]. In a Portuguese study [93] overestimation of age was found in males. Inaccurate results found in both the genders denote inefficiency of universal charts and stresses on the need for separate charts for each sex. This method is not been tested so far in Indian population.

Limitations

There are no separate charts for males and females. It is a subjective method and hence chances of having observer bias are more. Eruption of the teeth is highly influenced by various local factors. Hence, if the development rate of any tooth is faster or slowed down then the use of this method may not be advisable. Secondly if the teeth are mal-aligned then the considerations of the consolidation of development of the teeth are not addressed in the literature. If multiple teeth match the different age estimates then which teeth to be considered for accurate estimation of the age is also not mentioned in the literature [90,93].

CONCLUSION

Based on the above literature it is observed that the dental maturity is influenced by various factors such as environmental, ethnicity, genetic and socioeconomic which can further lead to difference in the teeth development among the people living in different countries and also among residents within a limited geographical area. Hence one cannot expect to have accurate results when age estimation formulas derived from non Indian population is applied to the Indian population. Although attempt has been made by few Indian researchers to modify these formulas and give Indian specific formula, these studies are based on non Indian maturity scores, smaller sample size, improperly distributed sample and hence these formulas may not be generalized to the entire Indian Population. India is a large country represented by diverse group of population from various socio-economic and ethnic backgrounds. Considering this fact and the existing lacunae in the literature the author recommends a further research in developing Indian maturity scores which will help in invention of more accurate scoring based formula of age estimation for Indian population.

Age estimation is required most of the time for delivering justice to an individual either in civil or criminal litigations. Hence the method adopted should always be of more accuracy and have less error rates.

Hence the above evidence suggests that India needs a population specific formula for dental age estimation in children and adolescents based on a systematically designed study by considering a larger sample size represented by various regions of the country which will result in a better accuracy, minimal error rates and can be generalized to the whole population.

REFERENCES

- Cunha E, Baccino E, Martrille L, Ramsthaler F, Prieto J, Schuliar Y, et al. The problem of aging human remains and living individuals: a review. *Forensic Science Int.* 2009; 193: 1-13.
- United Nations Children's Fund, *The State of the World's Children 2017*, UNICEF, ISBN: 978-92-806-4930-7, December 2017.
- United Nations Children's Fund, *Birth Registration*. 2016. [Last accessed on 2020 April 28].
- National Crime Records Bureau (NCRB) – *Crime in India*. 2013.
- Jayaraman J. Dental age estimation in India: Do we have a role beyond publishing scientific evidences? *J Forensic Dent Sci.* 2018; 10: 55-57.
- Saunders E. 'The Teeth A Test of Age' considered with the reference to the factory children, addressed to the members of both Houses of Parliament. London: Renshaw, 1837.
- Brunilda Dharmo, Lea Kragt, Olja Grgic, Strahinja Vucic, Carolina Medina-Gomez, Fernando Rivadeneira, et al. Ancestry and dental development: A geographic and genetic perspective. *Am J Phys Anthropol.* 2018; 165: 299-308.
- E Cunha, E Baccino, L Martrille, F Ramsthaler, J Prieto, Y Schuliar, et al. The problem of aging human remains and living individuals: a review. *Forensic Sci Int.* 2009; 193: 1-13.
- Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. *Hum Biol.* 1973; 45: 211-27.
- Gaethofs M, Verdonck A, Carels C, de Zegher F. Delayed dental age in boys with constitutionally delayed puberty. *European journal of orthodontics.* 1999; 21: 711-5.
- Carvalho SPM, Alves da Silva RH, Lopes-Junior C, Peres AS. Use of images for human identification in forensic dentistry. *Radiol Bras.* 2009; 42: 1-12.
- Ministry of Youth Affairs and Sports, Government of India – *National Code against Age Fraud in Sports*. 2020.
- Sridhar M. *Legal Provisions Regarding Age of Child to Protect the Rights of Children*. SSRN. 2012; 12.
- Seth J, Agarwal A, Aeran H, Krishnan Y. Dental age estimation in children and adolescents. *Indian J Dent Sci.* 2018; 10: 248-51.
- Smith T, Brownlee L. *Age Assessment Practices: A Literature Review & Annotated Bibliography*. New York: United Nations Children's Fund (UNICEF); 2011.
- Nik-Hussein NN, Kee KM, Gan P. Validity of Demirjian and Willems methods for dental age estimation for Malaysian Children aged 5-15 years old. *Forensic Sci Int.* 2011; 204: 208.e1-6.
- Demirjian A, Buschnag PH, Tanguy R, Patterson DK. Interrelationship among measures of somatic, skeletal, dental and sexual maturity. *Am J Orthod.* 1985; 88: 433-8.
- Nelson SJ. *Wheeler's Dental Anatomy, Physiology and Occlusion-E-Book*. Elsevier Health Sciences; 2019.
- Priyadarshini, Manjunath P Puranik, SR Uma. *Dental Age Estimation Methods: A Review*. *Int J Adv Health Sci.* 2015; 1: 19-25.
- Ciapparelli L. The chronology of dental development and age assessment. In: Clark DH, (ed). *Practical forensic odontology*. Oxford: Wright Butterworth-Heinemann Ltd. 1992; 22-42.
- Panchbhai AS. Dental radiographic indicators, a key to age estimation. *Dentomaxillofac Radiol.* 2011; 40: 199-212.
- Schour I, Massler M. Development of human dentition. *J Am Dent Assoc.* 1941; 20: 379-427.
- Nolla CM. The development of permanent teeth. *J Dent Child.* 1960; 27: 254-266.
- Moorees CFA, Fanning EA, Hunt EE. Age variation of formation stages for ten permanent teeth. *J Dent Res.* 1963; 42: 1490-1502.
- Willems G, Van Olmen A, Spiessens B, Carels C. Dental age estimation in Belgian children: Demirjian's technique revisited. *J Forensic Sci.* 2001; 46: 893-5.

26. Chaillet N, Demirjian A. Dental maturity in South France: A comparison between Demirjian's method and polynomial functions. *J Forensic Sci.* 2004; 49: 1059-66.
27. Acharya AB. Age Estimation in Indians Using Demirjian's 8-teeth Method. *J Forensic Sci.* 2011; 56: 124-7.
28. Cameriere R, Ferrante L, Cingolani M. Age estimation in children by measurement of open apices in teeth. *Int J Legal Med.* 2006; 120: 49-52.
29. Rai B, Kaur J, Cingolani M, Ferrante L, Cameriere R. Age estimation in children by measurement of open apices in teeth: an Indian formula. *Int J Legal Med.* 2010; 124: 237-41.
30. AlQahtani SJ, Hector MP, Liversidge HM. Brief communication: The London atlas of human tooth development and eruption. *Am J Phys Anthropol.* 2010; 142: 481-900.
31. Logan WHG, Kronfeld R. Development of the human jaws and surrounding structures from birth to age fifteen. *J Am Dent Assoc.* 1933; 20: 379-427.
32. Baylis S, Bassed R. Precision and accuracy of commonly used dental age estimation charts for the New Zealand population. *Forensic Sci Int.* 2017; 277: 223-228.
33. 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: 70-8.
34. Boel T, Bahri TA. Age Estimation Using Schour-Massler Method Compared to the Demirjian Method. *Dentika Dental Journal.* 2019; 22: 15-9.
35. George GJ, Chatra L, Shenoy P, Veena KM, Prabhu RV, Kumar LV. Age determination by schour and massler method: A forensic study. *International Journal of Forensic Odontology.* 2018; 3: 36.
36. Garn SM, Lewis AB, Polacheck DL. Variability in tooth formation. *J Dent Res.* 1959; 38: 135-148.
37. Karjodkar FR. Role of dental radiology in forensic odontology, Text book of dental and maxillofacial radiology, (2nd edn). New Delhi: Jaypee Brothers Medical Publishers (P) Ltd, 2009; 929-963.
38. Lopes LJ, Nascimento HAR, Lima GP, Santos LAND, Queluz DP, Freitas DQ. Dental age assessment: Which is the most applicable method? *Forensic Sci Int.* 2018; 284: 97-100.
39. Paz Cortés MM, Rojo R, Mourelle Martínez MR, Dieguez Pérez M, 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 Sci Int.* 2019; 301: 318-325.
40. Melo M, Ata-Ali J. Accuracy of the estimation of dental age in comparison with chronological age in a Spanish sample of 2641 living subjects using the Demirjian and Nolla methods. *Forensic Sci Int.* 2017; 270: 276.e1-276.e7.
41. Kumaresan R, Cugati N, Chandrasekaran B, Karthikeyan P. Reliability and validity of five radiographic dental-age estimation methods in a population of Malaysian children. *J Investig Clin Dent.* 2016; 7: 102-9.
42. Mohammed RB, Sanghvi P, Perumalla KK, Srinivasaraju D, Srinivas J, Kalyan US, Rasool SM. Accuracy of four dental age estimation methods in southern Indian children. *J Clin Diagn Res.* 2015; 9: HC01.
43. Hegde S, Patodia A, Dixit U. A comparison of the validity of the Demirjian, Willems, Nolla and Häavikko methods in determination of chronological age of 5-15 year-old Indian children. *J Forensic Leg Med.* 2017; 50: 49-57.
44. D Senn, R Weems. Manual of Forensic Odontology. CRC Press, Florida. 2013.
45. Skanchy TL, Maness H, Al Dayeh A, Harris EF. A Comparison of Two Dental Age Estimation Techniques in Contemporary American Whites: The Moorrees and Demirjian Approaches. *Int J Forensic Sci Pathol.* 2016; 4: 243-8.
46. Martínez Gutiérrez VM, Ortega-Pertuz AI. Comparison of Nolla, Demirjian and Moorrees methods for dental age calculation for forensic purposes. *Revista Odontológica Mexicana.* 2017; 21: 155-64.
47. Phillips VM, van Wyk Kotze TJ. Testing standard methods of dental age estimation by Moorrees, Fanning and Hunt and Demirjian, Goldstein and Tanner on three South African children samples. *J Forensic Odontostomatol.* 2009; 27: 20-8.
48. Gupta B, Anegundi R, Sudha P. Comparison Of Dental Age Of Hubli Dharwad Children By Moore's Method With The Skeletal Age And Chronological. *The Internet Journal of Dental Science.* 2007; 6: 1-7.
49. Tanner J, Whitehouse R, Marshall W, Healty M, Goldstein H. Assessment of Skeleton Maturity and Maturity and Prediction of Adult Height (TW2 Method), 1975.
50. Demirjian A, Goldstein H. New systems for dental maturity based on seven and four teeth. *Ann Hum Biol.* 1976; 3: 411-421.
51. Khdairi N, Halilah T, Khandakji MN, Jost-Brinkmann PG, Bartzela T. The adaptation of Demirjian's dental age estimation method on North German children. *Forensic Sci Int.* 2019; 303: 109927.
52. Moness Ali AM, Ahmed WH, Khattab NM. Applicability of Demirjian's method for dental age estimation in a group of Egyptian children. *BDJ Open.* 2019; 5: 2.
53. Lopes LJ, Nascimento HAR, Lima GP, Santos LAND, Queluz DP, Freitas DQ. Dental age assessment: Which is the most applicable method? *Forensic Sci Int.* 2018; 284: 97-100.
54. 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: e0186682.
55. Al Balushi S, Thomson WM, Al-Harthi L. Dental age estimation of Omani children using Demirjian's method. *Saudi Dent J.* 2018; 30: 208-213.
56. Kelmendi J, Vodanović M, Koçani F, Bimbashi V, Mehmeti B, Galić I. Dental age estimation using four Demirjian's, Chaillet's and Willems' methods in Kosovar children. *Leg Med (Tokyo).* 2018; 33: 23-31.
57. Balgi P, Katge F, Singh S, Jayaraman J. Comparative assessment to determine the accuracy of Demirjian and DARLInG methods of dental age estimation in western Indian children. *Leg Med (Tokyo).* 2020; 42: 101629.
58. Hegde S, Patodia A, Shah K, Dixit U. The applicability of the Demirjian, Willems and Chaillet standards to age estimation of 5-15 year old Indian children. *J Forensic Odontostomatol.* 2019; 37: 40-50.
59. Hegde S, Patodia A, Dixit U. The applicability of the original and revised Demirjian standards to age estimations of 5-15 year old Indian children. *J Forensic Odontostomatol.* 2018; 36: 1-13.
60. Prasad H, Kala N. Accuracy of two dental age estimation methods in the Indian population - A meta-analysis of published studies. *J Forensic Odontostomatol.* 2019; 3: 2-11.
61. 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.
62. Mincer HH, Harris EF, Berryman HE. The ABFO study of third molar development and its use as an estimator of chronological age. *J Forensic Sci.* 1993; 38: 379-90.
63. Agrawal NK, Hackman L, Dahal S. Dental Age Assessment using

- Demirjian's Eight Teeth Method and Willems Method in a Tertiary Hospital. *JNMA J Nepal Med Assoc.* 2018; 56: 912-6.
64. Bijjaragi SC, Sangle VA, Saraswathi FK, Patil VS, Rani SA, Bapure SK. Age estimation by modified Demirjian's method (2004) and its applicability in Tibetan young adults: A digital panoramic study. *Journal of oral and maxillofacial pathology: JOMFP.* 2015; 19: 100.
65. Sathawane RS, Agrawal N. Applicability of Chaillet-Demirjian's and Willem's age assessment methods in Chhattisgarh population: proposing Chhattisgarh population specific formula. *International Journal of Maxillofacial Imaging.* 2017; 3: 8-11.
66. Mohanty I, Panda S, Dalai RP, Mohanty N. Predictive accuracy of Demirjian's, Modified Demirjian's and India specific dental age estimation methods in Odisha (Eastern Indian) population *J Forensic Odontostomatol.* 2019; 37: 32-39.
67. Rath H, Rath R, Mahapatra S, Debta T. Assessment of Demirjian's 8-teeth technique of age estimation and Indian-specific formulas in an East Indian population: A cross-sectional study. *J Forensic Dent Sci.* 2017; 9: 45.
68. 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. *J Forensic Dent Sci.* 2015; 7: 44-8.
69. Balla SB, Venkat Baghirath P, Hari Vinay B, Vijay Kumar J, Babu DB. Accuracy of methods of age estimation in predicting dental age of preadolescents in South Indian children. *J Forensic Leg Med* 2016; 43: 21-5.
70. Sarkar S, Kailasam S, Kumar PM. Accuracy of estimation of dental age in comparison with chronological age in Indian population—A comparative analysis of two formulas. *J Forensic Leg Med.* 2013; 20: 230-3.
71. Teivens A, Mörnstad H. A modification of the Demirjian method for age estimation in children. *The Journal of forensic odonto-stomatology.* 2001; 19: 26-30.
72. Ogodescu AE, Bratu E, Tudor A, Ogodescu A. Estimation of child's biological age based on tooth development. *Rom J Leg Med.* 2011; 19: 115-24.
73. Cameriere R, De Angelis D, Ferrante L, Scarpino F, Cingolani M. Age estimation in children by measurement of open apices in teeth: a European formula. *Int J Legal Med.* 2007; 121: 449-53.
74. Cameriere R, Brkic H, Ermenc B, Ferrante L, Ovsenik M, Cingolani M. The measurement of open apices of teeth to test chronological age of over 14-year olds in living subjects. *Forensic Sci Int.* 2008; 174: 217-21.
75. De Luca S, De Giorgio S, Butti AC, Biagi R, Cingolani M, Cameriere R. Age estimation in children by measurement of open apices in tooth roots: Study of a Mexican sample. *Forensic Sci Int.* 2012; 221: 155.e1-7.
76. AlShahrani I, Yassin SM, Togoo RA, Tikare S, Khader MA, Alkahtani ZM. Age estimation by measurement of open apices in tooth roots: Study using Saudi Arabian samples. *J Forensic Leg Med.* 2019; 62: 63-68.
77. Angelakopoulos N, De Luca S, Palacio LAV, Coccia E, Ferrante L, Pinchi V, Cameriere R. Age estimation by measuring open apices in teeth: a new formula for two samples of South African black and white children. *Int J Legal Med.* 2019; 133: 1529-1536.
78. Mazzilli LEN, Melani RFH, Lascala CA, Palacio LAV, Cameriere R. Age estimation: Cameriere's open apices methodology accuracy on a southeast Brazilian sample. *J Forensic Leg Med.* 2018; 58: 164-168.
79. Halilah T, Khadiri N, Jost-Brinkmann PG, Bartzela T. Age estimation in 5–16-year-old children by measurement of open apices: North German formula. *Forensic science international.* 2018; 293: 1-103.
80. Guo YC, Yan CX, Lin XW, Zhou H, Li JP, Pan F, et al. Age estimation in northern Chinese children by measurement of open apices in tooth roots. *Int J Legal Med.* 2015; 129: 179-86.
81. Rai B. Accuracy of Cameriere et al regression equation in Haryana population. *Rom J Leg Med.* 2009; 17: 147-50.
82. Nair VV, Thomas S, Thomas J, Salim SF, Thomas D, Thomas T. Comparison of Cameriere's and Demirjian's methods of age estimation among children in Kerala: a pilot study. *Clin Pract.* 2018; 8: 991.
83. Begum N. Dental age estimation by using cameriere's method in mangalorean children: a pilot study. *Paripex - Indian Journal of Research.* 2017; 6.
84. Pratyusha K, Prasad MG, RadhaKrishna AN, Saujanya K, Raviteja NV, Chandrasekhar S. Applicability of Demirjian's method and modified Cameriere's methods for dental age assessment in children. *J Clin Diagn Res.* 2017; 11: ZC40.
85. Attiguppe PR, Yavagal C, Maganti R, Mythri P. Age Assessment in Children: A Novel Cameriere's Stratagem. *Int J Clin Pediatr Dent.* 2016; 9: 330.
86. Wedl JS, Schmelzle R, Friedrich RE. The eruption times of permanent teeth in boys and girls in the Stormarn District, Schleswig-Holstein (Germany). *Anthropol Anz.* 2005; 63: 189-197.
87. Bengston RG. A study of the time of eruption and root development of the permanent teeth between six and thirteen years. *Northwest Univ Bull.* 1935; 35: 3-9.
88. Namwong W, Mânica S. Testing the London atlas for age estimation in Thai population. *Acta Odontol Scand.* 2020; 78: 161-164.
89. Sousa AMDS, Jacometti V, AlQahtani S, Silva RHAD. Age estimation of Brazilian individuals using the London Atlas. *Arch Oral Biol.* 2020; 113: 104705.
90. Alsudairi DM, AlQahtani SJ. Testing and comparing the accuracy of two dental age estimation methods on Saudi children: Measurements of open apices in teeth and the London Atlas of Tooth Development. *Forensic Sci Int.* 2019; 295: 226.e1-226.e9
91. Gelbrich B, Carl C, Gelbrich G. Comparison of three methods to estimate dental age in children. *Clin Oral Investig.* 2020; 24: 2469-2475.
92. Adams DM, Ralston CE, Sussman RA, Heim K, Bethard JD. Impact of population-specific dental development on age estimation using dental atlases. *Am J Phys Anthropol.* 2019; 168: 190-199.
93. Pavlović S, Palmela Pereira C, Vargas de Sousa Santos RF. Age estimation in Portuguese population: The application of the London atlas of tooth development and eruption. *Forensic Sci Int.* 2017; 272: 97-103.

Cite this article

Prabhu R, Chatra L, Shenoy P, Prabhu V (2020) Is there a Need for an India Specific Dental Age Estimation Formula for Children and Adolescents? - A Critical Review. *Ann Forensic Res Anal* 7(1): 1057.