



## Age Estimation: Current State and Research Challenges

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There exist several methods and a fairly substantial literature on the field of age estimation. However, different methods are associated with varying degrees of uncertainty and precision, and this is not always well understood. From a statistical-methodological point of view, there are reasons to believe that a combination of different measurement methods and a more conscious use of the relevant statistical methodology may provide more reliable estimates and better quantification of associated levels of uncertainty. When the uncertainty is known, considering the acceptance level of the error rates, methods are to be found out to rectify it to the maximum possible extent to make it in acceptable limits with maximum validity as there are no methods, by which the age of an individual can be precisely estimated.

Key words: Age estimation, methods, errors, reliability, acceptance levels

### INTRODUCTION

The human body grows and matures with age, especially in children and adolescents. Therefore, the main idea behind the various methods of age estimation is to compare the measurements of physical maturity of the body with age. However, due to individual variations in the timing of skeletal and dental development, the results of any method are subject to uncertainty when applied to a single individual. There are also issues related to the relevance and representativeness of the available reference populations. There exist several methods and a fairly substantial literature on the field. However, there will always be biological variations and uncertainty associated with age estimates. From a statistical-methodological point of view, there are reasons to believe that a combination of different measurement methods and a more conscious use of the relevant statistical methodology may provide more reliable estimates and better quantification of associated levels of uncertainty. When the uncertainty is known, considering the acceptance level of the error rates, methods are to be found out to rectify it to the maximum possible extent to make it within acceptable limits with maximum validity as there are no methods by which the age of an individual can be precisely estimated.

### HISTORICAL PERSPECTIVE OF FORENSIC ODONTOLOGY

According to the Old Testament, Adam was convinced by Eve to put a “bite mark” on the apple.<sup>1</sup> Hammurabi codified medical law circa in 2200 BC and medicolegal issues were covered in early Jewish law. Later, other civilizations – the Greeks, ancient India, and the Roman Empire – evolved jurisprudential standards involving medical fact or opinion.<sup>2</sup> Although interest in forensic odontology was heightened in the latter part of the 19<sup>th</sup> century, the process has been used for more than 2000 years.<sup>1</sup> Raja Jai Chandra Rathore of Canauj died on the battlefield in 1191 AD and was identified by his false anterior teeth. This was possibly the first case of identification from dentition from India.<sup>1,3</sup> First formally reported dental identification was done in 1453, when soldier John Talbot was identified following the battle of Castillon.<sup>1</sup> Charles the Bold, Duke of Burgundy, was killed in the Battle of Nancy in 1477 while trying to create an independent state between France and Germany. The Duke’s page was able to

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identify him according to his dentition as he lost some teeth previously.<sup>1,4</sup> As for the first case of identification of a person by a dentist, credit goes to Paul Revere (1776), a practicing dentist in the USA, who identified the remains of his friend and patient, Dr. Joseph Warren, from the silver wire fixed bridge made by him.<sup>1-5</sup> Saunders, a dentist, was the first to publish information regarding dental implications in age assessment by presenting a pamphlet entitled, “Teeth a Test of Age” to the English Parliament in 1837. He examined 1049 children’s teeth and height to estimate age and concluded that “teeth were a much more reliable guide to age than height.”<sup>6,7</sup> Dental evidence was first accepted by law in the USA in the Webster-Parkman case in 1849. Nathan Cooley kept identified the incinerated remains of Dr. Gorge Parkman, resulting in the conviction and execution of Webster for murder.<sup>2</sup> Dr. Oscar Amoedo, who has been called the “Father of Forensic Odontology,” published a paper entitled, “The role of the dentist in the identification of the victims of the catastrophe of the Bazar de la Charite, Paris, on May 4, 1897,” and later presented it at the International Medical Congress of Moscow.<sup>2,8</sup> Hitler and his mistress Eva Braun’s bodies were also identified in 1945 by their dentist Kathe Hensman Fritz Echtmann.<sup>1,9</sup>

## HISTORICAL PERSPECTIVE OF FORENSIC RADIOLOGY

Wilhelm Conrad Roentgen’s discovery of the X-ray in 1895 led to increased use of the noninvasive technology to help diagnose disease. The first use of X-rays in criminal forensics actually occurred a few days before Roentgen submitted his discovery for publication when a radiograph helped demonstrate a bullet fragment lodged in a shooting victim’s leg. Physics Professor in Canada had conducted the X-ray examination; the radiograph was submitted as evidence of attempted murder in court.<sup>10</sup> Perhaps, one of the earliest celebrity cases that utilized radiology was that of President Theodore Roosevelt. On October 14, 1912, while running for a third term, a fanatic shot President Roosevelt in the chest. An X-ray examination showed that the bullet had entered his right chest medial and inferior to the nipple and was embedded in a rib, splintering its internal surface so that the pleura was compromised. The bullet was not extracted for fear of complication and Roosevelt carried it with him to his grave some years later.<sup>2</sup> Another famous forensic case was that of Adolph Hitler. After the war, speculation and rumors suggested that Hitler was not really dead and that he had somehow escaped. Fortunately, a radiographic study of Hitler’s skull taken years before revealed distinctive dental work.<sup>1,2</sup> Thousands of people lost their lives in the World Trade Center disaster in the USA on September 11, 2001. DNA extracts

from tooth brushes of the victims were used in identification of some victims.<sup>11</sup> According to a USA website (CNN NEWS), dental identification was used to confirm the identities of the bodies of the two sons of Saddam Hussain.<sup>11</sup>

## AGE ESTIMATION

Age refers to a period of human life, measured by years, from birth, and is usually marked by a certain degree or stage of mental or physical development and involves legal responsibility and capacity. When the identification of human remains is required, one of the important factors to determine about the individual is the chronological age at death. The procedures of age determination are complex and involve the consideration of many factors.

Forensic age estimation in individuals is mainly contributed by three components:<sup>7</sup>

1. Evaluation of skeletal maturity
2. Expression of secondary sexual characteristics.
3. Assessment of dental development.

### Evaluation of skeletal maturity

Skeletal age can be obtained with the help of the appearance and fusion of ossification centers, closure of cranial sutures, and changes associated with pubic symphysis. Twenty ossification centers are generally used for determining skeletal age.<sup>12</sup> These include as follows:

- a. Carpal bones, metacarpals, and patella in both sexes
- b. Distal and middle phalanges in boys
- c. Distal and proximal phalanges in girls.

Skeletal age is more advanced in girls than in boys. Further, skeletal age should be estimated by a radiologist without considering the clinical profile of the case.

### Expression of secondary sexual characteristics

The process of maturation at puberty is a multidimensional set of events that can be, and has been, utilized for age-related evaluation. Female maturation within this process is generally assessed based on the age of onset of menses, degree of breast development, and degree of axillary and pubic hair. Male maturation is generally assessed on the basis of testicular and penile enlargement and also on the degree of hair development, mainly pubic but also axillary and facial.<sup>7</sup>

### Assessment of dental development

Dental age is estimated by comparing the dental development status in a person of unknown age with published developmental surveys. Basically, two main groups of well-known techniques based on dental maturation are available for this purpose:<sup>13</sup>

1. The atlas techniques: In these methods, dental development (mineralization) is compared with published standards
2. The scoring techniques: In these methods, dental development is divided into various stages that are then assigned a score which is evaluated through statistical analysis.

### Applications of age estimation

Importance of age estimation is manifold:

1. For the purpose of identification of a mutilated body of a victim (in forensic identifications)
2. In anthropological studies research: In anthropology, knowledge of age will assist the evaluation of age group distribution and give a picture of the way of life in a certain era/area
3. Treatment planning of various abnormalities
4. Medicolegal issues
5. Judicial:
  - a. Criminal
  - b. Juvenile law enforcement: According to the Juvenile Act 1986, juvenile means a boy below 16 and a girl below 18 years and no delinquent juvenile shall be sentenced to death or imprisonment and court may direct to send the offence committed juvenile to the juvenile home; and
  - c. Civil issues such as marriage contract or for insurance.

### AGE ESTIMATION USING TEETH

Historically, age assessment using teeth was first published by Edwin Saunders, who claimed that teeth provided the most reliable guide to age, compared to age estimation from height, which was a standard method during that time. A number of reports in the field of forensic odontology have dealt with estimating chronological age in humans, living, or dead. According to an extensive literature review, teeth are better suited for age estimations than bones.<sup>6,14</sup> A number of methods of dental age estimation have been proposed. These may be described in four categories namely as follows:<sup>10</sup>

1. Visual observation: Observation of stages of eruption of teeth and evidence of changes due to function, such as attrition, which can give an approximate estimation of age
2. Physical and chemical analysis: Analyses of dental hard tissues to determine alterations in ion levels with age
3. Histological methods: These require the preparation of tissues for detailed microscopic examination which can determine more accurately the stage of development of dentition
4. Radiographic methods: These can provide in detail gross stages of development of dentition.

### Radiographic methods of age estimation by teeth

Age estimation is grouped into three phases:

- A. Age estimation in prenatal, neonatal, and postnatal ages
- B. Age estimation in children and adolescents
- C. Age estimation in adults.

### Age estimation in prenatal, neonatal, and postnatal ages<sup>15-20</sup>

Deciduous teeth start to develop in the 6<sup>th</sup>–8<sup>th</sup> gestational week and permanent teeth in about the 20<sup>th</sup> week of gestation. In age estimation, the term “tooth formation” usually refers to the mineralization of dental hard tissues and does not necessarily consider unmineralized formative stages of the tooth germ. Age estimation using dental development during fetal and neonatal periods must be based on the degree of calcification of deciduous dentition which can be observed by radiographic means. Radiographically, the mineralization of deciduous incisors starts at the 16<sup>th</sup> week of intrauterine life.

### Stages by Kraus and Jordan:<sup>18-20</sup>

Kraus and Jordan studied the early mineralization in various deciduous teeth as well as in the permanent first molars. Calcification proceeded faster mesiodistally than vertically. In molar teeth of both the maxilla and mandible, mesiobuccal cusp was the first to undergo calcification followed with mesiolingual, distobuccal, and finally, distolingual cusp. The development was described in ten stages, denoted by Roman numerals from I to X; the IX<sup>th</sup> stage including three substages and the X<sup>th</sup> stage including five substages [Figure 1].

### Age estimation in children and adolescents<sup>21-25</sup>

There are numerous methods available in literature for estimation of age in children and adolescents. These methods include the following:

1. Schour and Massler method<sup>21</sup>
2. Gleiser and Hunt method<sup>22</sup>
3. Demirjian, Goldstein, and Tamer method<sup>23</sup>
4. Nolla's method<sup>24</sup>
5. Open apices method.<sup>25</sup>

### Schour and Massler method<sup>21</sup>

In 1941, Schour and Massler studied development of deciduous and permanent teeth and described 21 steps ranging from 4 to 21 years of age and published numerical charts for them [Figure 2]. In 1982, American dental association updated these charts and published them thus, making them possible to directly compare calcification stages of teeth on radiographs with the standards. These charts do not have separate survey for

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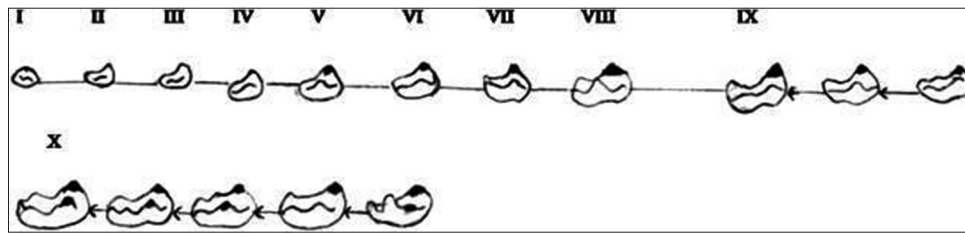


Figure 1: Dental development chart by Kraus and Jordan

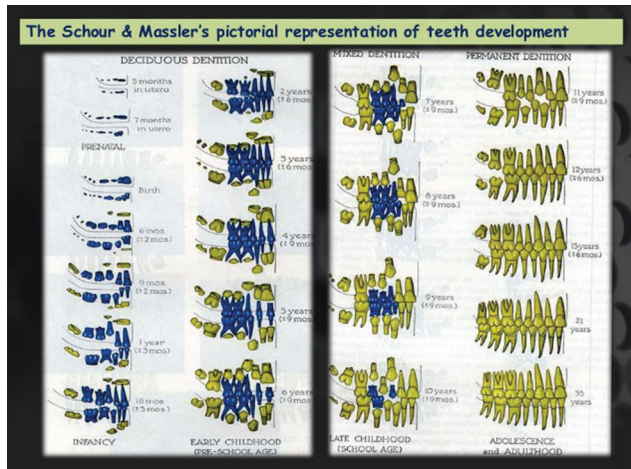


Figure 2: Dental development chart by Schour and Massler

molars. Kohl and Schwartz in 1998 updated Schour and Massler data and showed a delay in development of permanent dentition.

### Gleiser and Hunt method<sup>22</sup>

In 1955, Glesier and Hunt described detailed calcification of mandibular first molars based on radiographs [Figure 3]. Garn *et al.* published data on all permanent mandibular premolars using lateral oblique jaw X-rays. In 1956, Demisch and Wartman presented data on mandibular third molars. Moorees *et al.* rewrote the age attainment for 14 developmental stages from “initial cusp formation” to “complete apical closure” and had separate surveys for males and females.

### Demirjian, Goldstein, and Tamer Method<sup>23</sup>

Demirjian *et al.* in 1973 and 1976 defined four developmental crowns and four developmental root stages which were based on radiological tooth germs. They used Figure A-H instead of numbers to present the impression of an equal duration of each stage [Figure 4]. Stage O was given for nonappearance of any mineralization on radiograph. If there was no sign of calcification, a rating 0 was given; crypt formation was not taken into consideration. They rated seven mandibular permanent teeth in order of second molars (M2), first molars (M1), second premolars (PM2), first premolars (PM1), canines (C), lateral incisors (I2), and central incisors (I1). In this approach, a scoring

system was used for the formation of left mandibular teeth. Every stage was assigned a certain dental score with adding-up all scores giving the dental maturity scores which contributed and indicated for individual dental maturity. These stages were taken as the indicators of dental maturity of each tooth. The differences in the dental development between males and females were not supposed to be apparent until the age of 5 years. Each stage of mineralization was given a score which provided an estimate of dental maturity on a scale of 0–100 on percentile charts. The maturity scores (s) for all the teeth was/were added and the total maturity scores might be converted directly into a dental age as per the standard table given, or they were substituted in regression formulae. Females and males had separate formulae.

In females, the formula was given below:

$$\text{Age} = (0.000055 \times S_3) - (0.0095 \times S_2) + (0.6479 \times S) - 8.4583.$$

In males, the formula was given below:

$$\text{Age} = (0.0000615 \times S_3) - (0.0106 \times S_2) + (0.6997 \times S) - 9.3178.$$

In this method, missing teeth from one side could be replaced by those from the other side. If the first molars used to be absent, the central incisors could be substituted for them as their developmental ages coincide. This method was the most highly developed of all the dental age surveys. The only drawbacks included that the survey did not include the developing third molars and the mandibular teeth needed to be present for the survey to be applicable.

### Nolla's method<sup>24</sup>

Nolla in 1960 developed a method in which development of each tooth was divided into ten recognizable stages and categorically numbered 1–10 [Figure 5]. Bolanos developed scales based on Nolla's tables applicable to three and four teeth making Nolla's tables more practical for epidemiological studies.<sup>28,29</sup>

By this method, the development of each tooth of the maxillary and mandibular arch could be assessed. The radiograph of the patient was matched with the comparative figures. After every tooth was assigned reading, a total was made of the maxillary and mandibular teeth and then, the total was compared with the table given by Nolla.



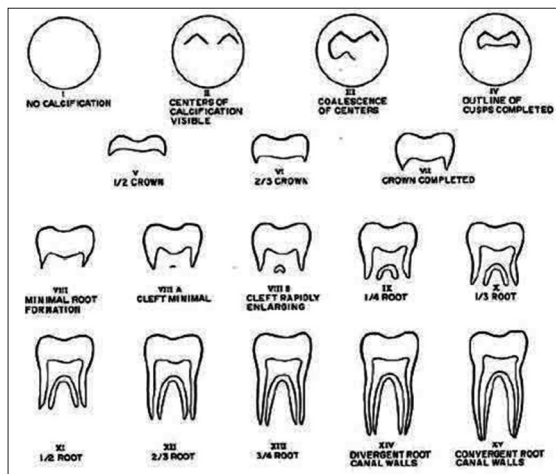


Figure 3: Dental development chart by Gleiser and Hunt

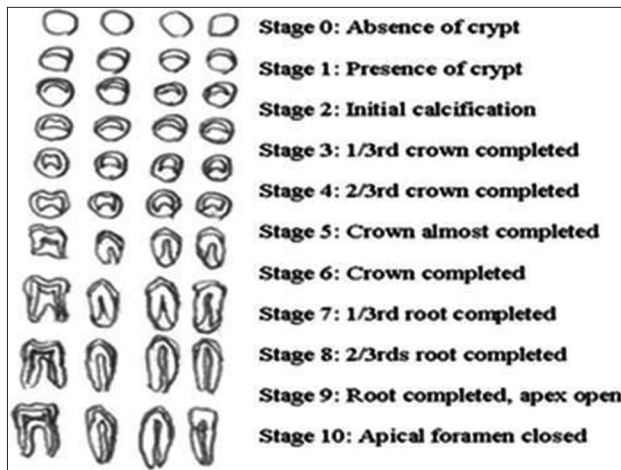


Figure 5: Dental development chart by Nolla

### Age estimation using open apices<sup>25</sup>

In 2006, Cameriere *et al.* presented a method for assessing chronological age in children based on the relationship between age and measurement of open apices in teeth. Seven left permanent mandibular teeth were evaluated. The numbers of teeth with root development completed with apical ends completely closed were calculated ( $N_0$ ). For the teeth with incomplete root development and with open apices, the distance between the inner sides of the open apices was measured (A) [Figure 6]. For the teeth with two roots, the sum of the distances between the inner sides of the two open apices was evaluated. To nullify the magnification, the measurement of open apex or apices (if multirooted) was divided by the tooth length (L) for each tooth and these normalized measurements of seven teeth were used for age estimation. The dental maturity was calculated as the sum of normalized open apices and the numbers of teeth with root development completed ( $N_0$ ). The



Figure 4: Dental development chart by Demirjian *et al.*

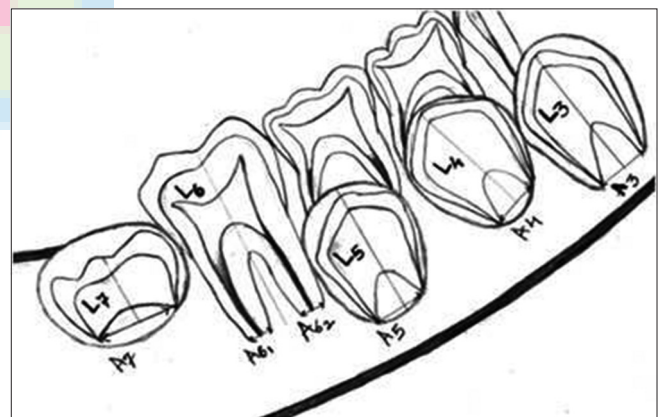


Figure 6: Measurements' chart by Cameriere *et al.*, L=length of tooth (L1, L2), A=distance between inner sides of open apex (A1, A2)

values were substituted in the following regression formula for age estimation:

$$\text{Age} = 0.816 + 0.375 g + 0.498 N_0 - 1.034 s$$

### Age estimation in adults<sup>26-34</sup>

Once the third molars have fully erupted (17–21 years of age), permanent dentition is said to have completely developed and it is difficult to estimate age based on radiographs. For age estimation of adults, there are two methods which are followed for age estimation. These methods include:

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- Volume assessment of the teeth:<sup>26-28</sup>
  - a. Pulp-to-tooth area ratio (AR) method<sup>29,30</sup>
  - b. Coronal pulp cavity index.<sup>31,32</sup>
- Development of third molars<sup>33,34</sup>
  - a. Harris and Nortje's method<sup>33</sup>
  - b. Van Heerden system.<sup>34</sup>

### Volume assessment of teeth<sup>26-28</sup>

Since 1925, Bodecker identified the apposition of secondary dentine as being related to chronological age. Detailed studies of the pattern and rate of secondary dentin apposition in the upper anterior teeth were performed by Philippas and Applebaum (1966, 1967, 1968) but without the goal of estimating age at death. The secondary dentine deposition was included in the method pioneered by Gustafson, wherein the dentine transparency and the secondary dentine values showed the highest correlation with age as the following studies of Johanson (1971), Maples (1978), and Metzger *et al.* (1980) demonstrated. Other authors as Nalbandian and Sognnaes (1960) were, also, of the opinion that it was necessary to include the secondary dentine in the estimation of age. Some authors, on the contrary, argued that secondary dentine changes have not proven useful as biomarkers for systemic aging (Lamendin *et al.*, 1990; Morse, 1991).

### Pulp-to-tooth area ratio method by Kvaal *et al.*<sup>29,30</sup>

Kvaal *et al.* introduced an age estimation method by indirectly measuring secondary dentine deposition on radiographs and proposed a number of length and width measurements of teeth and pulp.<sup>29</sup> Cameriere *et al.*, later, put forth a similar method based on radiographic estimation of pulp-to-tooth AR in canines. Canines were favored as they were single-rooted teeth with the largest pulp area for ease of analysis.<sup>30</sup> In Kvaal's method, pulp-to-tooth ratio was calculated for six mandibular and maxillary teeth such as maxillary central and lateral incisors, maxillary second premolars, mandibular lateral incisor, mandibular canine, and mandibular first premolar. The age was derived using these pulp-to-tooth ARs in the formula for age determination. Using intraoral periapical radiographs, the variables  $P$  = complete pulp length/root length (from enamel-cementum junction [ECJ] to root apex),  $r$  = complete pulp length/complete tooth length,  $a$  = complete pulp length/root width at ECJ level,  $b$  = pulp/root width at midpoint level between ECJ level and mid-root level, and  $c$  = pulp/root width at mid-root level and pulp/tooth AR for all six teeth were measured as devised in Kvaal's and Cameriere's methods of age estimation, respectively [Figure 7]. Calculations of several length and width ratios were done to compensate for any magnification or angulation of the original tooth image on radiographs. Finally, a simple linear regression analysis was

carried out, wherein the variables mean (M) (mean of variables complete pulp length/root length [from ECJ to root apex]  $[p]$ , complete pulp length/complete tooth length  $[r]$ , complete pulp length/root width at ECJ level  $[a]$ , pulp/root width at midpoint level between ECJ level and mid-root level  $[b]$ , and pulp/root width at mid-root level  $[c]$ ) and difference between width and length ( $W - L$ ) were found to contribute significantly to the chronological age estimation and were utilized in the regression equation for Kvaal's method as per the given formula:

$$\text{Age} = 129.8 - (316.4 \times M) (6.8 \times [W - L]).$$

### Coronal pulp cavity index<sup>31,32</sup>

In 1985, Ikeda *et al.* took X-ray photographs of 116 extracted human teeth (53 incisors and 63 molars) and made their quadruple size prints. They measured the lengths of the coronal pulp cavity and crown and calculated the tooth coronal index [Figure 8]. Simple linear regression analysis was, then, carried out by regressing the proportional coronal pulp cavity length on the actual age for each group of teeth for males and females and for the combined sample.

Tooth-coronal index = Length of coronal pulp cavity/Length of the crown  $\times 100$ .

### Development of third molars<sup>33,34</sup>

#### Harris and Nortje's method<sup>33</sup>

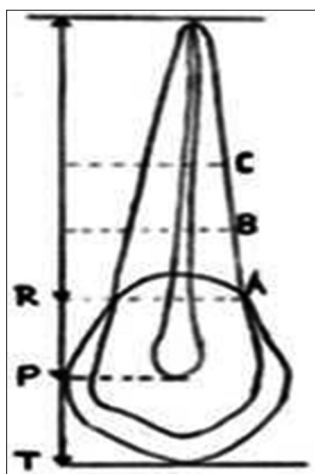
Harris and Nortje gave five stages [Figure 9] of the third molar root development with corresponding mean ages and mean length including Stage 1 (cleft rapidly enlarging-one-thirds of the root formed), Stage 2 (half of the root formed), Stage 3 (two-thirds of the root formed), Stage 4 (diverging root canal walls), and Stage 5 (converging root canal walls).

#### Van Heerden system<sup>34</sup>

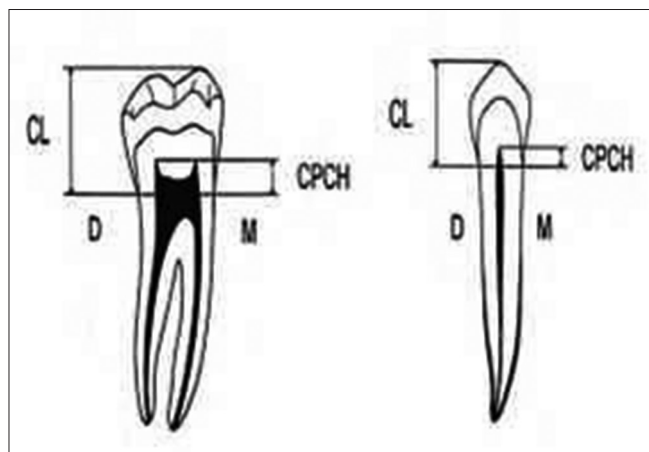
Van Heerden assessed the development of the mesial root of the third molar to determine age. He described the development of the mesial root in five stages using panoramic radiographs. The males and females were surveyed separately, and no significant differences were found between them.

## CONCLUSION

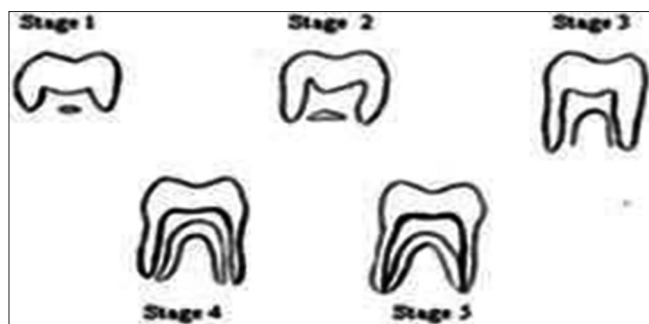
The long-term research objectives are to develop, validate, and facilitate for the application of the most accurate methods for age estimation of children and adolescents. These are certain methods which give more objective and repeatable measurements, i.e., give more consistent results. The research, however, does not end here as there are no methods, by which the age of an individual can be precisely estimated. The goal of future research, therefore, must be within practical and financial constraints and respect recognized ethical standards. Properties and shortcomings of the various existing methods must be reviewed systematically to achieve this



**Figure 7:** Measurements' chart by Kvaal and Cameriere *et al.* using pulp-to-tooth area ratios,  $P$ =Complete pulp length/root length (from enamel-cementum junction to root apex),  $r$ =Complete pulp length/complete tooth length,  $a$ =Complete pulp length/root width at enamel-cementum junction level,  $b$ =Pulp/root width at midpoint level between enamel-cementum junction level and mid-root level and  $c$ =Pulp/root width at mid-root level; and pulp/tooth area ratio



**Figure 8:** Measurements' chart by Ikeda *et al.* using coronal pulp cavity index, CH=Coronal height, CPCH=Coronal pulp cavity height, TCI=Coronal index



**Figure 9:** Dental development chart by Harris and Nortje

objective. In addition, the opportunities provided by combining different methods must be examined. A systematic review of the

studies of reference populations is necessary. New and complex reference data, where age is known, should be collected through international collaboration, and the possibilities for exploiting better existing reference data should be investigated. If one is to reach the objective, in full, multinational collaboration among researchers should be established.

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### Conflicts of interest

There are no conflicts of interest.

### REFERENCES

1. Senn DR, Stimson PG. Forensic Dentistry. 2<sup>nd</sup> ed. Boca Raton: CRC Press; 2010.
2. Silver WE, Souviron RR. Dental Autopsy. 1<sup>st</sup> ed. Boca Raton: CRC Press; 2009.
3. Harris EF. Dental Anthropology. Vol. 16. Geneva: An Official Publication of the Dental Anthropology Association; 2002.
4. Taylor J. A brief history of forensic odontology and disaster victim identification practices in Australia. J Forensic Odontostomatol 2009;27:64-74.
5. Saxena S. Age estimation of Indian adults from orthopantomographs. Braz Oral Res 2011;25:225-9.
6. 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.
7. Sue Black, Aggrawal Anil, Jason Payne. Age Estimation in the Living: The Practitioner's Guide. Hoboken, United States: Wiley; 2008.
8. Robert Michael Bruce-Chwatt. A brief history of Forensic Odontology since 1775. J Forensic Odontostomatol 2009;27:64-74.
9. Dayal PK. Textbook of Forensic Odontology. 1<sup>st</sup> ed. Hyderabad: Paras Medical Publishers; 1998.
10. Wilson DF, Brown KA. Forensic Odontology. In: Prabhu SR, Wilson DF, Daftary DK, Johnson NW. Oral Diseases in the Tropics. UK: Oxford University Press; 1993.
11. Chandra Shekar BR, Reddy CV. Role of dentist in person identification. Indian J Dent Res 2009;20:356-60.
12. Ghai OP. Essential Paediatrics. 2<sup>nd</sup> ed. New Delhi: Interprint; 1990.

## Age estimation: Overview and research challenges

13. Willems G. A review of the most commonly used dental age estimation techniques. *J Forensic Odontostomatol* 2001;19:9-17.
14. Mary Walsh, Pauline Reeves, Susan Scott. When disaster strikes: The role of forensic radiographer. *Radiology* 2004;10:33-34.
15. Acharya AB, Sivapathasundharan B. Forensic odontology. In: Rajendran R, Sivapathasundharan B, (eds). *Shafer's Textbook of Oral Pathology*. 6<sup>th</sup> ed. India: Elsevier Private Ltd; 2009. p. 871-92.
16. Masthan KMK. Age and Sex. *Textbook of Forensic Odontology*. New Delhi: Jaypee Brothers Medical Publishers (P) Ltd; 2009. p. 59-65.
17. Whittakar DK, McDonald DG. Age determination from teeth: A color atlas of forensic dentistry. England: Wolfe Medical Publications Ltd; 1989. p. 58-66.
18. Karjodkar FR. Role of dental radiology in forensic odontology. *Textbook of Dental and Maxillofacial Radiology*. 2<sup>nd</sup> ed. New Delhi: Jaypee Brothers Medical Publishers (P) Ltd; 2009. p. 929-63.
19. Scheuer L, Black SM. Developmental juvenile osteology London. Elsevier Private Ltd; 2000. p. 155.
20. Stewart RE, Barber TK, Troutman KC. *Paediatric Dentistry: Scientific foundations and clinical practice*. St. Louis: CV Mosby; 1982.
21. Schour I, Massler M. Development of human dentition. *J Am Dent Assoc* 1941;20:379-427.
22. Glesier I, Hunt EE. The permanent mandibular first molar: Its calcification, eruption and decay. *Am J Anthropol* 1955;13:253-83.
23. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. *Hum Biol* 1973;45:211-27.
24. Nolla CM. The development of permanent teeth. *J Dent Child* 1960;27:254-66.
25. 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.
26. Moorees CFA, Fanning EA, Hunt EE. Age variation of formation stages for ten permanent teeth. *J Dent Res* 1963;42:1490-502.
27. Panchbhair AS. Dental radiographic indicators: A key to age estimation. *Dentomaxillofac Radiol* 2011;40:199-212.
28. Gustafson G. Age determination on teeth. *J Am Dent Assoc* 1950;41:45-54.
29. Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. *Forensic Sci Int* 1995;74:175-85.
30. Cameriere R, Ferrante L, Cingolani M. Variations in pulp/tooth area ratio as an indicator of age: A preliminary study. *J Forensic Sci* 2004;49:317-9.
31. Drusini AG. The coronal pulp cavity index: A forensic tool for age determination in human adults. *Cuad Med Forense* 2008;14:235-49.
32. Drusini AG, Toso O, Ranzato C. The coronal pulp cavity index: A biomarker for age determination in human adults. *Am J Phys Anthropol* 1997;103:353-63.
33. Harris MPJ, Nortje CJ. The mesial root of the third mandibular molar. *J Forensic Odontostomatol* 1984;2:39-43.
34. Van Heerden PJ. The mesial root of the third mandibular molar as a possible indicator of age. *Dissertation for Diploma in Forensic Odontology*. London Hospital Medical College; 1985.

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